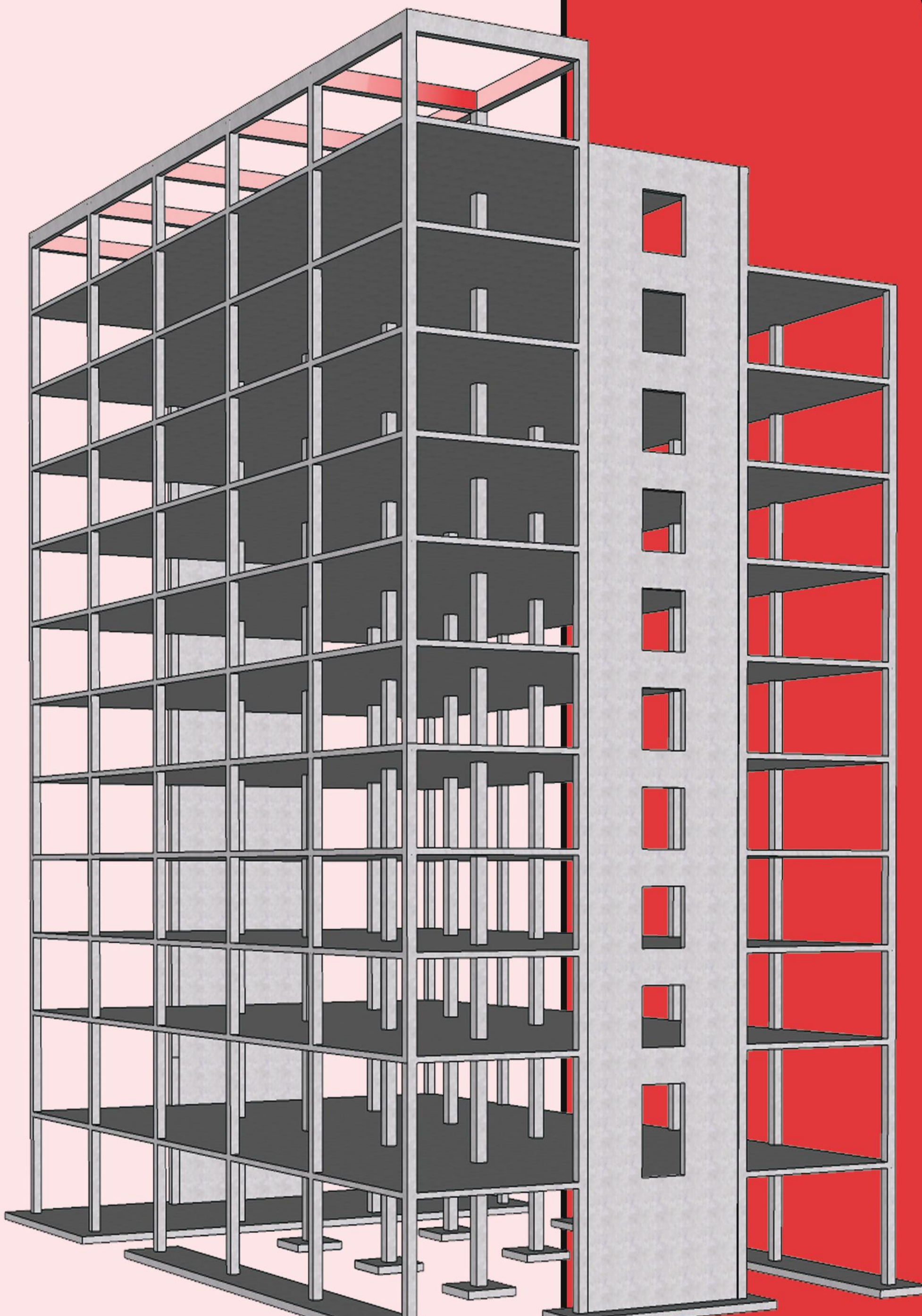
# spBeam

v10.00

# Technical Manual



StructurePoint

Version 10.00

This Computer program (including software design, programming structure, graphics, manual, and on-line help) was created and published by STRUCTUREPOINT, formerly the Engineering Software Group of the Portland Cement Association (PCA) for the engineering analysis and design of reinforced concrete beams and slab floor systems.

While STRUCTUREPOINT has taken every precaution to utilize the existing state-of-the-art and to assure the correctness of the analytical solution techniques used in this program, the responsibilities for modeling the structure, inputting data, applying engineering judgment to evaluate the output, and implementing engineering drawings remain with the structural engineer of record. Accordingly, STRUCTUREPOINT does and must disclaim any and all responsibility for defects or failures of structures in connection with which this program is used.

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## Chapter 4: MODELING METHODS



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CHAPTER

1

# INTRODUCTION

Formerly pcaSlab and ADOSS, spSlab is a computer software program for the analysis and design of reinforced concrete beams and slab floor systems. Two-way slab systems are analyzed using the Equivalent Frame Method. Beams and frames of up to 22 spans can be analyzed and designed. In addition to the design option, spBeam and spSlab have the capability of investigating existing beams and slab systems. spSlab includes provisions for slab band systems as well as punching shear check and deflection calculations using cracked or gross sections. For beams, moment redistribution, as well as combined shear and torsion design, are available. In addition to the required area of reinforcing steel at the critical sections, spSlab provides a complete reinforcing bar schedule that includes the number of bars and bar sizes and lengths. spSlab checks the applicable provisions of the selected code.

Formerly pcaBeam, spBeam is a limited version of spSlab. It includes all elements that apply to beams and one-way slab systems. Two-way slab systems are available in spSlab only and topics related to two-way slab systems are denoted with spslab icon.

## 1.1. Program Features

- Code support for ACI 318-14, ACI 318-11, ACI 318-08, ACI 318-05, ACI 318-02, and ACI 318-99
- Code support for CSA A23.3-14, CSA A23.3-04, and CSA A23.3-94
- English (U.S.) and Metric (SI) unit systems
- Design and investigation of beams, one and two-way slabs including one-way joist systems (standard and wide module) and two-way joist systems (waffle slabs)
- Slab band system design and investigation for CSA A23.3-14/04
- Flexure and shear design and investigation with live load reduction and patterning
- Torsion design and investigation for beams/one-way slab systems
- Longitudinal reinforcement for combined flexure, shear, and torsion per CSA A23.3-14/04
- Automatic or manual moment distribution factors and strip widths
- Moment redistribution for beams/one-way slab systems
- Calculation of instantaneous deflections at three load levels; dead load, dead load plus sustained live load, and dead load plus live load
- Calculation of incremental long-term deflections
- Instantaneous and long-term design strip deflections for two-way systems
- Analytical modeling of variable support stiffness in systems with rectangular, and circular supports
- One and two-way (punching) shear investigation considering the effects of drop panels, column capitals, longitudinal beams, transverse beams, and slab bands.
- Boundary conditions including vertical and rotational springs
- Top and bottom bar details including development lengths and material quantities
- Specialty design requirements including crack control, integrity reinforcing, and corner column checking
- Mixed span types within one-way or two-way systems
- Import input data from PCA-Beam and pcaSlab
- Object-based modeling of two-way and one-way systems with a full featured graphical interface
- Templates of predefined and loaded models allowing the user to select and generate quick

models for two-way systems (flat plate, flat slab, slab on beams, and two-way joist) and one-way systems (one-way slab, one-way joist, rectangular beams, and flanged beams)

- Structural grids to facilitate the placement of structural members in plan view
- Point, uniform line, variable line, and uniform area load types to model typical slab and beam loading conditions
- Automatic computation of element self-weights with the option to include or exclude them in the analysis
- Isometric (3D) view of the modeled system with ability to view grids, loads and other model features in typical CAD environment in multi viewports with up to 6 concurrent views
- Data validation during input
- Frame solution results including tabulated column axial forces and moments
- Diagrams to visualize the analysis and design results
- Print/Export module for viewing, customizing, and exporting screenshots
- Tables module for viewing and exporting input and output data
- Reporter module for customizing, generating, viewing, exporting, and printing results
- User-controlled screen display settings including a full color palette
- Ability to save defaults and settings for future input sessions
- Detailed manual and online resources

## 1.2. Program Capacity

- 21 supports (22 spans including left and right cantilevers)
- 6 load cases
- 50 load combinations
- 999 partial dead loads per case
- 999 partial live loads per case
- 2 top bar layers (Design mode)
- 2 bottom bar layers (Design mode)
- 15 bar sets per span

## 1.3. System Installation Requirements

Any computer running Microsoft Windows 10 or Windows 11 operating system is sufficient to run the spSlab and spBeam programs provided that .NET 7.0 is installed. If it is not detected by the installation program, then it will be installed automatically.

The actual program capacity depends on system resources available on the computer on which spSlab and spBeam are running. To solve models with the maximum number of supports and load combinations, a 64-bit operating system with at least 8GB of RAM is required. It is recommended to run the model on the local computer hard drive for fastest response.

For instructions on how to purchase, download, install, license, and troubleshoot issues, please refer to support pages on the StructurePoint website at Structurepoint.org/slg.asp.

## 1.4. Terms & Conventions

The following terms are used throughout this manual. A brief explanation is given to help familiarize you with them.

| | |
|---|---|
| **Windows** | refers to the Microsoft Windows environment as listed in System Requirements. |
| **[ ]** | indicates equivalent value expressed in metric unit or CSA code requirement corresponding ACI code requirement. |
| **Click on** | means to position the cursor on top of a designated item or location and press and release the left-mouse button (unless instructed to use the right-mouse button). |
| **Double-click on** | means to position the cursor on top of a designated item or location and press and release the left-mouse button twice in quick succession. |
| **Marquee select** | means to depress the mouse button and continue to hold it down while moving the mouse. As you drag the mouse, a rectangle (known as a marquee) follows the cursor. Release the mouse button and the area inside the marquee is selected. |

Various styles of text and layout have been used in this manual to help differentiate between different kinds of information. The styles and layout are explained below

| | |
|---|---|
| spSlab | placed in a topic header means that the topic applies to spSlab only |
| *Italic* | indicates a glossary item, or emphasizes a given word or phrase. |
| **Bold** | All bold typeface makes reference to either a menu or a menu item command such as **File** or **Save**, or a tab such as **General Information** or **Columns**. |
| `Mono-space` | indicates something you should enter with the keyboard. For example type "`c:\filename.txt`". |
| KEY + KEY | indicates a key combination. The plus sign indicates that you should press and hold the first key while pressing the second key, then release both keys. For example, "ALT + F" indicates that you should press the "ALT" key and hold it while you press the "F" key. Then release both keys. |
| SMALL CAPS | Indicates the name of an object such as a dialog box or a dialog box component. For example, the OPEN dialog box or the CANCEL or MODIFY buttons. |

CHAPTER

2

# SOLUTION METHODS

## 2.1. Introduction

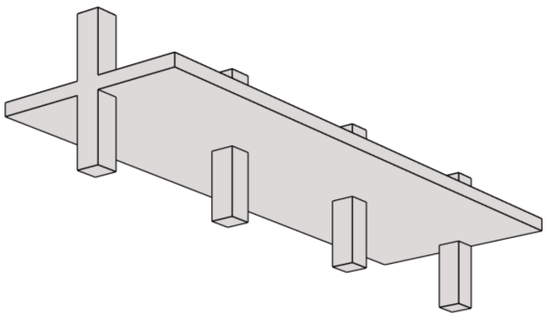
spSlab and spBeam are advanced software tools used worldwide for the modeling, analysis, and design of reinforced concrete floor slab and beam systems. They are designed to handle two-way and one-way slab systems, including flat plates, flat slabs, slabs on beams, slab bands, two-way waffle slabs, one-way solid slabs, one-way ribbed slabs, rectangular beams, and flanged beams. Equipped with the American (ACI 318) and Canadian (CSA A23.3) concrete codes, spSlab and spBeam provide robust solutions for analyzing and designing conventional concrete floor systems under various loading conditions. The programs leverage sophisticated methods, such as the Equivalent Frame Method and the Matrix Stiffness Method, to perform analyses that comply with code provisions while offering flexibility in modeling and adaptability to diverse design and investigation scenarios. Their comprehensive approach includes rigorous geometry and code checks to ensure accurate and code-compliant design outcomes. Additionally, the programs flag potential issues, such as inadequate reinforcement, excessive deflections, or geometry conflicts, requiring further attention or adjustment. As industry-leading tools, spSlab and spBeam simplify complex design challenges, enabling engineers to confidently address the most demanding structural scenarios encountered in reinforced concrete buildings and structures.

## 2.1.1. Slab Systems

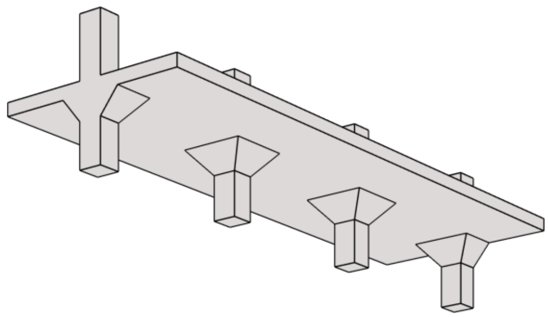
spSlab and spBeam can be used to model, analyze, and design two-way and one-way systems such as flat plate, flat slab, slab on beams, slab bands, two-way joist slab (waffle slab), one-way slab (solid slab), one-way joist slab (ribbed slab), rectangular and flanged beams. Samples of such systems are illustrated below:

### 2.1.1.1. Two-Way System

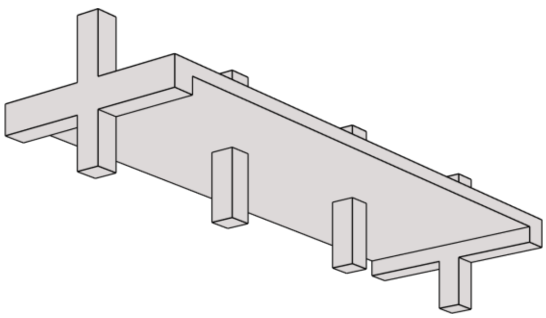
**Flat Plate**



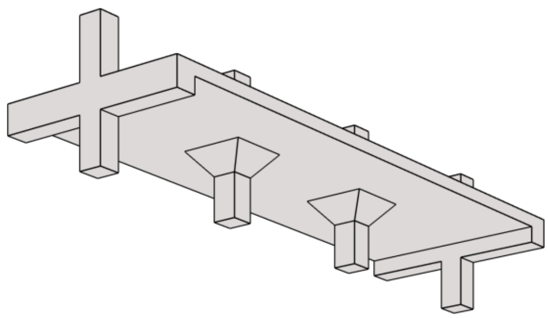
Flat Plate



with Column Capitals

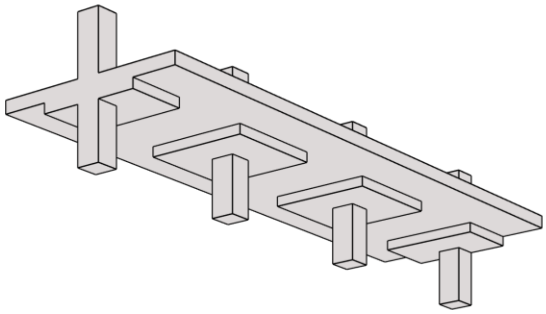


with Spandrel Beams

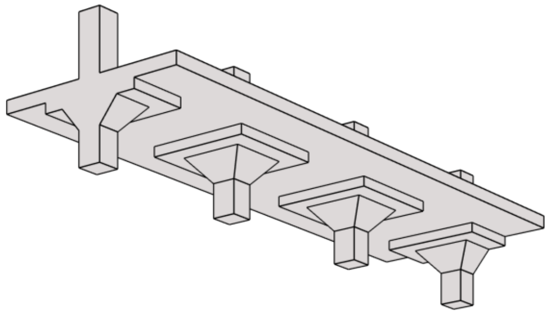


with Spandrel Beams & Column Capitals

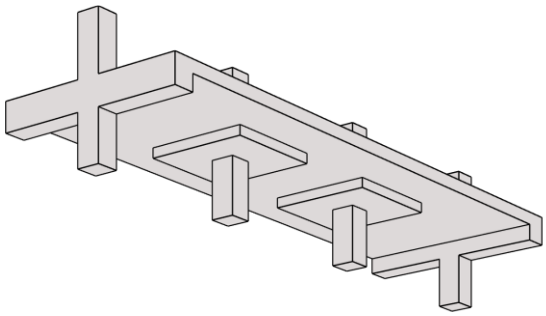
## Flat Slab



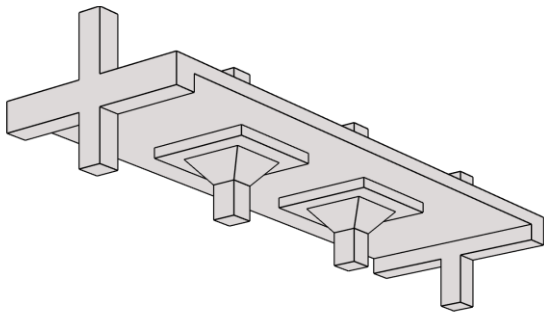
Flat Slab



with Column Capitals

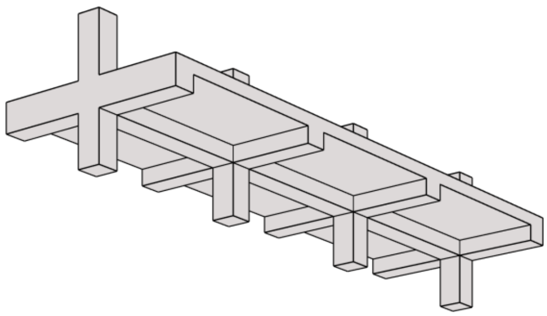


with Spandrel Beams



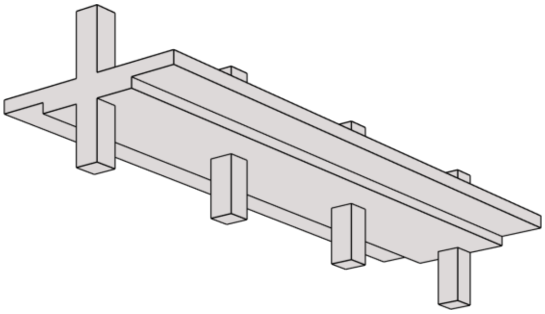
with Spandrel Beams & Column Capitals

## Slab on Beams

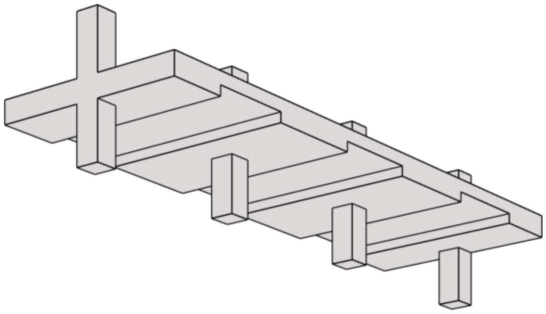


Two-Way Beam-Supported Slab

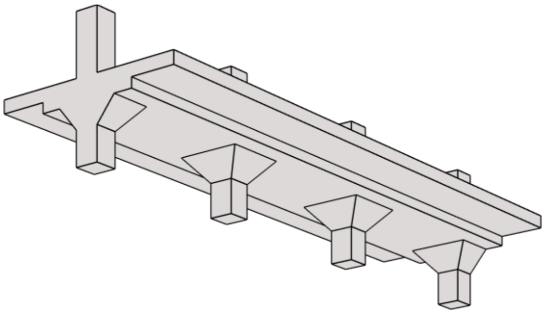
## Slab Bands



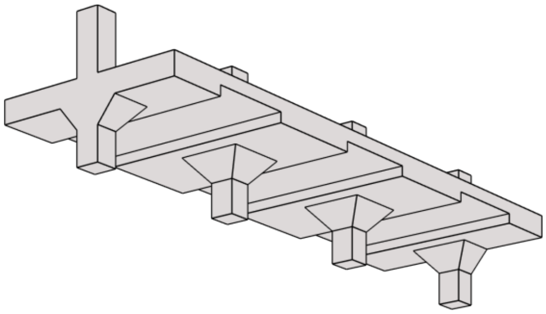
Longitudinal Bands



Transverse Bands

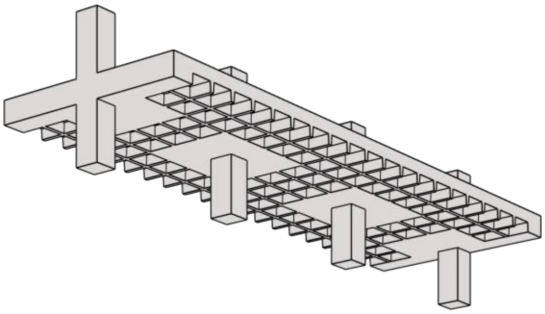


Longitudinal Bands with Column Capitals

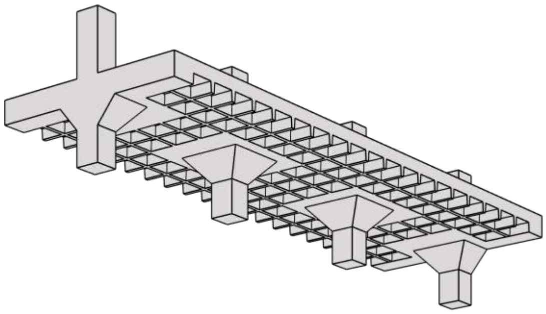


Transverse Bands with Column Capitals

## Two-Way Joist (Waffle)



Waffle Slab



Waffle Slab with Column Capitals

### 2.1.1.2. One-Way System

**One-Way Slab (Solid)**

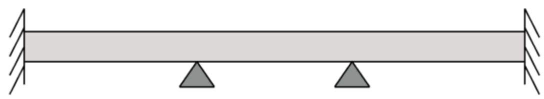
Simply Supported

Fixed Ends

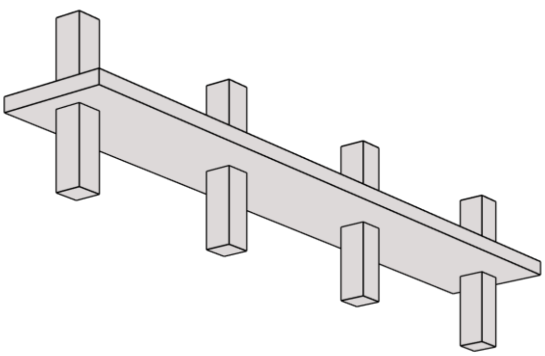
Simple Cantilever

Propped Cantilever

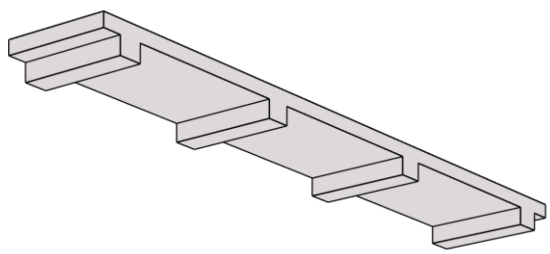
Continuous – Pinned Ends



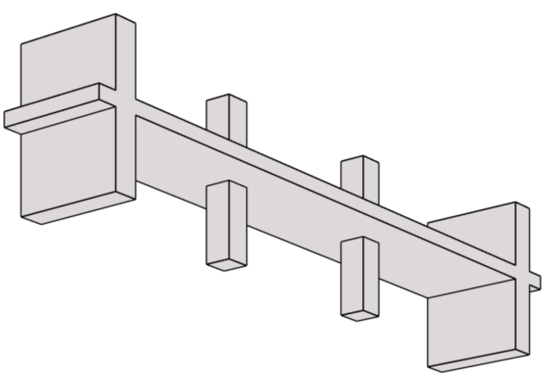
Continuous – Fixed Ends



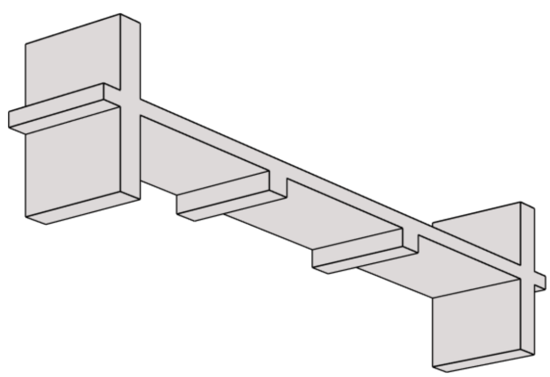
Continuous – Column Supports



Continuous – Beam Supports

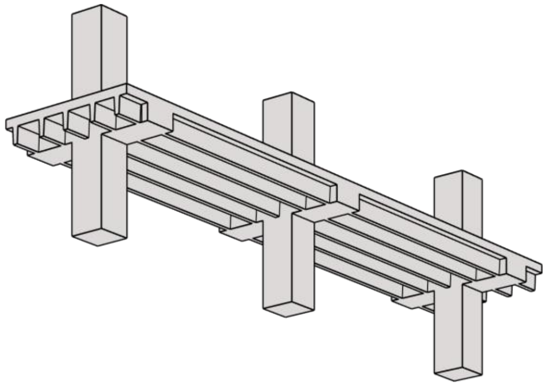


Column Supports – End Walls

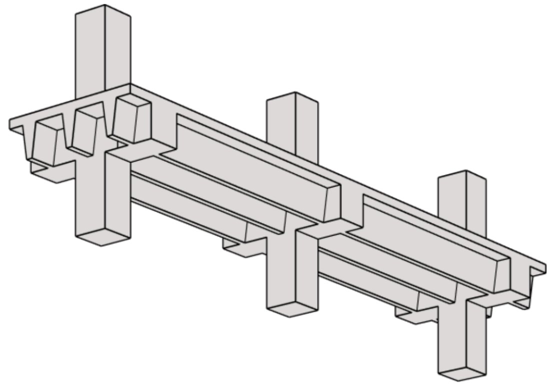


Beam Supports – End Walls

## One-Way Joist (Ribbed)

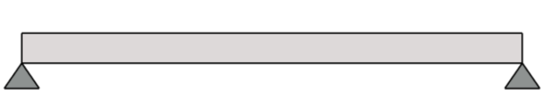


Joist-standard Module

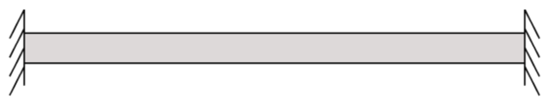


Joist-wide Module

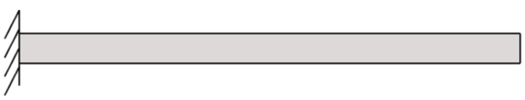
## Rectangular Beams



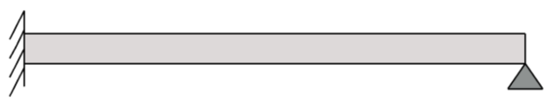
Simply Supported



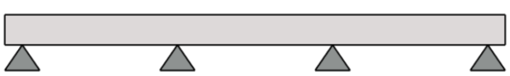
Fixed Ends



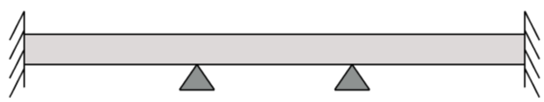
Simple Cantilever



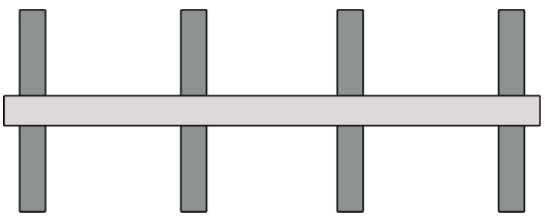
Propped Cantilever



Continuous – Pinned Ends



Continuous – Fixed Ends



Continuous – Column Supports

## Flanged Beams

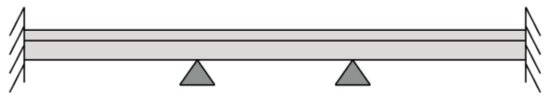
Simply Supported

Fixed Ends

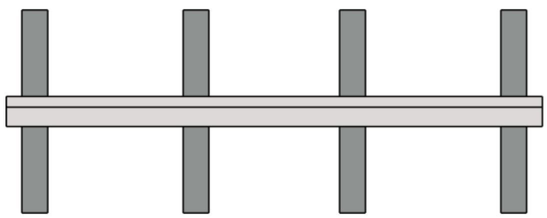
Simple Cantilever

Propped Cantilever

Continuous – Pinned Ends



Continuous – Fixed Ends



Continuous – Column Supports

### 2.1.2. Coordinate Systems

The top surface of the slab/beam lies in the XY plane of the right-handed XYZ rectangular coordinate system shown in Figure 2.1. The slab thickness (and/or beam depth) is measured in the direction of the Z-axis. When looking at the screen, the positive X-axis points horizontally to the right on the screen, the positive Y-axis points directly out of the screen towards the user, and positive Z-axis points vertically downwards on the screen. Thus, the XY plane is defined as being in the plane of the screen. Note that the loads shown in the figure are all positive and may not match the typical sign conventions. More details related to Span Loads can be found in Section 5.2.4.3.

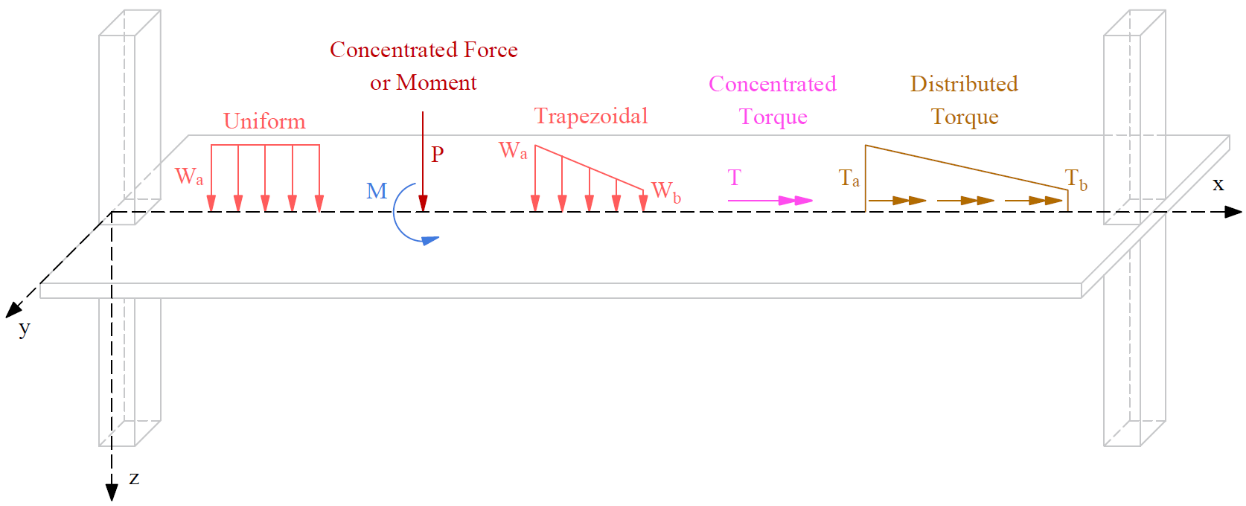



Figure 2.1 – Coordinate System

Consistent with this sign convention, the tabular results in the program output such as reinforcement values are presented for each span, beginning with the zero value of the X coordinate referred to as the Left zone and working towards the full span length in the X direction also designated as the Right zone. between the Right and Left zones of a span is the Midspan zone represents commonly important values from the structural analysis and design.

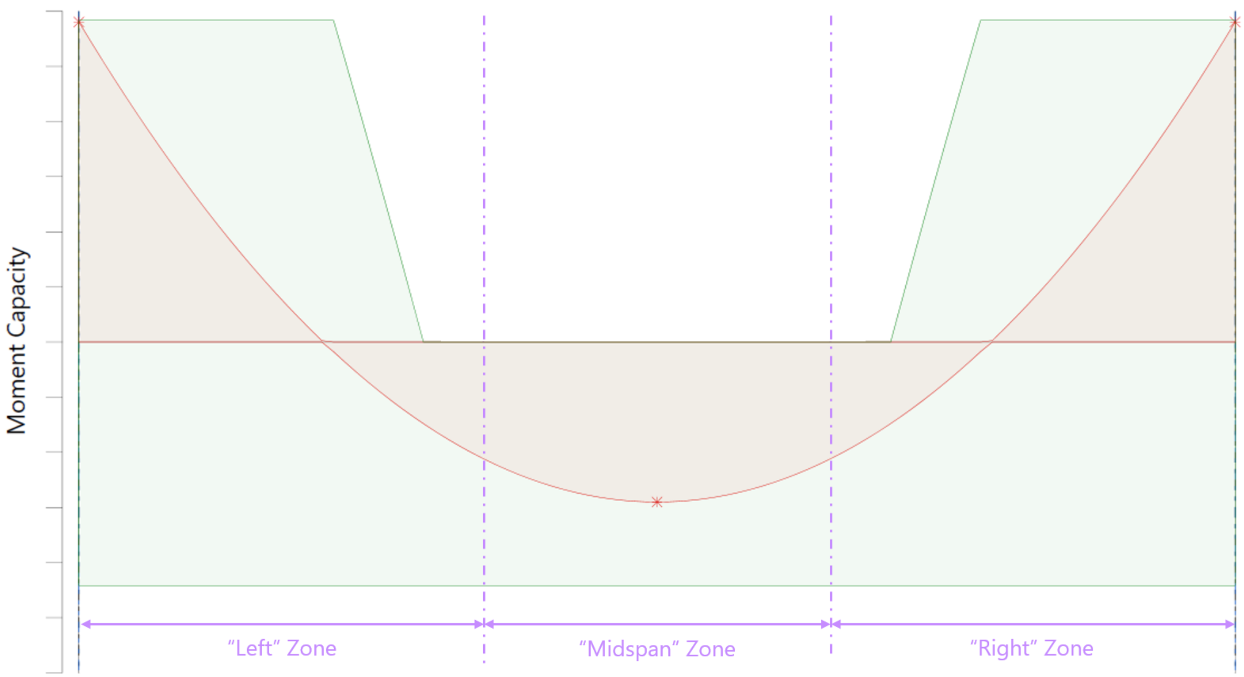



Figure 2.2 – Span Zones

As a result of the coordinate system described above, results output is presented as follows for shear force diagram, bending moment diagram, and torsion force diagram.

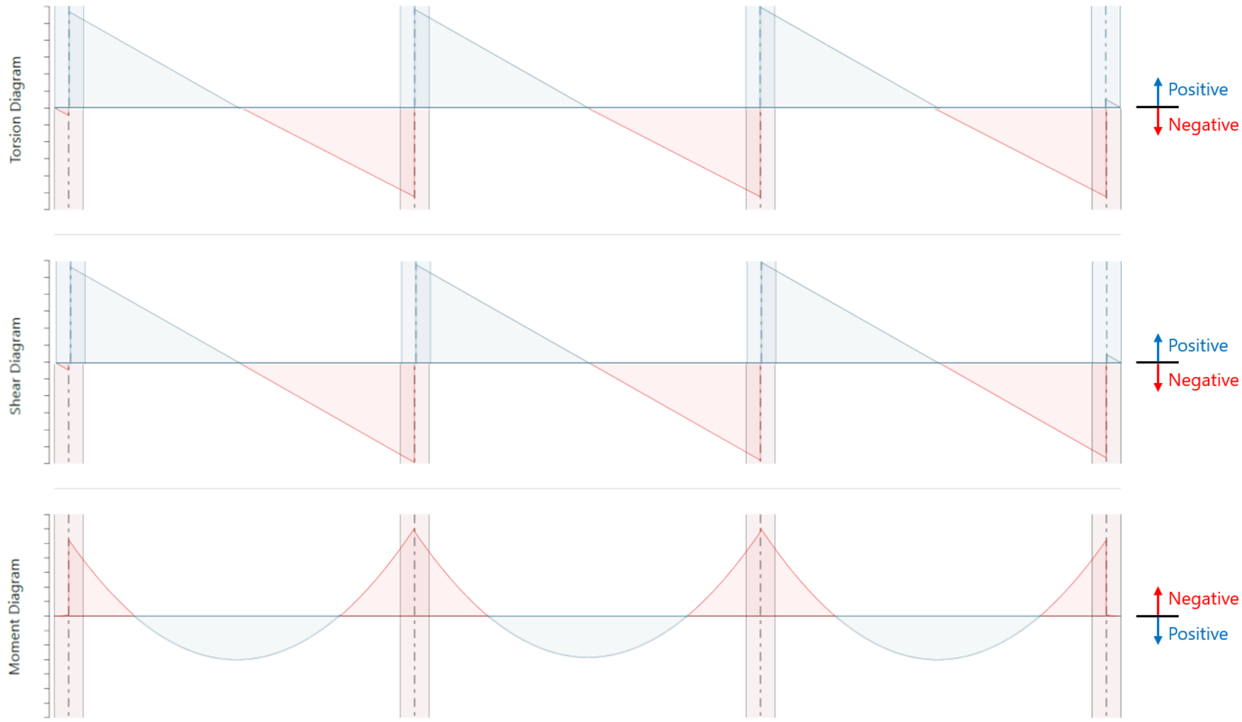



Figure 2.3 – Result Output Sign Convention

# 2.2. Codes and Standards Provisions

## 2.2.1. Code Checks

### 2.2.1.1. Geometry Considerations

#### Minimum Thickness – One-Way Construction

The program checks beam or one-way slab thickness based on minimum requirement for ACI-318[1] code as specified in Table 9.5(a) or for CSA code[2] according to Table 9.2. For lightweight concrete with density

90 lb/ft$^3$ $\leq w_c \leq$ 115 lb/ft$^3$ [1440 kg/m$^3$ $\leq w_c \leq$ 1840 kg/m$^3$] for ACI 318-14, ACI 318-11, and ACI 318-08

90 lb/ft$^3$ $\leq w_c \leq$ 120 lb/ft$^3$ [1440 kg/m$^3$ $\leq w_c \leq$ 1920 kg/m$^3$] for ACI 318-05

90 lb/ft$^3$ $\leq w_c \leq$ 120 lb/ft$^3$ [1500 kg/m$^3$ $\leq w_c \leq$ 2000 kg/m$^3$] for ACI 318-02, and ACI 318-99,

the minimum slab thickness is additionally increased by adjustment factor (1.65 – 0.005$w_c$), but not less than 1.09. For CSA standards, the adjustment is calculated as (1.65 – 0.0003$w_c$), but not less than 1.0, for structural low density ($w_c \leq$ 1850 kg/m$^3$) and structural semi-low density (1850 kg/m$^3$ $\leq w_c \leq$ 2150 kg/m$^3$) concrete[3].

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1 ACI 318-14,7.3.1.1.,9.3.1.1; ACI 318-11, 9.5.2.1; ACI 318-08, 9.5.2.1; ACI 318-05, 9.5.2.1; ACI 318-02, 9.5.2.1; ACI 318-99, 9.5.2.1

2 CSA A23.3-14, 9.8.2.1; CSA A23.3-04, 9.8.2.1 (Ref. [10])

3 CSA A23.3-04, 2.2; CSA A23.3-94 (Ref. [13]), 2.1

## Minimum Slab Thickness – Two-Way Construction

spSlab

The program checks slab thickness against minimum slab thickness defined by design standards for two-way systems with long to short span ratio not greater than 2.0[4]. Slabs with thickness below the minimum value will be flagged by the program, however, they are allowed provided that calculated deflections do not exceed maximum permissible computed deflections[5].

For two-way system with a long to short span ratio greater than 2.0, the program will calculate minimum thickness requirements based on the provisions of one-way construction including any cantilevered spans.

Minimum thickness of slabs with beams spanning between supports on all sides is calculated for ACI 318 codes in US customary units from[6]:

$$h = \begin{cases} \dfrac{l_n\left(0.8+\dfrac{f_y}{200{,}000}\right)}{36+5\beta\left(\alpha_{fm}-0.2\right)} \geq 5 \text{ in.} & \text{if } 0.2 < \alpha_{fm} \leq 2.0 \\ \dfrac{l_n\left(0.8+\dfrac{f_y}{200{,}000}\right)}{36+9\beta} \geq 3.5 \text{ in.} & \text{if } \alpha_{fm} > 2.0 \end{cases} \qquad \text{Eq. 2-1}$$

4 ACI 318-14, 8.3.1.1; ACI 318-11, 9.5.3.1, 13.6.1.2; ACI 318-08, 9.5.3.1, 13.6.1.2; ACI 318-05, 9.5.3.1, 13.6.1.2; ACI 318-02, 9.5.3.1, 13.6.1.2; ACI 318-99, 9.5.3.1, 13.6.1.2; CSA A23.3-14, 13.2.2, 2.2; CSA A23.3-04, 13.2.2, 2.2; CSA A23.3-94, 13.3.2, 13.1

5 ACI 318-14, 8.3.2.1; ACI 318-11, 9.5.3.4; ACI 318-08, 9.5.3.4; ACI 318-05, 9.5.3.4; ACI 318-02, 9.5.3.4; ACI 318-99, 9.5.3.4; CSA A23.3-14, 13.2.7; CSA A23.3-04, 13.2.7; CSA A23.3-94, 13.3.6

6 ACI 318-14, 8.3.1.2; ACI 318-11, 9.5.3.3; ACI 318-08, 9.5.3.3; ACI 318-05, 9.5.3.3; ACI 318-02, 9.5.3.3; ACI 318-99, 9.5.3.3

in metric unit system for ACI 318-14, ACI 318-11, ACI 318-08, and ACI 318-05 from[7]:

$$h = \begin{cases} \dfrac{l_n\left(0.8 + \dfrac{f_y}{1,400}\right)}{36 + 5\beta\left(\alpha_{fm} - 0.2\right)} \geq 125 \text{ mm} & \text{if } 0.2 < \alpha_{fm} \leq 2.0 \\ \dfrac{l_n\left(0.8 + \dfrac{f_y}{1,400}\right)}{36 + 9\beta} \geq 90 \text{ mm} & \text{if } \alpha_{fm} > 2.0 \end{cases} \qquad \text{Eq. 2-2}$$

and in metric unit system for ACI 318-02 and ACI 318-99 from[8]:

$$h = \begin{cases} \dfrac{l_n\left(0.8 + \dfrac{f_y}{1,500}\right)}{36 + 5\beta\left(\alpha_{fm} - 0.2\right)} \geq 120 \text{ mm} & \text{if } 0.2 < \alpha_{fm} \leq 2.0 \\ \dfrac{l_n\left(0.8 + \dfrac{f_y}{1,500}\right)}{36 + 9\beta} \geq 90 \text{ mm} & \text{if } \alpha_{fm} > 2.0 \end{cases} \qquad \text{Eq. 2-3}$$

where:

$l_n$ = longer clear span measured face-to-face of beams,

$\beta$ = ratio of the clear spans in long to short direction,

$f_y$ = yield stress of reinforcing steel,

$\alpha_{fm}$ = average value of $\alpha_f$, the ratio of flexural stiffness of a beam section to the flexural stiffness of a width of slab bounded laterally by centerlines of adjacent panels on either side of the beam, for all beams supporting the edges of a slab panel.

[7] ACI 318M-11, 9.5.3.3; ACI 318M-08, 9.5.3.3; ACI 318M-05, 9.5.3.3

[8] ACI 318M-02, 9.5.3.3; ACI 318M-99, 9.5.3.3

The program assumes that beams are present on all sides of a panel if the span under consideration includes a longitudinal beam and there are transverse beams defined at both ends of the span. If this assumption is satisfied but in reality beams are not present on all sides (e.g. design strip next to the one under consideration has no longitudinal beam) then the user is advised to check deflections even if slab thickness is larger than the minimum slab thickness reported by the program.

For the design of ACI slabs without beams ($\alpha_{fm} \leq 0.2$) spanning between interior supports the minimum thickness shall conform to ACI 318 Table 9.5(c) and will not be less than 5.0 in. [125 mm for ACI 318M-11/08/05 or 120 mm for ACI 318M-02/99] for flat plates (slabs without drop panel) and not less than 4.0 in. [100 mm] for two-way flat slab systems (slab with drop panels)[9]. For flat slabs that contain valid drop panels (see Figure 2.4), Table 9.5(c) reduces the minimum thickness by approximately 10%. For values of $f_y$ between the ones given in the table, minimum thickness is determined by linear interpolation.

For design strips that have neither beams between all supports nor beams between interior supports (e.g. exterior strips with beams on the outside edges only), the program reports maximum value of minimum slab thickness resulting from both Table 9.5(c) and Equations. However, since this case is not explicitly covered by the ACI code, the user is advised to check deflections even if slab thickness is larger than the minimum slab thickness reported by the program.

[9] ACI 318-14, 8.3.1.1; ACI 318-11, 9.5.3.2; ACI 318-08, 9.5.3.2; ACI 318-05, 9.5.3.2; ACI 318-02, 9.5.3.2; ACI 318-99, 9.5.3.2; ACI 318M-08, 9.5.3.2; ACI 318M-05, 9.5.3.2; ACI 318M-02, 9.5.3.2; ACI 318M-99, 9.5.3.2

For CSA A23.3 standard[10], the minimum thickness of slab with beams spanning between all supports is:

$$h_s \geq \frac{l_n \left(0.6 + \dfrac{f_y}{1,000}\right)}{30 + 4\beta\alpha_m} \qquad \alpha_m \text{ taken} < 2.0 \tag{Eq. 2-4}$$

with the value of $\alpha_m$ evaluated for CSA A23.3-04 using the following beam moment of inertia:

$$I_b = \frac{b_w h^3}{12} 2.5\left(1 - \frac{h_s}{h}\right) \tag{Eq. 2-5}$$

For flat plates and slabs with column capitals[11], the minimum slab thickness is:

$$h_s \geq \frac{l_n \left(0.6 + \dfrac{f_y}{1,000}\right)}{30} \tag{Eq. 2-6}$$

For slabs with drop panels[12], the minimum slab thickness satisfies the conditions:

$$h_s \geq \frac{l_n \left(0.6 + \dfrac{f_y}{1,000}\right)}{30\left[1 + \left(\dfrac{2x_d}{l_n}\right)\left(\dfrac{h_d - h_s}{h_s}\right)\right]} \qquad (\text{CSA A23.3-94}) \tag{Eq. 2-7}$$

$$h_s \geq \frac{l_n \left(0.6 + \dfrac{f_y}{1,000}\right)}{30} - \frac{2x_d}{l_n}\Delta_h \qquad (\text{CSA A23.3-14/04}) \tag{Eq. 2-8}$$

[10] CSA A23.3-14, 13.2.5; CSA A23.3-04, 13.2.5; CSA A23.3-94, 13.3.5

[11] CSA A23.3-14, 13.2.3; CSA A23.3-04, 13.2.3; CSA A23.3-94, 13.3.3

[12] CSA A23.3-14, 13.2.4; CSA A23.3-04, 13.2.4; CSA A23.3-94, 13.3.4

where ($h_d - h_s$) shall not be greater than $h_s$ and

$x_d$ = dimension from face of column to edge of drop panel, but not more than $l_n / 4$,

$2x_d / l_n$ = the smaller of the values determined in the two directions,

$\Delta_h$ = additional thickness of the drop panel below the soffit of the slab and shall not be taken more than $h_s$.

The minimum thickness in a span that contains a discontinuous edge will be increased by 10%, if the edge beam provided has a stiffness ratio, $\alpha_f$, of less than 0.80[13]. The first and last spans are considered to contain a discontinuous edge as well as a span that contains an exterior edge.

The minimum thickness of slab bands follows the requirements for the beams[14].

13 ACI 318-14, 8.3.1.2; ACI 318-11, 9.5.3.3 (d); ACI 318-08, 9.5.3.3 (d); ACI 318-05, 9.5.3.3 (d); ACI 318-02, 9.5.3.3 (d); ACI 318-99, 9.5.3.3 (d), CSA A23.3-14, 13.2.3, 13.2.4; CSA A23.3-04, 13.2.3, 13.2.4; CSA A23.3-94, 13.3.3

14 CSA A23.3-04, 13.2.6

## Drop Panel Dimensions

Per ACI[15], a valid drop must extend in each direction at least one-sixth the center-to-center span length in that direction (Figure 2.4). The depth of an invalid drop will not be used in the calculation of the depth used to reduce the amount of negative reinforcement required over a column[16]. If the valid drop depth is greater than one-quarter the distance from the edge of the drop panel to the face of the column (*x*) the excess depth exceeding ¼ *x* will not be considered in the calculation of the effective depth used to reduce the amount of negative reinforcement required at a column (Figure 2.5)[17]. Slabs that contain valid drops are allowed a 10% decrease in minimum slab depth[18].

[15] ACI 318-14, 8.2.4; ACI 318-11, 13.2.5; ACI 318-08, 13.2.5; ACI 318-05, 13.2.5; ACI 318-02, 13.3.7.1, 13.3.7.2; ACI 318-99, 13.3.7.1, 13.3.7.2

[16] ACI 318-14, 8.2.4; ACI 318-11, 13.2.5; ACI 318-08, 13.2.5; ACI 318-05, 13.2.5, 13.3.7; ACI 318-02, 13.3.7; ACI 318-99, 13.3.7

[17] ACI 318-14, 8.5.2.2; ACI 318-11, 13.3.7; ACI 318-08, 13.3.7; ACI 318-05, 13.3.7; ACI 318-02, 13.3.7.3; ACI 318-99, 13.3.7.3; CSA A23.3-14, 13.10.7; CSA A23.3-04, 13.10.7; CSA A23.3-94, 13.11.6

[18] ACI 318-14, 8.3.1.1; ACI 318-11, 9.5.3.2; ACI 318-08, 9.5.3.2; ACI 318-05, 9.5.3.2; ACI 318-02, 9.5.3.2, ACI 318-99, 9.5.3.2

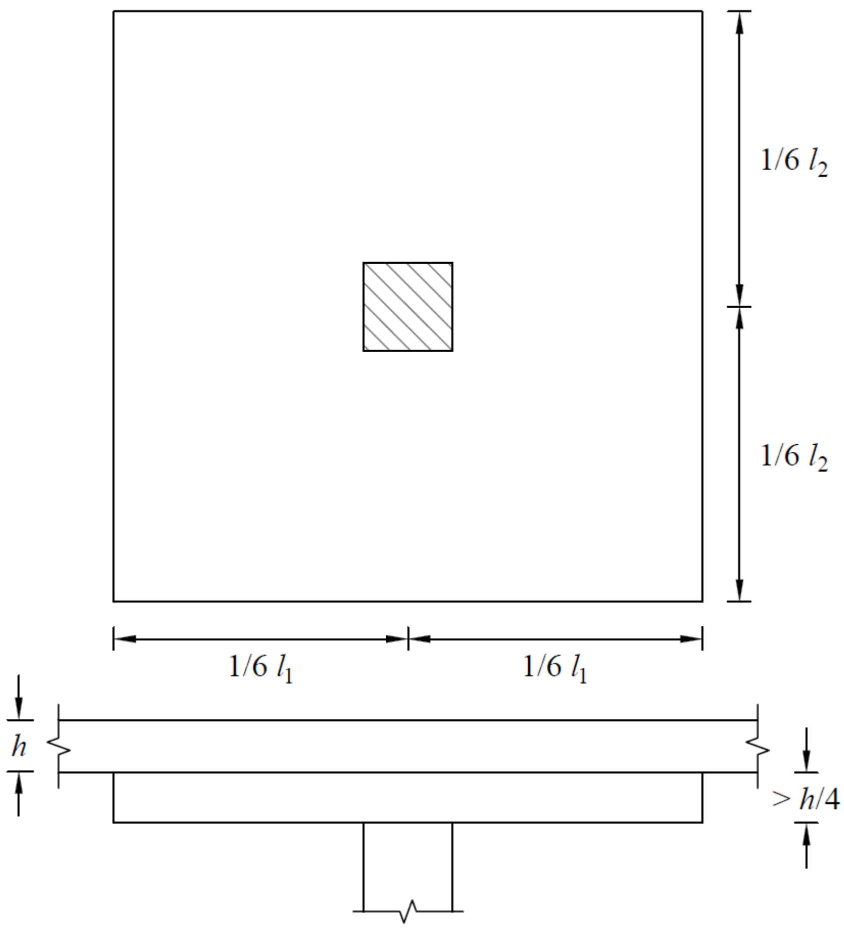


Figure 2.4 – Valid Drop Dimensions

The input drop dimensions will be used for self-weight computations, when computing slab stiffness to determine deflections, moments, shears, and when computing punching shear around a column[19].

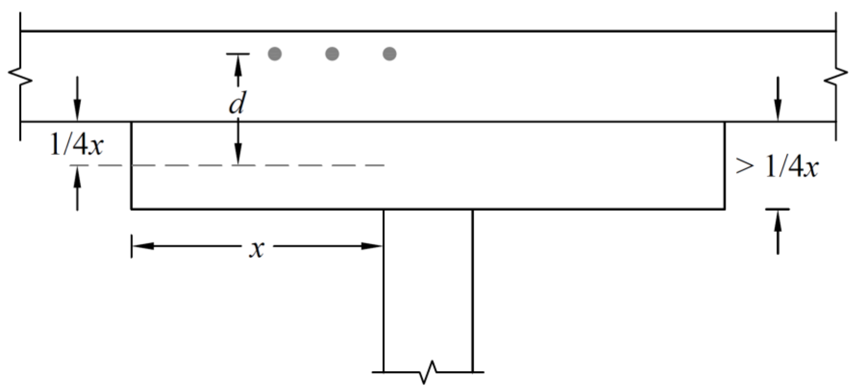


Figure 2.5 – Excess Drop Depth

[19] ACI 318-14, 8.2.4; ACI 318-11, R13.2.5; ACI 318-08, R13.2.5; ACI 318-05, R13.2.5

## Beam Dimensions

The program follows linear distribution of strain (plain section) assumption[20] for flexure design which is applicable to shallow flexural members. In case of deep beams[21], design standards recommend using non-linear distribution of strain or strut-and-tie method. The program checks beam dimensions and if a beam with the following clear span, $l_n$, to overall depth, $h$, ratio is found:

| | | |
|---|---|---|
| $l_n \le 4h$ | ACI 318-11, ACI 318-08, ACI 318-05 and ACI 318-02 | Eq. 2-9 |
| $l_n \le 2.5h$ | ACI 318-99, continous spans | |
| $l_n \le 1.25h$ | ACI 318-99, simple spans | |
| $l_n \le 2h$ | CSA A23.3-14, CSA A23.3-04 and CSA A23.3-94 | |

a warning is issued alerting the user that additional deep beam design and detailing is required. For cantilevers, the warning is issued only if their clear span is larger than overall depth.

[20] ACI 318-14, 22.2.1.2; ACI 318-11, 10.2.2; ACI 318-08, 10.2.2; ACI 318-05, 10.2.2; ACI 318-02, 10.2.2; ACI 318-99, 10.2.2; CSA A23.3-14, 10.1.2; CSA A23.3-04, 10.1.2; CSA A23.3-94, 10.1.2

[21] ACI 318-14, 9.9.1.2; ACI 318-11, 10.7.1; ACI 318-08, 10.7.1; ACI 318-05, 10.7.1; ACI 318-02, 10.7.1; ACI 318-99, 10.7.1; CSA A23.3-14; 10.7.1; CSA A23.3-04; 10.7.1; CSA A23.3-94, 10.7.1

### 2.2.1.2. Material Considerations

By entering the concrete density and compressive strength of the members, default values for the other concrete properties are determined. The slabs/beams and columns may have different concrete properties.

The density of concrete is used to determine the type of concrete, modulus of elasticity, and self-weight.

The concrete type is determined in accordance with Table 2.1.

<table>
<tr><th rowspan="3">Type</th><th colspan="2">ACI 318-14<br>ACI 318-11<br>ACI 318-08</th><th colspan="2">ACI 318-05<br>ACI 318-02<br>ACI 318-99</th></tr>
<tr><th colspan="2">$w_c$</th><th colspan="2">$w_c$</th></tr>
<tr><th>pcf</th><th>kg/m$^3$</th><th>pcf</th><th>kg/m$^3$</th></tr>
<tr><td>Normal</td><td>$135 \leq w_c$</td><td>$2,155 \leq w_c$</td><td>$130 \leq w_c$</td><td>$2,000 \leq w_c$</td></tr>
<tr><td>Sand-Lightweight</td><td>$115 < w_c < 135$</td><td>$1,840 < w_c < 2,155$</td><td>$105 < w_c < 130$</td><td>$1,700 < w_c < 2,000$</td></tr>
<tr><td>All-Lightweight</td><td>$w_c \leq 115$</td><td>$w_c \leq 1,840$</td><td>$w_c \leq 105$</td><td>$w_c \leq 1,700$</td></tr>
</table>

<table>
<tr><th rowspan="3">Type</th><th colspan="2">CSA A23.3-14<br>CSA A23.3-04</th><th colspan="2">CSA A23.3-94</th></tr>
<tr><th colspan="2">$\gamma_c$</th><th colspan="2">$\gamma_c$</th></tr>
<tr><th>kg/m$^3$</th><th>pcf</th><th>kg/m$^3$</th><th>pcf</th></tr>
<tr><td>Normal</td><td>$2,150 \leq \gamma_c$</td><td>$134.2 \leq \gamma_c$</td><td>$2,000 \leq \gamma_c$</td><td>$124.8 \leq \gamma_c$</td></tr>
<tr><td>Low Density</td><td>$1,850 < \gamma_c < 2,150$</td><td>$115.5 < \gamma_c < 134.2$</td><td>$1,700 < \gamma_c < 2,000$</td><td>$106.1 < \gamma_c < 124.8$</td></tr>
<tr><td>Semi-low Density</td><td>$\gamma_c \leq 1,850$</td><td>$\gamma_c \leq 115.5$</td><td>$\gamma_c \leq 1,700$</td><td>$\gamma_c \leq 106.1$</td></tr>
</table>

Table 2.1 – Concrete Weight Classification

Once the compressive strength of concrete $f_c'$ is input, various parameters are set to their default values.

The modulus of elasticity is computed as[22]:

$$E_c = 33 w_c^{1.5} \sqrt{f_c'} \qquad \text{Eq. 2-15}$$

where:

$w_c$ = the unit weight of concrete.

For CSA A23.3 standard[23]

$$E_c = \left(3{,}300\sqrt{f_c'} + 6{,}900\right)\left(\frac{\gamma_c}{2{,}300}\right)^{1.5} \qquad \text{Eq. 2-16}$$

where:

$\gamma_c$ = the density of concrete.

The square root of $f_c'$ is limited to 100 psi for the computation of shear strength provided by concrete, $V_c$, and development lengths.[24]

For CSA A23.3-14/04 standard the value of square root of $f_c'$ used to calculate factored shear resistance $v_r$ shall not exceed 8 MPa.[25]

[22] ACI 318-14,19.2.2.1 (a); ACI 318-11, 8.5.1; ACI 318-08, 8.5.1; ACI 318-05, 8.5.1; ACI 318-02, 8.5.1; ACI 318-99, 8.5.1; CSA A23.3-14, 8.6.2.2; CSA A23.3-04, 8.6.2.2; CSA A23.3-94, 8.6.2.2

[23] CSA A23.3-14, 8.6.2.2; CSA A23.3-04, 8.6.2.2; CSA A23.3-94, 8.6.2.2

[24] ACI 318-14, 22.5.3.1, 22.6.3.1; ACI 318-11, 11.1.2; ACI 318-08, 11.1.2; ACI 318-05, 11.1.2; ACI 318-05, 11.1.2; ACI 318-99, 11.1.2

[25] CSA A23.3-14, 13.3.4.2; CSA A23.3-04, 13.3.4.2

The modulus of rupture is used to determine the cracking moment when computing the effective moment of inertia in deflection calculations. For ACI 318 code, the default value of modulus of rupture, $f_r$, is set equal to:[26]

$$f_r = 7.5\lambda\sqrt{f'_c} \qquad \text{Eq. 2-17}$$

and for the CSA A23.3 standard, the default value of modulus of rupture $f_r$ is:[27]

$$f_r = 0.6\lambda\sqrt{f'_c} \qquad \text{Eq. 2-18}$$

For two-way slabs analyzed in accordance with CSA A23.3-94 as well as for beams, one-way, and two-way slabs analyzed in accordance with CSA A23.3-14/04, the default value is reduced to its half value[28], i.e.

$$f_r = \frac{0.6\lambda\sqrt{f'_c}}{2} \qquad \text{Eq. 2-19}$$

Factor $\lambda$ reflecting the reduced mechanical properties of lightweight concrete is equal to[29]:

$$\lambda = \begin{cases} 1.00 & \text{for normal density concrete} \\ 0.85 & \text{for sand-lightweight (structural semi-low-density) concrete} \\ 0.75 & \text{for all-lightweight (structural low-density) concrete} \end{cases}$$

Refer to Table 2.1 for determination of concrete type.

There is no limit imposed on $f_r$. Entering a large value of $f_r$ will produce deflections based on gross properties (i.e. uncracked sections).

The default values for the longitudinal reinforcement yield strength, $f_y$, and shear reinforcement yield strength, $f_{yv}$, if applicable, are set equal to 60 ksi [413 MPa] for ACI and 400 MPa for CSA.

[26] ACI 318-14, 19.2.3.1; ACI 318-11, 9.5.2.3; ACI 318-08, 9.5.2.3; ACI 318-05, 9.5.2.3; ACI 318-02, 9.5.2.3; ACI 318-99, 9.5.2.3

[27] CSA A23.3-14, 8.6.4; CSA A23.3-04, 8.6.4; CSA A23.3-94, 8.6.4

[28] CSA A23.3-14, 9.8.2.3; CSA A23.3-04, 9.8.2.3; CSA A23.3-94, 13.3.6

[29] ACI 318-14, 19.2.4; ACI 318-11, 8.6; ACI 318-08, 8.6; ACI 318-05, 11.2.1.2; ACI 318-02, 11.2.1.2; ACI 318-99, 11.2.1.2; CSA A23.3-14, 8.6.5; CSA A23.3-04, 8.6.5; CSA A23.3-94, 8.6.5

### 2.2.1.3. Loading Considerations

#### Load Cases and Load Combinations

Each load is applied to the span element under one of the 6 (A through F) load cases. The span element is analyzed and designed under load combinations. A load combination is the algebraic sum of each of the load cases multiplied by a user specified load factor.

The program allows defining up to 50 load combinations. The user has full control over the combinations used. The program contains predefined (built into the program) default primary load combinations for the supported codes. These default combinations are created when starting a new project.

For the design of span elements, the required area of steel is calculated due to the element internal forces from the ultimate level combinations. On the other hand, displacement envelopes are determined using the displacement from the service level combinations.

Basic load cases and the corresponding load factors for load combinations are suggested as defaults to facilitate user's input. The default load cases and load combination factors should be modified as necessary at the discretion of the user to satisfy project and code requirements.

Given the numerous applications of spSlab/spBeam to structural floor systems, the load combinations must be examined in detail to consider the myriad of possible conditions that can exist. A detailed discussion of load case and combination factors is provided in Appendix A.1.

#### Load Patterns

The evaluation of floor systems requires consideration of various live load configurations to capture the critical effects on structural responses. To address these scenarios, the program automatically generates live load cases using predefined patterns. The program also incorporates a live load pattern reduction ratio, defaulting to 75% for two-way systems per code requirements, with user customization available between 0–100%. A detailed discussion of load patterns is provided in Section 2.3.3.4.

## Off-Centered Loads for Two-Way

For two-way slab systems, the distribution of loads along the analysis direction becomes simplified while utilizing the Equivalent Frame Method (EFM), eliminating the need to consider additional torsion and moments for “Off-Centered” loads. The following figure highlights how different load types - uniform distributed loads (A), concentrated loads (B), and line loads (C) - are translated into equivalent load input values for spSlab. Each load is converted into the corresponding program input format, ensuring accurate representation of the structural behavior. This approach streamlines the modeling process while maintaining the integrity of the applied loads in the analysis. It is critical that the engineer and user exercise maximum judgment in this area based on his thorough understanding of the EFM and how its application in two directions should be managed. The simplification of taking a two-way concrete floor system and breaking it into two individual one-way systems should not overlook how the overall system will ultimately behave. As such, loads handled in one direction will have to also be reconsidered in the orthogonal direction where they may present a more governing condition.

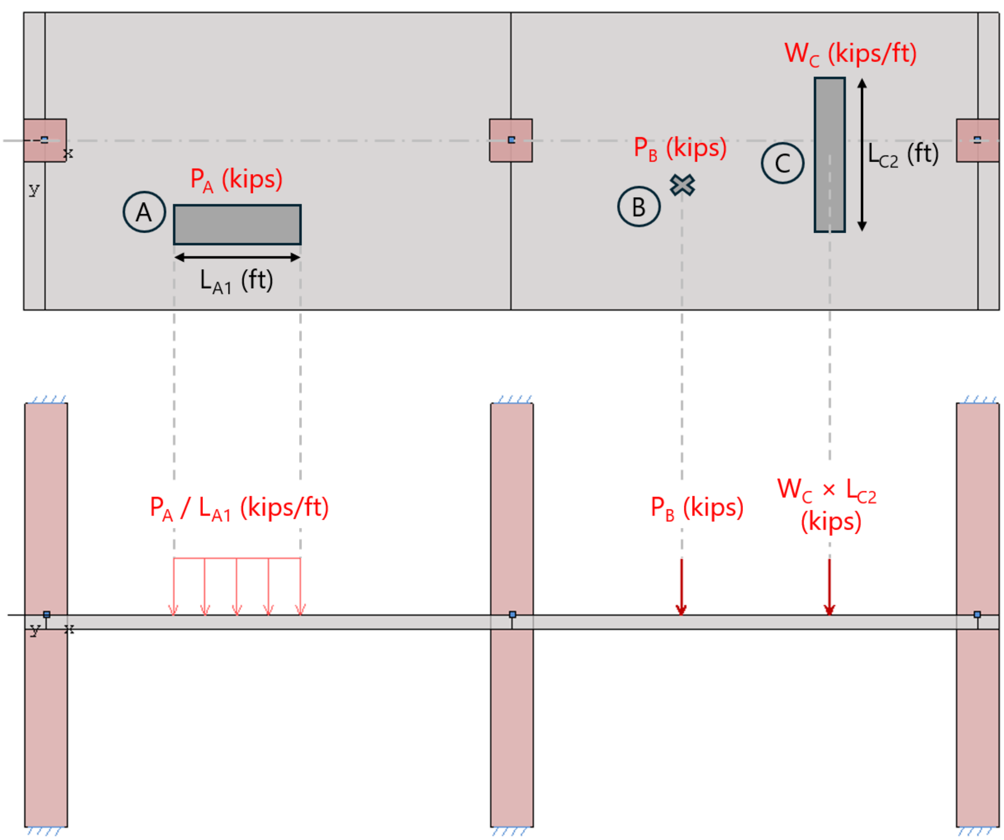


Figure 2.6 – Entering “Off-Centered” loads into spSlab model as equivalent load input

## Loads Due to Openings

When a floor system contains an opening, usually it is due to an important Mechanical, Electrical or Piping (MEP) equipment that are passing through such opening. As such, the presence of the opening complicates the analysis using the EFM. The engineer has to consider the absence of some or an entire part of the column strip or the middle strip. In addition, the additional loads from attachments borne by the MEP equipment or stairs or any other accessories have to also be added to an area that is already compromised by the opening. Such loads are commonly concentrated point loads that are close or in direct contact with the support creating concentrated shear forces that have to be handled carefully depending on their proximity to the support.

The impact of such floor openings and concentrated forces on the shear force and bending moment diagrams and ultimately the reinforcement required will depend greatly on a number of variables that are difficult to quantify, nor are they clearly explained in the current codes and standards.

StructurePoint's experience indicates that occasionally engineers have to forego the intended two-way behavior and resort to one-way action in certain spans or in an entire design strip. In some instances, additional beams and framing should be added to accommodate such loss of section and the concentration of forces. The engineering end-user is advised to e-mail and contact StructurePoint's experts to discuss such conditions and find the proper application of the EFM to model their floor system in spSlab to that specific condition.

#### 2.2.1.4. Special Considerations for Joist Systems

The following considerations are applicable to one-way (standard and wide module) and two-way (waffle) joist systems unless noted. More details about this topic can be found in "Two-Way Joist Concrete Slab Floor (Waffle Slab) System Analysis and Design" and "One-Way Wide Module (Skip Joist) Concrete Floor System Design" Design Examples from StructurePoint.

##### Rib Dimensions

Rib dimensions will be considered valid if the rib width is at least 4 in. [100 mm], the depth is no more than 3-1/2 times the rib width, and the clear spacing between ribs does not exceed 30 in. [800 mm][30]. If rib dimensions do not meet these requirements (e.g. wide module joist systems) the code requires such ribs to be designed as beams[31]. The program treats the design of wide-spaced joists the same way as for valid slabs, regardless of code limitation. If the code limits are exceeded, the condition is flagged and the 10% increase of rib shear capacity is not used. The user is then responsible to validate the resulting design and reconcile the code requirements.

##### Minimum Thickness for Joist Systems

The minimum slab thickness allowed for joist slabs is one-twelfth the clear rib spacing, or 1.5 in. [40 mm] for ACI code[32] and 50 mm for CSA code[33].

##### Joist System Analysis and Design

For the purposes of analysis and design, the program replaces the ribbed slab with solid slabs of equivalent moment of inertia, weight, punching shear capacity, and one-way shear capacity.

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30 ACI 318-14, 8.8.1.2, 8.8.1.4, 9.8.1.2, 9.8.1.4; ACI 318-11, 8.13.2, 8.13.3; ACI 318-08, 8.13.2, 8.13.3; ACI 318-05, 8.11.2, 8.11.3; ACI 318-02, 8.11.2, 8.11.3; ACI 318-99, 8.11.2, 8.11.3; CSA A23.3-14, 10.4.1; CSA A23.3-04, 10.4.1; CSA A23.3-94, 10.4.1

31 ACI 318-14, 8.8.1.8, 9.8.1.8; ACI 318-11, 8.13.4; ACI 318-08, 8.13.4; ACI 318-05, 8.11.4; ACI 318-02, 8.11.4; ACI 318-99, 8.11.4; CSA A23.3-14, 10.4.2; CSA A23.3-04, 10.4.2; CSA A23.3-94, 10.4.2

32 ACI 318-14, 8.8.2.1.1, 9.8.2.1.1; ACI 318-11, 8.13.5.2; ACI 318-08, 8.13.5.2; ACI 318-05, 8.11.5.2; ACI 318-02, 8.11.5.2; ACI 318-99, 8.11.5.2

33 CSA A23.3-14, 10.4.1; CSA A23.3-04, 10.4.1; CSA A23.3-94, 10.4.1

The equivalent thickness based on system weight is used to compute the system self-weight. This thickness, $h_w$, is given by:

$$h_w = \frac{V_{\text{mod}}}{A_{\text{mod}}} \qquad \text{Eq. 2-10}$$

where:

$V_{mod}$ = the volume of one joist module,

$A_{mod}$ = the plan area of one joist module.

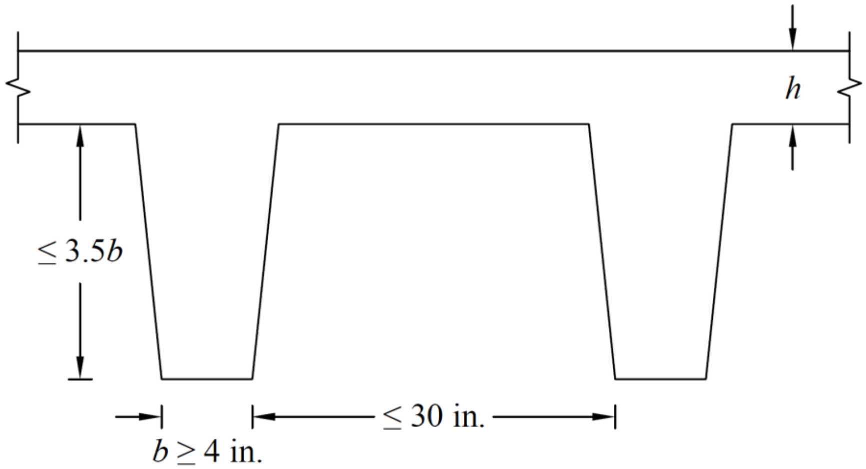



Figure 2.7 – Valid Rib Dimensions

The equivalent thickness based on moment of inertia is used to compute slab stiffness. The ribs spanning in the transverse direction are not considered in the stiffness computations. This thickness, $h_{MI}$, is given by:

$$h_{MI} = \left(\frac{12 I_{rib}}{b_{rib}}\right)^{\frac{1}{3}} \qquad \text{Eq. 2-11}$$

where:

$I_{rib}$ = moment of inertia of one joist section between centerlines of ribs,

$b_{rib}$ = the center-to-center distance of two ribs (clear rib spacing plus rib width).

The drop panel depth for two-way joist (waffle) slab systems is set equal to the rib depth. The equivalent drop depth based on moment of inertia, $d_{MI}$, is given by:

$$d_{MI} = h_{MI} + h_{rib} \qquad \text{Eq. 2-12}$$

where:

$h_{rib}$ = rib depth below slab,

$h_{MI}$ = equivalent slab thickness based on moment of inertia.

A drop depth entered for a waffle slab system other than 0 will be added to $d_{MI}$, thus extending below the ribs.

One-way shear capacity, $V_c$ (increased by 10% for ACI code[34]), is calculated assuming the shear cross-section area consisting of ribs and the portion of slab above, decreased by concrete cover. For such section the equivalent shear width of single rib is calculated from the formula:

$$b_v = b + \frac{d}{12} \qquad \text{Eq. 2-13}$$

where:

$b$ = rib width,

$d$ = distance from extreme compression fiber to tension reinforcement centroid.

[34] ACI 318-14, 8.8.1.5, 9.8.1.5; ACI 318-11, 8.13.8; ACI 318-08, 8.13.8; ACI 318-05, 8.11.8; ACI 318-02, 8.11.8; ACI 318-99, 8.11.8

The equivalent thickness based on shear area is used to compute the area of concrete section resisting punching shear transfer, $A_c$ around drop panels in two-way joist (waffle) systems. The equivalent slab thickness, $h_V$, used to compute $A_c$, is given by:

$$h_v = \frac{A_{rib}}{b_{rib}} + d_{reinf} \qquad \text{Eq. 2-14}$$

where:

$A_{rib}$ = the entire rib area below the slab plus the slab thickness minus the distance to the reinforcement centroid, $d_{reinf}$, within the rib width, i.e., the slab depth between the ribs is not considered as contributing to shear capacity,

$b_{rib}$ = the center-to-center distance of two ribs (clear rib spacing plus rib width),

$d_{reinf}$ = the distance to reinforcement centroid from the slab top at the support.

When calculating flexural capacity for negative bending moments, the distance between center of top reinforcement to the soffit of the rib is used as an effective depth, $d$, while assuming the width of compression zone as equal to the center-to-center distance of two ribs ($b_{rib}$). This assumption results in higher estimates of negative moment capacity since the space between ribs is void. The user may switch to a single rib design or investigation as a beam in order to consider rib width only in the compression zone.

## 2.2.2. Geometry Checks

spSlab and spBeam provide various geometric checks to avoid an analysis with an inconsistent system. Dimensions of slabs, beams, drops, bands and column capitals are checked and modified to produce a code compliant system.

### 2.2.2.1. Slabs

If a slab cantilever length is less than one-half the column dimension in the direction of analysis, $c_1$, or less than the lateral extension of the transverse beam into the cantilever, the cantilever length will be increased to the larger of these two lengths. If the slab width is less than one-half the column dimension transverse to the direction of analysis, $c_2$, or less than one-half the longitudinal beam width, the slab width will be increased to the larger of these two widths.

### 2.2.2.2. Drop Panels

If a drop panel extends beyond the end of a slab cantilever, the drop panel dimensions will be reduced so that it extends only to the cantilever tip.

Guidance is absent from all standards and reference documents regarding continuous extension of drop panels between supports. If a slab band is discontinuous, to model this condition, it must be completed with a user-defined drop panel of corresponding width and thickness on a discontinuous end, as a minimum, in order to complete the analysis.

### 2.2.2.3. Column Capitals

When a column capital is defined, the program checks if capital side slope (depth/extension ratio) is more than 1, i.e. the angle between capital side and column axis is no greater than 45 degrees[35]. The upper limit for the side slope is 50. If a column with capital frames into a drop panel (or a beam), extension of the capital will be automatically adjusted – if necessary – so that projected sides of the capital do not fall outside of the drop panel (or the beam) edges before reaching slab

[35] ACI 318-14 (Ref. [1]), 8.4.1.4; ACI 318-11 (Ref. [1]), 13.1.2; ACI 318-08 (Ref. [3]),13.1.2; ACI 318-05 (Ref. [4]), 13.1.2; ACI 318-02 (Ref. [5]), 13.1.2; ACI 318-99 (Ref. [6]), 13.1.2; CSA A23.3-04, 2.2; CSA A23.3-94, 13.1

soffit (see Figure 2.8). The modified column capital extension will be used when computing column stiffness and in punching shear calculations.

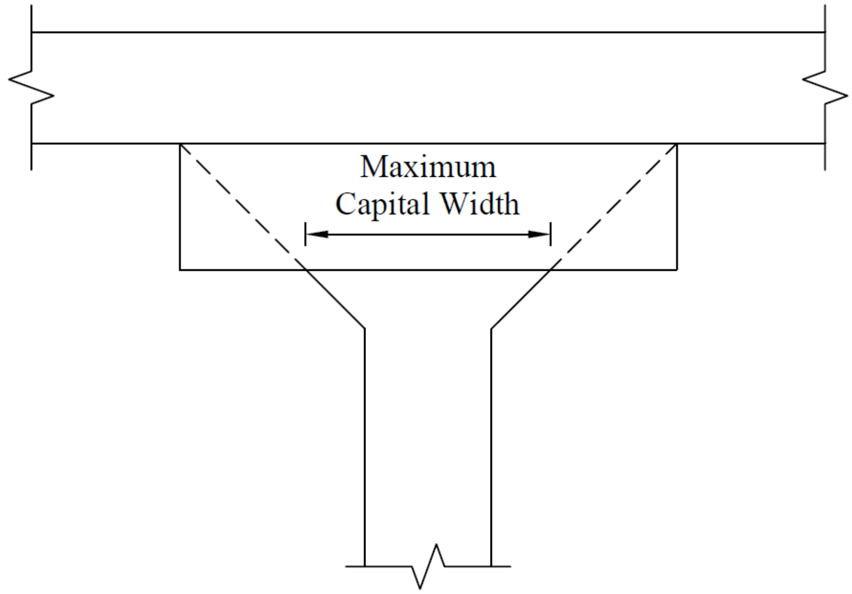



Figure 2.8 – Maximum Capital Width

### 2.2.3. Definitions and Assumptions

The analysis of the reinforced concrete members performed by spSlab/spBeam conforms to the provisions of the Strength Design Method and Unified Design Provisions and is based on the following basic assumptions:

- All conditions of strength satisfy the applicable conditions of equilibrium and strain compatibility
- Strain in the concrete and in the reinforcement is directly proportional to the distance from the neutral axis. In other words, plane sections normal to the axis of bending are assumed to remain plane after bending.
- An equivalent uniform rectangular concrete stress block is used with a maximum usable ultimate strain at the extreme concrete compression fiber equal to 0.003 for ACI codes and 0.0035 for CSA codes
- Tensile strength of concrete in flexural calculations is neglected
- For reinforcing steel, the elastic-plastic stress-strain distribution is used
- Assumptions related to the analysis method, along with detailed provisions and equations for the design codes and unit systems supported by spSlab/spBeam, are outlined in Sections 2.3, 2.4, and 2.5.

## 2.3. Analysis Methods

### 2.3.1. Overview of Equivalent Frame Method

The equivalent frame method, as described in the code[36], is used by spSlab for both analysis and design. The code specifies procedures for the analysis and design of slab systems reinforced for flexure in more than one direction, with or without beams between the supports. A two-way slab[37] system, including the slab and its supporting beams, columns, and walls may be designed by either of the following procedures

- The Direct Design Method
- The Equivalent Frame Method

spSlab uses the Equivalent Frame Method of analysis which is based on extensive analytical and experimental studies conducted at the University of Illinois. Note also that there are no restrictions on the number of slab spans or on dead-to-live load ratios in this method of analysis.

The first step in the frame analysis is to divide the three-dimensional building into a series of two-dimensional frames extending to the full height of the building. Horizontal members for each frame are formed by slab strips as shown in Figure 2.9. For vertical loads, each story (floor and/or roof) may be analyzed separately with the supporting columns being considered fixed at their remote ends (Figure 2.10).

The required reinforcing and resulting deflections for an interior or exterior panel in a floor system shall be combined from the analysis of two equivalent frames in orthogonal directions in order to arrive at the final design.

[36] ACI 318-14, 8.11; ACI 318-11, 13.7; ACI 318-08, 13.7; ACI 318-05, 13.7; ACI 318-02, 13.7; ACI 318-99, 13.7; CSA A23.3-14, 13.8; CSA A23.3-04, 13.8; CSA A23.3-94, 13.9

[37] Implies a slab supported by isolated supports which permits the slab to bend in two orthogonal directions.

## 2.3.1.1. Stiffness Characteristics

The stiffness factors for the horizontal members (the slab beams) and the vertical members (the equivalent columns) are determined using segmental approach.

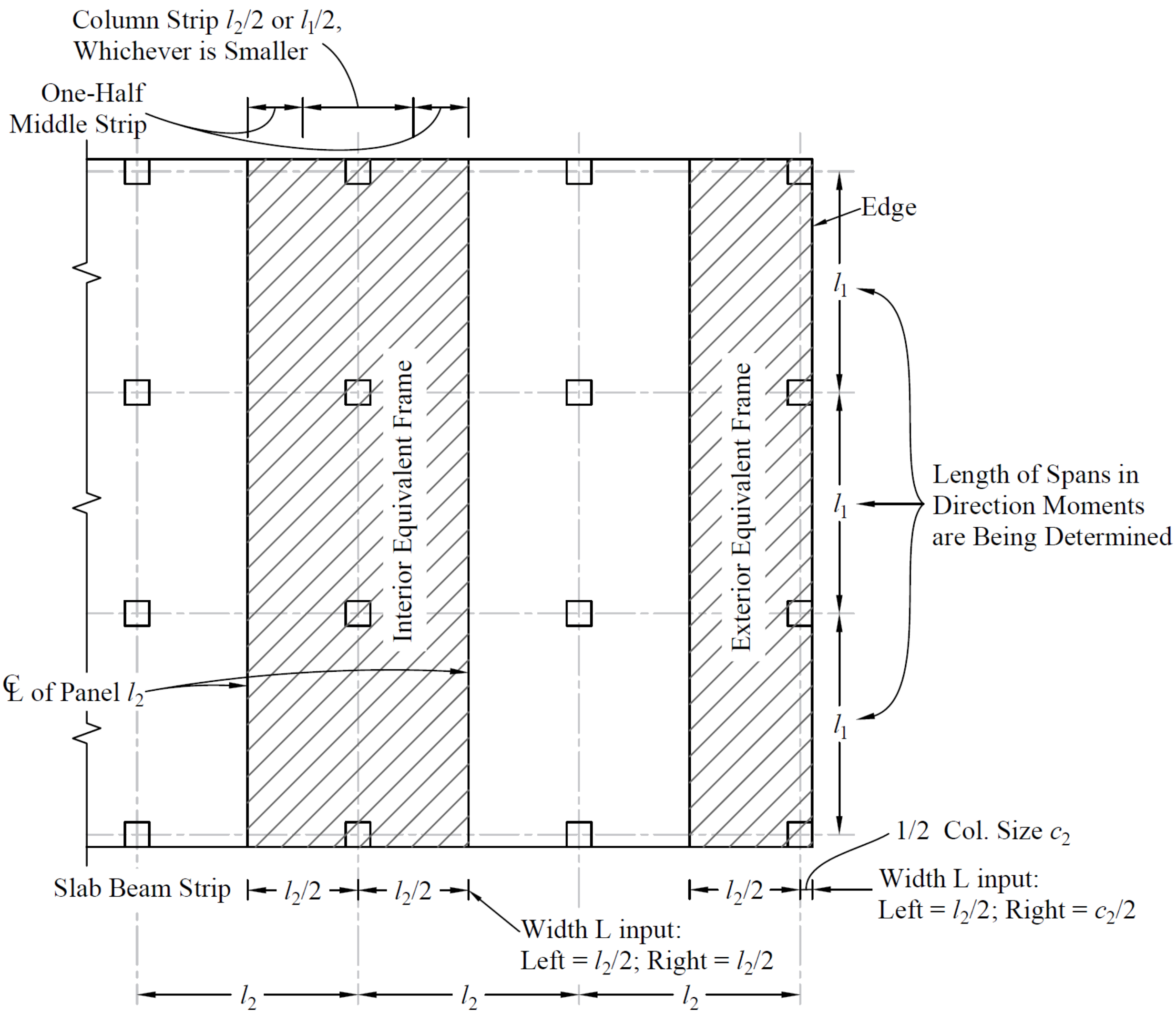



Figure 2.9 – Design Strips

### 2.3.1.2. Slab Beams

The moment of inertia of the slab beam elements between the faces of the columns (or column capitals) is based on the uncracked section of the concrete including beams or drop panels. The moment of inertia from the face of the column (or capital) to the centerline of the column (or capital) is considered finite and is dependent on the transverse dimensions of the panel and support. This reduced stiffness (as compared to the infinite stiffness assumed in previous codes) is intended to soften the slab at the joint to account for the flexibility of the slab away from the support. This is consistent with provisions of the code.[38] Figure 2.11 shows the changes in stiffness between a slab, and a drop panel, and a column (or capital).

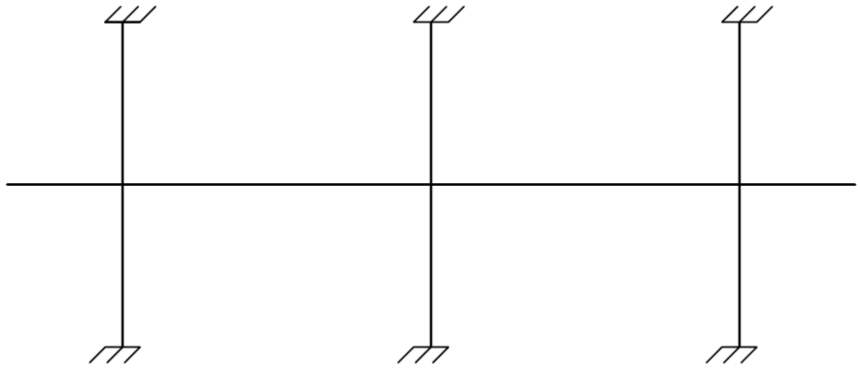


Figure 2.10 – Analytical Model for Vertical Loads for a Typical Story

### 2.3.1.3. Columns

The computation of the column stiffness is more complicated as it utilizes the concept of an equivalent column. Theoretical slab studies have shown that the positive moment in a slab may increase under pattern loads, even if rigid columns are used, because of the flexibility of the slab away from the column. However, if a two-dimensional frame analysis is applied to a structure with rigid columns, pattern loads will have little effect.

38 ACI 318-14, 8.11.3; ACI 318-11, 13.7.3; ACI 318-08, 13.7.3; ACI 318-05, 13.7.3; ACI 318-02, 13.7.3; ACI 318-99, 13.7.3; CSA A23.3-14, 13.8.2.3; CSA A23.3-04, 13.8.2.3; CSA A23.3-94, 13.9.2.3

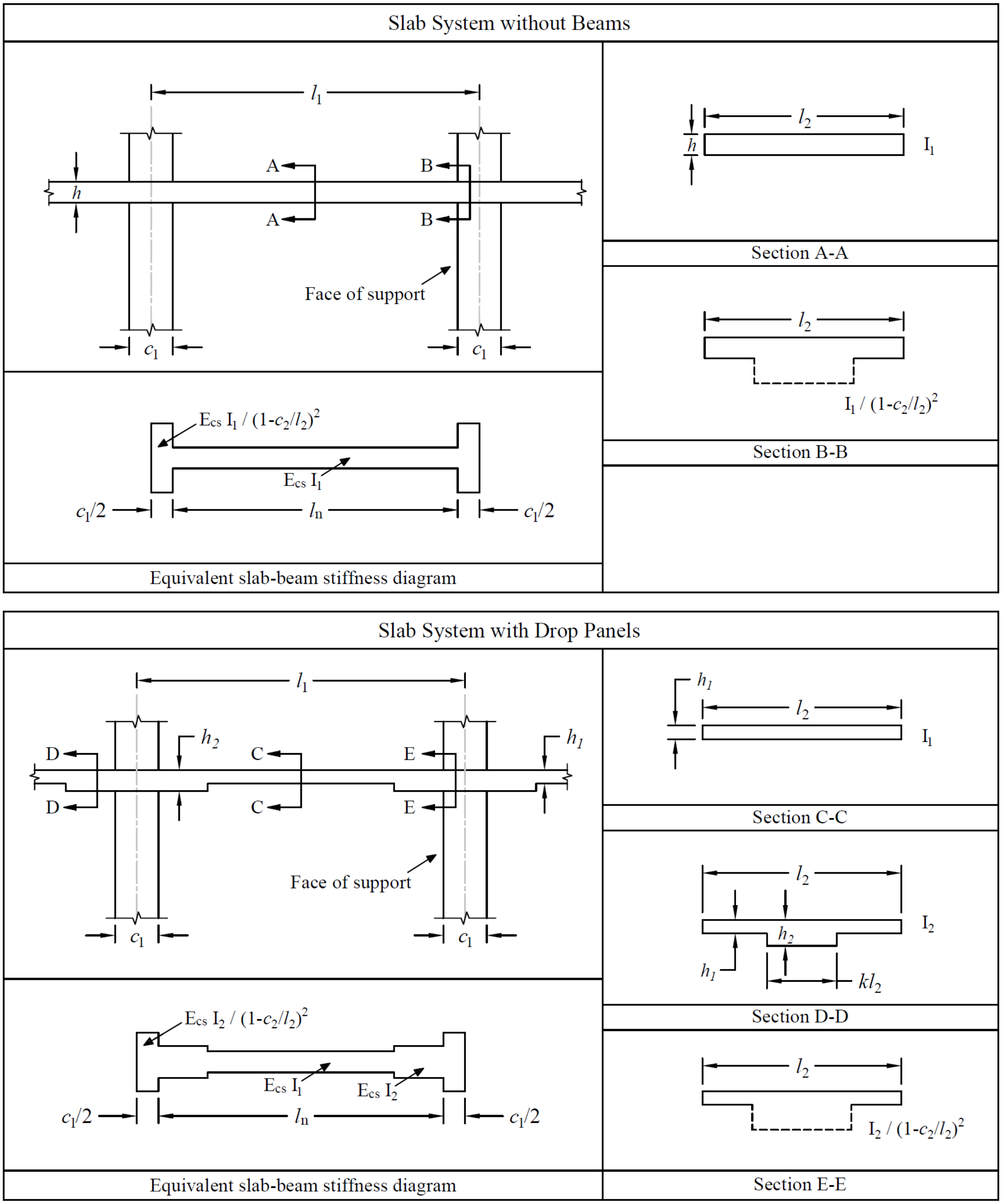



Figure 2.11 – Sections for Calculating Slab-Beam Stiffness, $K_{sb}$

To account for this difference in behavior between slab structures and frames, the equivalent column torsional member, as shown in Figure 2.13, runs transverse to the direction in which the moments are being determined. The transverse slab beam can rotate even though the column may be infinitely stiff, thus permitting moment distribution between adjacent panels. It is seen that the stiffness of the equivalent column is affected by both the flexural stiffness of the columns and the torsional stiffness of the slabs or beams framing into the columns. Note that the method of computation of column stiffness is in accordance with the requirements of the code[39]. Figure 2.15 shows a schematic representation of the stiffness of typical columns.

[39] ACI 318-14, 8.11.4; ACI 318-11, 13.7.4; ACI 318-08, 13.7.4; ACI 318-05, 13.7.4; ACI 318-02, 13.7.4; ACI 318-99, 13.7.4; CSA A23.3-14, 13.8; CSA A23.3-04, 13.8; CSA A23.3-94, 13.9

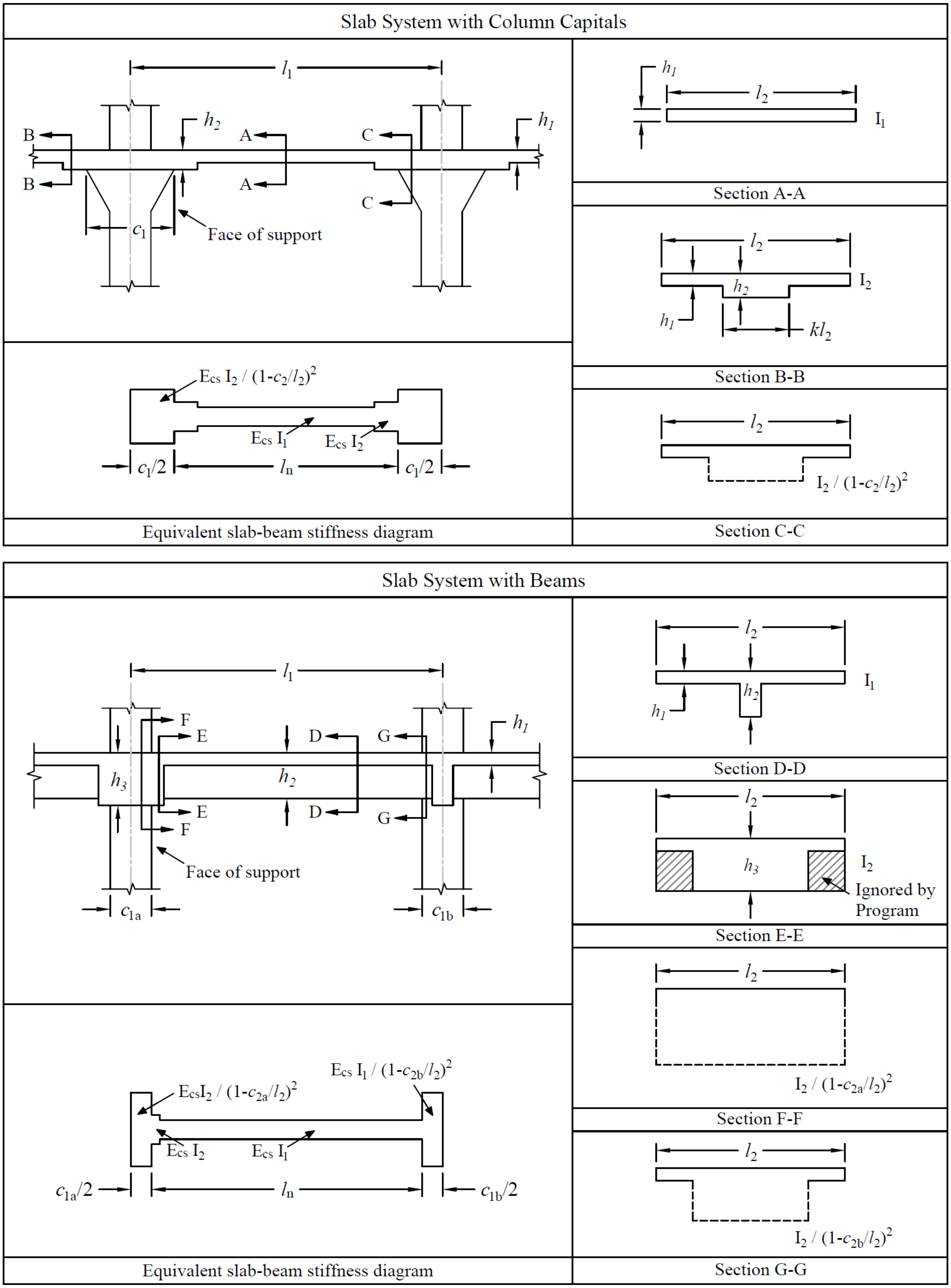



Figure 2.12 – Continued

The column stiffness is based on the column height, $l_c$, measured from mid-depth of the slab above, to the mid-depth of the slab below. spSlab calculates the stiffness of the column below the design slab, taking into account the design slab system at its top end. spSlab calculates the stiffness of the column above the design slab taking only the slab depth into account at its bottom end; column capitals, beams, or drops are ignored.

The computation of the torsional stiffness of the member requires several simplifying assumptions. The first step is to assume dimensions of the transverse torsional slab-beam members. Assumptions for dimensions of typical torsional members are shown in Figure 2.14.

The stiffness, $K_t$, of the torsional member is given by the following expression[40]:

$$K_t = \sum \frac{9E_{cs}C}{l_t\left(1-\frac{c_2}{l_t}\right)^3} \qquad \text{Eq. 2-20}$$

where:

$\Sigma$ = denotes summation over left and right side torsional member,

$E_{cs}$ = modulus of elasticity for slab concrete,

$C$ = cross-sectional constant defined in Eq. 2-21,

$c_2$ = size of rectangular column or capital measured transverse to the direction in which moments are being determined,

$l_t$ = $l_{2L}$ and $l_{2R}$, lengths of span transverse to $l_1$, measured on each side of the column for ACI 318; for CSA A23.3 value of $l_t$ is taken as the smaller of $l_{1a}$ and $l_{2a}$ where $l_{1a}$ is the average $l_1$ and $l_{2a}$ is the average $l_2$ on each side of an interior column. In case of an exterior columns, $l_{1a}$ and $l_{2a}$ are taken respectively as $l_1$ (if the column is exterior with respect to the direction of analysis) and $l_2$ (if column is exterior in the transverse direction) of the adjacent span, i.e. cantilevers, if any, are neglected.

[40] ACI 318-14, 8.11.5; ACI 318-11, 13.7.5; ACI 318-08, 13.7.5; ACI 318-05, 13.7.5; ACI 318-02, 13.7.5; ACI 318-99, 13.7.5; CSA A23.3-14, 13.8.2.8; CSA A23.3-04, 13.8.2.8; CSA A23.3-94, 13.9.2.8

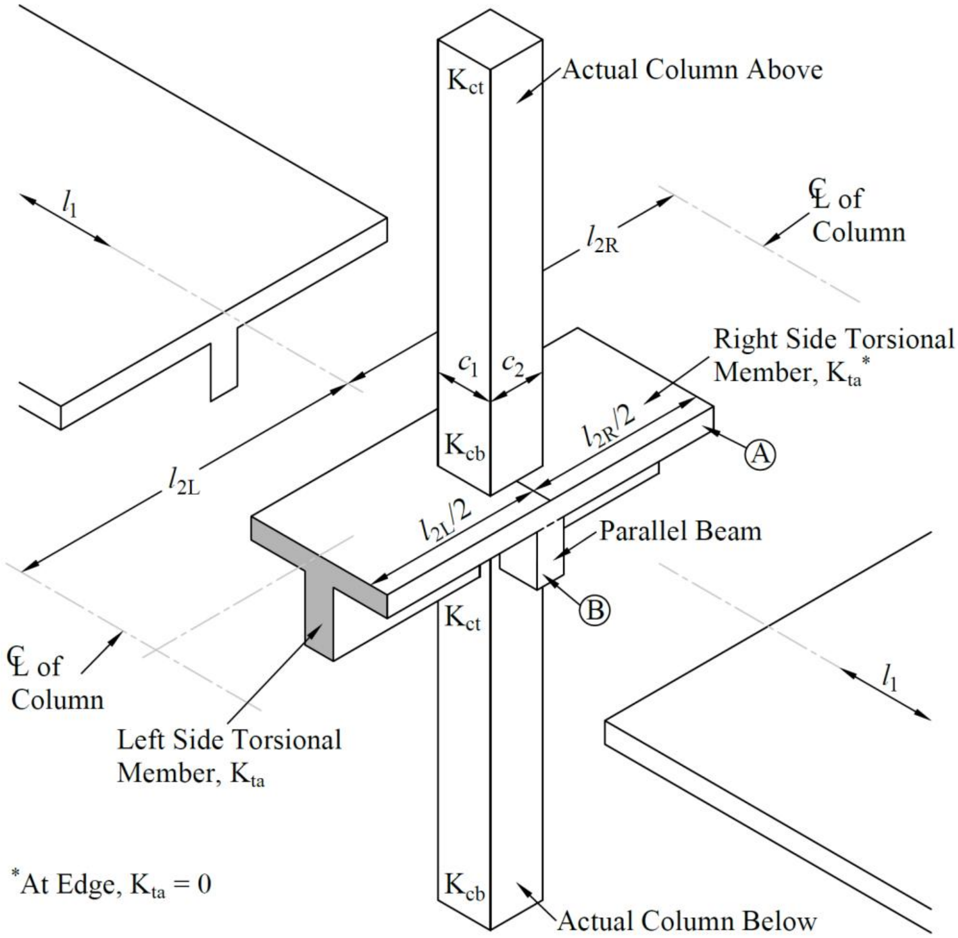



Figure 2.13 – Equivalent Column

The constant $C$ is evaluated for the cross section by dividing it into separate rectangular parts and by carrying out the following summation[41]:

$$C = \sum \left(1 - 0.63\frac{x}{y}\right)\frac{x^3 y}{3} \qquad \text{Eq. 2-21}$$

where:

$x$ = short overall dimension of the rectangular part of a cross section,

$y$ = long overall dimension of the rectangular part of a cross section.

[41] ACI 318-14, 8.10.5.2; ACI 318-11, 13.6.4.2; ACI 318-08, 13.6.4.2; ACI 318-05, 13.6.4.2; ACI 318-02, 13.0; ACI 318-99, 13.0; CSA A23.3-14, 13.8.2.9; CSA A23.3-04, 13.8.2.9; CSA A23.3-94, 13.9.2.9

The program divides the section into rectangles in such a way that the value of constant $C$ is maximum (Figure 2.14).

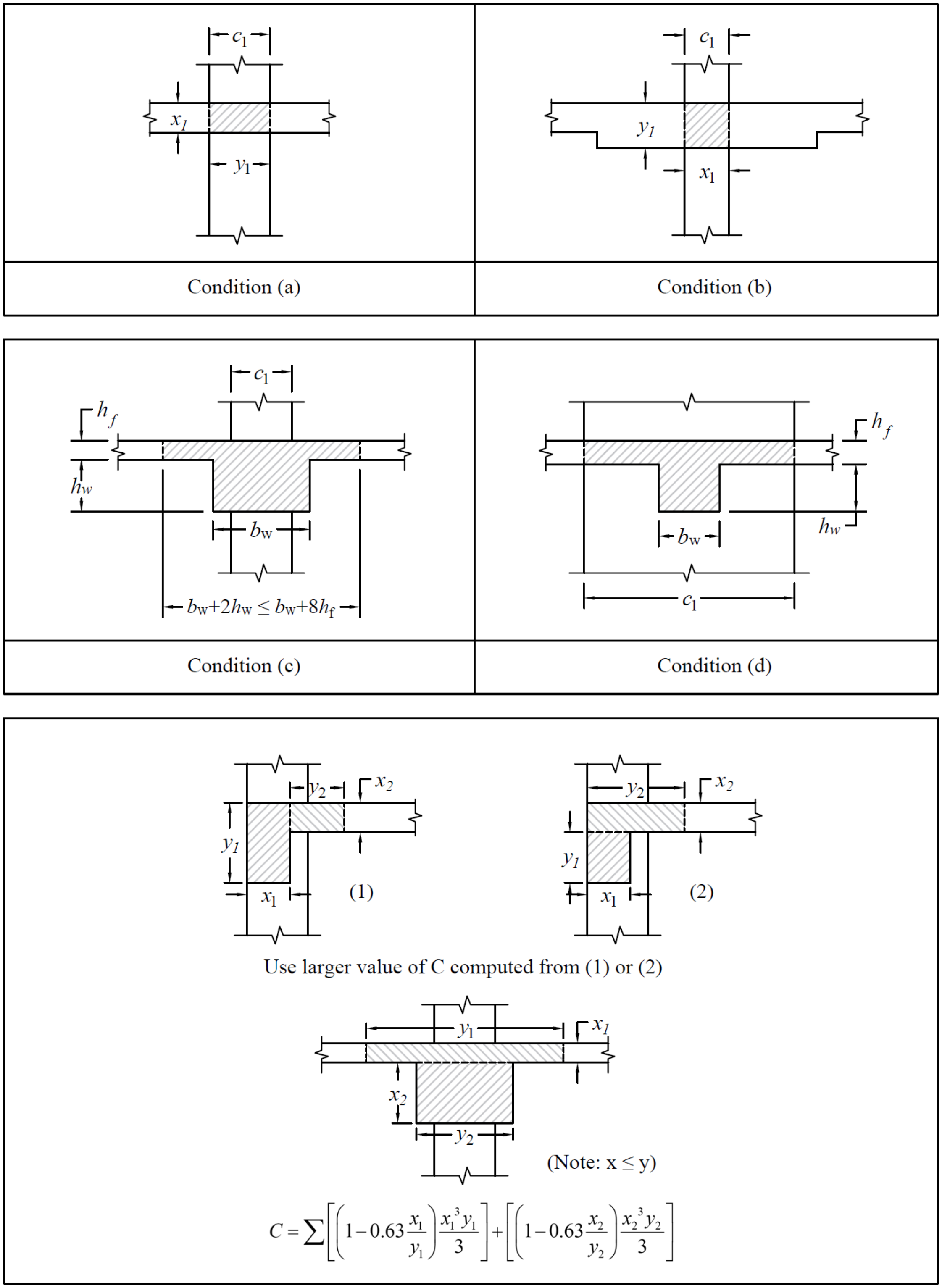
Walls perpendicular to the direction analysis can be modeled as wide columns. If a column/wall runs full length of the total design strip[42], the program modifies moment distribution factors to achieve uniform distribution of moments along the column and middle strips. If the width of the wall is less than 75% of the total design strip then no modification of distribution factors is applied. For column/wall widths between 75% and 100% of total strip widths, moment distribution factors are linearly interpolated between regular values and uniformly distributed values.

When beams frame into the column in the direction of analysis, the value of $K_t$ as computed in Eq. 2-20 is multiplied by the ratio of the moment of inertia of the slab with the beam ($I_{sb}$) to the moment of inertia of the slab without the beam ($I_s$), as shown:

$$K_{ta} = K_t \frac{I_{sb}}{I_s} \qquad \text{Eq. 2-22}$$

With reference to Figure 2.13, $I_s$ is computed from part A (slab without beam), whereas $I_{sb}$ is computed from both parts A and B (slab with beam).

[42] For walls running full width of the slab ($c_2 = l_2$), the program slightly adjusts the width of the wall to avoid singularity in the denominator of Eq. 2-20.




$$C=\sum\left[\left(1-0.63\frac{x_1}{y_1}\right)\frac{x_1^{\,3}y_1}{3}\right]+\left[\left(1-0.63\frac{x_2}{y_2}\right)\frac{x_2^{\,3}y_2}{3}\right]$$

Figure 2.14 – Section of the attached Torsional Members

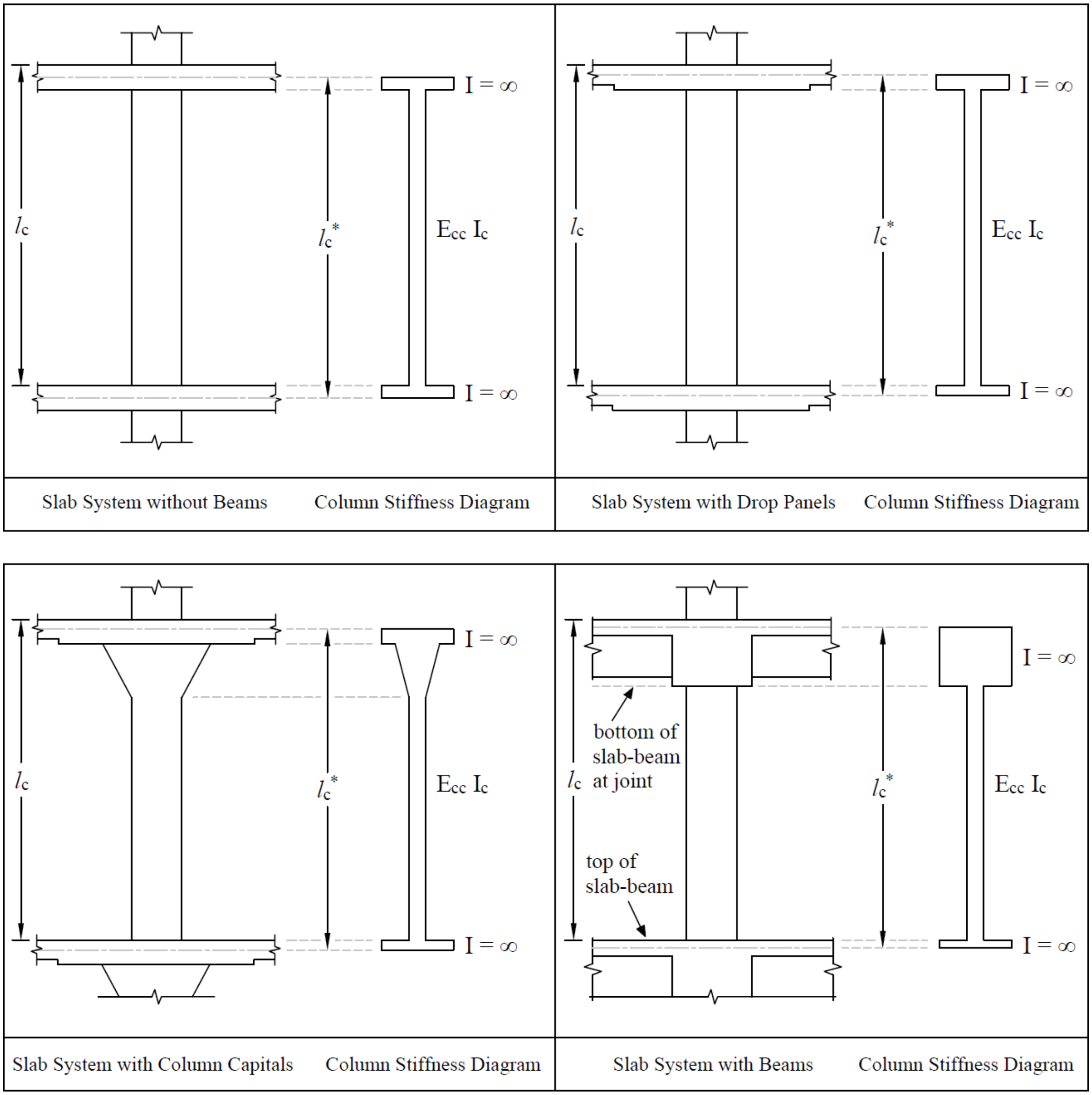



Figure 2.15 – Section for Calculating the Stiffness ($K_c$) of the Column Below the Design Floor ($l_c$-input, $l_c^*$-computed)

Having the column stiffness, $K_c$, and the stiffness of the attached torsional member, $K_t$, the stiffness of the equivalent column, $K_{ec}$, is computed from the equation:

$$K_{ec} = \frac{K_{ct} + K_{cb}}{1 + \dfrac{K_{ct} + K_{cb}}{K_{ta}^{l} + K_{ta}^{r}}} \qquad \text{Eq. 2-23}$$

where:

$K_{ct}$ = top column stiffness,

$K_{cb}$ = bottom column stiffness,

$K_{ta}$ = torsional stiffness of the left ( $K_{ta}^{l}$ ) and the right ( $K_{ta}^{r}$ ) member.

## 2.3.2. Modeling of Supports

By default spSlab assumes that column-slab/beam joints can only rotate and that they do not undergo any translational displacements. Rotation of a joint is affected by the stiffness of elements it connects i.e. slabs/beams, transverse beams, and columns. Columns are assumed by default to be fixed at their far ends as shown in Figure 2.10. These default assumptions can be altered using the **Column** and **Restraint** commands.

By specifying vertical spring support constant with $K_z$ value other than 0, you can allow the joint to displace vertically. This movement is then controlled by the stiffness of the spring $K_z$ in addition to the stiffness of the column below. The column above is assumed not to constrain the vertical movement of the joint. Additional rotational spring support can be applied to the joint by specifying the value of $K_{ry}$. Also, the far end column conditions can be selected as either fixed or pinned as shown in the Figure 2.16. All elements controlling the displacements of a joint are shown in the Figure 2.16. More information about creating support elements in spSlab/spBeam can be found in Section 5.2.4.2.

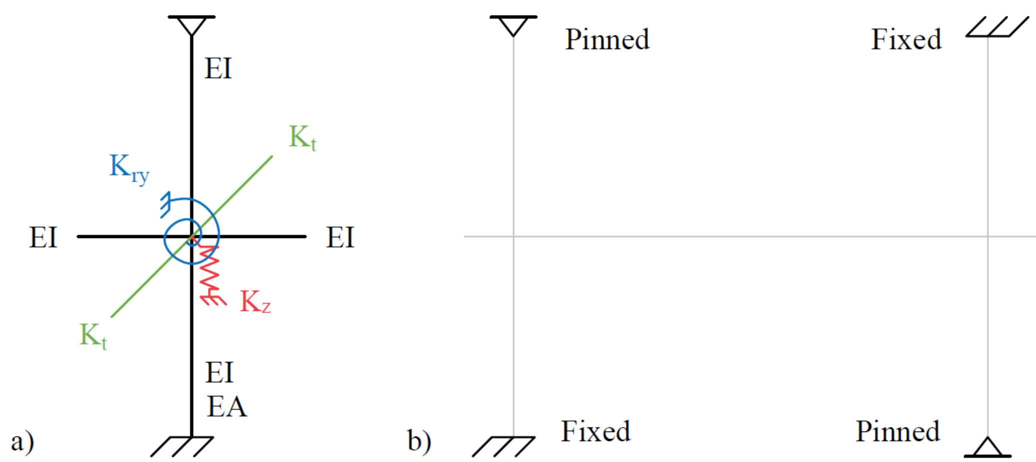



Figure 2.16 – (a) Elements controlling joint displacements (b) Far End Column Boundary Conditions

### 2.3.3. Modeling of Loads

All applied loads are input as unfactored loads. There are no limitations imposed on the ratio of dead to live loads in the Equivalent Frame Method. Results of gravity load and lateral load analyses may be combined, however, the effects of cracking and reinforcement on stiffness must be accounted for in the lateral load analysis.

#### 2.3.3.1. Self-Weight

The self-weight of the system is automatically calculated and assigned to the reserved load self-weight load case, SELF, which is by default defined in all new data files. The weights of the slabs, drops, and longitudinal and transverse beams are considered in the self-weight computations. Only the concrete weight is considered, the reinforcement weight is ignored. The weight of longitudinal beams is ignored starting at the column centerline, for a length equal to one-half $c_1$, the column dimension in the direction of analysis. This will produce slightly less self-weight than actually present for beams wider than $c_2$, the column's transverse dimension.

If load case SELF is removed then the program will ignore self-weight in all ultimate load combinations as well as in internally defined service load combination used to calculate displacements.

#### 2.3.3.2. Superimposed Loading

All superimposed vertical loading is considered to act over the entire transverse width of the slab. For slab systems with beams, loads supported directly by the beam (such as the weight of the beam stem or a wall supported directly by the beams) are also assumed to be distributed over the entire transverse width of the strip. An additional analysis may be required, with the beam section designed to carry these loads in addition to the portion of the slab moments assigned to the beam.

### 2.3.3.3. Lateral Loading

For lateral loads, each frame should be analyzed as a unit for the entire height of the building (Figure 2.17). Computer programs, such as spFrame, are available for performing such analyses. It should be realized that, for lateral load analysis, slab-beam elements may have a reduced stiffness due to cracking as well as other assumptions made for the effective slab width used for the lateral analysis. The moments obtained from such an analysis may then be input into the equivalent frame model using the program to determine the appropriate design moments under combined vertical and lateral loads.

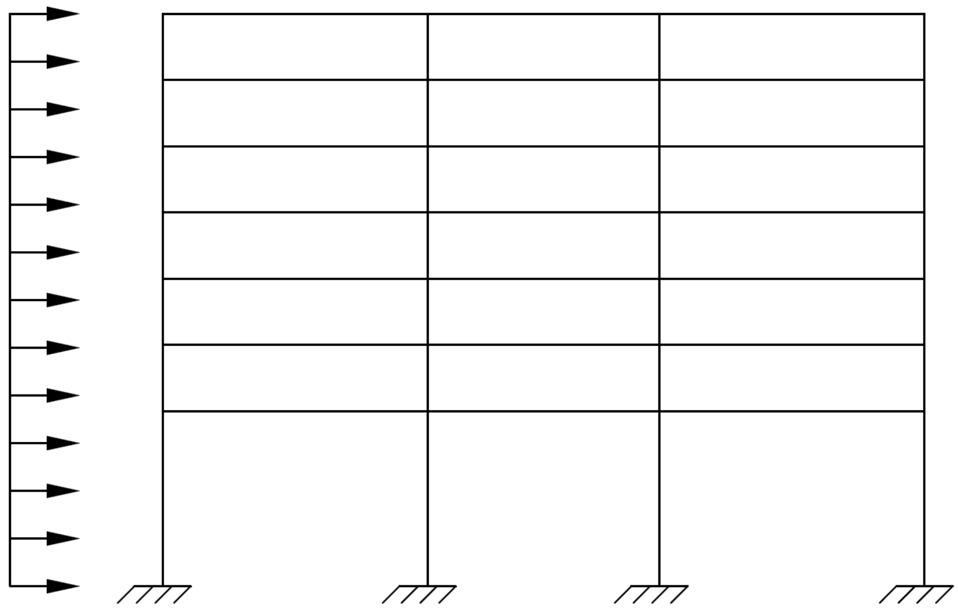


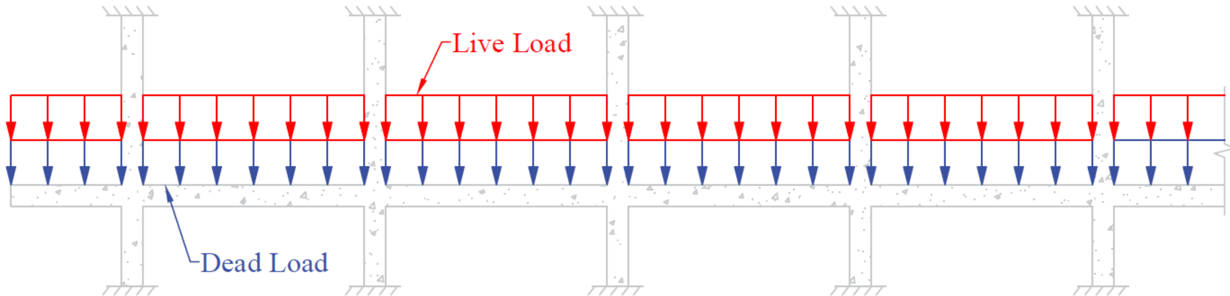
Figure 2.17 – Analytical Model for Lateral Loads

The program distributes the effect of the superimposed lateral load moments to the column strip and middle strip according to the moment distribution factors computed for gravity loads (see Table 2.2 through Table 2.4 later in this chapter).

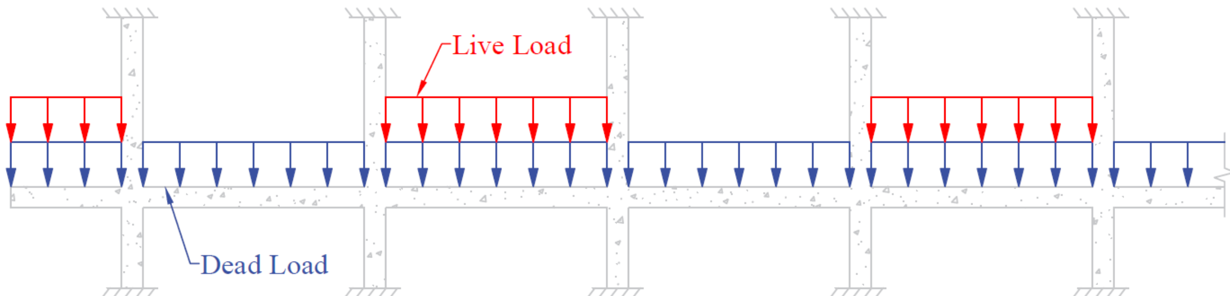
#### 2.3.3.4. Load Patterns

The analysis of floor systems requires the consideration of several loading configurations. For example, the two adjacent spans loaded may produce the maximum shear stress around a column, while the alternate spans loaded may produce the maximum flexural moments. To cover different loading scenarios the program generates live load case based on the following load patterns (Figure 2.18):

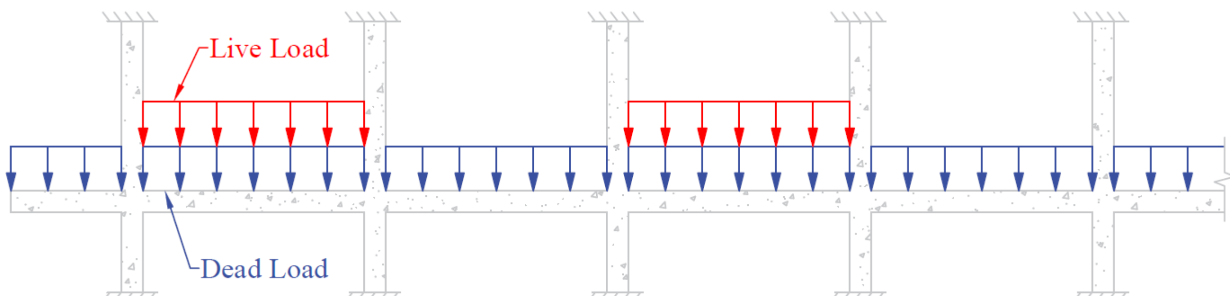
- Pattern No. l (All): All spans loaded with live load,
- Pattern No. 2 (Odd): Starting at span 1, alternate spans loaded with live load,
- Pattern No. 3 (Even): Starting at span 2, alternate spans loaded with live load,
- Pattern No. 3+N (SN): Two spans adjacent to support No. N loaded with live load.



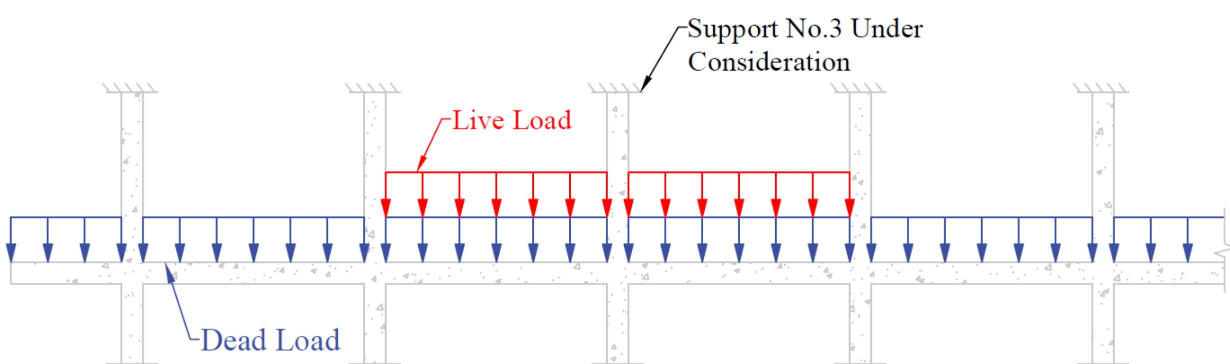

LOADING PATTERN No. 1 (All)




LOADING PATTERN No. 2 (Odd)




LOADING PATTERN No. 3 (Even)




LOADING PATTERN No. 6 (S3)

Figure 2.18 – Live Load Patterns

The program reduces the magnitude of live load patterns No. 2 through No. (3+n) by a predefined ratio. For two-way systems, the default live load pattern ratio selected by the program equals 75% as permitted by the code[43]. The user has the ability to select different value for the pattern ratio within the range 0-100%. If 0% is selected then load patterning effects will be neglected. However, the pattern No. 1 with all spans loaded (as specified by the user) is always considered with full unreduced magnitude.

[43] ACI 318-14, 6.4.3.3; ACI 318-11, 13.7.6.3; ACI 318-08, 13.7.6.3; ACI 318-05, 13.7.6.3; ACI 318-02, 13.7.6.3; ACI 318-99, 13.7.6.3; CSA A23.3-14, 13.8.4; CSA A23.3-04, 13.8.4; CSA A23.3-94, 13.9.4

### 2.3.4. Column and Middle Strip Widths

The code[44] defines the width of the column strip on each side of the column centerline as being one-fourth of the smaller of either the transverse or the longitudinal span. These widths are printed as part of the design results.

The strip widths at a support are computed by (see Figure 2.19)

- column strip

$$w_{cs} = \min\left\{\begin{aligned} &\min\left\{\frac{l_{2,l}}{4},\frac{l_1}{4}\right\}_i &&+\min\left\{\frac{l_{2,r}}{4},\frac{l_1}{4}\right\}_i \\ &\min\left\{\frac{l_{2,l}}{4},\frac{l_1}{4}\right\}_{i+1} &&+\min\left\{\frac{l_{2,r}}{4},\frac{l_1}{4}\right\}_{i+1}\end{aligned}\right\} \qquad \text{Eq. 2-24}$$

- middle strip

$$w_{ms} = \min\left\{l_{2,i}, l_{2,i+1}\right\} - w_{cs} \qquad \text{Eq. 2-25}$$

[44] ACI 318-14, 8.4.1.5; ACI 318-11, 13.2.1; ACI 318-08, 13.2.1; ACI 318-05, 13.2.1; ACI 318-02, 13.2.1; ACI 318-99, 13.2.1; CSA A23.3-14, 2.2; CSA A23.3-04, 2.2; CSA A23.3-94, 13.1

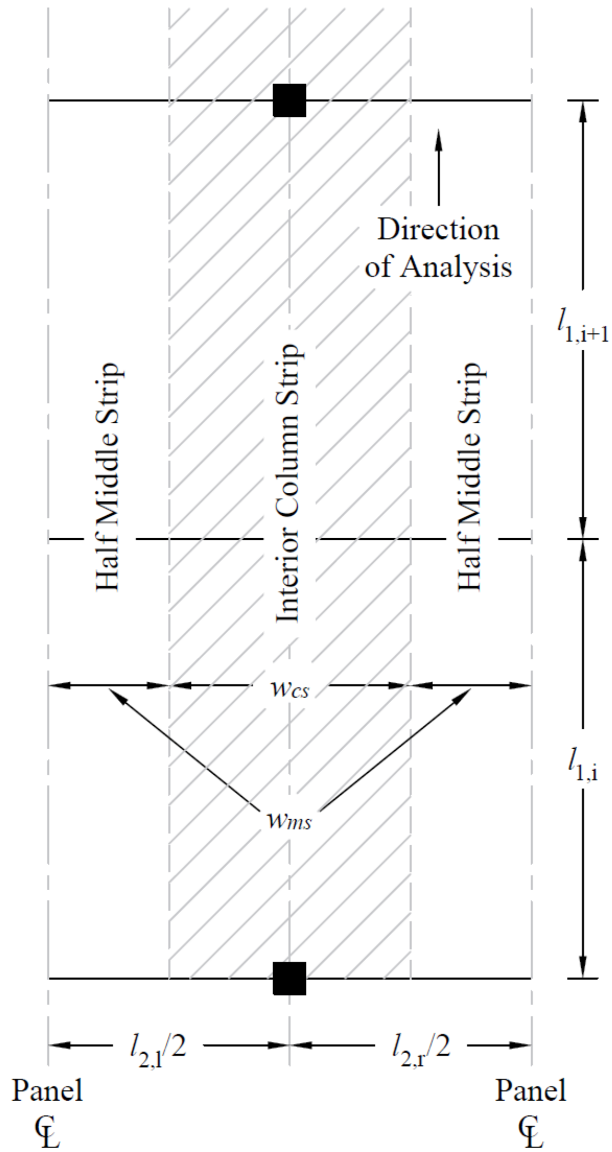



Figure 2.19 – Strips Widths at Support

The strip widths in the span are defined as (see Figure 2.20):

- column strip

$$w_{cs} = \min\left\{\frac{l_{2,l}}{4}, \frac{l_1}{4}\right\} + \min\left\{\frac{l_{2,r}}{4}, \frac{l_1}{4}\right\} \qquad \text{Eq. 2-26}$$

- middle strip

$$w_{ms} = l_2 - w_{cs} \qquad \text{Eq. 2-27}$$

where:

$l_1$ = span length in the direction of analysis,

$l_{2,l}$ = the input transverse strip widths on the left of column centerline,

$l_{2,r}$ = the input transverse strip widths on the right of column centerline,

$l_2$ = $l_{2,l}$ / 2 + $l_{2,r}$ / 2, the total input transverse strip width.

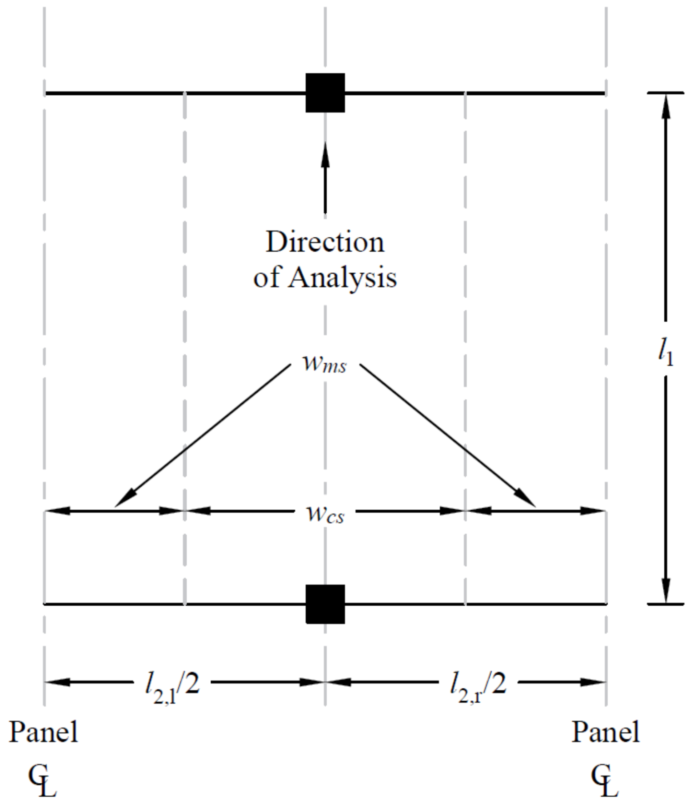



Figure 2.20 – Strips Widths in Span

If a longitudinal slab band is defined (CSA A23.3-14/04 standard only) then the column strip width is automatically adjusted to be equal to the band width:

$$w_{cs} = w_{band} \qquad \text{Eq. 2-28}$$

If a longitudinal beam exists then the adjusted column strip width, $\overline{w}_{cs}$, is calculated by subtracting the beam width, $w_{beam}$, from the width of the column strip:

$$\overline{w}_{cs} = w_{cs} - w_{beam} \qquad \text{Eq. 2-29}$$

If the user selects the BEAM T-SECTION DESIGN option in **Design Options** tab under **Solve** command in the **Ribbon**, the beam width, $w_{beam}$, used by the program will include portion of the slab on each side of the beam equal to projection of the beam below the slab, but not greater than slab thickness[45]. Otherwise, only web width is used. If the beam width, $w_{beam}$, is greater than the column strip width, $w_{cs}$, then the adjusted column strip width is set to zero and moment distribution factors are adjusted to apply all column strip moment to the beam. This may occur when modeling a slab band with a wide longitudinal beam for codes other than CSA A23.3-14/04. In case of CSA A23.3-14/04 standard, the dedicated LONGITUDINAL SLAB BAND option in the **Project Left Panel** is available to model slab band systems explicitly.

By selecting USER SLAB STRIP WIDTH and USER STRIP DISTRIBUTION FACTORS options in the **Design & Modeling** panel under **Define** command in the **Ribbon**, the user has the ability to manually override strip widths and moment distribution factors calculated automatically by the program and requires engineering judgment.

Note: For exterior frames, the edge width should be specified to the edge of the slab from the column centerline. Entering edge width greater than $l_1$ / 4 involves engineering judgment regarding two-way behavior of the system and the applicability of the equivalent frame method.

[45] ACI 318-14, 8.4.1.8; ACI 318-11, 13.2.4; ACI 318-08, 13.2.4; ACI 318-05, 13.2.4; ACI 318-02, 13.2.4; ACI 318-99, 13.2.4; CSA A23.3-04 Figure N13.1.2.(a) in Ref. [12], CSA A23.3-94, 13.1

### 2.3.5. Strip Design Moments

For design purposes[46], spSlab considers negative moments as those producing tension at the top of the slab and positive moments as those producing tension at the bottom of the slab. The negative design moment is taken at the face of the column below the slab, or at the face of the column capital, but in no case is it considered at a location greater than 0.175 of the longitudinal span length, $l_1$, away from the center of the column.[47] This imposes a limit on long narrow supports, in order to prevent undue reduction in the design moment. For slab systems with transverse beams, the face of a beam is not considered as the face of support. For end columns with capitals, the negative moments are taken at the midpoint of the capital extension.[48] If a positive moment occurs at a support then its value at the face of the column above the slab is considered (or at the support centerline if there is no column above the slab).

spSlab computes the amount of reinforcement for the moments on the left and the right side of the support. The negative design moment is the moment which requires the most area of reinforcement to be resisted. The location, left or right of the support, of the maximum moment may vary when systems differ on each side of the support (for example, a system with beams on one side only).

spSlab automatically calculates the values of strip moment distribution factors for column strips and longitudinal beams (if present). Portion of the total factor moment not assigned to a column strip or a beam is then proportionally assigned to the remaining middle strip.

Note: By checking USER STRIP DISTRIBUTION FACTORS option in **Design & Modeling** panel under **Define** command in the **Ribbon**, the user has the ability to manually adjust strip moment distribution factors calculated automatically by the program.

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[46] ACI and CSA provisions for the location of critical section for flexure referred to in this paragraph apply to two-way systems. Due to lack of similar provisions for one-way systems and beams in ACI and CSA standards, the program consistently applies the same rules (with the exception of $0.175\ell_1$ limitation) to one-way systems and beams.

[47] ACI 318-14, 8.11.6.1; ACI 318-11, 13.7.7.1; ACI 318-08, 13.7.7.1; ACI 318-05, 13.7.7.1; ACI 318-02, 13.7.7.1; ACI 318-99, 13.7.7.1; CSA A23.3-14, 13.8.5.1; CSA A23.3-04, 13.8.5.1; CSA A23.3-94, 13.9.5.1

[48] ACI 318-14, 8.11.6.2, 8.11.6.3; ACI 318-11, 13.7.7.2; ACI 318-08, 13.7.7.2; ACI 318-05, 13.7.7.2; ACI 318-02, 13.7.7.2; ACI 318-99, 13.7.7.2; CSA A23.3-14, 13.8.5.2; CSA A23.3-04, 13.8.5.2; CSA A23.3-94, 13.9.5.2

#### 2.3.5.1. ACI 318 and CSA A23.3-94[49]

The column strips are proportioned to resist the portions in percent of interior negative factored moments according to Table 2.2.[50]

| $l_2/l_1$ | 0.5 | 1.0 | 2.0 |
|---|---|---|---|
| $(\alpha_{f1}\ l_2/l_1) = 0$ | 75 | 75 | 75 |
| $(\alpha_{f1}\ l_2/l_1) \geq 1.0$ | 90 | 75 | 45 |

Table 2.2 – Column Strip Percent of Interior Negative Factored Moments at Supports

The column strips are proportioned to resist the portions in percent of exterior negative factored moments according to Table 2.3.[51]

| $l_2/l_1$ | | 0.5 | 1.0 | 2.0 |
|---|---|---|---|---|
| $(\alpha_{f1}\ l_2/l_1) = 0$ | $\beta_t = 0$ | 100 | 100 | 100 |
| | $\beta_t \geq 2.5$ | 75 | 75 | 75 |
| $(\alpha_{f1}\ l_2/l_1) \geq 1.0$ | $\beta_t = 0$ | 100 | 100 | 100 |
| | $\beta_t \geq 2.5$ | 90 | 75 | 45 |

Table 2.3 – Column Strip Percent of Exterior Negative Factored Moments at Supports

49 For CSA A23.3-94 standard, the program assumes by default values given by ACI code which fall within the ranges specified in CSA A23.3-94, 13.12.2

50 ACI 318-14, 8.10.5.1; ACI 318-11, 13.6.4.1; ACI 318-08, 13.6.4.1; ACI 318-05, 13.6.4.1; ACI 318-02, 13.6.4.1; ACI 318-99, 13.6.4.1; CSA A23.3-14, 13.9.5; CSA A23.3-04, 13.9.5; CSA A23.3-94, 13.9.5.1; CSA A23.3-94, 13.8.5.1

51 ACI 318-14, 8.10.5.2, 8.10.5.3; ACI 318-11, 13.6.4.2; ACI 318-08, 13.6.4.2; ACI 318-05, 13.6.4.2; ACI 318-02, 13.6.4.2; ACI 318-99, 13.6.4.2

The values $\alpha_{f1}$ in Table 2.2 and Table 2.3 and $\beta_t$ in Table 2.3 are defined as:

$\alpha_{f1}$ = ratio of flexural stiffness of the beam section to flexural stiffness of a width of slab bounded by centerlines of adjacent panels (if any) on each side of the beam in the direction of analysis. For flat plates, flat slabs, and waffle $(\alpha_{f1}\ l_2 / l_1) = 0$,

$\beta_t$ = ratio of torsional stiffness of an edge beam section to flexural stiffness of a width of slab equal to the span length of the beam, center-to-center of supports.[52] When no transverse beams are present, $\beta_t = 0$, otherwise

$$\beta_t = \frac{E_{cb}C}{2E_{cs}I_s} \qquad \text{Eq. 2-30}$$

where:

$E_{cb}$ = modulus of elasticity of beam concrete,

$E_{cs}$ = modulus of elasticity of slab concrete,

$C$ = cross-sectional constant, see Eq. 2-21,

$I_s$ = moment of inertia of the gross section of the slab about its centroidal axis.

For intermediate values of $(l_2 / l_1)$, $(\alpha_{f1}\ l_2 / l_1)$ and $\beta_t$ the values in Table 2.2 and Table 2.3 are interpolated using equations Eq. 2-31 and Eq. 2-32.

Percentage of negative factored moment at interior support to be resisted by column strip:

$$75+30\left(\frac{\alpha_{f1}l_2}{l_1}\right)\left(1-\frac{l_2}{l_1}\right) \qquad \text{Eq. 2-31}$$

Percentage of negative factored moment at exterior support to be resisted by column strip:

$$100-10\beta_t+12\beta_t\left(\frac{\alpha_{f1}l_2}{l_1}\right)\left(1-\frac{l_2}{l_1}\right) \qquad \text{Eq. 2-32}$$

[52] ACI 318-14, 8.10.5.2, 8.10.5.3; ACI 318-11, 13.6.4.2; ACI 318-08, 13.6.4.2; ACI 318-05, 13.6.4.2; ACI 318-02, 13.0; ACI 318-99, 13.0; CSA A23.3-94, 13.0

When a column width, $c_2$, is equal to or greater than 75 percent of the tributary strip width $l_2$, the distribution factor for negative column strip moment is linearly interpolated between the factor for regular support, and the factor equal 0.50 (moment uniformly distributed across $l_2$). This extends the requirement of the design code[53], by providing continuous linear transition between standard and uniform moment distributions, depending on the relative dimension of the support with respect to strip width. User may override software assumptions by selecting user defined distribution factors.

When designing by the CSA A23.3-94 code, a portion of the total positive or interior negative moment equivalent to[54]:

$$\frac{\alpha_{f1}}{1+\left(\frac{l_2}{l_1}\right)^2} \qquad \text{Eq. 2-33}$$

is resisted by the beam. For exterior supports, the beam is proportioned to resist 100% of the negative moment.

That portion of the moment not resisted by the beam is resisted by the slab. The reinforcement required to resist this moment is distributed evenly across the slab.

For ACI designs the longitudinal beams are proportioned to resist 85 percent of the column strip moments if $\alpha_{f1}\ l_2 / l_1$ is equal to or greater than 1.0. For values of $\alpha_{f1}\ l_2 / l_1$ between 0 and 1.0, the beam is designed to resist a proportionate percentage of the column strip moment between 0 and 85.[55]

The middle strips are proportioned to resist the portion of the total factored moments that is not resisted by the column strips.

53 ACI 318-14, 8.10.5.4; ACI 318-11, 13.6.4.3; ACI 318-08, 13.6.4.3; ACI 318-05, 13.6.4.3; ACI 318-02, 13.6.4.3; ACI 318-99, 13.6.4.3

54 CSA A23.3-94, 13.13.2.1

55 ACI 318-14, 8.10.5.7; ACI 318-11, 13.6.5; ACI 318-08, 13.6.5; ACI 318-05, 13.6.5; ACI 318-02, 13.6.5; ACI 318-99, 13.6.5

The column strips are proportioned to resist the portions in percent of positive factored moments according to Table 2.4.[56]

| $l_2/l_1$ | 0.5 | 1.0 | 2.0 |
|---|---|---|---|
| $(\alpha_{f1}\ l_2/l_1) = 0$ | 60 | 60 | 60 |
| $(\alpha_{f1}\ l_2/l_1) \geq 1.0$ | 90 | 75 | 45 |

Table 2.4 – Column Strip Percent of Positive Factored Moments

For intermediate values of $(l_2 / l_1)$ and $(\alpha_{f1}\ l_2 / l_1)$ the values in Table 2.4 are interpolated using Eq. 2-34 as follows:

$$60+30\left(\frac{\alpha_{f1}l_2}{l_1}\right)\left(1.5-\frac{l_2}{l_1}\right) \qquad \text{Eq. 2-34}$$

Note: For flat plates, flat slabs, and waffle slabs, $\alpha_{f1}\ l_2 / l_1 = 0$.

[56] ACI 318-14, 8.10.5.5; ACI 318-11, 13.6.4.4; ACI 318-08, 13.6.4.4; ACI 318-05, 13.6.4.4; ACI 318-02, 13.6.4.4; ACI 318-99, 13.6.4.4

#### 2.3.5.2. CSA A23.3-14/04

For slabs without drop panels (with or without transverse beams) the following moment factors are used[57]:

- Negative moment at interior column, factor = 0.80
- Negative moment at exterior column, factor = 1.00
- Positive moment at all spans, factor = 0.60

For slabs with drop panels (with or without transverse beams) the following moment factors are used[58]:

- Negative moment at interior column, factor = 0.825
- Negative moment at exterior column, factor = 1.00
- Positive moment at all spans, factor = 0.60

For slabs with longitudinal slab bands[59]:

- Negative moment at interior column, factor = 0.90
- Negative moment at exterior column, factor = 1.00
- Positive moment at all spans, factor = 0.90

[57] CSA A23.3-14, 13.11.2.2; CSA A23.3-04, 13.11.2.2

[58] CSA A23.3-14, 13.11.2.3; CSA A23.3-04, 13.11.2.3

[59] CSA A23.3-14, 13.11.2.4; CSA A23.3-04, 13.11.2.4

For slabs with transverse slab bands[60]:

- Negative moment at interior column in width $b_b$, factor from 0.05 to 0.15 range is selected so that the remaining moment is distributed evenly over the entire frame width (including $b_b$ width) and at least one-third of the total factored moment[61] is applied to the band width $b_b$.
- Negative moment at exterior column, factor = 1.00
- Positive moment at all spans where $(l_1 / l_2) \geq 1.0$, factor = 0.55
- Positive moment at all spans where $(l_1 / l_2) < 1.0$, factor = 0.55 $(l_1 / l_2)$

For slabs with beams between all the supports[62], the positive and interior negative factored moments are distributed as follows:

$$\frac{\alpha_1}{0.3+\alpha_1}\left(1-\frac{l_2}{3l_1}\right) \qquad \text{Eq. 2-35}$$

Factored negative moments at exterior supports are assigned in 100% proportion to beams.

CSA A23.3-14/04 does not stipulate requirement for distributing moments in slab systems with beams between some (but not all) supports. For estimation of the moment resisted by the beams in this case, the program applies the ACI approach described in the previous section where longitudinal beams are proportioned to resist 85 percent of the column strip moments if $\alpha_{f1}\, l_2 / l_1$ is equal to or greater than 1.0. For values of $\alpha_{f1}\, l_2 / l_1$ between 0 and 1.0, the beam is designed to resist a proportionate percentage of the column strip moment between 0 and 85%.

[60] CSA A23.3-14, 13.11.2.5; CSA A23.3-04, 13.11.2.5

[61] CSA A23.3-14, 13.11.2.7; CSA A23.3-04, 13.11.2.7

[62] CSA A23.3-14, 13.12.2; CSA A23.3-04, 13.12.2

### 2.3.6. Moment Redistribution

Redistribution of negative moments applies to one-way and beam systems only. It can be engaged by checking the MOMENT REDISTRIBUTION option in the **Design & Modeling** panel under **Define** command in the **Ribbon**.

The program allows for redistribution of negative moments at supports. Only reduction in negative moments is considered. Increase of negative moments at the support is not taken into account even though it is allowed by the code[63]. Static equilibrium is maintained meaning that bending moments and shear forces along the span are adjusted in accordance with the reduction of moments applied at the supports. The following procedure is followed to obtain moment redistribution factors at the supports.

From elastic static analysis, the largest moments from all load combinations and load patterns are determined at support faces on both ends of each span except cantilevers. These moments are used to calculate the maximum percentage adjustment of moments, $\delta$, allowed by the codes.

For ACI 318-14, ACI 318-11, ACI 318-08, ACI 318-05, and ACI 318-02[64]:

$$\delta = \begin{cases} 0 & \text{if } \varepsilon_t < 0.0075 \\ 1{,}000\varepsilon_t & \text{if } \varepsilon_t \geq 0.0075 \end{cases} \qquad \text{Eq. 2-36}$$

where $\varepsilon_t$ is net tensile strain in extreme tension steel at nominal strength.

63 ACI 318-14, 6.6.5.1; ACI 318-11, 8.4.1; ACI 318-08, 8.4.1; ACI 318-05, 8.4.1; ACI 318-02, 8.4.1; ACI 318-99, 8.4.1; CSA A23.3-14, 9.2.4; CSA A23.3-04, 9.2.4; CSA A23.3-94, 9.2.4

64 ACI 318-14, 6.6.5.3; ACI 318-11, 8.4.1 and 8.4.3; ACI 318-08, 8.4.1 and 8.4.3; ACI 318-05, 8.4.1 and 8.4.3; ACI 318-02, 8.4.1 and 8.4.3

For ACI 318-99[65]:

$$\delta = \begin{cases} 0 & \text{if } (\rho - \rho') > 0.5\rho_b \\ 20\left(1 - \dfrac{\rho - \rho'}{\rho_b}\right) & \text{if } (\rho - \rho') \leq 0.5\rho_b \end{cases} \qquad \text{Eq. 2-37}$$

where:

$\rho$ = tension reinforcement ratio.

$\rho'$ = compression reinforcement ratio.

$\rho_b$ = balanced reinforcement ratio.

For CSA A23.3[66]:

$$\delta = 30 - 50\frac{c}{d} \qquad \text{Eq. 2-38}$$

where:

$c$ = distance from extreme compression fiber to neutral axis.

$d$ = distance from extreme compression fiber to centroid of tension reinforcement.

In the investigation mode, program uses the area of provided reinforcement to obtain redistribution factors. In the design mode the required reinforcement area is used. Additionally, $\delta$ is limited to 20% and not to exceed the maximum values specified by the user. Negative moments at span ends are reduced by the amount of redistribution factors and new moment values are iteratively used to obtain new redistribution factors. This iterative procedure is repeated until the change in distribution factor is negligible (does not exceed 0.01%), but no more than 10 times.

[65] ACI 318-99, 8.4.1 and 8.4.3

[66] CSA A23.3-14, 9.2.4; CSA A23.3-04, 9.2.4; CSA A23.3-94, 9.2.4

### 2.3.7. Shear Analysis of Slabs

Shear analysis in spSlab takes into account one way shear and two-way shear. For two-way shear, the program considers contributions of factored shear force[67], $V_u$, and fraction of unbalanced moment transferred by shear[68], $\gamma_v M_{unb}$. spSlab does not consider torsional stresses in the slab. If in the engineer's judgment this may control, it must be computed manually.

spSlab checks one-way shear at a critical section located at a distance not less than the effective depth away from the face of the support[69]. If a concentrated load is applied closer than the effective depth away from the face of the support then critical section is located at the face of the support. Factored shear force at the critical section is obtained from the analysis of the equivalent frame[70].

67 ACI 318-14, 8.4.4.2.3; ACI 318-11, 11.11.7.2; ACI 318-08, 11.11.7.2; ACI 318-05, 11.12.6.2; ACI 318-02, 11.12.6.2; ACI 318-99, 11.12.6.2; CSA A23.3-14, 13.3.5.2; CSA A23.3-04, 13.3.5.2; CSA A23.3-94, 13.4.5.2

68 ACI 318-14, 8.4.4.2.1; ACI 318-11, 11.11.7.1; ACI 318-08, 11.11.7.1; ACI 318-05, 11.12.6.1; ACI 318-02, 11.12.6.1; ACI 318-99, 11.12.6.1; CSA A23.3-14, 13.4.5.3; CSA A23.3-04, 13.4.5.3; CSA A23.3-94, 13.4.5.3

69 ACI 318-14, 7.4.3.2, 8.4.3.2, 9.4.3.2; ACI 318-11, 13.5.4, 11.1.3; ACI 318-08, 13.5.4, 11.1.3; ACI 318-05, 13.5.4, 11.1.3; ACI 318-02, 13.5.4, 11.1.3; ACI 318-99, 13.5.4, 11.1.3; CSA A23.3-14, 13.3.6.1, 11.3.2; CSA A23.3-04, 13.3.6.1, 11.3.2; CSA A23.3-94, 13.4.6.1; CSA A23.3-94, 13.4.6.1; 11.3.2

70 ACI 318-14, 8.11.1.1; ACI 318-11, 13.7.1; ACI 318-08, 13.7.1; ACI 318-05, 13.7.1; ACI 318-02, 13.7.1; ACI 318-99, 13.7.1; CSA A23.3-04, 13.8.1.1; CSA A23.3-94, 13.9.1.1

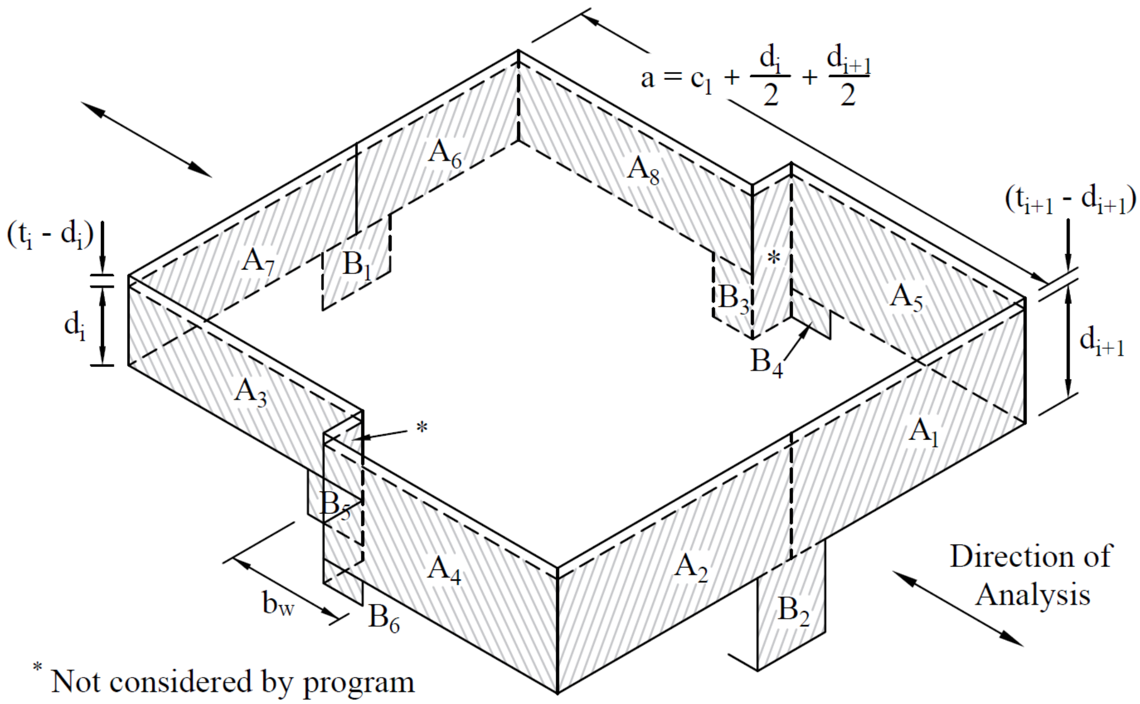



Figure 2.21 – Critical Section for Two-Way Shear

Figure 2.21 shows the general two-way shear area[71] used by spSlab. Note that the shaded area represents the general case and is modified for special considerations as explained below.

Beams are considered in the two-way shear as indicated in Figure 2.21 by areas $B_1$, $B_2$, $B_3$, $B_4$, $B_5$, and $B_6$. Ordinarily, transverse beams transfer unbalanced moment to the column through torsion along the beam and not through shear between the slab and column. However, the code leaves the transfer method to the engineer's judgment concerning the point at which punching shear is no longer applicable and beam shear becomes the dominate element in shear transfer to the column. spSlab makes no such distinction and computes unbalanced moment transfer stress without regard to any beams framing into the column. When a beam is present, the depth of the beam increases the depth of the critical section where it intersects with the beam. The distances from the face of the support to the critical section will also be increased, i.e. effective depth of the beam will be used to calculate the distance instead of effective depth of the slab, if it results in a critical section that is still within the beam. Otherwise, distances to the critical section are not increased.

71 ACI 318-14, 22.6.4.1; ACI 318-11, 11.11.1.2; ACI 318-08, 11.11.1.2; ACI 318-05, 11.12.1.2; ACI 318-02, 11.12.1.2; ACI 318-99, 11.12.1.2; CSA A23.3-14, 13.3.3; CSA A23.3-04, 13.3.3; CSA A23.3-94, 13.4.3

For circular supports (column or column capital), ACI code and CSA standard differ in their treatment and do not provide clear guidance towards the applicability of an equivalent rectangular section for checking punching shear around circular supports. Therefore, spSlab provides as a default option the calculation of properties of the critical section for punching shear based on circular critical shear perimeter. This option is possible given that both the soffit around the perimeter of circular support and the soffit around the perimeter of circular critical shear perimeter are flat & critical shear perimeter stays circular.

If circular critical shear perimeter is not achievable or possible, then, the program calculates properties of the critical section for punching shear based on an equivalent rectangular support with the same centroid and equal perimeter length[72]. The equivalent rectangular support is a square with side length equal to $\pi D/4 \approx 0.785D$ where $D$ is the diameter of the circular support as shown in Figure 2.22.

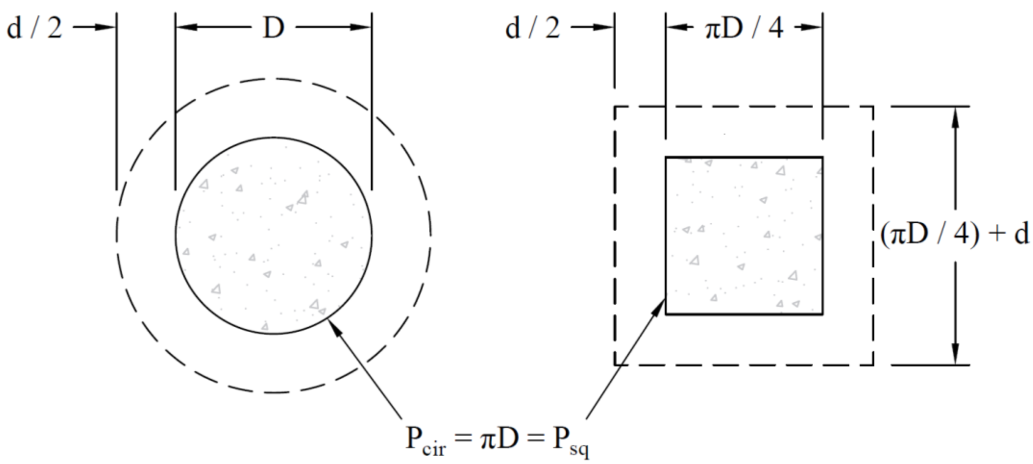



Figure 2.22 – Critical Section for Circular Column

While this approach is widely used, it produces an equivalent section but not an equivalent shear perimeter. It is, therefore, left to the end-user discretion to judge the use of the circular shear perimeter as it produces more conservative results compared with the traditional equivalent square option.

[72] See Fig.13-38(b) and Fig. 13-57 in Ref. [16], and Fig. 10.5(f) in Ref. [25]

The critical section is considered closed if the concrete slab around a column extends to a distance greater than or equal to the specified threshold value. In spSlab, the user may define the distance extended beyond the column face in order to consider the section closed. If the critical section does not meet the distance requirement, it is considered open.

ACI 318-08 code introduced the definition of the shear cap[73] which, alternatively to column capital, can be used to increase the critical section around the column. spSlab users can use the capital geometry to model a shear cap and calculate the punching shear through the thickness of the slab itself (shear cap acting as capital). Other failure modes, such as punching within the perimeter of the shear cap, need to be verified by the user manually. The dimensions of the substitute capital have to be selected such that the resulting critical section is equivalent to critical section for a column with a shear cap. ACI code[74] requires shear caps to extend beyond the face of the column by at least the distance equal to cap depth, and so depth/extension ratio should not exceed 1.0. For column capitals depth/extension ratio should not be less than 1.0. Therefore to model shear cap acting as capital, the substituted capital should have depth/extension ratio equal to 1.0.

73 ACI 318-14, 2.3; ACI 318-11, 2.2; ACI 318-08, 2.2

74 ACI 318-14, 8.2.5; ACI 318-11, 13.2.6; ACI 318-08, 13.2.6

### 2.3.7.1. Critical Section

### For Interior Supports of Interior Frames

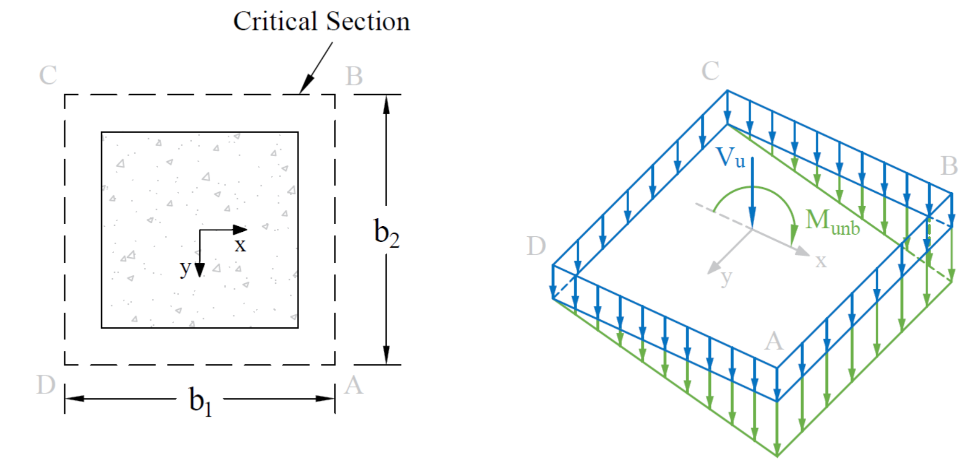
The critical section (Figure 2.23) consists of four vertical surfaces through the slab, located at distances of *d*/2 beyond the support faces.

The critical section for interior supports of interior frames is always closed. A closed section will have all its faces defined in Figure 2.21 resisting shear as indicated by Eq. 2-39:

$$A_c = \sum_{i=1}^{8} A_i \qquad \text{Eq. 2-39}$$

If beams frame[75] into the column, then the critical section includes the dimensions of the beams ($B_1$ through $B_6$ in Figure 2.21).

ACI 318 & CSA A23.3




Punching Shear - Critical Section

Punching Shear Stress ($v_u$) Profile

Figure 2.23 – Interior Supports of Interior Frames

[75] A beam is considered as framing into the column if the beam is within a face of the column.

### For Exterior Supports of Interior Frames

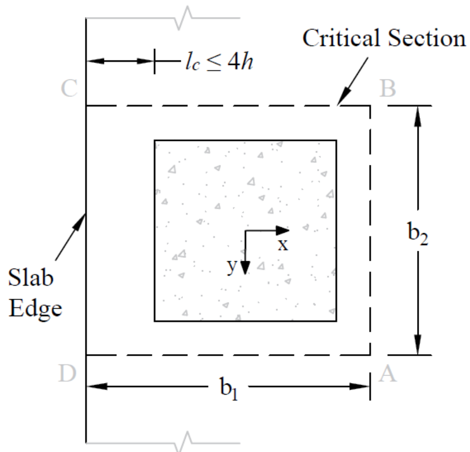
The critical section for exterior supports of interior frames (Figure 2.24) will be either closed (full $A_7$ and $A_6$ for the first column or $A_1$ and $A_2$ for the last column in Figure 2.21) or open, depending upon the length of the cantilever in relation to slab thickness. The critical section will be considered closed when the clear cantilever span, $l_c$, is greater than or equal to the distance defined by the user beyond the column face. The default value of the distance is $4h$ when an ACI code is selected[76] and $5d$ for the CSA standard[77]. The user can modify the default value to accommodate scenarios when larger distances are required, e.g. $10h$ for slabs with openings[78]. If beams frame into the column then the critical section includes the contributions from the beam dimensions ($B_1$ through $B_6$ in Figure 2.21).

[76] Critical Sections near Holes and at Edges in Ref. [15], pp.672, Fig 13-59 (b) and (c)

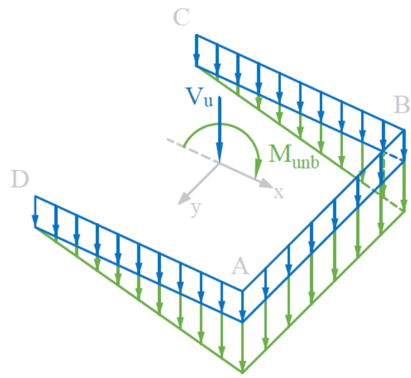
[77] CSA A23.3-04 Figure N13.3.3.4 (b) in Ref. [12]; CSA A23.3-94 Figure N13.4.3.4 (b) in Ref. [14]

[78] ACI 318-14, 22.6.4.3; ACI 318-11, 11.11.6; ACI 318-08, 11.11.6; ACI 318-05, 11.12.5; ACI 318-05, 11.12.5; ACI 318-05, 11.12.5; CSA A23.3-14, 13.3.3.4; CSA A23.3-04, 13.3.3.4; CSA A23.3-94, 13.4.3.4

ACI 318

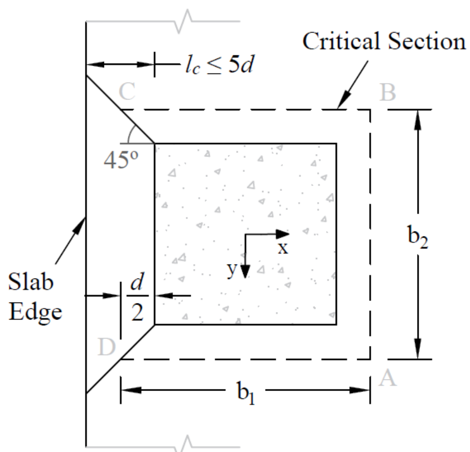



Punching Shear - Critical Section

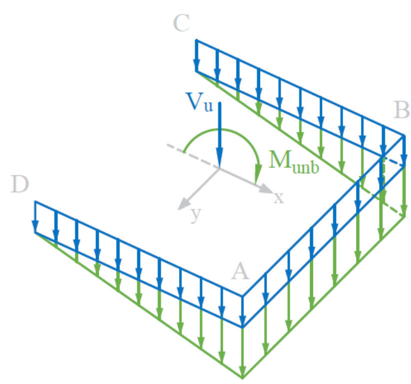



Punching Shear Stress ($v_u$) Profile

CSA A23.3




Punching Shear - Critical Section




Punching Shear Stress ($v_u$) Profile

Figure 2.24 – Exterior Supports of Interior Frames

## For Interior Supports of Exterior Frames

Figure 2.25 shows the critical section for shear for an interior support of an exterior frame. Note that the section is considered as U-shaped ($A_5$ = 0, $A_8$ = 0, $B_3$ = 0, $B_4$ = 0 in Figure 2.21) and it extends up to the edge of the exterior face of the support. If beams frame into the column, then the critical section includes the contribution from the beam dimensions ($B_1$ through $B_6$ in Figure 2.21). If the exterior cantilever span, $l_c$, is greater than or equal to the distance defined by the user beyond the column face (the default value is 4*h* when an ACI code is selected[81] and 5*d* for the CSA standard[82]), the section is treated as closed, that is, the support is treated as an interior support of an interior frame.

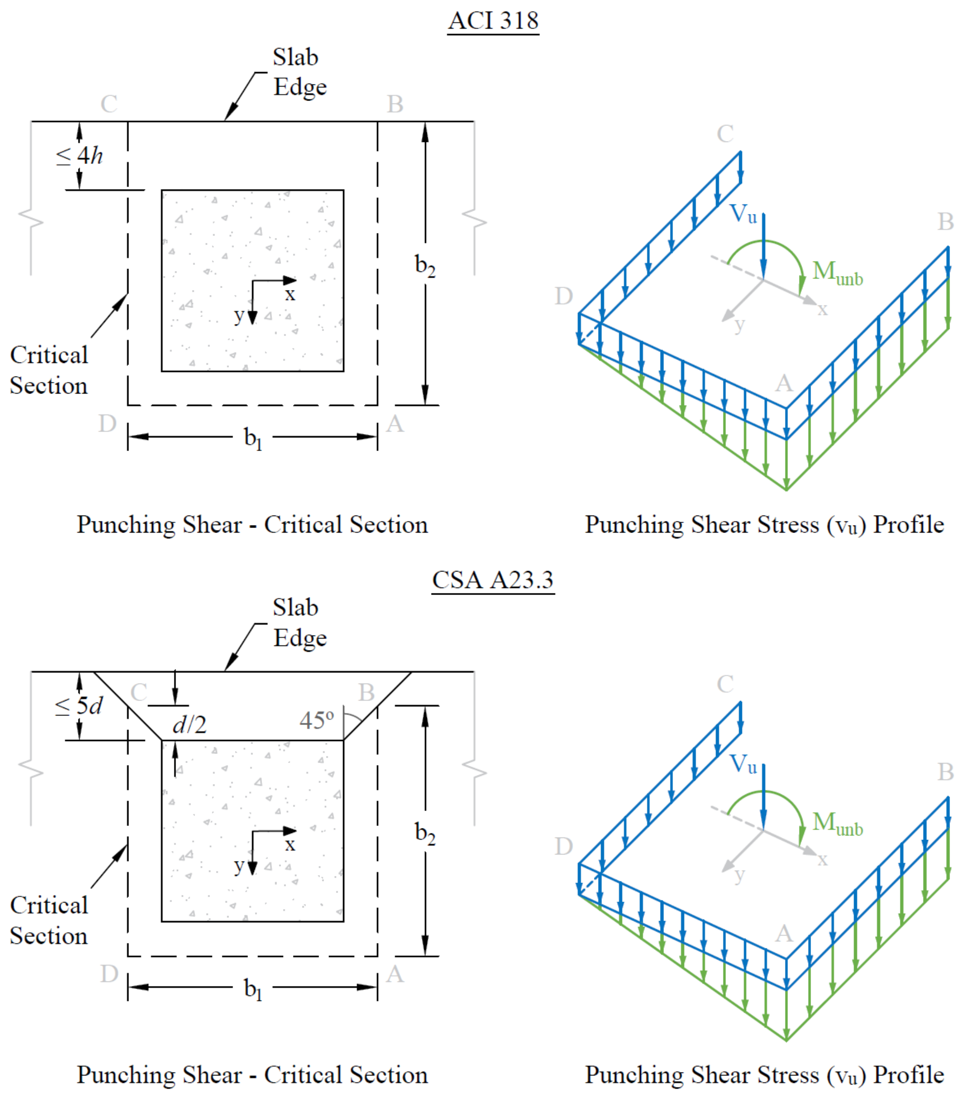



Figure 2.25 – Interior Supports of Exterior Frames

## For Exterior Supports of Exterior Frames

The critical section for an exterior support of an exterior frame will typically be L-shaped as shown in the Figure 2.26. If the cantilever span, $l_c$, (in the direction of analysis) is greater than or equal to the distance defined by the user beyond the column face (the default value is $4h$ when an ACI code is selected[81] and $5d$ for the CSA standard[82]), then the section is treated as a U-shaped interior support. If, in addition, the cantilever span in transverse direction is greater than or equal to the distance defined by the user beyond the column face, the section is treated as closed. If beams frame into the column, then the critical section includes the contributions from the beam dimensions.

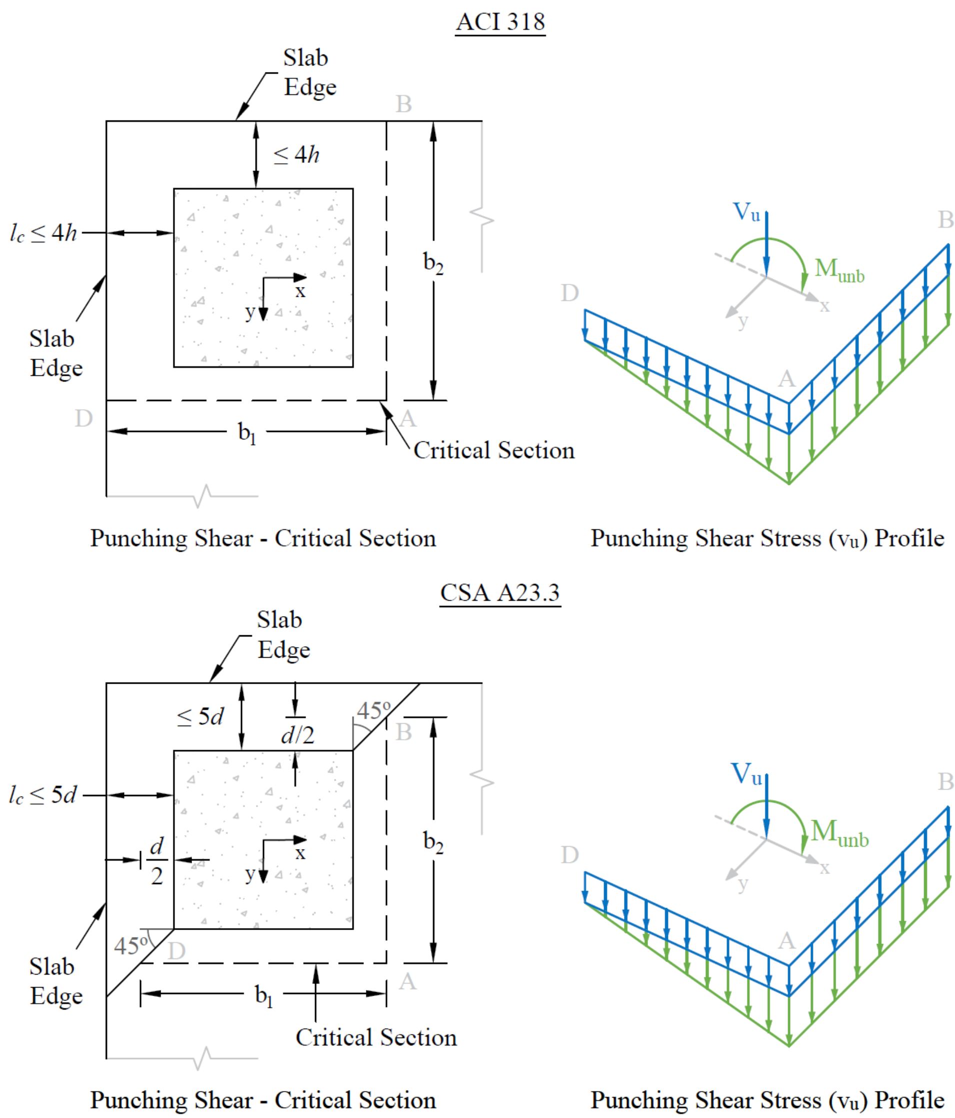



Figure 2.26 – Exterior Supports of Exterior Frames

### 2.3.7.2. Computation of Allowable Shear Stress at Critical Section

spSlab

One-way shear strength of slabs is limited[79] to $2\lambda\sqrt{f'_c}$. Two-way shear strength of slabs is affected by concrete strength, relationship between size of loaded area and slab thickness, loaded area aspect ratio, and shear-to-moment ratio at slab-column connections.

These variables are taken into account in the allowable shear stress, $v_c$, computed at distances of $d/2$ around the columns and drops (if applicable). For the ACI 318 code, $v_c$ is taken as the smallest of the 3 quantities[80]:

$$v_c = \left(2 + \frac{4}{\beta_c}\right)\lambda\sqrt{f'_c} \qquad \text{Eq. 2-40}$$

$$v_c = \left(2 + \frac{\alpha_s d}{b_o}\right)\lambda\sqrt{f'_c} \qquad \text{Eq. 2-41}$$

$$v_c = 4\lambda\sqrt{f'_c} \qquad \text{Eq. 2-42}$$

where:

$\beta_c$ = the ratio of the long to the short side of the column,

$\alpha_s$ = a constant dependent on the column location, (40 for an interior 4-sided effective critical area, 30 for an exterior 3-sided critical area, 20 for a corner 2-sided effective critical area),

$d$ = distance from the slab bottom to centroid of the slab tension reinforcement at support (average value is used if $d$ changes along critical section perimeter),

$b_o$ = the perimeter of the critical section,

$\lambda$ = factor[81] reflecting the reduced mechanical properties of lightweight concrete equal to 0.75 for all-lightweight concrete, 0.85 for sand-lightweight concrete and 1.0 for normal weight concrete. Refer to Table 2.1 for determination of concrete type.

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79 ACI 318-14, 22.5.5.1; ACI 318-11, 11.2.1.1; ACI 318-08, 11.2.1.1; ACI 318-05, 11.3.1.1; ACI 318-02, 11.3.1.1; ACI 318-99, 11.3.1.1

80 ACI 318-14, 22.6.5.2, 22.6.5.3; ACI 318-11, 11.11.2.1; ACI 318-08, 11.11.2.1; ACI 318-05, 11.12.2.1; ACI 318-02, 11.12.2.1; ACI 318-99, 11.12.2.1

81 ACI 318-14, 22.6.5.2, 22.6.5.3; ACI 318-11, 11.11.2.1; ACI 318-08, 11.11.2.1; ACI 318-05, 11.2.1.2; ACI 318-02, 11.2.1.2; ACI 318-99, 11.2.1.2

For the CSA A23.3[82], the allowable shear stresses are calculated as the minimum of the following metric equations:

$$v_c = \left(1 + \frac{2}{\beta_c}\right)\eta\lambda\phi_c\sqrt{f'_c} \qquad \text{Eq. 2-43}$$

$$v_c = \left(\frac{\alpha_s d}{b_o} + \eta\right)\lambda\phi_c\sqrt{f'_c} \qquad \text{Eq. 2-44}$$

$$v_c = 2\eta\lambda\phi_c\sqrt{f'_c} \qquad \text{Eq. 2-45}$$

where:

$\eta$ = 0.19 for CSA A23.3-14/04 and 0.20 for CSA A23.3-94,

$\alpha_s$ = a constant dependent on the column location, (4 for an interior 4-sided effective critical area, 3 for an edge column, 2 for a corner column),

$d$ = distance from the slab bottom to centroid of the slab tension reinforcement at support (average value is used if $d$ changes along critical section perimeter),

$\phi_c$ = resistance factor for concrete[83] equal to 0.60 for CSA A23.3-94 and for CSA A23.3-14/04 it is equal to 0.65 for regular and 0.70 for precast concrete,

$\lambda$ = factor[84] reflecting the reduced mechanical properties of lightweight concrete equal to 0.75 for structural low-density concrete, 0.85 structural semi-low-density concrete and 1.0 for normal density concrete. Refer to Table 2.1 for determination of concrete type,

$\sqrt{f'_c}$ ≤ 8 MPa.

When the value of $d$ is greater than 300 mm, allowable stress $v_c$ obtained from the above three equations shall be multiplied by 1300 / (1000 + $d$) as required by CSA A23.3-14/04 code[85].

82 CSA A23.3-14, 13.3.4; CSA A23.3-04, 13.3.4; CSA A23.3-94, 13.4.4

83 CSA A23.3-14 8.4.2, 16.1.3; CSA A23.3-04 8.4.2, 16.1.3; CSA A23.3-94 8.4.2

84 CSA A23.3-14, 8.6.5; CSA A23.3-04, 8.6.5; CSA A23.3-94, 8.6.5

85 CSA A23.3-14, 13.3.4.3; CSA A23.3-04, 13.3.4.3

The allowable shear stress around drops when waffle slabs are used is computed as:

$$v_c = \begin{cases} 2\lambda\sqrt{f'_c} & \text{for ACI} \\ 0.20\phi_c\lambda\sqrt{f'_c} & \text{for CSA A23.3-94} \\ 0.19\phi_c\lambda\sqrt{f'_c} & \text{for CSA A23.3-04} \end{cases} \qquad \text{Eq. 2-46}$$

For waffle slab systems with valid ribs defined earlier in this chapter, the allowable shear stress is increased by 10% for ACI designs[86].

### 2.3.7.3. Computation of Factored Shear Force at Critical Section

The factored shear force $V_u$ in the critical section, is computed as the reaction at the centroid of the critical section (e.g., column centerline for interior columns) minus the self-weight and any superimposed surface dead and live load acting within the critical section. If the section is considered open, two 45° lines are drawn from the column corners to the nearest slab edge (lines AF and DE in Figure 2.25) and the self-weight and superimposed surface dead and live loads acting on the area ADEF are omitted from $V_u$.

86 ACI 318-14, 8.8.1.5, 9.8.1.5; ACI 318-11, 8.13.8; ACI 318-08, 8.13.8; ACI 318-05, 8.11.8; ACI 318-02, 8.11.8; ACI 318-99, 8.11.8

### 2.3.7.4. Computation of Unbalanced Moment at Critical Section

The factored unbalanced moment used for shear transfer, $M_{unb}$, is computed as the sum of the joint moments to the left and right. Moment of the vertical reaction with respect to the centroid of the critical section is also taken into account by:

$$M_{unb} = \left(M_{u,left} - M_{u,right}\right) - V_u c_g \qquad \text{Eq. 2-47}$$

where:

$M_{u,left}$ = factored bending moment at the joint on the left hand side of the joint,

$M_{u,right}$ = factored bending moment at the joint on the right hand side of the joint,

$V_u$ = factored shear force in the critical section described above,

$c_g$ = location of the centroid of the critical section with respect to the column centerline (positive if the centroid is to the right in longitudinal direction with respect to the column centerline).

### 2.3.7.5. Computation of Shear Stresses at Critical Section

The punching shear stress computed by the program is based on the following[87]:

$$v_u = \frac{V_u}{A_c} \qquad \text{Eq. 2-48}$$

where:

$V_u$ = factored shear force in the critical section described above,

$A_c$ = area of concrete, including beam if any, resisting shear transfer.

Under conditions of combined shear, $V_u$, and unbalanced moment, $M_{unb}$, $\gamma_v M_{unb}$ is assumed to be transferred by eccentricity of shear about the centroidal axis of the critical section. The shear stresses computed by the program for this condition correspond to[88]:

$$v_{AB} = \frac{V_u}{A_c} + \frac{\gamma_v M_{unb} c_{AB}}{J_c} \qquad \text{Eq. 2-49}$$

$$v_{CD} = \frac{V_u}{A_c} - \frac{\gamma_v M_{unb} c_{CD}}{J_c} \qquad \text{Eq. 2-50}$$

where:

$M_{unb}$ = factored unbalanced moment transferred directly from slab to column, as described above,

$\gamma_v$ = $(1 - \gamma_f)$, Eq. 2-51

is a fraction of unbalanced moment considered transferred by the eccentricity of shear about the centroid of the assumed critical section[89],

$c$ = distance from centroid of critical section to the face of section where stress is being

[87] ACI 318-14, 8.4.4.2.3; ACI 318-11, 11.11.7.2; ACI 318-08; 11.11.7.2; ACI 318-05, 11.12.6.2; ACI 318-02, 11.12.6.2; ACI 318-99, 11.12.6.2; CSA A23.3-14, 13.3.5; CSA A23.3-04, 13.3.5; CSA A23.3-94, 13.4.5

[88] ACI 318-14, R8.4.4.2.3; ACI 318-11, R11.11.7.2; ACI 318-08, R11.11.7.2; ACI 318-05, R11.12.6.2; ACI 318-02, R11.12.6.2; ACI 318-99, R11.12.6.2; CSA A23.3-14, 13.3.5.5; CSA A23.3-04, 13.3.5.5; CSA A23.3-94, 13.4.5.5; Ref. [24]

[89] ACI 318-14, 8.4.4.2.1, 8.4.4.2.2; ACI 318-11, 11.11.7.1; ACI 318-08, 11.11.7.1; ACI 318-05, 11.12.6.1; ACI 318-02, 11.12.6.1; ACI 318-99, 11.12.6.1; CSA A23.3-04, Eq. 13-8; CSA A23.3-94, Eq. 13-8

computed,

$J_c$ = property of the assumed critical section analogous to polar moment of inertia.

Factor $\gamma_f$ in Eq. 2-51 is calculated as[90]:

$$\gamma_f = \frac{1}{1+(2/3)\sqrt{b_1/b_2}} \qquad \text{Eq. 2-52}$$

where:

$b_1$ = width of critical section in the direction of analysis,

$b_2$ = width of the critical section in the transverse direction.

If an ACI 318 standard is selected then the program provides an option to use an increased value[91] of $\gamma_f$. For edge and corner columns with unbalanced moment about an axis parallel to the edge, the value can be increased to 1.0 if the factored shear force at the support doesn't exceed $0.75\phi V_c$ for edge columns and $0.5\phi V_c$ for corner columns. For ACI 318-99, ACI 318-02, and ACI 318-05, condition that reinforcement ratio in the effective slab width doesn't exceed $0.375\rho_b$ must also be satisfied to apply the increase. For interior columns and for edge columns with unbalanced moment perpendicular to the edge, $\gamma_f$ can be increased 25% but the final value of $\gamma_f$ cannot exceed 1.0. The increase can be applied if the shear doesn't exceed $0.4\phi V_c$. Also, the net tensile strain in the effective slab has to exceed 0.010 for the ACI 318-08, ACI 318-11, and ACI 318-14. For earlier ACI 318 editions, the condition that reinforcement ratio does not exceed $0.375\rho_b$ applies.

spSlab calculates $v_u$ as the absolute maximum of $v_{AB}$ and $v_{CD}$. Local effects of concentrated loads are not computed by spSlab and must be calculated manually.

90 ACI 318-14, 8.4.2.3.2; ACI 318-11, 13.5.3.2; ACI 318-08, 13.5.3.2; ACI 318-05, 13.5.3.2; ACI 318-02, 13.5.3.2; ACI 318-99, 13.5.3.2; CSA A23.3-04, Eq. 13-8; CSA A23.3-94, Eq. 13-7

91 ACI 318-14, 8.4.2.3.4; ACI 318-11, 13.5.3.3; ACI 318-08, 13.5.3.3; ACI 318-05, 13.5.3.3; ACI 318-02, 13.5.3.3; ACI 318-99, 13.5.3.3

### 2.3.7.6. Shear Resistance at Corner Columns

For the CSA A23.3 code in design mode, the program performs one-way shear resistance check in the vicinity of corner columns. A corner column is determined in spSlab as the exterior support along an exterior left or exterior right equivalent frame. For slabs with edge beams or drop panels a supplementary check including the contribution of these components should be performed manually.

For the CSA A23.3-94 edition, a critical shear section is located *d*/2 from the column corner. The minimum length section is selected using an optimization algorithm which analyzes sections at different angles. The extension to the cantilevered portion is considered by a length not to exceed effective slab thickness *d*.

For the CSA A23.3-14/04 edition, a critical shear section is located not further than *d*/2 from the edge of the column or column capital. The extension to the cantilevered portion is considered by a length not to exceed effective slab thickness *d*. The factored shear resistance is calculated as follows[92]:

$$v_c = \beta \lambda \phi_c \sqrt{f_c'} \qquad \text{Eq. 2-53}$$

where:

$\beta$ = factor accounting for shear resistance of cracked concrete[93].

[92] CSA A23.3-14, 13.3.6.2; CSA A23.3-04, 13.3.6.2

[93] CSA A23.3-14, 11.3.6.2 and 11.3.6.3; CSA A23.3-04, 11.3.6.2 and 11.3.6.3

### 2.3.7.7. Shear Resistance in Slab Bands

When performing two-way shear analysis for models with non-continuous longitudinal slab bands a non-standard partial drop panel is anticipated to close the slab band and the calculations are performed as follows. Punching shear around the column is checked using effective depth of the slab band on one side of the column and the depth of the extension drop panel on the other side of the column. On each four sides of the column the critical section is located ½ of the respective depth from the face of the column. Punching shear calculation around the drop panel/slab band assumes that the plane of critical section, which cuts perpendicularly through slab band, is located ½ $d$ of the slab band from the face of column. For three remaining column faces critical section is located ½ $d$ of the slab measured from the respective edges of drop panel or slab band.

### 2.3.8. One-Way Shear Analysis of Longitudinal Beams and Slabs

When longitudinal beams are present in a span, the program computes the shear reinforcement requirements for the beams. **Beam Transverse Reinforcement Capacity** dialog box in the program output provides values of $V_u$, $V_c$, and $Av/s$ for selected segment locations of each span. Segment lengths are chosen not to exceed the beam section depth. The beginning of first segment and the end of last segment correspond to the locations of critical sections on the left and right support respectively. The critical sections are located at a distance $d$, the effective beam depth, away from the column face at both the left and the right ends of the beam. However, if concentrated loads are present within distance $d$ from the column face, critical section is selected at the column face.

$V_u$ is computed from the load acting over the entire width of the design strip. The program makes no distinction between shallow beams ($\alpha_{f1}\, l_2 / l_1 < 1$) and deeper beams ($\alpha_{f1}\, l_2 / l_1 > 1$).

### 2.3.8.1. Shear Calculations for ACI 318 and CSA A23.3-94

Shear strength provided by concrete, $V_c$, is computed by[94]:

$$V_c = \begin{cases} 2\lambda\sqrt{f_c'}b_w d & \text{for ACI 318} \\ 0.17\lambda\sqrt{f_c'}b_w d & \text{for ACI 318M-11/08/05} \\ \lambda\sqrt{f_c'}b_w d/6 & \text{for ACI 318M-02/99} \\ 0.20\phi_c\lambda\sqrt{f_c'}b_w d & \text{for CSA A23.3-94} \end{cases} \qquad \text{Eq. 2-54}$$

where:

$\phi_c$ = resistance factor for concrete[95] equal to 0.60.

In CSA A23.3-94 design, for beams without minimum stirrup reinforcement and greater than 300 mm deep, $V_c$ is calculated from the following equation[96]:

$$V_c = \left(\frac{260}{1{,}000+d}\right)\lambda\phi_c\sqrt{f_c'}b_w d \geq 0.10\lambda\phi_c\sqrt{f_c'}b_w d \qquad \text{Eq. 2-55}$$

When $V_u > \phi V_c/2$, the beam must be provided with at least a minimum shear reinforcement of[97]:

$$A_{v,\min} = \begin{cases} \max\left(0.75\sqrt{f_c'}, 50\right) & \text{for ACI 318-11/08/05/02} \\ 50 & \text{for ACI 318-99} \\ \max\left(0.062\sqrt{f_c'}, 0.35\right) & \text{for ACI 318M-11/08/05} \\ \max\left(\sqrt{f_c'}/16, 0.33\right) & \text{for ACI 318M-02} \\ 1/3 & \text{for ACI 318M-99} \\ 0.06\sqrt{f_c'} & \text{for CSA A23.3-94} \end{cases} \qquad \text{Eq. 2-56}$$

94 ACI 318-14, 22.5.5.1; ACI 318-11, 11.2.1.1; ACI 318-08, 11.2.1.1; ACI 318-05, 11.3.1.1; ACI 318-02, 11.3.1.1; ACI 318-99, 11.3.1.1; ACI 318M-08, 11.2.1.1; ACI 318M-05, 11.3.1.1; ACI 318M-02, 11.3.1.1; ACI 318M-99, 11.3.1.1; CSA A23.3-94, 11.3.5.1

95 CSA A23.3-94, 8.4.2

96 CSA A23.3-94, 11.3.5.2

97 ACI 318-14, 9.6.3.3; ACI 318-11, 11.4.6.3; ACI 318-08, 11.4.6.3; ACI 318-05, 11.5.6.3; ACI 318-02, 11.5.5.2; ACI 318-99, 11.5.5.2; ACI 318M-08, 11.4.6.3; ACI 318M-05, 11.5.6.3; ACI 318M-02, 11.5.5.2; ACI 318M-99, 11.5.5.2; CSA A23.3-94, 11.2.8.4

where:

$A_v$ = area of all stirrup legs,

$s$ = stirrups spacing,

$b_w$ = longitudinal beam width,

$f_{yt}$ = yield strength of the shear reinforcement.

In the investigation mode, if the ACI-318 spacing requirement for shear reinforcement[98] or minimum shear reinforcement requirement are not met, the shear strength of the section is taken as one-half of the shear strength provided by concrete.

When $V_u > \phi V_c$, shear reinforcement must be provided so that:

$$\frac{A_v}{s} = \begin{cases} \dfrac{V_u - \phi V_c}{\phi f_{yt} d} = \dfrac{V_s}{\phi f_{yt} d} & \text{for ACI 318-11/08/05/02} \\[2ex] \dfrac{V_u - V_c}{\phi_s f_{yt} d} = \dfrac{V_s}{\phi_s f_{yt} d} & \text{for CSA A23.3-94} \end{cases} \qquad \text{Eq. 2-57}$$

where:

$V_u$ = factored shear force at the section being considered,

$V_s$ = shear strength provided by shear reinforcement,

$d$ = effective depth of the beam at the same location,

$\phi$ = strength reduction factor for shear calculations[99] equal to 0.85 for ACI 318-99 and equal to 0.75 for ACI 318-14, ACI 318-11, ACI 318-08, ACI 318-05, and ACI 318-02,

$\phi_s$ = resistance factor for reinforcement[100] equal to 0.85.

98 ACI 318-14, 9.7.6.2.2, 9.7.6.2.3; ACI 318-11, 11.4.5; ACI 318-08, 11.4.5; ACI 318-05, 11.5.5; ACI 318-02, 11.5.4; ACI 318-99, 11.5.4

99 ACI 318-14, 21.2.1; ACI 318-11, 9.3.2.3; ACI 318-08, 9.3.2.3; ACI 318-05, 9.3.2.3; ACI 318-02, 9.3.2.3; ACI 318-99, 9.3.2.3

100 CSA A23.3-94, 8.4.3

The capacity of shear reinforcement $V_s$ is limited to $V_{s,max} = 8\sqrt{f_c'}b_w d$ ($V_{s,max} = 0.8\lambda\phi_c\sqrt{f_c'}b_w d$ for CSA A23.3-94). When $V_u$ exceeds $\phi V_c + \phi V_{s,max}$ ($V_c + V_{s,max}$ for CSA A23.3-94), the beam section dimensions must be increased or a higher concrete strength must be provided[101].

When $V_u \le \phi 10\sqrt{f_c'}b_w d$, the spacing is computed as:

$$s = \frac{1}{\dfrac{A_v}{s}}\left(n\,A_{sb}\right) \qquad \text{Eq. 2-58}$$

where:

$A_{sb}$ = stirrup bar area (one leg),

$n$ = number of stirrup legs.

The maximum stirrup spacing for ACI codes[102] must not exceed $d/2$ or 24 in when $V_s \le 4\sqrt{f_c'}b_w d$ $\left[V_s \le 0.33\sqrt{f_c'}b_w d\right]$. When $V_s > 4\sqrt{f_c'}b_w d$, the maximum stirrup spacing must be reduced by half, to $d/4$ or 12 in. For the CSA A23.3-94 standard[103], maximum spacing must not exceed the smaller of 0.7$d$ and 600 mm when $V_u < 0.1\lambda\phi_c f_c' b_w d$ or the smaller of 0.35$d$ and 300 mm when $V_u \ge 0.1\lambda\phi_c f_c' b_w d$.

When $V_s > 8\sqrt{f_c'}b_w d$ $\left[V_s \le 0.66\sqrt{f_c'}b_w d\right]$ for ACI codes and $V_s > 0.8\lambda\phi_c\sqrt{f_c'}b_w d$ for CSA A23.3-94 code, the beam section dimensions must be increased or a higher concrete strength must be provided[104].

[101] ACI 318-14, 22.5.1.2; ACI 318-11, 11.4.7.9; ACI 318-08, 11.4.7.9; ACI 318-05, 11.5.7.9; ACI 318-02, 11.5.6.9; ACI 318-99, 11.5.6.9; CSA A23.3-94, 11.3.4

[102] ACI 318-14, 9.7.6.2.2, 9.7.6.2.3; ACI 318-11, 11.4.5; ACI 318-08, 11.4.5; ACI 318-05, 11.5.5; ACI 318-02, 11.5.4; ACI 318-99, 11.5.4; CSA A23.3-94, 11.2.11

[103] CSA A23-3-94, 11.2.11

[104] ACI 318-14, 22.5.1.2; ACI 318-11, 11.4.7.9; ACI 318-08, 11.4.7.9; ACI 318-08, ACI 318-05, 11.5.7.9; ACI 318-02, 11.5.6.9; ACI 318-99, 11.5.6.9, CSA A23.3-94, 11.3.4

The minimum shear reinforcement requirement is waived[105] for joist construction and for beams satisfying the following criteria:

For ACI 318-14, ACI 318-11 and ACI 318-08:

- Beams with depth not exceeding 10 in. [250 mm].
- Beams integral with slabs (assumed by the program for all beams in two-way systems and beams within one-way slabs with overall width larger than effective beam flange width), with beam depth not exceeding 24 in. [600 mm] and not greater than the larger of 2.5 times flange thickness and 0.5 times web width.

For ACI 318-05/02/99:

- Beams with depth not exceeding the largest of 10 in. [250 mm], 2.5 times flange thickness, and half of web width (rectangular beams are assumed by the program to have flange thickness equal to zero and web width equal to beam width).

For CSA A23.3-94:

- Beams with depth not exceeding 250 mm.
- Beams integral with slabs (assumed by the program for all beams in two-way systems and beams within one-way slabs with overall width larger than effective beam flange width), with beam depth not exceeding the larger of 600 mm and 0.5 times web width.

[105] ACI 318-14, 7.6.3.1, 9.6.3.1; ACI 318-11, 11.4.6.1; ACI 318-08, 11.4.6.1; ACI 318-05, 11.5.6.1; ACI 318-02, 11.5.5.1; ACI 318-99, 11.5.5.1; ACI 318M-08, 11.4.6.1; ACI 318M-05, 11.5.6.1; ACI 318M-02, 11.5.5.1; ACI 318M-99, 11.5.5.1; CSA A23.3-94, 11.2.8.1

### 2.3.8.2. Shear Calculation for CSA A23.3-14/04

For CSA A23.3-04 code, the program calculates shear strength $V_c$ provided by concrete from the following equation[106]:

$$V_c = \phi_c \lambda \beta \sqrt{f'_c} b_w d_v \qquad \text{Eq. 2-59}$$

where:

$\phi_c$ = resistance factor for concrete equal to 0.65 for regular and 0.70 for precast concrete,

$\lambda$ = factor to account for low-density concrete,

$b_w$ = beam web width,

$d_v$ = effective shear depth equal to greater of 0.9$d$ or 0.72$h$,

$\beta$ = factor accounting for shear resistance of cracked concrete,

$\sqrt{f'_c} \leq$ 8 MPa.

When $V_u > V_c$, the beam must be provided with at least minimum shear reinforcement[107]. Additionally minimum shear reinforcement is required for beam sections with overall thickness exceeding 750 mm. Minimum area of shear reinforcement is calculated from the following formula[108]:

$$A_v = 0.06 \sqrt{f'_c} \frac{b_w s}{f_y} \qquad \text{Eq. 2-60}$$

[106] CSA A23.3-14, 11.3.4; CSA A23.3-04, 11.3.4

[107] CSA A23.3-14, 11.2.8.1; CSA A23.3-04, 11.2.8.1

[108] CSA A23.3-14, 11.2.8.2; CSA A23.3-04, 11.2.8.2

Shear strength provided by shear reinforcement, $V_s$, is calculated from the following equation[109]:

$$V_s = \frac{\phi_s A_v f_y d_v \cot(\theta)}{s} \quad \text{Eq. 2-61}$$

where:

$\phi_s$ = resistance factor for reinforcement steel[110] equal to 0.85,

$A_v$ = area of shear reinforcement within distance $s$,

$f_y$ = yield strength of reinforcement,

$d_v$ = effective shear depth equal to greater of 0.9$d$ or 0.72$h$,

$s$ = spacing of transverse reinforcement,

$\theta$ = the angle of inclination of diagonal compressive stresses.

Spacing of transverse reinforcement, $s$, must not exceed the smaller[111] of 0.7$d$ and 600 mm when $V_u \le 0.125\lambda\phi_c f'_c b_w d$ or the smaller[112] of 0.35$d$ and 300 mm when $V_u > 0.125\lambda\phi_c f'_c b_w d$.

When $V_u > 0.25\lambda\beta\sqrt{f'_c} b_w d_v$, the beam section dimensions must be increased or a higher concrete strength must be provided[113].

[109] CSA A23.3-14, 11.3.5.1; CSA A23.3-04, 11.3.5.1

[110] CSA A23.3-14, 8.4.3(a); CSA A23.3-04, 8.4.3(a)

[111] CSA A23.3-14, 11.3.8.1; CSA A23.3-04, 11.3.8.1

[112] CSA A23.3-14, 11.3.8.3; CSA A23.3-04, 11.3.8.3

[113] CSA A23.3-94, 11.3.3

The program recognizes special member types and assumes values of $\beta$ = 0.21 and $\theta$ = 42° in the following cases[114]:

- Slabs (including slab bands for CSA code) having thickness not exceeding 350 mm.
- Beams having thickness not exceeding 250 mm.
- Concrete joist construction.
- Beams cast monolithically with the slab and having the depth below the slab not exceeding one-half of the width or 350 mm.

For other general cases the program utilizes the so called simplified method. The value of $\theta$ is assumed as 35°. For sections having or requiring at least minimum transverse reinforcement $\beta$ = 0.18 is assumed. For sections with no transverse reinforcement the value of $\beta$ is calculated as follows[115]:

$$\beta = \frac{230}{1,000 + d_v} \qquad \text{Eq. 2-62}$$

[114] CSA A23.3-14, 11.3.6.2; CSA A23.3-04, 11.3.6.2

[115] CSA A23.3-14, 11.3.6.3(b); CSA A23.3-04, 11.3.6.3(b)

### 2.3.8.3. Shear Distribution

When no ribs are present, one way shear is proportioned to the slab and beam according to the following ratios:

$$\alpha_{f1} l_2 / l_1, \qquad 1 - \alpha_{f1} l_2 / l_1 \qquad \text{Eq. 2-63}$$

When ribs are present (joist systems), one way shear is proportioned to the slab and beam according to the following ratios of cross-section areas:

$$\frac{A_{ribs}}{A_{ribs} + A_{beam}}, \quad \frac{A_{beam}}{A_{ribs} + A_{beam}} \qquad \text{Eq. 2-64}$$

Per requirement[116] of CSA A23.3-14/04, the program allows distributing one-way shear in the slab between column and middle strips using the distribution factors which are proportional to the factors used for negative moment distribution. The fraction of the shear transferred to the beam remains unchanged irrespective of the use of this feature. This functionality is also provided for other design codes, to be selected at engineer's discretion.

[116] CSA A23.3-14, 13.3.6.1; CSA A23.3-04, 13.3.6.1

### 2.3.8.4. One-Way Shear in Slab Bands (CSA A23.3-14/04)

One-way shear calculations in slab bands are done similar to shear in two-way slabs, except the column strip is substituted by the band strip. Shear forces are distributed between the band and the middle strip proportionally to negative moment distribution factors. Transverse reinforcement is not considered.

### 2.3.8.5. Shear in Drop Panels

When calculating one-way shear capacity for two-way solid and waffle slabs, the contribution of the drop panel cross-section can be optionally selected. For such slabs, the shear capacity is calculated in three regions, with increased $V_c$ values in support (drop panel) locations. In case shear is distributed into column and middle strips, drop panel contribution is divided according to the share of drop panel cross-section area in each strip.

### 2.3.9. Torsion and Shear

Torsion analysis can be engaged for beam and one-way systems by selecting YES for **Consider Torsion** run option located in the **Project Left Panel** under **Project** command in the **Ribbon**.

As far as torsional analysis is concerned, it is assumed that columns provide perfectly rigid supports so there is no transfer of torsional moments between spans. Within a span, torsional moments are considered only if a longitudinal beam is present. Torsion can be induced by concentrated and redistributed torsional loads and also, in the case of a beam with unsymmetrical cross sections, by self weight and area loads. A T-section with different flange widths is an example of a cross section which is not symmetrical. It can be obtained if a beam and a slab with different left and right widths are combined in the same span. However, in order for a flange to be considered in the torsional analysis its thickness has to be greater than twice the cover. If a flange is wider than the effective width then only the effective width is taken into account.

The design for torsion is based on a thin-walled tube, space truss analogy. For the Canadian code the simplified method is used. The program allows both equilibrium and compatibility torsion conditions. In the equilibrium mode, which is assumed by default, unreduced total value of the torsional design moment is used in the design. In the compatibility mode[117], factored torsional moments that exceed cracking moment $T_{cr}$ ($0.67T_{cr}$ for CSA) are reduced to the value of $T_{cr}$ ($0.67T_{cr}$ for CSA). However, it is user's responsibility to determine which mode is appropriate and the program does not perform any redistribution of internal forces if compatibility torsion is selected.

If torsion analysis is engaged then both torsion and shear actions contribute to the amount of required transverse (stirrup) reinforcement. However, additional longitudinal bars distributed along the perimeter of a cross-section are also required to provide torsional capacity.

[117] ACI 318-14, 22.7.5.1; ACI 318-11, 11.5.2.2; ACI 318-08, 11.6.2.2; ACI 318-05, 11.6.2.2; ACI 318-02, 11.6.2.2; ACI 318-99, 11.6.2.2; CSA A23.3-14, 11.2.9.2; CSA A23.3-04, 11.2.9.2; CSA A23.3-94, 11.2.9.2

For torsion design a span is divided into segments in the same way as for shear design. Governing values within a segment are used to design the whole segment. For stirrups, the governing values of torsional moment and shear force (acting simultaneously) will be these that produce the highest intensity of required stirrup area. On the other hand, the required area of longitudinal bars depends only on the torsional moment so the highest absolute value of torsional moment will govern. Since stirrup area depends both on shear and torsion whereas longitudinal bar area depends only on torsion, the governing values for stirrups and longitudinal bars can occur at different locations within a segment and for different load combinations. Governing values along with their location and associated load combination are provided in the design results report.

Effect of torsion within a segment will be neglected if the factored torsional moment, $T_u$, at every segment location is less than one fourth of the torsion cracking moment, $T_{cr}$, which equals:

for ACI code[118]

$$T_{cr} = 4\phi\lambda\sqrt{f'_c}\,\frac{A_{cp}^2}{p_{cp}} \qquad \text{Eq. 2-65}$$

for CSA A23.3-94 code[119]

$$T_{cr} = 0.4\phi_c\lambda\sqrt{f'_c}\,\frac{A_{cp}^2}{p_{cp}} \qquad \text{Eq. 2-66}$$

for CSA A23.3-14/04 code[120]

$$T_{cr} = 0.38\phi_c\lambda\sqrt{f'_c}\,\frac{A_{cp}^2}{p_{cp}} \qquad \text{Eq. 2-67}$$

$A_{cp}$ denotes the area enclosed by outside perimeter of concrete section and $p_{cp}$ is equal to the outside perimeter of concrete section.

[118] ACI 318-08, R11.5.1; ACI 318-05, R11.6.1; ACI 318-02, R11.6.1; ACI 318-99, R11.6.1

[119] CSA A23.3-94, 11.2.9.1

[120] CSA A23.3-04, 11.2.9.1

To be adequate for torsion design, a section has to be proportioned in such a way that combined shear stress due to shear and torsion does not exceed the limit value specified by the code. In ACI code this condition reads as[121]:

$$\sqrt{\left(\frac{V_u}{b_w d}\right)^2+\left(\frac{T_u p_h}{1.7A_{oh}^2}\right)^2}\leq\phi\left(\frac{V_c}{b_w d}+8\sqrt{f_c'}\right) \qquad \text{Eq. 2-68}$$

The simplified method of CSA A23.3-94 standard defines this relation as[122]:

$$\frac{V_u}{b_w d}+\frac{T_u p_h}{A_{oh}^2}\leq 0.25\phi_c f_c' \qquad \text{Eq. 2-69}$$

Similar requirement for CSA A23.3-04 reads as follows[123]:

$$\sqrt{\left(\frac{V_u}{b_w d}\right)^2+\left(\frac{T_u p_h}{1.7A_{oh}^2}\right)^2}\leq 0.25\phi_c f_c' \qquad \text{Eq. 2-70}$$

In above relations, $A_{oh}$ is the area enclosed by centerline of the outermost closed transverse reinforcement and $p_h$ is the perimeter of that area. By default, flanges do not contribute to $A_{oh}$ and $p_h$. For sections with flanges, flanges will only be taken into account for $A_{oh}$ and $p_h$ if the option to include stirrups in flanges is engaged in the torsion design. In the program output, the combined stress (left hand side of the above inequalities) is denoted as $v_f$ and the limit value as $\phi s_{vt}$.

[121] ACI 318-14, 22.7.7.1; ACI 318-11, 11.5.3.1; ACI 318-08, 11.5.3.1; ACI 318-05, 11.6.3.1; ACI 318-02, 11.6.3.1; ACI 318-99, 11.6.3.1

[122] CSA A23.3-94, 11.3.9.8

[123] CSA A23.3-14, 11.3.10.4(b); CSA A23.3-04, 11.3.10.4(b)

The required intensity of stirrup area to provide required torsional capacity is calculated from the following formula[124]:

$$\frac{A_t}{s}=\begin{cases}\dfrac{T_u}{2\phi A_o f_{yt}} & \text{for ACI 318}\\[2ex] \dfrac{T_u}{2\phi_s A_o f_{yt}} & \text{for CSA A23.3-94}\\[2ex] \dfrac{T_u}{2\phi_s A_o f_{yt}\cot(\theta)} & \text{for CSA A23.3-14/04}\end{cases} \qquad \text{Eq. 2-71}$$

where the gross area enclosed by the shear path[125], $A_o$, is taken as $0.85A_{oh}$ × $A_t/s$ is the quantity per stirrup leg. Concrete shear and torsion strength reduction factor[126], $\phi$, for ACI-318 codes is equal to 0.75 for the 99 edition and 0.75 for later editions.

The total requirement for stirrup intensity combining shear and torsion equals[127]:

$$\frac{A_{v+2t}}{s}=\frac{A_v}{s}+2\frac{A_t}{s} \qquad \text{Eq. 2-72}$$

[124] ACI 318-14, 22.7.6.1; ACI 318-11, 11.5.3.6; ACI 318-08, 11.5.3.6; ACI 318-05, 11.6.3.6; ACI 318-02, 11.6.3.6; ACI 318-99, 11.6.3.6; CSA A23.3-14, 11.3.10.3; CSA A23.3-04, 11.3.10.3; CSA A23.3-94, 11.3.9.4

[125] CSA A23.3-14, 11.3.10.3; CSA A23.3-04, 11.3.10.3; CSA A23.3-94, 11.3.9.7

[126] ACI 318-14, 21.2.1; ACI 318-11, 9.3.2.3; ACI 318-08, 9.3.2.3; ACI 318-05, 9.3.2.3; ACI 318-02, 9.3.2.3; ACI 318-99, 9.3.2.3

[127] ACI 318-14, R9.5.4.3; ACI 318-11, R11.5.2.8; ACI 318-08, R11.5.3.8; ACI 318-05, R11.6.3.8; ACI 318-02, R11.6.3.8; ACI 318-99, R11.6.3.8

This value cannot be taken less than minimum stirrup area required by the codes. The minimum code requirements can be written in the following form[128]:

$$A_{v+2t} = \frac{b_w s}{f_{yt}} \times \begin{cases} \max\left(0.75\sqrt{f_c'}, 50\right) & \text{for ACI 318-11/08/05/02} \\ 50 & \text{for ACI 318-99} \\ \max\left(0.062\sqrt{f_c'}, 0.35\right) & \text{for ACI 318M-11/08/05} \\ \max\left(\sqrt{f_c'}/16, 0.33\right) & \text{for ACI 318M-02} \\ 0.33 & \text{for ACI 318M-99} \\ 0.06\sqrt{f_c'} & \text{for CSA A23.3-04/94} \end{cases} \qquad \text{Eq. 2-73}$$

In addition to stirrup spacing requirement defined for shear, program imposes one more torsion specific requirement for all ACI codes[129] which limits the spacing to the smallest of $p_h/8$, and 12 in [300 mm]. Based on the total required stirrup area intensity and spacing requirements, the program attempts to select stirrups taking also into account that if stirrups with more than two legs have to be used then the area of an outer leg must not be less than $A_t$.

128 ACI 318-14, 9.6.4.2; ACI 318-11, 11.5.5.2; ACI 318-08, 11.5.5.2; ACI 318-05, 11.6.5.2; ACI 318-02, 11.6.5.2; ACI 318-99, 11.6.5.2; ACI 318M-11, 11.5.5.2; ACI 318M-08, 11.5.5.2; ACI 318M-05, 11.6.5.2; ACI 318M-02, 11.6.5.2; ACI 318M-99, 11.6.5.2; CSA A23.3-14, 11.2.8.2; CSA A23.3-04, 11.2.8.2; CSA A23.3-94, 11.2.8.4

129 ACI 318-14, 9.7.6.3.3; ACI 318-11, 11.5.6.1; ACI 318-08, 11.5.6.1; ACI 318-05, 11.6.6.1; ACI 318-02, 11.6.6.1; ACI 318-99, 11.6.6.1

### 2.3.9.1. Additional Longitudinal Reinforcement for ACI 318 and CSA A23.3-94

The area of additional longitudinal reinforcement, $A_l$, is calculated from[130]:

$$A_l = \frac{T_u p_h}{2\phi A_o f_y} \qquad \text{Eq. 2-74}$$

For ACI code it is also checked against the following minimum value[131]:

$$A_{l,\min} = \frac{5\sqrt{f_c'}A_{cp}}{f_y} - \left(\frac{A_t}{s}\right)p_h \frac{f_{yt}}{f_y} \qquad \text{Eq. 2-75}$$

where $A_t$ / $s$ is calculated from Eq. 2-56 but is not taken less than $25b_w$ / $f_{yt}$. Longitudinal bars are selected in such a way that their area is not less than $A_l \geq A_{l,min}$ and that number of longitudinal bars in a section is enough to provide a bar in every corner of a stirrup and preserve spacing between bars not higher than 12 in [300 mm]. Also, bar sizes are selected not to have diameter less than No. 3 bar and not less than 1/24 of stirrup spacing for ACI codes[132] and 1/16 for CSA standard[133].

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[130] ACI 318-14, 22.7.6.1; ACI 318-11, 11.5.3.7; ACI 318-08, 11.5.3.7; ACI 318-05, 11.6.3.7; ACI 318-02, 11.6.3.7; ACI 318-99, 11.6.3.7; CSA A23.3-94, 11.3.9.5

[131] ACI 318-14, 9.6.4.3, 9.7.5.1; ACI 318-11, 11.5.5.3; ACI 318-08, 11.5.5.3; ACI 318-05, 11.6.5.3; ACI 318-02, 11.6.5.3; ACI 318-99, 11.6.5.3

[132] ACI 318-14, 9.7.5.1, 9.7.5.2; ACI 318-11, 11.5.6.2; ACI 318-08, 11.5.6.2; ACI 318-05, 11.6.6.2; ACI 318-02, 11.6.6.2; ACI 318-99, 11.6.6.2

[133] CSA A23.3-14, 11.2.7; CSA A23.3-04, 11.2.7; CSA A23.3-94, 11.2.7

### 2.3.9.2. Additional Longitudinal Reinforcement for CSA A23.3-14/04

The additional longitudinal reinforcement, $A_l$, will only be calculated for CSA A23.3-14/04 if COMBINED M-V-T REINF. DESIGN option is unchecked in the **Design Options** tab under **Solve** command in the **Ribbon**. If this option is checked (default setting) then no additional longitudinal reinforcement is calculated because the regular top and bottom reinforcement will automatically be proportioned to resist combined action of flexure, shear and torsion.

Proportioning of longitudinal reinforcement for sections subjected to combined shear and torsion in flexural regions is based on the requirement that the resistance of the longitudinal reinforcement has to be greater or equal to the axial force that can be developed in this reinforcement. In sections with no axial action ($N_f = 0$ and $V_p = 0$) that force is equal to[134]:

- flexural tension side

$$F_{lt} = \underbrace{\frac{M_f}{d_v}}_{F_{lt,\,flexure}} + \underbrace{\cot\theta\sqrt{\left(V_f - 0.5V_s\right)^2 + \left(\frac{0.45 p_h T_f}{2A_o}\right)^2}}_{F_{lt,shear}} = F_{lt,\,flexure} + F_{lt,shear} \qquad \text{Eq. 2-76}$$

- flexural compression side

$$F_{lc} = \underbrace{-\frac{M_f}{d_v}}_{F_{lc,\,flexure}} + \underbrace{\cot\theta\sqrt{\left(V_f - 0.5V_s\right)^2 + \left(\frac{0.45 p_h T_f}{2A_o}\right)^2}}_{F_{lc,shear}} = F_{lc,\,flexure} + F_{lc,shear} \qquad \text{Eq. 2-77}$$

[134] CSA A23.3-14, 11.3.9.2, 11.3.9.3, 11.3.10.6; CSA A23.3-04, 11.3.9.2, 11.3.9.3, 11.3.10.6

These forces can be decomposed[135] into flexure and shear components. The flexure components, $F_{lt,flexure}$ and $F_{lc,flexure}$, account for the action of the bending moment, $M_f$, whereas the shear components, $F_{lt,shear}$ and $F_{lc,shear}$, account for the action of the shear force, $V_f$, and the torsional moment, $T_f$. The amounts of reinforcement needed to resist the flexure components are calculated separately in the flexure and axial design procedure. The total amount of the additional longitudinal reinforcement, $A_l$, needed to resist shear and torsion will be determined as follows:

$$A_l = \frac{F_{lt,shear} + F_{lc,shear}}{\phi_s f_y} = \frac{2\cot\theta\sqrt{\left(V_f - 0.5V_s\right)^2 + \left(\dfrac{0.45 p_h T_f}{2A_o}\right)^2}}{\phi_s f_y} \qquad \text{Eq. 2-78}$$

If only torsion is present ($V_f = 0$ and $V_s = 0$), then (assuming[136] $\theta = 35^o$) $A_l$ would reduce to

$$A_l = 2\cot\left(35^o\right)\frac{\left(\dfrac{0.45 p_h T_f}{2A_o}\right)}{\phi_s f_y} = 1.285\frac{p_h T_f}{2A_o \phi_s f_y} \qquad \text{Eq. 2-79}$$

which is comparable (and conservative) to the additional amount of longitudinal reinforcement due to torsion required in accordance with the previous edition of the CSA A23.3 standard[137].

[135] See Eq. 7-42, pp 294 in Ref. [7]

[136] CSA A23.3-14, 11.3.6.3; CSA A23.3-04, 11.3.6.3

[137] CSA A23.3-94, 11.3.9.5

### 2.3.9.3. Investigation Mode

In the investigation mode when transverse and longitudinal reinforcement is input by the user, the program checks the combined shear and torsional capacity of the system in terms of required and provided reinforcement area. In other words, the provided area of reinforcement is compared to the area of reinforcement required to resist applied loads. This is a different approach than for flexure and shear actions without coupling where design forces are directly compared to capacity. In the case where torsion and shear stirrup requirements are combined, the approach of comparing total reinforcement area is more convenient since it does not require dividing stirrup area into a part that resists torsion only and a part that resists shear only. For consistency, additional longitudinal reinforcement required for torsion and shear is also checked in terms of provided and required area. Other requirements, e.g. bar or stirrup spacing, number of longitudinal bars, area of stirrup outer leg, and combined stresses in concrete due to shear and torsion are checked also. Exceeded capacity and other conditions are flagged in the **Design Results** section of the report.

## 2.3.10. Deflections

### 2.3.10.1. Instantaneous Deflections

Instantaneous deflections are obtained directly by the program from elastic analysis of the defined system for three load levels. The first corresponds to dead load only, the second corresponds to dead load plus sustained part of live load only, and the third corresponds to dead load plus live load on all spans (total deflection). The deflection occurring when the live load is applied can be computed as the total load deflection (due to the dead and the live load) minus the dead load only deflection[138]. Depending on the option selected by the user, the program will calculate flexural stiffness of the members based on either gross moment of inertia or the effective moment of inertia which takes cracking into account.

$$\Delta Live = \Delta Total - \Delta Dead$$

The program results section provides detailed summary of the frame section properties, frame effective section properties, column and middle strip properties at midspan, and a summary of extreme deflection values for each load level along the span.

[138] Example 9-5 Calculation of Immediate Deflections in Ref. [15], pp. 443, Step 5

### 2.3.10.2. Cracking

When calculating the deflections for effective (cracked) section properties, the frame solution is obtained for three load levels: dead load, dead load plus sustained part of live load, and dead load plus full live load on all spans. Flexural stiffness is assumed corresponding to the load level.

A reduction in the flexural stiffness caused by cracking leads to an increase in deflections. Several methods of deflection analyses taking cracking into account are reviewed in Ref. [22]. The program uses the approach based on the effective moment of inertia as permitted by the code[139].

The effective moment of inertia, $I_e$, developed by Branson (Ref. [17]) and incorporated into the code equals:

$$I_e = \left(\frac{M_{cr}}{M_{\max}}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_{\max}}\right)^3\right] I_{cr} \qquad \text{Eq. 2-102}$$

where:

$I_g$ = moment of inertia of the gross uncracked concrete section,

$I_{cr}$ = moment of inertia of the cracked transformed concrete section[140],

$M_{cr}$ = cracking moment,

$M_{max}$ = maximum bending moment at the load level for which the deflection is computed.

To calculate $I_e$ for two-way slabs, the values of all terms for the full width of the equivalent frame are used in Eq. 2-102. This approach averages the effects of cracking in the column and middle strips.

[139] ACI 318-14, 19.2.3.1, 24.2.3.5; ACI 318-11, 9.5.2.3; ACI 318-08, 9.5.2.3; ACI 318-05, 9.5.2.3; ACI 318-02, 9.5.2.3; ACI 318-99, 9.5.2.3; CSA A23.3-14, 9.8.2.3; CSA A23.3-04, 9.8.2.3; CSA A23.3-94, 9.8.2.3

[140] See formulas for various cross sections in Table 10-2 in Ref. [18]

The value of $I_e$ at midspan for a simple span and at support for a cantilever is taken[141] to calculate flexural stiffness of a member. For other conditions, an averaged effective moment of inertia, $I_{e,avg}$ is used. For spans with both ends continuous, $I_{frame}$ is given by[142]:

$$I_{e,avg} = 0.70 I_e^+ + 0.15\left(I_{e,l}^- + I_{e,r}^-\right) \qquad \text{Eq. 2-103}$$

where:

$I_e^+$ = effective moment of inertia for the positive moment region,

$I_{e,l}^-$ = effective moment of inertia for the negative moment region at the left support,

$I_{e,r}^-$ = effective moment of inertia for the negative moment region at the right support.

For spans with one end continuous the value of $I_{frame}$ is given by[143]:

$$I_{e,avg} = 0.85 I_e^+ + 0.15 I_e^- \qquad \text{Eq. 2-104}$$

where:

$I_e^+$ = effective moment of inertia for the positive moment region,

$I_e^-$ = effective moment of inertia for the negative moment region at the continuous end.

[141] ACI 318-14, 24.2.3.6, 24.2.3.7; ACI 318-11, 9.5.2.4; ACI 318-08, 9.5.2.4; ACI 318-05, 9.5.2.4; ACI 318-02, 9.5.2.4; ACI 318-99, 9.5.2.4

[142] ACI 435R-95 (Ref. [19]), 2.5.1, Eq. (2.15a); CSA A23.3-14, 9.8.2.4(a); CSA A23.3-04, 9.8.2.4(a); CSA A23.3-94, 9.8.2.4, Eq. 9.3

[143] ACI 435R-95 (Ref. [19]), 2.5.1, Eq. (2.15b); CSA A23.3-14, 9.8.2.4(b); CSA A23.3-04, 9.8.2.4(b); CSA A23.3-94, 9.8.2.4, Eq. 9.4

### 2.3.10.3. Long-Term Deflections

The program estimates additional long-term deflection resulting from creep and shrinkage, $\Delta_{cs}$, by multiplying the immediate deflection due to sustained load, $\Delta_{sust}$, by the factor, $\lambda_\Delta$, equal to[144]:

$$\lambda_\Delta = \frac{\xi}{1+50\rho'} \qquad \text{Eq. 2-105}$$

where:

$\xi$ = time dependent factor with the maximum value of 2.0 (the actual value is interpolated from the values and the chart given in the code[145] based on the load duration specified by the user in the input),

$\rho'$ = ratio of compressive reinforcement at midspan for simple and continuous spans and at support for cantilevers.

Deflection due to the sustained load, $\Delta_{sust}$, is the deflection induced by the dead load (including self weight), plus sustained portion of the live load.

And long-term deflection resulting from creep and shrinkage equals:

$$\Delta_{cs} = \Delta_{sust}\lambda_\Delta \qquad \text{Eq. 2-106}$$

The program calculates incremental deflection which occurs after partitions are installed in two ways. In the first approach, it is assumed that the live load has been applied before installing the partitions and the incremental deflection equals[146]:

$$\Delta_{cs+lu} = \Delta_{cs} + \left(\Delta_{total} - \Delta_{sust}\right) \qquad \text{Eq. 2-107}$$

[144] ACI 318-14, 24.2.4.1.1, 24.2.4.1.2, 24.2.4.1.3; ACI 318-11, 9.5.2.5; ACI 318-08, 9.5.2.5; ACI 318-05, 9.5.2.5; ACI 318-02, 9.5.2.5; ACI 318-99, 9.5.2.5; CSA A23.3-14, 9.8.2.5; CSA A23.3-04, 9.8.2.5; CSA A23.3-94, 9.8.2.5A23.3

[145] Fig. R24.2.4.1; Fig. R9.5.2.5 in ACI 318-11, ACI 318-08; ACI 318-05; ACI 318-02, and ACI 318-99; Fig. N9.8.2.6 in CSA A23.3-04 and CSA A23.3-94

[146] CSA A23.3-04 N9.8.2.5, CSA A23.3-94 N9.8.2.5

In the second approach, the assumption is that the full live load, including the sustained portion of the live load, has been applied after the partitions are installed which results in the incremental deflection equal to[147]:

$$\Delta_{cs+l} = \Delta_{cs} + \Delta_{live} \qquad \text{Eq. 2-108}$$

The total long-term deflection $(\Delta_{total})_{lt}$ is also calculated as[148]:

$$\left(\Delta_{total}\right)_{lt} = \Delta_{sust}\left(1+\lambda_{\Delta}\right)+\left(\Delta_{total}-\Delta_{sust}\right) \qquad \text{Eq. 2-109}$$

[147] See Example 10.1 in Ref. [18]

[148] CSA A23.3-04 N9.8.2.5; CSA A23.3-94 N9.8.2.5

## 2.3.10.4. Deflections of Two-Way Systems

spslab

Calculation of deflections of reinforced concrete two-way slabs is complicated by a large number of significant parameters such as: the aspect ratio of the panels, the vertical and torsional deflection of supporting beams, the stiffening effect of drop panels and column capitals, cracking, and the time-dependent nature of the material response. Based on studies (Ref. [20]-[22]), an approximate method consistent with the equivalent frame method was developed (Ref. [23]) to estimate the column and middle strip deflections.

Under vertical loads, Reference 20 indicates that the midspan deflection of an equivalent frame can be considered as the sum of three parts: that of the panel assumed to be fixed at both ends of its span, $\Delta_{f,ref}$ and those due to the known rotation at the two support lines, $\Delta_{\theta,L}$ and $\Delta_{\theta,r}$. Calculation of midspan deflection of the column strip or the middle strip under fixed-end conditions is based on M/EI ratio of the strip to that of the full-width panel:

$$\Delta_{f,strip} = \Delta_{f,ref} \frac{M_{strip}}{M_{frame}} \frac{E_c I_{frame}}{E_c I_{strip}} \qquad \text{Eq. 2-110}$$

The ratio ($M_{strip}/M_{frame}$) can be considered as a lateral distribution factor, *LDF*.

For ACI and CSA A23.3-94 codes the lateral distribution factor, *LDF*, at an exterior negative moment region is:

$$LDF_{neg,ext} = 100 - 10\beta_t + 12\beta_t \left(\alpha_{f1} \frac{l_2}{l_1}\right)\left(1 - \frac{l_2}{l_1}\right) \qquad \text{Eq. 2-111}$$

The *LDF* at an interior negative moment region is

$$LDF_{neg,int} = 75 - 30\left(\alpha_{f1} \frac{l_2}{l_1}\right)\left(1 - \frac{l_2}{l_1}\right) \qquad \text{Eq. 2-112}$$

The *LDF* at a positive moment region is

$$LDF_{pos} = 60 + 30\left(\alpha_{f1} \frac{l_2}{l_1}\right)\left(1.5 - \frac{l_2}{l_1}\right) \qquad \text{Eq. 2-113}$$

where:

$\alpha_{f1}$ = the ratio of flexure stiffness of a beam section to the flexural stiffness of a width of slab bounded laterally by centerlines of adjacent panels on either side of the beam,

$\beta_t$ = ratio of torsional stiffness of an edge beam section to the flexural stiffness of a width of slab equal to the span length of the beam, center-to-center of the supports (see Eq. 2-30).

For CSA A23.3-14/04 code lateral distribution factors are based on tabulated values presented earlier in the chapter.

When $\alpha_{f1}\, l_2 / l_1$ is greater than 1.0, $\alpha_{f1}\, l_2 / l_1$ will be set equal to 1.0.

The column and middle strip LDF's can be computed by:

$$LDF_c = \frac{LDF_{pos} + \dfrac{LDF_{neg,l} + LDF_{neg,r}}{2}}{2} \qquad \text{Eq. 2-114}$$

$$LDF_m = 100 - LDF_c \qquad \text{Eq. 2-115}$$

where:

$LDF_{neg,l}$ = $LDF$ for the negative moment region at the left end of the span,

$LDF_{neg,r}$ = $LDF$ for the negative moment region at the right end of the span.

The total midspan deflection for the column or middle strip is the sum of three parts:

$$\Delta_{strip} = \Delta_{f,strip} + \Delta\theta_{,l} + \Delta\theta_{,r} \qquad \text{Eq. 2-116}$$

where:

$\Delta\theta_{,l}$, $\Delta\theta_{,r}$ = midspan deflection due to rotation of left and right supports, respectively.

The above procedure was implemented starting in v5.00 to follow the reference recommendations exactly and eliminate overestimation of the column strip deflection and underestimation of the middle strip deflection especially for the exterior span.

The deflections should be used in conjunction with the deflections obtained from an analysis in the transverse direction. For square panels ($l_1 = l_2$), the mid-panel deflection is obtained from the following equation as shown in Figure 2.27.

$$\Delta = \Delta_{cy} + \Delta_{mx} = \Delta_{cx} + \Delta_{my} \qquad \text{Eq. 2-117}$$

For rectangular panels, ($l_1 \neq l_2$), the mid panel deflection is obtained from:

$$\Delta = \frac{\left(\Delta_{cy} + \Delta_{mx}\right) + \left(\Delta_{my} + \Delta_{cx}\right)}{2} \qquad \text{Eq. 2-118}$$

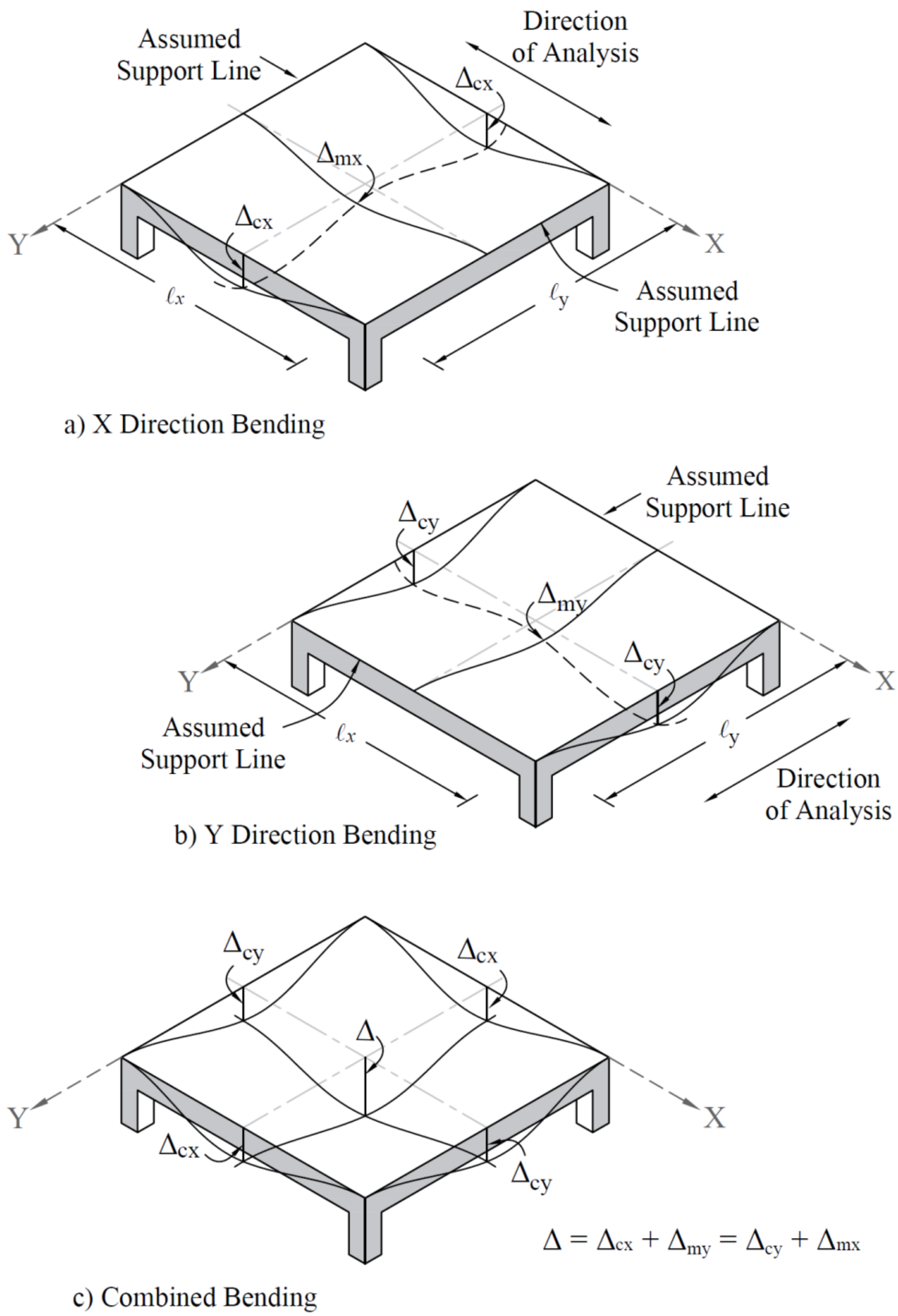



Figure 2.27 – Deflection Computation for a Square Panel

# 2.4. Design Methods

## 2.4.1. Area of Reinforcement

The program calculates the required area of reinforcement (top and bottom) based on the values of bending moment envelope within the clear span. For rectangular sections with no compression reinforcement, the design flexural strength of the column strip, middle strip and beam must equal the factored design moment:

$$M_u = \phi f_y A_s \left( d - \frac{A_s f_y}{2(0.85 f_c')b} \right) \qquad \text{Eq. 2-80}$$

The reinforcement can therefore be computed from:

$$A_s = \frac{0.85 f_c' b}{f_y} \left( d - \sqrt{d^2 - \frac{2M_u}{\phi 0.85 f_c' b}} \right) \qquad \text{Eq. 2-81}$$

For CSA A23.3:

$$M_r = \phi_s f_y A_s \left( d - \frac{\phi_s A_s f_y}{2\alpha_1 \phi_c f_c' b} \right) \qquad \text{Eq. 2-82}$$

The effective depth of the section is taken as the overall section depth minus the distance from the extreme tension fiber to the tension reinforcement centroid. The column strip depth may include all or part of the drop panel depth. The drop depth will not be included in the effective depth of the column strip when the drop does not extend at least one-sixth the center-to-center span length in all directions, or when the drop depth below the slab is less than one-quarter the slab depth. If the drop extends at least one-sixth the center-to-center span length and the drop depth is greater than one-quarter the distance from the edge of the drop panel to the face of the column or column capital, the excess depth will not be included in the column strip effective depth. If the drop width is less than the column strip width, the drop width will be used in the computation of the required reinforcement.

When computing negative slab reinforcement and additional reinforcement for negative unbalanced moments over the supports, the contribution of the depth of transverse beam can be optionally selected. The contribution of transverse beam will be considered, if it extends beyond the critical section and if its depth exceeds the depth of the drop panel. The increase of the slab thickness is limited to ¼ of the extent of the transverse beam beyond the face of support, identical to design depth limitations for drop panels. If transverse beam depth exceeds the limit, excess depth is disregarded in the reinforcement calculations.

For two-way slabs with beams, an option exists when designing reinforcement for positive bending moments, to include a portion of slab as beam flanges[149](T-Section). The width of the column strip is then decreased accordingly. The extent of the flanges on each side is limited to four times slab thickness and not more that the projection of the beam under the slab. When this option is not selected, beam geometry is treated as rectangular. When calculating required reinforcement for negative bending moments the geometry of the beam is treated as rectangular, having beam width equal to web width. However, when a T-Section is selected, reinforcing bar design is performed assuming that they are distributed across the beam width including the flanges.

For the ACI 318-99 code the strength reduction factor for flexure calculations is specified as $\phi$ = 0.90[150]. For the ACI 318-14, ACI 318-11, ACI 318-08, ACI 318-05, and ACI 318-02 codes the strength reduction factor for tension-controlled sections ($\varepsilon_t \geq 0.005$) is equal $\phi = 0.90$. For transition sections ($f_y / E_s \leq \varepsilon_t \leq 0.005$) the strength reduction factor can be linearly interpolated by the formula[151]:

$$\phi = 0.65 + \frac{0.90 - 0.65}{0.005 - f_y / E_s}\left(\varepsilon_t - f_y / E_s\right) \qquad \text{Eq. 2-83}$$

[149] See footnote 50

[150] ACI 318-99, 9.3.2

[151] ACI 318-14, 21.2.1; ACI 318-11, 9.3.2; ACI 318-08, 9.3.2; ACI 318-05, 9.3.2; ACI 318-02, 9.3.2

ACI 318-14, ACI 318-11, ACI 318-08, ACI 318-05, and ACI 318-02 codes specify the strength reduction factor for compression controlled sections ($\varepsilon_t < f_y / E_s$) as equal $\phi$ = 0.65. The reduction factors for transition or compression controlled sections have application primarily in investigation mode of the program. In design mode the program performs the calculations assuming a tension controlled section ($\varepsilon_t \geq 0.005$) or a section with compressive reinforcement (if enabled).

The ACI 318-99 code[152] requires keeping the steel ratio below the maximum value, $\rho_{max}$, equal to 75% of steel ratio producing balanced strain condition, $\rho_b$, where[153]:

$$\rho_d = 0.85\beta_1 \frac{f'_c}{f_y}\frac{87}{87+f_y} \qquad \text{Eq. 2-84}$$

with

$$\beta_1 = \begin{cases} 0.85 & \text{for } f'_c \leq 4 \text{ ksi} \\ 0.65 & \text{for } f'_c \geq 8 \text{ ksi} \\ 1.05 - 0.05 f'_c & \text{for } 4 \text{ ksi} < f'_c < 8 \text{ ksi} \end{cases}$$

For CSA code the value of $\rho_{max}$ equals $\rho_b$ and is calculated as follows[154]:

$$\rho_{\max} = \rho_b = \alpha_1\beta_1 \frac{\phi_c}{\phi_s}\frac{f'_c}{f_y}\frac{700}{700+f_y} \qquad \text{Eq. 2-85}$$

where:

$\alpha_1 \;=\; 0.85 - 0.0015 f'_c \geq 0.67$,

$\beta_1 \;=\; 0.97 - 0.0025 f'_c \geq 0.67$.

152 ACI 318-99, 10.3.3

153 ACI 318-99, 8.4.3

154 CSA A23.3-14, 10.5.2; CSA A23.3-04, 10.5.2; CSA A23.3-94, 10.5.2; Eq. 4-24, pp 110 in Ref. [16]

The ACI 318-14, ACI 318-11, ACI 318-08, ACI 318-05, and ACI 318-02 codes control the amount of reinforcement by limiting the value of net tensile strain ($\varepsilon_t \geq 0.004$)[155]. The program satisfies this condition by assuming a tensioned controlled section with $\varepsilon_t \geq 0.005$. From this assumption the equivalent maximum reinforcement ratio for rectangular section can be written as:

$$\rho_{\max} = \frac{0.003}{0.003+0.005}\frac{0.85\beta_1 f_c'}{f_y} \qquad \text{Eq. 2-86}$$

If the calculated reinforcement exceeds the maximum allowed, a message will appear in the output. In such cases, it is recommended that the engineer review the slab thickness to ensure a more satisfactory design. If compression reinforcement calculations are enabled, the program will attempt to add compression reinforcement to the section. The program is capable to design compressive reinforcement for any design strip (column, middle, and beam) including also unbalanced moment strip[156].

The amount of reinforcement provided will not be less than the code prescribed minimum. For the ACI 318 code, the minimum ratio of reinforcement area to the gross sectional area of the slab strip using Grade 60 reinforcement is taken as 0.0018. When reinforcement yield strength exceeds 60 ksi, the minimum ratio is set to $0.0018 \times 60 / f_y$. For reinforcement with yield strength less than 60 ksi, the minimum ratio is set to 0.0020. In no case will this ratio be less than 0.0014 (See Table 2.5)[157]. The CSA Standard requires a minimum ratio of slab reinforcement area to gross sectional area of the slab strip equal to 0.002 for all grades of reinforcement[158].

155 ACI 318-14, 7.3.3.1, 8.3.3.1, 9.3.3.1; ACI 318-11, 10.3.5; ACI 318-08, 10.3.5; ACI 318-05, 10.3.5; ACI 318-02, 10.3.5

156 ACI 318-14, 8.4.2.3.2, 8.4.2.3.3; ACI 318-11, 13.5.3.2; ACI 318-08, 13.5.3.2; ACI 318-05, 13.5.3.2; ACI 318-02, 13.5.3.2; ACI 318-99, 13.5.3.2; CSA A23.3-14, 13.3.5.3; CSA A23.3-04, 13.3.5.3; CSA A23.3-94, 13.11.2

157 ACI 318-14, 7.6.1.1, 8.6.1.1; ACI 318-11, 7.12.2.1; ACI 318-08, 7.12.2.1; ACI 318-05, 7.12.2.1; ACI 318-02, 7.12.2.1; ACI 318-99, 7.12.2.1

158 CSA A23.3-14, 7.8.1; CSA A23.3-04, 7.8.1; CSA A23.3-94, 7.8.1

| $f_y$ (ksi) | $A_s / A_g$ |
|---|---|
| < 60 | 0.0020 |
| $\geq 60$ | $\dfrac{0.0018 \times 60}{f_y} \geq 0.0014$ |

Table 2.5 – Minimum Ratios of Reinforcement to Gross Concrete Area

According to ACI code for beams and positive moment regions of joist slabs, minimum reinforcement provided will not be less than[159]:

$$A_{s,\min} = \frac{3\sqrt{f'_c}}{f_y} b_w d \qquad \text{Eq. 2-87}$$

and not less than $200 b_w d / f_y$ where $b_w$ is the web width of the section. For statically determinate sections with flange in tension, $b_w$ is replaced by the smaller of $2b_w$ and the width of the flange.

Similar equation prescribed by CSA A23.3 code has the form[160]:

$$A_{s,\min} = \frac{0.2\sqrt{f'_c}}{f_y} b_t h \qquad \text{Eq. 2-88}$$

where $b_t$ is the width of the tension zone of the section. Additionally, for T-sections having flange in tension the CSA code limits value of $b_t$ to $1.5b_w$ for single sided flanges and to $2.5b_w$ for double sided flanges.

When designing reinforcement for longitudinal slab bands according to CSA code, program assumes identical minimum steel requirements as for beams.

159 ACI 318-14, 9.6.1.1, 9.6.1.2; ACI 318-11, 10.5.1; ACI 318-08, 10.5.1; ACI 318-05, 10.5.1; ACI 318-02, 10.5.1; ACI 318-99, 10.5.1

160 CSA A23.3-14, 10.5.1.2(b); CSA A23.3-04, 10.5.1.2(b); CSA A23.3-94, 10.5.1.2(b)

#### 2.4.1.1. Design for Combined Flexure, Shear, and Torsion

CSA A23.3-14/04 requires, in proportioning of longitudinal reinforcement, to include additional tension forces caused by shear and torsion[161]. To achieve this, the program calculates forces developed in the longitudinal reinforcement due to flexure, shear, and torsion.

On the flexural tension side the force in longitudinal reinforcement is equal to[162]:

$$F_{lt} = \frac{|M_f|}{d_v} + \cot\theta \sqrt{\left(|V_f| - 0.5V_s\right)^2 + \left(\frac{0.45 p_h T_f}{2A_o}\right)^2} \qquad \text{Eq. 2-89}$$

On the flexural compression side the force in longitudinal reinforcement is equal to[163]:

$$F_{lc} = \cot\theta \sqrt{\left(|V_f| - 0.5V_s\right)^2 + \left(\frac{0.45 p_h T_f}{2A_o}\right)^2} - \frac{|M_f|}{d_v} \qquad \text{Eq. 2-90}$$

but not less than zero.

For these forces, longitudinal reinforcement area is calculated from the following equations[164]:

$$A_{lt} = \frac{F_{lt}}{\phi_c f_y} \qquad \text{Eq. 2-91}$$

$$A_{lc} = \frac{F_{lc}}{\phi_c f_y} \qquad \text{Eq. 2-92}$$

161 CSA A23.3-14, 11.3.9; CSA A23.3-04, 11.3.9

162 CSA A23.3-14, 11.3.9.2 and 11.3.10.6; CSA A23.3-04, 11.3.9.2 and 11.3.10.6

163 CSA A23.3-14, 11.3.9.3 and 11.3.10.6; CSA A23.3-04, 11.3.9.3 and 11.3.10.6

164 CSA A23.3-14, 11.3.9.1; CSA A23.3-04, 11.3.9.1

Taking into account both positive and negative bending moments (resulting from all load combinations and load patterns) and checking against area of steel required for flexure only, the final areas of top and bottom reinforcement can be calculated from:

$$A_{top} = \begin{cases} \max\left\{A'_s, A_{lc}\right\} & \text{if } M_f \geq 0 \\ \max\left\{A_s, A_{lt}\right\} & \text{if } M_f < 0 \end{cases} \qquad \text{Eq. 2-93}$$

$$A_{bot} = \begin{cases} \max\left\{A_s, A_{lt}\right\} & \text{if } M_f \geq 0 \\ \max\left\{A'_s, A_{lc}\right\} & \text{if } M_f < 0 \end{cases} \qquad \text{Eq. 2-94}$$

## 2.4.2. Concentration and Additional Reinforcement

spSlab computes the fraction of the unbalanced moment, $\gamma_f M_u$, that must be transferred by flexure within an effective slab width (a band) equal to the column width plus one and one-half the slab or drop panel depth (1.5$h$) on either side of the column where[165]

$$\gamma_f = \frac{1}{1 + \frac{2}{3}\sqrt{b_1 / b_2}} \qquad \text{Eq. 2-100}$$

The amount of reinforcement required to resist this moment is computed. The amount of reinforcement already provided for flexure is then computed from the bar schedule (i.e. the number of bars that fall within the effective slab width multiplied by the area of each bar). Depending on load conditions, additional negative or positive reinforcement may be required. If the reinforcement area provided for flexure is greater than or equal to the reinforcement requirements to resist moment transfer by flexure, no additional reinforcement is provided, and the number of additional bars will be set to 0. If the amount of reinforcement provided for flexure is less than that required for moment transfer by flexure, additional reinforcement is required. The additional reinforcement is the difference between that required for unbalanced moment transfer by flexure and that provided for design bending moment in the slab, and it is selected based on the bar size already provided at the support.

For ACI codes the value of $\gamma_f$ on selected supports can be automatically adjusted to the maximum permitted value. The corresponding value of $\gamma_v = 1 - \gamma_f$ is adjusted accordingly. This option allows relaxing stress levels for two-way shear around the columns by transferring increased part of the unbalanced moment through flexure. The adjustment is performed independently for each load case and pattern. If for given load case the corresponding two-way shear $V_u$ exceeds the appropriate limits $0.75\phi V_c$ at an edge support, $0.5\phi V_c$ at a corner support, or $0.4\phi V_c$ at an interior support, adjustment of both factors is not performed. When the adjustment of $\gamma_f$ and $\gamma_v$ factors is selected, the reinforcement calculated within the transfer width should be limited according to the code to

[165] ACI 318-14, 8.4.2.3.2, 8.4.2.3.3; ACI 318-11, 13.5.3.2; ACI 318-08, 13.5.3.2; ACI 318-05, 13.5.3.2; ACI 318-02, 13.5.3.2; ACI 318-99, 13.5.3.2; CSA A23.3-14, 13.3.5.3; CSA A23.3-04, 13.3.5.3; CSA A23.3-94, 13.11.2 and 13.4.5.3

reinforcement ratio $\rho < 0.375\rho_b$, as stipulated in ACI 318-99/02/05[166], or limitation of net tensile strain $\varepsilon_t > 0.010$, as required by ACI 318-14, ACI 318-11 and ACI 318-08[167]. Violation of this requirement is reported by the software as exceeding maximum allowable reinforcement indicating that the option to adjust the factor $\gamma_f$ should be turned off by the user at the support where the violation occurs.

It should be noted that the ACI code[168] requires either concentration of reinforcement over the column by closer spacing, or additional reinforcement, to resist the transfer moment within the effective slab width. spSlab satisfies this requirement by providing additional reinforcement without concentrating existing reinforcement.

When computing additional reinforcement for the transfer of negative and positive unbalanced moments over the supports through flexure in systems with longitudinal beams, the contribution of the longitudinal beam cross-section can be optionally selected. If selected, this contribution will be considered. For CSA designs this functionality extends also to design of banded reinforcement in $b_b$ strip.

The CSA A23.3 code requires at least one-third of the total negative reinforcement for the entire design strip at interior supports to be concentrated in the band width, $b_b$, extending $1.5h_s$ from the sides of the columns[169]. The program fulfills this requirement by concentrating a portion of reinforcement assigned to the design strip that includes width $b_b$. This strip will typically be the column strip. However, if longitudinal slab bands or slab-band-like beams wider than band width $b_b$ are present, then reinforcement assigned to these elements is concentrated. At exterior supports, the total negative reinforcement is placed in the $b_b$ band width[170] or if a beam narrower than $b_b$ is

[166] ACI 318-14, 8.4.2.3.4; ACI 318-11, 13.5.3.3; ACI 318-05, 13.5.3.3; ACI 318-02, 13.5.3.3; ACI 318-99, 13.5.3.3

[167] ACI 318-14, 8.4.2.3.4; ACI 318-11, 13.5.3.3; ACI 318-08, 13.5.3.3

[168] ACI 318-14, 8.4.2.3.5; ACI 318-11, 13.5.3.4; ACI 318-08, 13.5.3.4; ACI 318-05, 13.5.3.4; ACI 318-02, 13.5.3.4; ACI 318-99, 13.5.3.4

[169] CSA A23.3-14, 13.11.2.7; CSA A23.3-04, 13.11.2.7; CSA A23.3-94, 13.12.2.1

[170] CSA A23.3-14, 13.10.3; CSA A23.3-04, 13.10.3; CSA A23.3-94, 13.12.2.2, 13.13.4.2

present, then the total reinforcement is placed within the beam width[171]. The reinforcement in the $b_b$ and the remaining portions of the design strip is also checked for compliance with spacing and minimum reinforcement requirements.

[171] CSA A23.3-04, 13.12.2.2; CSA A23.3-04, 13.12.2.2; CSA A23.3-94, 13.13.2.2

# 2.5. Detailing Provisions

Proper reinforcement detailing is a critical step in ensuring the performance and safety of structural systems designed using spSlab and spBeam. The detailing process involves selecting the size, spacing, and extension of reinforcement in accordance with the requirements of design codes, such as ACI 318 and CSA A23.3. Adhering to these guidelines ensures that the structural elements achieve the intended capacities while maintaining durability, ductility, and resistance to cracking and progressive collapse.

This section outlines the methodology and criteria employed by spSlab and spBeam to assist users in determining optimal reinforcement layouts. It covers key aspects of reinforcement detailing, spacing limitations, development lengths, and structural integrity reinforcement. The iterative design approach used by the programs incorporates considerations such as bar sizes, clear spacing, and crack control requirements to meet both minimum and maximum limits required by the code.

Additionally, provisions for structural integrity and corner reinforcement are discussed to enhance the redundancy and ductility of the structural system.

## 2.5.1. Reinforcement Detailing

### 2.5.1.1. Minimum Clear Spacing

According to ACI-318 code[172], the default minimum clear spacing of reinforcement for both slabs and beams is taken as the larger of the two prescribed minima of one bar diameter, $d_b$, or 1 in. According to CSA code[173], the default minimum clear spacing of reinforcement for both slabs and beams is taken as the larger of the two prescribed minima of 1.4 times the bar diameter, $d_b$, or 1.2 in (30mm). The user may select a clear spacing greater than the default value to take into account

[172] ACI 318-14, 25.2.1; ACI 318-11, 7.6.1; ACI 318-08, 7.6.1; ACI 318-05, 7.6.1; ACI 318-02, 7.6.1; ACI 318-99, 7.6.1

[173] CSA A23.3-14, Annex A, 6.6.5.2; CSA A23.3-04, Annex A, 6.6.5.2; CSA A23.3-94, Annex A, A12.5.2

tolerances for reinforcement placement[174] and other project specific considerations.

For two-way systems, the maximum spacing of reinforcement is kept at two times the slab thickness for the ACI code[175] and three times the slab thickness for the CSA code[176], but no more than 18 in. or 500 mm respectively. For joist systems the limit is increased to 5 times the slab thickness[177]. When calculating negative support reinforcement for the CSA code[178], the program assumes that banded reinforcement over supports is spaced at a maximum of 1.5$h_s$ and no more than 250 mm.

For one-way slabs, the maximum spacing is limited to[179] the smaller of three times the slab thickness and 18 in. [500 mm]. Additionally, the maximum spacing of reinforcement, *s*, in beams and one-way slabs is selected so that the following crack control requirements of the ACI and the CSA codes[180] are met:

$$s \le \min\left(\frac{900,000}{f_y} - 2.5c_c, \frac{480,000}{f_y}\right) \qquad \text{(ACI 318-11/08/05)}$$

$$s \le \min\left(\frac{900}{f_y} - 2.5c_c, \frac{432}{f_y}\right) \qquad \text{(ACI 318-02/99)} \qquad \text{Eq. 2-95}$$

$$0.6 f_y \left(d_c A\right)^{\frac{1}{3}} \le z_{\max} \qquad \text{(CSA A23.3-14/04/94)}$$

where:

174 See ACI 317-06 (Ref. [7])

175 ACI 318-14, 8.7.2.2; ACI 318-11, 13.3.2; ACI 318-08, 13.3.2; ACI 318-05, 13.3.2; ACI 318-02, 13.3.2; ACI 318-99, 13.3.2

176 CSA A23.3-14, 13.10.4; CSA A23.3-04, 13.10.4; CSA A23.3-94, 13.11.3(b)

177 ACI 318-14, 7.7.6.2.1, 8.7.2.2; ACI 318-11, 7.12.2.2; ACI 318-08, 7.12.2.2; ACI 318-05, 7.12.2.2; ACI 318-02, 7.12.2.2; ACI 318-99, 7.12.2.2; CSA A23.3-14, 7.8.3; CSA A23.3-04, 7.8.3; CSA A23.3-94, 7.8.3

178 CSA A23.3-14, 13.10.4; CSA A23.3-04, 13.10.4; CSA A23.3-94, 13.11.3(a)

179 ACI 318-14, 7.7.2.3, 8.7.2.2; ACI 318-11, 7.6.5; ACI 318-08, 7.6.5; ACI 318-05, 7.6.5; ACI 318-02, 7.6.5, ACI 318-99, 7.6.5; CSA A23.3-14, 7.4.1.2; CSA A23.3-04, 7.4.1.2; CSA A23.3-94, 7.4.1.2

180 ACI 318-14, 24.3.2, 24.3.3; ACI 318-11, 10.6.4; ACI 318-08, 10.6.4; ACI 318-05, 10.6.4; ACI 318-02, 10.6.4; ACI 318-99, 10.6.4; CSA A23.3-14, 10.6.1; CSA A23.3-04, 10.6.1; CSA A23.3-94, 10.6.1

$c_c$ = least distance from the surface of bar to the tension face,

$d_c$ = distance from extreme tension fiber to center of the closest longitudinal bar,

$A$ = effective tension area of concrete surrounding the flexural tension reinforcement and extending from the extreme tension fiber to the centroid of the flexural tension reinforcement and an equal distance past that centroid, divided by the number of bars or wires,

$z_{max}$ = 30,000 N/mm for interior exposure or 25,000 N/mm for exterior exposure, multiplied by a factor of 1.2 for epoxy-coated reinforcement.

An iterative process is performed to determine the number of bars and bar size. The initial number of bars is determined by dividing the total reinforcement area required, $A_s$, by the area of one bar, $A_{sb}$, of the input minimum bar size. Next, the spacing is determined. If the minimum spacing limitations are violated, the bar size is increased and the iterative process is repeated until all bars sizes have been checked. If the maximum spacing limitations are not met, the number of bars required to satisfy these limitations is computed and the iteration process terminates.

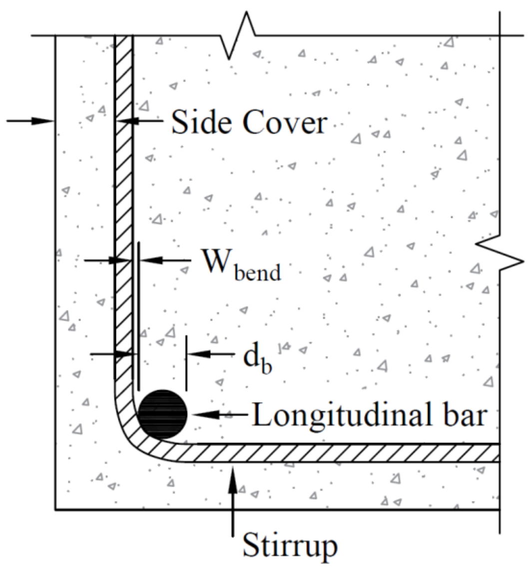



Figure 2.28 – Width due to Stirrup Bend

For beams, layered reinforcement is provided if sufficient beam width is not available. The clear distance between layers is assumed 1.0 in [30 mm] but the user can change this value. By default, the program assumes a 1.5 in [40 mm] side cover to stirrup for width calculations and this value can also be changed by the user. The program also assumes that the longitudinal bar makes contact at the middle of the stirrup bend where the minimum inside diameter of the bend is four times stirrup diameter[181]. Therefore, an additional width is added to the cover for longitudinal bars less than size #14 (#45 for CAN/CSA-G30.18) (Figure 2.28 – Figure 2.29). This additional width due to the bend, $w_{bend}$, is equal to:

$$w_{bend} = \left(1 - \frac{\sqrt{2}}{2}\right)\left(r - \frac{d_b}{2}\right) \qquad \text{Eq. 2-96}$$

where:

$d_b$ = diameter of the longitudinal bar,

$r$ = inside radius of bend for stirrup.

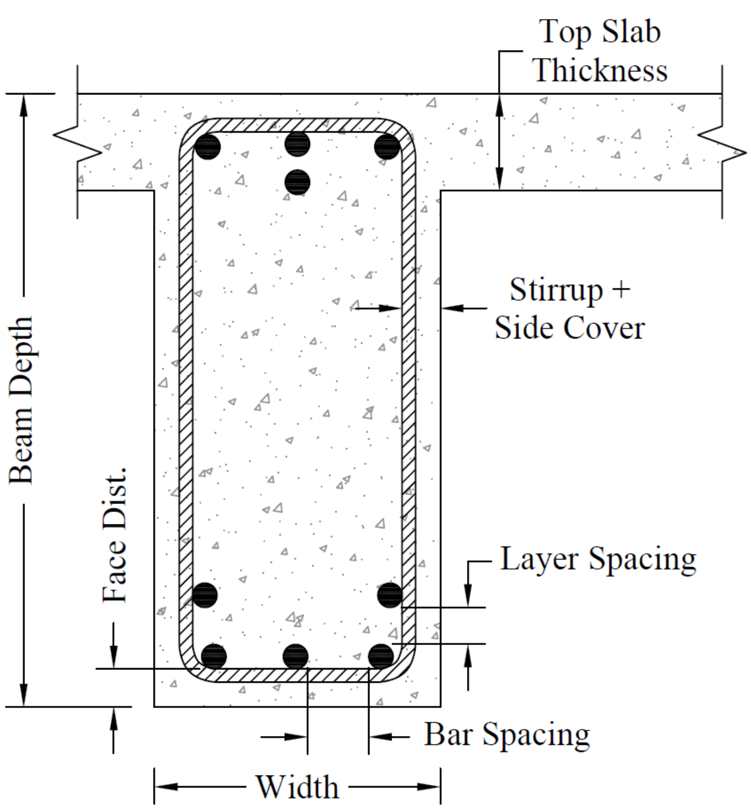



Figure 2.29 – Detail Reinforcement in Longitudinal Beams

[181] ACI 318-14, 25.3.2; ACI 318-11, 7.2.2; ACI 318-08, 7.2.2; ACI 318-05, 7.2.2; ACI 318-02, 7.2.2; ACI 318-99, 7.2.2; CSA A23.3-04, 7.1.1 and Table 16 in Annex A; CSA A23.3-94, 7.1.1 and Table 16 in Annex A

### 2.5.1.2. Development Length Computation

Bar-length computations are performed for two-way slabs and longitudinal beams. For top reinforcement at the supports, the length for long bars is given by:

$$l_{long} = \max \begin{cases} \max\left(l_{50\%}\right) + l_{d,long} \\ \max\left(l_{pi}\right) + \max\left\{d, 12d_b, l_n/16\right\} \\ l_{fos} + l_{cr,long} \end{cases} \quad \text{Eq. 2-97}$$

and the length for short bars is given by:

$$l_{short} = \max \begin{cases} \max\left(l_{50\%}\right) + \max\left\{d, 12d_b\right\} \\ l_{fos} + \max\left\{l_{d,short}, l_{cr,short}\right\} \end{cases} \quad \text{Eq. 2-98}$$

where:

max ($l_{50\%}$) = maximum distance to the points of 50% demand,

max ($l_{pi}$) = maximum distance to the points of inflection (P.I.),

$l_d$ = bar development length[182],

$d$ = effective depth,

$d_b$ = bar diameter,

$l_n$ = clear span length,

$l_{fos}$ = distance to the face of support (column),

$l_{cr}$ = minimum code prescribed extension.

These bar lengths are then compared and adjusted if necessary to meet the minimum extension requirements for reinforcement specified by the code.[183] Additionally the program may select

[182] Chapter 25 in ACI 318-14; Chapter 12 in ACI 318-11, ACI 318-08, ACI 318-05, ACI 318-02, and ACI 318-99; CSA A23.3-14, Clause 12.2; CSA A23.3-04, Clause 12.2; CSA A23.3-94, Clause 12.2

[183] Figure 8.7.4.3a in ACI 318-14; Figure 13.3.8 in ACI 318-11, ACI 318-08, ACI 318-05, ACI 318-02, and ACI 318-99; CSA A23.3-14, Figure 13.1; CSA A23.3-04, Figure 13.1; CSA A23.3-94, Figure 13.1

continuous top bars in those spans where steel is required by calculation in mid-span at top.

If the computed bar lengths overlap, it is recommended that such reinforcement be run continuously. The printed bar lengths do not include hooks or portions of bars bent down into spandrel beams or other bar-bend configurations. If a bar starts (or ends) at a column support the length of the bar is measured from (or to) the center line of the column. The selection of bar lengths for positive reinforcement for flat plates, flat slabs, and beam-supported slabs, is based strictly on the minimum values of the code.

The development length depends on the following factors: concrete cover, minimum transverse reinforcement, special transverse reinforcement, layer location bar size and bar clear spacing. The development length is calculated from the general expression[184] below, but not less[185] than 12 in [300 mm]:

$$l_d = d_b \frac{f_y}{\sqrt{f_c'}} \frac{\psi_t \psi_e \psi_s}{\left(\dfrac{c_d + K_{tr}}{d_b}\right)} \times \begin{cases} \dfrac{3}{40\lambda} & \text{for ACI 318-11/08} \\ \dfrac{1}{1.1\lambda} & \text{for ACI 318M-11/08} \\ \dfrac{3\lambda}{40} & \text{for ACI 318-05/02/99} \\ \dfrac{\lambda}{1.1} & \text{for ACI 318M-05/02/99} \\ \dfrac{1.15\pi\lambda}{4} & \text{for CSA A23.3-14/04/94} \end{cases} \qquad \text{Eq. 2-99}$$

where:

$\Psi_t$ = reinforcement location factor equal to 1.3 if more than 12 in [300 mm] of fresh concrete is cast in the member below the development length or splice, or equal to 1.0 otherwise,

$\Psi_e$ = coating factor equal to 1.0 for uncoated reinforcement; for epoxy coated reinforcement with covers less than $3d_b$ or clear spacing less than $6d_b$ the factor is equal to 1.5 and for all

[184] ACI 318-14, 25.4.2.3; ACI 318-11, 12.2.3; ACI 318-08, 12.2.3; ACI 318-05, 12.2.3; ACI 318-02, 12.2.3; ACI 318-99, 12.2.3; ACI 318M-11,12.2.3; ACI 318M-08, 12.2.3; ACI 318M-05, 12.2.3; ACI 318M-02, 12.2.3; ACI 318M-99, 12.2.3; CSA A23.3-14, 12.2.2; CSA A23.3-04, 12.2.2; CSA A23.3-94, 12.2.2

[185] ACI 318-14, 25.4.2.1; ACI 318-11, 12.2.1; ACI 318-08, 12.2.1; ACI 318-05, 12.2.1; ACI 318-02, 12.2.1; ACI 318-99, 12.2.1; CSA A23.3-14, 12.2.1; CSA A23.3-04, 12.2.1; CSA A23.3-94, 12.2.1

other epoxy coated bars it equals 1.2,

$\Psi_s$ = reinforcement size factor equal to 1.0 for bars #7 [22] and larger or equal to 0.8 for bars #6 [19] and smaller if ACI 318 [ACI 318M] is selected; for CSA A23.3 the factor is equal to 1.0 for bars 25M and larger or equal to 0.8 for bars 20M and smaller,

$\lambda$ = lightweight aggregate concrete factor equal to 1.0 for normal concrete and:

0.75 for lightweight concrete per ACI 318-14, ACI 318-11 and ACI 318-08

1.3 for lightweight concrete per ACI 318-05/02/99

1.3 for low density concrete per CSA A23.3-14/04/94

1.2 for semi low density concrete per CSA A23.3-14/04/94

$K_{tr}$ = transverse reinforcement index conservatively assumed zero,

$c_b$ = smaller of the distance form bar surface to the closest concrete surface and one-half (two thirds for CSA[186]) center-to-center bar spacing[187].

Additionally, the product of $\Psi_t\Psi_e$ is not taken greater than 1.7 and the development length, $l_d$, is reduced[188] by the factor of $A_{s,req}$ to $A_{s,prov}$ where the provided area of flexural reinforcement, $A_{s,prov}$, exceeds the area required by analysis, $A_{s,req}$.

The final calculated or minimum development length for each bar is tabulated in the design results section of the program results report. In two-way slab systems without beams, the development length presented is often controlled by the minimum development length.

Where flexural reinforcement is terminated in a tension zone, spSlab and spBeam provide a warning to require an extension of the bar beyond what is required for flexure. For ACI code, the shear capacity at the cutoff point for each bar is evaluated for satisfying the shear demand does not

[186] Denoted as $d_{cs}$ in CSA A23.3-14, 3.2; CSA A23.3-04, 2.3 and CSA A23.3-94, 12.0

[187] ACI 318-05, 2.1; ACI 318-02, 12.2.4; ACI 318-99, 12.2.4

[188] ACI 318-14, 25.4.10.1; ACI 318-11, 12.2.5; ACI 318-08, 12.2.5; ACI 318-05, 12.2.5; ACI 318-02, 12.2.5; ACI 318-99, 12.2.5; CSA A23.3-14, 12.2.5; CSA A23.3-04, 12.2.5; CSA A23.3-94, 12.2.5

exceed permissible shear limit[189]. Final bar length shall be extended beyond the minimum reported to meet one of the three conditions outlined in ACI 318[190].

## 2.5.2. Structural Integrity Reinforcement

Enhancing redundancy and ductility is necessary in the event of damage to a major supporting element resulting from an abnormal shock or blast loading event.

Minor changes in reinforcement detailing typically result in substantial enhancement in the overall integrity of a structure by confining the resulting damage to a small area and improving the resistance to progressive collapse.

The ACI code requires all bottom bars in the column strip to extend continuously (or with splices) in the entire span and at least two of these bars to pass within the column core and to be anchored at exterior supports[191]. In continuous beams, including longitudinal beams in two-way slab systems, spSlab and spBeam produce, in design mode, reinforcement that satisfies ACI requirements for structural integrity. In perimeter (exterior) beams, at least one sixth of the negative tension reinforcement and not less than two bars are continuous[192]. Also, at least one fourth of the positive tension reinforcement and not less than two bars are continuous in all beams[193].

For the CSA code, the program performs calculation of the amount of integrity reinforcement at slab column connections in design mode. The integrity reinforcement is required for slabs without

[189] ACI 318-14, 7.7.3.5(a); ACI 318-11, 12.10.5.1; ACI 318-08, 12.10.5.1; ACI 318-05, 12.10.5.1; ACI 318-02, 12.10.5.1; ACI 318-99, 12.10.5.1

[190] ACI 318-14, 7.7.3.5, 7.7.3.5(a), 7.7.3.5(b), 7.7.3.5(c); ACI 318-11, 12.10.5, 12.10.5.1, 12.10.5.2, 12.10.5.3; ACI 318-08, 12.10.5, 12.10.5.1, 12.10.5.2, 12.10.5.3; ACI 318-05, 12.10.5, 12.10.5.1, 12.10.5.2, 12.10.5.3; ACI 318-02, 12.10.5, 12.10.5.1, 12.10.5.2, 12.10.5.3; ACI 318-99, 12.10.5, 12.10.5.1, 12.10.5.2, 12.10.5.3

[191] ACI 318-14, 8.7.4.2.1, 8.7.4.2.2; ACI 318-11, 13.3.8.5; ACI 318-08, 13.3.8.5; ACI 318-05, 13.3.8.5; ACI 318-02, 13.3.8.5; ACI 318-99, 13.3.8.5

[192] ACI 318-14, 9.7.7.1(a); ACI 318-11, 7.13.2.2(a); ACI 318-08, 7.13.2.2(a); ACI 318-05, 7.13.2.2(a); ACI 318-02, 7.13.2.2(a); ACI 318-99, 7.13.2.2

[193] ACI 318-14, 9.7.7.1(b); ACI 318-11, 7.13.2.2(b) and 7.13.2.4; ACI 318-08, 7.13.2.2(b) and 7.13.2.4; ACI 318-05, 7.13.2.2(b) and 7.13.2.4; ACI 318-02, 7.13.2.2(b) and 7.13.2.4; ACI 318-99, 7.13.2.2 and 7.13.2.3

beams. Integrity reinforcement is not required if there are beams containing shear reinforcement in all spans framing into the column. Otherwise, the sum of all bottom reinforcement connecting the slab to the column on all faces of the periphery should consist of at least two bars and meet the condition[194]:

$$\sum A_{sb} \geq \frac{2V_{se}}{f_y} \qquad \text{Eq. 2-101}$$

where $V_{se}$ is the larger of shear force transmitted to column or column capital due to specified (unfactored) loads and shear force corresponding to twice the self-weight of the slab.

**Design Results - Integrity Reinforcement at Supports**

NOTE: The sum of bottom reinforcement crossing the perimeter of the support on all sides shall not be less than the below listed values.

| Support | Vse | Asb |
|---|---|---|
| | kN | mm² |
| 1 | 197.59 | 988 |
| 2 | 414.95 | 2075 |
| 3 | 414.95 | 2075 |
| 4 | 197.59 | 988 |

Figure 2.30 – Integrity Reinforcement at Supports

### 2.5.3. Corner Reinforcement

spSlab

The program performs calculation of the amount of reinforcement in exterior corners of slabs with stiff edge beams ($\alpha$ greater than 1.0)[195]. This reinforcement is required within a region equal to 1/5 of the shorter span. The amount of corner reinforcement is calculated from the moment per unit width intensity corresponding to the maximum positive moment in span. The code allows the corner reinforcement to be placed at top and bottom of the slab in bands parallel to the sides of the slab edges.

[194] CSA A23.3-14, 13.10.6.1 and 13.10.6.2; CSA A23.3-04, 13.10.6.1 and 13.10.6.2; CSA A23.3-94, 13.11.5.1 and 13.11.5.2

[195] ACI 318-14, 8.7.3.1; ACI 318-11, 13.3.6; ACI 318-08, 13.3.6; ACI 318-05, 13.3.6; ACI 318-02, 13.3.6; ACI 318-99, 13.3.6; CSA A23.3-14, 13.12.5; CSA A23.3-04, 13.12.5; CSA A23.3-94, 13.13.5

## 2.6. Special Topics

Conventionally reinforced concrete floor systems, including slabs and beams, contain a diverse variety of parameters and considerations that could be achieved by the flexibility of cast-in-place concrete forming systems. Notwithstanding prestressing and post-tensioning, engineers and design professionals will encounter numerous special conditions to handle and deal with in the design of a concrete floor system, ranging from the placement of concrete to optimizing of shapes and cross sections for gravity and lateral load effects.

### 2.6.1. Lateral Load Effects & Restraint

When analyzing lateral loads, each frame may be evaluated as a single unit for the full height of the building. Structural analysis software, such as spFrame and ETABS, can be used to perform this type of analysis. It is important to recognize that for lateral load assessment, slab-beam elements may experience reduced stiffness due to cracking, along with modifications to the effective slab width used in the analysis.

The bending moments generated at the two ends of a span due to lateral loads, such as wind or seismic forces, can be obtained from such an analysis. These moments can then be incorporated into the spSlab model as Lateral Load Effects input, allowing for the determination of the appropriate design moments when considering both gravity and lateral loading.

The scope of lateral load consideration in spSlab is limited to this process, where externally computed lateral moments can be applied within the equivalent frame model to evaluate their effects on the structural design as shown in the following figure. More information about this topic can be found in Section 2.3.3.3 and Section 5.2.4.3.

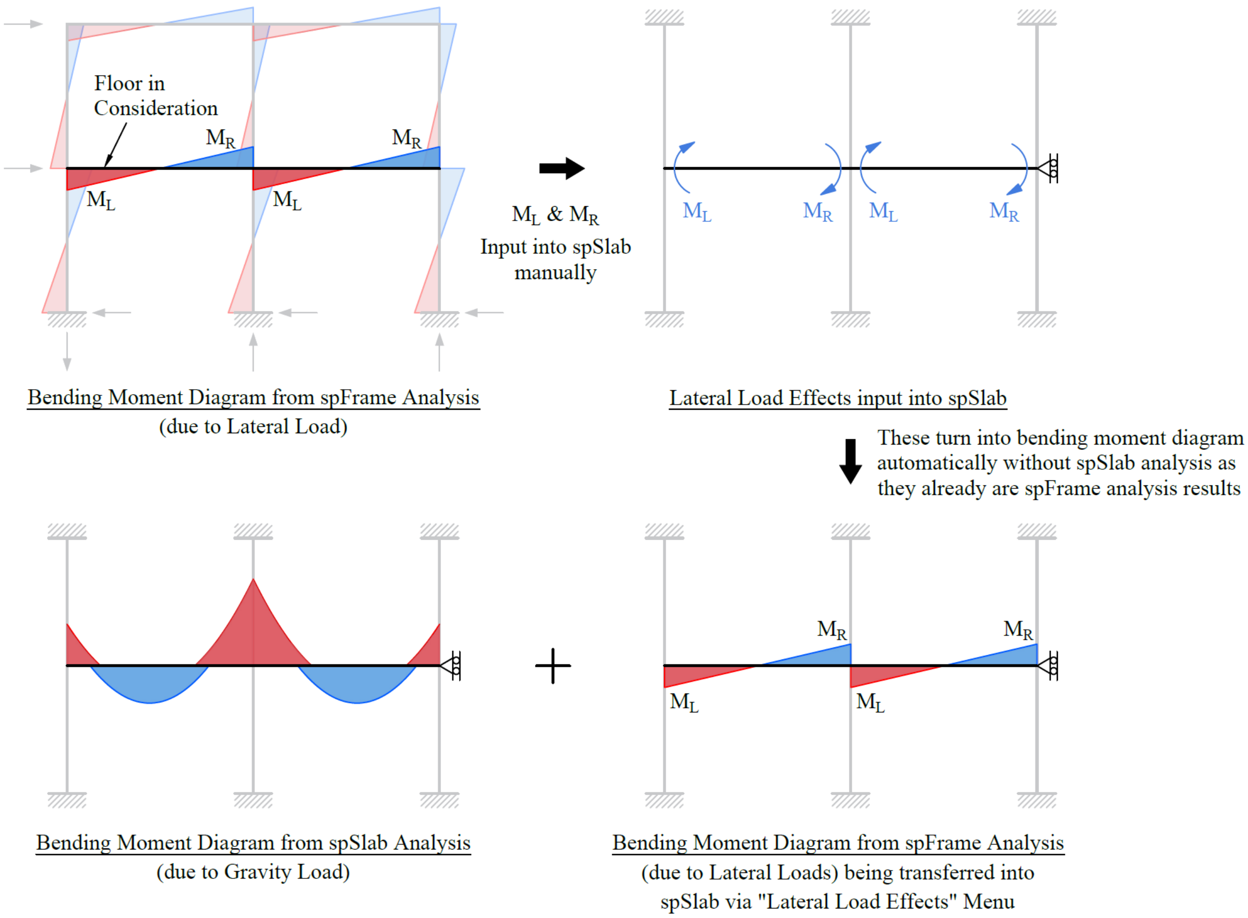



Figure 2.31 – Incorporation of Bending Moments due to Lateral Loads from spFrame into spSlab Gravity Load Analysis

## 2.6.2. Loads Along the Span Imposed by Lateral Loading

In some conditions, lateral loads acting on an equipment supported on a span may impose point loads and/or moments in that given span. The Program does not have a lateral type span load option in order to accommodate such point forces or moments at a span due to lateral loads. Although it is neither ideal nor recommended, the user may consider utilizing Snow load case to enter point forces or moments imposed by such lateral loads along the span in order to obtain the internal forces and for the flexural and shear design purposes. In the Program, since Snow load case is a Dead load type, its implications to deflection calculations would require considerable engineering judgment.

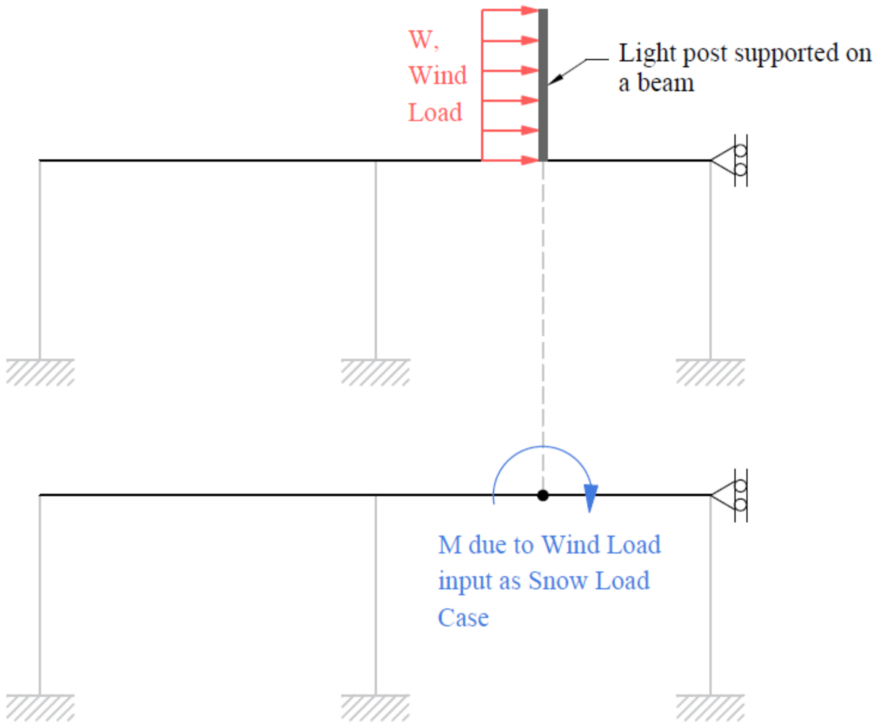



Figure 2.32 – Loads along the Span imposed by Lateral Loading

StructurePoint anticipates the inclusion of additional load cases to accommodate lateral loads being applied to the span in future releases once adequate consideration and research has been done to the effects of live load patterning and deflection calculations for lateral forces. It is anticipated that the inclusion of lateral forces will complicate greatly the procedure of live load arrangement and patterning, in addition to the added complexity of calculating sustained live loads that are an essential part of the deflection calculations specifically long term.

### 2.6.3. Gravity Frame Analysis under Sidesway

The spBeam program is a powerful tool for modeling one-way, multi-story, two-dimensional concrete frames, allowing users to analyze individual stories as separate frames. Each story is modeled with slab beam elements and columns above and below, employing an equivalent column concept and restraining horizontal translational degrees of freedom at the story level. However, in scenarios where unsymmetrical vertical loading, variations in support stiffness, or boundary conditions induce horizontal sidesway, the spFrame program provides a more comprehensive analysis. Unlike spBeam, spFrame accommodates the entire height of a two-dimensional frame, accurately accounting for sidesway effects on internal force magnitudes. A comparative analysis, conducted in "Comparison of Gravity Loaded Concrete Frame Models in spBeam and spFrame under Sidesway" Technical Article from StructurePoint, illustrates that while spBeam assumes sidesway restraint, spFrame considers its effects, leading to more reliable results for design under such conditions.

## 2.6.4. Openings in Concrete Slabs

spSlab

Openings in concrete slabs significantly influence their structural behavior, particularly in terms of shear strength and load distribution. The presence of openings alters the flow of internal forces, potentially reducing the slab's capacity to resist shear and flexure while introducing stress concentrations around the perimeters of the openings. Theoretical approaches outlined in design codes such as ACI 318 and CSA A23.3 provide guidance on analyzing and designing slabs with openings, emphasizing the importance of maintaining adequate shear transfer mechanisms. The scope of these provisions includes practical design scenarios for slabs with various types and sizes of openings, ensuring that safety and functionality are preserved. The purpose of these guidelines is to enable engineers to design reinforced concrete slabs with openings that meet structural performance criteria while accommodating architectural or functional requirements, such as ductwork, piping, and access points, without compromising the slab's integrity or serviceability. More information about this topic can be found in "Shear Strength of Concrete Slabs with Openings (ACI 318)" and "Shear Strength of Concrete Slabs with Openings (CSA A23.3)" Design Examples from StructurePoint.

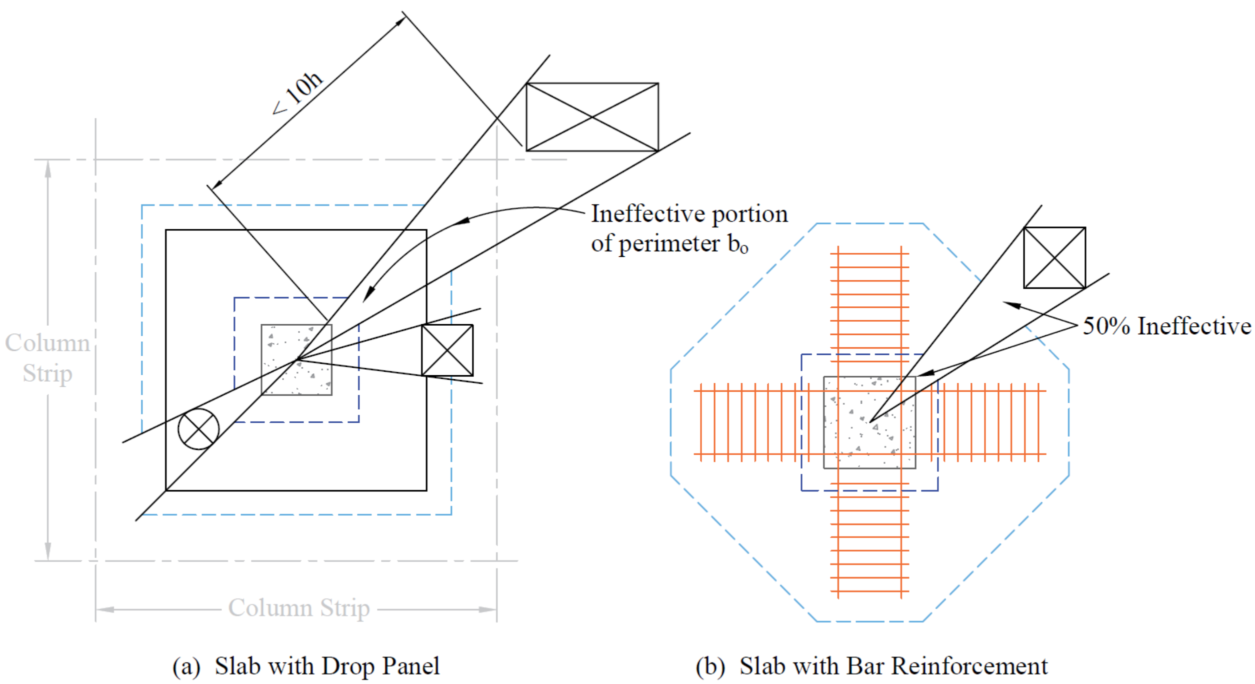



Figure 2.33 – Effect of Openings on Slabs Shear Strength

### 2.6.5. Support Conditions

In spSlab and spBeam, defining appropriate support conditions is essential for accurate analysis and design of structural elements in a concrete floor system. By default, column-slab/beam joints are assumed to rotate freely while restricting translational displacement. The rotational stiffness of a joint is influenced by connected elements (such as slabs, beams, transverse beams, and columns) and can be adjusted using the **Restraint** command. Columns are typically modeled with fixed far-end boundary conditions but can be adjusted using the **Column** command to meet specific design needs. Engineers can specify vertical spring constants ($K_z$) to allow vertical displacement of joints or adjust rotational stiffness using rotational spring constants ($K_{ry}$). Far-end column conditions can also be set as either fixed or pinned to match design assumptions. These options enable modeling of support conditions to achieve a closer reflection of physical conditions into the analytical models and generate more accurate results. For more details, refer to Section 2.3.2, Section 5.2.4.2, and "Deflection Observations in Girder-Supported Beams and One-way Slabs" Technical Article from StructurePoint.

### 2.6.6. Moment Redistribution

Moment redistribution is a design approach applied to optimize reinforcement placement and reduce material usage. The technique involves leveraging the plastic behavior of structures, which allows for a redistribution of bending moments beyond the elastic analysis results. This redistribution reduces peak negative moments at supports, typically shifting them to positive moments in spans, enabling more efficient utilization of structural capacity. Governed by standards such as ACI 318 and CSA A23.3, moment redistribution requires sufficient ductility in plastic hinge regions to ensure stability and maintain static equilibrium. By reducing reinforcement congestion in critical areas like the support regions, this method as permissible by codes, offers advantages in material savings, labor efficiency, and improved constructability. Advanced software tools, such as spSlab and spBeam, streamline the iterative calculations involved, making the process more accessible and precise.

In some instances, while investigating existing buildings and their concrete floor systems for added forces or loads and changing occupancy, this technique has proven to eliminate the need for very costly and expensive repairs that may be very time-consuming, deeming the building uninhabitable. Used properly and with caution, this technique can also result in the ability to repurpose an existing building for long-term, durable, and safe use with new higher loads. This alone can be the main difference between increasing the carbon footprint with new construction compared with the reuse of an existing durable structure towards an additional cycle of service life and contributing to the sustainable development of the built environment.

For more details regarding moment redistribution, refer to Section 2.3.6, "Continuous Beam Design with Moment Redistribution" Design Example, and "spSlab/spBeam Moment Redistribution Applications" Technical Article from StructurePoint.

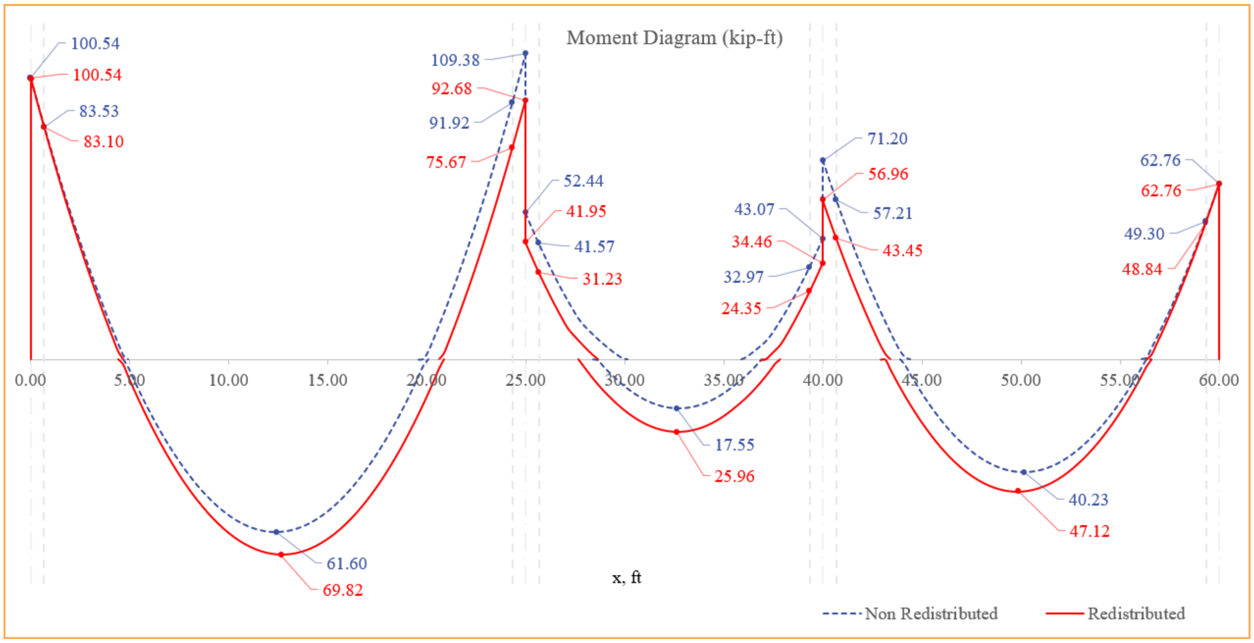



Figure 2.34 – Redistribution of Moments

### 2.6.7. Default Load Assignment Impact on Deflections

In spBeam and spSlab, the deflection calculations are performed by considering all assigned loading belonging to Load Cases of “Dead” and “Live” Load Type with a service load factor of 1.0 automatically. This process is followed by default by the Program regardless of the Load Cases utilized with non-zero load factors in the Load Combinations Menu for the ultimate-level design of the model.

The models generated through the Template Module incorporate Dead and Live Load assignments by default unless the load magnitude is modified to zero (0) by the user. These Load Cases with default assigned load factors of 1.0 will be utilized in deflection calculations even if they are given a zero (0) load factor in the Load Combinations Menu for project-specific reasons. Therefore, to obtain accurate deflection results, the user is advised to review all the load assignments before running the model and eliminate any unnecessary default load assignments that may have been assigned in the Templates Module. While this condition is not frequently needed in practical analysis and design applications, the software approaches the deflection calculations systematically for the traditional deflection calculations.

### 2.6.8. Reinforcing Bar Arrangement Impact on Deflections

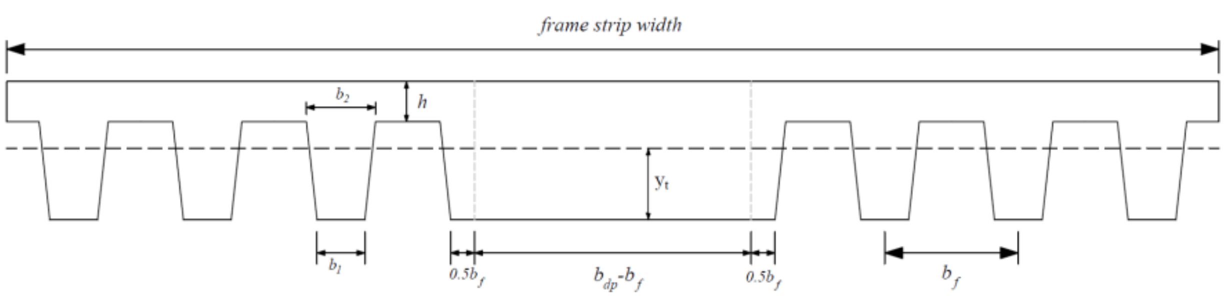
In spSlab and spBeam, reinforcing bar arrangement plays an important role in accurately calculating deflections in concrete structural elements. These programs offer flexible solve options, including the activation of the compression reinforcement, which influences how reinforcing bars are considered in the calculation of the cracked moment of inertia ($I_{cr}$). This feature affects deflection results significantly, especially when both continuous and discontinuous reinforcement types are present. By understanding the impact of these solve options and the associated bar arrangements, engineers can optimize structural analysis and achieve design outcomes tailored to project requirements. More information about this topic can be found in the "spSlab/spBeam Reinforcing Bar Arrangement Impact on Deflections" Technical Article from StructurePoint.

### 2.6.9. Design of Doubly Reinforced Beam Sections

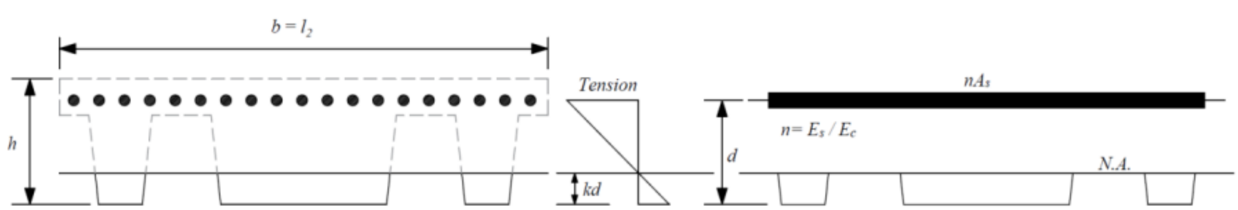
The design of doubly reinforced beam sections incorporates both tension and compression reinforcements, allowing for enhanced ductility and strength while maintaining the section within the tension-controlled region. This approach is particularly valuable in scenarios where architectural constraints limit beam dimensions or where reducing beam weight is a priority. By adding compression reinforcement, engineers can effectively utilize higher percentages of tension reinforcement without exceeding strain limits, thereby achieving the required moment capacity efficiently. This design methodology aligns with the principles outlined in ACI 318 and CSA A23.3 codes, ensuring structural performance and safety. The process includes selecting an appropriate tension reinforcement ratio, integrating compression reinforcement to enhance ductility, and verifying section strength against design requirements. For more details regarding doubly reinforced beam design, refer to "Doubly Reinforced Concrete Beam Design" Design Example from StructurePoint.

## 2.6.10. Waffle Slabs Analysis & Design Approach

A waffle slab, also known as a two-way ribbed slab, is a structural system designed for applications requiring long spans and the ability to carry heavy loads. Its unique geometry, consisting of ribs in two directions, provides an efficient and economical solution for floors and roofs. The Equivalent Frame Method (EFM) is commonly used to analyze and design waffle slabs, simplifying the complexities of their ribbed structure while ensuring compliance with design standards. For a detailed explanation of the analysis and design methodology, including considerations for rib dimensions, slab thickness, drop panels (drop heads), shear analysis, and deflection calculations, refer to Section 2.2.1.4 and "Two-Way Joist (Waffle) Slab Design Approach and Methodology" Technical Article from StructurePoint.




Gross section – negative moment section




Cracked transformed section - negative moment section

Figure 2.35 – Immediate Deflection Considerations for Negative Moment Sections

## 2.6.11. Material Quantities

The program computes concrete and reinforcing steel quantities. The quantity of concrete is based on an average of the slab, drop, and beam sizes. The total quantity of reinforcing steel computed by the program corresponds to the actual bar sizes and lengths required by design. No allowance is made for bar hooks, anchorage embedment, and so forth. It should be noted that the quantity of reinforcement printed by the program pertains to bending in one direction only. In practice, the total amount of reinforcement for the structure should also include the quantities obtained for the appropriate transverse equivalent frames.

**Design Results - Material TakeOff - Reinforcement in the Direction of Analysis**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Top Bars | 320.4 | lb | <=> | 5.34 | lb/ft | <=> | 5.340 | lb/ft² | |
| Bottom Bars | 320.4 | lb | <=> | 5.34 | lb/ft | <=> | 5.340 | lb/ft² | |
| Stirrups | 102.0 | lb | <=> | 1.70 | lb/ft | <=> | 1.700 | lb/ft² | |
| Total Steel | 742.8 | lb | <=> | 12.38 | lb/ft | <=> | 12.380 | lb/ft² | |
| Concrete | 80.0 | ft³ | <=> | 1.33 | ft³/ft | <=> | 1.333 | ft³/ft² | |

Figure 2.36 – spSlab Material Takeoff Table

## 2.7. References


[1] Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14), American Concrete Institute, 2014.

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[20] ACI Committee 435, Subcommittee 7, Deflections of Continuous Concrete Beams, Journal of the American Concrete Institute, Proceedings V. 70, No. 12, December 1973, pp. 781-787.

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[22] ACI Committee 435, State-of-the-Art Report, Deflection of Two-Way Floor Systems, Special Publication SP43-3, American Concrete Institute, 1974.

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[24] Wight, J. K., Falconer, D., Checking Punching Shear Strength by the ACI Code, Concrete International, November 2005, pp. 76.

[25] Park, W. and Gamble, W. L., Reinforced Concrete Slabs, Second Edition, John Wiley & Sons, Inc., 2000

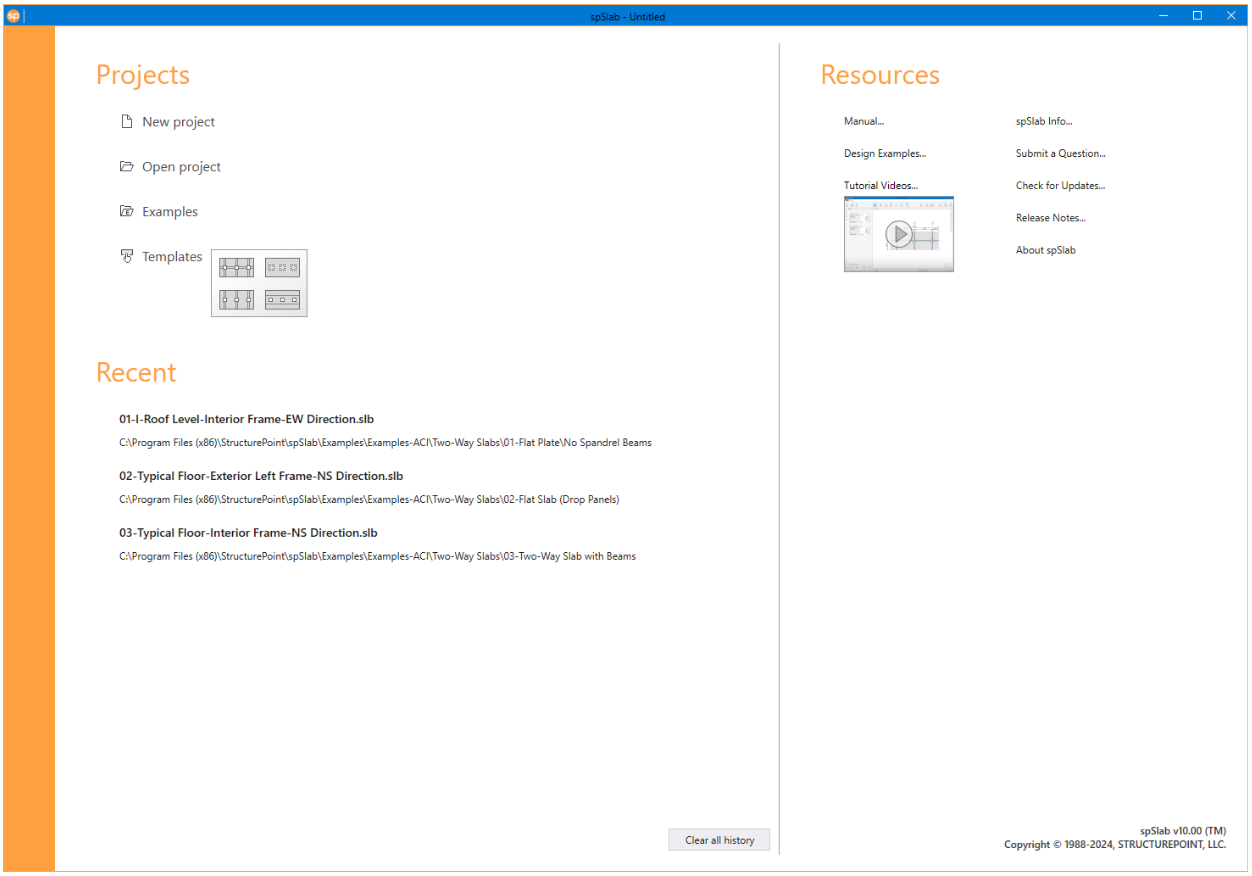
CHAPTER

3

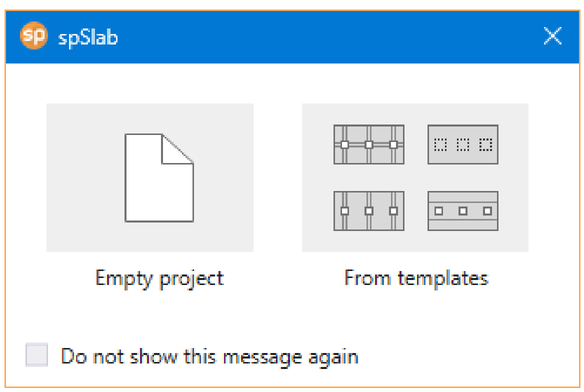
# PROGRAM INTERFACE

## 3.1. Start Screen

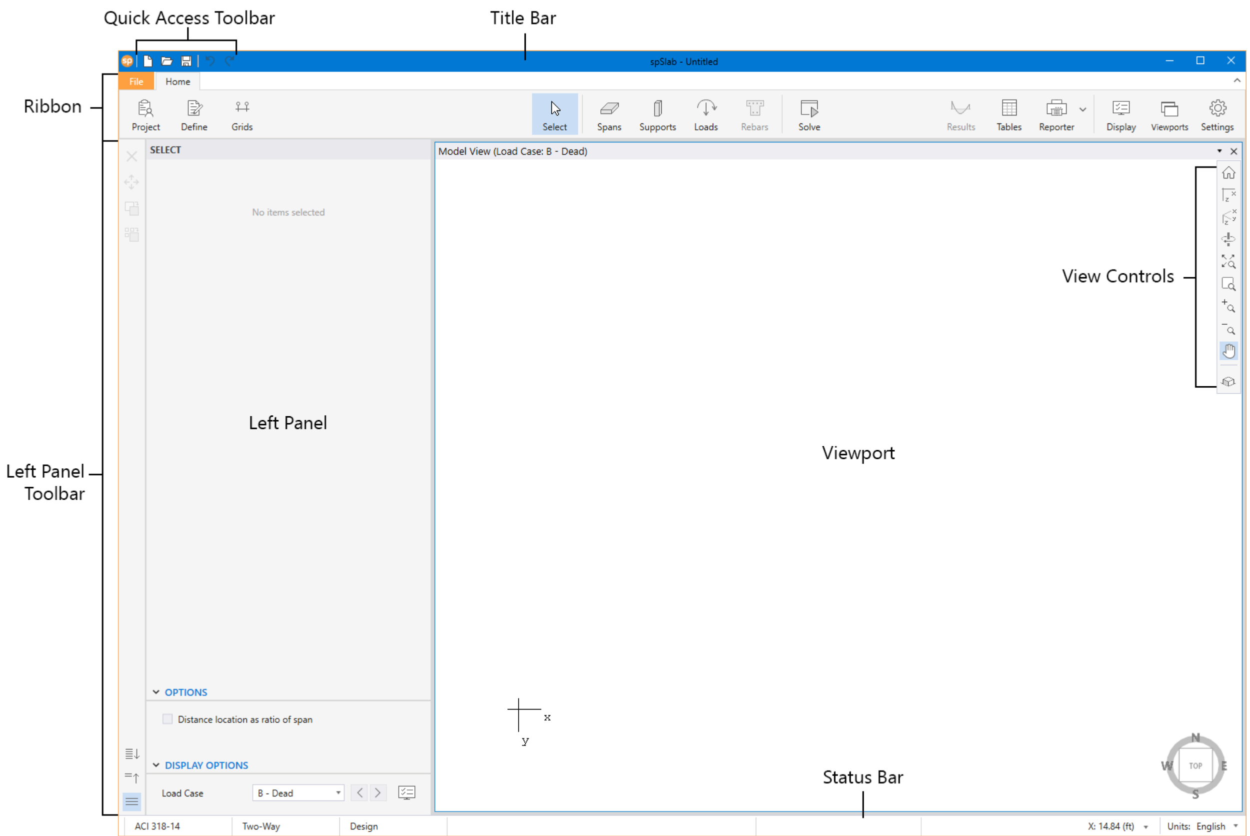
When the Program is launched, a start screen appears as shown below. The Start Screen consists of options to start **New Project**, **Open** existing **Project**, open **Examples** folder, open **Templates**, links to available program **Resources** and a list of **Recent** files. The program name and copyright information are located in the bottom right of the start screen.




When selecting **New Project**, a dialog box appears allowing the user to choose between starting a blank project or using a predefined template.



# 3.2. Main Program Window




The **Main Program Window** shown above consists of the following:

## 3.2.1. Quick Access Toolbar

The **Quick Access Toolbar** includes **New**, **Open**, **Save** and **Undo** and **Redo** commands.

## 3.2.2. Title Bar

The Title Bar displays the name of the program, along with the filename of the current data file in use. If the file is new and has not yet been saved, the word “Untitled” is displayed in the **Title Bar**. It also displays “(Modified)” if the file has been changed and not saved yet.

### 3.2.3. Ribbon

The **Ribbon** consists **File** and **Home** tabs.

**File** Tab consists of commands to go **Back** to **Home** Tab, create **New** file, **Open** an existing file, **Save** a file, **Save as**, and **Exit**. In addition, the entire **Start Screen** is present under the **File** Tab.

**Home** Tab gives quick access to commands which are needed to complete the task of creating a model, executing it and analyzing solutions. These commands are:

**Project**: enables to enter GENERAL, MATERIALS, RUN OPTIONS, and PROJECT DESCRIPTION.

**Define**: enables to define **Concrete**, and **Reinforcing Steel** materials; **Slabs & Ribs**, **Beams**, **Beam Stirrups**, and **Bar Set** reinforcement criteria; **Design & Modeling** options; **Load Cases** and **Load Combinations**.

**Grids**: enables to add new or edit existing grids and spans.

**Select**: enables to select various model items.

**Spans**: enables to create slabs, longitudinal beams and ribs.

**Supports**: enables to create columns, drop panels, column capitals, transverse beams and restraints.

**Loads**: enables to assign area loads, line loads, point loads, support loads, and lateral load effects to the model.

**Rebars**: For two-way floor systems, the **Rebars** command allows the user to specify longitudinal reinforcement details for the column strip, middle strip, and beams, as well as shear reinforcement for beams. In beam or one-way slab systems, the user can specify flexural bars, stirrups, and torsional longitudinal reinforcement. The **Rebars** command is disabled when the Design run mode is selected in the RUN OPTIONS from the **Project** left panel. To enable it, select the Investigation run mode.

Note: When switching from DESIGN Mode to INVESTIGATION Mode, spSlab automatically assumes the results of the DESIGN Mode as an input for INVESTIGATION Mode.

**Solve**: enables to specify design options, deflection options, and solve the model. Please note that design options for two-way systems are different from beams/one-way slab systems.

**Results**: after a successful run, enables to view graphical results such as internal forces, moment capacity, shear capacity, deflection and reinforcement.

**Tables**: enables to open Tables module to view tabular input and output.

**Reporter**: enables to open Reporter module to view the report.

**Display**: enables to toggle on/off model items.

**Viewports**: enables to select from a predefined viewport configuration.

**Settings**: enables to modify various program settings.

### 3.2.4. Left Panel

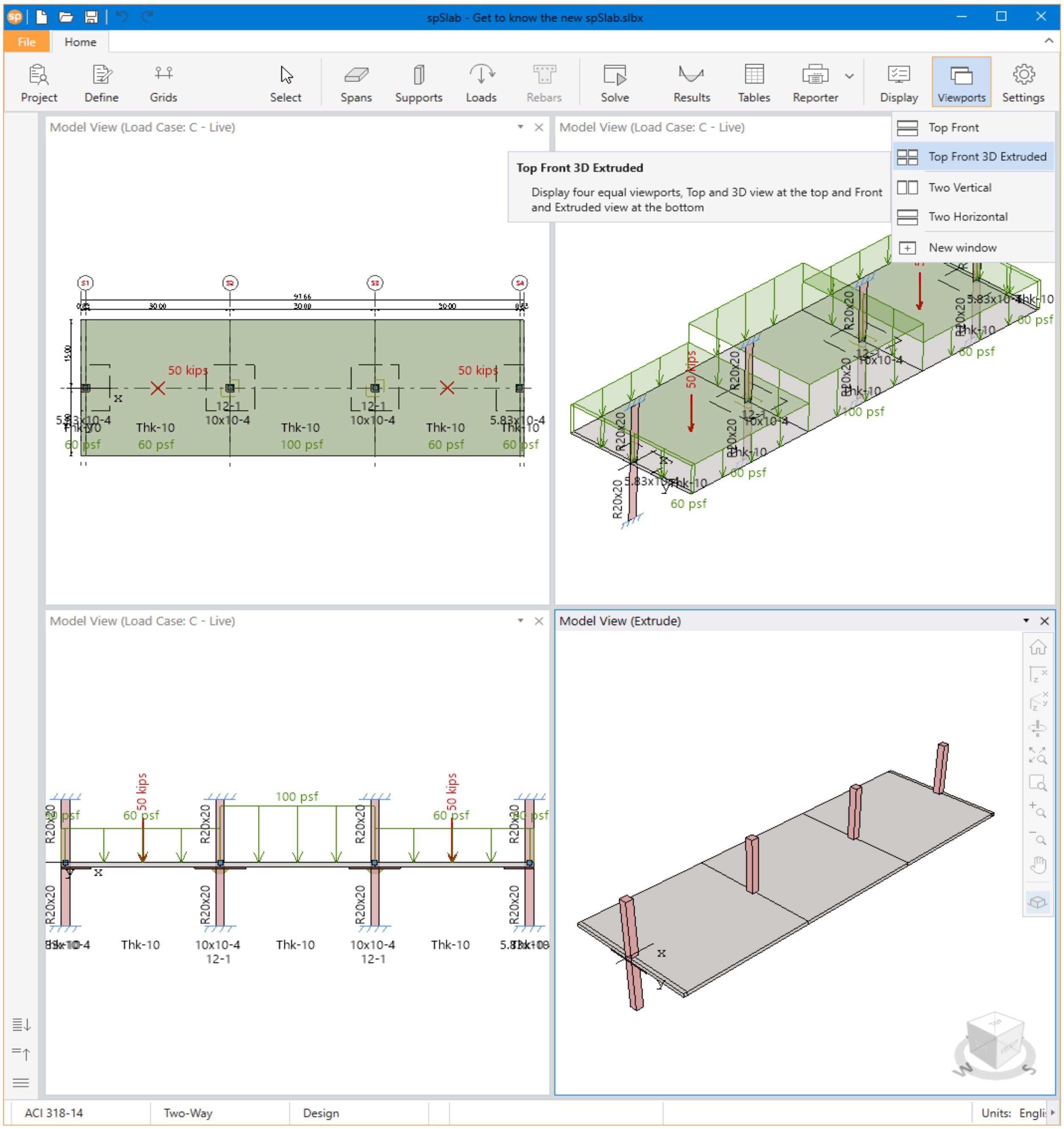
The properties of active commands under **Home** Tab or the properties of items selected in the **Viewport** are displayed in the **Left Panel** which can then be used to execute the commands or edit the selected items. After execution the **Left Panel** also displays various commands and options which can be used to investigate the solution diagrams in the **Viewport**.

### 3.2.5. Left Panel Toolbar

The **Left Panel Toolbar** contains commands that can be used to edit various items in the **Viewport**.

### 3.2.6. Viewport

The **Viewport** covers the majority of the main program window. It is the space where models can be created and graphical results can be viewed. Up to 6 **Viewports** can be used at once. Viewports can be moved and docked in a number of predefined locations using the docking tool. A viewport may be split out to a separate screen entirely for added flexibility and to enlarge the model view work area providing more accurate drafting controls.



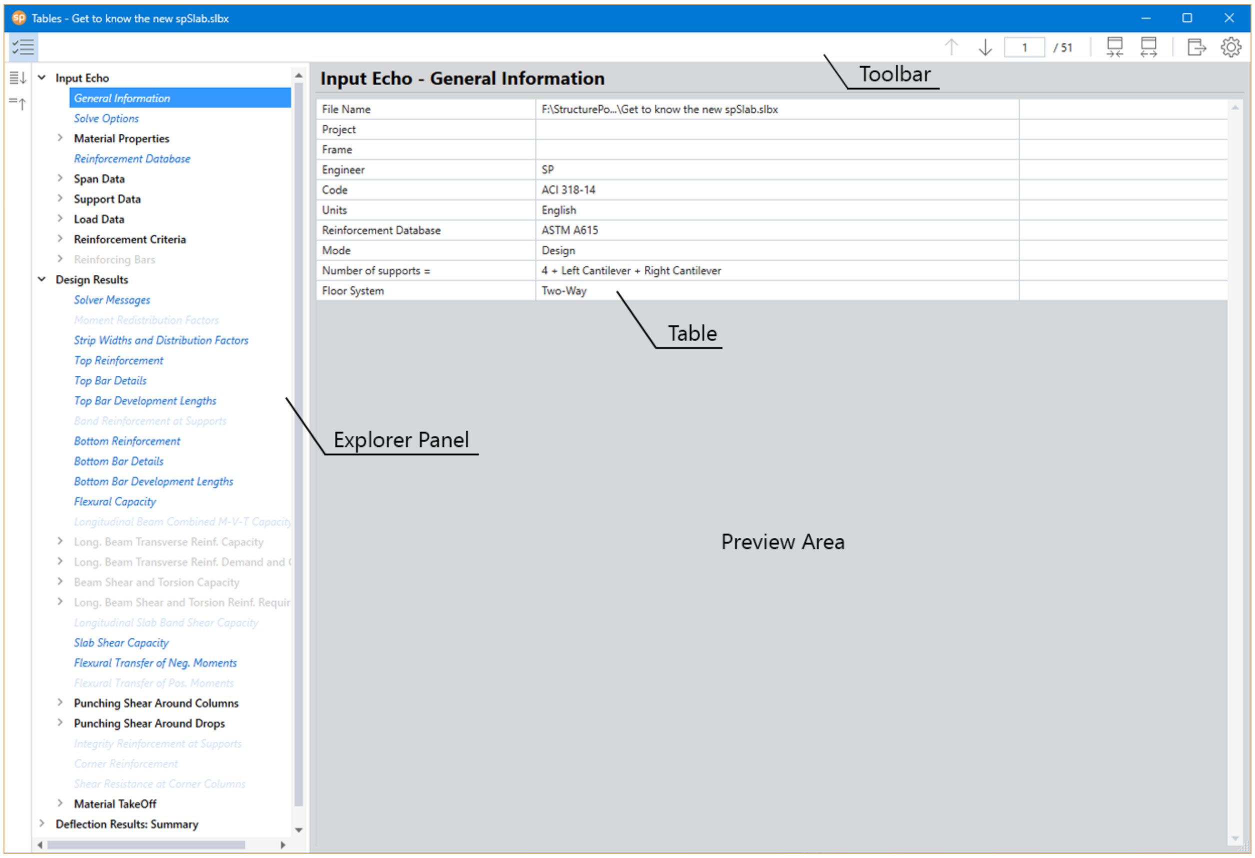
### 3.2.7. View Controls

The **View Controls** contains various commands which can be used to adjust the views of **Viewport** both during modeling or viewing the graphical results.

### 3.2.8. Status Bar

The **Status Bar** displays key information, including the design code, run options, cursor position, and current units.

## 3.3. Tables Window




The **Tables Module** interface shown above enables the user to view program inputs and outputs in tables and export them in different formats.

The **Tables Module** is accessed from within the Main Program Window by clicking the **Tables** button from the **Ribbon**. Alternatively, **Tables Module** can also be accessed by pressing the F6 key. If the model has not been executed yet, then the **Tables Module** will only contain a list of input data tables. When a model has been successfully executed, the **Tables Module** will also display the output data tables.

### 3.3.1. Toolbar

The **Toolbar** contains commands which can be used to navigate through various Tables

**Previous table**

Displays the previous table.

**Next table**

Displays the next table.

**Table number box**

Displays the table with the table number entered in the box.

**Auto fit column width to view area**

When toggled on always fits the width of table to the **Preview Area** width.

**Maintain maximum column width**

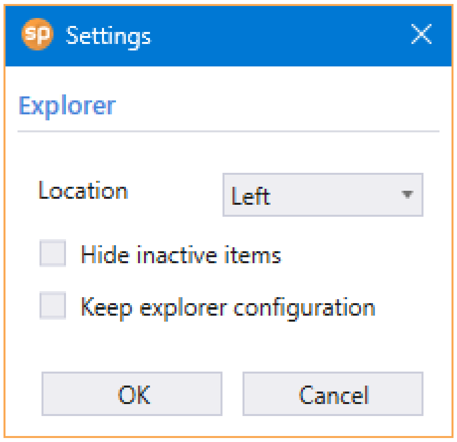
Restores all table columns to their default maximum width.

**Export current table**

Exports the table being viewed in the selected format.

## Settings

Contains settings for the **Explorer Panel**.




- LOCATION: Displays **Explorer Panel** on the left or right side of screen depending on selection.

- HIDE INACTIVE ITEMS: Hides unused tables from the explorer view.

- KEEP EXPLORER CONFIGURATION: Saves the explorer configuration i.e., information about selected tables and opened/closed sections so that it is available the next time user opens **Tables** Module.

## Explorer

Shows or hides the **Explorer Panel**.

### 3.3.2. Explorer Panel

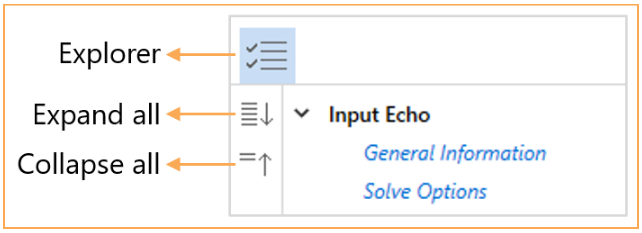
The **Explorer Panel** consists of all the available items of the inputs and results classified into sections and arranged hierarchically. Any item in the **Explorer Panel** can be clicked on to display the corresponding table in the **Preview Area**.

**Expand all**

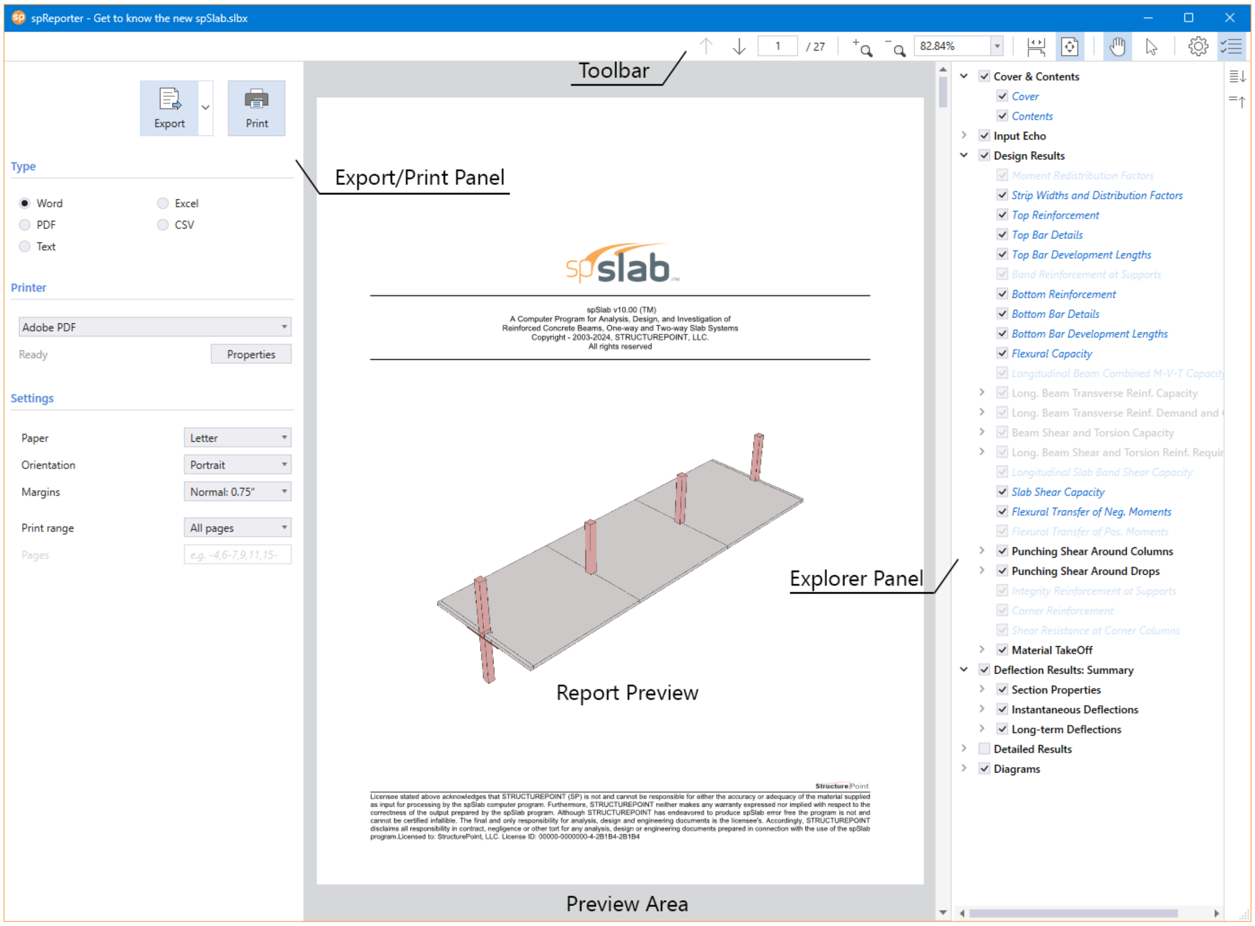
Expands item list.

**Collapse all**

Collapses item list.



# 3.4. Reporter Window




The **Reporter Module** interface shown above enables the user to view, customize, print and export reports in different formats.

The **Reporter Module** is accessed from within the Main Program Window by clicking the **Reporter** button from the **Ribbon**. Alternatively, **Reporter Module** can also be accessed by pressing the F7 key. If the model has not been solved then the **Reporter Module** will only contain a list of input data reports. When a model has been successfully executed, the **Reporter Module** will also display the output data reports. Immediately after opening the **Reporter Module**, you can export and/or print the default report by pressing **Export/Print** button. Various options to customize the report before printing and/or exporting it are also provided. Once the work in **Reporter Module** is complete, click the close button in the top right corner to exit **Reporter** window.

### 3.4.1. Toolbar

**Previous page**

Displays the previous page of the report.

**Next page**

Displays the next page of the report.

**Page number box**

Displays the page with the page number entered in the box.

**Zoom in**

Zooms in on the report (Ctrl + Mouse wheel up).

**Zoom out**

Zooms out on the report (Ctrl + Mouse wheel down).

**Zoom box**

Zooms on the report preview to the extent typed in the box or selected from the dropdown list.

**Fit to window width and enable scrolling**

Fits the width of report to the preview space width and enables scrolling.

**Fit one full page to window**

Fits one full page in the preview space.

**Pan**

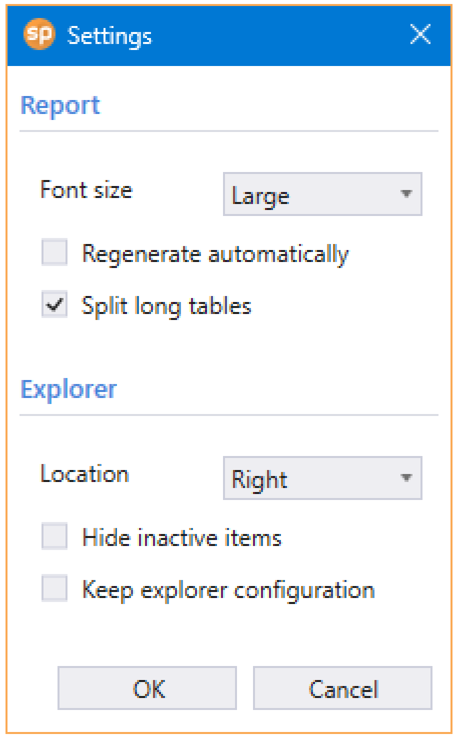
When toggled on and report is bigger than preview window, enables panning the report.

**Text selection**

When toggled on enables selecting text in the report.

## Settings

Modifies settings for **Report** and **Explorer Panel**.




### Report settings

- FONT SIZE: Provides the options to use small, medium or large font sizes in the report.
- REGENERATE AUTOMATICALLY: Enables automatic regeneration of report when content selection is modified by the user.
- SPLIT LONG TABLES: Displays table headings in all pages when tables are split along several pages.

### Explorer settings

- LOCATION: Displays **Explorer Panel** on the left or right side of screen depending on selection.
- HIDE INACTIVE ITEMS: Hides unused tables from the explorer view.

- KEEP EXPLORER CONFIGURATION: Saves the explorer configuration i.e., information about selected tables and opened/closed sections so that it is available the next time user opens **Reporter**.

**Explorer**

Shows or hides the **Explorer Panel**.

### 3.4.2. Export / Print Panel

**Export**

Exports the report in the selected format, with an option to automatically open the report or its file location.

**Print**

Prints the report in the selected format when the option is available.

**Type**

Provides 5 format options to print and/or export the reports

- WORD: produces a Microsoft Word file with .docx extension.
- PDF: produces an Adobe Acrobat file with .pdf extension.
- TEXT: produces a Text file with .txt extension.
- EXCEL: produces a Microsoft Excel file with .xlsx extension.
- CSV: produces a Comma Separated file with .csv extension.

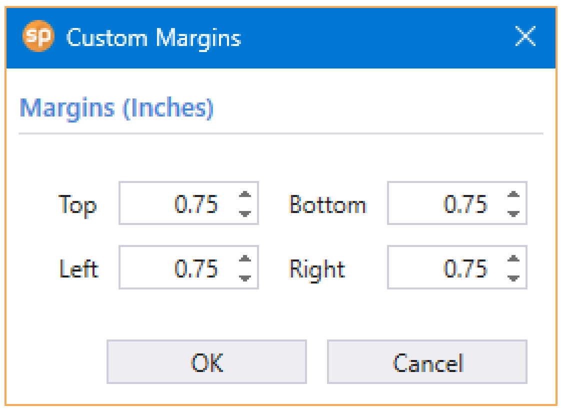
**Printer**

Provides the option to select available printers and change printer properties.

## Settings

Provides the options to modify print settings.

- PAPER: Provides the options to select from available paper sizes.
- ORIENTATION: Provides the options to select between landscape or portrait paper orientation.
- MARGINS: Provides the options to use narrow, normal, wide or custom margins to the report




- PRINT RANGE: Provides the options to select the pages to print and/or export.

### 3.4.3. Explorer Panel

The **Explorer Panel** consists of all the available report items classified into sections and arranged hierarchically. Each item listed in the **Explorer Panel** is preceded by a checkbox. The user can check/uncheck the checkbox to include or exclude from the report, the items or sections.

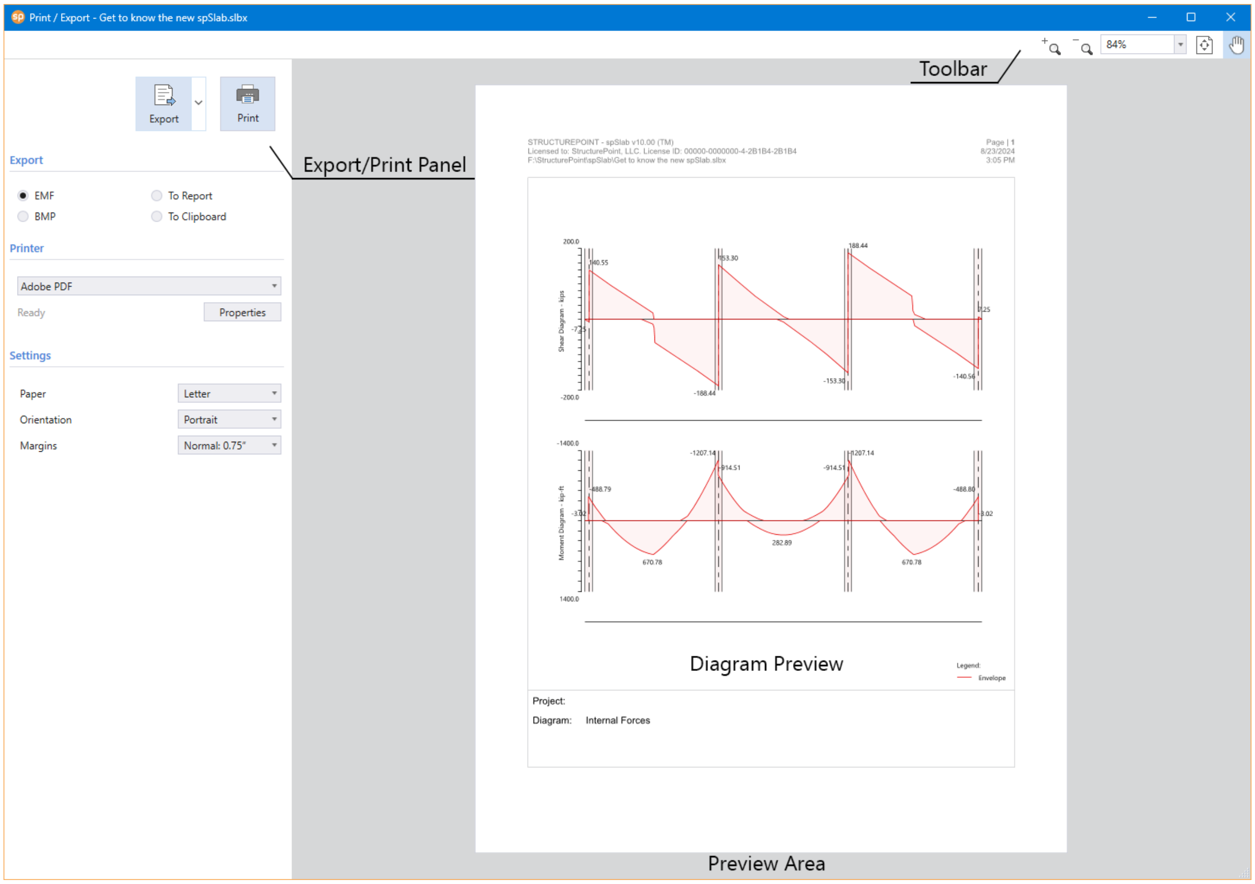
**Expand all**

Expands item list.

**Collapse all**

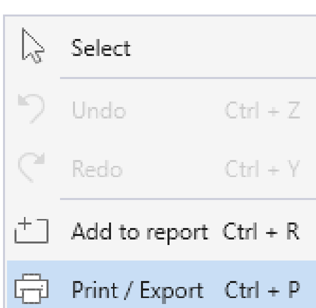
Collapses item list

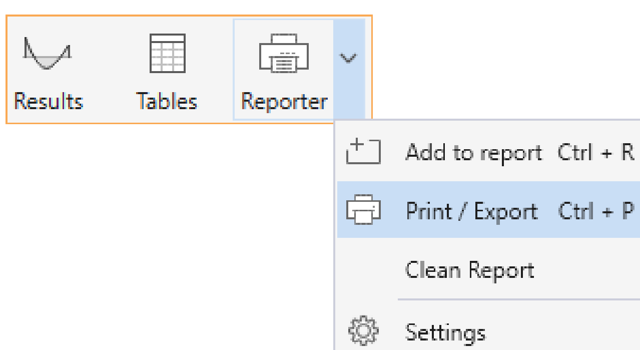
# 3.5. Print/Export Window




**Print/Export Module** interface shown above enables the user to view, customize, print and export diagrams in different formats.

The **Print/Export Module** is accessed from within the **Main Program Window** by using the **Right Click Menu** or from the **Reporter Submenu** in the **Ribbon**.



Alternatively pressing the "CTRL + P" also opens the **Print/Export Module**. Once the module is open the rest of the program is locked until the **Print/Export Module** is closed.

Immediately after opening the **Print/Export Module**, you can export and/or print the generated diagram by pressing **Export/Print** button. Options to customize the diagram orientation, paper size and margins are provided. Once the work in **Print/Export Module** is complete, click the close button in the top right corner to exit the module.

### 3.5.1. Toolbar

**Zoom in**

Zooms in on the report (Ctrl + Mouse wheel up).

**Zoom out**

Zooms out on the report (Ctrl + Mouse wheel down).

**Zoom box**

Zooms on the report preview to the extent typed in the box or selected from the dropdown list.

**Fit one full page to window**

Fits one full page in the preview space.

**Pan**

When toggled on and report is bigger than preview window, enables panning the report.

### 3.5.2. Export / Print Panel

**Export**

Exports the report in the selected format, with an option to automatically open the report or its file location.

**Print**

Prints the displayed diagram.

**Type**

Provides 4 format options to export the reports

- EMF produces a file with .emf extension
- BMP produces a file with .bmp extension
- TO REPORT adds the diagram to the report
- TO CLIPBOARD copies the diagram to clipboard to be pasted elsewhere

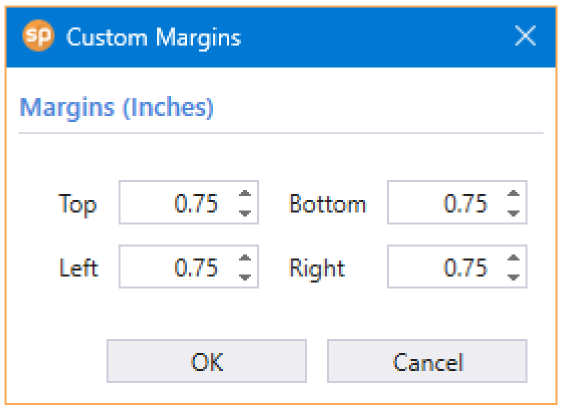
**Printer**

Provides the option to select available printers and change printer properties.

## Settings

Provides the options to modify print settings.

- PAPER: Provides the options to select from available paper sizes.
- ORIENTATION: Provides the options to select between landscape or portrait paper orientation.
- MARGINS: Provides the options to use narrow, normal, wide or custom margins to the report.



CHAPTER

4

# MODELING METHODS

## 4.1. Model Creation Concepts

The key to effectively implementing spSlab/spBeam in a project is understanding the program's robust approach to modeling, analyzing, designing, and evaluating reinforced concrete slabs and beams under a variety of loading conditions. Of utmost importance is the understanding of the methods utilized in the program for the analysis of reinforced concrete floor slab systems. This section provides insights into the methods, assumptions, and factors that the design professional must consider while modeling using spSlab/spBeam for analysis, design, and detailing.

As a foundational guideline, the geometry of the analytical model should represent the physical structure as closely as possible to ensure accurate analysis results.

Users must confirm that the project criteria align with applicable design codes and standards. This includes considerations for load types, load factors, load combinations, material properties, reinforcement requirements, deflection criteria, and detailing provisions, ensuring compliance with industry standards and best practices.

### 4.1.1. Physical Modeling Terminology

In spSlab, the terminology around elements and members is critical for understanding how the program models reinforced concrete slabs and beams. spSlab utilizes elements to represent structural components in the Equivalent Frame Method (EFM). Elements are the primary modeling units within spSlab, corresponding closely to the physical structural members in the project. The EFM is a very well established analysis method used exclusively for two-way concrete floor systems. In this method, a great variety of floor systems are covered in its scope. As a result. Many structural elements contribute to the making of a concrete floor system. These elements allow users to capture the geometry and material properties of slabs, beams, slab bands, columns, drop panels, and column capitals within the analytical model. These elements are used at the engineer's discretion to combat design challenges pertaining to one-way shear, two-way shear, inadequate flexural strength, or unacceptable deflections.

The EFM in spSlab simplifies modeling by focusing on frame strips representing the slab-beam-column system. Users only need to define the primary elements, which spSlab discretizes into equivalent frame members for analysis. This streamlined modeling method saves time and simplifies the design process.

By using the EFM, spSlab enables both efficient modeling and accurate structural behavior prediction without requiring more elaborate and intricate analysis processes such as the Finite Element Method (FEM) of analysis. Instead, users can focus on defining element properties and ensuring that the geometry of the analytical model accurately reflects the physical structure.

It is crucial to understand the concept of elements in spSlab, as it forms the foundation for creating effective and efficient models. Once familiar with this approach, users can appreciate the simplicity and power of the EFM in modeling complex slab and beam systems.

### 4.1.2. Structural Elements

The spSlab program uses elements to represent physical structural members. When creating a model, users begin by defining the geometry of slabs, beams, and other structural elements within the program using drawing area common Computer-Aided Design (CAD) tools and then assign properties and loading to these elements, fully specifying the structural model for analysis.

To complete the model of a concrete floor system, two essential element types are required in spSlab:

- Span Elements: Used to represent slabs, longitudinal beams, ribs, and longitudinal slab bands.
- Support Elements: Used to represent columns, drop panels, column capitals, transverse beams, and restraints.

As a general rule, the geometry of each element should represent that of the actual physical member as closely as possible. This approach enhances visualization of the model and reduces potential errors during input. However, engineers can omit small changes in shape and geometry where added model accuracy or complexity is not consequential to the analysis & design results. A great deal of engineering judgment is involved in the conversion of a physical structure into an analytical model. However, significant gains can be achieved by keeping model simple & practical to the extent possible.

It is also essential that beginner users must establish smaller simpler models at first to gain a better understanding of the program and its features. This will help greatly in understanding the method of solution as well as figure out what to do when there is an issue to diagnose or verify in the output. It is always much easier to discover the source of an error when working with a simple model and a few loading conditions. Once a model becomes complicated with numerous loads and load combinations, it becomes increasingly difficult to discover the source of an issue or a concern in the output, graphical or tabular.

### 4.1.3. Properties

Material and geometric properties for model elements in spSlab and spBeam are categorized into two groups: **Defined Properties** and **Unique Properties**. This distinction provides users with the flexibility to manage elements properties consistently across the model while accommodating variations for specific spans and supports.

**Defined Properties** refer to material properties, including concrete material properties (compressive strength $f_c'$, unit density $W_c$, Young's modulus $E_c$, and rupture modulus $f_r$), and reinforcing steel material properties (yield stress for flexural steel $f_y$, yield stress for stirrups $f_{yt}$, and Young's modulus $E_s$). Concrete material properties are consistent across all slab and beam elements but can differ for column elements, allowing for tailored input to reflect different structural requirements. Reinforcing steel material properties, however, remain the same throughout the model, including slabs, beams, and columns, ensuring uniformity in reinforcing steel characteristics. The program enables users to define these properties globally, maintaining consistency and alignment with design standards such as ACI 318 and CSA A23.3, while accommodating necessary distinctions between slabs, beams, and columns where applicable.

**Unique Properties**, on the other hand, refer to element geometric properties that are specific to individual spans and supports. These properties (such as slab/beam width, thickness, column width, depth, or height) are assigned on a per-element basis, enabling the program to account for variations in geometry that influence structural behavior. Each span and support can therefore have distinct geometric attributes, allowing for a more refined and realistic representation of the structure.

### 4.1.4. Input Preparation

If you do not find a suitable template to begin your project, you can start with a blank project. A blank project requires a lot more care in the construction of the model and much more effort to complete the details of the input. To begin, start by setting up the grids in the **Grid** command to define the layout. Next, use the **Spans** command to add slab, beam, or rib elements and adjust their dimensions as needed. Finally, use the **Supports** command to add support elements such as columns, beams, or restraints, and configure their properties, including height, size, and end conditions. The following guidelines can be used in this scenario:

- To establish a comprehensive model for structural analysis, the user begins by defining grids and specifying span lengths to ensure an accurate layout representation. If the span lengths need to be adjusted later, the user can return to the **Grid** command and modify the span lengths using the Span table.

- The user must define frame location and evaluate which location best aligns with the design intent. Detailed insights and guidance on selecting appropriate frame location can be found in Section 5.2.2.4 of the manual.

- A critical decision involves addressing cantilever extensions - whether they function as true cantilevers (e.g., balcony or canopy projections) or are intended to encompass the column to contribute to two-way shear resistance. In the Span table under **Grid** command, users can select USER-DEFINED for cantilevers on the left and right to simulate a true cantilever or choose ADJUST TO SUPPORT FACE to encompass the column.

- Building on the selection of cantilever behavior, choosing ADJUST TO SUPPORT FACE in the Span table allows the cantilever to align its geometry with the support face. When selected, the program assigns a placeholder cantilever length of 5 ft until an exterior support is defined. If the model is run without assigning the required support, the process will be interrupted, and the program will display an error message, indicating the requirement for a column or transverse beam at the cantilever edge joint. The figure below illustrates this process.

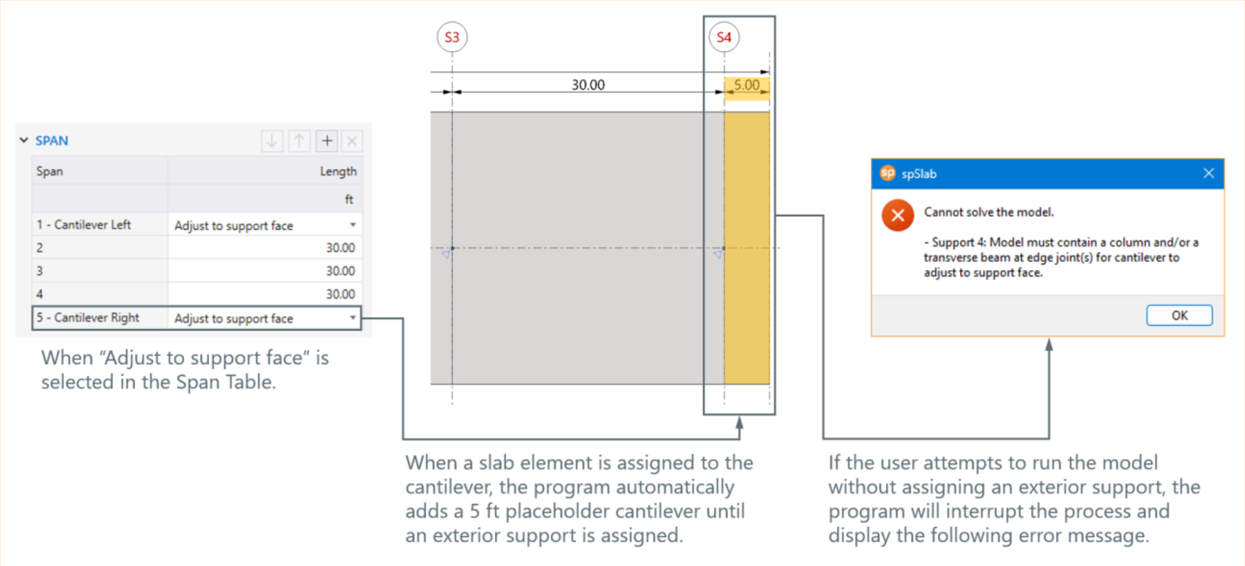



Figure 4.1 – Adjust to Support Face Option

- When NONE is selected for the right and left cantilevers in the Span table, the model assumes that no cantilever extensions are required. For that case, if the user runs the program without assigning any additional supports, the program will automatically assign default pin supports at the slab joints. This allows the model to run without interruptions, ensuring the structural analysis proceeds under simplified support conditions.

## 4.1.5. Modeling Considerations

### 4.1.5.1. Sway and Non-Sway Considerations

When considering sway versus non-sway conditions in structural analysis, it is essential to account for lateral effects in the model to ensure accurate results. In non-sway conditions, programs like spSlab and spBeam assume horizontal translational restraint, excluding lateral effects directly from the analysis. This approach simplifies the modeling process and is suitable for frames where lateral displacements are minimal or restrained, such as single-story frames with balanced vertical loads and consistent boundary conditions.

However, in sway conditions, where unsymmetrical vertical loading, support stiffness variations, or boundary conditions induce lateral movements, the lateral effects must be explicitly included. These can be added as member-end forces, such as moments acting at the ends of each span, using **Lateral Load Effects**, which can be assigned from the **Lateral** command in the **Left Panel** under **Loads** command. This allows users to input lateral loads like wind or seismic forces as moments at the ends of members, enabling the program to account for combined vertical and lateral effects accurately.

For cases where significant lateral displacements or sidesway effects are expected, it is recommended to use spFrame, which models the frame as a two-dimensional unit for the entire building height. spFrame accurately captures the influence of sidesway on internal force magnitudes, ensuring reliable results for design.

This dual approach - leveraging spSlab and spBeam for simplified non-sway analysis and spFrame for sway-sensitive scenarios - ensures flexibility and precision in addressing varying structural conditions. Additional details about this topic can be found in Section 2.6.10, Section 5.2.4.3, and "Comparison of Gravity Loaded Concrete Frame Models in spBeam and spFrame under Sidesway" Technical Article from StructurePoint.

#### 4.1.5.2. Unbalanced Moments in Column Design

Unbalanced moments in a floor system play a critical role in the design of columns located above and below the slab-beam structure. These moments arise from the distribution of loads and are transferred from the slab to the support columns in proportion to their relative stiffness. This transfer creates forces in the columns, which must be accurately calculated and incorporated into their design to ensure structural integrity. Additional details about this topic can be found in Section 2.3.7.4.

Column end moments and axial forces can be found in the results table. These forces for various load combinations and live load patterns can be then exported to spColumn for detailed design or investigation of a column cross-section. StructurePoint prepared several design examples for a complete floor system including the calculation of unbalanced moments in columns and the investigation of column section reinforcing to provide the required strength in the column.

Detailed discussion of unbalanced moments in column design can be found in the following design examples from StructurePoint:

"Two-Way Flat Plate Concrete Slab Floor Analysis and Design" Section 2.2.7. and Section 3.

"Two-Way Flat Slab (Drop Panels) Concrete Floor Analysis and Design" Section 2.1.7. and Section 3.

"Two-Way Concrete Floor Slab with Beams System Analysis and Design" Section 2.7. and Section 3.

"Two-Way Joist Concrete Slab Floor (Waffle Slab) System Analysis and Design" Section 2.1.7. and Section 3.

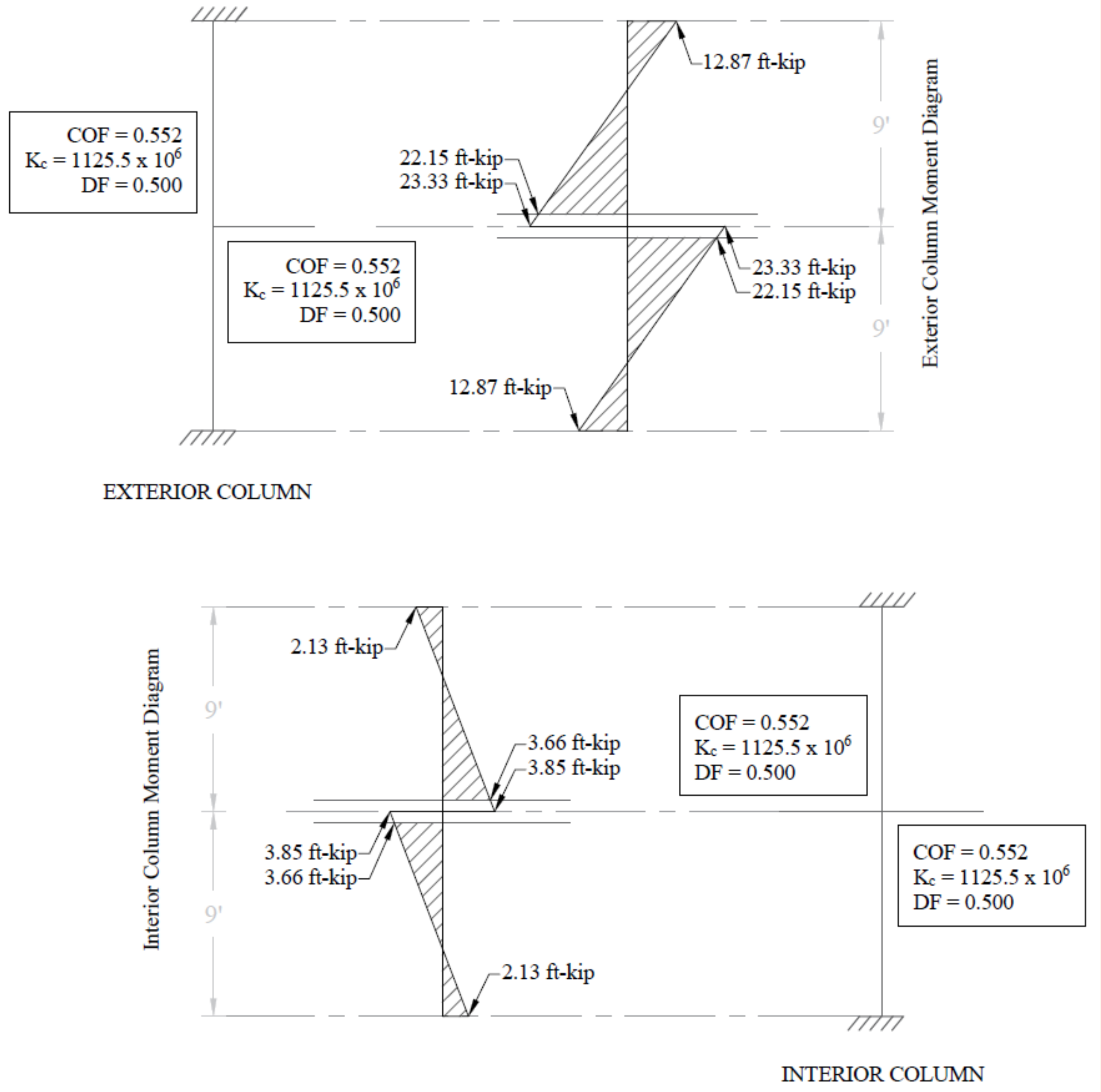



Figure 4.2 – Column Moments (Unbalanced Moments from Slab-Beam)

### 4.1.5.3. One-Way Slabs on Transverse Beams

In modeling one-way slabs supported by transverse beams, several important and consequential considerations must be addressed to ensure accurate analysis and design. The rotational resistance of exterior supports plays a significant role in moment distribution. Two common conditions are recognized:

- **Unrestrained exterior supports:** Treated as pin supports, they provide no rotational resistance at the slab end. This is the default assumption in spSlab/spBeam, with the rotational stiffness ($K_{ry}$) set to zero.

- **Integral exterior supports:** Provide rotational resistance and are modeled as semi-rigid connections. For example, spandrel beams integrated with the slab can be assigned rotational stiffness approximated iteratively using design codes provisions or other sources for moment factors, offering a more realistic representation.

Additionally, modeling transverse beams or girders can incorporate their added stiffness, reducing the effective slab span and yielding a closer approximation to actual conditions. While this approach enhances the accuracy of moment distribution, it introduces additional modeling parameters, requiring careful engineering judgment. Additional details about this topic can be found in "One-Way Slab Analysis and Design" Design Example from StructurePoint.

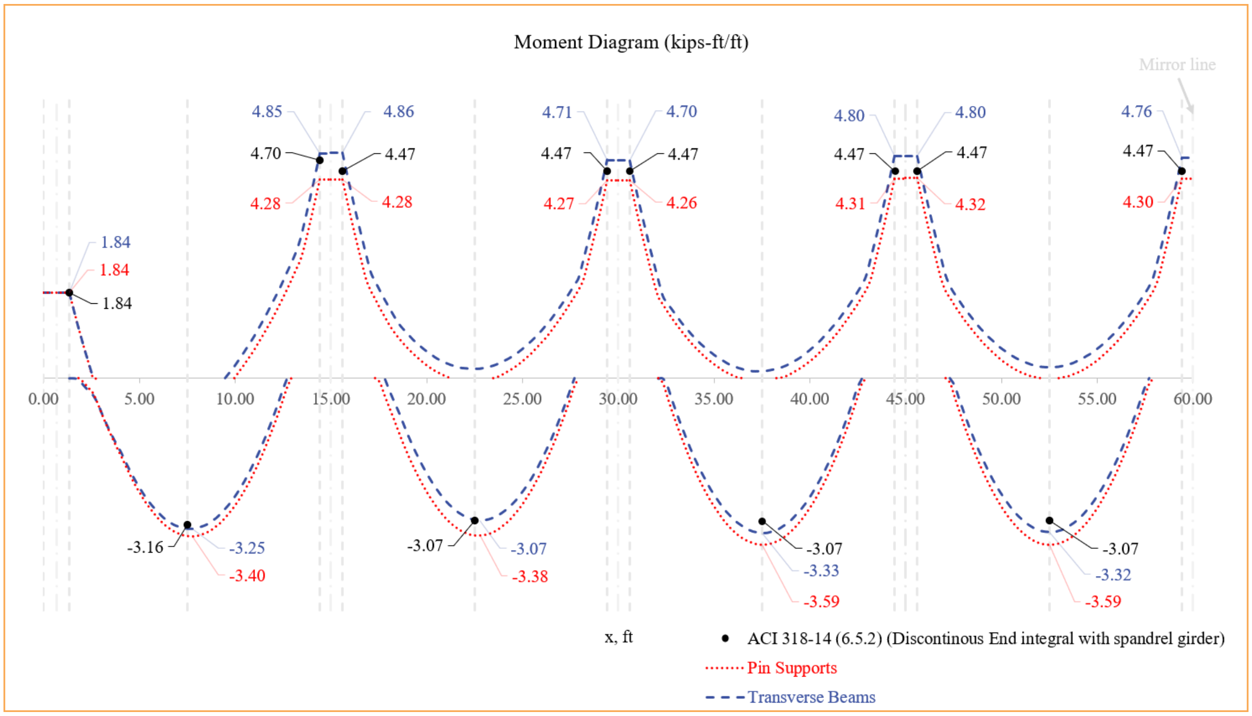



Figure 4.3 – One-Way Slabs on Transverse Beams

### 4.1.5.4. Boundary Condition Effects on Continuous Beam Deflections

Boundary conditions significantly influence the deflection behavior of continuous beams in reinforced concrete structures. Properly modeling these conditions in spBeam ensures accurate analysis and design results. This section explores the effects of different support conditions:

- **Beam Supported by Columns:** The stiffness of columns above and below the beam is modeled to calculate rotational stiffness at the joint. This accurately determines beam end moments. Support stiffness is adjustable, with values ranging from 0 (pinned) to 999 (fixed support), providing flexibility in simulating various boundary conditions.

- **Beam Supported by Transverse Beams:** Transverse beams are modeled using rotational stiffness values. ACI and CSA codes approximate moments at transverse beam supports as two-thirds of those at column supports. For more precise design, dummy columns can be used to define critical sections for shear and moment calculations.

- **Beam Supported by Transverse Walls:** Beams cast monolithically with shear walls are modeled as having walls defined as elongated columns to simulate integral behavior.

- **Beam Supported by Masonry Bearing Walls:** Masonry walls are modeled as pinned supports with zero stiffness, effectively simulating their bearing behavior without rotational constraints.

- **Beam Supported by Longitudinal Walls:** Beams are modeled up to the face of the wall with fixed supports at the wall face, ignoring wall width in the analysis.

Deflection comparisons highlight the variations due to boundary conditions. For example, beams with transverse beam supports show higher deflections compared to those supported by walls, emphasizing the importance of modeling boundary conditions accurately. For further details, refer to "Reinforced Concrete Continuous Beam Analysis and Design" Design Example from StructurePoint.

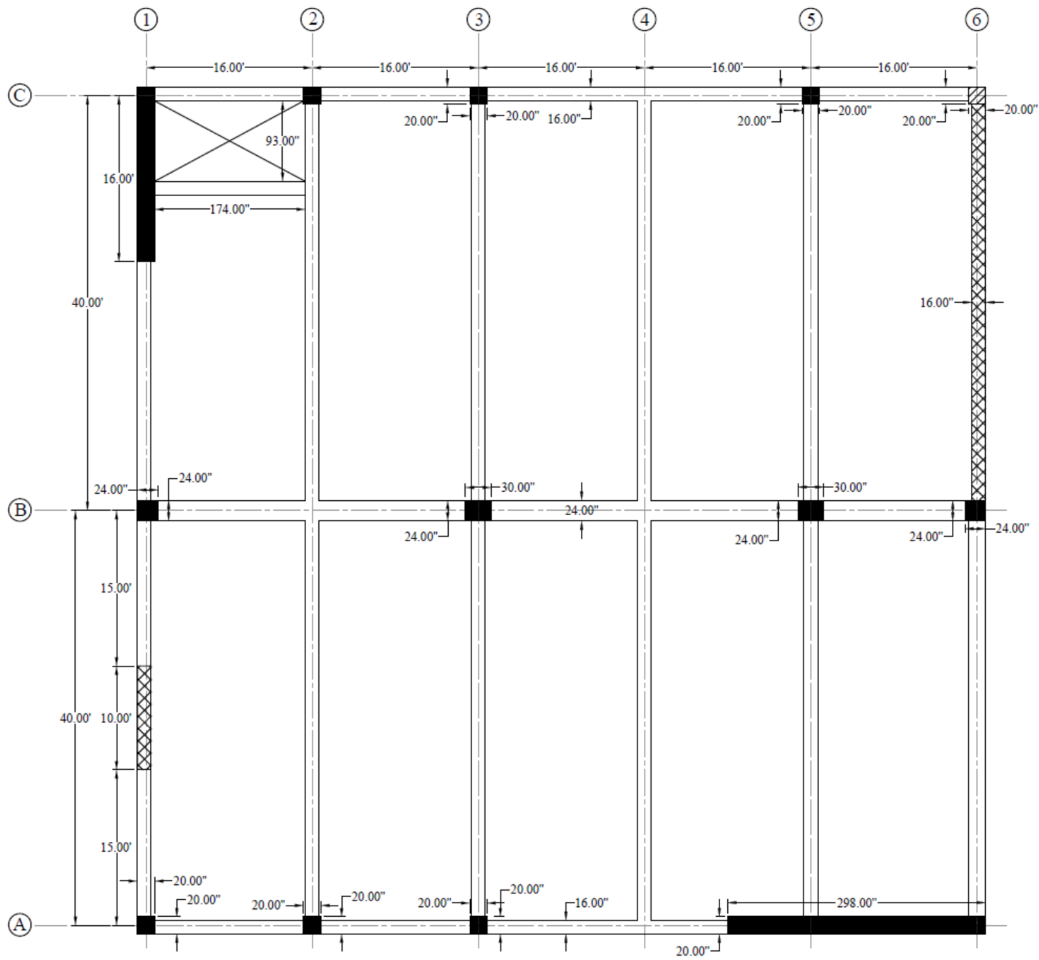



Figure 4.4 – Plan View of Continuous Beams with Different Boundary Conditions

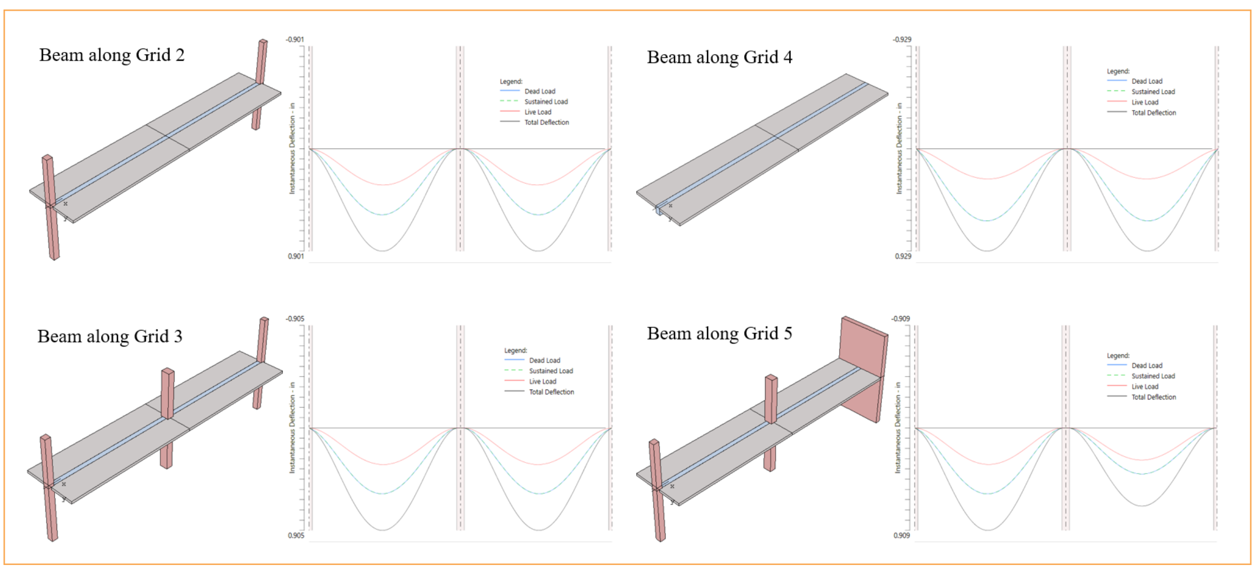



Figure 4.5 – Comparison of Continuous Beams with Different Boundary Conditions (Deflections)

### 4.1.5.5. Design of New Buildings vs. Investigation of Existing Buildings

In spSlab/spBeam, the modeling approach depends on whether the project involves the design of a new building or the investigation of an existing building. The program offers two distinct run modes to address these scenarios: DESIGN mode and INVESTIGATION mode.

In DESIGN mode, the program performs structural analysis and determines the required flexural, shear, and torsional reinforcement based on the selected design code. This mode is ideal for new structures, as it provides a baseline design that ensures compliance with applicable codes and standards.

In INVESTIGATION mode, the user inputs the existing flexural, shear, and torsional reinforcement. The program then evaluates the adequacy of the provided reinforcement given the section shape and material properties used. This mode is particularly suited for assessing the safety and performance of existing structures or making modifications to them.

Even for investigations, it is recommended to initially use DESIGN mode to establish a reinforcement baseline that aligns with current codes. This design output can then serve as a starting point for further analysis and refinement in INVESTIGATION mode, ensuring consistency and accuracy throughout the modeling process. For detailed guidance, refer to Sections 5.2.3.2 and 5.2.4.4.

### 4.1.5.6. Modeling and Design of T-Beams

In spSlab/spBeam, T-beams are modeled to account for the contribution of flanges, which can be formed either by monolithic casting of slabs and beams or as isolated T-beams, such as precast elements. The inclusion of flanges enhances structural performance by utilizing the flange as part of the flexural member, improving both strength and efficiency.

One advantage of flanges in T-beams is their ability to increase the compression area, boosting the beam's flexural capacity without requiring significant additional reinforcement. This makes T-beams highly effective for handling larger moments compared to rectangular beams. Another advantage lies in material efficiency. In T-beams, integrating the slab as part of the beam section reduces the concrete and steel required for the same structural capacity.

Shear design for T-beams can be more complex due to the nonuniform stress distribution in the web caused by the flange. This requires careful modeling and analysis to ensure accurate results. For precast T-beams, connection details between the beam and the surrounding structure must be considered to achieve the intended performance. Proper construction practices are crucial in both cases. For monolithic T-beams, ensuring the slab and beam are cast together effectively is essential for accurate structural behavior. For precast T-beams, the quality of the connections and proper alignment during installation are critical.

In spSlab/spBeam, flange dimensions and configurations are defined during modeling using the **Spans** command. Additionally, users can engage relevant code provisions for T-beam analysis, design, and deflection calculations through the **Design Options** and **Deflection Options** available under the **Solve** command. These features provide flexibility and precision in modeling and designing T-beams in accordance with applicable standards.

StructurePoint has prepared a number of T-beam case studies to assist in understanding the complexity of this important structural element. These cases illustrate the number of ways to handle the flexural design given single or doubly reinforce configurations as shown in the following table.

| Case Study | Description | Notes |
|---|---|---|
| Case One | • Rectangular Section Behavior<br>• Singly reinforced | • The stress block depth "*a*" is less than the flange thickness<br>• 2 layers of tension reinforcement |
| Case Two | • T-Section Behavior<br>• Singly reinforced | • The stress block depth "*a*" is more than the flange thickness<br>• 2 layers of tension reinforcement |
| Case Three | • T-Section Behavior<br>• Singly reinforced | • The stress block depth "*a*" is more than the flange thickness<br>• 3 layers of tension reinforcement |
| Case Four | • Rectangular Section Behavior<br>• Doubly reinforced | • The stress block depth "*a*" is less than the flange thickness<br>• 3 layers of tension reinforcement<br>• 1 layer of compression reinforcement |
| Case Five | • T-Section Behavior<br>• Doubly reinforced | • The stress block depth "*a*" is more than the flange thickness<br>• 3 layers of tension reinforcement<br>• 1 layer of compression reinforcement |

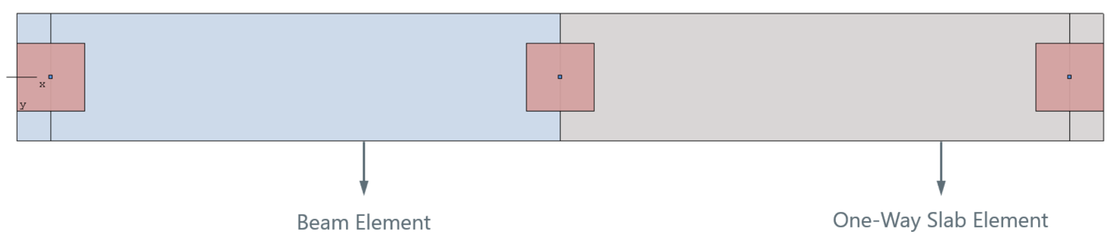
Table 4.1 – StructurePoint T-Beams Case Studies

### 4.1.5.7. One-Way Slab System Considerations

In spSlab/spBeam, users have the option to model span elements as either slabs or beams; however, it is crucial to exercise sound engineering judgment to select the appropriate span element type. While the program permits the use of beam elements to model a one-way slab system, users must understand the implications of this choice, particularly concerning design code requirements.

Design codes, such as ACI 318 and CSA A23.3, differentiate between the minimum reinforcement ratios for slabs and beams. When modeling one-way systems, it is advisable to use slab elements for components behaving as slabs and reserve beam elements for structural members specifically designed as beams. Misusing these span elements may lead to incorrect reinforcement calculations as well as impact shear strength and deflection estimates.

spSlab/spBeam empowers users with the tools to model various structural configurations but relies on the engineer's expertise to ensure the modeling choices align with the intended design purpose and applicable standards.




**Beam Element**

Minimum Area of Flexural Reinforcement

$$A_{s,min} = \begin{cases} \text{Larger of } \begin{Bmatrix} \dfrac{3\sqrt{f'_c}}{f_y} b_w d \\ \dfrac{200}{f_y} b_w d \end{Bmatrix} & \text{Except if } A_{s,prov} > \dfrac{4}{3} A_{s,req} \quad \text{for ACI 318} \\ \dfrac{0.2\sqrt{f'_c}}{f_y} b_t h & \text{Except if } M_r > \dfrac{4}{3} M_f \quad \text{for CSA A23.3} \end{cases}$$

One-Way Shear Calculations

$$V_u \le \phi f_{yt} d \frac{A_v}{s} + \phi 2\lambda \sqrt{f'_c} b_w d \qquad \text{for ACI 318}$$

$$V_f \le \frac{\phi_s A_v f_y d_v \cot\theta}{s} + \phi_c \lambda \beta \sqrt{f'_c} b_w d_v \qquad \text{for CSA A23.3}$$

**One-Way Slab Element**

Minimum Area of Flexural Reinforcement

$$A_{s,min} = \begin{cases} 0.0018 \times A_g & \text{for ACI 318} \\ 0.0020 \times A_g & \text{for CSA A23.3} \end{cases}$$

One-Way Shear Calculations

$$V_u \le \phi 2\lambda \sqrt{f'_c} b_w d \qquad \text{for ACI 318}$$

$$V_f \le \phi_c \lambda \beta \sqrt{f'_c} b_w d_v \qquad \text{for CSA A23.3}$$

Figure 4.6 – Modeling Span Elements as Either Slabs or Beams

# 4.2. Model Editing Concepts

## 4.2.1. Editing Elements

During the course of creating a model, it may be necessary to edit the model. This can be done through the **Select** button in the **Ribbon**. Then, any element that is present on the active **Viewport** can be selected and edited by the tools available within the **Left Panel Toolbar** and **Left Panel**. The editing tools at the **Left Panel Toolbar** can also be invoked by right-clicking the mouse button in the active **Viewport**. The editing tools that are available at the **Left Panel Toolbar** per element are:

- **Span Element:** Span elements can be duplicated or advanced copied.
- **Support Element:** Support elements can be deleted, moved, duplicated, or advanced copied.

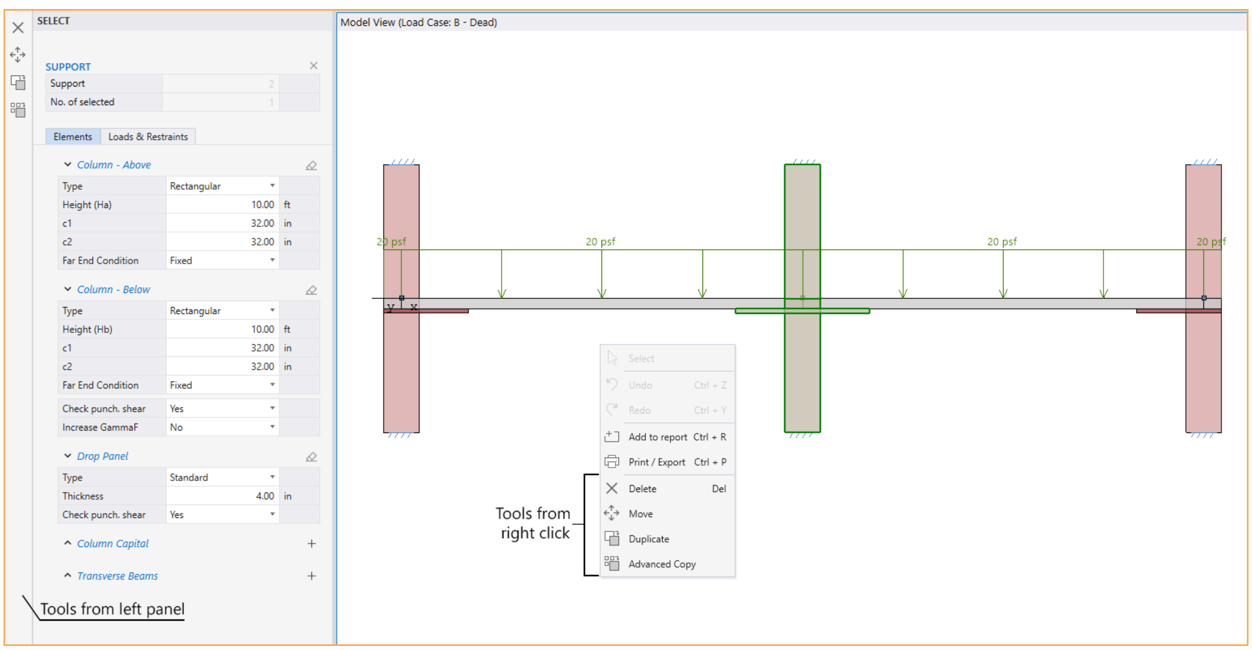



Figure 4.7 – Editing Tools

The **Duplicate** tool provides a straightforward way to copy all assigned elements and loads directly from the original to the destination span or support. In contrast, the **Advanced Copy** tool offers a more flexible approach by displaying a dialog box with selectable options.

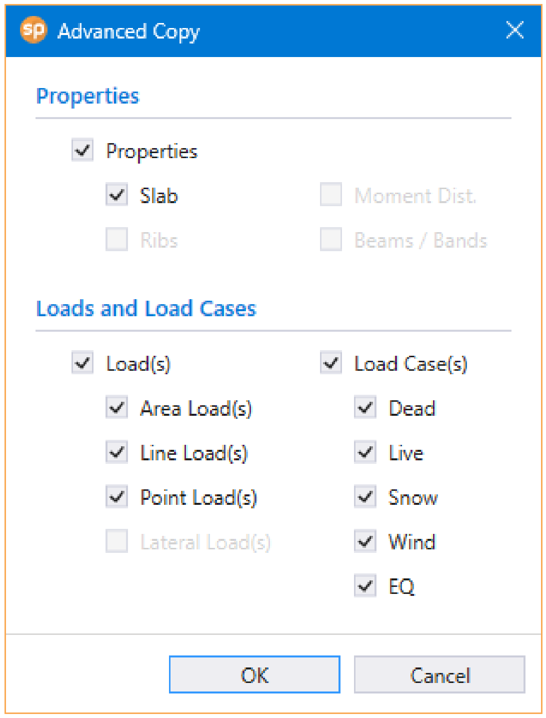



Figure 4.8 – Advance Copy Dialog Box

The **Left Panel** can also be utilized to edit an Element further:

- **Span Elements:** In addition to the editing tools available in the **Left Panel Toolbar**, users can edit slab or flange dimensions (including thickness and width), longitudinal beam dimensions (including width, depth, and offset), rib dimensions (including bottom width, depth, and clear spacing at the bottom), as well as area loads, line loads, point loads, and lateral load effects.
- **Support Elements:** In addition to the editing tools available in the **Left Panel Toolbar**, users can edit columns (including type, height, cross-sectional dimensions, far end condition, punching shear check and $\gamma_f$ adjustment), drop panels (including type, thickness, and punching shear check), column capitals (including depth and side slope), transverse beams (including width, depth, and offset), as well as support restraints, support springs, support loads, supports displacements, and redistribution limits.

### 4.2.2. Span Length and Grid Spacing

In spSlab/spBeam, the grid spacing defined by the user determines the span lengths of the model. Any modifications to the grid spacing directly translate into changes in span lengths, which can significantly impact the placement and application of loads. For instance, if a point load is initially applied at 15ft relative to a specific span and the grid spacing is later modified (e.g., reducing the span from 30ft to 10ft), the load retains its global position within the model. This may result in the load appearing in a different span or outside its intended span entirely.

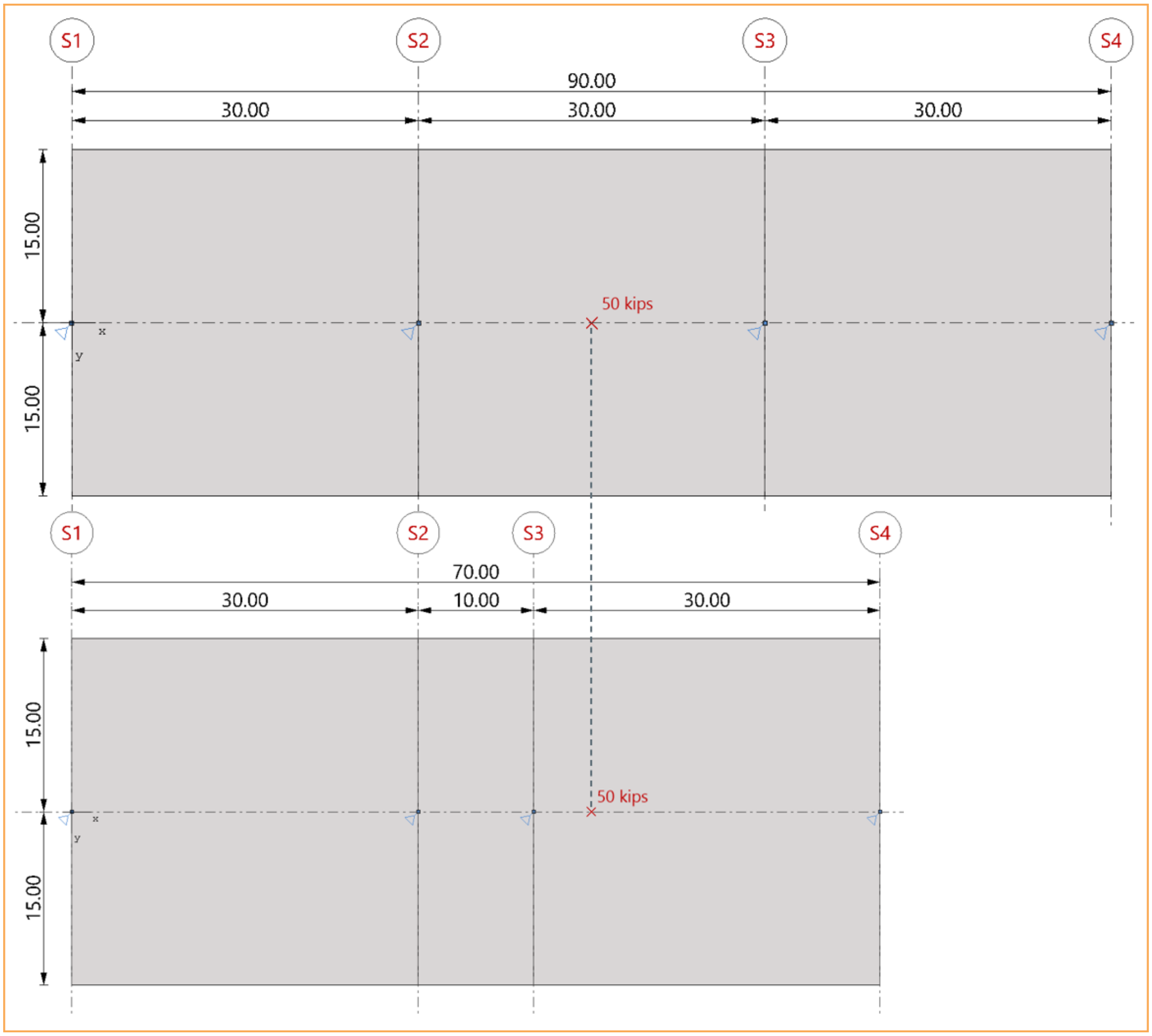



Figure 4.9 – Effect of Grid Spacing on Span Length and Load Location

When such discrepancies occur and the model is executed, the program issues an error, such as "Span 2, case: Dead, load falls outside the span", to alert the user of invalid load placement.

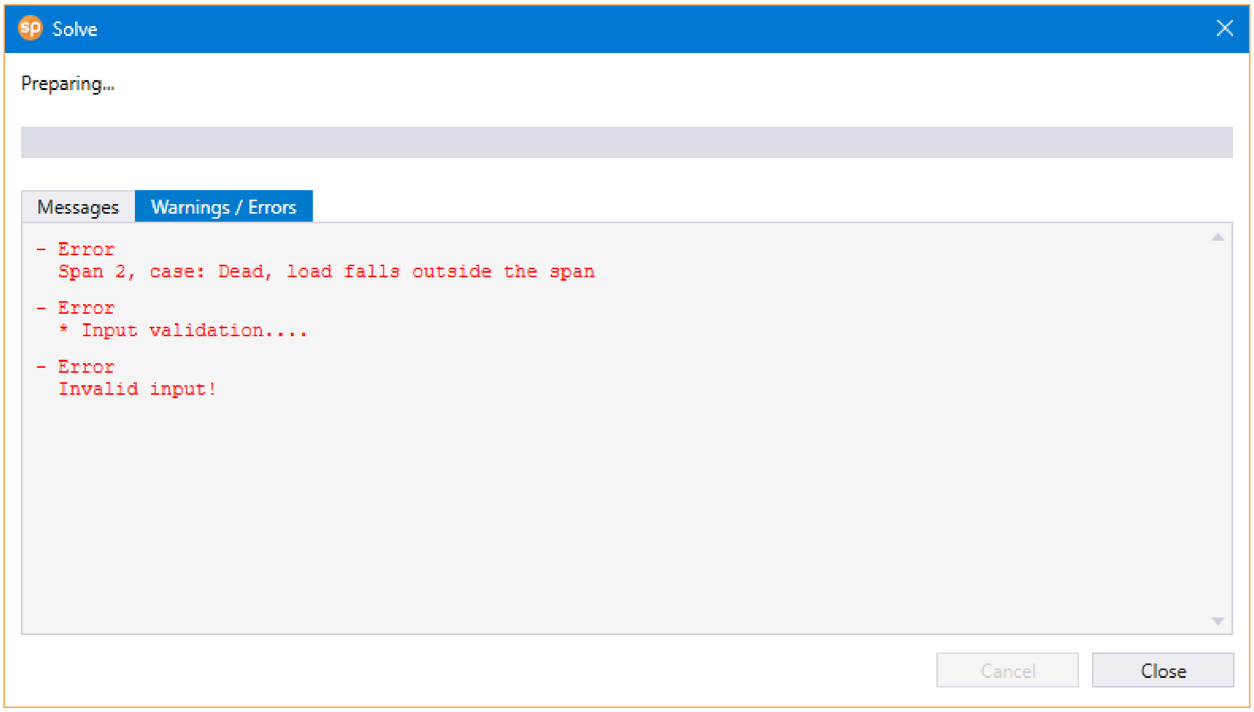



Figure 4.10 – Warnings / Errors Tab in Solver Dialog

To avoid such issues, it is strongly recommended to finalize the grid spacing - and therefore the span lengths - before assigning supports and loads. Any subsequent adjustments to grid spacing will require careful review and reassignment of loads to ensure accurate structural analysis and design.

### 4.2.3. Changing Floor System Location

In spSlab/spBeam, the **Templates** module allows users to define the floor level of the modeled system, providing flexibility to represent various configurations such as first floors, intermediate floors, or roofs. The selected floor level determines the presence and arrangement of supports, such as columns, above and below the slab.

For first and intermediate floors, setting the floor level to STORY enables the program to include columns both above and below the slab, accurately reflecting the structural conditions. When the floor level is changed to ROOF, the program automatically removes columns above the slab, as roofs typically do not have supporting elements above them.

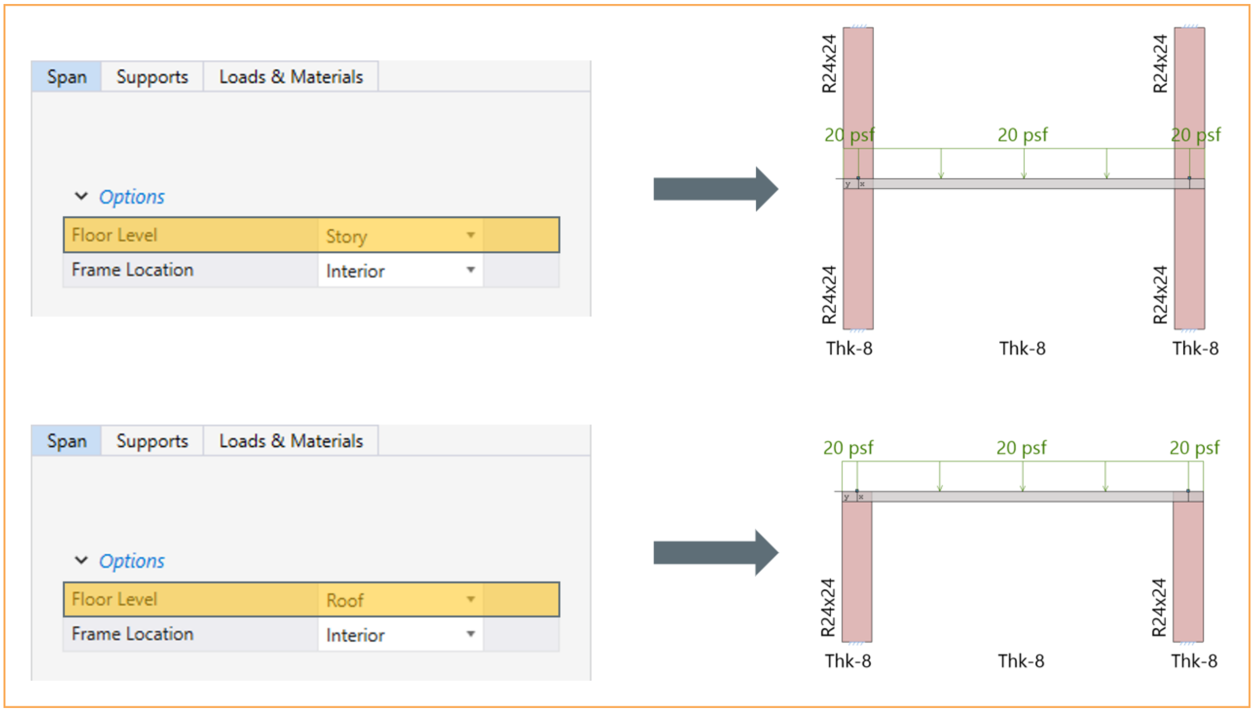



Figure 4.11 – Floor Level Location

While users can manually create similar scenarios by modifying supports, the templates module provides a faster and more efficient way to set up these common layouts. By automating much of the setup, templates save time and simplify the modeling process, making it easier to ensure consistency and accuracy in model generation.

## 4.2.4. Editing Loads

In spSlab/spBeam, editing applied loads can be accomplished using two options: REPLACE EXISTING LOAD or ADD TO EXISTING LOAD. These options provide users with the flexibility to update load conditions without needing to reset or delete previously applied loads.

The REPLACE EXISTING LOAD option allows users to completely overwrite the current load on the element or span with a new value. This is particularly useful when the load conditions have changed entirely, and the previous load no longer applies to the design scenario.

The ADD TO EXISTING LOAD option enables users to incrementally add new loads to the currently applied load. This approach is especially valuable for modeling additional load components, such as live loads or lateral load effects, while preserving the baseline loads already assigned.

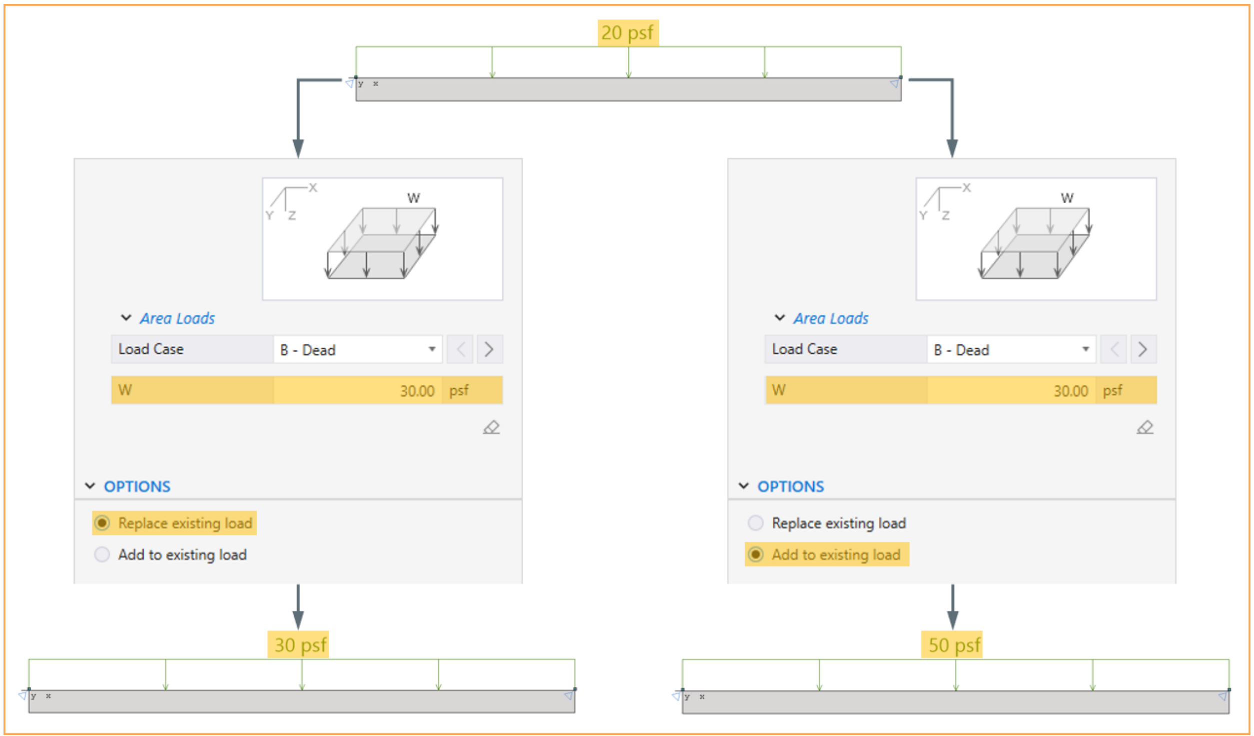



Figure 4.12 – Adding / Editing Loads

These features apply to all load types supported by the program, including area loads, line loads, point loads, support loads, and lateral load effects. By providing these options, spSlab/spBeam streamlines the process of refining and updating load conditions to accommodate a wide range of design requirements efficiently.

## 4.2.5. Managing Load Locations

In spSlab/spBeam, the location of line loads and point loads can be specified using two methods: **absolute distance** or **distance as a ratio of span**. These options provide users with flexibility in controlling how loads are positioned on spans, particularly when span lengths are subject to modification during the modeling process.

Using the **absolute distance** method, the load location is defined as a fixed value measured from the start of the span. This method is active when the user unchecks the DISTANCE LOCATION AS RATIO OF SPAN option. While this approach provides precise control in static models, any changes to the span length will leave the load at its original fixed position, which may result in the load being misplaced relative to the updated span geometry as shown in the previous section.

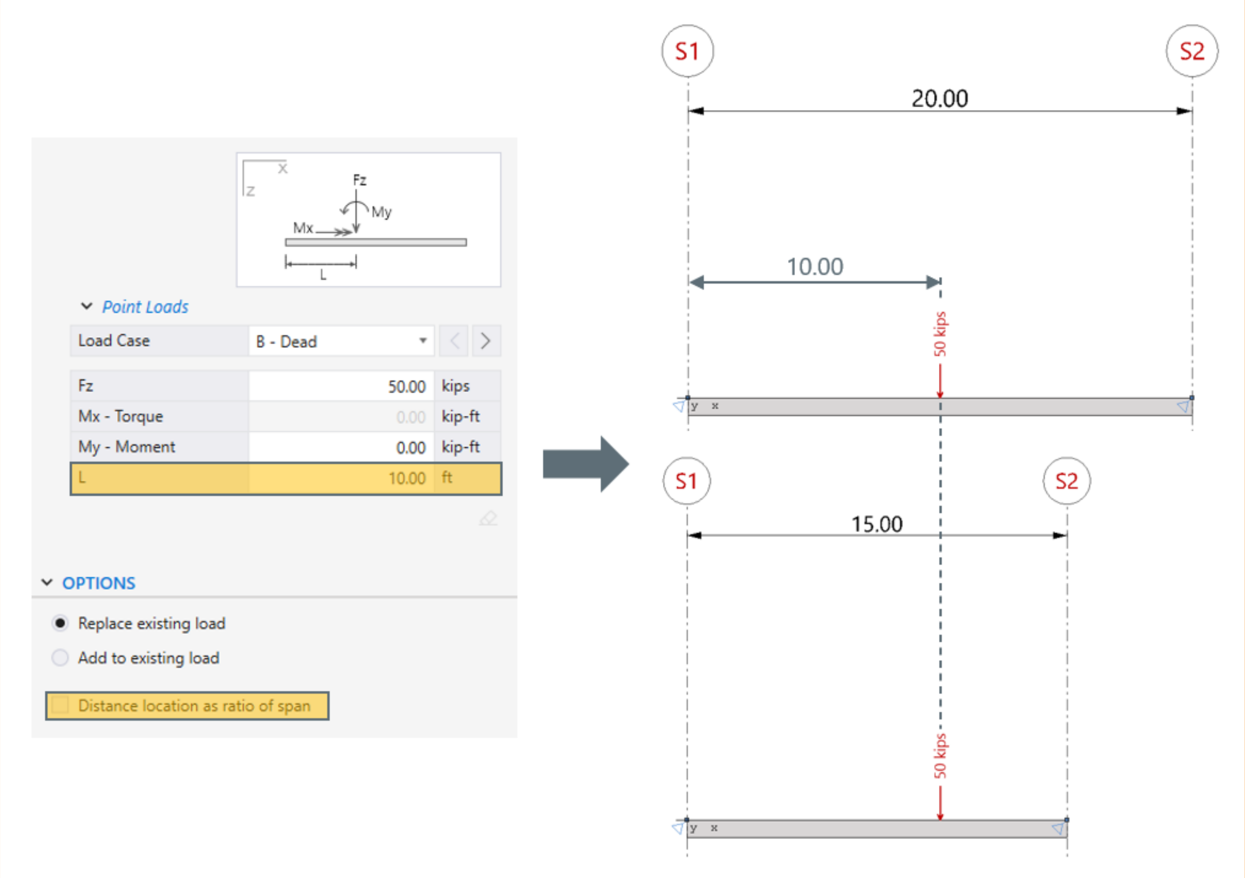



Figure 4.13 – Managing Load Locations – Absolute Distance

To assist users in such cases, the program issues a warning: "Span length(s) has changed. Check the validity of span load locations". This notification reminds users to reevaluate and adjust load positions after modifying span lengths.

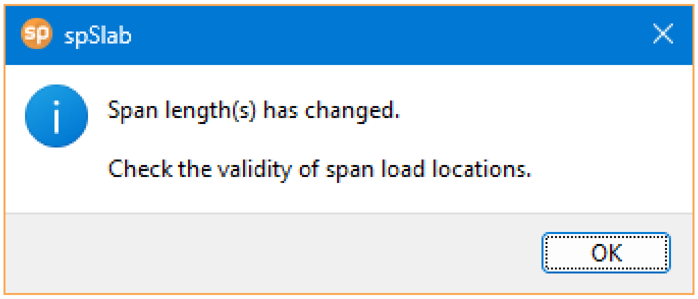



Figure 4.14 – Span Length Warning Dialog Box

Alternatively, the **distance as a ratio of span** method allows the load location to be defined as a percentage of the span length. This method is enabled when the user checks the DISTANCE LOCATION AS RATIO OF SPAN option. It ensures that the load location adjusts proportionally when the span length changes, maintaining its relative position within the span. This approach is particularly advantageous for projects where span lengths may be updated, as it eliminates the need for manual load adjustments following changes to the span configuration.

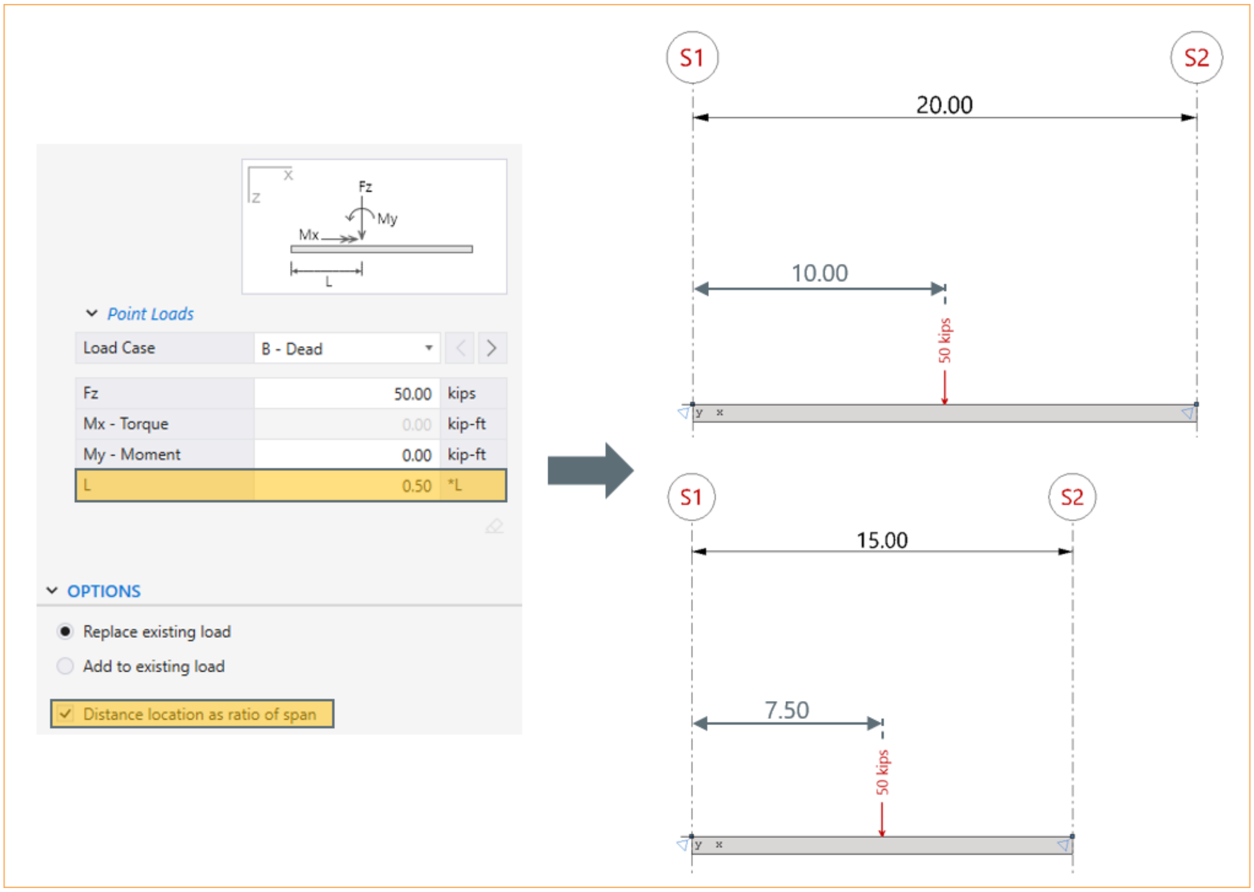


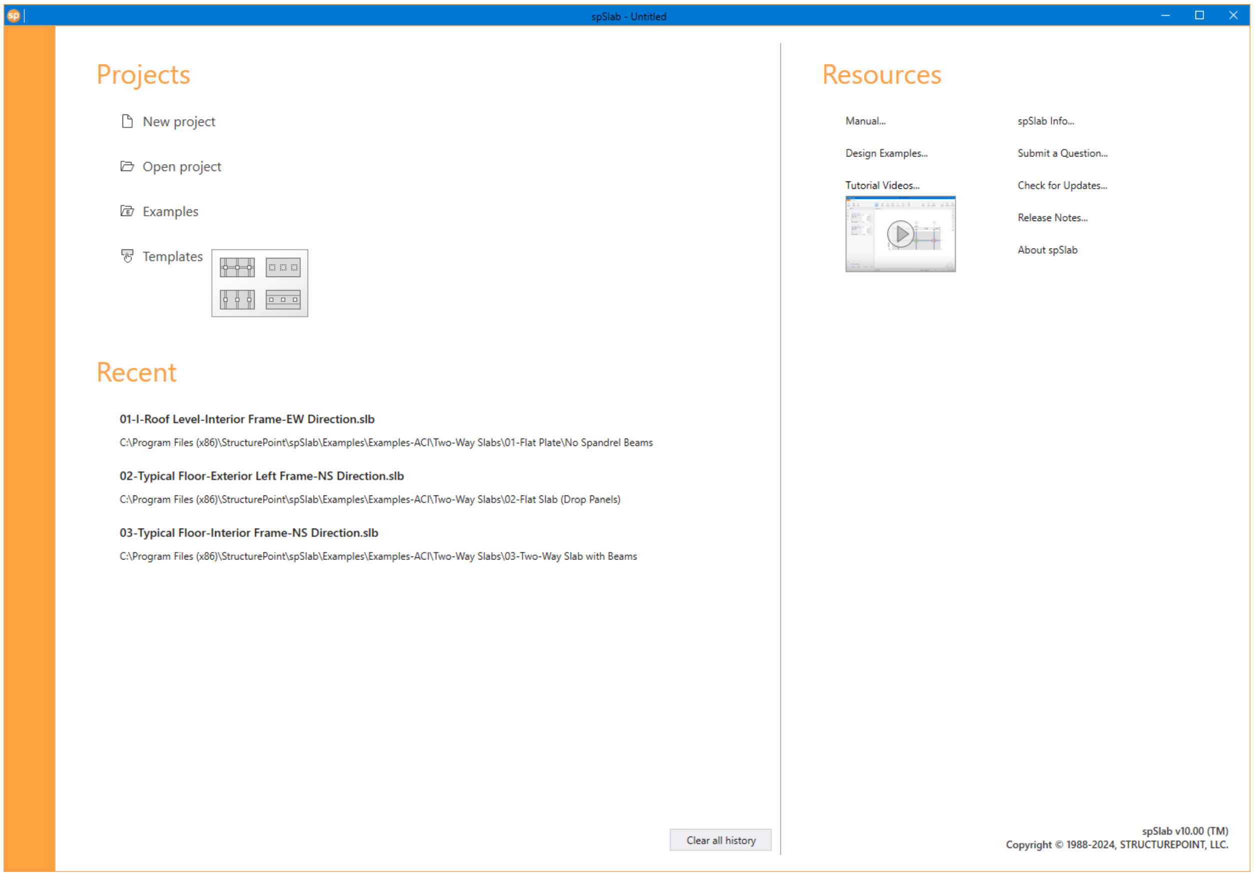

Figure 4.15 – Managing Load Locations – Distance as a Ratio of Span

CHAPTER

5

# MODEL DEVELOPMENT

In spSlab/spBeam, models can be started by utilizing one of the four methods under **Projects** within **Start Screen**. These are namely; **Open Project**, **New Project**, **Templates**, and **Examples**. Each of these methods can be used to create a new model from scratch, edit a model developed previously for an earlier project, start with pre-defined template, or use an existing example file from the provided library. Each of the methods are described in detail in this chapter.

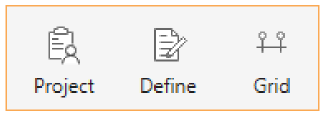

spSlab - Untitled
Projects
New project
Open project
Examples
Templates
Recent
01-I-Roof Level-Interior Frame-EW Direction.slb
C:\Program Files (x86)\StructurePoint\spSlab\Examples\Examples-ACI\Two-Way Slabs\01-Flat Plate\No Spandrel Beams
02-Typical Floor-Exterior Left Frame-NS Direction.slb
C:\Program Files (x86)\StructurePoint\spSlab\Examples\Examples-ACI\Two-Way Slabs\02-Flat Slab (Drop Panels)
03-Typical Floor-Interior Frame-NS Direction.slb
C:\Program Files (x86)\StructurePoint\spSlab\Examples\Examples-ACI\Two-Way Slabs\03-Two-Way Slab with Beams
Clear all history
Resources
Manual...
Design Examples...
Tutorial Videos...
spSlab Info...
Submit a Question...
Check for Updates...
Release Notes...
About spSlab
spSlab v10.00 (TM)
Copyright © 1988-2024, STRUCTUREPOINT, LLC.

## 5.1. Opening Existing Models

In the **Start Screen** under **Projects** select the **Open Project** option and browse to the folder that contains an existing spSlab/spBeam input file. The input files created in spSlab/spBeam v5.50 (.slb) and in spSlab/spBeam v10 (.slbx) can be opened. The input files for the prior versions of the Program require to be saved in consecutively newer version until .slb file is obtained. Then, that file can be opened in v10. Input file created in the newer version of the spSlab/spBeam program cannot be opened by a previous version.

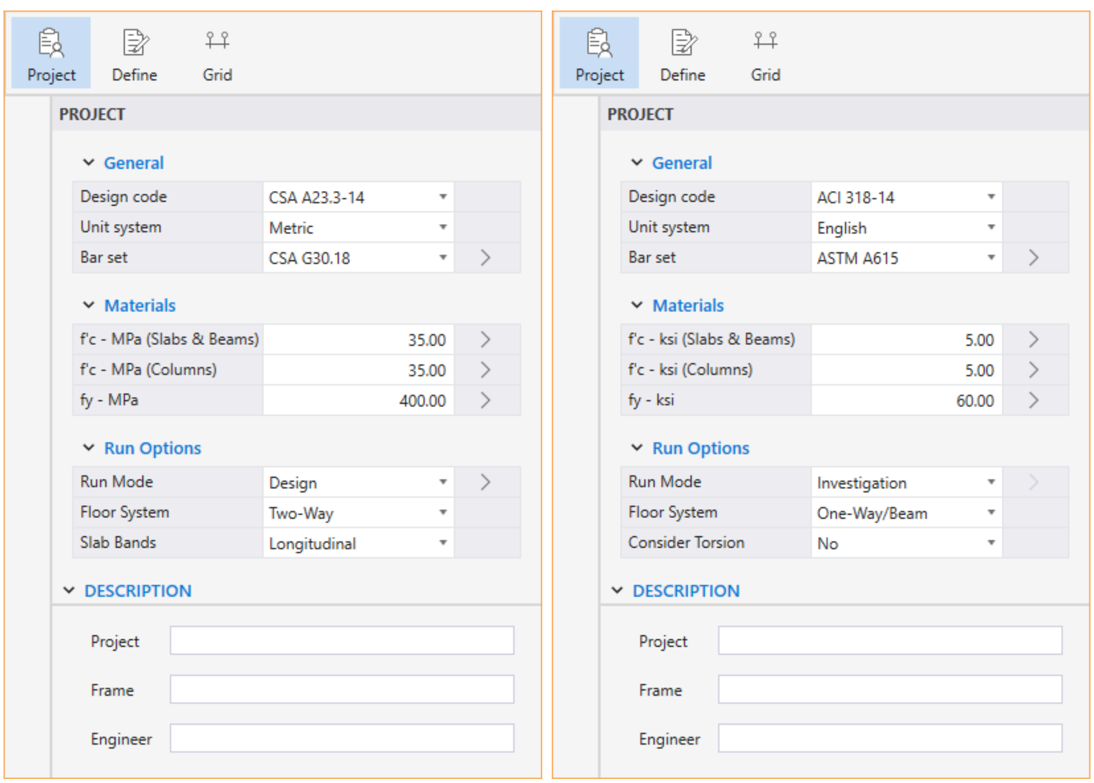
## 5.2. Creating New Models

In the **Start Screen** under **Projects**, select the **New Project** option, then select **Empty Project** option from the **New Project** dialog box. The model development process may require general input regarding a specific project. Project Information is entered through the **Project** command button, and Structural Grids are entered through the **Grid** command button.




### 5.2.1. Project Information

The project information regarding to DESIGN CODE, UNIT SYSTEM, BAR SET, CONCRETE STRENGTH, REINFORCING STEEL STRENGTH, RUN MODE, FLOOR SYSTEM, PROJECT, FRAME, and ENGINEER can be entered into the model through the **Project Left Panel**. The Program supports American (ACI 318) and Canadian (CSA A23.3) Design Codes, and English and Metric unit systems.

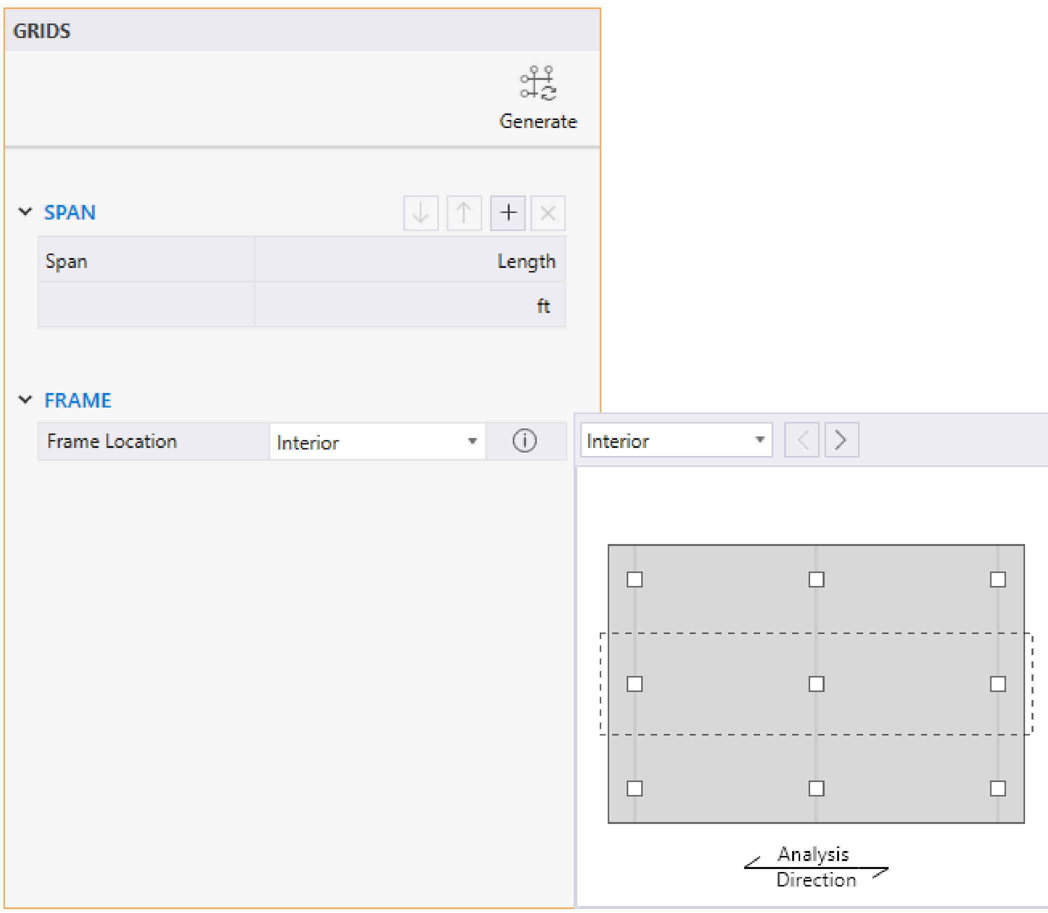


## 5.2.2. Structural Grids

Structural grids must be defined to create a model in spSlab/spBeam. These grids establish the spans and support locations. The spans and supports created by grids then act as placeholders for model elements. Once the spans and supports are set, the user can populate the model with various span elements (slabs, ribs and longitudinal beams/bands) and support elements (columns, capitals, drop panels and transverse beams/bands)  to complete the model.

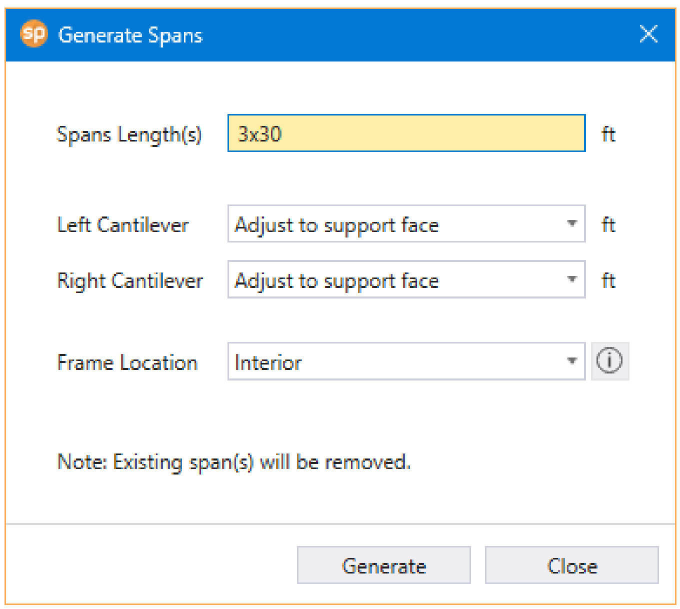
### 5.2.2.1. Working with Grids

You can select the **Grid** command button from the **Ribbon**. The corresponding **Grids Left Panel** provides various tools and options for effectively working with grids.



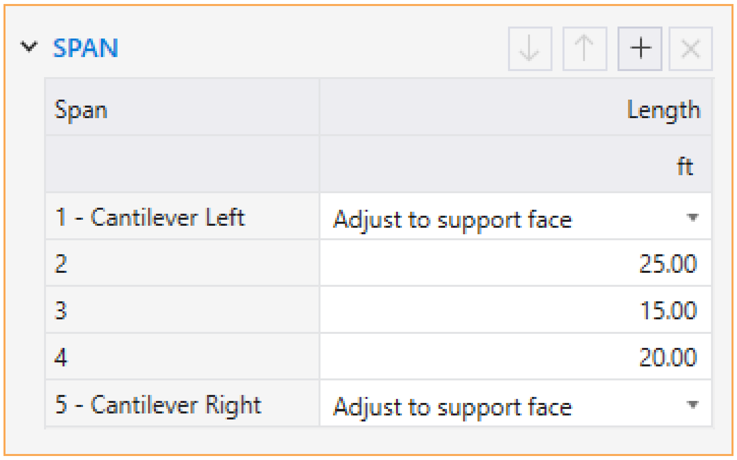
### 5.2.2.2. Generating Spans

- Click the **Generate** icon to display the GENERATE SPANS dialog box
- To create multiple spans at once enter:
  `number of spans x span length` in the SPANS LENGTH(S) input box
- You can create spans at different lengths by separating the span lengths by space
- To add cantilevers, select either USER-DEFINED or ADJUST TO SUPPORT FACE in the LEFT CANTILEVER and RIGHT CANTILEVER input boxes
- You can select the frame location from the FRAME LOCATION drop-down list



### 5.2.2.3. Using the Span Table

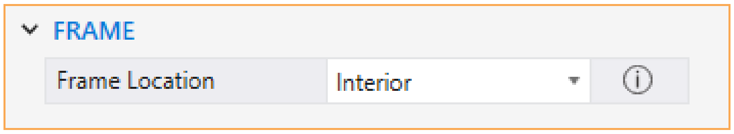
You can use the Span table to change the cantilever options and the LENGTH of the spans. The table can also be used to add or delete specific spans.



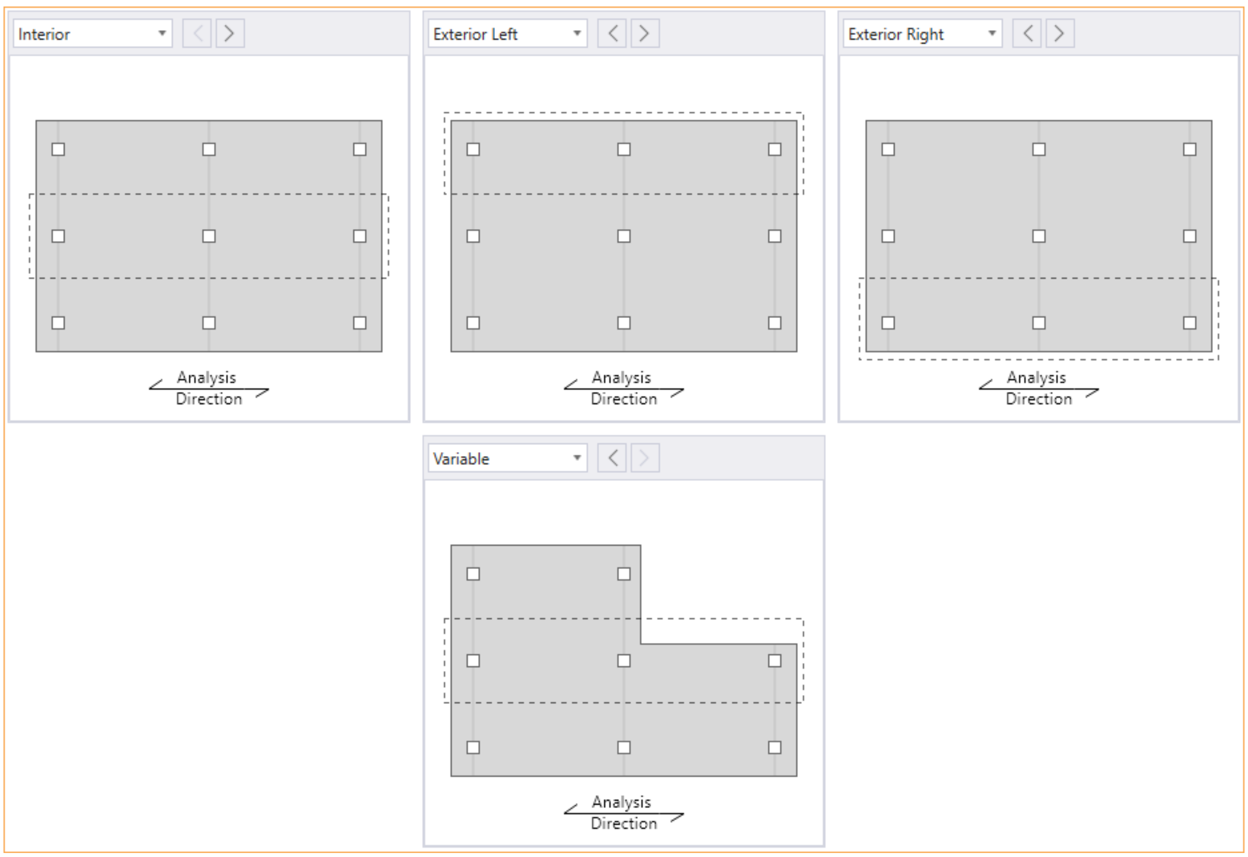

- Click on the button to add a span.
- Click on the button to delete the selected span in the table.
- Click on the button to move up the selected span in the table.
- Click on the button to move down the selected span in the table.
- LENGTH of the span can also be changed by clicking on the respective field and typing in the desired value.
- For cantilevers:
  - Select NONE if no cantilever is required.
  - Select ADJUST TO SUPPORT FACE to extend the span to the support face.
  - Select USER-DEFINED to manually specify the cantilever length.

### 5.2.2.4. Working with Frame Location

You can select the span location from the FRAME LOCATION drop-down list.

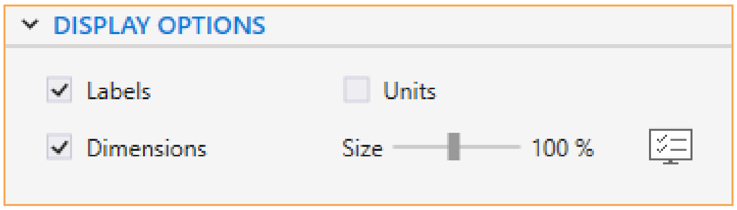



Three types of locations are available: INTERIOR, EXTERIOR LEFT and EXTERIOR RIGHT. If the frame being analyzed has more than one of the above-mentioned locations, then VARIABLE can be selected and the individual span locations provided accordingly. The "left" and "right" are defined as you look along the direction of analysis. If a span has design strips on both sides, it should be an "INTERIOR" span. If a span has only a left design strip, it should be an "EXTERIOR RIGHT" span. If a span has only a right design strip, it should be an "EXTERIOR LEFT" span.



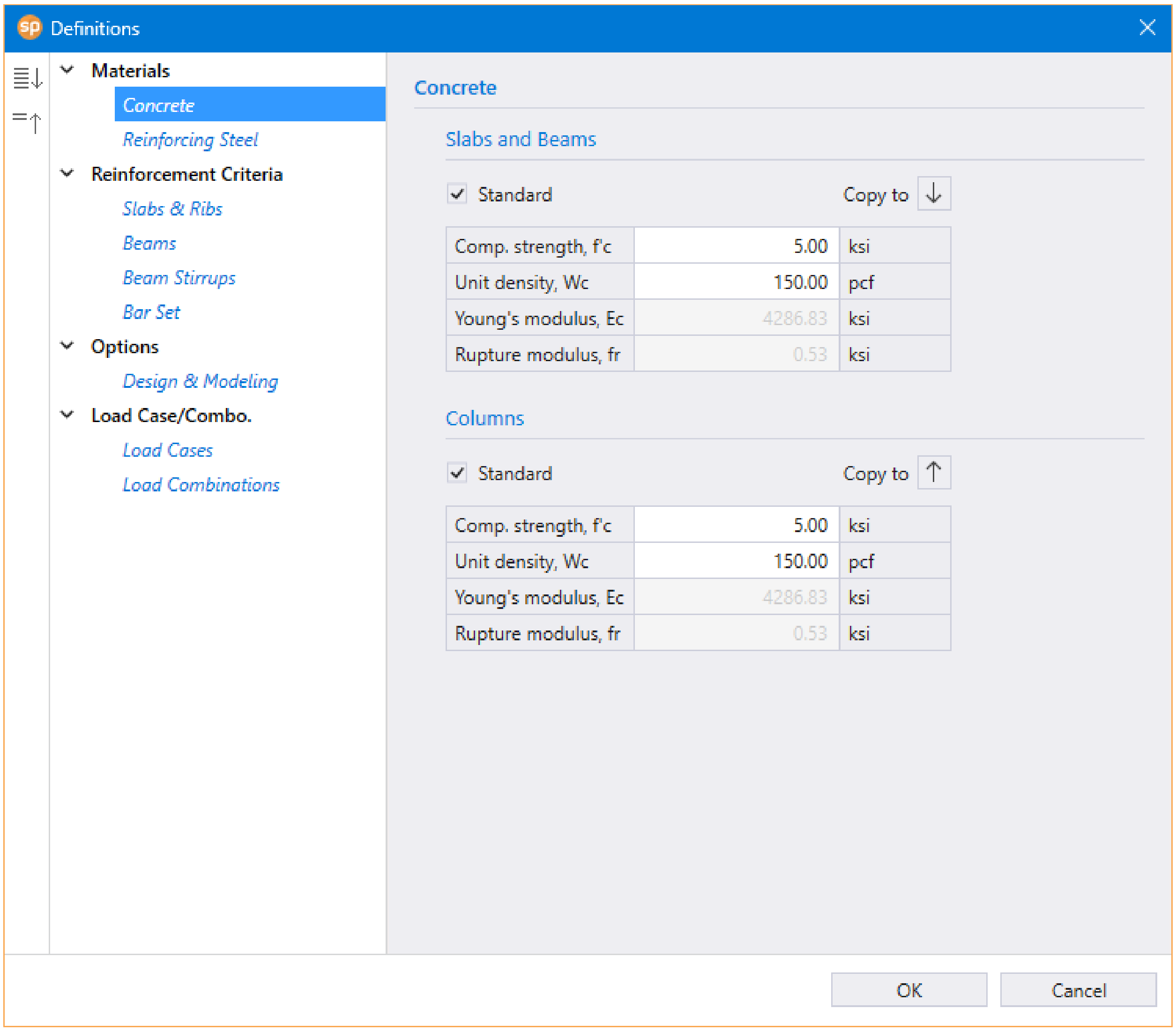
### 5.2.2.5. Grids Display Options

- Use the checkboxes to toggle the display of various grid items in the model.
- You can use the slider to adjust the SIZE of the grid LABELS, UNITS and DIMENSIONS displayed.



### 5.2.3. Generating Definitions

The DEFINITIONS dialog box contains four categories: **Materials**, **Reinforcement Criteria**, **Design and Modeling Option**s, and **Load Case/Combo**. You can access this dialog box by selecting the **Define** command from the **Ribbon**.



### 5.2.3.1. Materials

The **Materials** that can be defined are: **Concrete** and **Reinforcing Steel**.

#### Concrete

The following properties for slab, beam, and column concrete, are entered by the user:

- COMPRESSIVE STRENGTH, $f'_c$, and
- UNIT DENSITY, $W_c$

Other concrete properties:

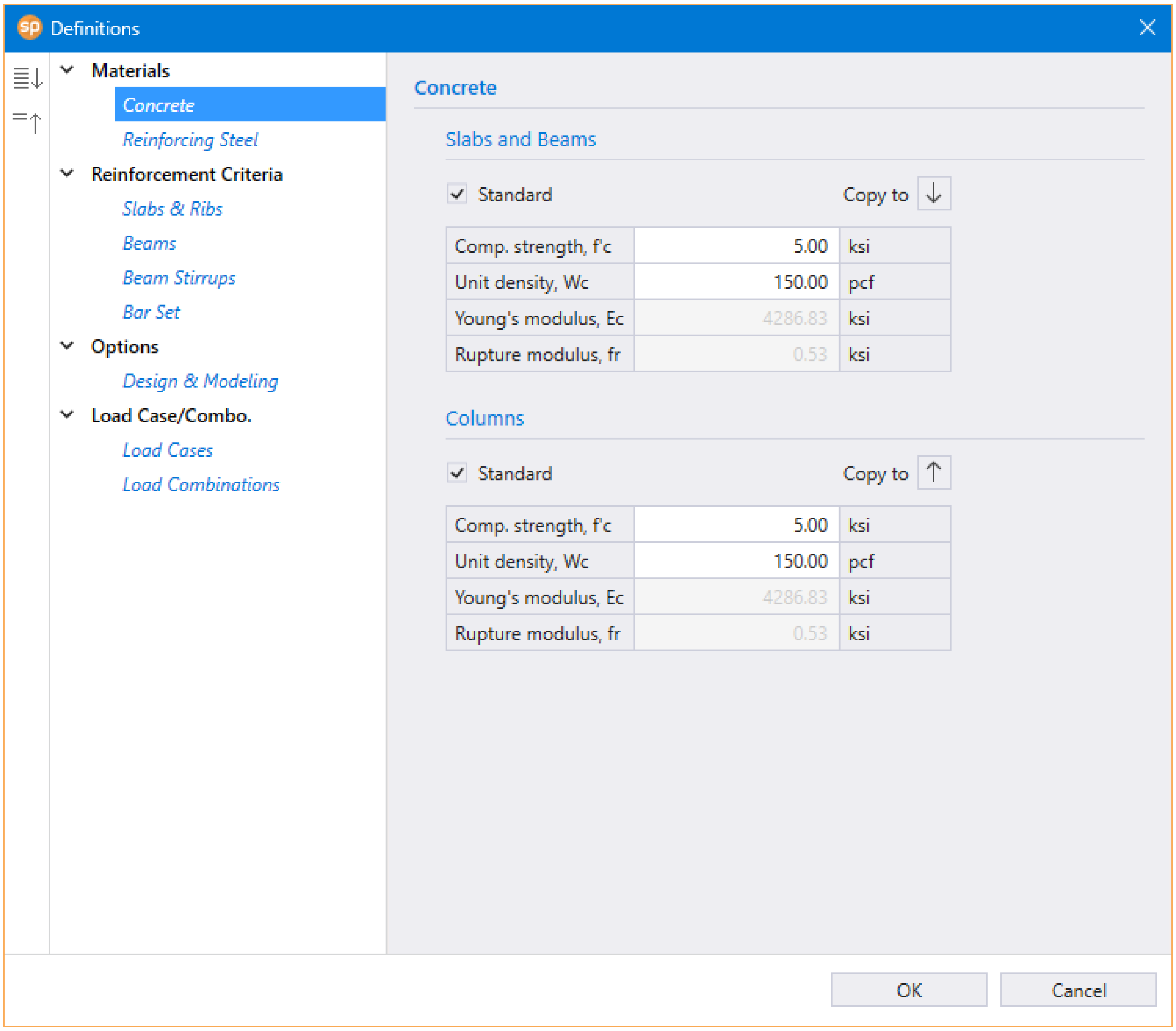
- YOUNG'S MODULUS, $E_c$, and
- RUPTURE MODULUS, $f_r$

are automatically computed and displayed when STANDARD option is selected. The user can manually modify any of the values by deselecting the option.

When STANDARD option is selected, Design Code mandated default values for the young's modulus, $E_c$ , and the rupture modulus, $f_r$ , for the slabs, beams, and columns are computed automatically and are based on $f'_c$ and $\lambda$ where $\lambda$ is function of $W_c$ . The modulus of rupture is used to determine the cracking moment when computing the effective moment of inertia in deflection calculations. Refer to Section 2.2.1.2 for default $E_c$ , and $f_r$ equations per ACI 318 and CSA A23.3 Design Codes. Unchecking the STANDARD option shall enable the User to input $E_c$ and $f_r$ manually that deviates from Equations in Section 2.2.1.2. Therefore, it may lead to an output not in compliance with ACI 318 and CSA A23.3 if used without sound Engineering Judgment.

If precast concrete is used, check PRECAST CONCRETE checkbox [1].

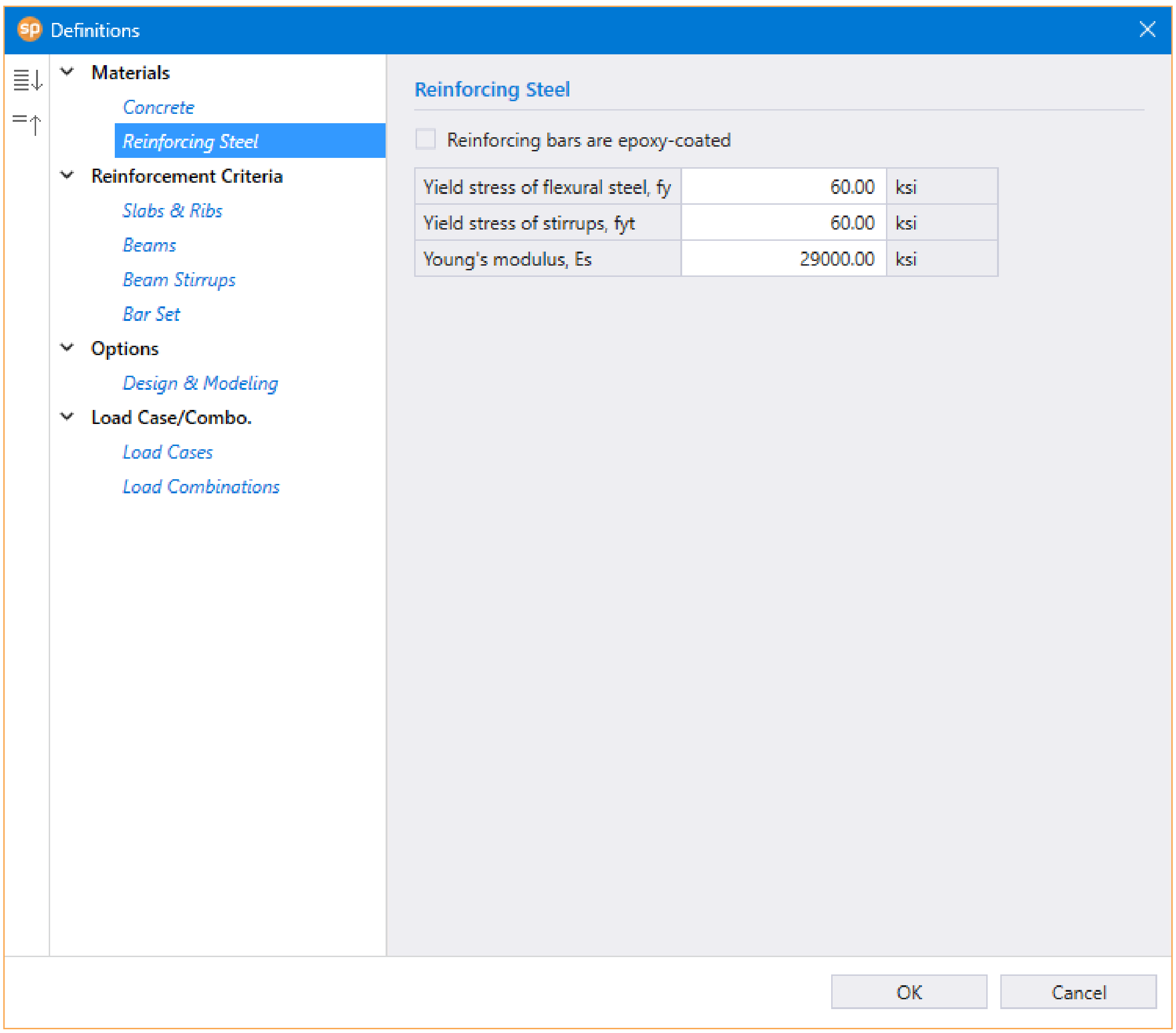
[1] CSA A23.3-14, 8.4.2, 16.1.3; CSA A23.3-04, 8.4.2, 16.1.3


Definitions
Materials
Concrete
Reinforcing Steel
Reinforcement Criteria
Slabs & Ribs
Beams
Beam Stirrups
Bar Set
Options
Design & Modeling
Load Case/Combo.
Load Cases
Load Combinations
Concrete
Slabs and Beams
Standard
Copy to
Comp. strength, f'c 5.00 ksi
Unit density, Wc 150.00 pcf
Young's modulus, Ec 4286.83 ksi
Rupture modulus, fr 0.53 ksi
Columns
Standard
Copy to
Comp. strength, f'c 5.00 ksi
Unit density, Wc 150.00 pcf
Young's modulus, Ec 4286.83 ksi
Rupture modulus, fr 0.53 ksi
OK
Cancel

## Reinforcing Steel

The following properties are entered by the user.

- YIELD STRESS OF FLEXURAL STEEL, $f_y$
- YIELD STRESS OF STIRRUPS, $f_{yt}$
- YOUNG'S MODULUS, $E_s$
- If reinforcement is epoxy-coated, check REINFORCING BARS ARE EPOXY-COATED checkbox. This selection affects development lengths.



#### 5.2.3.2. Reinforcement Criteria

The **Reinforcement Criteria** that can be defined are for: **Slabs & Ribs**, **Beams**, **Beam Stirrups**, and **Bar Set**.

##### Slabs & Ribs

To define **Reinforcement Criteria** for **Slab and Ribs**:

- Enter the minimum bar size to start the iteration for determining flexural reinforcement.
- Enter the maximum bar size. This number will be used as a stop in the iteration for determining flexural bars in beams.
- Enter minimum bar spacing for slab and rib flexural reinforcement. This number should be based on aggregate size or detailing considerations. Default spacing is 1 in. [30 mm] for slabs and ribs.
- Enter maximum bar spacing for slab and rib flexural reinforcement. Default spacing is 18 in. [450 mm] for slabs and ribs.
- Enter minimum Reinforcement Ratio for slab and rib flexural reinforcement. Default ratio is 0.14% [0.14%] for slabs and ribs. If the user specified value is smaller than 0.14%, 0.14% is used by spSlab. If the user specified value is greater than 0.14%, the specified value is used by spSlab.
- Enter maximum Reinforcement Ratio for slab and rib flexural reinforcement. Default ratio is 5% for slabs and ribs.
- Enter the clear covers for top and bottom reinforcing bars. For the top reinforcement, this distance is from the top of the slab to the top of the top bars. For the bottom reinforcement, this distance is from the bottom of the slab to the bottom of the bottom bars (see Figure 5.1). The default value is 0.75 in. [20 mm] for both input items.
- If the top bars have more than 12 in. [300 mm] of concrete below them, check the corresponding check box.

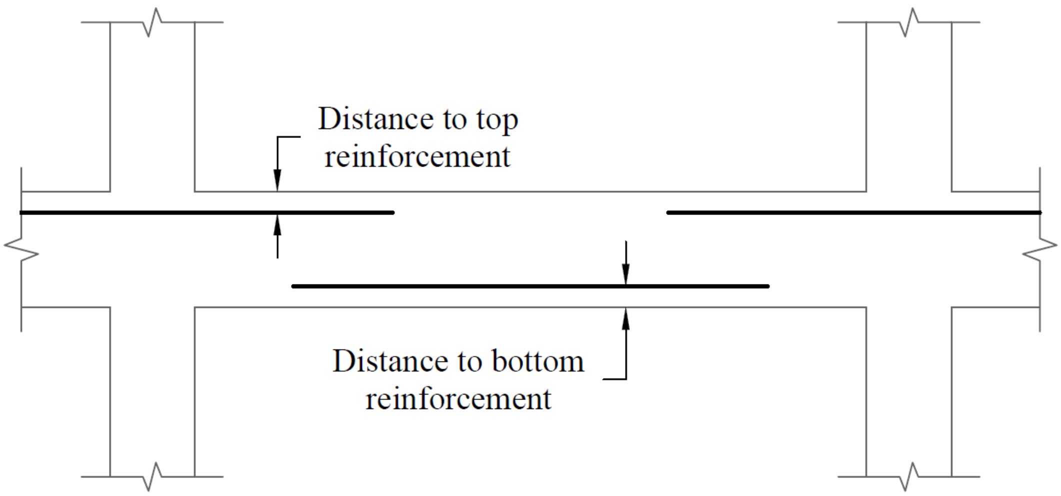
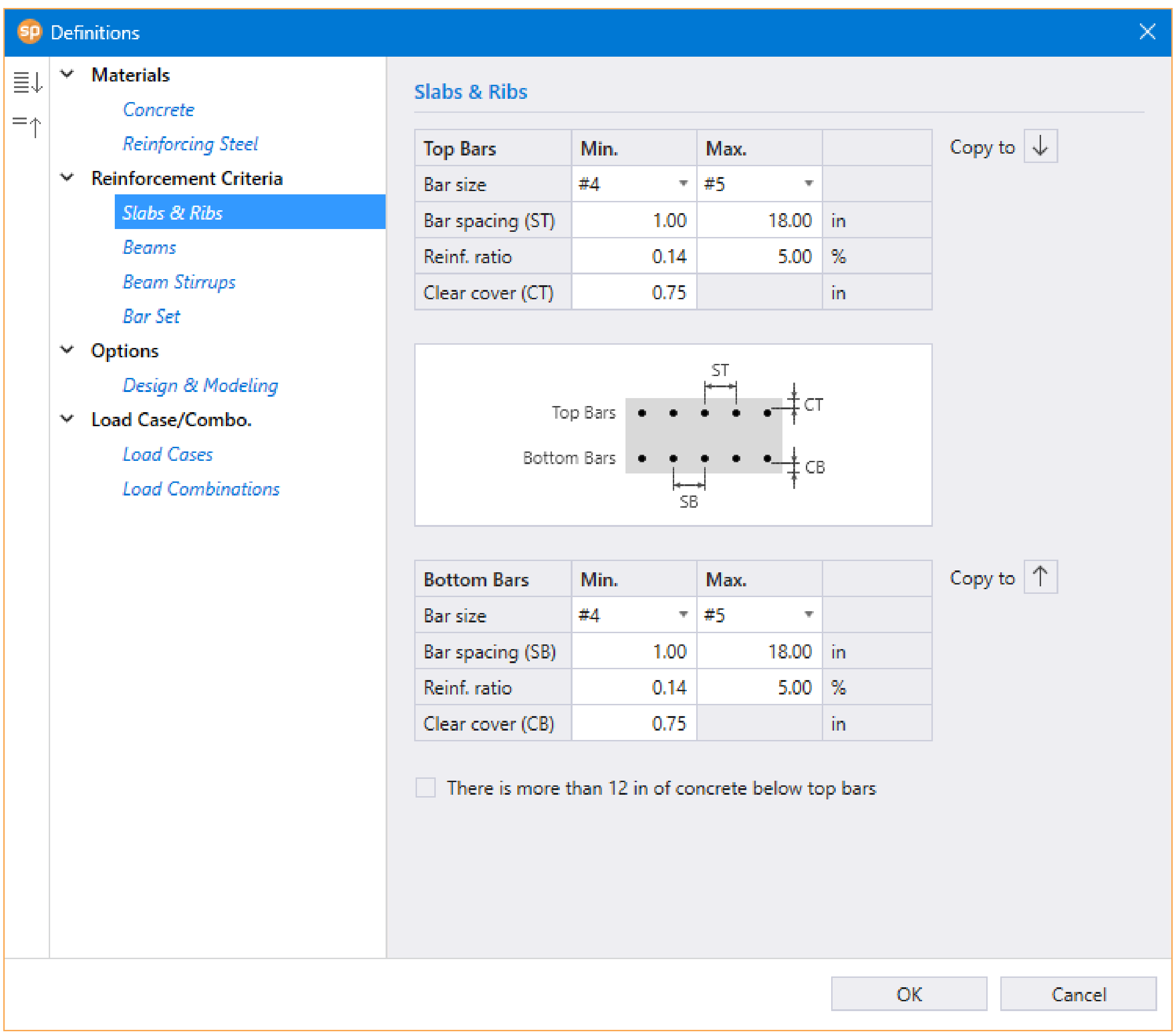


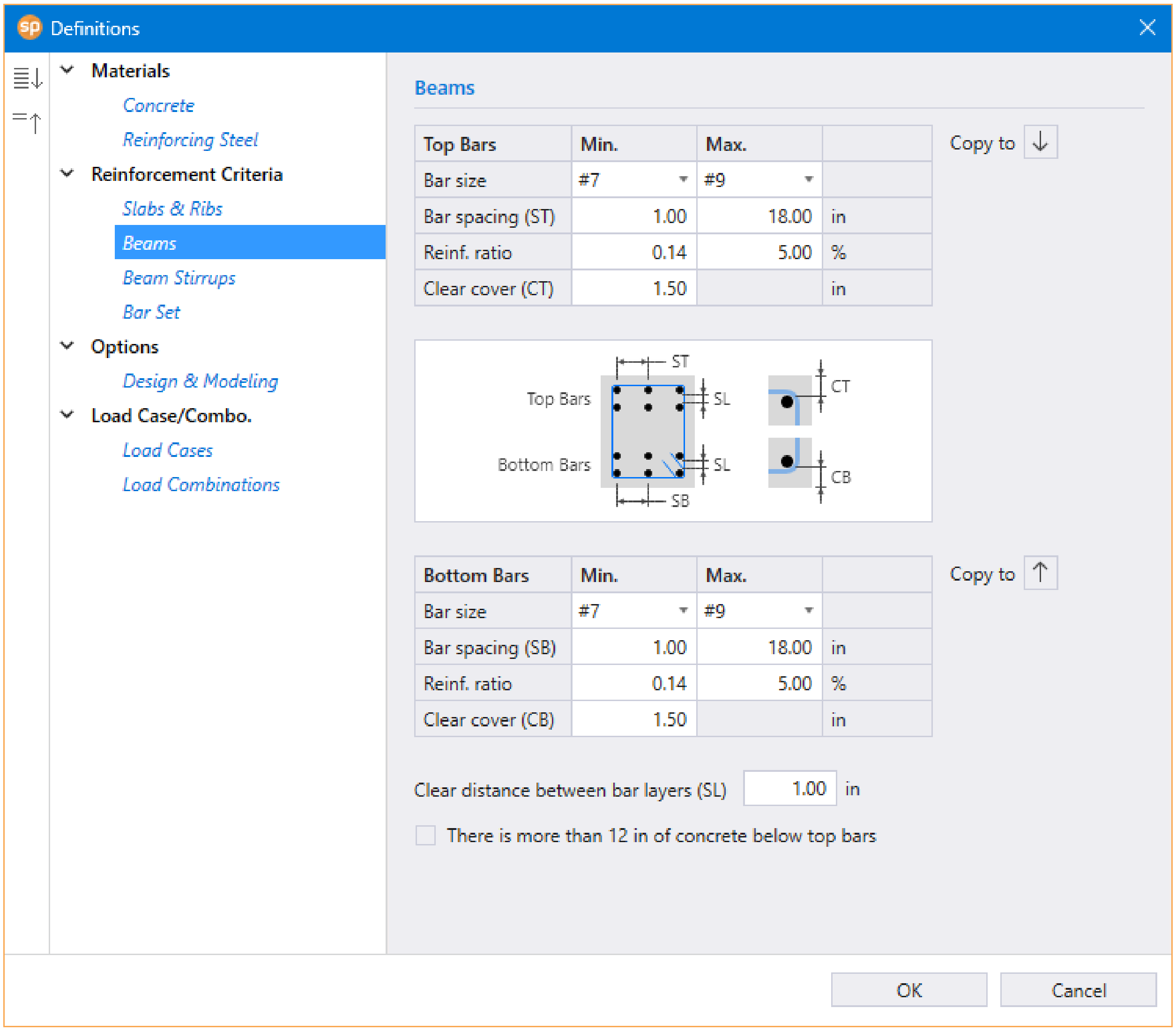

Figure 5.1 – Clear Cover to Reinforcement



## Beams

To define **Reinforcement Criteria** for **Beams**:

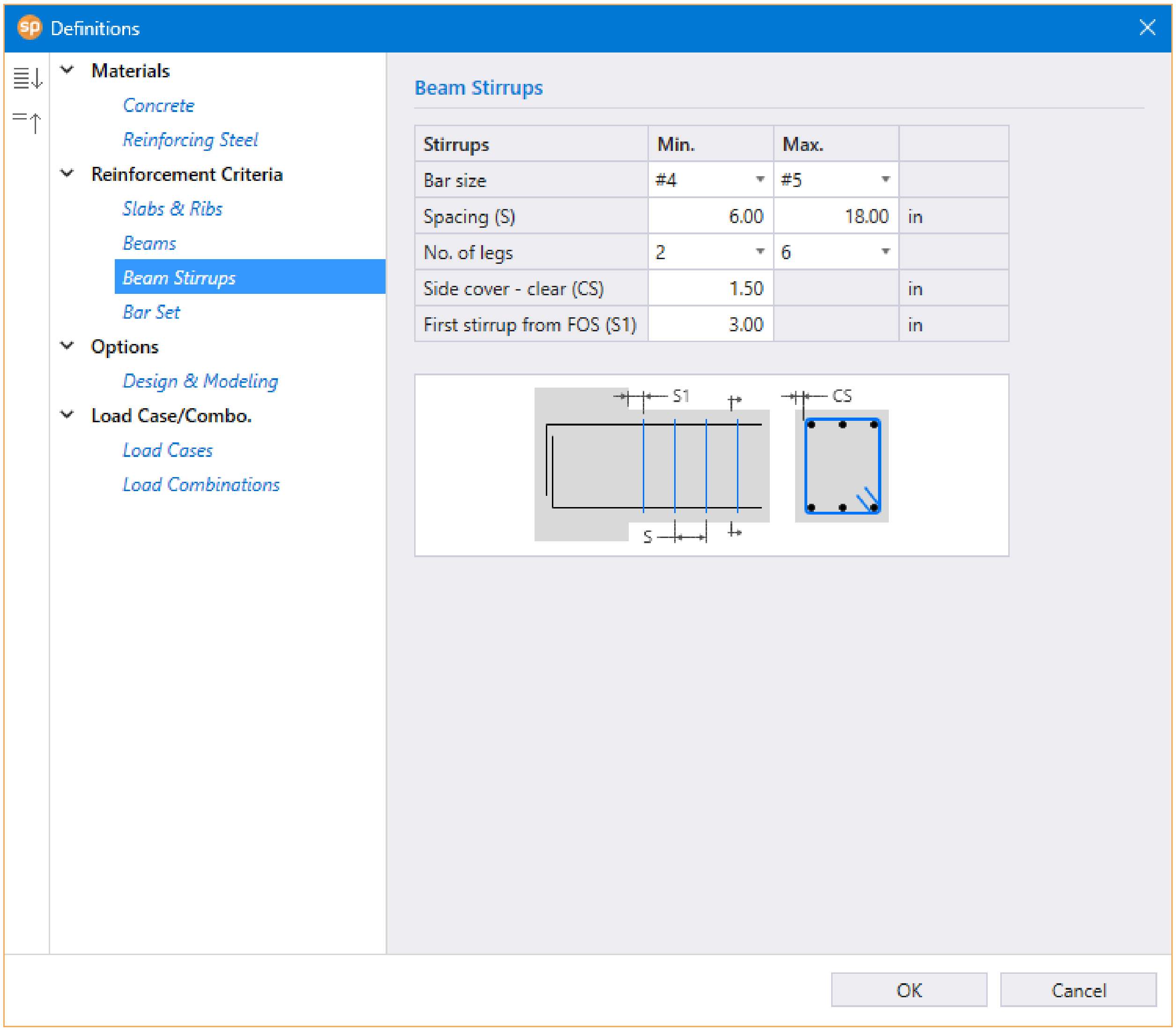
- Enter the minimum bar size for top and bottom bars to start the iteration for determining flexural reinforcement.
- Enter the maximum bar size for top and bottom bars. This number will be used as a stop in the iteration for determining flexural bars in beams.
- Enter the minimum bar spacing for beam flexural reinforcement. This number should be based on aggregate size or detailing considerations. The default minimum reinforcement bar spacing is 1 in. [30 mm].
- Enter the maximum bar spacing for beam flexural reinforcement. The default maximum reinforcement spacing is 18 in. [450 mm].
- Enter the minimum Reinforcement Ratio for beam flexural reinforcement. Default ratio is 0.14% [0.14%] for beams. If the user specified value is smaller than 0.14%, 0.14% is used by spSlab. If the user specified value is greater than 0.14%, the specified value is used by spSlab.
- Enter the maximum Reinforcement Ratio for beam flexural reinforcement. Default ratio is 5% for beams.
- Enter the covers for top and bottom reinforcing bars for beams. For the top reinforcement, this distance is from the top of the beam to the top of the top bars; and for the bottom reinforcement, this distance is from the bottom of the beam to the bottom of the bottom bars (see Figure 5.1). The default value is 1.5 in. [30mm] for both input items.
- Enter the clear distance between bar layers to use if the program needs to distribute flexural bars in multiple layers. Default distance is 1 in. [30 mm] for beams.
- If the top bars have more than 12 in. [300 mm] of concrete below them, check the corresponding check box.


Definitions
Materials
Concrete
Reinforcing Steel
Reinforcement Criteria
Slabs & Ribs
Beams
Beam Stirrups
Bar Set
Options
Design & Modeling
Load Case/Combo.
Load Cases
Load Combinations
Beams
Top Bars | Min. | Max.
Bar size | #7 | #9
Bar spacing (ST) | 1.00 | 18.00 | in
Reinf. ratio | 0.14 | 5.00 | %
Clear cover (CT) | 1.50 | | in
Copy to
ST
Top Bars
SL
CT
Bottom Bars
SL
CB
SB
Bottom Bars | Min. | Max.
Bar size | #7 | #9
Bar spacing (SB) | 1.00 | 18.00 | in
Reinf. ratio | 0.14 | 5.00 | %
Clear cover (CB) | 1.50 | | in
Copy to
Clear distance between bar layers (SL) 1.00 in
There is more than 12 in of concrete below top bars
OK
Cancel

## Beam Stirrups

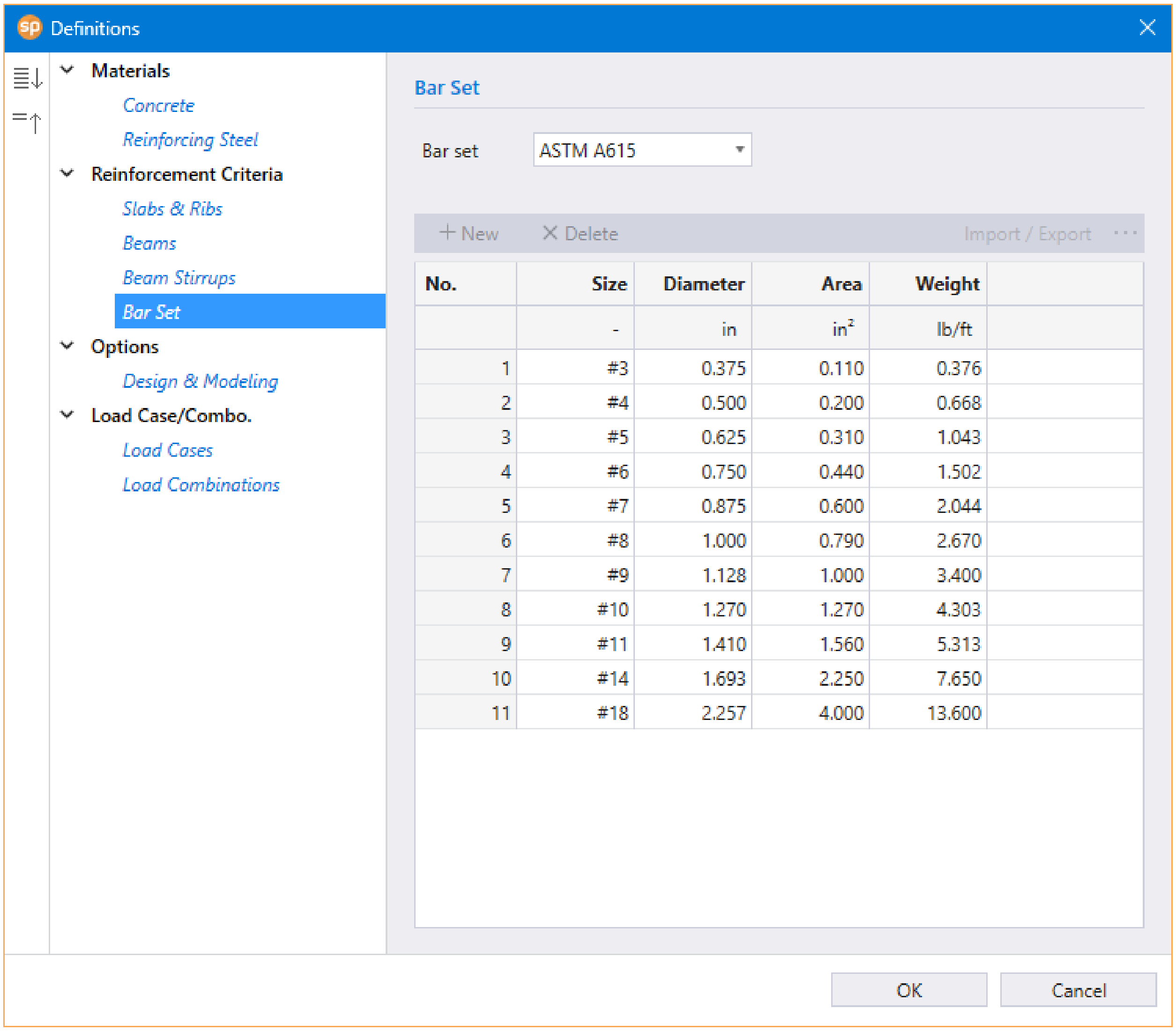
To define **Reinforcement Criteria** for **Beam Stirrups**:

- Enter the minimum bar size for stirrups to start the iteration for determining shear reinforcement.
- Enter the maximum bar size for stirrups. This number will be used as a stop in the iteration for determining shear reinforcement in beams.
- Enter the minimum spacing for stirrups. This number should be based on aggregate size or detailing considerations. The default stirrup spacing is 6 in. [150 mm].
- Enter the maximum spacing for stirrups. The default maximum stirrup spacing is 18 in. [450 mm].
- Enter the side cover which is measured from the side face of a beam to the face of the stirrup (see Figure 2.28). The default value is 1.5 in [30 mm].
- Enter the distance from face of support (FOS) to first stirrup. The default value is 3.0 in [75 mm].


Definitions
Materials
Concrete
Reinforcing Steel
Reinforcement Criteria
Slabs & Ribs
Beams
Beam Stirrups
Bar Set
Options
Design & Modeling
Load Case/Combo.
Load Cases
Load Combinations
Beam Stirrups
Stirrups
Min.
Max.
Bar size
#4
#5
Spacing (S)
6.00
18.00
in
No. of legs
2
6
Side cover - clear (CS)
1.50
in
First stirrup from FOS (S1)
3.00
in
S1
CS
S
OK
Cancel

## Bar Set

The **Bar Set** can be selected from pre-defined standard sets or can be USER-DEFINED. For a new USER-DEFINED set entry, the SIZE, DIAMETER, AREA and WEIGHT of the bar are required. USER-DEFINED set can also be imported or exported.




| No. | Size | Diameter | Area | Weight |
|---|---|---|---|---|
| | - | in | in² | lb/ft |
| 1 | #3 | 0.375 | 0.110 | 0.376 |
| 2 | #4 | 0.500 | 0.200 | 0.668 |
| 3 | #5 | 0.625 | 0.310 | 1.043 |
| 4 | #6 | 0.750 | 0.440 | 1.502 |
| 5 | #7 | 0.875 | 0.600 | 2.044 |
| 6 | #8 | 1.000 | 0.790 | 2.670 |
| 7 | #9 | 1.128 | 1.000 | 3.400 |
| 8 | #10 | 1.270 | 1.270 | 4.303 |
| 9 | #11 | 1.410 | 1.560 | 5.313 |
| 10 | #14 | 1.693 | 2.250 | 7.650 |
| 11 | #18 | 2.257 | 4.000 | 13.600 |

### 5.2.3.3. Options

#### Design & Modeling

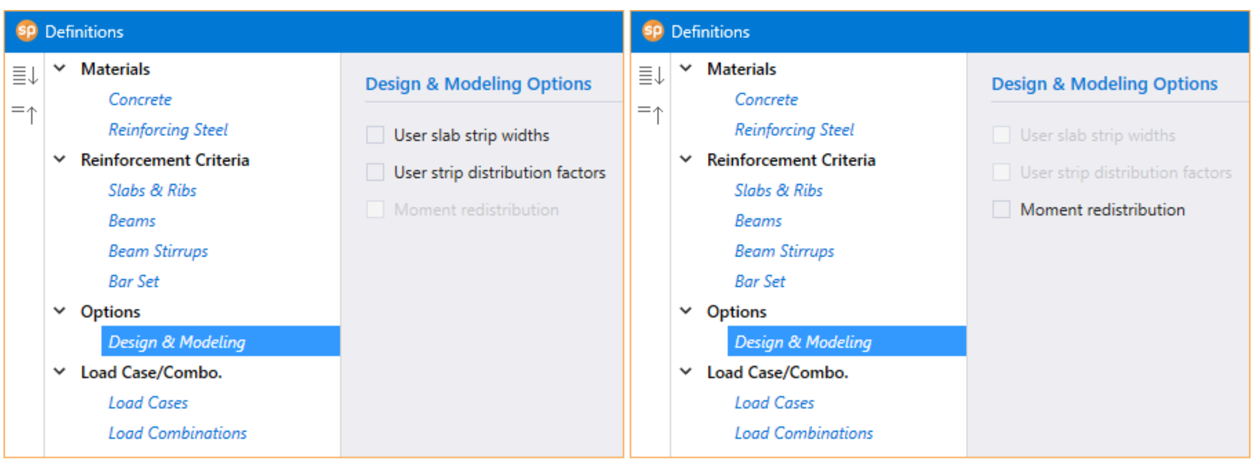
To specify **Design & Modeling Options** for two-way systems:

- Check USER SLAB STRIP WIDTHS to enable manual input of column strip width. The default values are calculated according to design code selected. The validity of the assumptions when entering user defined values are to be decided by the Designer.

- Check USER STRIP DISTRIBUTION FACTORS to enable manual input of moment distribution factors. The default values are calculated according to design code selected. The validity of the assumptions when entering user defined values are to be decided by the Designer.

To specify **Design & Modeling Options** for beams/one-way slab systems:

- Check MOMENT REDISTRIBUTION checkbox if it is to be considered in the analysis. This option has to be checked for the **Moment Redistribution** tab to be available in the **Supports** command.




Two-Way Slab Systems Beams/One-Way Slab Systems

### 5.2.3.4. Load Case / Combo.

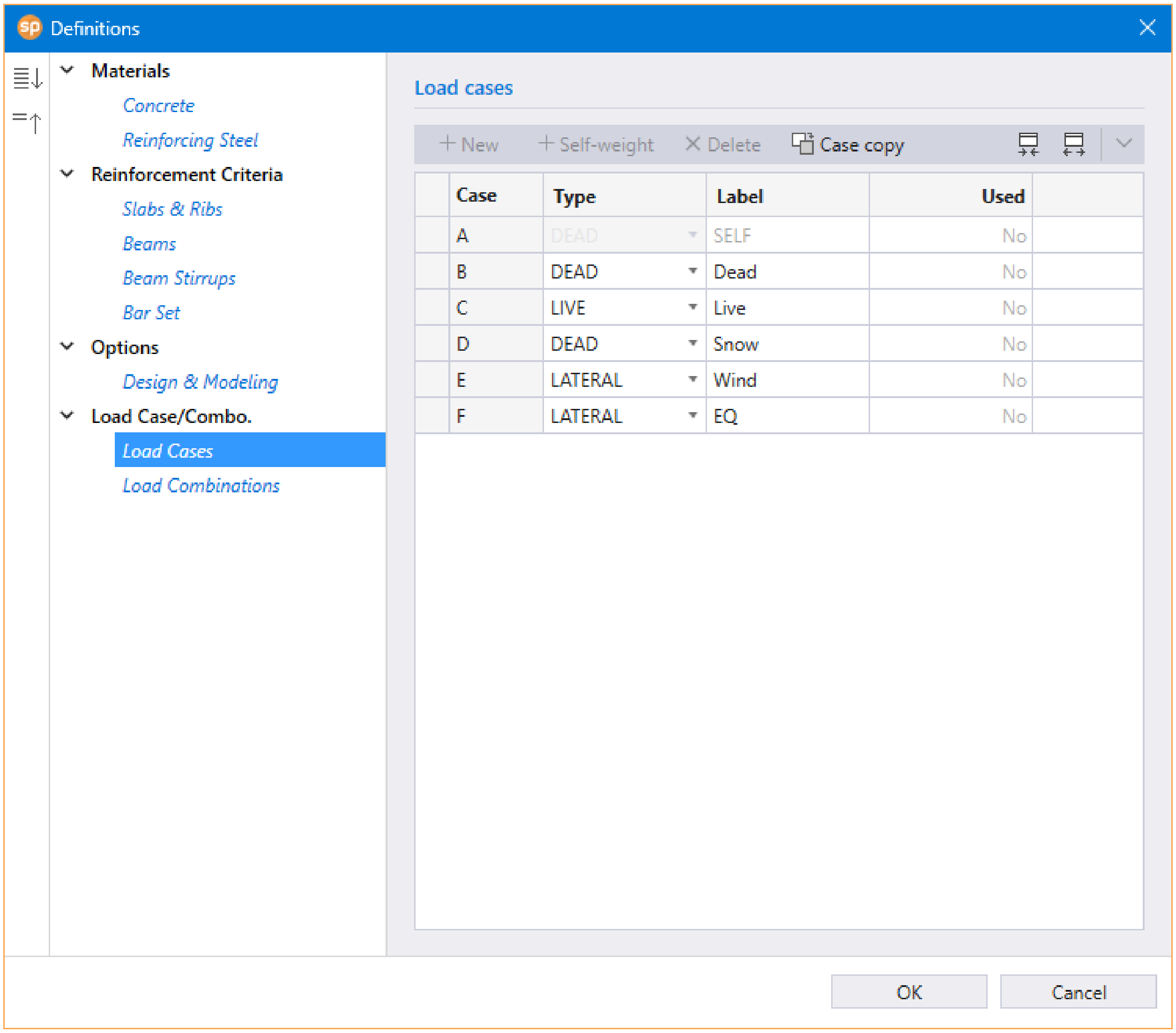
The **Load Case / Combo.** that can be defined are: **Load Cases** and **Load Combinations**.

#### Load Cases

The **Load Cases** definition consists of the CASE, TYPE, LABEL, and whether the **Load Cases** is USED in the model or not.

Up to 6 load cases of dead load, live load or lateral load can be defined in the **Load Cases** dialog box. The default five load case labels (types) are SELF (dead load), Dead (dead load), Live (live load), Wind (wind load), and EQ (seismic load). Once the maximum number is reached, the NEW button will be disabled.

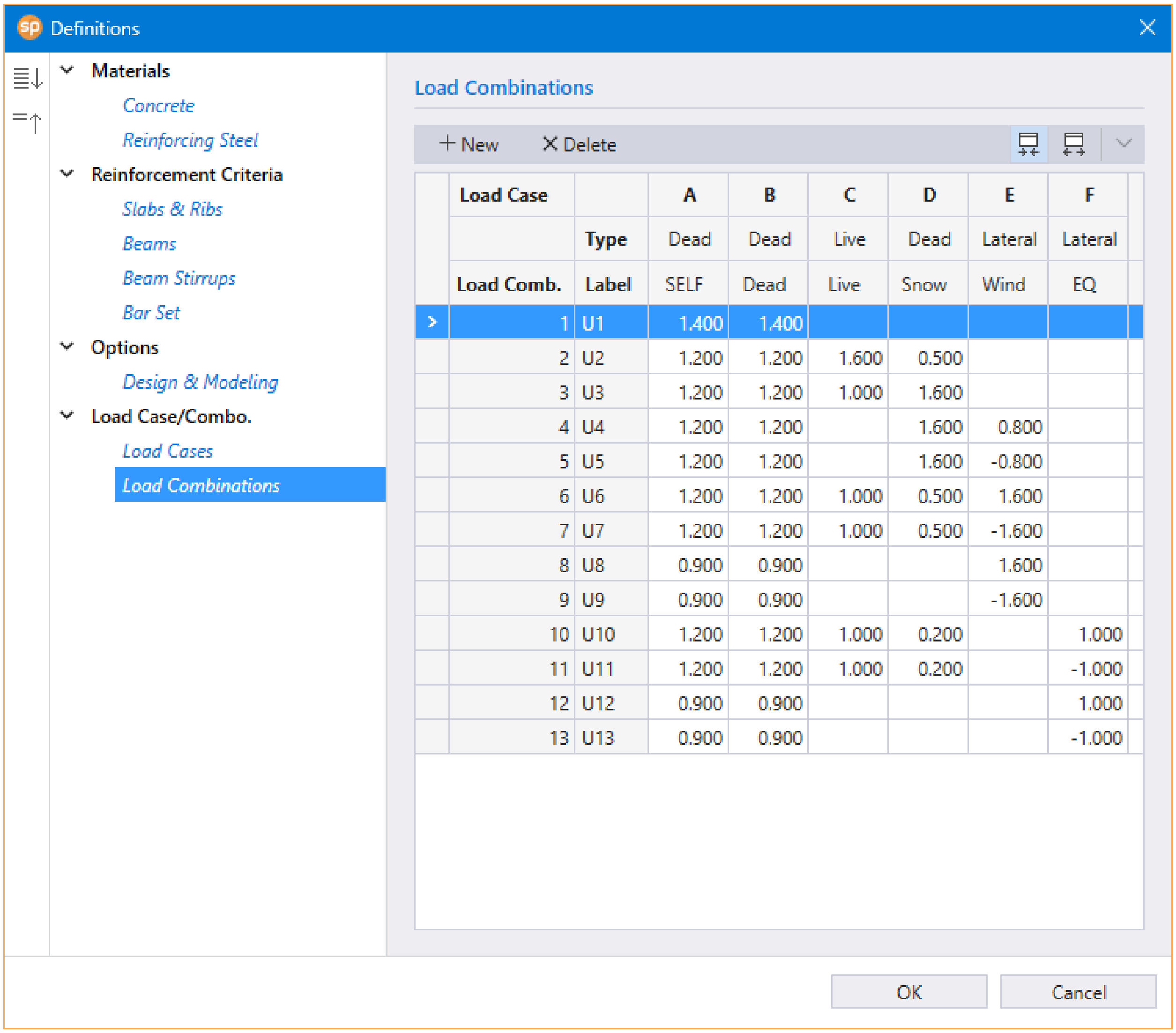
Note: Only one case of live load can be defined. Load case label must be unique for each of the load cases. To ignore self-weight in both strength and deflection calculations remove load case SELF from the list of load cases.


Definitions
Materials
Concrete
Reinforcing Steel
Reinforcement Criteria
Slabs & Ribs
Beams
Beam Stirrups
Bar Set
Options
Design & Modeling
Load Case/Combo.
Load Cases
Load Combinations
Load cases
New
Self-weight
Delete
Case copy
Case
Type
Label
Used
A
DEAD
SELF
No
B
DEAD
Dead
No
C
LIVE
Live
No
D
DEAD
Snow
No
E
LATERAL
Wind
No
F
LATERAL
EQ
No
OK
Cancel

## Load Combinations

The **Load Combinations** definition consists of the LOAD CASES, LOAD CASE TYPE, LOAD COMBINATION NUMBER, LOAD COMBINATION LABEL, and LOAD FACTORS.

Up to fifty load combinations may be defined. All the combinations are indexed automatically from U1 to U50.



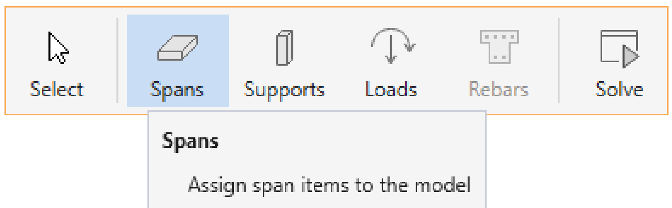

| Load Case | | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| | Type | Dead | Dead | Live | Dead | Lateral | Lateral |
| Load Comb. | Label | SELF | Dead | Live | Snow | Wind | EQ |
| 1 | U1 | 1.400 | 1.400 | | | | |
| 2 | U2 | 1.200 | 1.200 | 1.600 | 0.500 | | |
| 3 | U3 | 1.200 | 1.200 | 1.000 | 1.600 | | |
| 4 | U4 | 1.200 | 1.200 | | 1.600 | 0.800 | |
| 5 | U5 | 1.200 | 1.200 | | 1.600 | -0.800 | |
| 6 | U6 | 1.200 | 1.200 | 1.000 | 0.500 | 1.600 | |
| 7 | U7 | 1.200 | 1.200 | 1.000 | 0.500 | -1.600 | |
| 8 | U8 | 0.900 | 0.900 | | | 1.600 | |
| 9 | U9 | 0.900 | 0.900 | | | -1.600 | |
| 10 | U10 | 1.200 | 1.200 | 1.000 | 0.200 | | 1.000 |
| 11 | U11 | 1.200 | 1.200 | 1.000 | 0.200 | | -1.000 |
| 12 | U12 | 0.900 | 0.900 | | | | 1.000 |
| 13 | U13 | 0.900 | 0.900 | | | | -1.000 |

## 5.2.4. Creating Model Elements

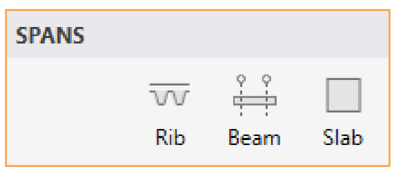
The Elements that can be created are: **Slabs, Longitudinal Beams/Bands, Ribs, Columns, Drop Panels, Column Capitals and Transverse Beams/Bands.**

### 5.2.4.1. Spans Elements

You can create **Spans Elements** using the **Spans** command from the **Ribbon**.

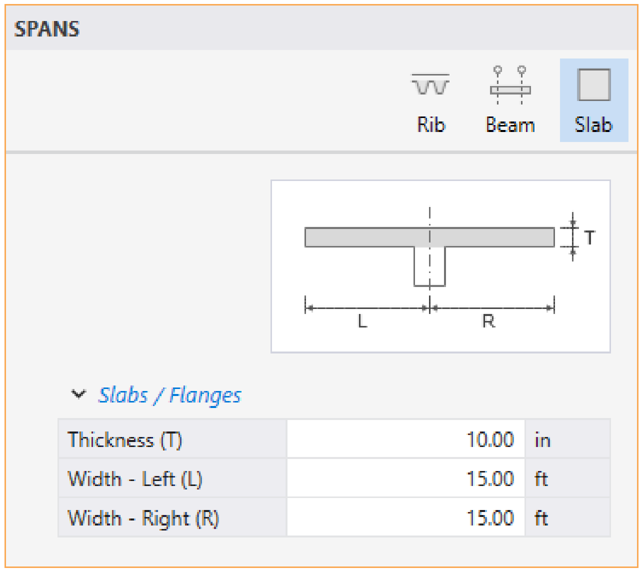



You can create **Slabs**, Longitudinal **Beams** and **Ribs** by using one of the following three tools in the **Spans Left Panel**.



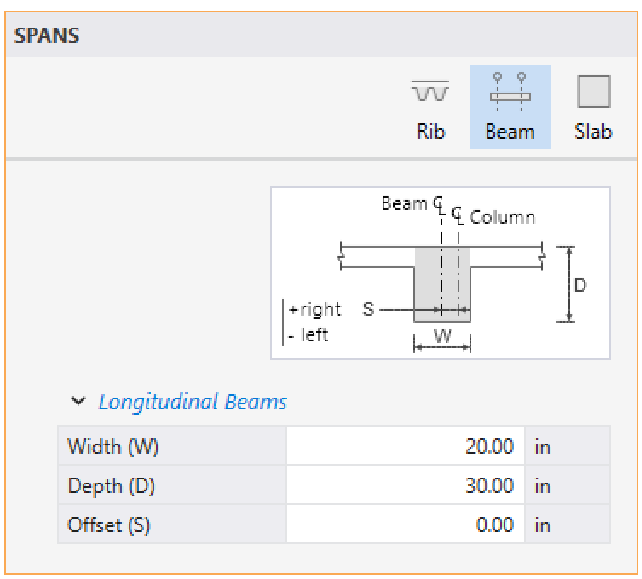
## Slab

You can enter the slab THICKNESS, WIDTH – LEFT, and WIDTH – RIGHT data in the **Left Panel**. Then click on the desired span (or drag over multiple spans) to assign the slab.




## Longitudinal Beam

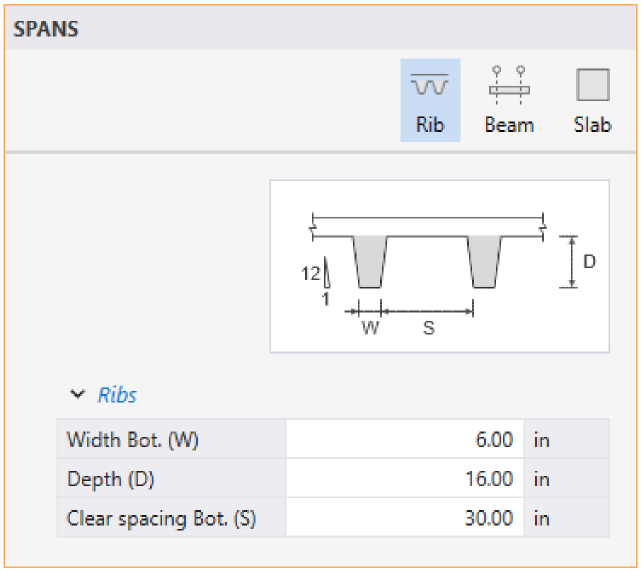
You can enter the beam WIDTH, DEPTH, and OFFSET data in the **Left Panel**. Then click on the desired span (or drag over multiple spans) to assign the beam.



## Rib

For joist systems, you must define the rib geometry. The ribs are assumed to be the same throughout the strip.

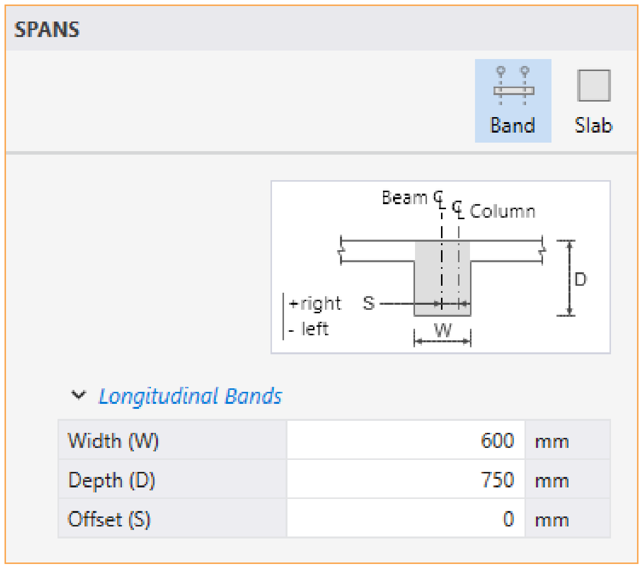
You can enter the rib WIDTH BOTTOM, DEPTH, and CLEAR SPACING BOTTOM data in the **Left Panel**. Then click on the desired span (or drag over multiple spans) to assign the ribs.



## Longitudinal Slab Bands

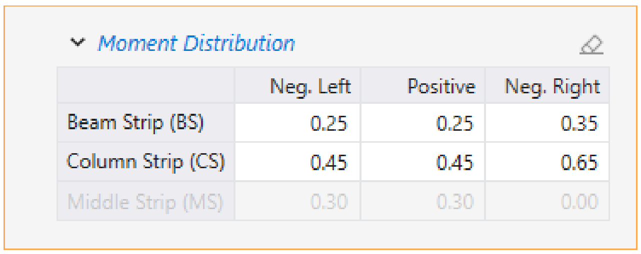
Longitudinal slab bands are only available for two-way floor systems when LONGITUDINAL is selected for **Slab Bands** under **Run Options** in **Project Left Panel** (CSA A23.3-14/04 only).

You can enter the slab band WIDTH, DEPTH, and OFFSET data in the **Left Panel**. Then click on the desired span (or drag over multiple spans) to assign the slab band.



## Strip Moment Distribution Factors

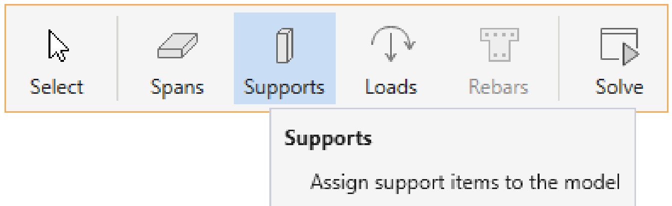
User has the ability to manually adjust strip moment distribution factors for two-way floor systems when USER STRIP DISTRIBUTION FACTORS option is checked in the **Design & Modeling Options** under the **Define** command. However, in spSlab v10.00, strip distribution factor is a select only property. For details on how to assign or edit these factors, refer to Editing Model Elements Using the Left Panel section. In such case, the strip **Moment Distribution** table will become available under **Spans Left Panel** when the **Select** command button is toggled on. This table contains fields for inputting distribution factors in column and beam strips. The distribution factors for middle strip are recalculated internally.


Moment Distribution

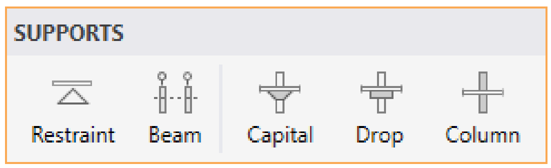
| | Neg. Left | Positive | Neg. Right |
|---|---|---|---|
| Beam Strip (BS) | 0.25 | 0.25 | 0.35 |
| Column Strip (CS) | 0.45 | 0.45 | 0.65 |
| Middle Strip (MS) | 0.30 | 0.30 | 0.00 |

### 5.2.4.2. Supports Elements

You can create **Supports Elements** using the **Supports** command from the **Ribbon**.



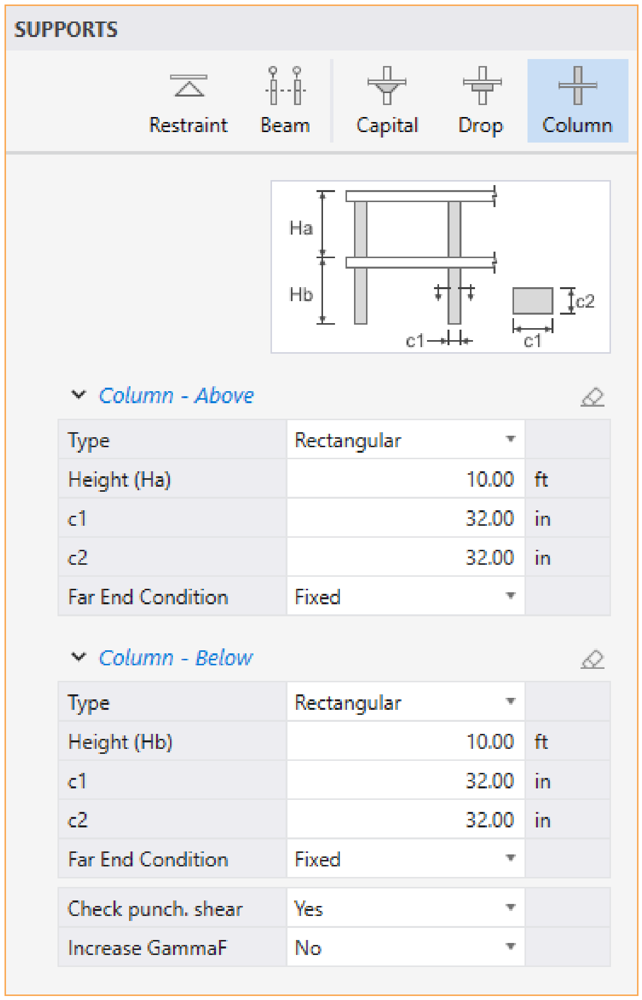

You can create **Columns**, **Drop** Panels, column **Capitals**, Transverse **Beams**, and **Restraints** by using one of the following tools in the **Supports Left Panel**.



## Column

**Column** data is optional. If no column is specified at the supports, the support is assumed pinned.

You can enter the COLUMN ABOVE, COLUMN BELOW, and COLUMN OPTIONS data in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the column.

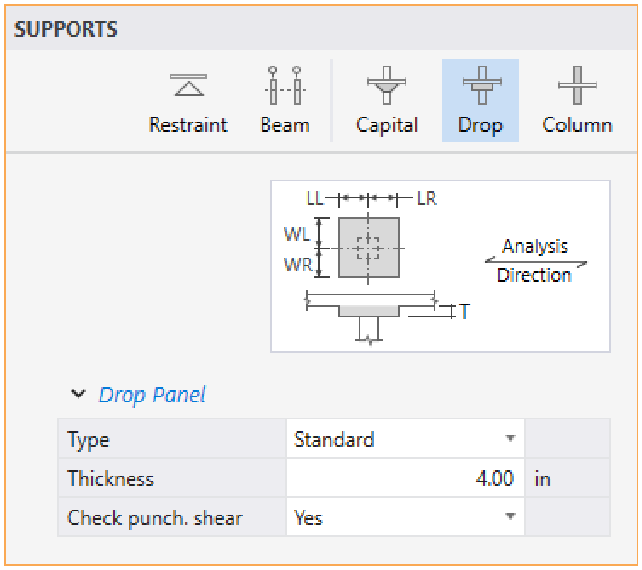


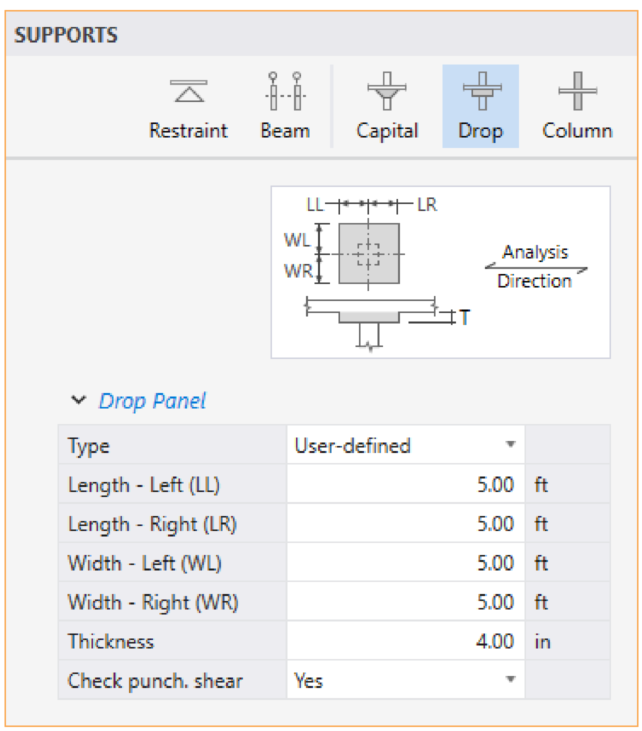

More information about columns FAR END CONDITION can be found in the Restraint section.

## Drop Panel

**Drops** are available for the flat slab or waffle slab systems and can be defined at all the support locations.

You can enter the TYPE, THICKNESS, and CHECK PUNCHING SHEAR data in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the drop panel.



If spSlab is to compute the drop dimensions, the STANDARD option should be selected from the TYPE drop-down list and then only the drop depth will be available. When the STANDARD drop option is selected, spSlab will calculate drop panel dimensions in accordance with ACI 318[2]. Similar requirements contained in previous editions of the CSA A23.3 Standard have been removed from the 1994 edition. As a result, the ACI minimum specifications for drop panels are also used in CSA A23.3 runs when the STANDARD drop option is selected. If you would like to specify drop dimensions other than those computed by spSlab, you must select USER-DEFINED from the TYPE drop-down list.

Enter the dimension in the direction of analysis from the column centerline to the edge of the drop left of the column (see Figure 5.2). If this is a STANDARD drop, this dimension will not be available and the length left is set equal to the slab span length left/6 for interior columns or the left cantilever length for the first column.

Enter the width dimension in the transverse direction (see Figure 5.2). If this is a STANDARD drop, this dimension will not be available and the width is set equal to slab width/3.

In order for spSlab to recognize drops, drop thickness are required for the flat slab systems even if STANDARD drop is selected. Enter the thickness of the drop from the span with the smaller slab depth (see Figure 5.2). For waffle slab systems, the thickness is automatically assumed to be equal to the rib depth below the slab. A value entered will be considered to exist below the rib depth during calculations.

Select whether spSlab should compute punching shear around drop panel.

[2] ACI 318-14, 8.5.2.2, 8.2.4; ACI 318-11, 13.3.7, 13.2.5; ACI 318-08, 13.3.7, 13.2.5; ACI 318-05, 13.3.7, 13.2.5

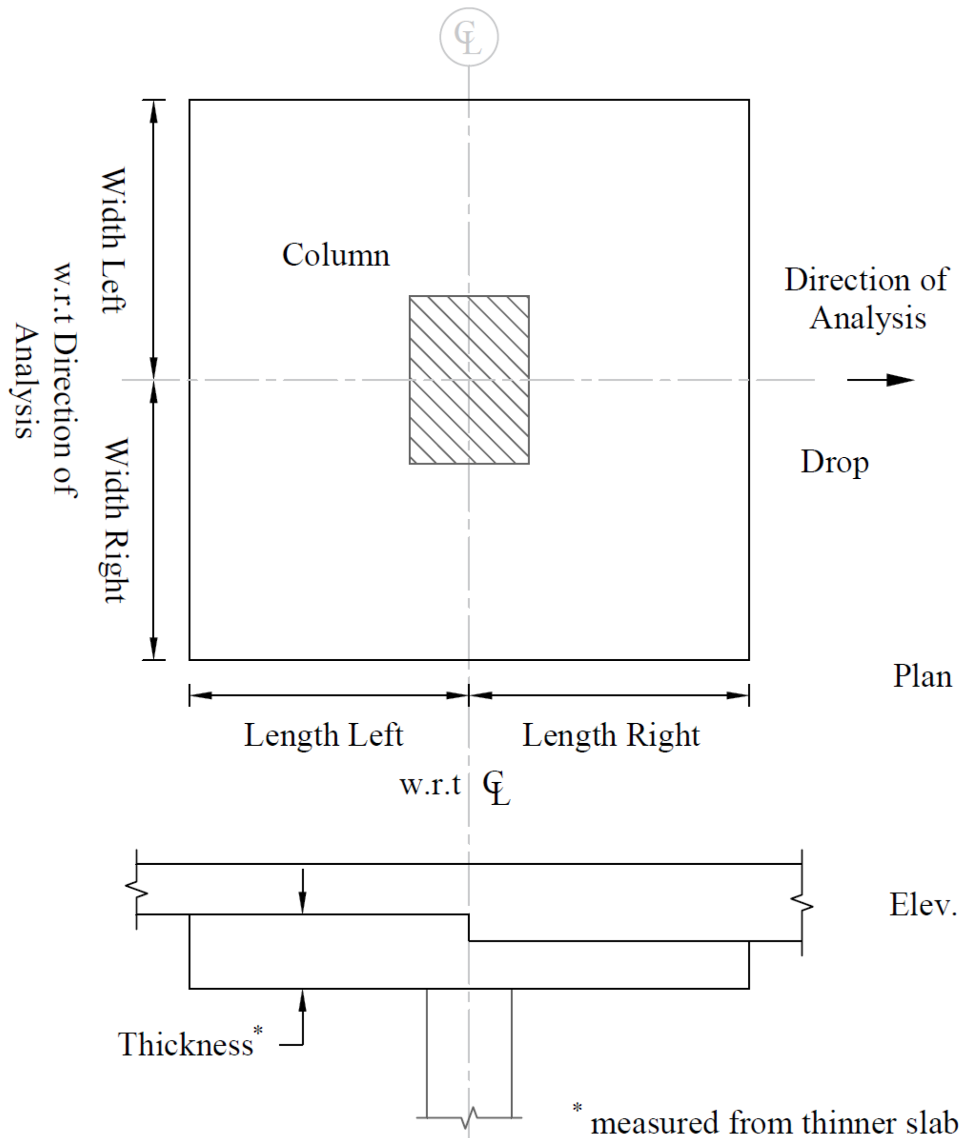
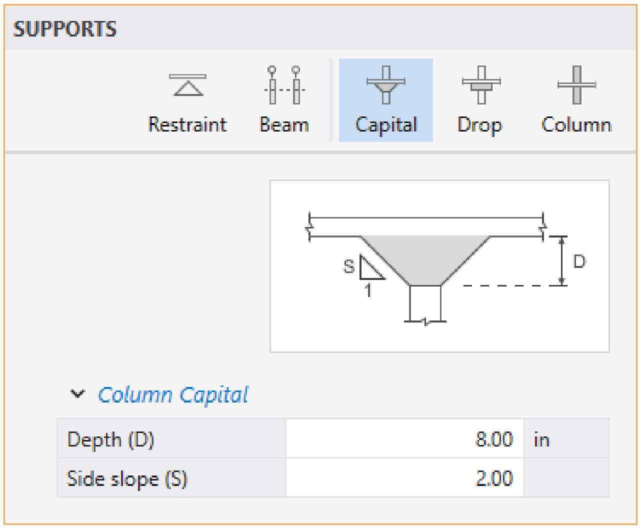



Figure 5.2 – Required Drop Panel Dimensions

## Column Capital

You can enter the DEPTH and SIDE SLOPE data in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the column capital.



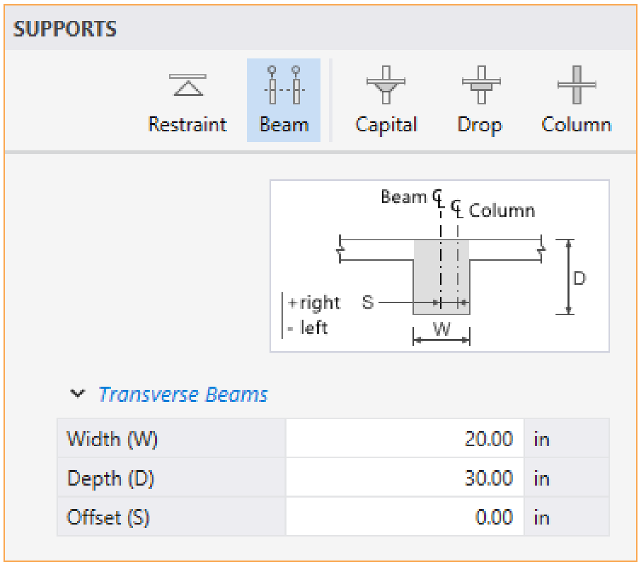

Enter the capital DEPTH which is the distance from the bottom of the soffit (slab, drop, or beam), to the bottom of the capital.

Enter the capital SIDE SLOPE which is the rate of depth to extension of the capital and it must be greater than 1 and smaller than 50.

For circular column capitals, in **Design Options** under **Solve** command, ensure the preferred option for punching shear perimeter is selected.

## Transverse Beams

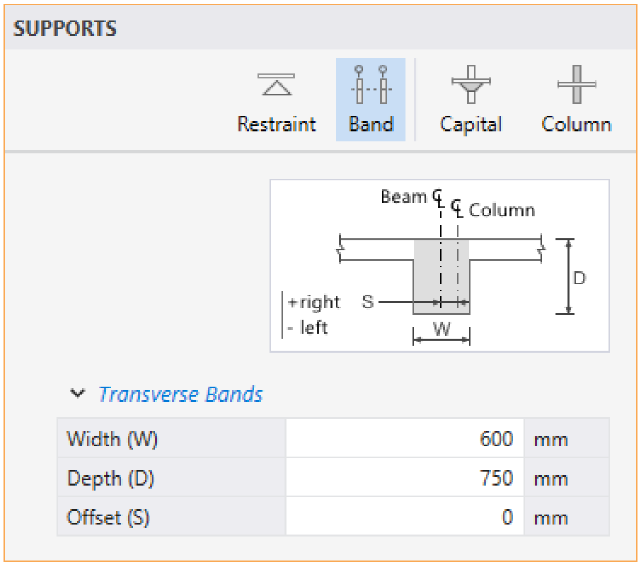
You can enter the WIDTH, DEPTH, and OFFSET data in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the beam.



## Transverse Slab Bands

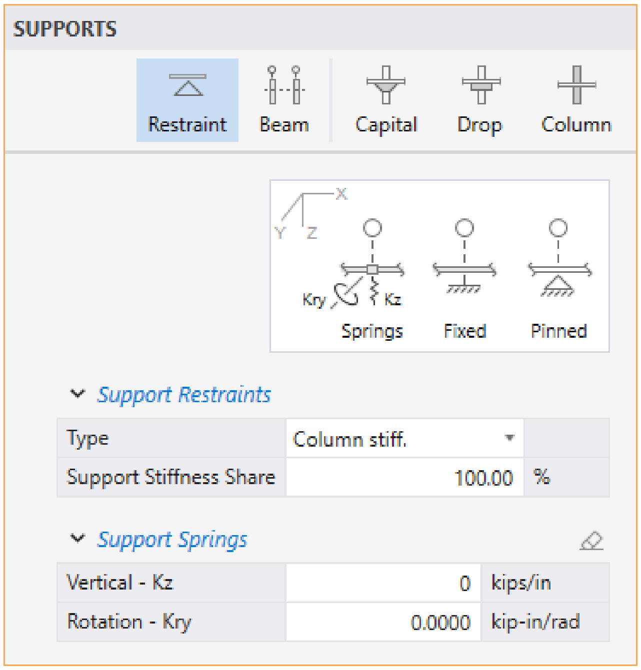
Transverse slab bands are only available for two-way floor systems when TRANSVERSE is selected for **Slab Bands** under **Run Options** in **Project Left Panel** (CSA A23.3-14/04 only). It is not required to input bands for every support. Supports where slab bands are not defined are modeled similar to regular two-way systems.

You can enter the WIDTH, DEPTH, and OFFSET data in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the slab band.



## Restraint

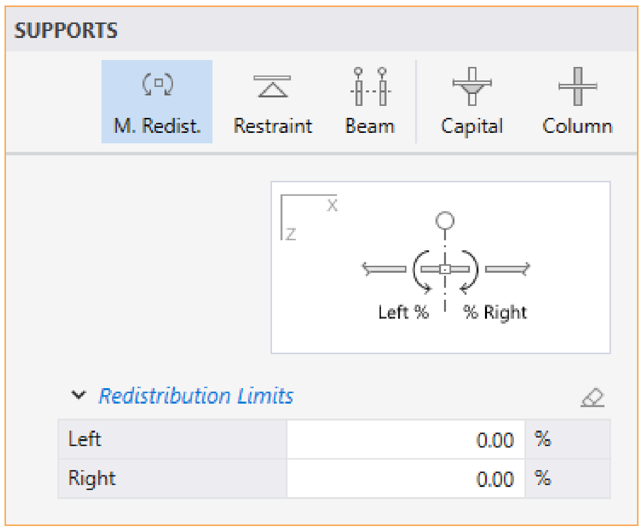
You can enter the SUPPORT RESTRAINTS, and SUPPORT SPRINGS data in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the restraint/spring.



## Moment Redistribution

This command is only available for one-way/beam floor systems when MOMENT REDISTRIBUTION option is checked in the **Design & Modeling Options** under the DEFINITIONS dialog box.

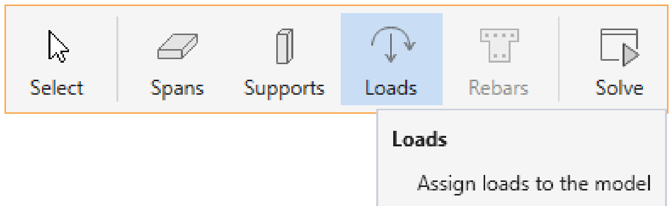
You can enter the redistribution factor you want to allow on the LEFT and RIGHT side of the support in the **Left Panel**. Then click on the desired support (or drag over multiple supports) to assign the redistribution limits.



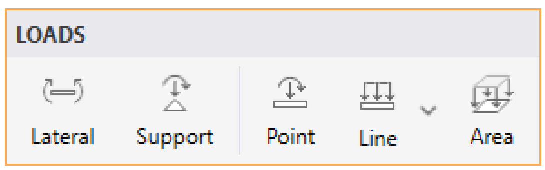
### 5.2.4.3. Loads

spSlab computes the self-weight of the floor system. Other loads applied to the structure have to be specified by the user.

You can create **Loads** using the **Loads** command from the **Ribbon**.

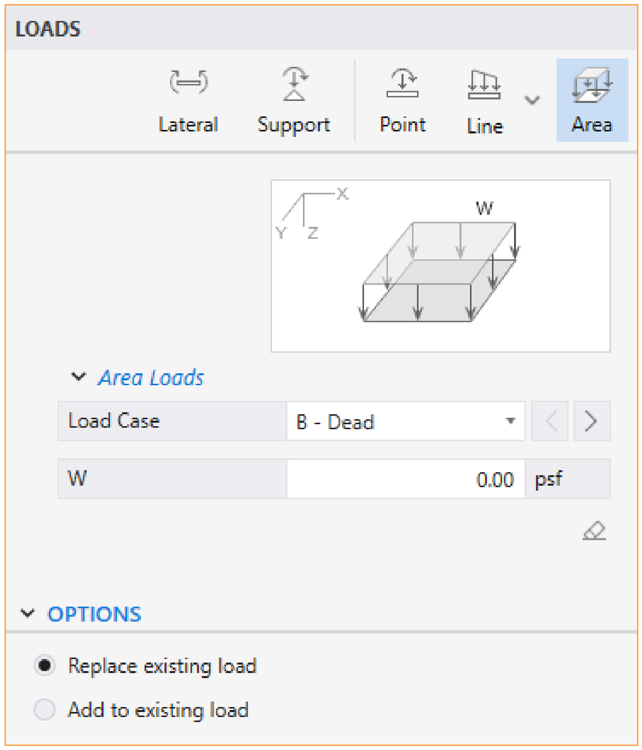



You can assign **Area** loads, **Uniform and Variable Line** loads, **Point** loads, **Support** loads and Displacements, and **Lateral** Load Effects loads by using one of the five options that are presented in the **Loads Left Panel**.



## Assigning Area Loads

**Area** loads can only be assigned to Spans with a **Slab** and/or a **Longitudinal Beam.**

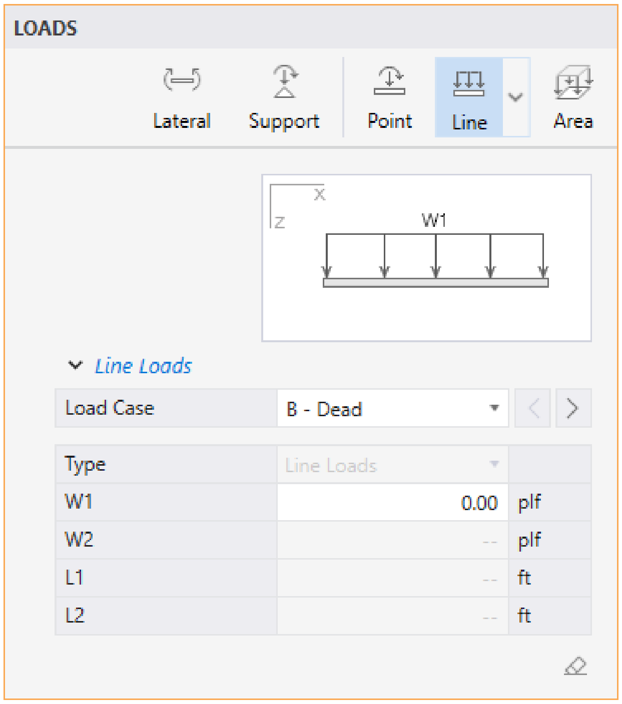


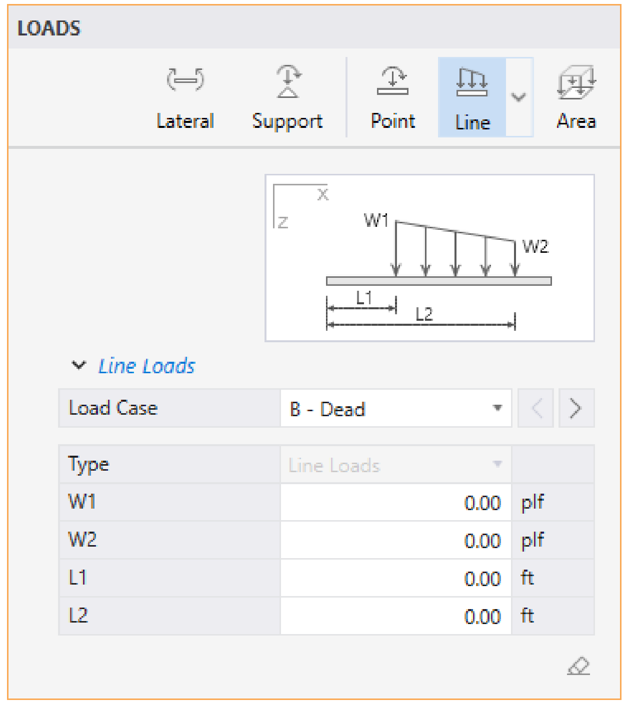

To assign an **Area** load, make sure that the **Area** command in the **Left Panel** is selected.

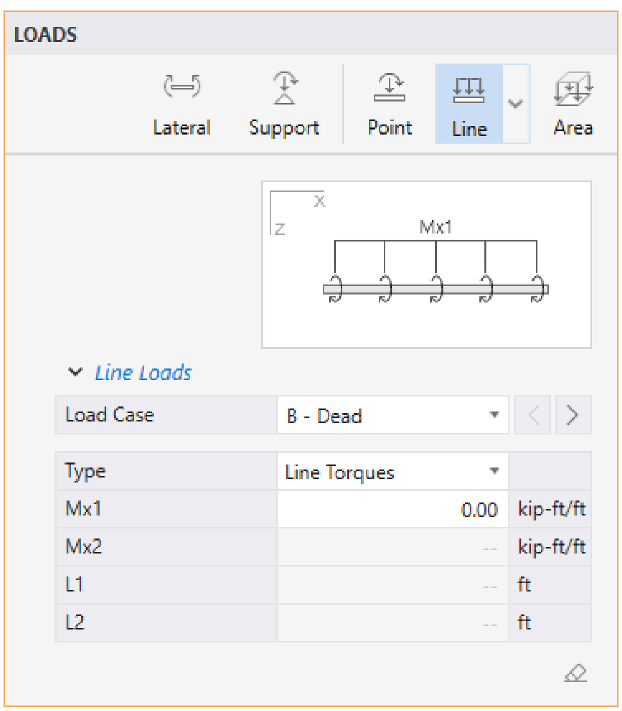
- Select the LOAD CASE you want the **Area** load to belong to. You can always define LOAD CASES in the DEFINITIONS dialog.
- In the W box, type in the required load value. Note that the thumbnail in the **Left Panel** shows the sign convention for the loads.
- From the OPTIONS select if you want to ADD TO EXISTING LOAD on the span or REPLACE EXISTING LOAD completely.
- Next, click on the span you want the load to be assigned to. You can also marquee select a group of spans to assign all of them the same area load.

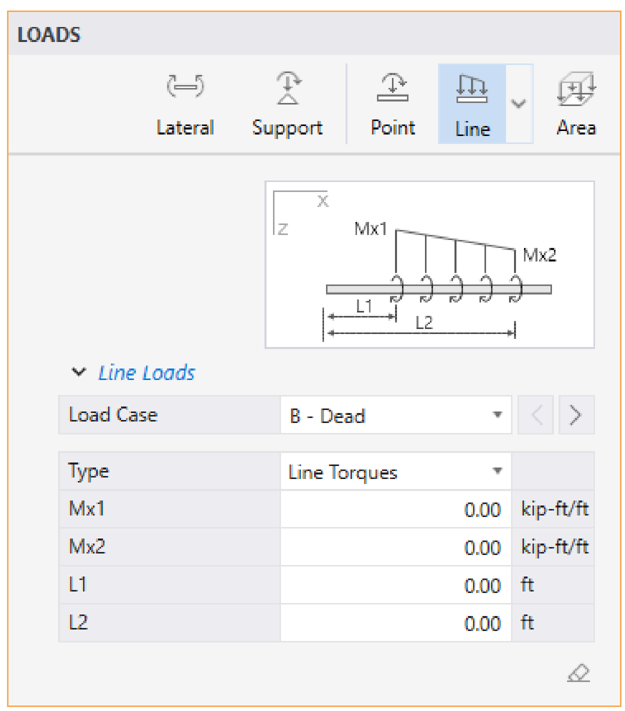
## Assigning Line Loads

**Line** loads can only be assigned to spans with a **Slab** and/or a **Longitudinal Beam**.



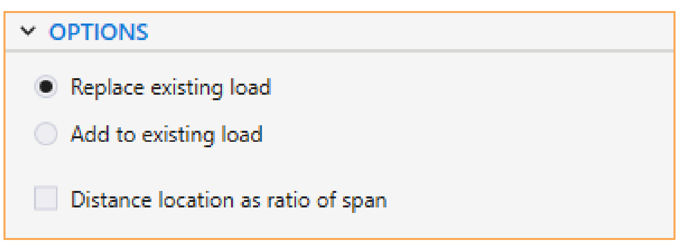



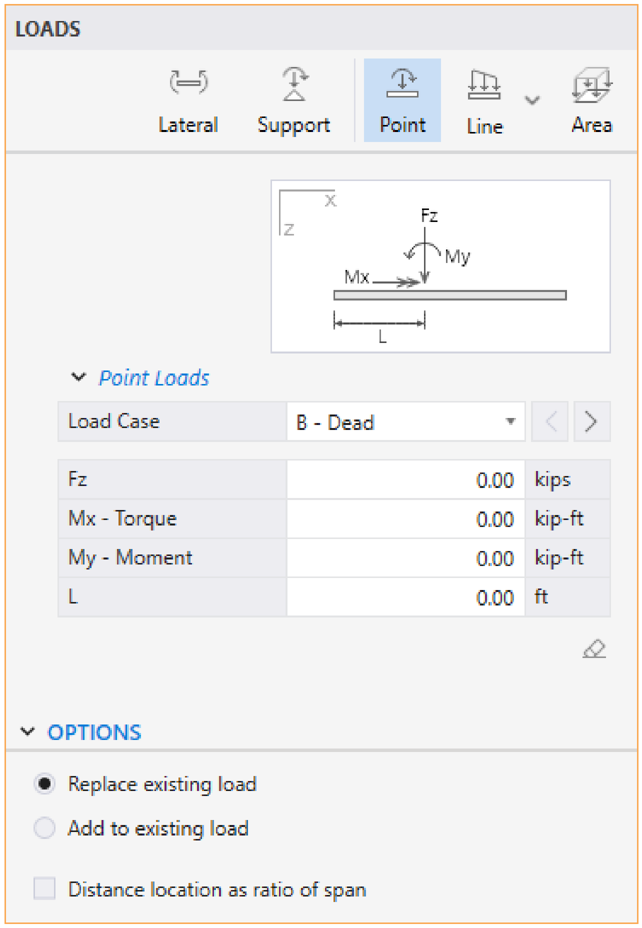
To assign a **Line** load, make sure that the **Line** command in the **Left Panel** is selected.

- Select the LOAD CASE you want the **Line** load to belong to. You can always define LOAD CASES in the DEFINITIONS dialog.
- Select the line load TYPE (UNIFORM LINE LOADS, UNIFORM LINE TORQUES, VARIABLE LINE LOADS, and VARIABLE LINE TORQUES). Note that UNIFORM LINE TORQUES and VARIABLE LINE TORQUES are only available for one-way floor systems when YES is selected for **Consider Torsion** under **Run Options** in **Project Left Panel**.
- In the boxes, type in the required location and load values. Note that the thumbnail in the **Left Panel** shows the sign convention for the loads.
- From the OPTIONS:
    - Select if you want to ADD TO EXISTING LOAD on the span or REPLACE EXISTING LOAD completely.
    - If you want to enter the required location as a ratio of the span length, check DISTANCE LOCATION AS RATIO OF SPAN checkbox.
- Next, click on the span you want the load to be assigned to. You can also marquee select a group of spans to assign all of them the same line loads.



## Assigning Point Loads

**Point** loads can only be assigned to spans with a **Slab and/or a Longitudinal Beam**.




To assign a **Point** load, make sure that the **Point** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Point** loads options.

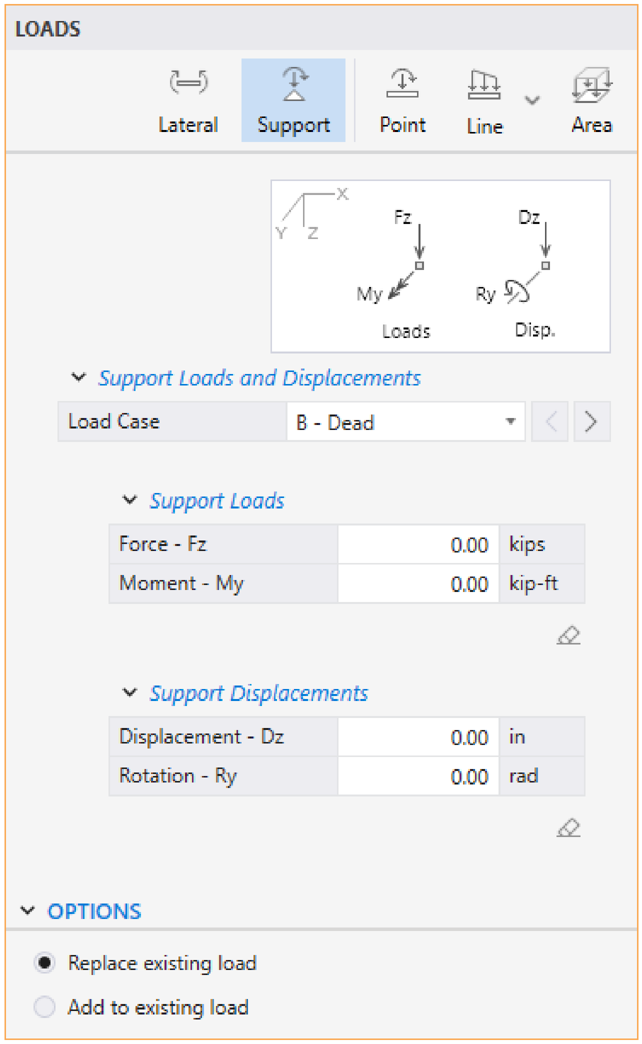
- Select the LOAD CASE you want the **Point** load to belong to. You can always define LOAD CASES in the DEFINITIONS dialog.
- In the boxes, type in the required load values and their locations. Note that the thumbnail in the **Left Panel** shows the sign convention for the loads, moments, and lengths.
- From the OPTIONS:
  - Select if you want to ADD TO EXISTING LOAD on the span or REPLACE EXISTING LOAD completely.

    - If you want to enter the required location as a ratio of the span length, check DISTANCE LOCATION AS RATIO OF SPAN checkbox.

- Next, click on the span you want the load to be assigned to. You can also marquee select a group of spans to assign all of them the same point loads.

## Assigning Support Loads and Displacements

**Support** loads and displacements can only be assigned at support locations.



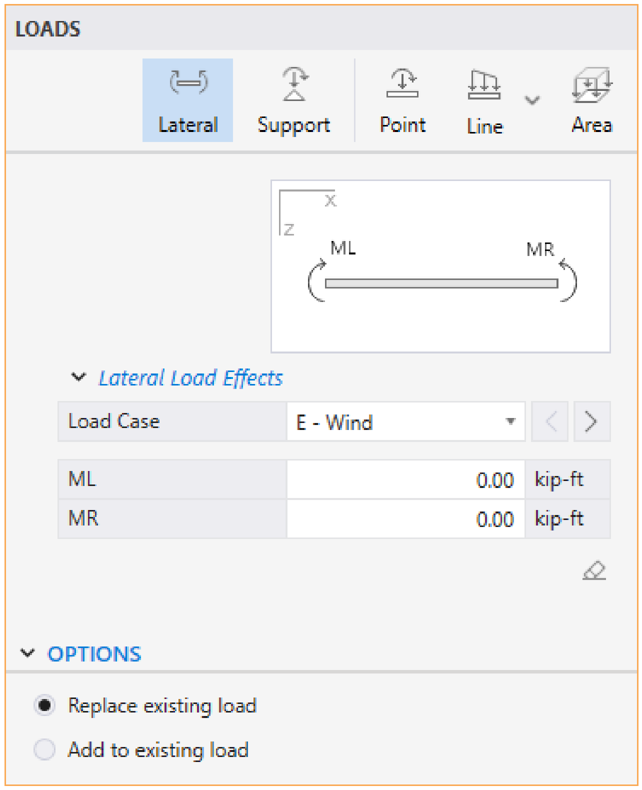

To assign a **Support** load and displacement, make sure that the **Support** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Support** loads and displacements options.

- Select the LOAD CASE you want the **Support** load and displacement to belong to. You can always define LOAD CASES in the DEFINITIONS dialog.
- In the SUPPORT LOADS boxes, type in the required FORCE and/or MOMENT values. Note that the thumbnail in the **Left Panel** shows the sign convention for the support loads.

- In the SUPPORT DISPLACEMENTS boxes, type in the required DISPLACEMENT and/or ROTATION values. Note that the thumbnail in the **Left Panel** shows the sign convention for the support displacements.
- From the OPTIONS select if you want to ADD TO EXISTING LOAD on the node or REPLACE EXISTING LOAD completely.
- Next, click on the support location you want the support load and displacement to be assigned to. You can also marquee select a group of supports to assign all of them the same support load and displacement.

## Assigning Lateral Load Effects

**Lateral Load Effects** can only be assigned to **Spans** with a **Slab** and/or a **Longitudinal Beam.**




To assign a **Lateral Load Effects**, make sure that the **Lateral** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Lateral** loads options.

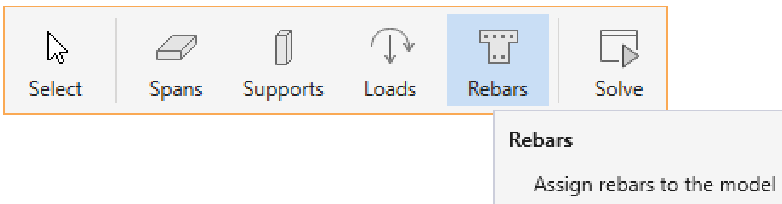
- Select the LOAD CASE you want the **Lateral Load Effects** to belong to. You can always define LOAD CASES in the DEFINITIONS dialog. Please note that at least one lateral load case is required to assign lateral load effects.
- In the boxes, type the moment values. Note that the thumbnail in the **Left Panel** show the sign convention for the lateral load effects.
- From the OPTIONS select if you want to ADD TO EXISTING LOAD on the span end or REPLACE EXISTING LOAD completely.
- Next, click on the span you want the lateral load effect to be assigned to. You can also marquee select a group of spans to assign all of them the same lateral load effect.

### 5.2.4.4. Rebars

**Rebars** command is only available if the RUN MODE of INVESTIGATION is selected in the **Project Left Panel** (This command is not available if RUN MODE of DESIGN is selected).

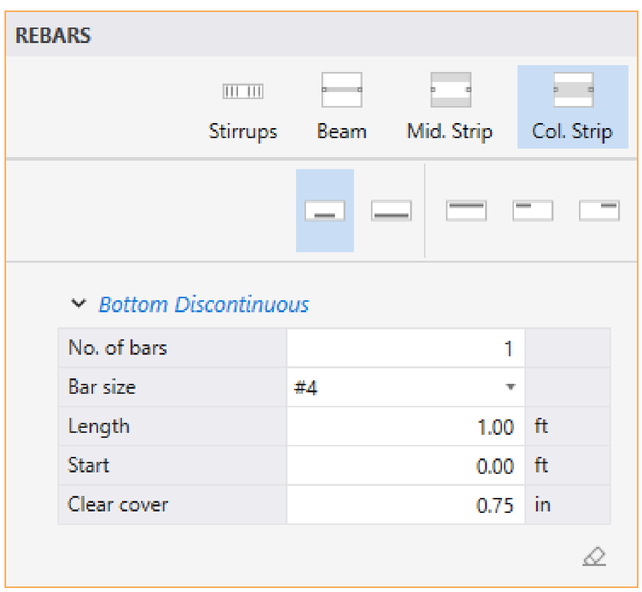
Note: When switching from DESIGN mode to INVESTIGATION mode, spSlab automatically assumes the results of the DESIGN mode as an input for INVESTIGATION mode.

You can create **Rebars** using the **Rebars** command from the **Ribbon**.




### Column Strip Rebars for Two-Way Slab Systems

The column strip rebars can be defined by users if the RUN MODE of INVESTIGATION and TWO-WAY FLOOR SYSTEM are selected in the **Project Left Panel**.



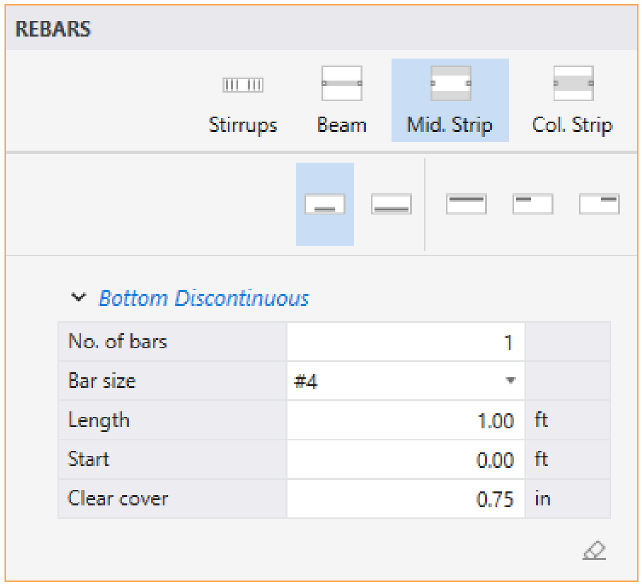

To define column strip rebars, make sure that the **Column Strip** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Column Strip** rebars types. Five types are available: **Top Right**, **Top Left**, **Top Continuous**, **Bottom Continuous** and **Bottom**

**Discontinuous**.

- Select the rebar type for which **Column Strip** rebars will be defined.
- In the boxes, type in the NO. OF BARS, BAR SIZE, and CLEAR COVER (also bar LENGTH and START location, if discontinuous rebars types are selected).
- Next, click on the span (or spans) you want the **Column Strip** rebars to be assigned to. You can also marquee select a group of spans to assign all of them the same **Column Strip** rebars.

## Middle Strip Rebars for Two-Way Slab Systems

The middle strip rebars can be defined by users if the RUN MODE of INVESTIGATION and TWO-WAY FLOOR SYSTEM are selected in the **Project Left Panel**.

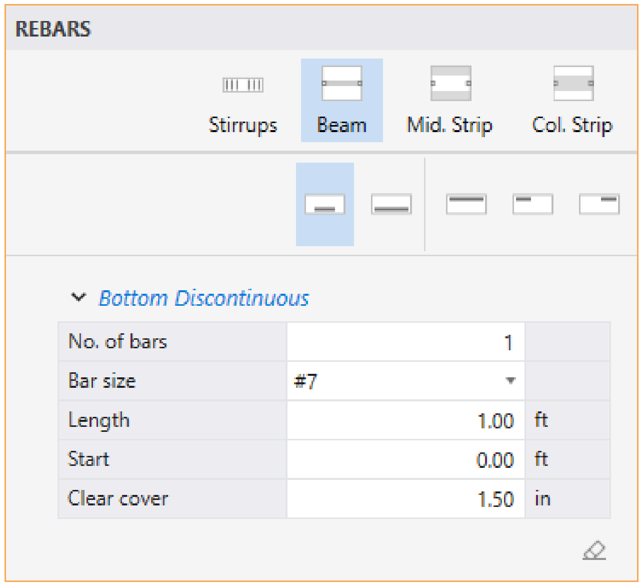



To define middle strip rebars, make sure that the **Middle Strip** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Middle Strip** rebars types. Five types are available: **Top Right**, **Top Left**, **Top Continuous**, **Bottom Continuous** and **Bottom Discontinuous**.

- Select the rebar type for which **Middle Strip** rebars will be defined.
- In the boxes, type in the NO. OF BARS, BAR SIZE, and CLEAR COVER (also bar LENGTH and START location, if discontinuous rebars types are selected).
- Next, click on the span (or spans) you want the **Middle Strip** rebars to be assigned to. You can also marquee select a group of spans to assign all of them the same **Middle Strip** rebars.

## Beam Rebars for Two-Way Slab Systems

The beam rebars can be defined by users if the RUN MODE of INVESTIGATION and TWO-WAY FLOOR SYSTEM are selected in the **Project Left Panel**.

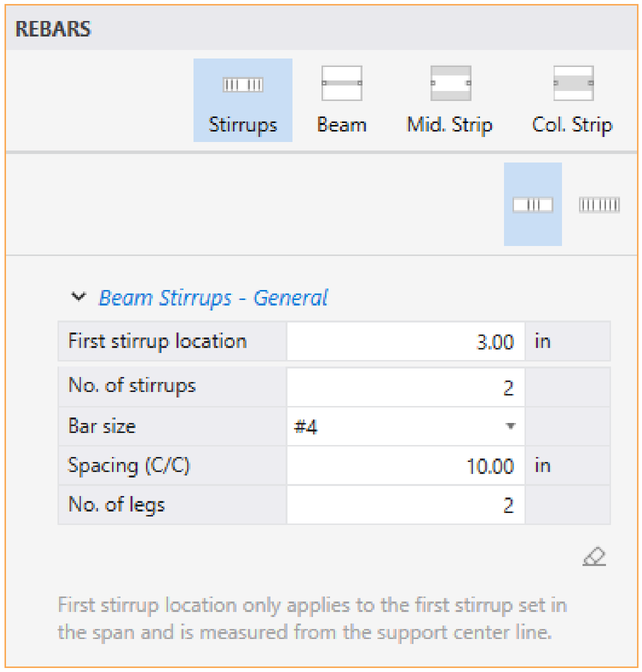



To define beam rebars, make sure that the **Beam** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Beam** rebars types. Five types are available: **Top Right**, **Top Left**, **Top Continuous**, **Bottom Continuous** and **Bottom Discontinuous**.

- Select the rebar type for which **Beam** rebars will be defined.
- In the boxes, type in the NO. OF BARS, BAR SIZE, and CLEAR COVER (also bar LENGTH and START location, if discontinuous rebars types are selected).
- Next, click on the span (or spans) you want the **Beam** rebars to be assigned to. You can also marquee select a group of spans to assign all of them the same **Beam** rebars.

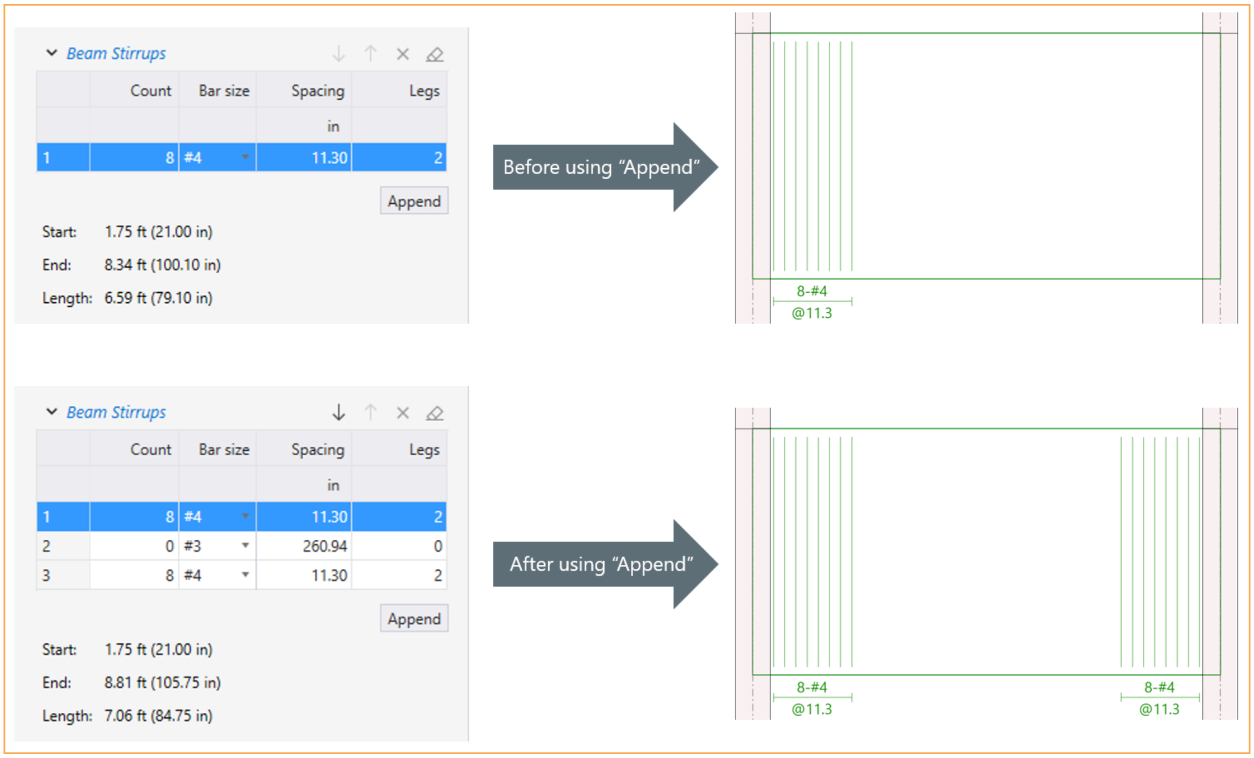
## Beam Stirrups for Two-Way Slab Systems

The beam stirrups can be defined by users if the RUN MODE of INVESTIGATION and TWO-WAY FLOOR SYSTEM are selected in the **Project Left Panel**.



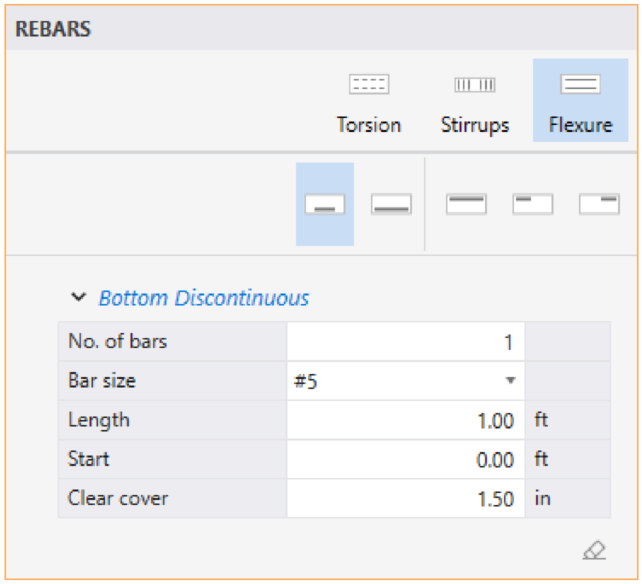

To define beam stirrups, make sure that the **Stirrups** command in the **Left Panel** is selected. The **Left Panel** should be displaying two **Stirrups** configurations: **Stirrups Entire Span** and **Stirrups General**.

- Select the stirrups configuration for which **Stirrups** will be defined.
- In the boxes, type in the NO. OF STIRRUPS, BAR SIZE, SPACING and NO. OF LEGS (also FIRST STIRRUP LOCATION when applicable).
- Next, click on the span (or spans) you want the **Stirrups** to be assigned to. You can also marquee select a group of spans to assign all of them the same **Stirrups**.
- In order to mirror stirrup set or sets at the end of the span, use APPEND button.


Beam Stirrups
Count
Bar size
Spacing
Legs
in
1
8
#4
11.30
2
Append
Start: 1.75 ft (21.00 in)
End: 8.34 ft (100.10 in)
Length: 6.59 ft (79.10 in)
Before using "Append"
8-#4
@11.3
Beam Stirrups
Count
Bar size
Spacing
Legs
in
1
8
#4
11.30
2
2
0
#3
260.94
0
3
8
#4
11.30
2
Append
Start: 1.75 ft (21.00 in)
End: 8.81 ft (105.75 in)
Length: 7.06 ft (84.75 in)
After using "Append"
8-#4
@11.3
8-#4
@11.3

## Flexure Rebars for Beams and One-Way Slab Systems

The flexure rebars can be defined by users if the RUN MODE of INVESTIGATION and ONE-WAY/BEAM FLOOR SYSTEM are selected in the **Project Left Panel**.

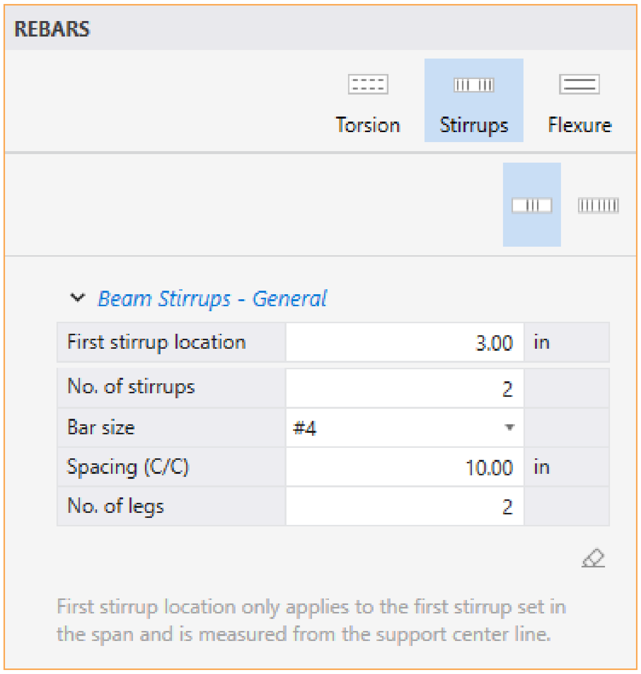



To define flexure rebars, make sure that the **Flexure** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Flexure** rebars types. Five types are available: **Top Right**, **Top Left**, **Top Continuous**, **Bottom Continuous** and **Bottom Discontinuous**.

- Select the rebar type for which **Flexure** rebars will be defined.
- In the boxes, type in the NO. OF BARS, BAR SIZE, and CLEAR COVER (also bar LENGTH and START location, if discontinuous rebars types are selected).
- Next, click on the span (or spans) you want the **Flexure** rebars to be assigned to. You can also marquee select a group of spans to assign all of them the same **Flexure** rebars.

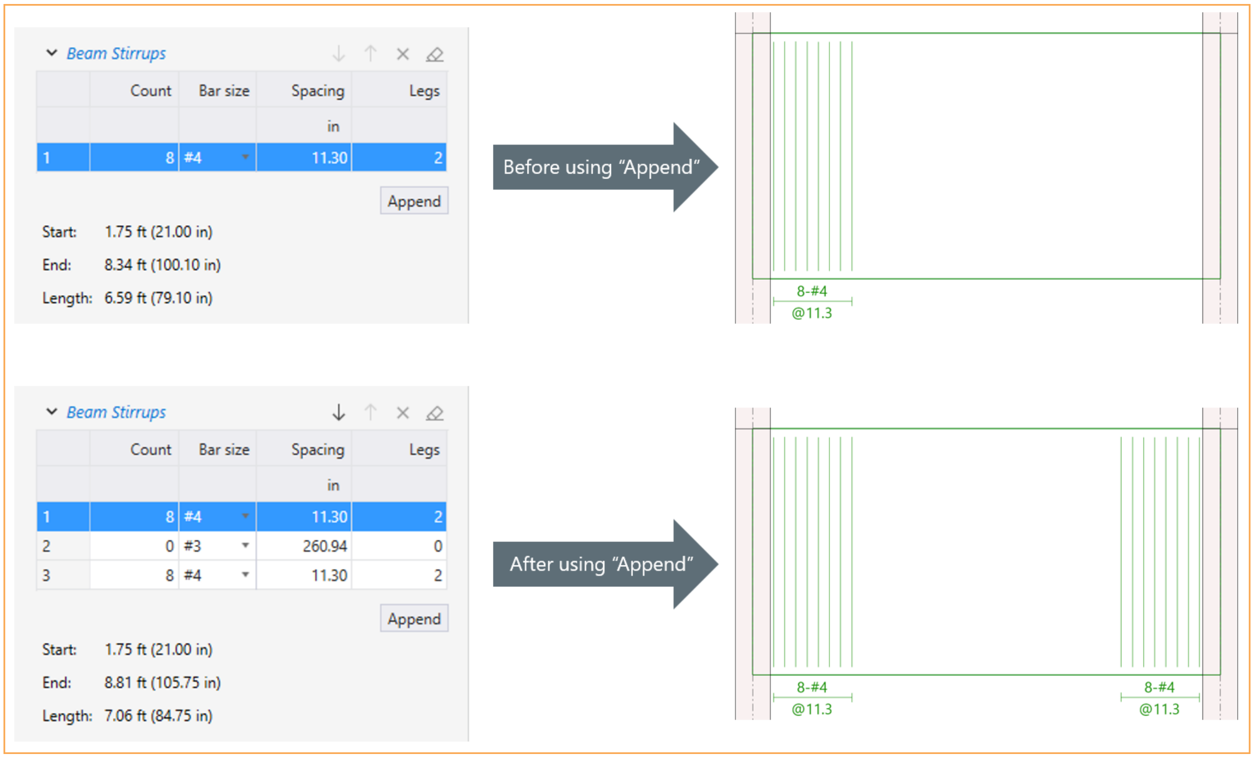
## Stirrups for Beams and One-Way Slab Systems

The stirrups can be defined by users if the RUN MODE of INVESTIGATION and ONE-WAY/BEAM FLOOR SYSTEM are selected in the **Project Left Panel**.



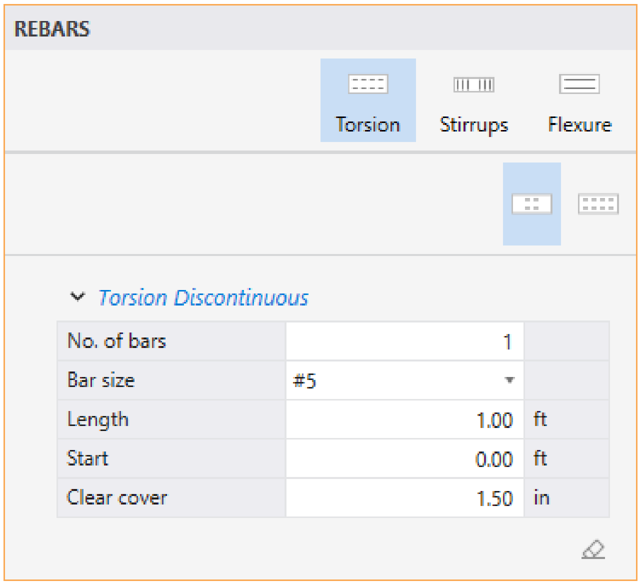

To define stirrups, make sure that the **Stirrups** command in the **Left Panel** is selected. The **Left Panel** should be displaying two **Stirrups** configurations: **Stirrups Entire Span** and **Stirrups General**.

- Select the stirrups configuration for which **Stirrups** will be defined.
- In the boxes, type in the NO. OF STIRRUPS, BAR SIZE, SPACING and NO. OF LEGS (also FIRST STIRRUP LOCATION when applicable).
- Next, click on the span (or spans) you want the **Stirrups** to be assigned to. You can also marquee select a group of spans to assign all of them the same **Stirrups**.
- In order to mirror stirrup set or sets at the end of the span, use APPEND button.


Beam Stirrups
Count
Bar size
Spacing
Legs
in
1
8
#4
11.30
2
Append
Start: 1.75 ft (21.00 in)
End: 8.34 ft (100.10 in)
Length: 6.59 ft (79.10 in)
Before using "Append"
8-#4
@11.3
Beam Stirrups
Count
Bar size
Spacing
Legs
in
1
8
#4
11.30
2
2
0
#3
260.94
0
3
8
#4
11.30
2
Append
Start: 1.75 ft (21.00 in)
End: 8.81 ft (105.75 in)
Length: 7.06 ft (84.75 in)
After using "Append"
8-#4
@11.3
8-#4
@11.3

## Torsional Longitudinal Rebars for Beams

The torsional longitudinal rebars can be defined by users if the RUN MODE of INVESTIGATION and ONE-WAY/BEAM FLOOR SYSTEM are selected in the **Project Left Panel**.




To define torsional longitudinal rebars, make sure that the **Torsion** command in the **Left Panel** is selected. The **Left Panel** should be displaying various **Torsion** rebars types. Two types are available: **Torsion Continuous** and **Torsion Discontinuous**.

- Select the rebar type for which **Torsion** rebars will be defined.
- In the boxes, type in the NO. OF BARS, BAR SIZE, and CLEAR COVER (also bar LENGTH and START location, if discontinuous rebars type is selected).
- Next, click on the span (or spans) you want the **Torsion** rebars to be assigned to. You can also marquee select a group of spans to assign all of them the same **Torsion** rebars.

## 5.2.5. Editing Model Elements

The model can be edited by using the **Left Panel**, **Left Panel Toolbar** or by using right-click at **Viewport**. To edit a model element, its corresponding placeholder (**Span** or **Support**) must be selected.

### 5.2.5.1. Using the Left Panel

The **Elements** that can be edited are: **Slabs, Longitudinal Beams/Bands, Ribs, Columns, Drop Panels, Column Capitals and Transverse Beams/Bands**.

#### Spans

The corresponding **Spans Left Panel** provides various tools and options for effectively working with **Span Elements**. You must have the **Select** command button toggled on to edit the **Span Elements**.

*Editing Span Elements*

To edit span elements:

- Click on the span (or spans) you want to edit to display its properties in the **Left Panel**.
- Then in the **Elements** tab in the **Span Left Panel**, simply change the desired parameter.
- Additionally, you can add new elements or remove existing elements to the selected span (or spans) by clicking on + or × next to the desired element, respectively.

*Editing Span Loads*

To edit span loads:

- Click on the span (or spans) you want to edit to display its properties in the **Left Panel**.
- Click on the **Loads** tab in the **Span Left Panel**, then simply change the load value as desired.

- Additionally, you can add new loads or remove existing loads to the selected span by clicking on  or  next to the desired load, respectively.

### *Editing Strip Moment Distribution Factors*

To edit strip Moment Distribution Factors:

- Enable check box USER STRIP DISTRIBUTION FACTORS under **Design & Modeling Options** under the **Define** command.
- You must have the **Select** command button toggled on to edit the **Spans**.
- Click on the span (or spans) you want to edit to display its properties in the **Left Panel**.
- Click on  next to the strips **Moment Distribution** table.
- Then in **Moment Distribution** table in the **Span Left Panel**, simply change the desired factors.

## Supports

The corresponding **Support Left Panel** provides various options for effectively working with **Support**. You must have the **Select** command button toggled on to edit the **Support**.

### *Editing Support Elements*

To edit support elements:

- Click on the support (or supports) you want to edit to display its properties in the **Left Panel**.
- Then in the **Elements** tab in the **Span Left Panel**, simply change the desired parameter.
- Additionally, you can add new elements or remove existing elements to the selected support (or supports) by clicking on + or × next to the desired element, respectively.

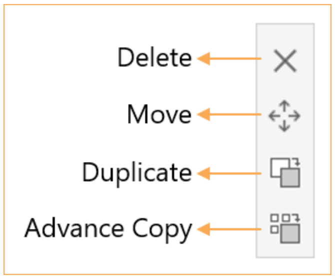
### *Editing Support Loads & Restraints*

To edit support loads & restraints:

- Click on the support (or supports) you want to edit to display its properties in the **Left Panel**.
- Click on the **Loads & Restraints** tab in the **Span Left Panel**, then simply change the load or restraint value as desired.
- Additionally, you can add new loads (or restraints) or remove existing loads (or restraints) to the selected support by clicking on + or × next to the desired load (or restraint), respectively.

#### 5.2.5.2. Using the Left Panel Toolbar

You must have the **Select** command button toggled on in order to use the tools available in the **Left Panel Toolbar**. You can use the tools in the **Left Panel Toolbar** to edit various model items.




**Delete**

The **Delete** command is active only when one or more supports are selected.

- Select the support or supports you want to remove from the model and click **Delete** to remove.

**Move**

The **Move** command is active only when one support is selected.

- Select the support you want to move and click the **Move** command.
- Specify the destination support to complete moving.

**Duplicate**

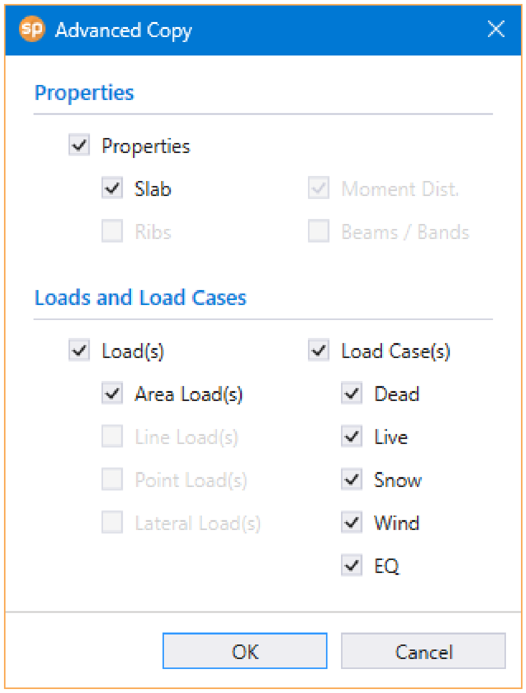
The **Duplicate** command is active only when one span or support is selected.

- Select the span or support you want to duplicate of and click the **Duplicate** command.
- Specify the destination span or support to complete duplication.

**Advance Copy**

The **Advanced Copy** command is active only when one span or support is selected.

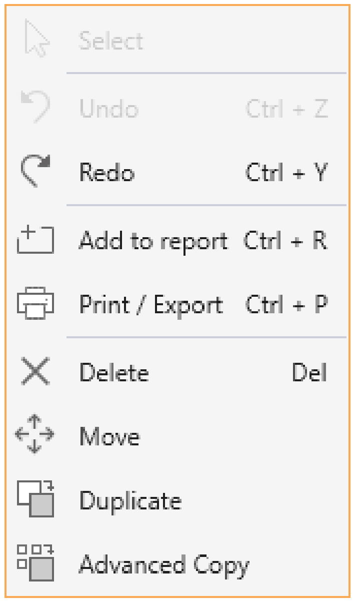
- Select the span or support you want to copy of and click the **Advanced Copy** command.
- Select the properties, load types and load cases you want to copy and click the **Ok** button.




- Specify the destination span or support to complete advanced copy.

### 5.2.5.3. Using the Right Click Menu at Viewport

All the tools in the **Left Panel Toolbar** are also available in the **Right Click** Menu at **Viewport** when the **Select** command button is toggled on.

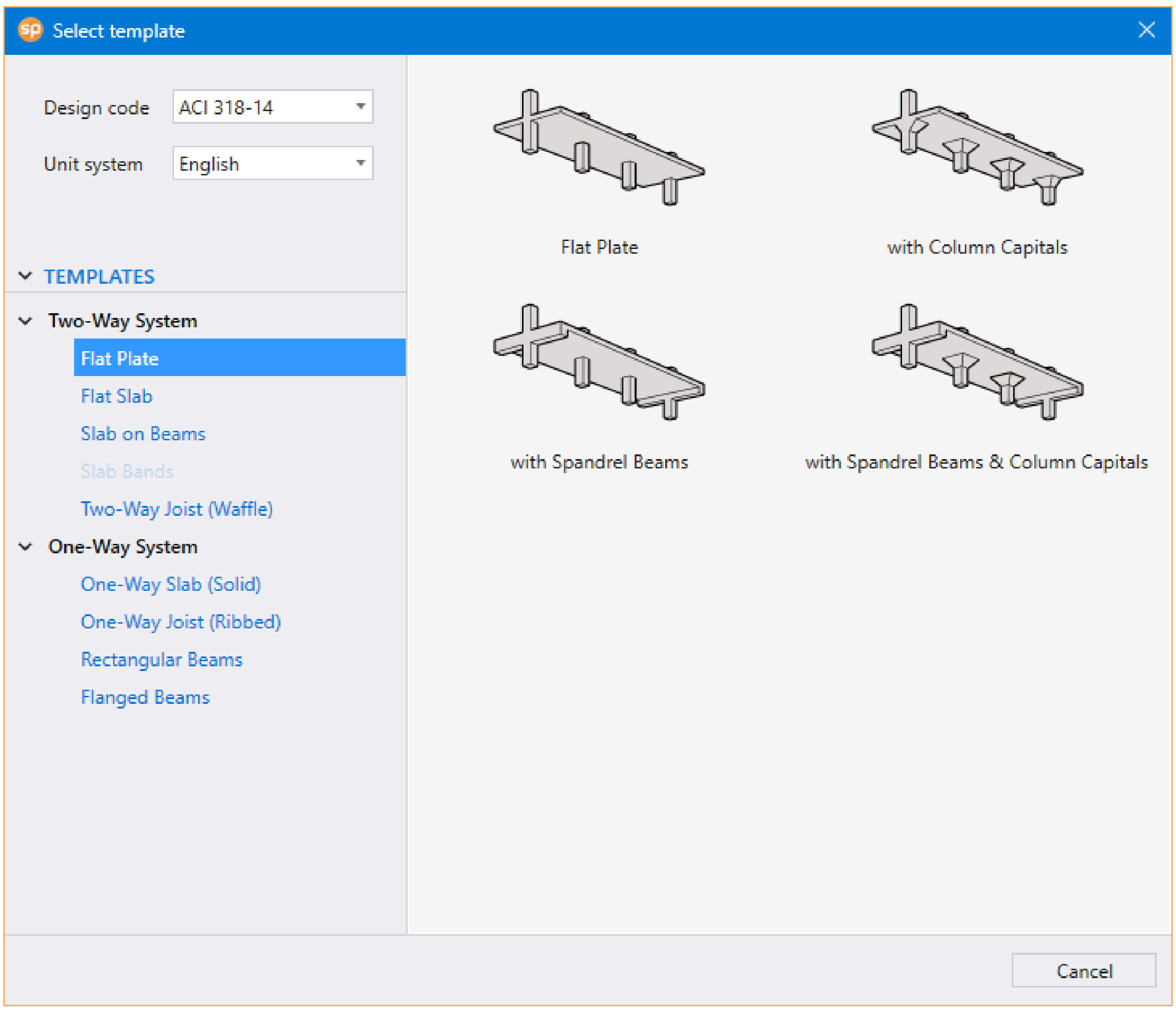


# 5.3. Modeling with Templates

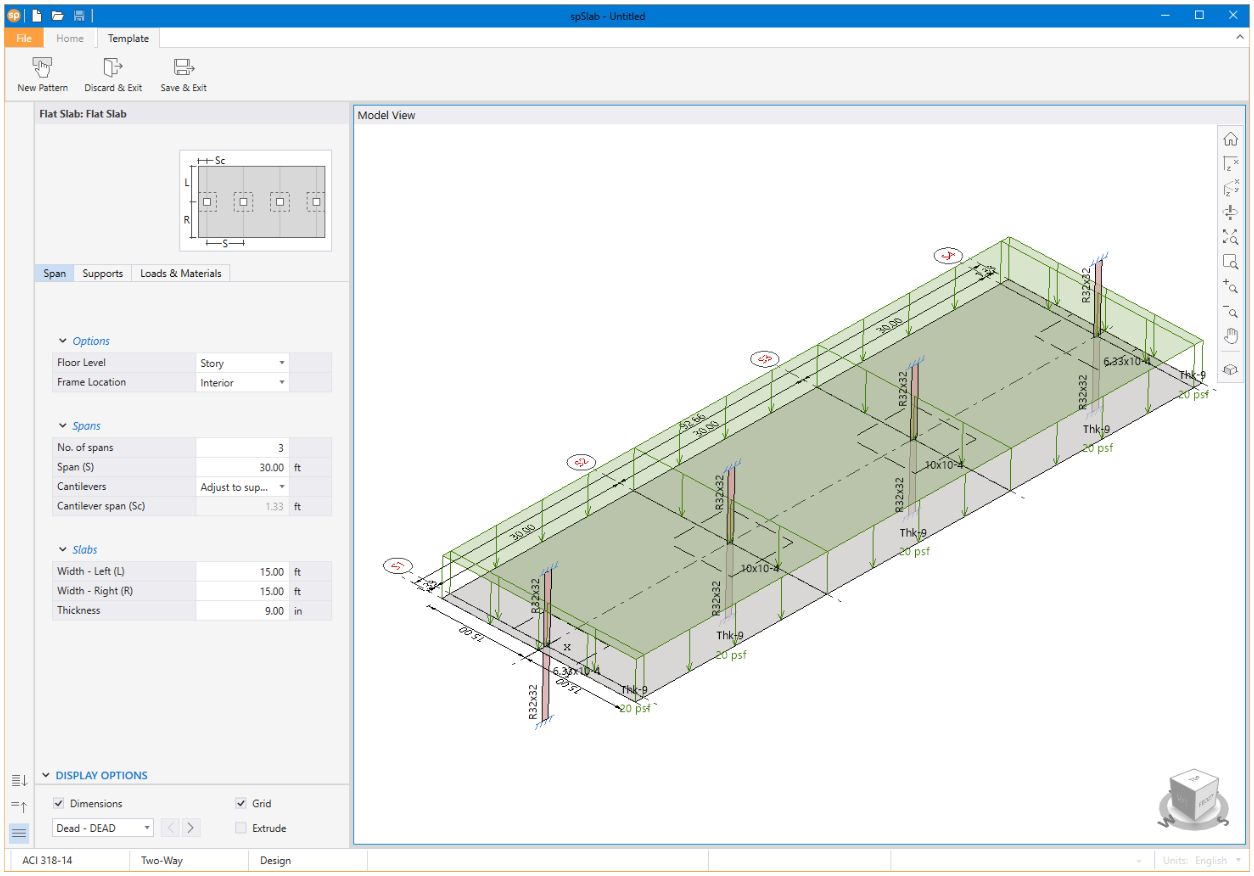
## 5.3.1. Utilizing Templates

Templates are an option for creating new models in the spSlab program. It enables the user to select from a set of pre-defined templates and edit them for quick model generation.

To begin, go to the **Start Screen** under **Projects** and select the **Templates** option. This will take you to the TEMPLATE selection Dialog Box.




Here you can select the desired template along with the DESIGN CODE and UNIT SYSTEM. Clicking on a template image will open the **Template Module** and load the selected Template.




Once you are done editing the template to reflect your project criteria, you can click the **Save & Exit** button to take it to spSlab for further modification or execution.

### 5.3.2. Template Ribbon

The **Template Ribbon** provides the following options:

#### 5.3.2.1. New Pattern

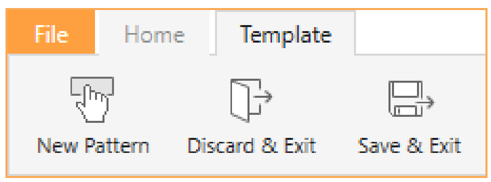
Opens the TEMPLATE Selection Dialog Box. Selecting a New template will discard the old template and load the new one.

#### 5.3.2.2. Discard & Exit

Discards the current template and exits to spSlab home screen.

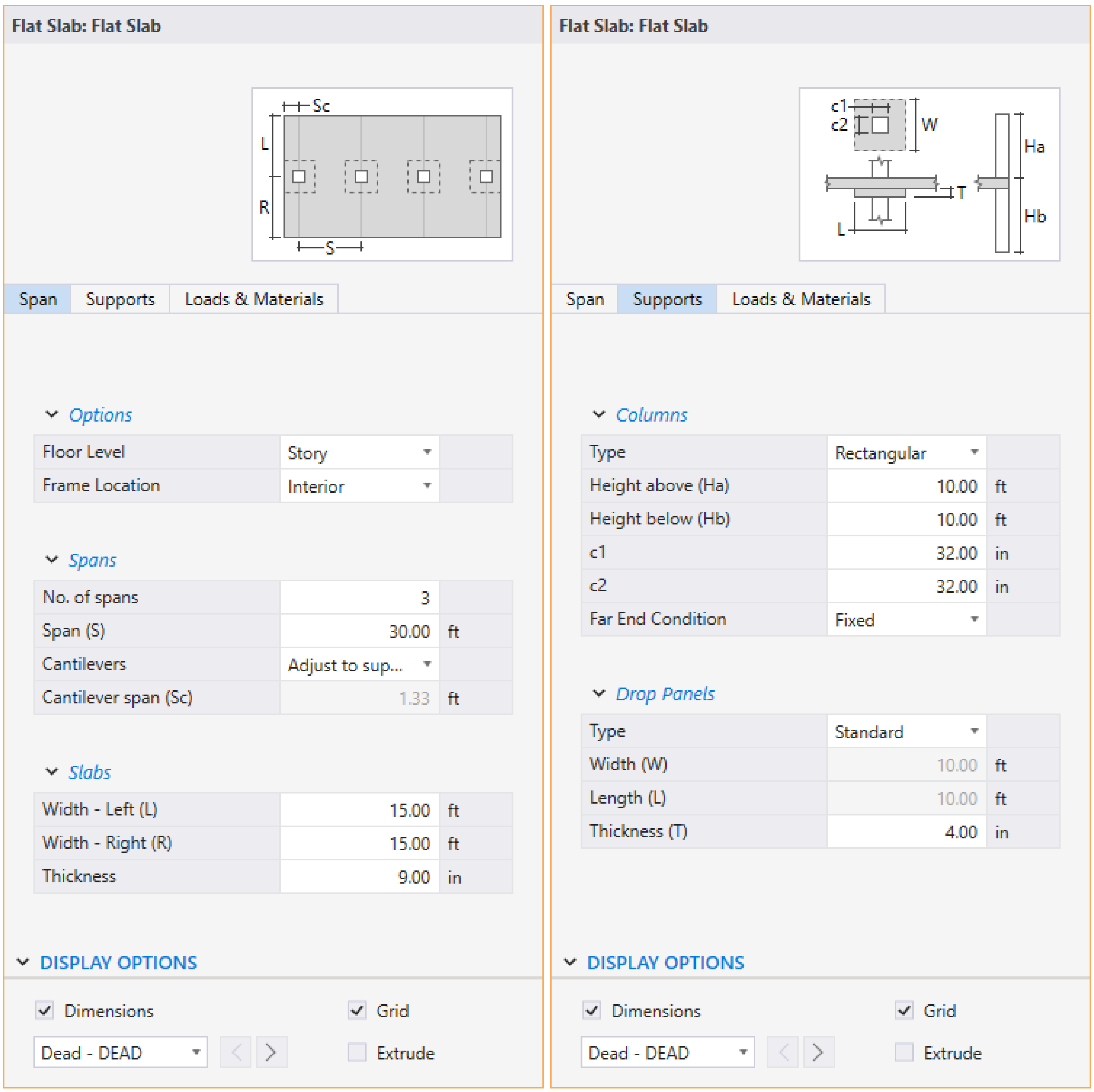
#### 5.3.2.3. Save & Exit

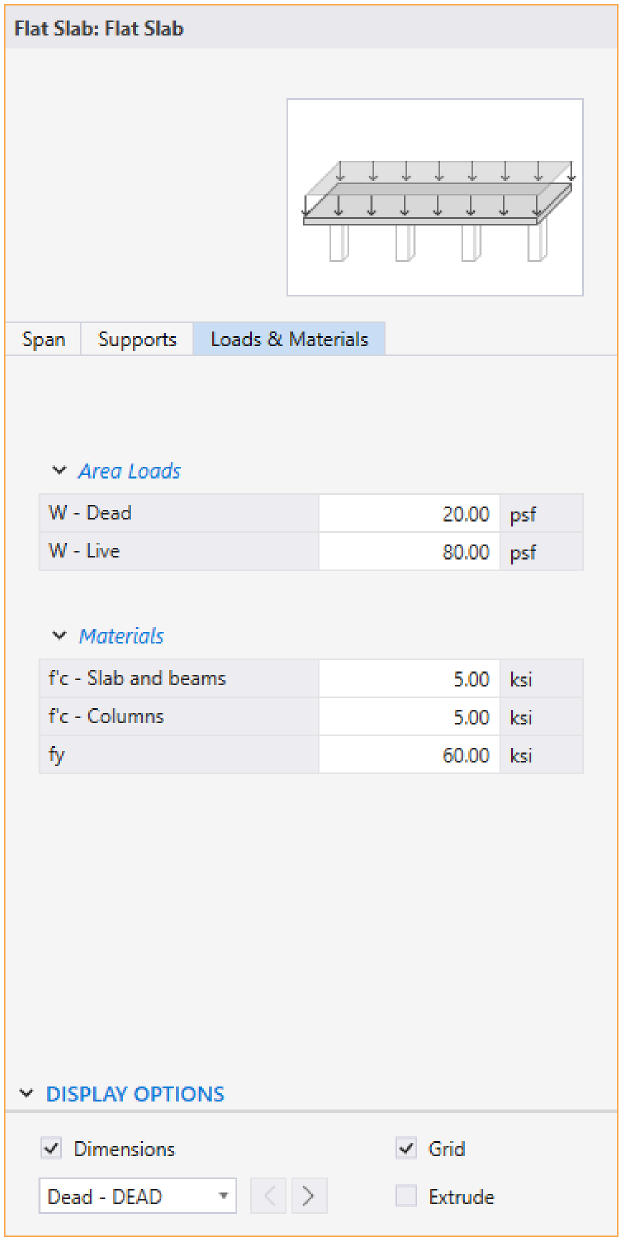
Imports the current template to spSlab.



### 5.3.3. Template Left Panel

The **Left Panel** lists various template properties that can be modified by the user. The bottom part of the **Left Panel** consists of **Display Options**. You can use these to toggle on/off several **Viewport** items and also switch between displaying Load Cases.

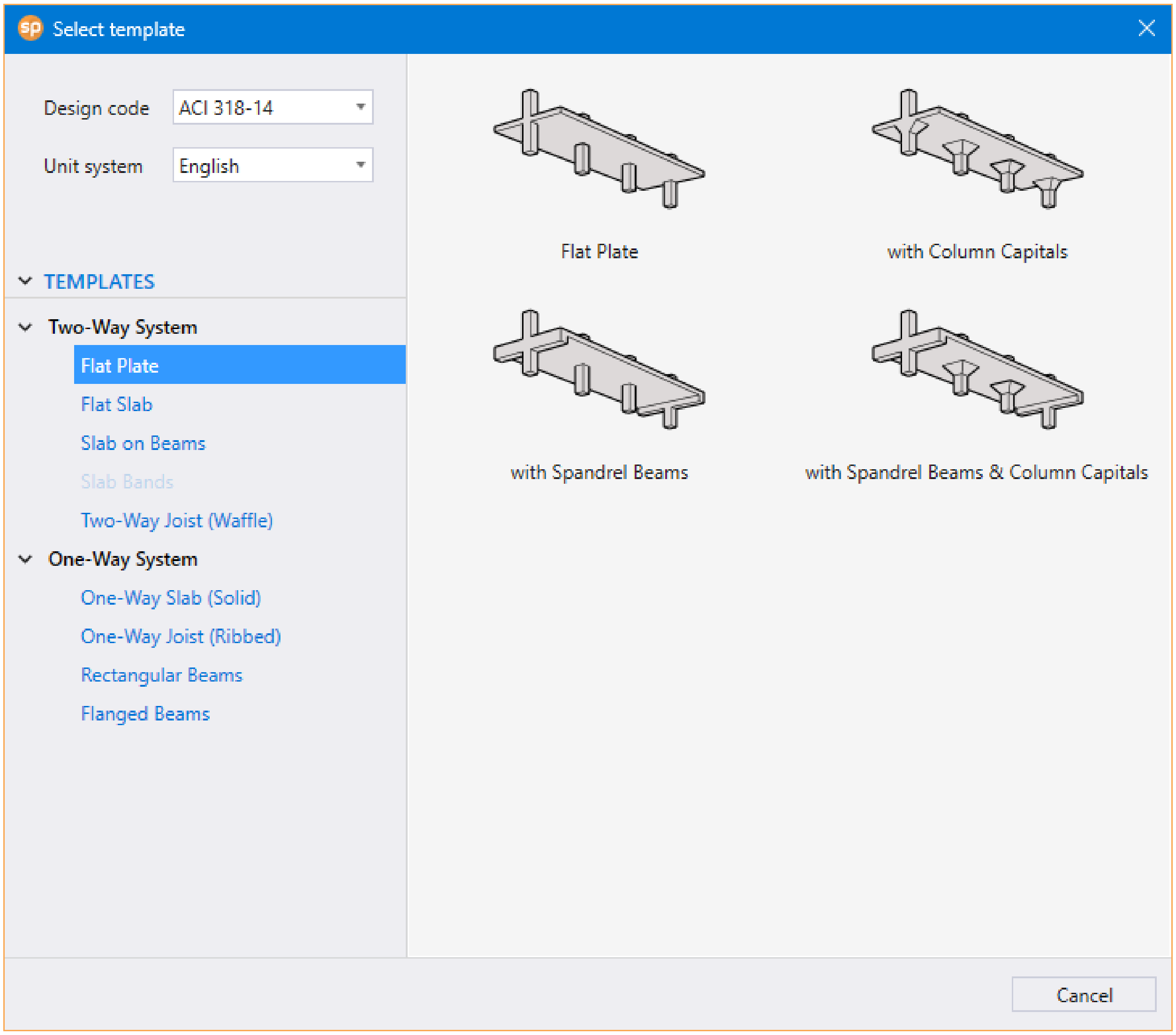



Flat Slab: Flat Slab
Span
Supports
Loads & Materials
Area Loads
W - Dead 20.00 psf
W - Live 80.00 psf
Materials
f'c - Slab and beams 5.00 ksi
f'c - Columns 5.00 ksi
fy 60.00 ksi
DISPLAY OPTIONS
Dimensions
Grid
Dead - DEAD
Extrude

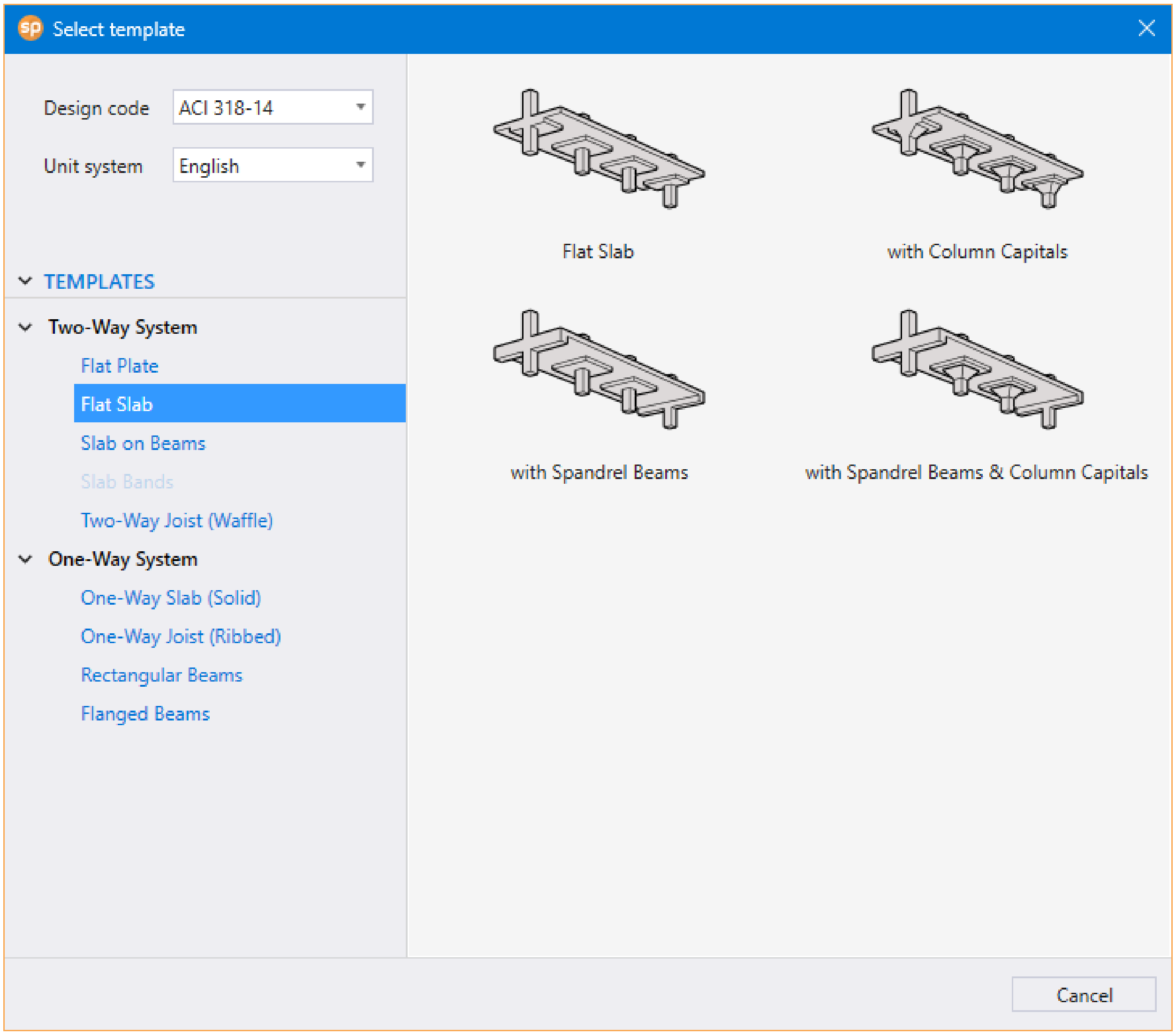
## 5.3.4. Types of Templates

### 5.3.4.1. Two-Way Systems

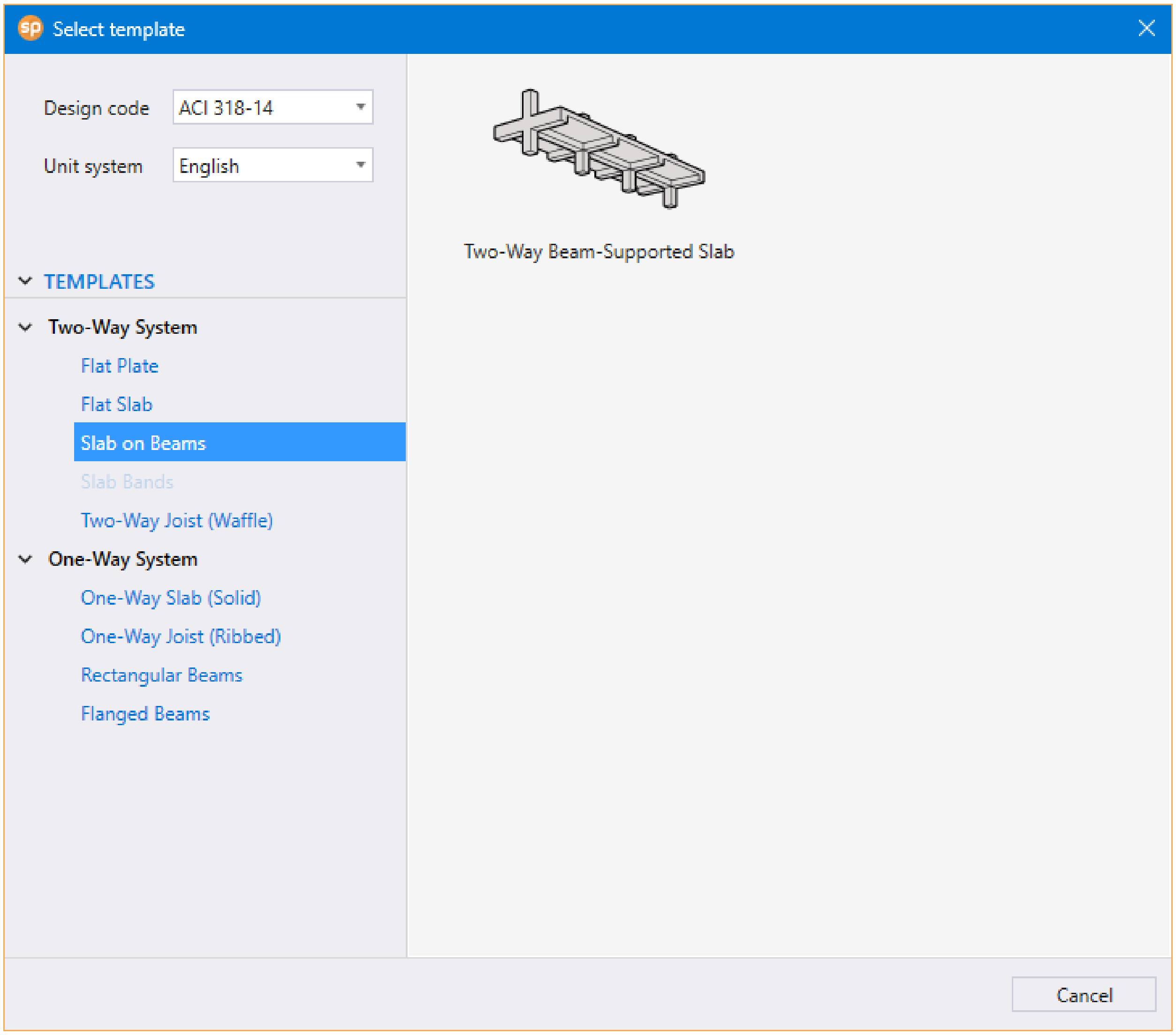
#### Flat Plate Systems



## Flat Slab Systems

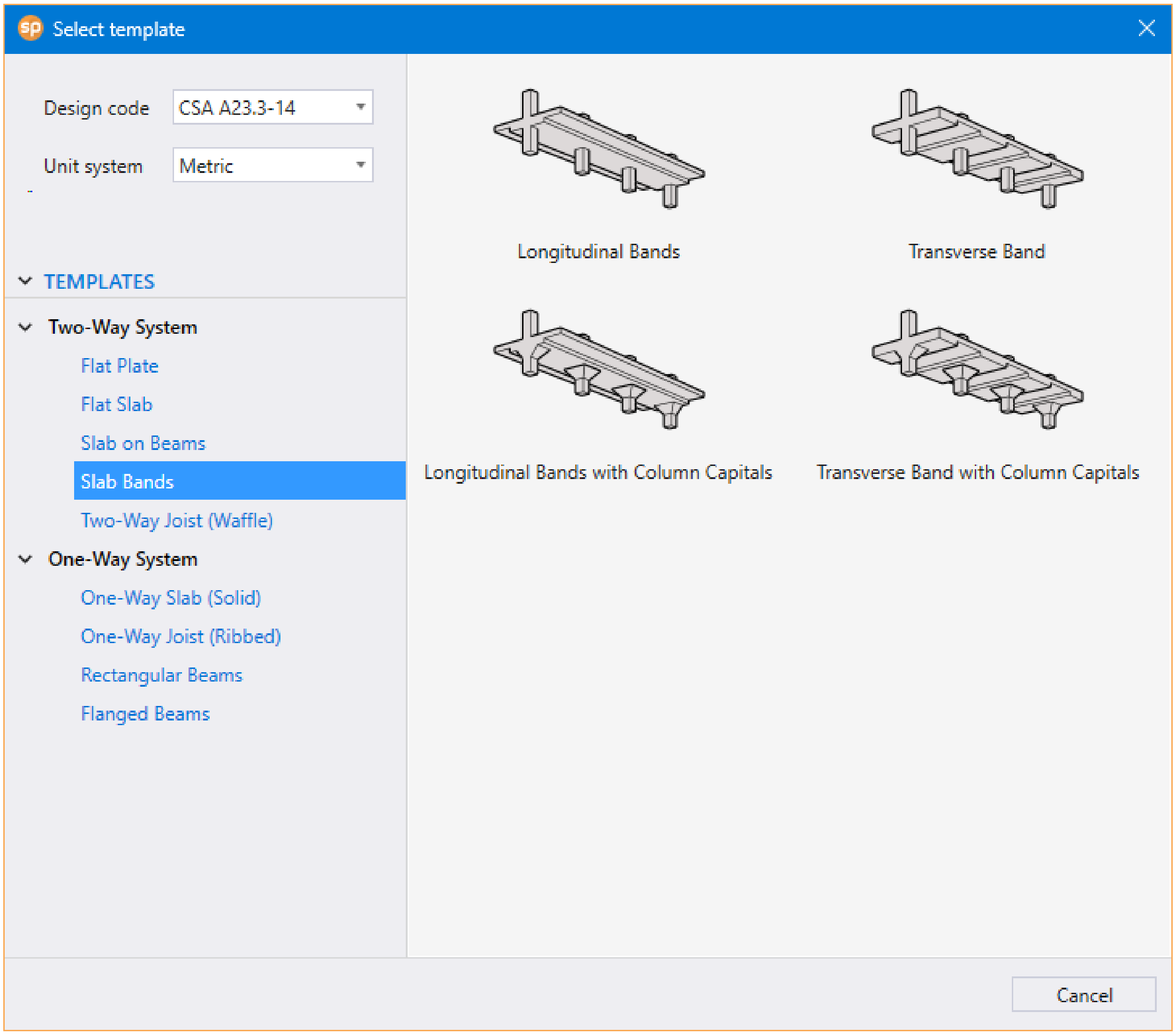


## Slab on Beams System

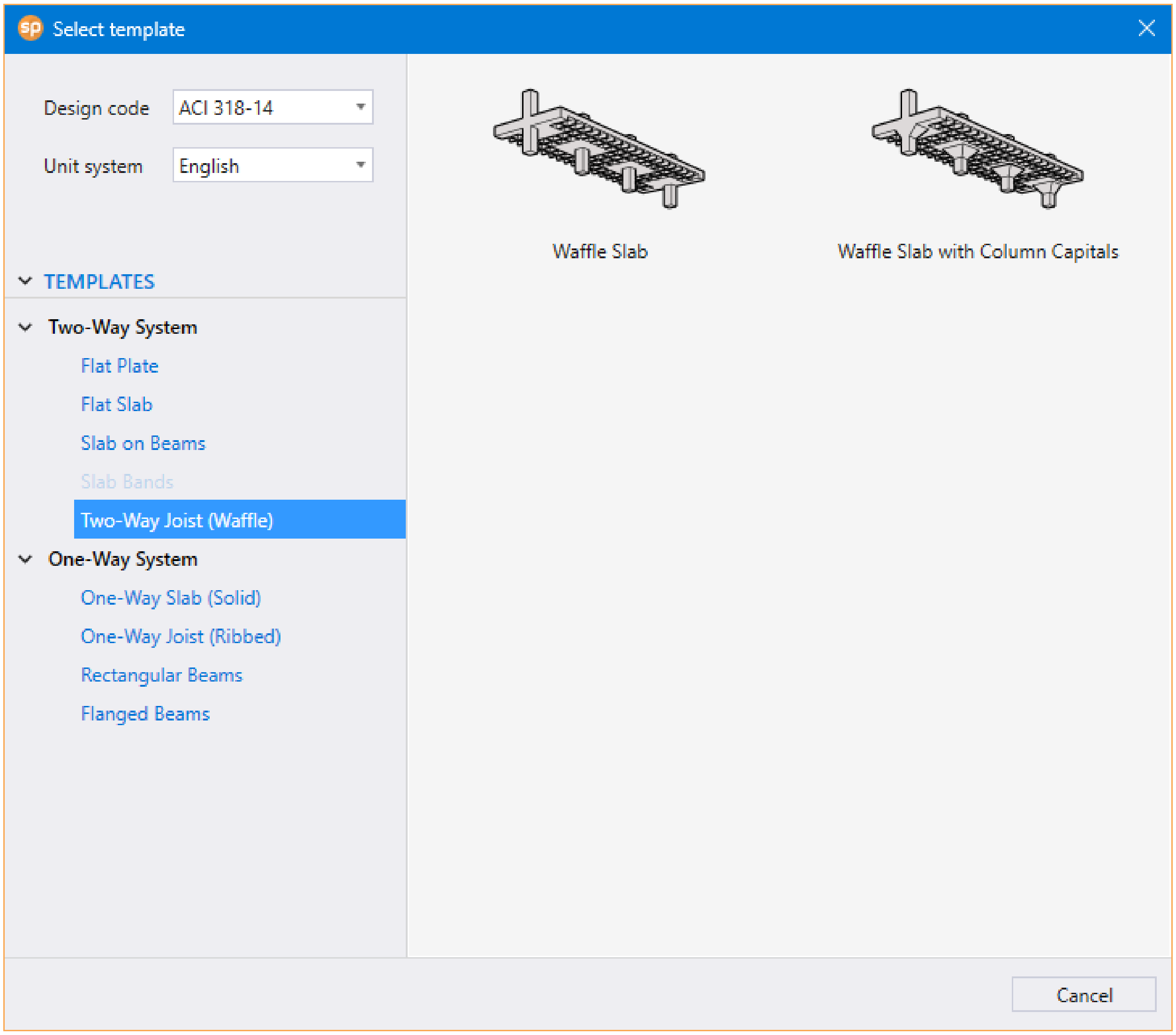


## Slab Bands Systems

These systems are only available when CSA A23.3-14 or CSA A23.3-04 are selected under **Design Code**.

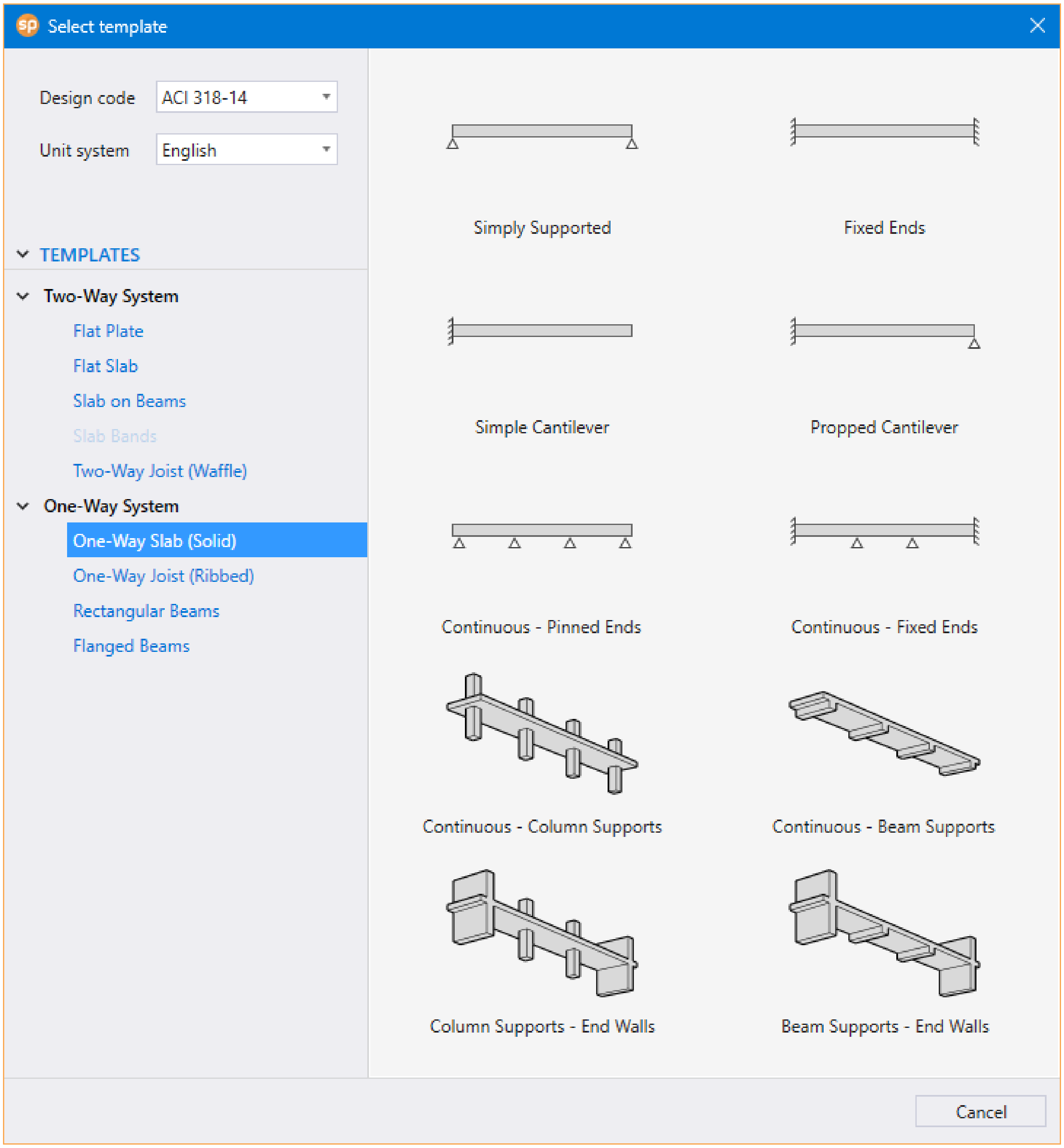


## Two-Way Joist (Waffle) Systems

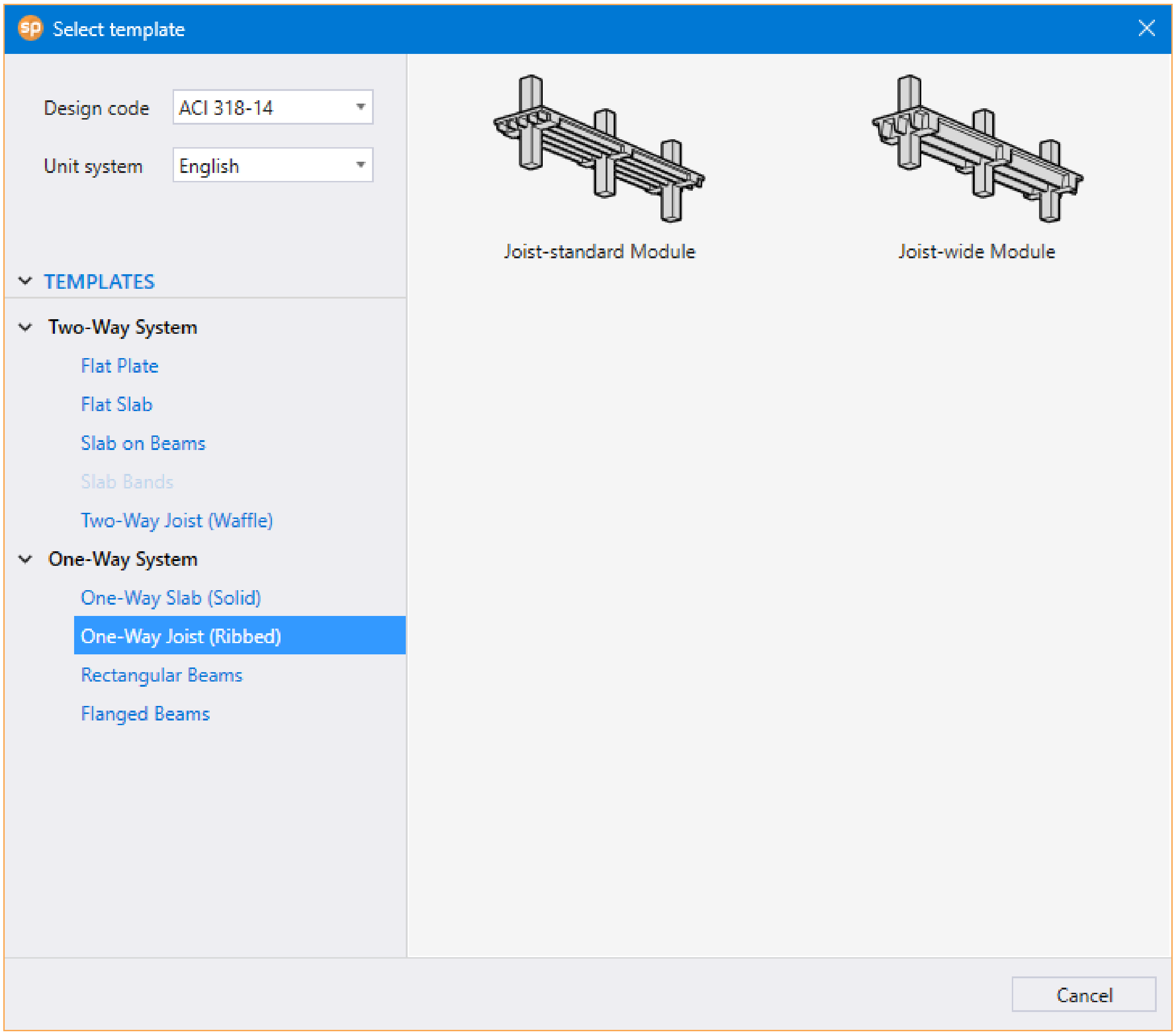


### 5.3.4.2. One-Way Systems

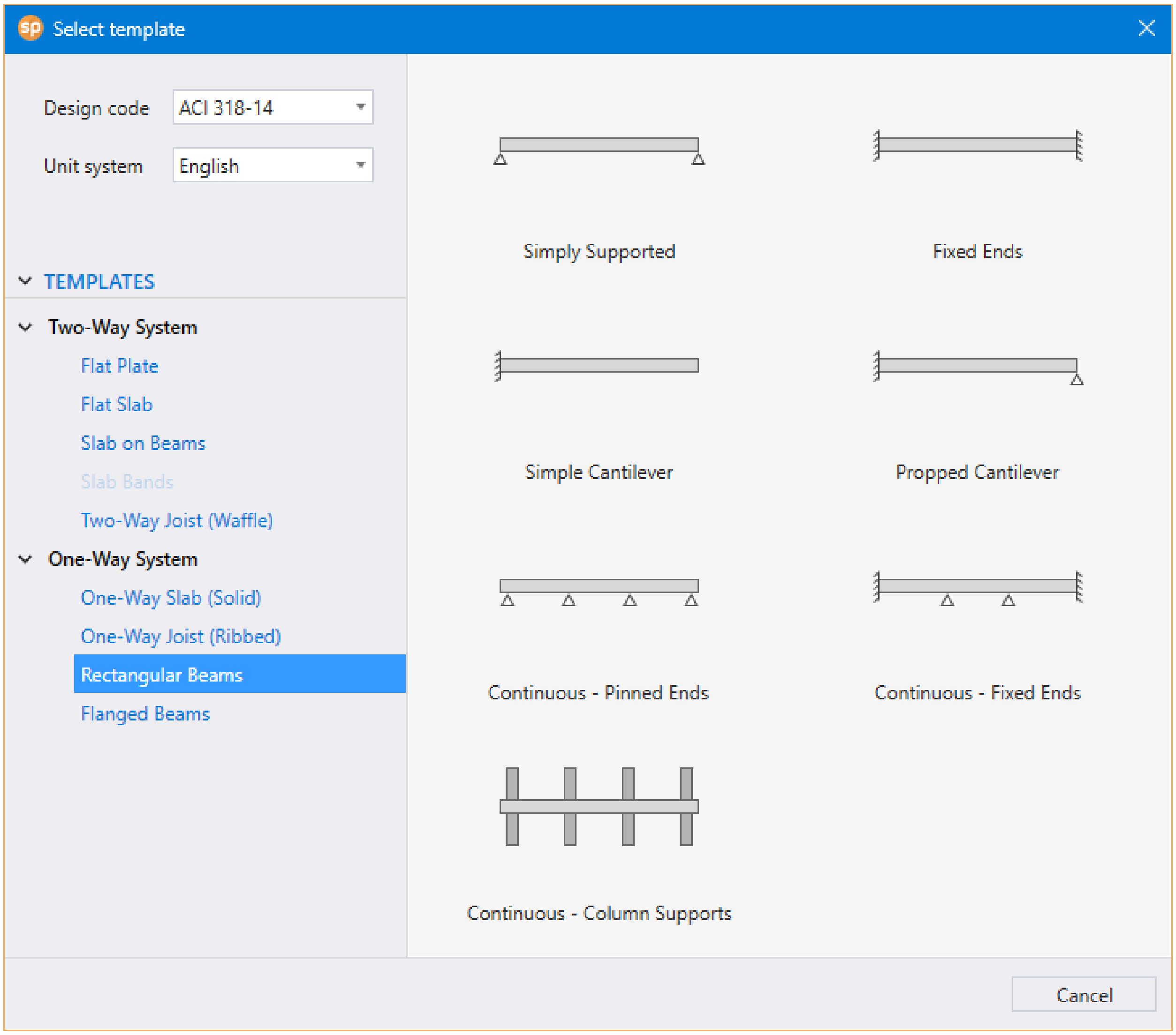
#### One-Way Slab (Solid) Systems



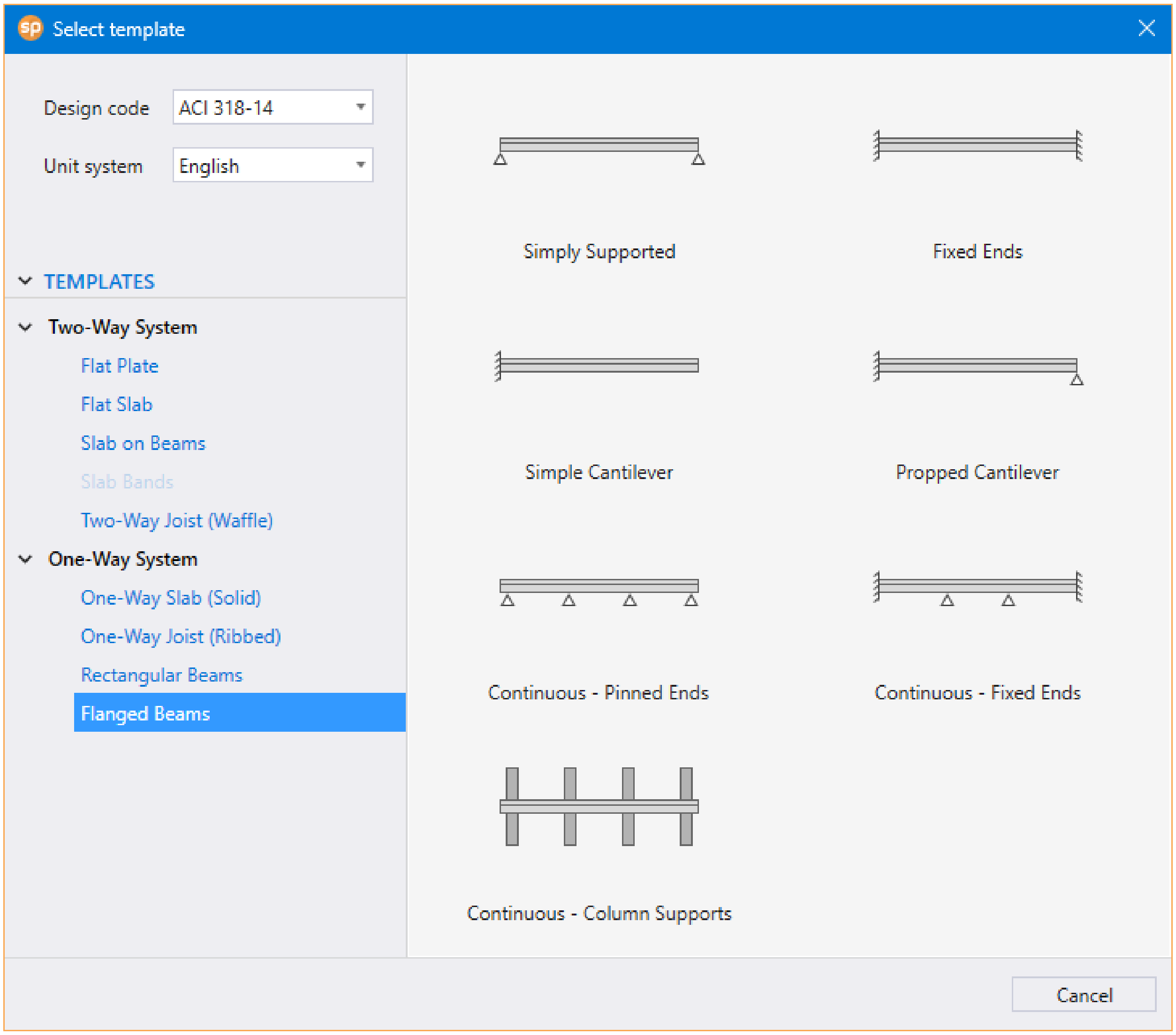
## One-Way Joist (Ribbed) Systems



## Rectangular Beams

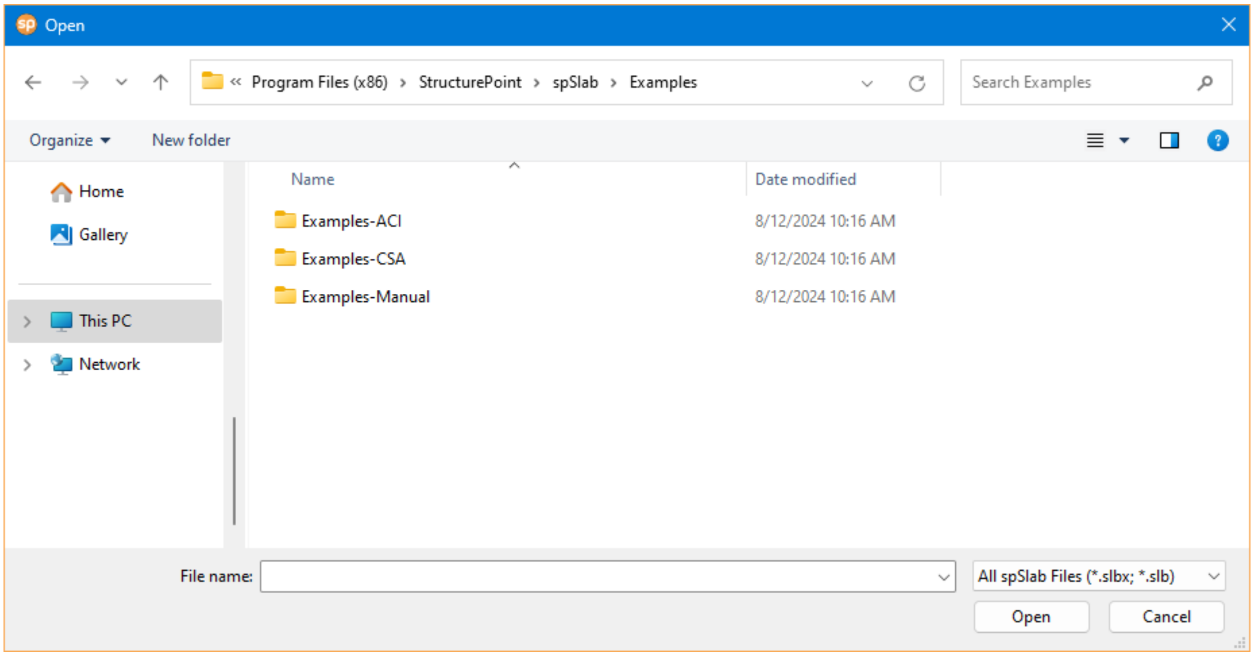


# Flanged Beams



# 5.4. Utilizing Predefined Examples

In the **Start Screen** under **Projects** select the **Examples** option. This will take you to the **Examples** folder under the spSlab installation folder.




The **Examples** folder contains predefined slab models that can be further utilized by the user.

CHAPTER

6

# MODEL SOLUTION

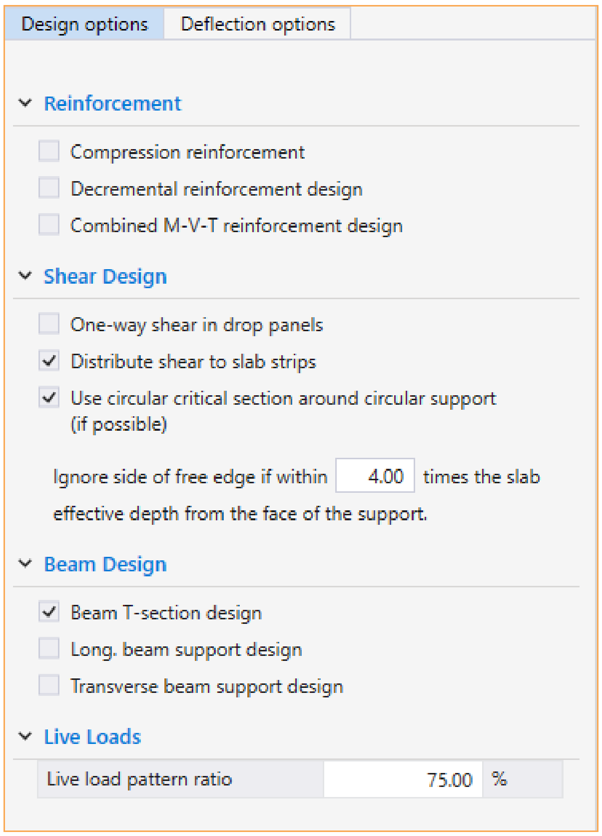
Once the model creation and development are completed, the analysis can begin using the spSlab Equivalent Frame Method (EFM) Solver by clicking on the **Solve** command. Solve Menu containing **Design Options** and **Deflection Options** will appear on the **Left Panel**.

Any solver warnings or errors encountered during the solution are issued in the **Solver Dialog** and recorded as solver messages in the results table.

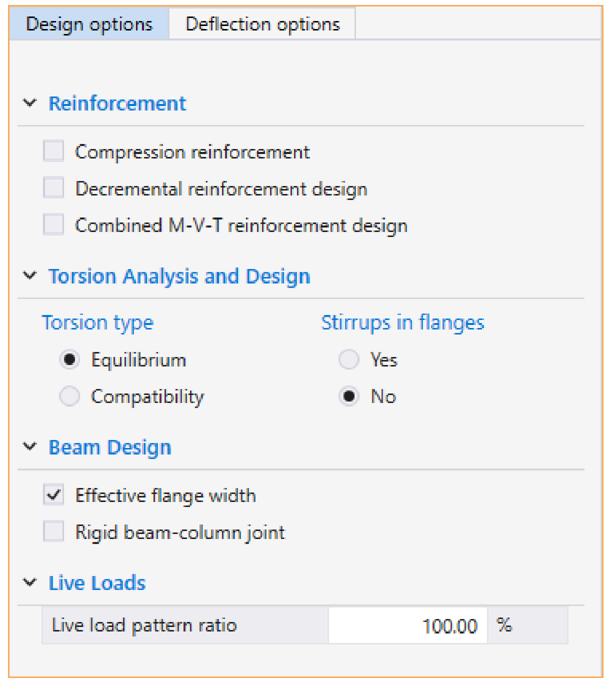
# 6.1. Design Options

The **Design Options** tab allows the user to select options and specify parameters that affect the analysis and design results. Changing these settings involves engineering judgment and so has to be done cautiously. The set of parameters is different for two-way and one-way systems.

Two-Way Systems




One-Way Systems




## 6.1.1. Reinforcement

- Check COMPRESSION REINFORCEMENT checkbox if it is to be considered when needed.
- Check DECREMENTAL REINFORCEMENT DESIGN to use alternative reinforcement design algorithm.
- Check COMBINED M-V-T REINF. DESIGN to proportion longitudinal reinforcement for combined action of flexure, shear, and torsion. This option is available only when CSA A23.3-14 or CSA A23.3-04 are selected.

### 6.1.2. Shear Design

These options are available only when TWO-WAY FLOOR SYSTEM **Run Option** is selected.

- Check ONE-WAY SHEAR IN DROP PANELS to include drop panel cross-section in slab one-way shear capacity calculations in support locations.
- Check DISTRIBUTE SHEAR TO SLAB STRIPS to distribute slab one-way shear between column and middle strips in proportion to moment distribution factors.
- Select whether circular critical section around circular supports is to be used or traditional equivalent rectangular critical section.
- Enter the multiplier that defines the distance between a column face and a free edge of a slab, within which a segment of punching shear critical section is to be ignored.

### 6.1.3. Torsion Analysis and Design

These options are available only when: ONE-WAY/BEAM FLOOR SYSTEM **Run Option** is selected, and YES is selected for CONSIDER TORSION **Run Option**.

- Select whether the TORSION TYPE is EQUILIBRIUM or COMPATIBILITY.
- Select YES or NO for STIRRUPS IN FLANGES option.

### 6.1.4. Beam Design

The following **Beam Design** options are available only when TWO-WAY FLOOR SYSTEM **Run Option** is selected.

- Check BEAM T-SECTION DESIGN to include portions of slab as flanges in beam cross-section for reinforcement design.
- Check LONG. BEAM SUPPORT DESIGN to include cross-section of longitudinal beam in reinforcement design for unbalanced moments over supports. This feature can be useful for slabs having wide longitudinal beams. When used together with USER STRIP DISTRIBUTION FACTORS, it can produce solutions consistent with the solutions for models

with longitudinal slab bands for CSA A23.3-14/04 code.

- Check TRANSVERSE BEAM SUPPORT DESIGN to include cross-section of transverse beam in reinforcement design for negative moments and unbalanced moments over supports. This feature is useful for slabs having wide transverse beams. When used together with USER STRIP DISTRIBUTION FACTORS, it can produce solutions consistent with the solutions for systems with transverse slab bands for CSA A23.3-14/04 code.

The following **Beam Design** options are available only when ONE-WAY/BEAM FLOOR SYSTEM **Run Option** is selected.

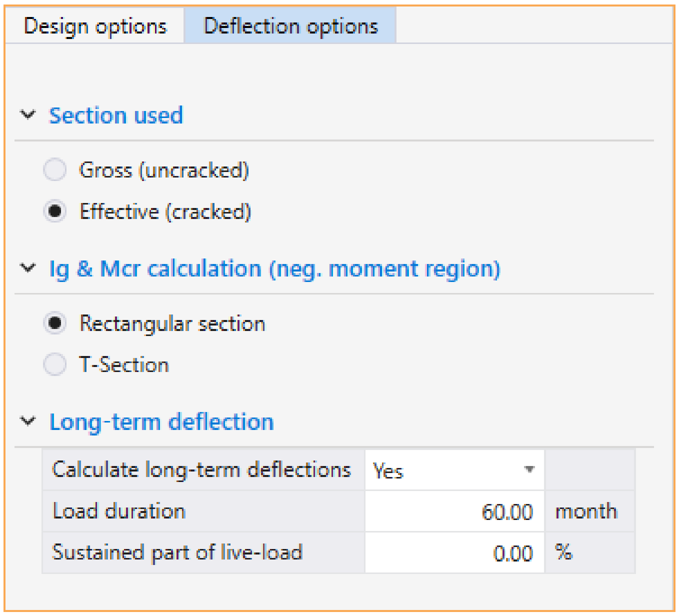
- Check EFFECTIVE FLANGE WIDTH if instead of the full flange width only the effective flange width is to be considered in the flexural design.
- Check RIGID BEAM-COLUMN JOINT to consider beam-column joint as rigid.

### 6.1.5. Live Loads

- Enter the live load pattern ratio. The default value is 75% for TWO-WAY FLOOR SYSTEM and 100% for ONE-WAY/BEAM FLOOR SYSTEM.

# 6.2. Deflection Options

The **Deflection Options** tab allows the user to select options and specify parameters that affect the analysis and design results. Changing these settings involves engineering judgment and so has to be done cautiously. The set of parameters is the same for two-way and one-way systems.




## 6.2.1. Section Used

- Choose if GROSS (UNCRACKED) or EFFECTIVE (CRACKED) sections are to be considered in the deflection calculations.

## 6.2.2. $I_g$ & $M_{cr}$ Calculation

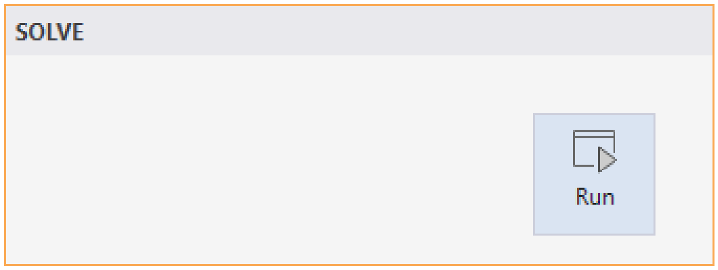
- Choose if in the case of a section with flanges in the negative moment region, only the web (RECTANGULAR SECTION) or the whole section (T-SECTION) is to be used to calculate the gross moment of inertia ($I_g$) and the cracking moment ($M_{cr}$).

### 6.2.3. Long-Term Deflection

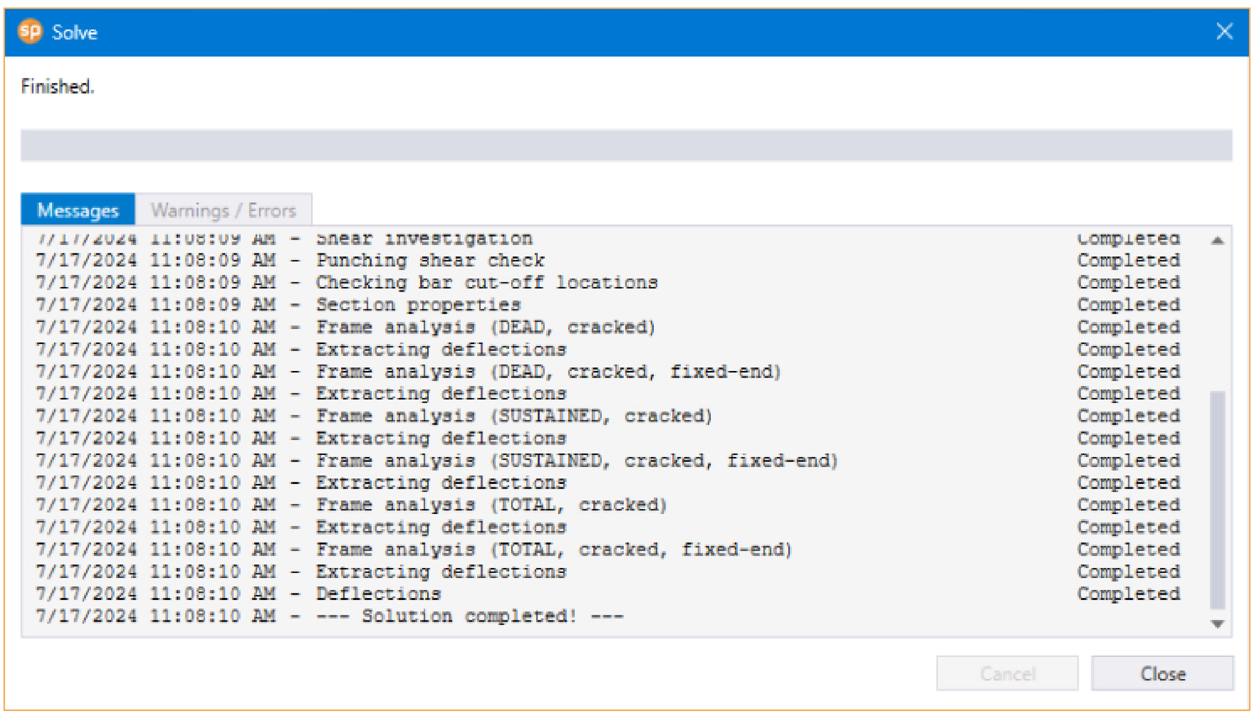
- Select YES for CALCULATE LONG-TERM DEFLECTIONS option if you want the program to calculate long-term deflections.
- Enter the LOAD DURATION in months. The default value is 60 months.
- Enter the percentage of the live load which is considered as sustained load (SUSTAINED PART OF LIVE-LOAD). The default percentage is 0%.

## 6.3. Running the Model

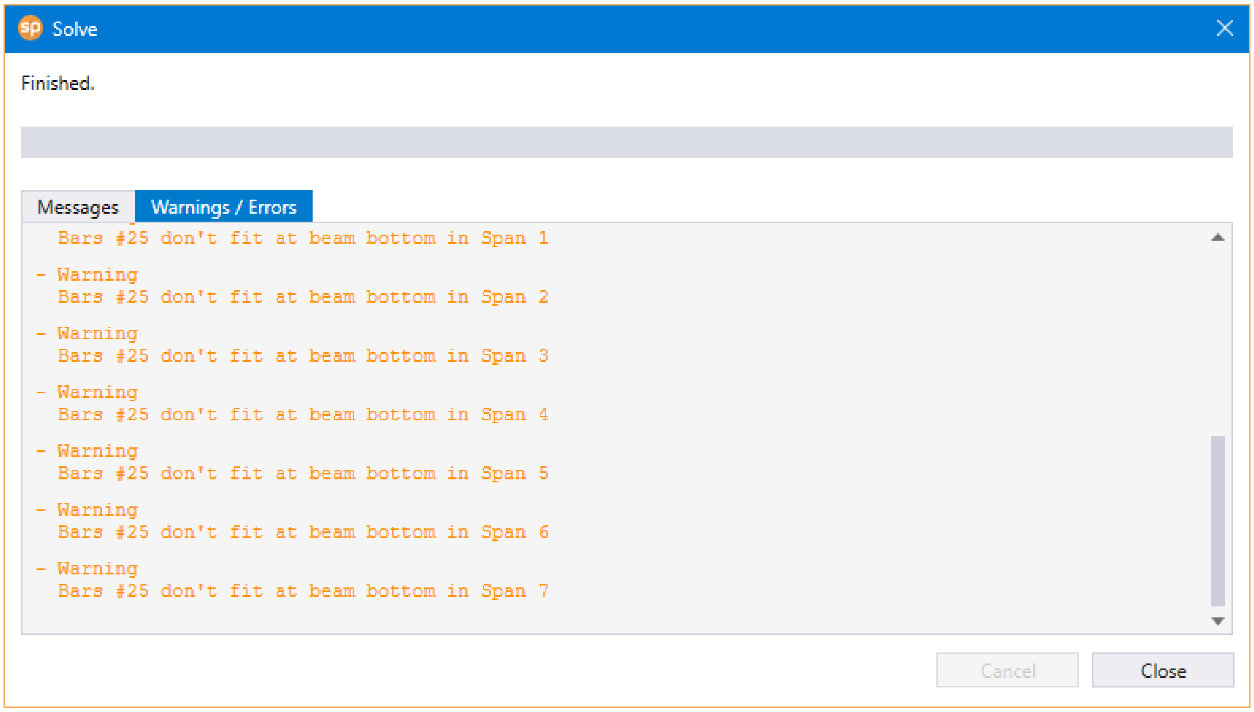
After inputting the model, the solver portion of the program can be invoked using the **Run** button in the **Solve** panel.




After you click the **Run** button, the program then switches control to the **Solver Module**. A dialog box reporting the progress and status of the solution is displayed under the **Messages** tab.




When the solution is successfully completed, the program automatically switches to the **Results** scope. Warnings and/or errors are displayed under the **Warnings/Errors** tab. Detailed information on the solution can be found in the **Solver Messages Table** in the **Tables** Window.


Solve
Finished.
Messages
Warnings / Errors
Bars #25 don't fit at beam bottom in Span 1
- Warning
Bars #25 don't fit at beam bottom in Span 2
- Warning
Bars #25 don't fit at beam bottom in Span 3
- Warning
Bars #25 don't fit at beam bottom in Span 4
- Warning
Bars #25 don't fit at beam bottom in Span 5
- Warning
Bars #25 don't fit at beam bottom in Span 6
- Warning
Bars #25 don't fit at beam bottom in Span 7
Cancel
Close

CHAPTER

7

# MODEL OUTPUT

The results of the analysis and following design and code calculations are presented by spSlab model output in two key categories.

1. **Tabular Output:** Text results organized in tables including all relevant exact numerical results formatted in columnar tables.

2. **Graphical Output:** Visual representations including diagrams of internal forces, moment capacity, shear capacity, deflections, and reinforcement details.

A detailed description of all the features of both output types is given below.

## 7.1. Tabular Output

The Tabular Output can be accessed through both the **Tables Module** and the **Reporter Module**. The **Tables Module** allows users to view and export output data at any stage of model development, while the **Reporter Module** is used for creating, exporting, and printing customized reports once the design is complete. Both modules share the same output sections, with a few distinctions: the **Reporter Module** includes additional sections for cover, contents, and screenshots, while the **Tables Module** includes a **Solver Messages** section to display warnings or error messages generated during model execution.

Diagram views are also available for selected output results to facilitate graphical analysis; however, final modeling decisions should be based on the comprehensive information provided in the tabular reports.

The Tabular output contains the following common input and results sections:

## 7.1.1. Input Echo

**Input Echo** section reports the data used in the analysis. Carefully check the contents of the section and compare it with the intended design model. This section contains the following input data blocks:

### 7.1.1.1. General Information

This block contains the information regarding the **Project** such as FILE NAME, PROJECT NAME, FRAME, ENGINEER, DESIGN CODE, UNITS, REINFORCEMENT DATABASE, MODE, NUMBER OF SUPPORTS, and FLOOR SYSTEM.

### 7.1.1.2. Solve Options

This block contains the information regarding to the **Solve Options** (**Design** and **Deflection Options**) input entered by the user.

### 7.1.1.3. Material Properties

This subsection has data blocks for CONCRETE: SLABS / BEAMS, CONCRETE: COLUMNS, and REINFORCING STEEL input data.

### 7.1.1.4. Reinforcement Database

This block contains the **Bar Set** input data such as SIZE, BAR DIAMETER, CROSS-SECTION AREA and UNIT WEIGHT for each bar.

### 7.1.1.5. Span Data

This subsection contains the information regarding to the **Spans** input data for spans utilized in the model. This subsection has data blocks for SLABS, LONGITUDINAL SLAB BANDS, and RIBS AND LONGITUDINAL BEAMS input data.

This subsection provides information about the span input data used in the model.

### 7.1.1.6. Support Data

This subsection contains the information regarding to the **Supports** input data for supports utilized in the model. This subsection has data blocks for COLUMNS, DROP PANELS, COLUMN CAPITALS, TRANSVERSE BEAMS, MOMENT REDISTRIBUTION LIMITS, and BOUNDARY CONDITIONS input data.

Notes: For circular column the transverse dimension $c_2$ is reported as zero. If dimensions of a drop panel are invalid it will be marked. Invalid or excessive drop panel geometry is not used in the analysis.

### 7.1.1.7. Load Data

This subsection contains the information regarding to the **Loads** input data for loads utilized in the model. This subsection has data blocks for LOAD CASES AND COMBINATIONS, AREA LOADS, LINE LOADS, POINT FORCES, POINT MOMENTS, LINE TORQUE, POINT TORQUE, SUPPORT LOADS, SUPPORT DISPLACEMENTS, and LATERAL LOAD EFFECTS input data.

### 7.1.1.8. Reinforcement Criteria

This subsection contains the information regarding to the **Reinforcement Criteria** input data for slabs, ribs, and beams reinforcement utilized in the model. This subsection has data blocks for SLABS & RIBS, LONGITUDINAL SLAB BANDS, and BEAMS input data.

### 7.1.1.9. Reinforcing Bars

This block is available only when Investigation Mode is selected. This subsection contains the information regarding to the **Rebars** input data for reinforcement utilized in the model. This subsection has data blocks for TOP BARS, BOTTOM BARS, TORSION BARS, and TRANSVERSE REINFORCEMENT input data.

Note: When switching from Design Mode to Investigation Mode, spSlab automatically assumes the results of the Design Mode as an input for Investigation Mode.

### 7.1.2. Design Results

This section contains the summary of the design results of the slab/beam system. The following paragraphs describe the blocks included in the section.

#### 7.1.2.1. Solver Messages

This block displays the progress and status of the solution. It also displays warnings or error messages generated during model execution.

#### 7.1.2.2. Moment Redistribution Factors

This block is only available for ONE-WAY/BEAM floor systems when MOMENT REDISTRIBUTION checkbox is selected.

The calculated moment redistribution factor (including undistributed ultimate moment, number of iterations, and net tensile strain in extreme tension steel), user limit, and applied moment redistribution factor for both sides of each supports are displayed.

#### 7.1.2.3. Strip Widths and Distribution Factors

This block is available only for TWO-WAY floor systems. It contains the information on design strip widths, moment distribution factors, and shear distribution factors (for CSA A23.3-14/04 standard and optionally for other standards if DISTRIBUTE SHEAR TO SLAB STRIPS is selected).

#### 7.1.2.4. Top Reinforcement

This block is available only when DESIGN run mode is selected. It reports the negative reinforcement requirements. The block contains the values of corresponding design strip widths (column, middle, and beam), maximum factored design moments per strip and critical location, minimum and maximum steel areas, spacing for bars selected based on required reinforcement area, steel areas required by ultimate condition, selected bar sizes and numbers. The quantities are given for left, center and right location of each span. For a detailed discussion, see Chapter 2, Section 2.4.1.

Note: This block does not include reinforcement quantities necessary to transfer unbalanced moments at supports. In case of CSA standard, the reported spacing is averaged between reinforcement placed in the $b_b$ band and in the remaining portion of the column strip outside of the $b_b$ band.

### 7.1.2.5. Top Bar Details and Development Lengths

The block contains a span-by-span listing of the longitudinal bars selected in column, middle and beam strips. This reinforcement schedule is intended as a guide for bar placement. In more complex cases the bar schedule selected by the program may have to be adjusted by the user for constructability reasons. The selected bar sizes are limited by user specified minimum and maximum sizes. Bar sizes and numbers are selected to satisfy the minimum and required steel areas in conjunction with the bar spacing requirements of the code. The program calculates the bar lengths based on the computed inflection points and the recommended minima of the code. The bar lengths are adjusted by appropriate development lengths. Hooks and bends are not included in bar length tables and figures. For beams, bars are placed in a single layer (see Figure 2.29), provided there is sufficient beam width. For a detailed discussion, see Chapter 2, Section 2.5.1.

Note: This block does not include additional reinforcement bars necessary to transfer negative unbalanced moment at supports.

### 7.1.2.6. Band Reinforcement at Supports

This block is available only when the CSA code is selected. This section describes how the negative reinforcement in column strips should be concentrated over supports. It reports the total width of the strip from which reinforcement is concentrated, the width of the $b_b$ band, and the remaining width. The total width of the subdivided strip will be equal to the column strip width when no wide beams (width greater than $b_b$) and no slab bands are present. If either one is present, then its width will be used. If a beam narrower than $b_b$ frames into an exterior support, then both the total strip width and the $b_b$ width will be reduced to the beam width.

The section also gives the area of reinforcement and the number of bars required in each strip. The sum of number of bars in the band strip and in the remaining strip should be equal to the total number of bars over each support in the strip from which the bars were concentrated. The total number of bars in this strip should also be consistent with the number of bars listed in the **Top Bar Details** dialog box.

Note: This output block does not include additional reinforcement bars necessary to transfer negative unbalanced moment at supports.

#### 7.1.2.7. Bottom Reinforcement

This block is available only when DESIGN run mode is selected. It reports the positive reinforcement requirements. The block contains the values of corresponding design strip widths (column, middle, and beam), maximum factored design moments per strip and critical location, minimum and maximum steel areas, spacing for bars selected based on required reinforcement area, steel areas required by ultimate condition, selected bar sizes and numbers. The quantities are given for mid-span regions of each span. For a detailed discussion, see Chapter 2, Section 2.4.1.

#### 7.1.2.8. Bottom Bar Details and Development Lengths

This block contains a span-by-span listing of the longitudinal bars selected in column, middle and beam strips. The reinforcement schedule is intended as a guide for bar placement. In more complex cases the bar schedule selected by the program may have to be adjusted by the user for constructability reasons. The selected bar sizes are limited by user specified minimum and maximum sizes. Bar sizes and numbers are selected to satisfy the minimum and required steel areas in conjunction with the bar spacing requirements of the code. The program calculates the bar lengths based on the computed inflection points and the recommended minima of the code. The bar lengths are adjusted by appropriate development lengths. Bottom bar development lengths are tabulated directly below the bottom bar details block. Hooks and bends are not included in bar length tables and figures. For beams, bars are placed in a single layer (see Figure 2.29), provided there is sufficient beam width. For a detailed discussion, see Chapter 2, Section 2.5.1.

### 7.1.2.9. Flexural Capacity

This block lists the selected top and bottom steel areas and corresponding negative and positive moment capacity values in each span. The data is subdivided between column, middle and beam strips. Each span is subdivided into segments reflecting the changes in geometry and bar placement.

### 7.1.2.10. Longitudinal Beam Combined M-V-T Capacity

This block is available if Combined M-V-T reinforcement design option is checked under CSA A23.3-04/14. It reports the requirement of top and bottom reinforcement for a longitudinal beam based on the required tension force due to the combined effects of moment, shear and torsion forces at top and bottom respectively.

### 7.1.2.11. Longitudinal Beam Transverse Reinforcement Capacity

This block is available only when Investigation Mode is selected and model contains longitudinal beam. It is applicable if Design Code is ACI 318, CSA A23.3-94, and CSA A23.3-04/14 given that Combined M-V-T reinforcement design option is unchecked. This block contains two subblocks namely Section Properties, and Beam Transverse Reinforcement Capacity.

### 7.1.2.12. Longitudinal Beam Transverse Reinforcement Demand and Capacity

This block is available only when Design Mode is selected and model contains longitudinal beam. It is applicable if Design Code is ACI 318, CSA A23.3-94, and CSA A23.3-04/14 given that Combined M-V-T reinforcement design option is unchecked. This block contains four subblocks namely Section Properties, Beam Transverse Reinforcement Demand, Beam Transverse Reinforcement Details, and Beam Transverse Reinforcement Capacity.

### 7.1.2.13. Beam Shear (and Torsion) Capacity

If torsion is not considered then this block lists the concrete section shear capacity $\phi V_c$, selected stirrup intensities and spacing, and corresponding beam shear capacity $\phi V_n$ values in each span. For CSA A23.3-14/04 code, the program additionally reports value of factor $\beta$. The maximum factored shear forces $V_u$ in beam strip along the span is also reported.

In the case of combined shear and torsion analysis (beams/one-way slab systems only), this block lists section properties, shear and torsion transverse reinforcement capacity, and longitudinal torsional reinforcement capacity. The provided and required capacities are expressed in terms of the provided and required areas of reinforcement.

### 7.1.2.14. Longitudinal Beam Shear and Torsion Reinforcement Required

This block is available only when Design Mode is selected, torsion is considered and model contains longitudinal beam. This block contains nine subblocks namely Section Geometrical Properties, Section Strength Properties, Transverse Reinforcement Demand, Required Longitudinal Reinforcement, Beam Transverse Reinforcement Details, Longitudinal Torsional Reinforcement Details, Beam Transverse Reinforcement Capacity (Required Area), Beam Transverse Reinforcement Capacity (Provided Area), and Beam Torsion Reinforcement Capacity.

### 7.1.2.15. Longitudinal Slab Band Shear Capacity

spSlab

This block is available only for two-way slab systems containing longitudinal slab bands in CSA A23.3-04/14. This block lists longitudinal slab band shear capacity $\phi V_c$ in each span.

### 7.1.2.16. Slab Shear Capacity

spSlab

This block lists the values of one-way slab shear capacity $\phi V_c$ in each span. For CSA A23.3-04 code, the program additionally reports value of factor $\beta$. The maximum factored shear force $V_u$ and the location of the critical section $X_u$ are also reported.

### 7.1.2.17. Flexural Transfer of Negative Unbalanced Moments

spSlab

This block contains the results for critical (effective) section width as per the code, width of the effective section on the tension side for negative unbalanced moments, distance to the centroid of reinforcement, the maximum negative unbalanced moment, the corresponding load combination and governing load pattern, the reinforcing steel area provided and additional steel required. The provided reinforcement area (main longitudinal bars) is reduced by the ratio of critical (effective) strip width to total strip width and does not include the required area due to unbalanced moments. The additional reinforcement is the difference between that required by unbalanced moment transfer by flexure and that provided for design bending moment. When additional reinforcement is required, it is selected based on the bar sizes already provided at the support. For a detailed discussion, see Chapter 2, Section 2.4.1, and Section 2.4.2.

### 7.1.2.18. Flexural Transfer of Positive Moments

spSlab

This block contains the results for critical (effective) section width as per the code, width of the effective section on the compression side for positive unbalanced moments, distance to the centroid of reinforcement, the maximum positive unbalanced moment, the corresponding load combination and governing load pattern, the reinforcing steel area provided and additional steel required. The provided reinforcement area (main longitudinal bars) is reduced by the ratio of critical (effective) strip width to total strip width and does not include the required area due to unbalanced moments. The additional reinforcement is the difference between that required by unbalanced moment transfer by flexure and that provided for design bending moment. When additional reinforcement is required, it is selected based on the bar sizes already provided at the support. For a detailed discussion, see Chapter 2, Section 2.4.1, and Section 2.4.2.

### 7.1.2.19. Punching Shear Around Columns

spSlab

The block contains two tables with values pertaining to punching shear check in critical sections around the columns. The first table lists geometrical properties of punching shear critical section. The reported properties of the critical section are overall dimensions in the direction of analysis, $b_1$, and in the perpendicular direction, $b_2$, perimeter, $b_0$, location of centroid with respect to column center line, $CG$, average distance from the slab bottom to centroid of the slab tension reinforcement, $d_{avg}$, distance from centroid to the left, $c_{left}$, and right, $c_{right}$, edge of critical section, area of concrete resisting shear transfer, $A_c$, and moment of inertia of critical section, $J_c$. The second table lists two sets of punching shear calculations – direct shear alone and direct shear with moment transfer. The output contains the values of the allowable shear stress $\phi v_c$, reactions $V_u$, unbalanced moments $M_{unb}$, governing load pattern, fraction of unbalanced moment $\phi V$, punching shear stress $v_u$. The calculation for moment transfer adjusts the unbalanced moment to the centroid of the critical section. The "shear transfer" is the unbalanced moment multiplied by $\gamma_v$. When calculated shear stress $v_u$ exceeds the allowable value $\phi v_c$, the program prints a warning flags for this support. For a detailed discussion, see Chapter 2, Section 2.3.7.

### 7.1.2.20. Punching Shear Around Drops

The block contains two tables with values pertaining to punching shear check in a critical section around the drop panels. The first table lists geometrical properties of punching shear critical section (see description in the Punching shear around Columns block). The second table displays the reactions $V_u$, governing load pattern, the punching shear stress around the drop $v_u$, and the allowable shear stress $\phi v_c$. When calculated shear stress $v_u$ exceeds the allowable value $\phi v_c$, the program prints a warning flags for this drop panel. For a detailed discussion, see Chapter 2, Section 2.3.7.

### 7.1.2.21. Integrity Reinforcement at Supports

This section is available only when the CSA code is selected. It lists the shear transferred to the column and the minimum area of bottom reinforcement crossing one face of the periphery of a column and connecting slab to the column to provide structural integrity. For a detailed discussion, see Chapter 2, Section 2.5.2.

### 7.1.2.22. Corner Reinforcement

This block refers to the reinforcement required in the exterior corners of a slab with beams between columns. The ratio of flexural stiffness of beam section to flexural stiffness of slab is listed as well as the area of reinforcement and the distance over which the reinforcement is required. The area applies to each layer of reinforcement in each direction. For a detailed discussion, see Chapter 2, Section 2.5.3.

### 7.1.2.23. Shear Resistance at Corner Columns

This section is available only when the CSA code is selected in design mode. It reports results of one-way shear check at corner columns. The results include the factored shear resistance and the factored shear force at the column. Also, the minimum length of the critical shear section and, for the 1994 edition, the angle at which the minimum length is obtained are listed. For a detailed discussion, see Chapter 2, Section 2.3.7.6 in Section 2.3.7.

### 7.1.2.24. Material Takeoff

This block lists the approximate total and unit quantities of concrete, and reinforcement. Note that the reinforcement estimate is for one direction only and ignores items such as hooks, bends, and waste. For a detailed discussion, see Chapter 2, Section 2.6.11.

### 7.1.3. Deflection Results: Summary

**Deflection Results: Summary** section reports the summary of the deflection results of the slab system. This section contains the following output blocks:

#### 7.1.3.1. Section Properties

This subsection has output summary blocks of FRAME SECTION PROPERTIES, for positive and negative moments, FRAME EFFECTIVE SECTION PROPERTIES for load levels, and STRIP SECTION PROPERTIES AT MIDSPAN (two-way systems only).

#### 7.1.3.2. Instantaneous Deflections

This subsection has output summary blocks of EXTREME INSTANTANEOUS FRAME DEFLECTIONS (COLUMN STRIP DEFLECTIONS and MIDDLE STRIP DEFLECTIONS only for two-way systems).

#### 7.1.3.3. Long-Term Deflections

This subsection, if selected in **Deflection Options**, has output summary blocks of LONG-TERM DEFLECTION FACTORS (COLUMN STRIP DEFLECTION FACTORS and MIDDLE STRIP DEFLECTION FACTORS only for two-way systems) and EXTREME LONG-TERM FRAME DEFLECTIONS (COLUMN STRIP DEFLECTIONS and MIDDLE STRIP DEFLECTIONS only for two-way systems).

If the deflection option GROSS (UNCRACKED) section is selected, only gross moment of inertia, $I_g$, is reported in the **Section Properties** table and the values of all deflections reported are based on gross section properties. If deflection option EFFECTIVE (CRACKED) section is used, the values of deflections reported are based on averaged effective moments of inertia, $I_{e,avg}$, which are then reported in the **Section Properties** table together with other properties of cracked sections. For a detailed discussion, see Chapter 2, Section 2.3.10.3.

## 7.1.4. Detailed Results

### 7.1.4.1. Column Forces and Redistributed Column Forces

Sections **Column Forces** and **Redistributed Column Forces** present the summary of axial forces (reactions) and bending moments in bottom and top columns and in springs attached to the column-slab joints. Also, moments at far ends of columns are reported. All reported values represent forces and moments at column ends, i.e. at joint level (not at slab or drop panel surface level). If moment redistribution is selected (beams/one-way slab systems only) both redistributed and un-redistributed values can be included. The values reported represent the loading of a single floor only. Any actions on the columns from the floors above must be added to this story's actions to properly analyze/design the columns. The output contains column axial forces and moments due to all load cases, including all live load patterns, and all load combinations. Positive axial forces mean compression and positive moments mean that fibers on the left hand side are in tension for top columns and for bottom column fibers on the right hand side are in tension. Also, reactions of additional translational and rotational springs applied at joints are reported in this block. Positive values mean upward translational spring reaction and clockwise rotational spring reaction.

### 7.1.4.2. Non – Redistributed and Redistributed Internal Forces: M – V

#### Load Cases

This section presents the summary of unfactored bending moments and shear forces for individual load cases including selfweight, dead load, live load and lateral cases. The reported values are presented using span-by-span segmental approach. If moment redistribution is selected (beams/one-way slab systems only) both redistributed and un-redistributed values can be included.

#### Load Combinations

This section presents the summary of bending moments and shear forces for each load combination. The reported values for each load combination are presented using span-by-span segmental approach. The negative and positive values of bending moments and shear forces are presented in separate columns in order to provide consistent format with enveloped output. If moment redistribution is selected (beams/one-way slab systems only) both redistributed and un-redistributed values can be included.

### Envelopes

This section presents the summary of bending moments and shear forces for envelope of all load combinations. The reported values are presented using span-by-span segmental approach. The negative and positive values of bending moments and shear forces are presented in separate columns for user convenience. The factored values presented in this section are used for design purposes (longitudinal and transverse reinforcement). If moment redistribution is selected (beams/one-way slab systems only) both redistributed and un-redistributed values can be included.

## 7.1.4.3. Internal Forces: T

### Load cases

This section presents the summary of unfactored beam torsion forces (beams/one-way slab systems with torsion analysis and design only) for individual load cases including selfweight, dead load, live load and lateral cases. The reported values are presented using span-by-span segmental approach.

### Load Combinations

This section presents the summary of beam torsion forces (beams/one-way slab systems with torsion analysis and design only) for each load combination. The reported values for each load combination are presented using span-by-span segmental approach. The negative and positive values of torsion forces are presented in separate columns in order to provide consistent format with enveloped output.

### Envelopes

This section presents the summary of beam torsion forces (beams/one-way slab systems with torsion analysis and design only) for envelope of all load combinations. The reported values are presented using span-by-span segmental approach. The negative and positive values of torsion forces are presented in separate columns for user convenience. The factored values presented in this section are used for design purposes (longitudinal and transverse reinforcement).

#### 7.1.4.4. Deflections – Load Cases

This section presents the summary of instantaneous deflections for unfactored (service) load cases including selfweight and dead load (DL), live load (LL), sustained load (DL + LLsustained), and total load (DL + LL) cases, and summary of long-term deflections for unfactored incremental and total deflections for one-way systems. For two-way systems, instantaneous frame deflections for fixed-end, end-rotation, and total (fixed-end and end rotation combined), instantaneous strip deflections, and long-term strip deflections. The reported values are presented using span-by-span segmental approach. For a detailed discussion, see Chapter 2, Section 2.3.10.

#### 7.1.4.5. Required Reinforcement

This section presents the summary of enveloped design moments and the required areas of longitudinal reinforcement required for flexure. If combined M-V-T option (available only for beam design/investigation per CSA A23.3-04) is selected in the **Solve Option** window then longitudinal reinforcement required for combined flexure, shear, and torsion (M-V-T) is also reported with the corresponding values of bending moment, shear force, and torsional moment. The values are tabulated for every design strip at every design segment.

# 7.2. Graphical Output

The graphical output is organized into diagrams that may be viewed, printed, exported or added to Report. spSlab provides the following diagrams:

## 7.2.1. Internal Forces

This graphical view displays the internal shear force, the internal bending moment and the torsional moment diagrams for ultimate load envelope or any individual ultimate load combinations.

## 7.2.2. Moment Capacity

This graphical view displays the design strips moment capacity diagrams for any span. For beams designed/investigated per CSA A23.3-14/04, longitudinal reinforcement capacity due to combined M-V-T action is also displayed.

## 7.2.3. Shear Capacity

This graphical view displays the design strips one-way shear (and torsion) capacity diagrams for any span.

## 7.2.4. Deflection

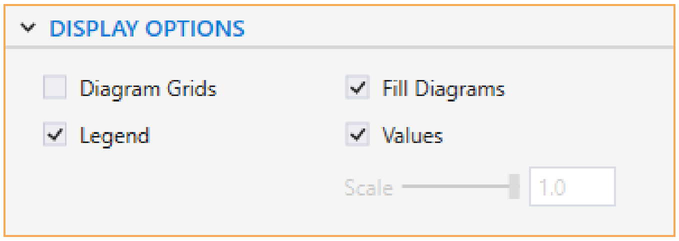
This graphical view displays instantaneous deflection diagrams for any span.

## 7.2.5. Reinforcement

This graphical view displays the design strips flexural and shear reinforcement diagrams for any span.

## 7.2.6. Diagrams Display Options

The diagrams **Display Options** allow the user to control the view of DIAGRAM GRIDS, LEGEND, FILL DIAGRAMS, VALUES, and SCALE.

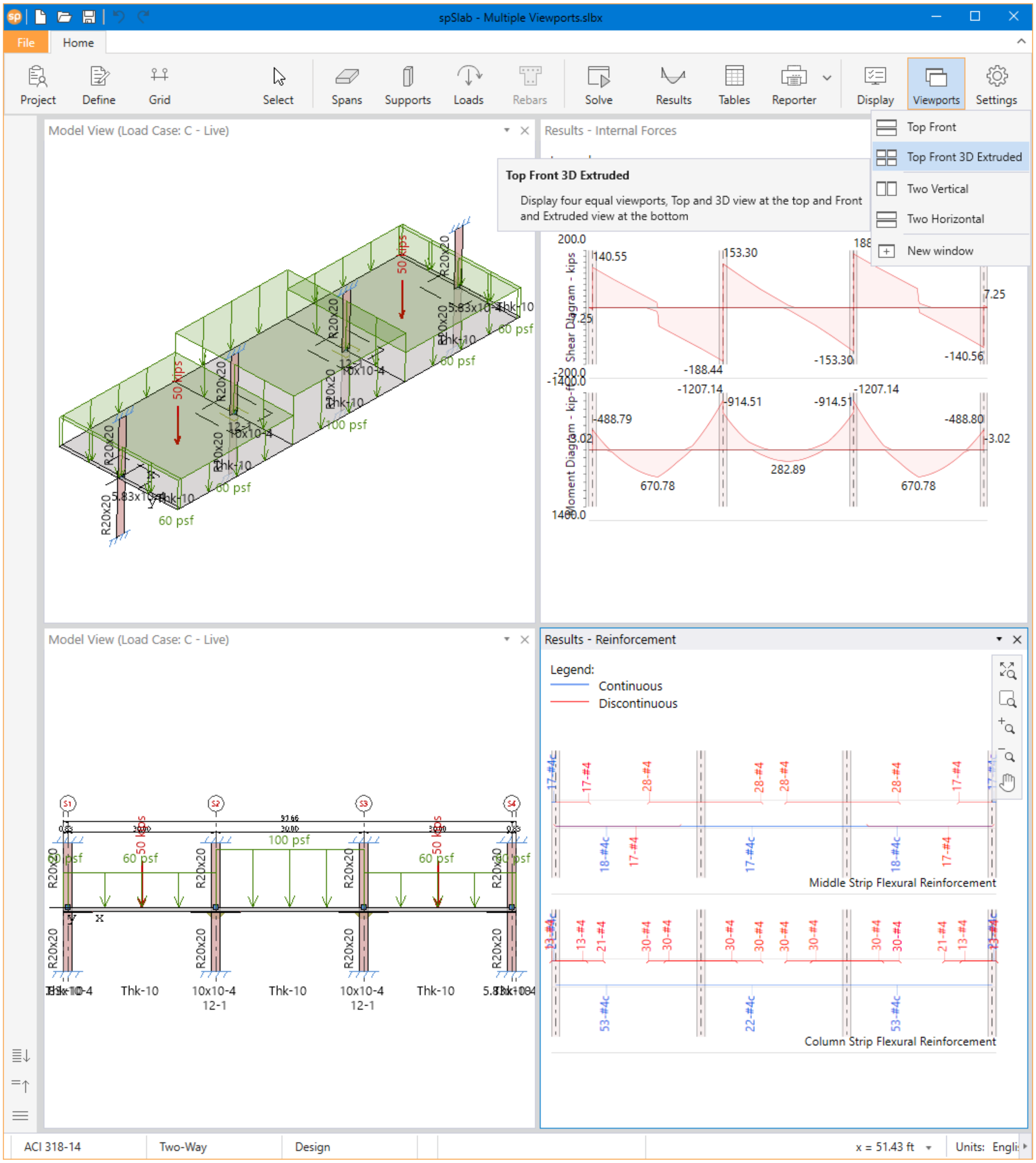



## 7.2.7. Viewing Aids

Viewing aids are those features in the program that facilitate viewing the graphical output results produced by the program.

### 7.2.7.1. Multiple Viewports

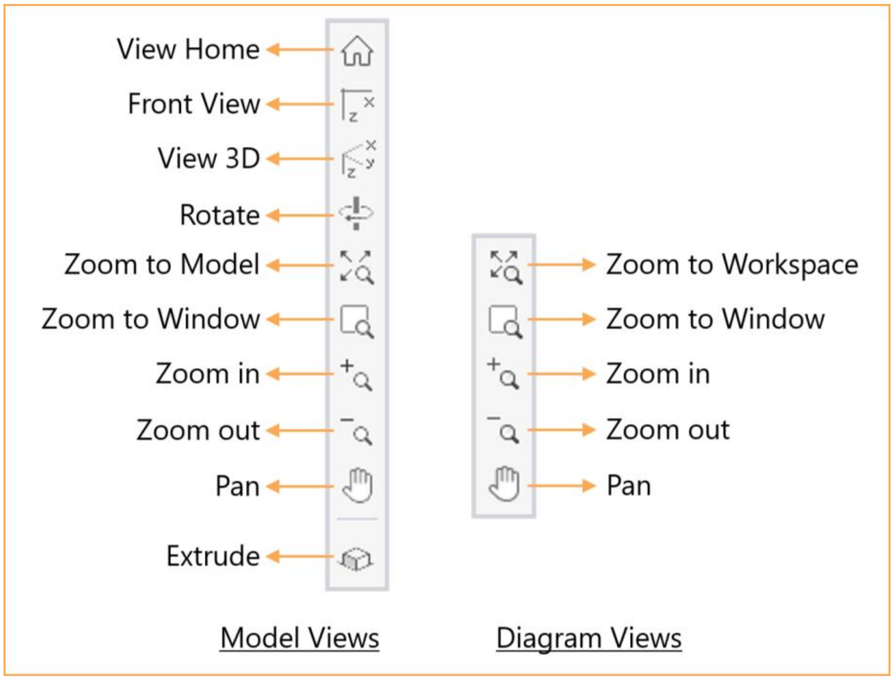
Multiple viewports can be used to view different diagrams and model views at the same time. The **Viewports** Command in the **Ribbon** can be used to select from a set of pre-defined viewport configurations or create a new viewport window. A maximum of 6 viewports can be used at one time.



### 7.2.7.2. View Controls

When a viewport is active it has a set of **View Controls** located in the top right corner. These commands can be used to aid in viewing the model and diagrams.

**View Controls** offer commands like ZOOM TO MODEL (ZOOM TO WORKSPACE), ZOOM TO WINDOW, ZOOM IN, ZOOM OUT, and PAN. Note that controls such as VIEW HOME, FRONT VIEW, VIEW 3D, ROTATE, and EXTRUDE are not available for diagrams views.

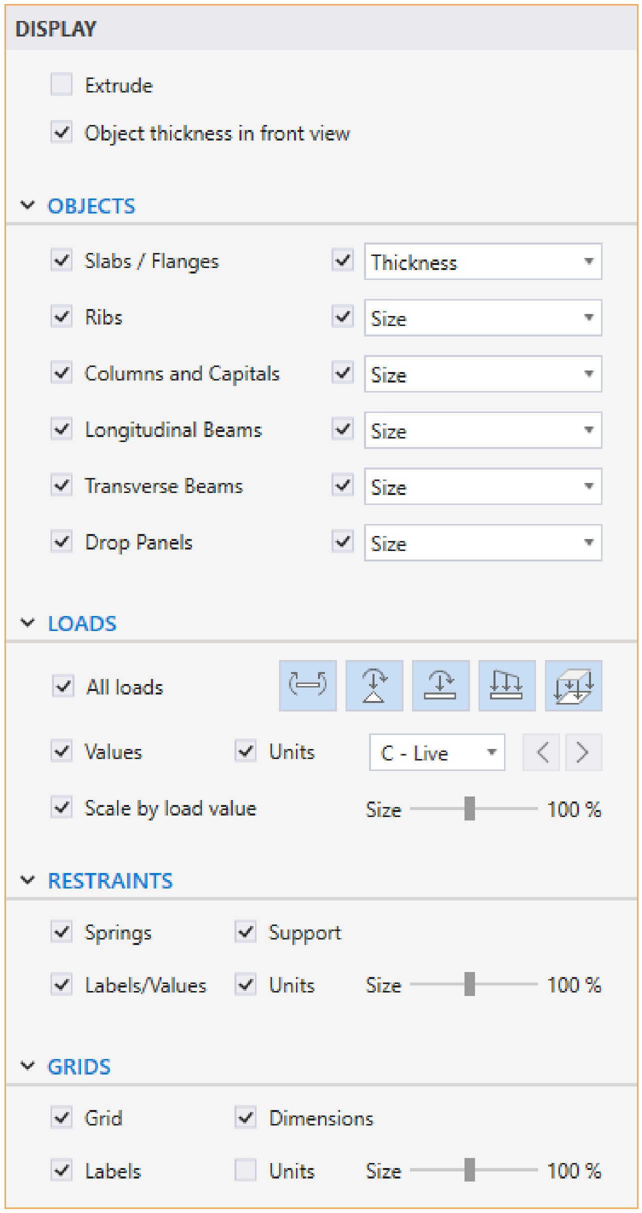



Users can also:

- Rotate Section in 3D: Enables rotating the model in three dimensions (shift + middle mouse button). This control is not available for diagrams views.
- Zoom in and zoom out using the mouse wheel and panned by holding the middle mouse button and moving the mouse around.

### 7.2.7.3. Display Options

The **Display** Command in the **Ribbon** can be used to open the DISPLAY OPTIONS dialog. This dialog facilitates toggling on/off the different Objects, Loads, Restraints, and Grids.



CHAPTER

8

# EXAMPLES

In this chapter, several examples are presented to demonstrate some of the many features and capabilities of the program. Generally, program results match closely the results found in the referenced textbooks. When discrepancies are observed, they result from variations in assumptions and solutions methods, and numerical accuracy.

Both beams/one-way slab systems as well as two-way slab systems are presented in the examples. The output of beams/one-way slab examples shows that spBeam program was used to solve them. This is to illustrate that spBeam program is available as a limited version of spSlab that includes only beams/one-way slab capabilities.

# 8.1. Example 1 – Spandrel Beam with Moment Redistribution

## 8.1.1. Problem Formulation

Determine the required reinforcement for the spandrel beam at an intermediate floor level as shown below, using moment redistribution to reduce total reinforcement required. (Note: the self-weight is already included in the specified dead load below.)[1]

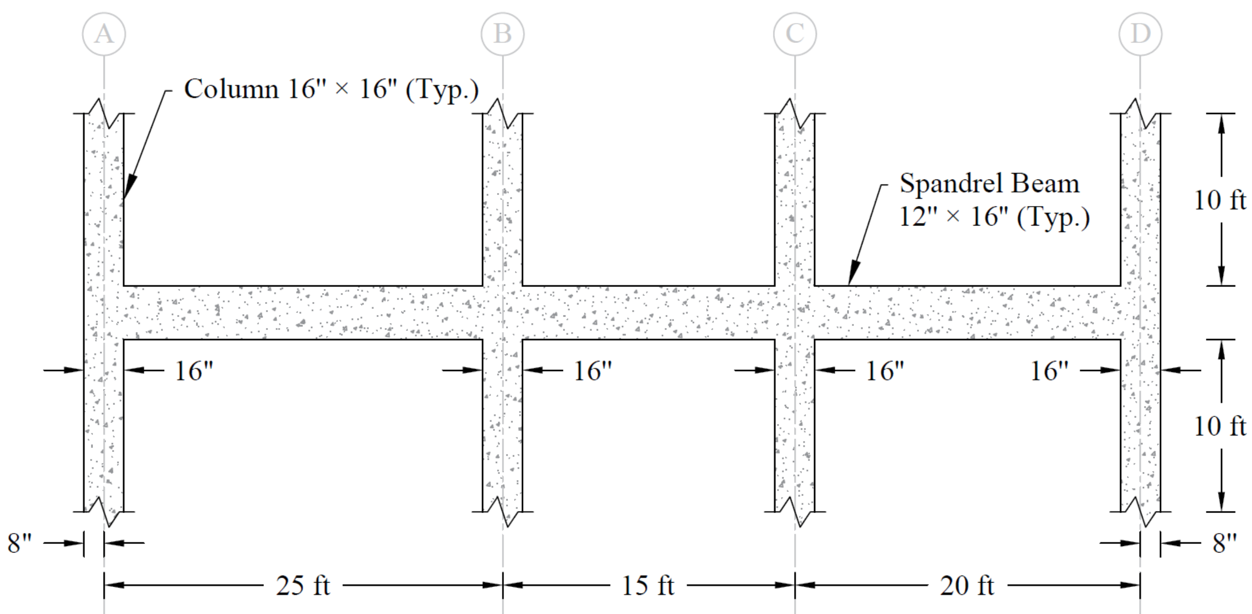



Figure 8.1 – Example Spandrel Beam Problem

1 *Notes on ACI 318-11 Building Code Requirements for Structural Concrete*, Twelfth Edition, 2013 Portland Cement Association, Example 8-2

**Design data**

DL = 1,167 lb/ft

LL = 450 lb/ft

$f_c'$ = 4,000 psi

$f_y$ = 60,000 psi

Columns: 16 × 16 in.

Story height: 10 ft

Spandrel beam: 12 × 16 in.

### 8.1.2. Preparing the Input

1. From the Start screen, select **New Project**.

2. From the **Main Program Window**, select **Project** from the **Ribbon**.

   - In the **General** section, select the DESIGN CODE, UNIT SYSTEM, and BAR SET.

   - In the **Materials** section, input the following:

     f'c (SLABS & BEAMS): 4.00 ksi

     f'c (COLUMNS): 4.00 ksi

     fy: 60.00 ksi

     Alternatively, detailed material properties for **Concrete** and **Reinforcement Steel** can be entered using **Definitions** dialog box (see Steps 4 and 5).

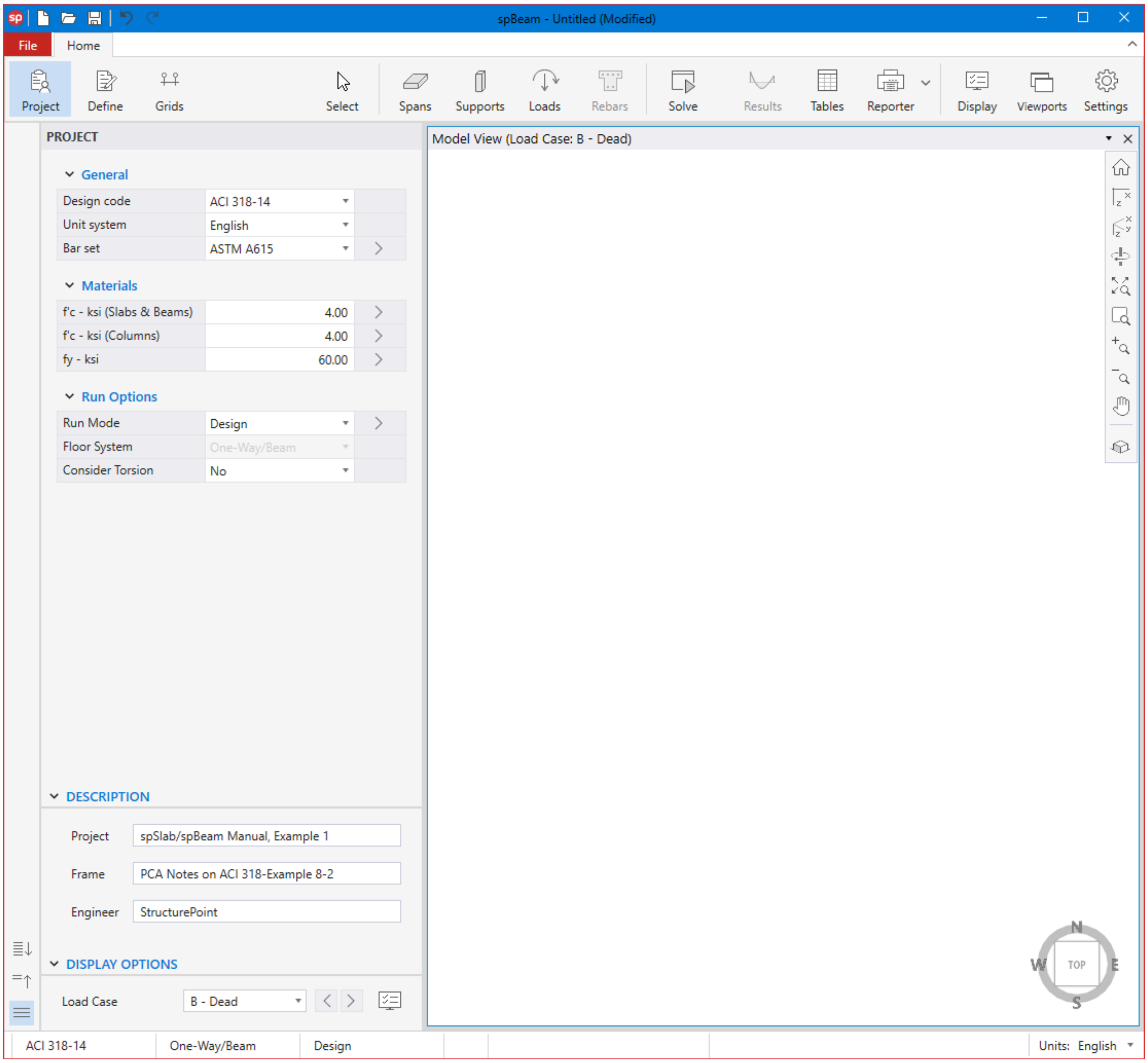
   - In the **Run Options** section, select the following:

     RUN MODE: Design

     FLOOR SYSTEM: One-Way/Beam

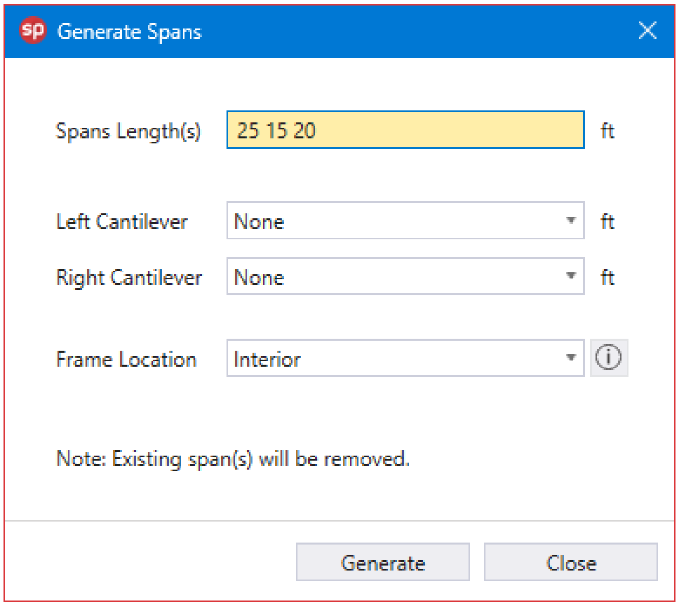
     CONSIDER TORSION: No

   - In the **Description** section, enter the PROJECT, FRAME, and ENGINEER.


spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
PROJECT
General
Design code
ACI 318-14
Unit system
English
Bar set
ASTM A615
Materials
f'c - ksi (Slabs & Beams)
4.00
f'c - ksi (Columns)
4.00
fy - ksi
60.00
Run Options
Run Mode
Design
Floor System
One-Way/Beam
Consider Torsion
No
DESCRIPTION
Project
spSlab/spBeam Manual, Example 1
Frame
PCA Notes on ACI 318-Example 8-2
Engineer
StructurePoint
DISPLAY OPTIONS
Load Case
B - Dead
Model View (Load Case: B - Dead)
N
W
TOP
E
S
ACI 318-14
One-Way/Beam
Design
Units:
English

3. From the **Ribbon**, select **Grids**.

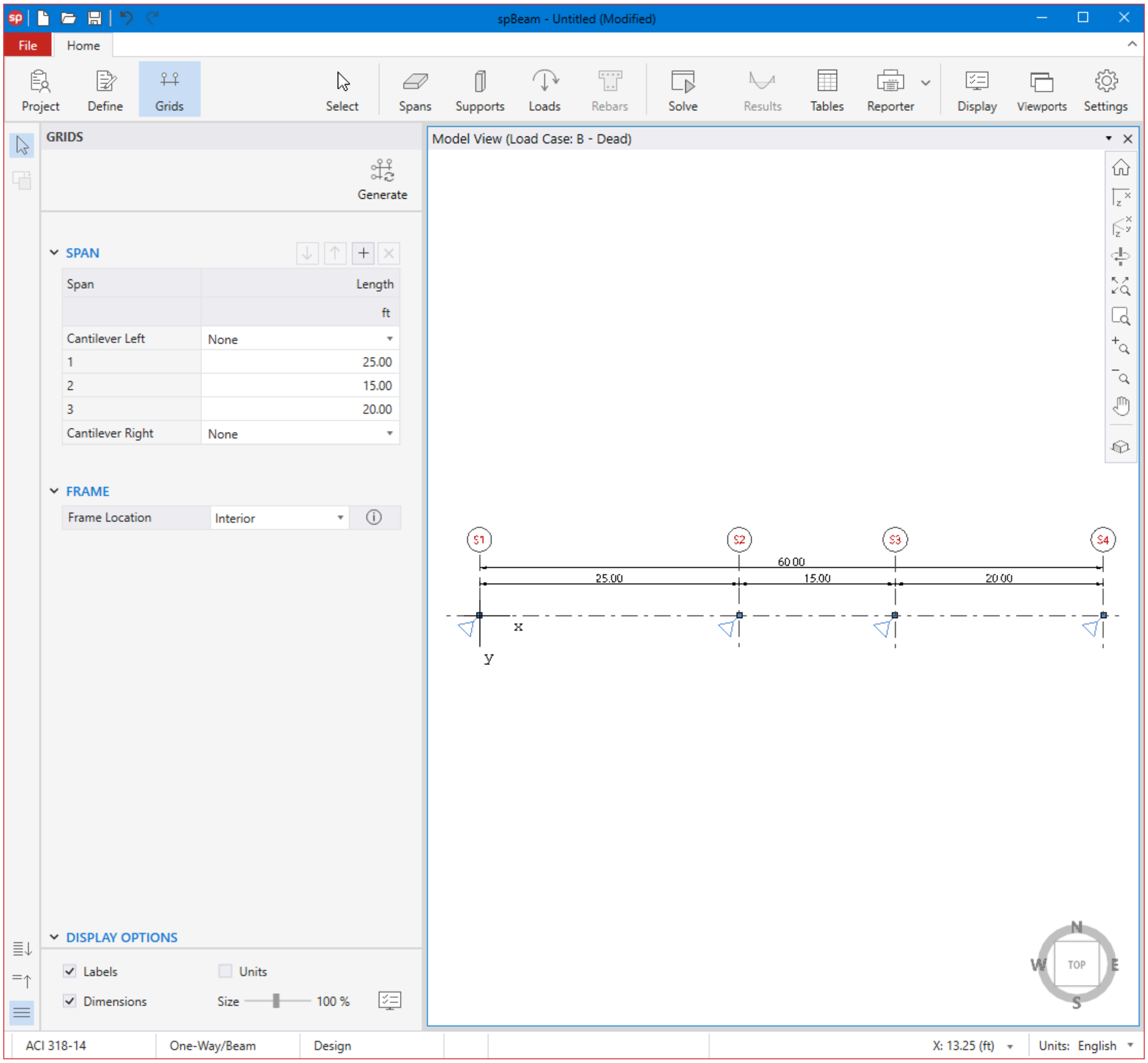
- Click on the **Generate** in the left panel to have the program surface the following:




- Enter the following values in the corresponding text boxes:

| | |
|---|---|
| SPANS LENGTH(S): | `25 15 20` |
| LEFT CANTILEVER: | None |
| RIGHT CANTILEVER: | None |
| FRAME LOCATION: | Interior |

- Click on the GENERATE button to return to the main window. Notice how the grid lines now appear in the VIEWPORT.

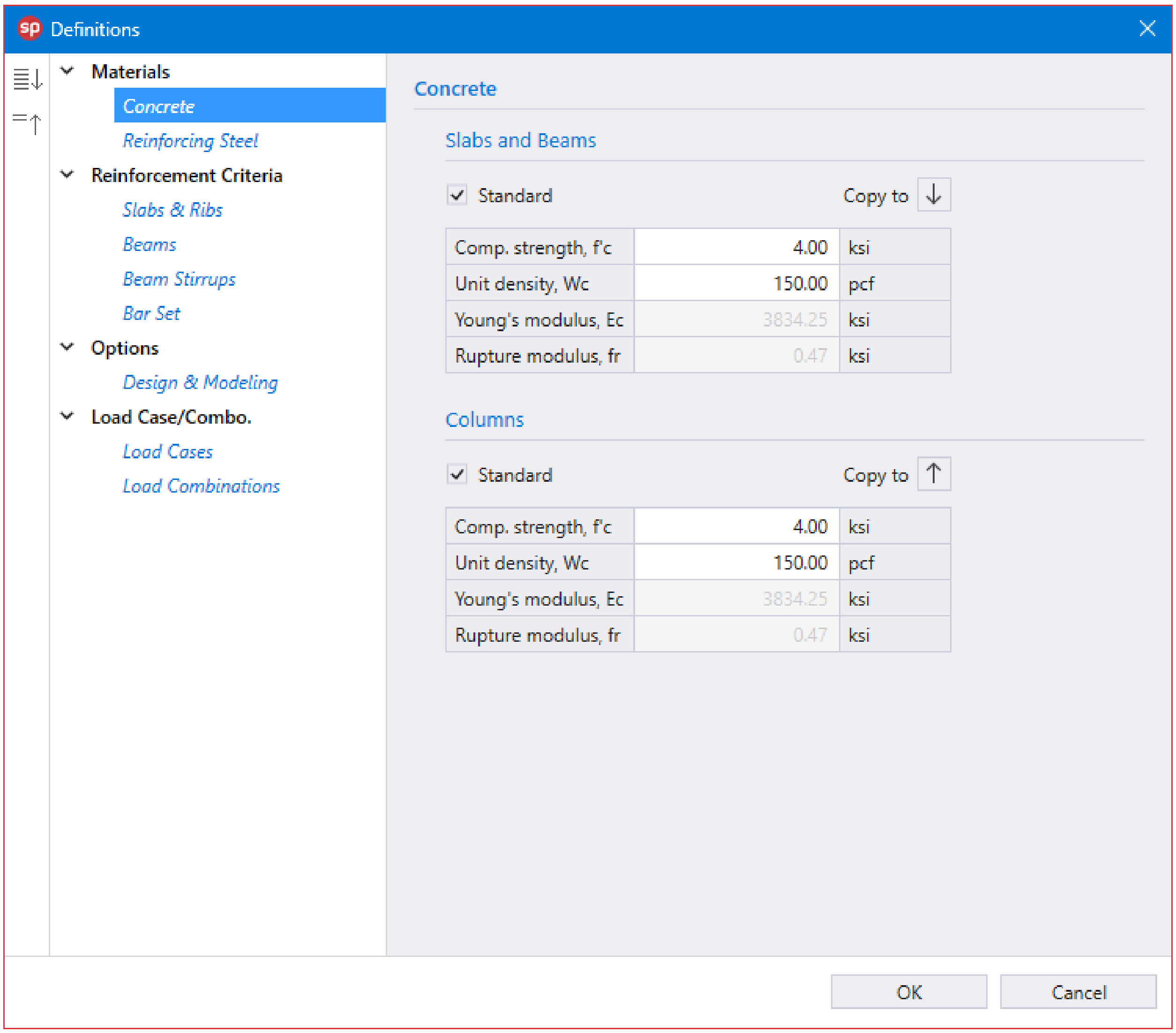

spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
GRIDS
Generate
SPAN
Span
Length
ft
Cantilever Left
None
1
25.00
2
15.00
3
20.00
Cantilever Right
None
FRAME
Frame Location
Interior
DISPLAY OPTIONS
Labels
Units
Dimensions
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
S3
S4
60.00
25.00
15.00
20.00
x
y
N
W
TOP
E
S
ACI 318-14
One-Way/Beam
Design
X: 13.25 (ft)
Units: English

4. From the **Ribbon**, select **Define,** then choose **Concrete** from **Materials** to display the **Concrete** dialog box.

   - Check STANDARD for SLABS AND BEAMS and COLUMNS.
   - Enter the following for SLABS AND BEAMS and COLUMNS:

   COMPRESSIVE STRENGTH, f'c: `4.00` ksi

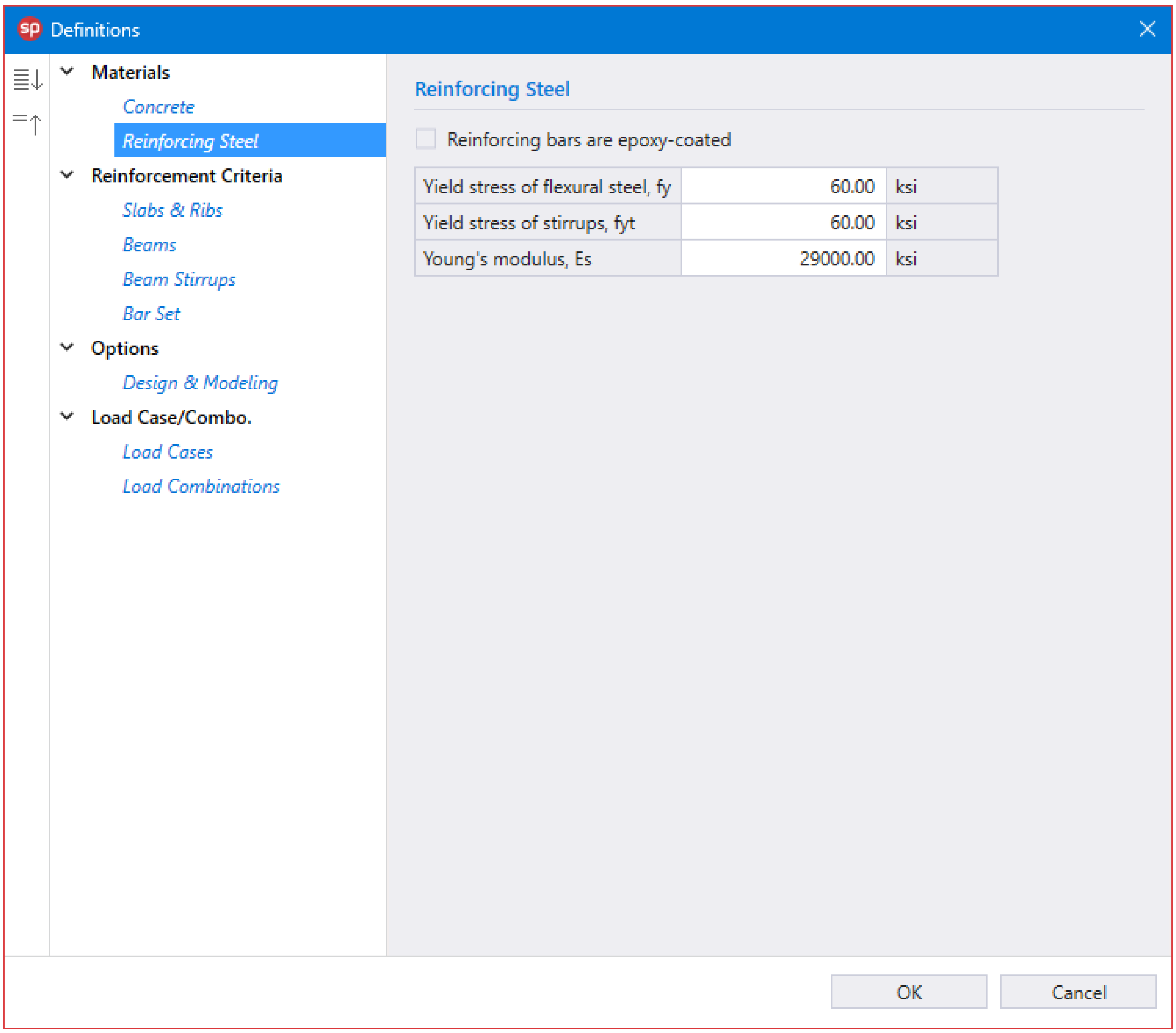
   UNIT DENSITY, Wc: `150.00` pcf



5. Click on **Reinforcing Steel** from **Materials** to display the **Reinforcing Steel** dialog box.

- Enter the following:

| | |
|---|---|
| YIELD STRESS OF FLEXURAL STEEL, fy: | 60.00 ksi |
| YIELD STRESS OF STIRRUP, fyt: | 60.00 ksi |
| YOUNG'S MODULUS, Es: | 29000.00 ksi |

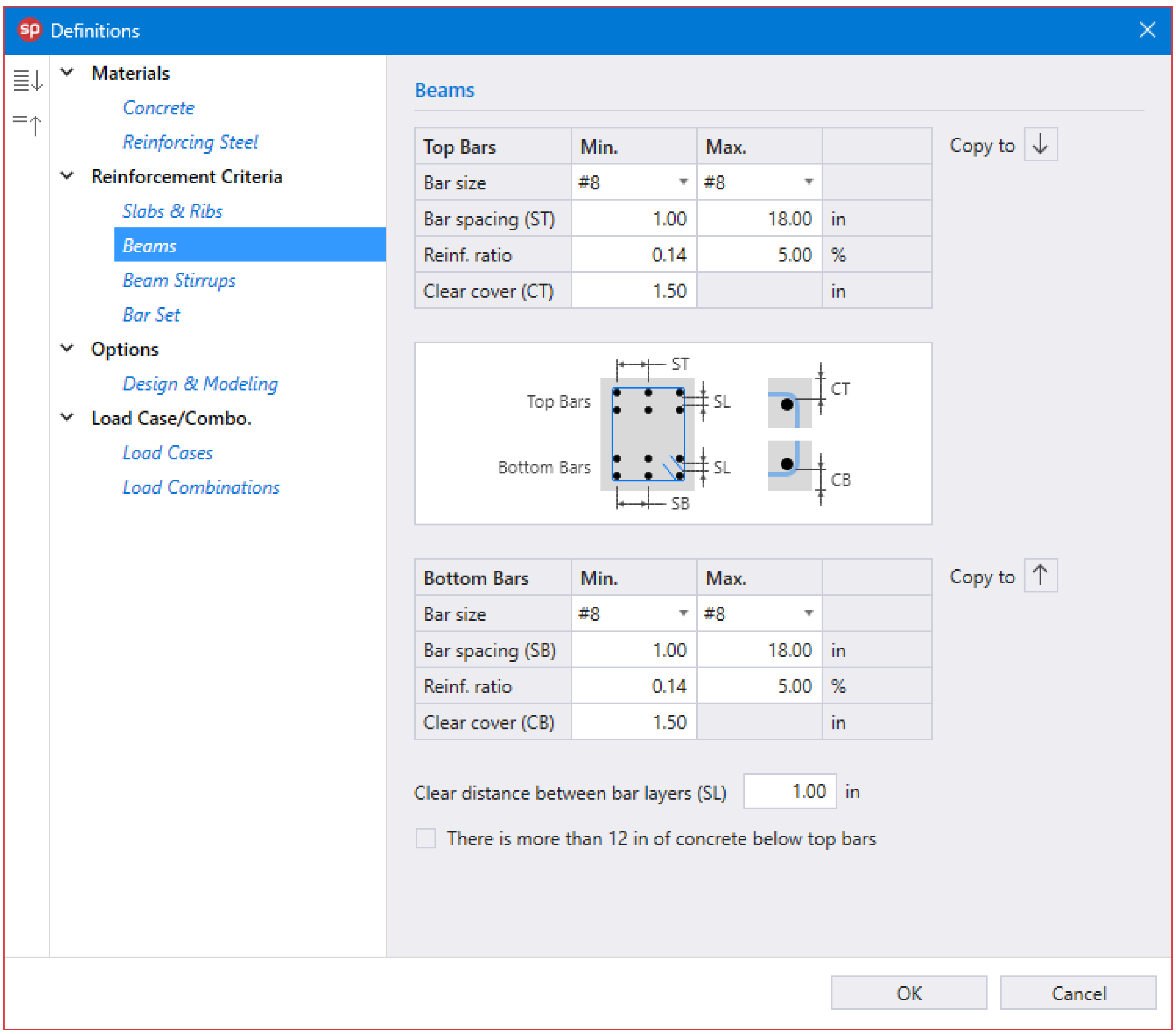


6. Click on **Beams** from **Reinforcement Criteria** to display the **Beams** dialog box.

- Enter the following for TOP BARS and BOTTOM BARS:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #8 | #8 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.50 in | |

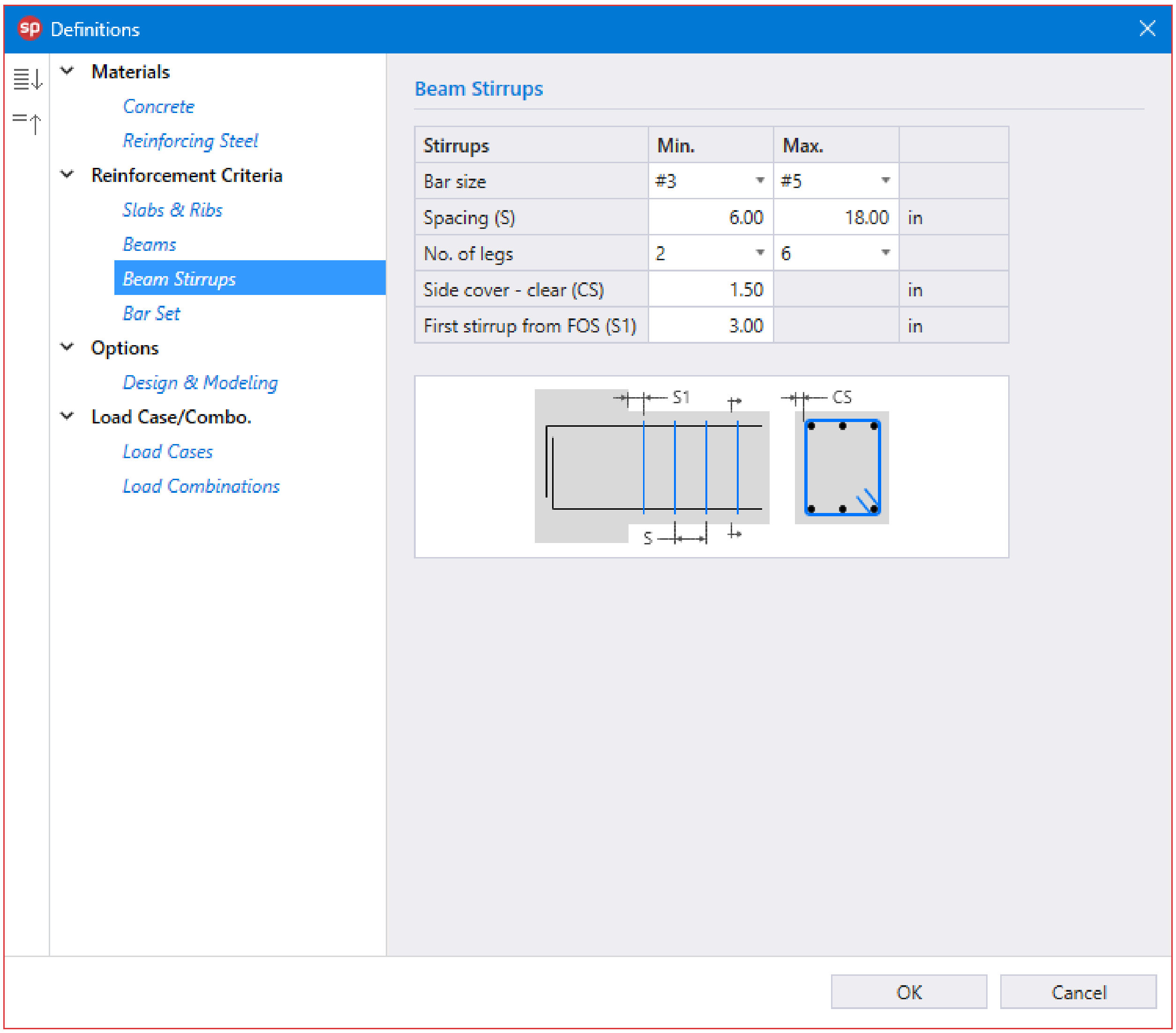
CLEAR DISTANCE BETWEEN BAR LAYERS (SL): 1.00 in



7. Click on **Beam Stirrups** from **Reinforcement Criteria** to display the **Beam Stirrups** dialog box.

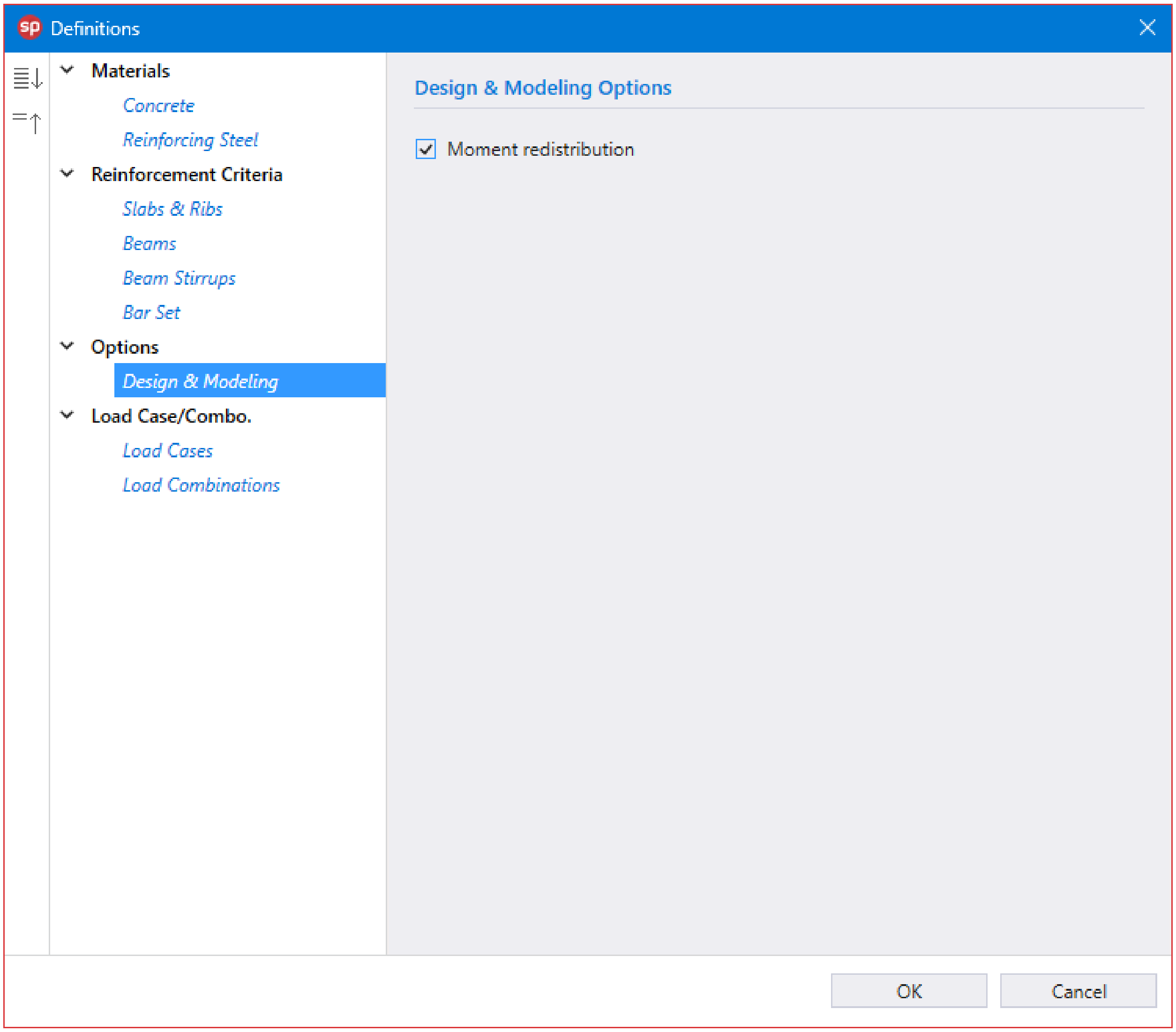
   - Enter the following:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #3 | #5 |
| BAR SPACING (S): | 6.00 in | 18.00 in |
| NUMBER OF LEGS: | 2 | 6 |
| SIDE COVER – CLEAR (CS): | 1.50 in | |
| FIRST STIRRUP FROM FOS (S1): | 3.00 in | |



8. Click on **Design & Modeling** from **Options** to display the **Design & Modeling** dialog box.

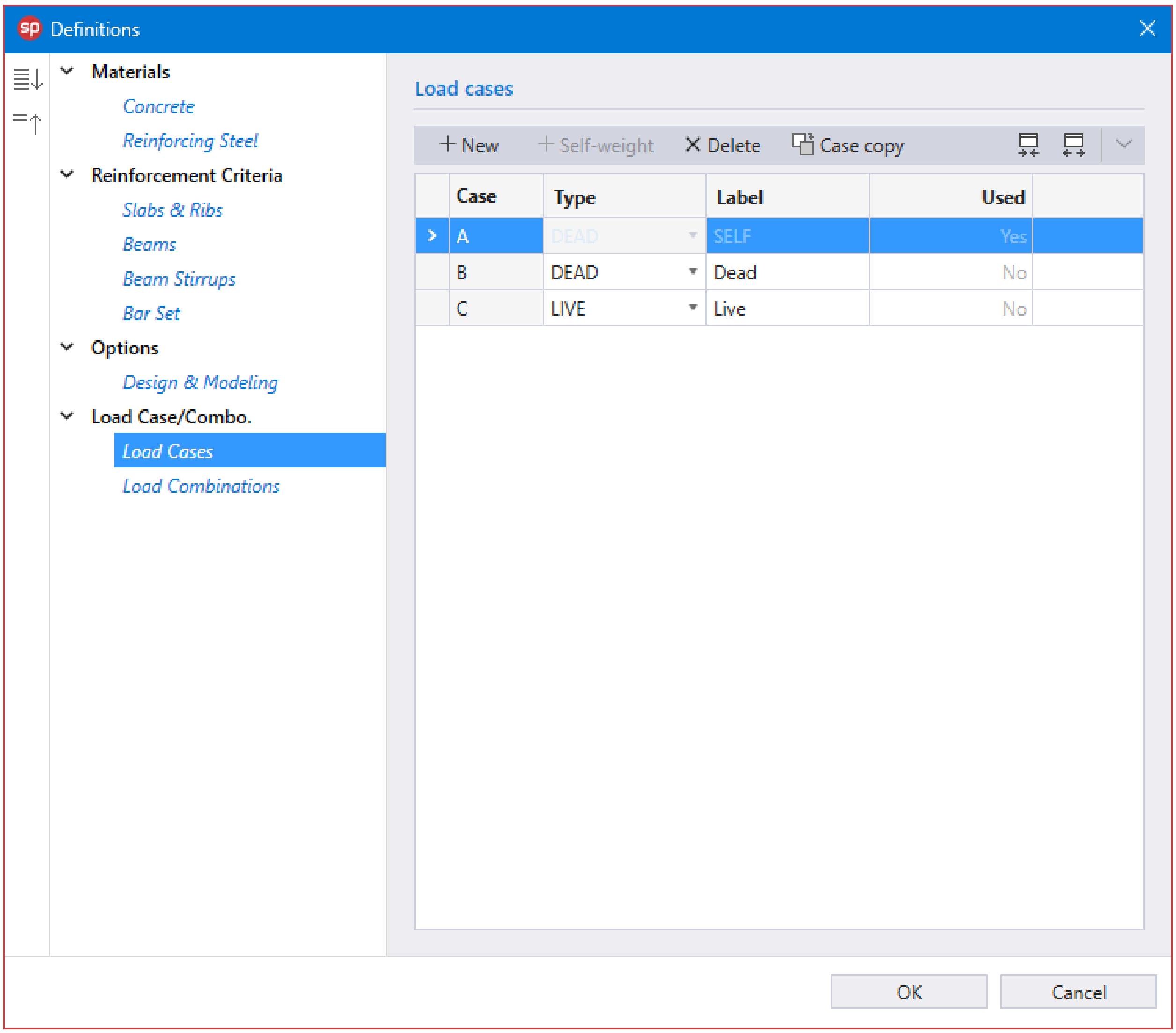
    - Check MOMENT REDISTRIBUTION.



9. Click on **Load Cases** from **Load Case/Combo.** to display the **Load Cases** dialog box.

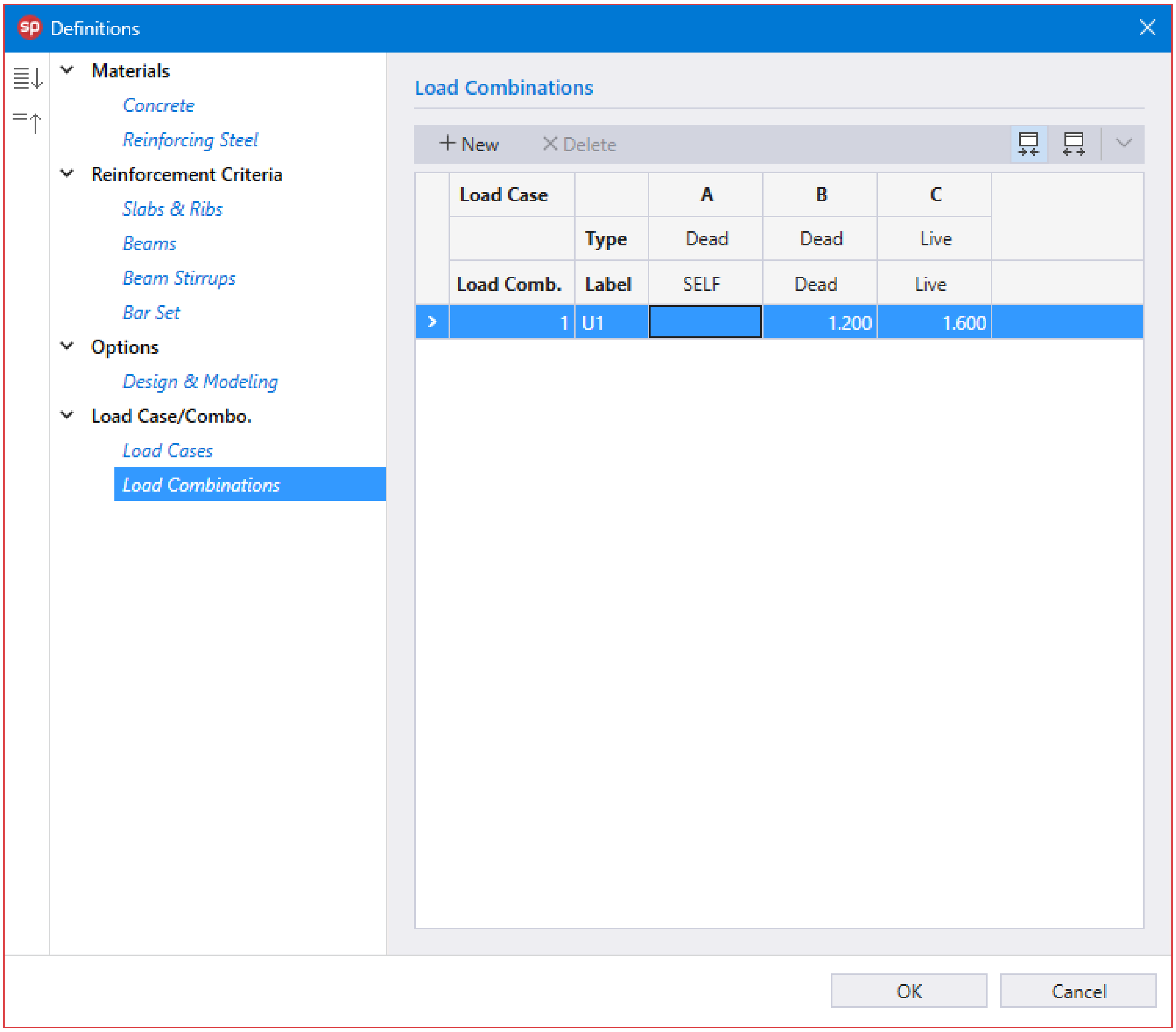
- Add SELF-WEIGHT for CASE A.
- Enter the following:

| | |
|---|---|
| CASE B: | `Dead` |
| CASE C: | `Live` |



10. Click on **Load Combinations** from **Load Case/Combo.** to display the **Load Combinations** dialog box.

- Enter the following load combination shown in the figure below:



## 8.1.3. Assigning Spans

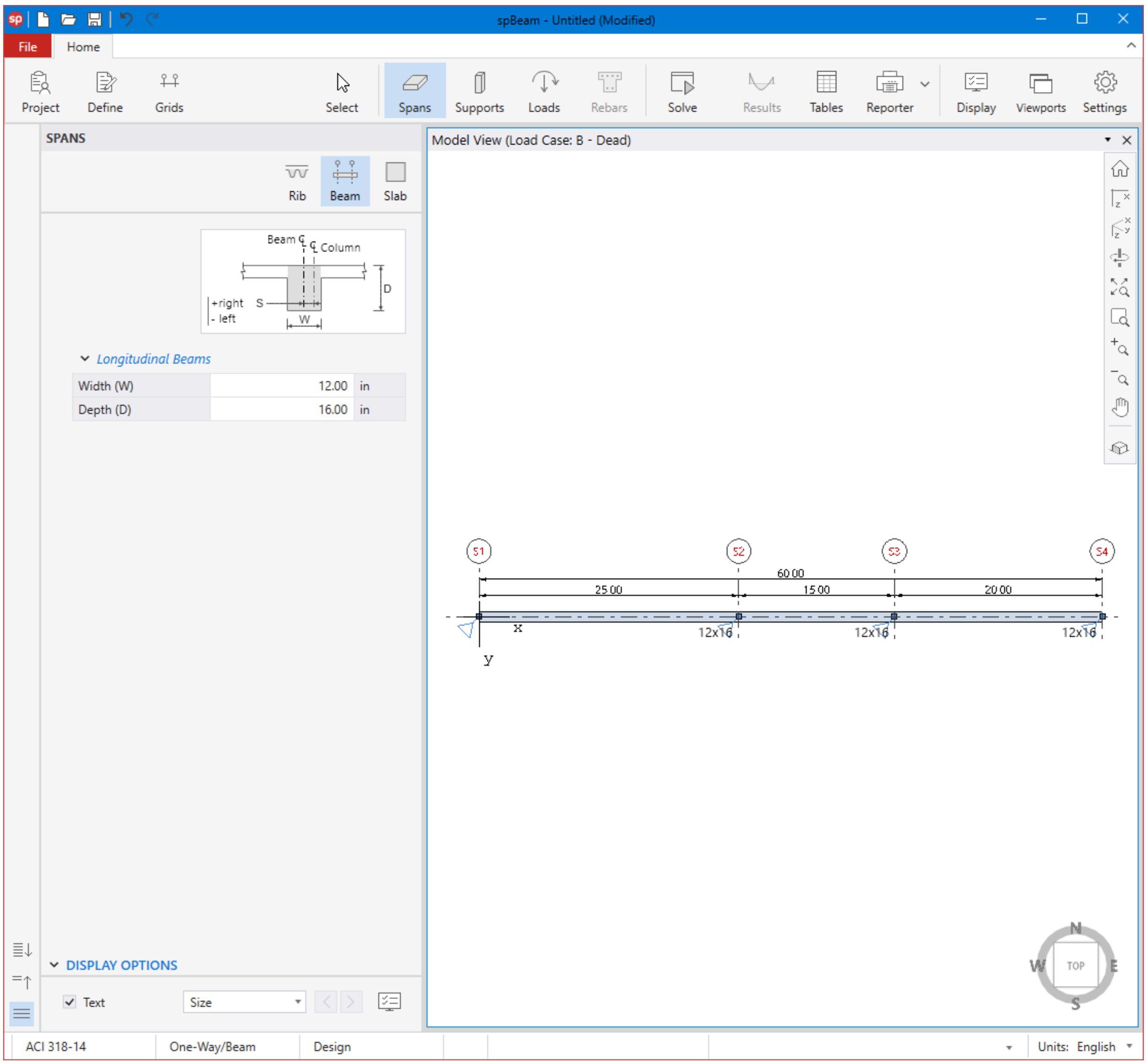
11. From the **Ribbon**, select **Spans** command.

   - In the left panel, select **Beam** and enter the following:

     WIDTH (W): `12.00` in

     DEPTH (D): `16.00` in

   - Apply to all spans as shown in the figure below.



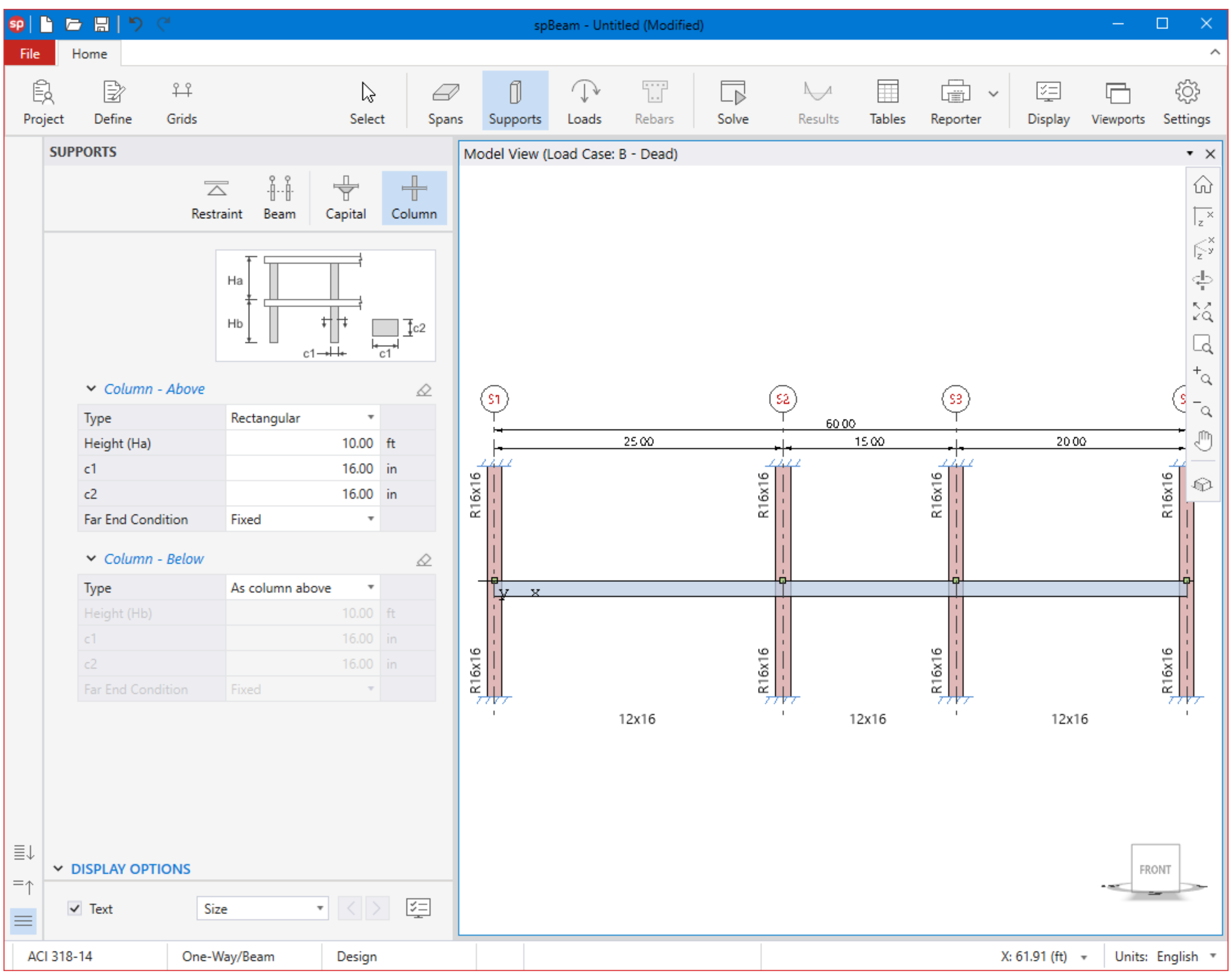
### 8.1.4. Assigning Supports

12. From the **Ribbon**, select **Supports** command.

- In the left panel, select **Column** and enter the following for COLUMN – ABOVE and COLUMN – BELOW:

| | |
|---|---|
| TYPE: | Rectangular |
| HEIGHT: | 10.00 ft |
| c1: | 16.00 in |
| c2: | 16.00 in |
| FAR END CONDITION: | Fixed |

- Apply to all supports as shown in the figure below.

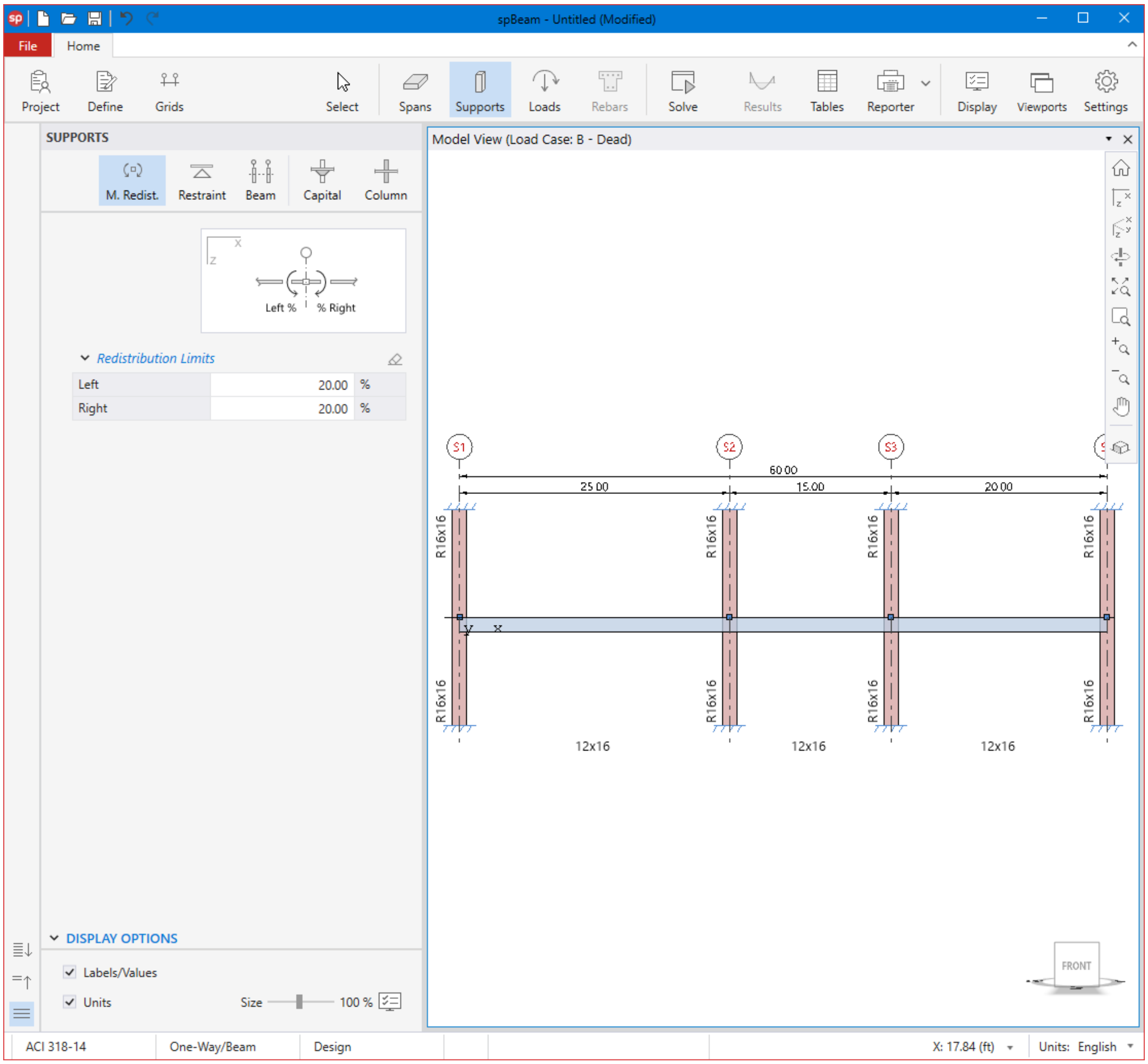


- In the left panel, select **Moment Redistribution** and enter the following:

LEFT: 20.00 %

RIGHT: 20.00 %

- Apply to Support 2 and Support 3 as shown in the figure below.



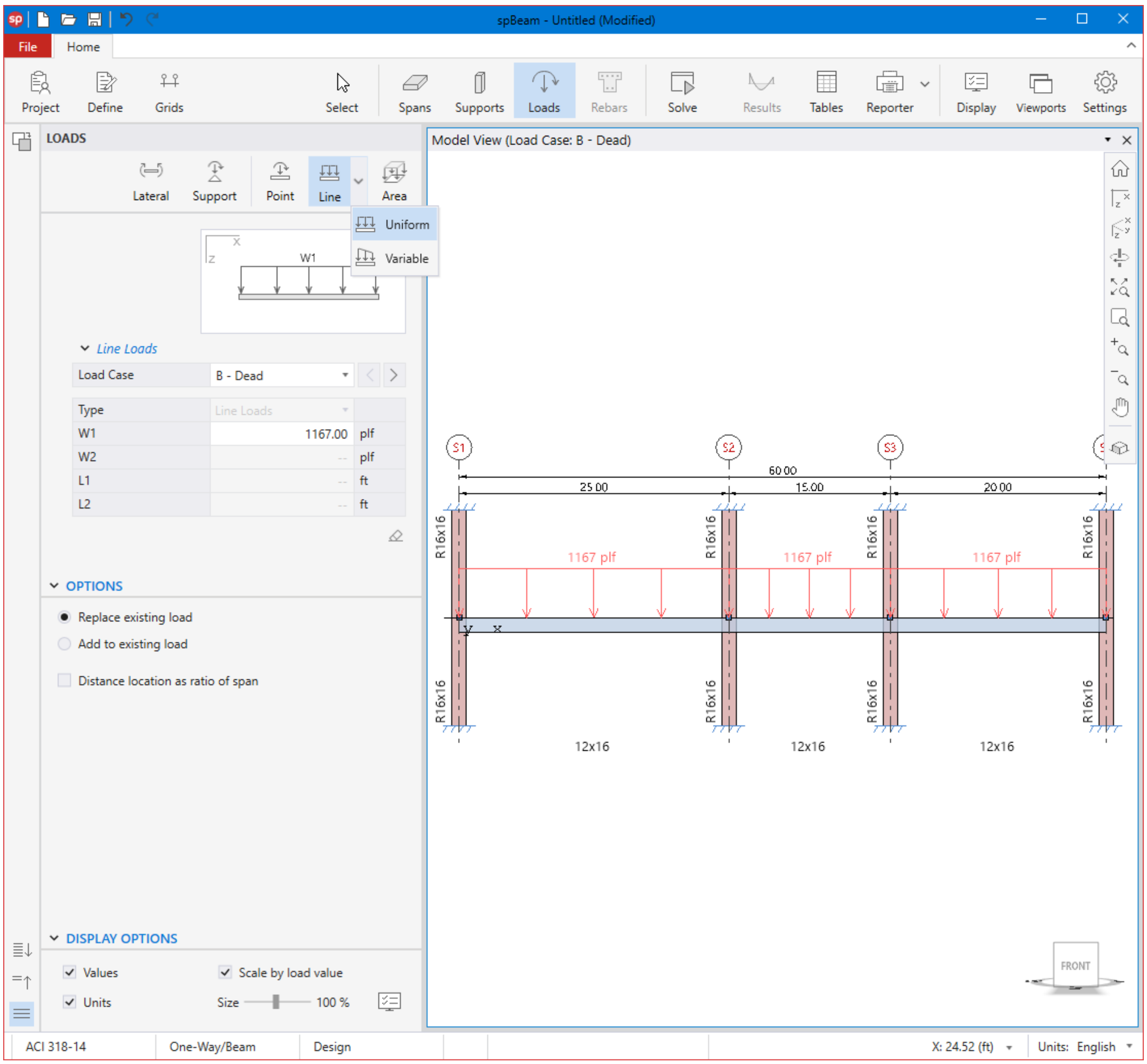
## 8.1.5. Assigning Loads

13. From the **Ribbon**, select **Loads** command.

- In the left panel, select **Uniform Line Loads** then select B-DEAD from LOAD CASE and enter the following:

  W$_1$: `1167.00` plf

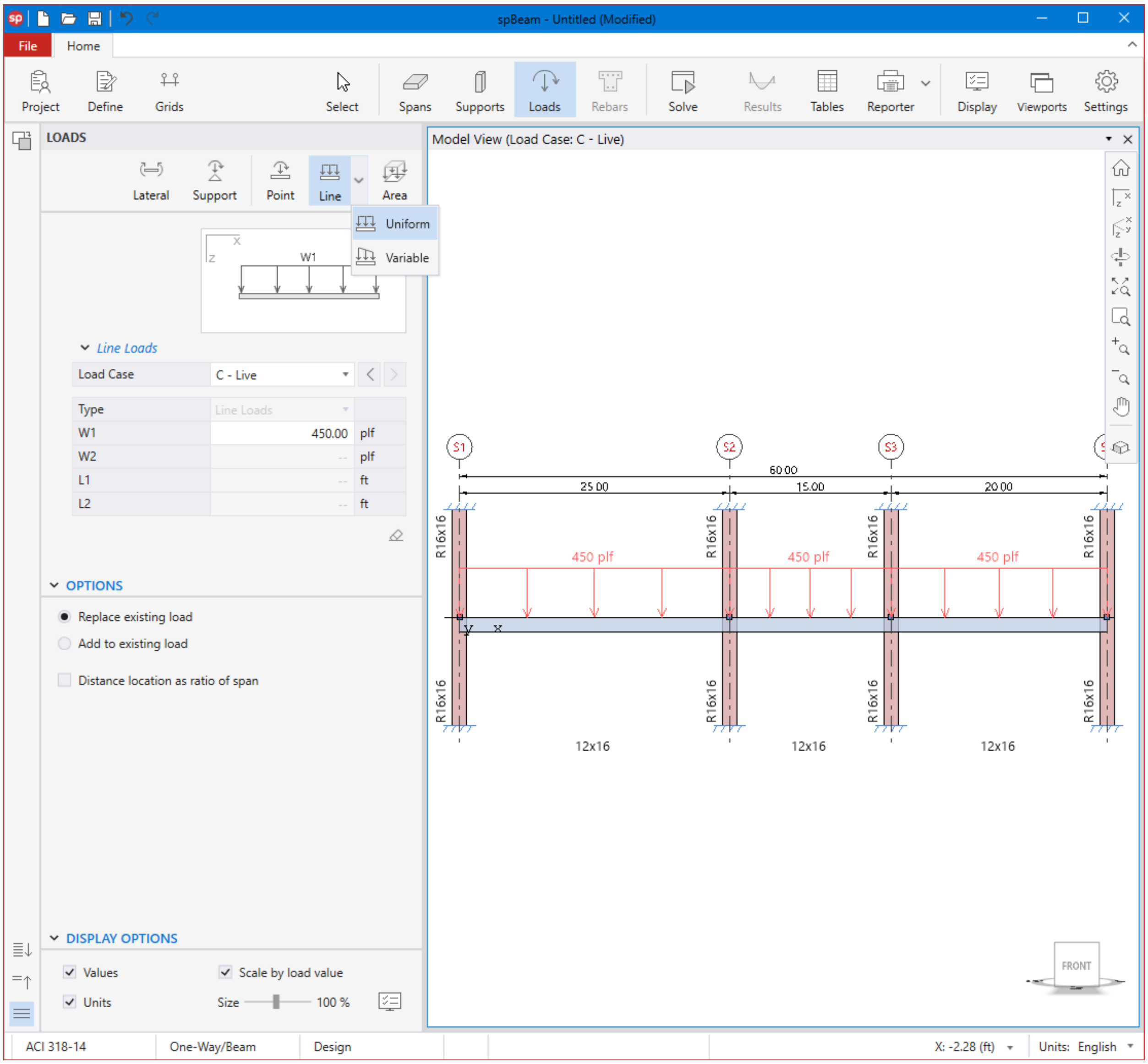
- Apply to all spans as shown in the figure below.



- Select C-LIVE from LOAD CASE and enter the following:

  $W_1$: `450.00` plf

- Apply to all spans as shown in the figure below.

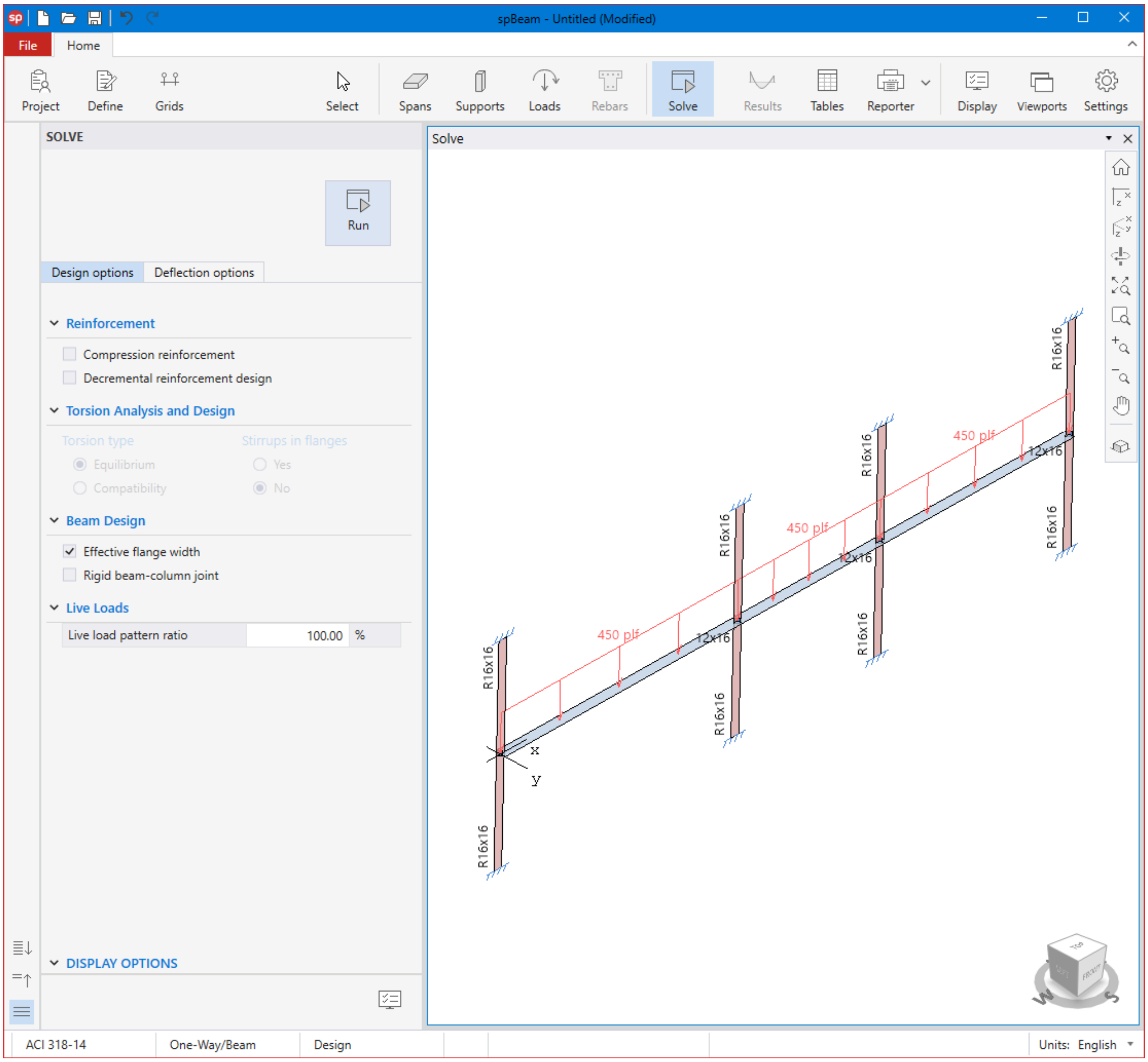


## 8.1.6. Solving

14. From the **Ribbon**, select **Solve** command.

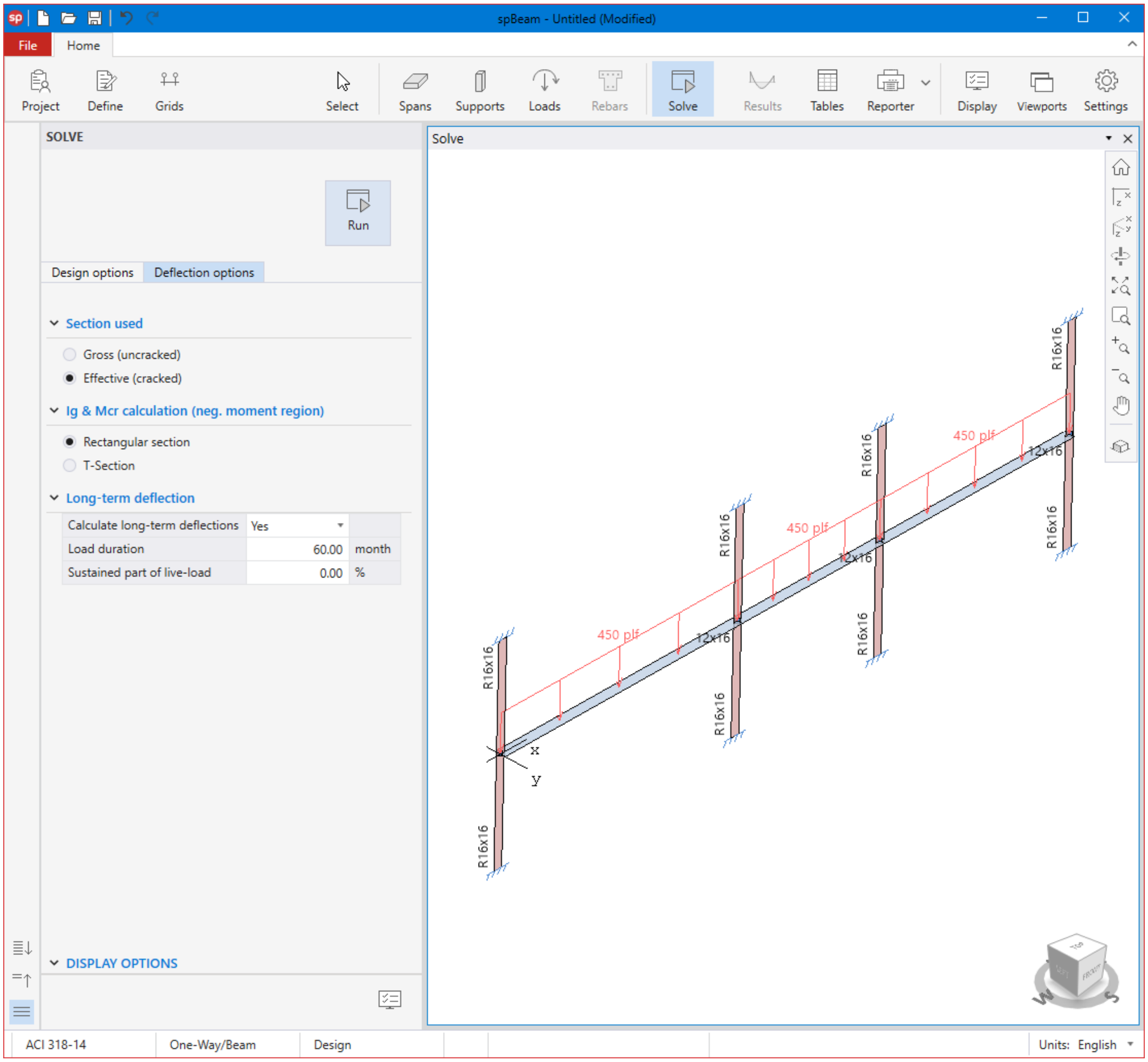
    For **Design Options**:

    - Leave all **Design Options** to their default settings.

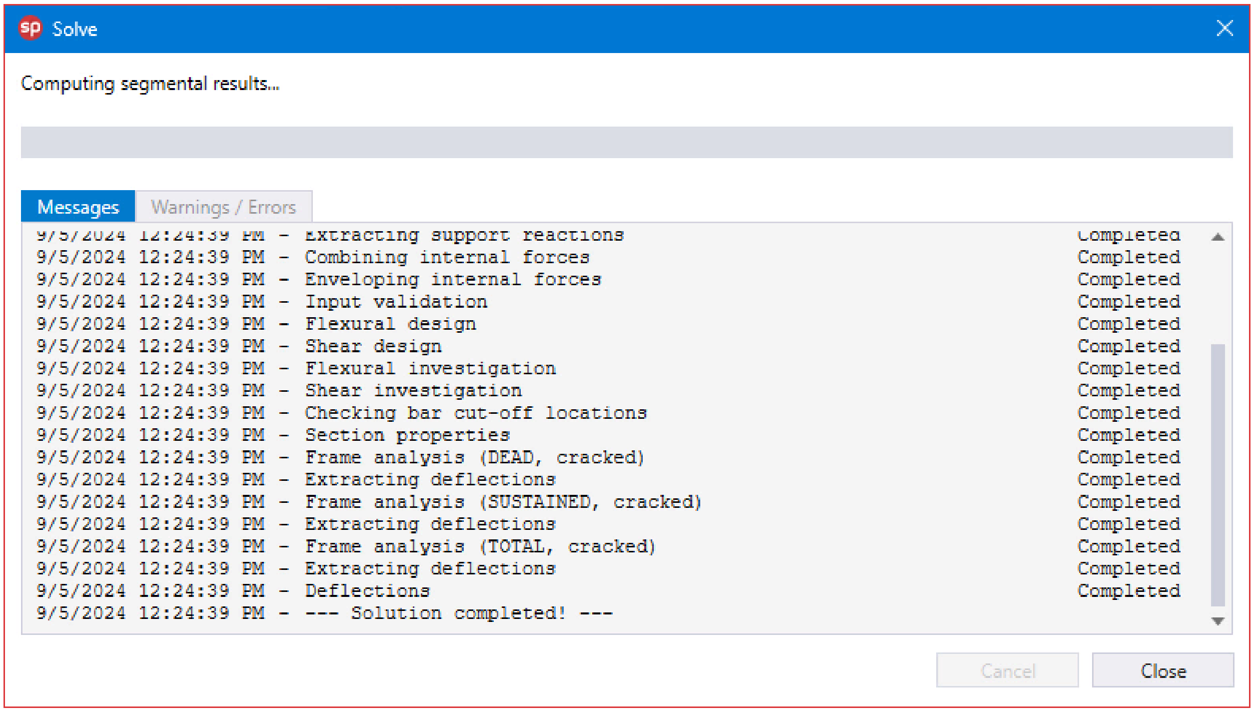


For **Deflection Options**:

- Leave all **Design Options** to their default settings.

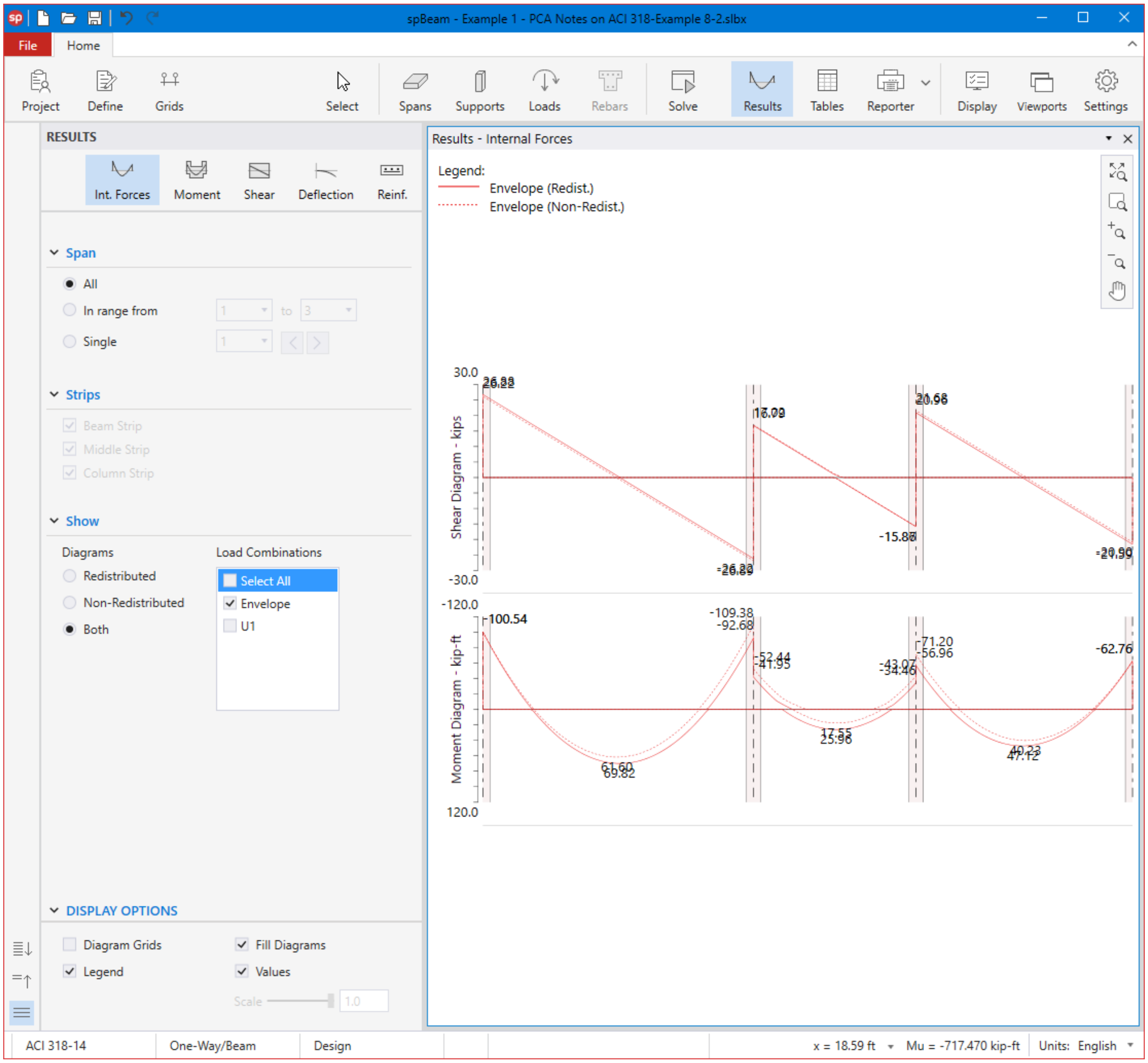


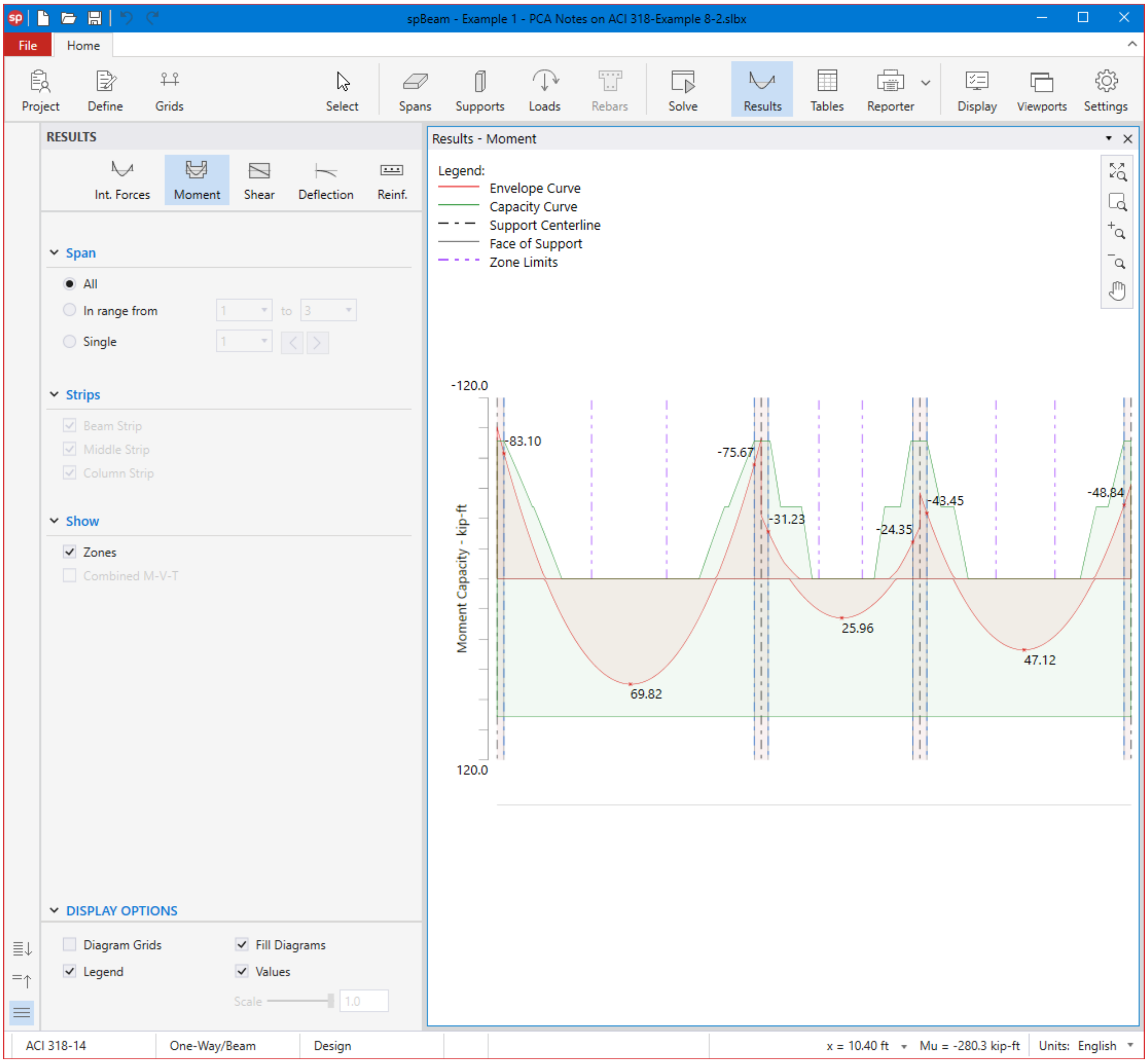
- Click on the **Run** button.
- The spBeam **Solver** window is displayed and the solver messages are listed. After the solution is done, the design will be performed and then the focus will immediately be passed to the **Results** scope.

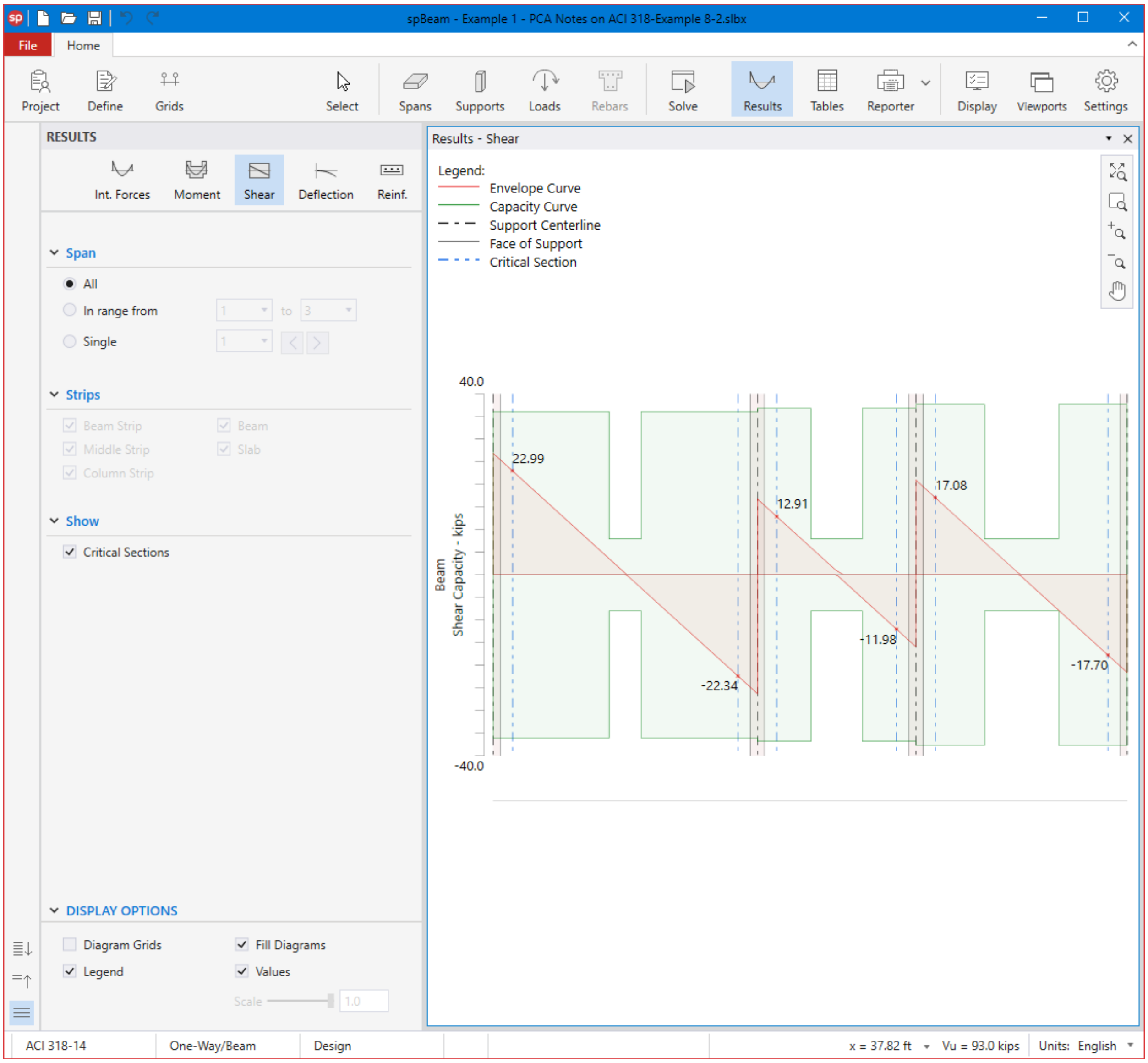


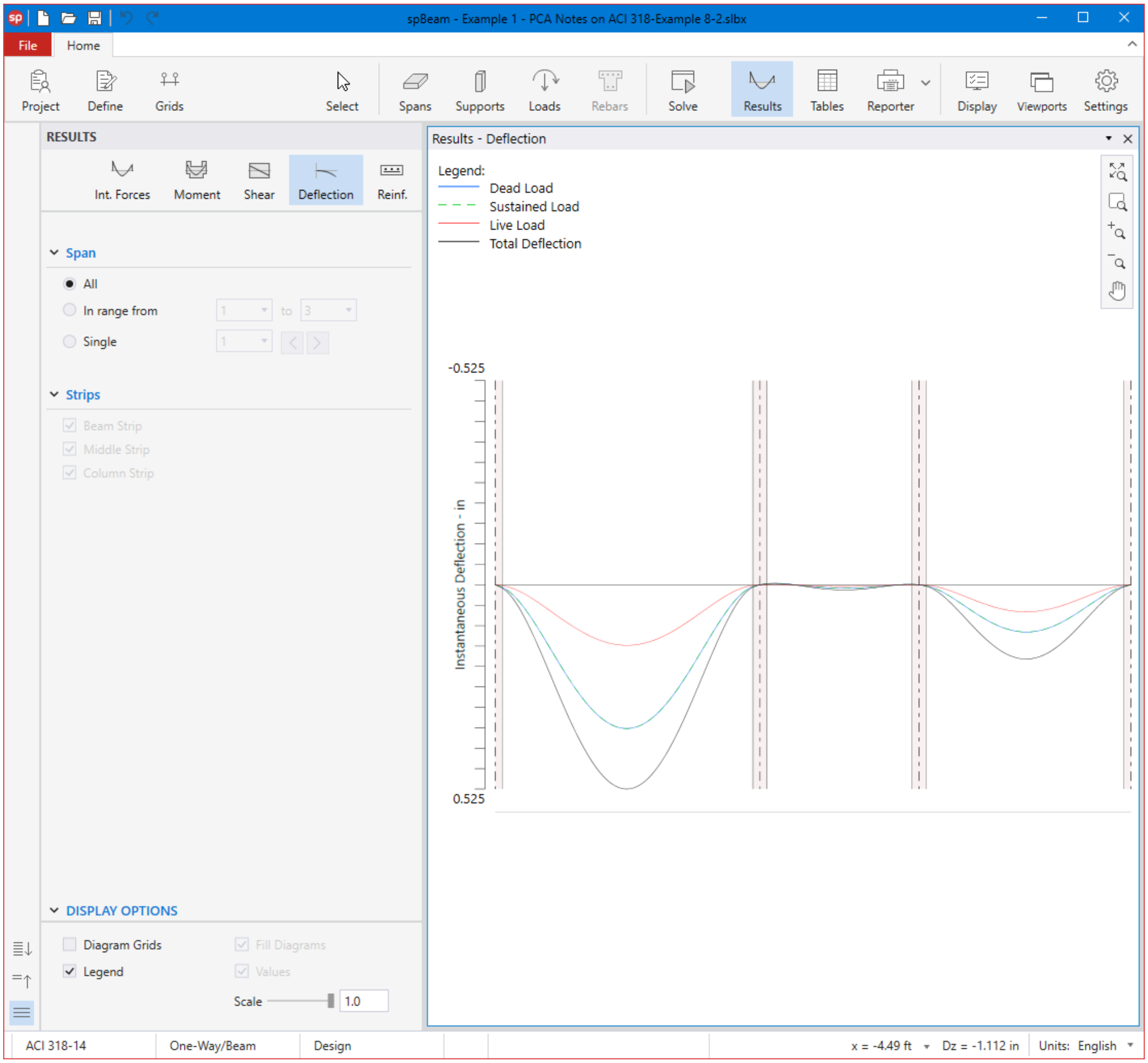
## 8.1.7. Viewing and Printing Results

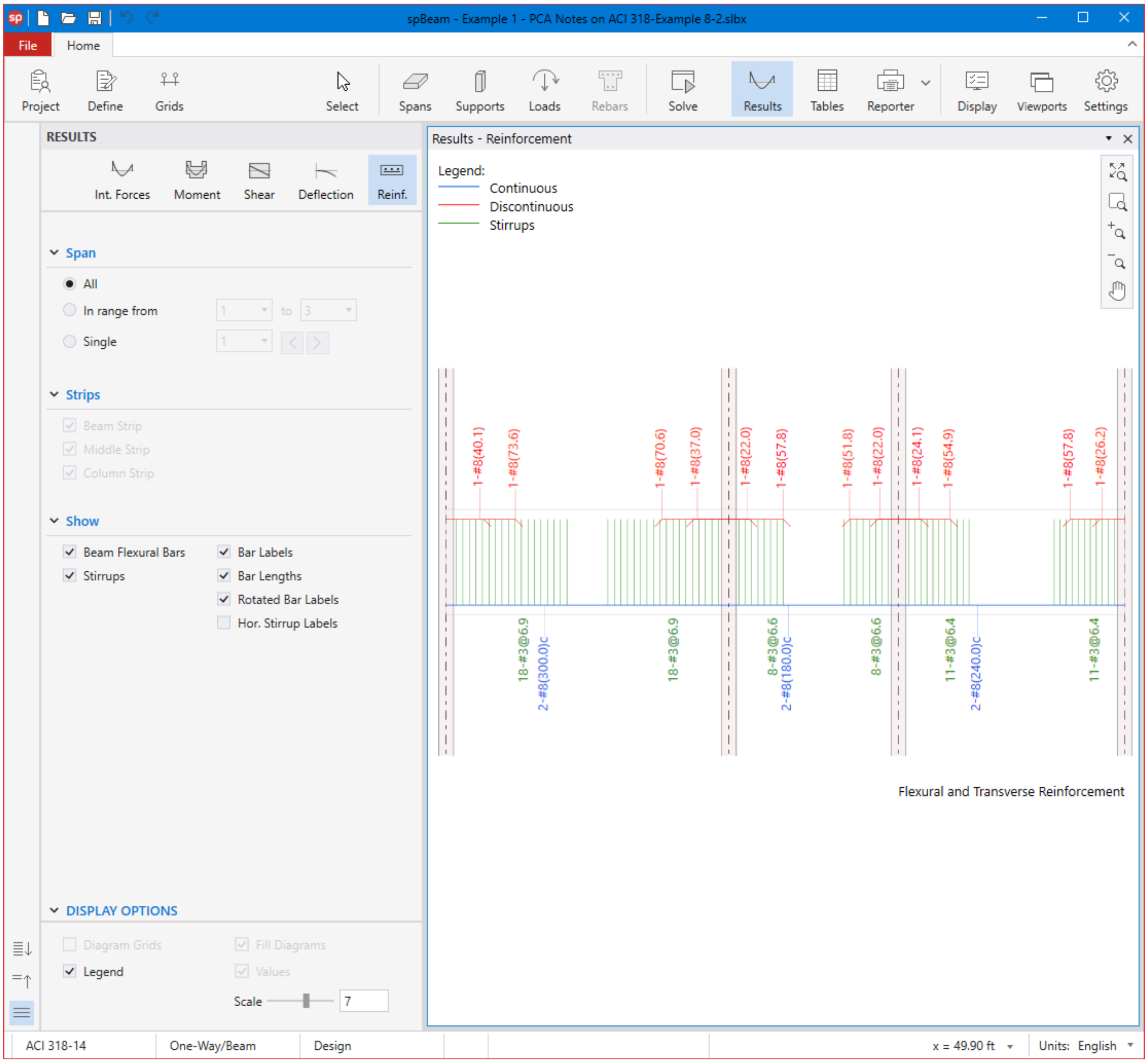
15. After a successful run, results can be viewed by selecting **Internal Forces**, **Moment Capacity**, **Shear Capacity**, **Deflection**, or **Reinforcement** from the left panel.



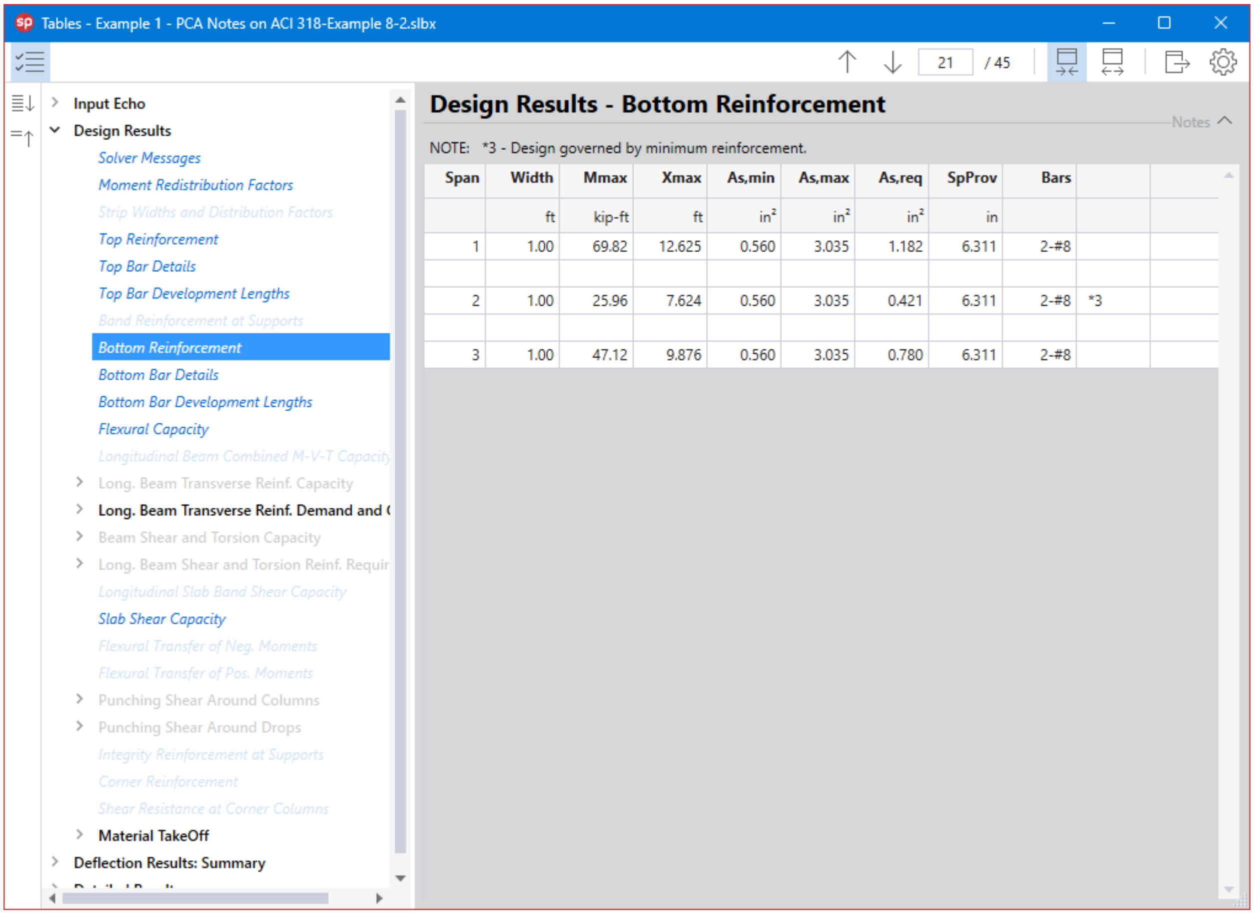

spBeam - Example 1 - PCA Notes on ACI 318-Example 8-2.slbx
Results - Moment
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Zone Limits
-120.0
-83.10
-75.67
-31.23
-24.35
-43.45
-48.84
25.96
47.12
69.82
120.0
Moment Capacity - kip-ft
ACI 318-14
One-Way/Beam
Design
x = 10.40 ft
Mu = -280.3 kip-ft
Units: English


spBeam - Example 1 - PCA Notes on ACI 318-Example 8-2.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Beam
Middle Strip
Slab
Column Strip
Show
Critical Sections
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Shear
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Critical Section
40.0
-40.0
Beam
Shear Capacity - kips
22.99
12.91
17.08
-11.98
-17.70
-22.34
ACI 318-14
One-Way/Beam
Design
x = 37.82 ft
Vu = 93.0 kips
Units: English

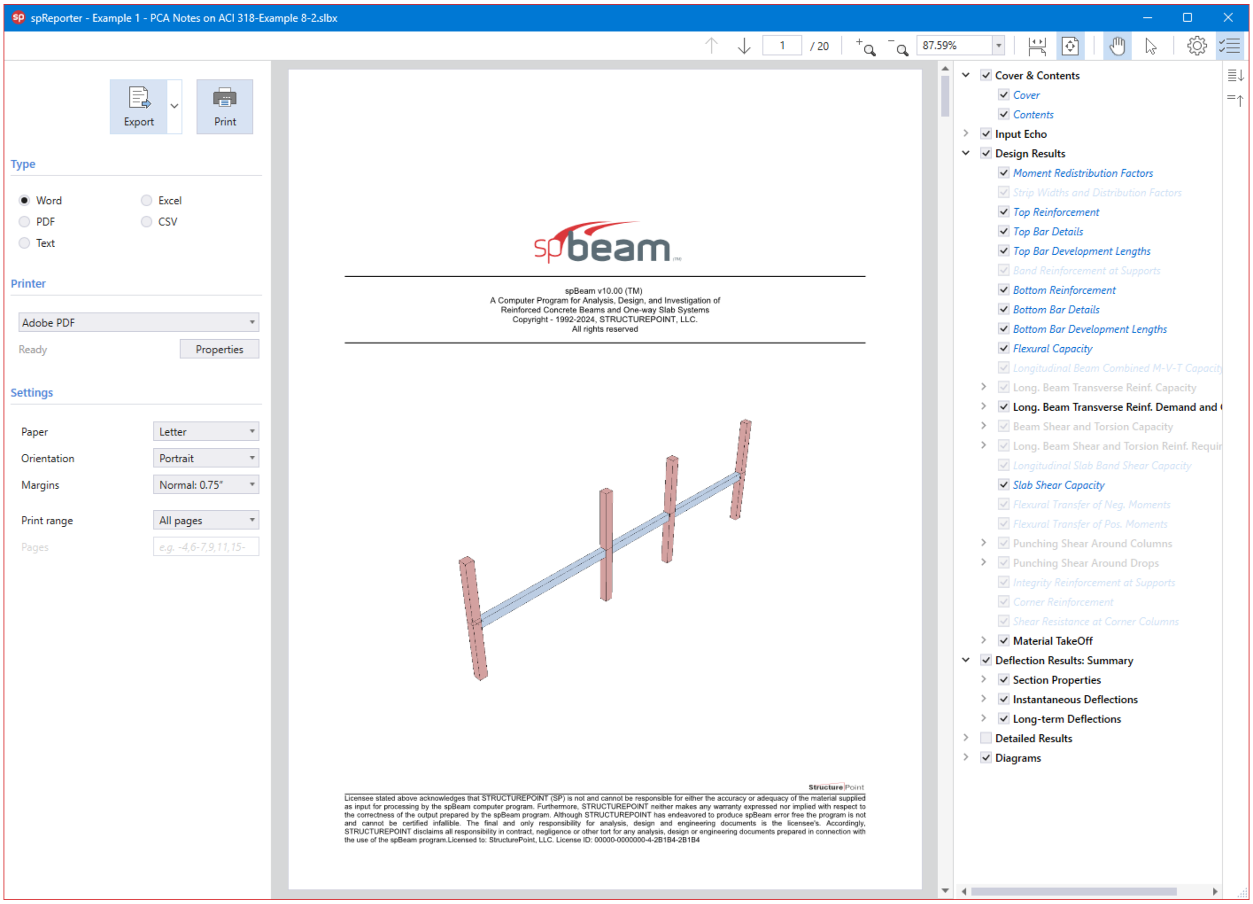

spBeam - Example 1 - PCA Notes on ACI 318-Example 8-2.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
1.0
Results - Deflection
Legend:
Dead Load
Sustained Load
Live Load
Total Deflection
-0.525
Instantaneous Deflection - in
0.525
ACI 318-14
One-Way/Beam
Design
x = -4.49 ft
Dz = -1.112 in
Units: English


spBeam - Example 1 - PCA Notes on ACI 318-Example 8-2.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
Show
Beam Flexural Bars
Stirrups
Bar Labels
Bar Lengths
Rotated Bar Labels
Hor. Stirrup Labels
DISPLAY OPTIONS
Diagram Grids
Legend
Fill Diagrams
Values
Scale
Results - Reinforcement
Legend:
Continuous
Discontinuous
Stirrups
1-#8(40.1)
1-#8(73.6)
1-#8(70.6)
1-#8(37.0)
1-#8(22.0)
1-#8(57.8)
1-#8(51.8)
1-#8(22.0)
1-#8(24.1)
1-#8(54.9)
1-#8(57.8)
1-#8(26.2)
18-#3@6.9
2-#8(300.0)c
18-#3@6.9
8-#3@6.6
2-#8(180.0)c
8-#3@6.6
11-#3@6.4
2-#8(240.0)c
11-#3@6.4
Flexural and Transverse Reinforcement
ACI 318-14
One-Way/Beam
Design
x = 49.90 ft
Units: English

16. Results can be also viewed in table format by selecting the **Tables** command from the **Ribbon.**



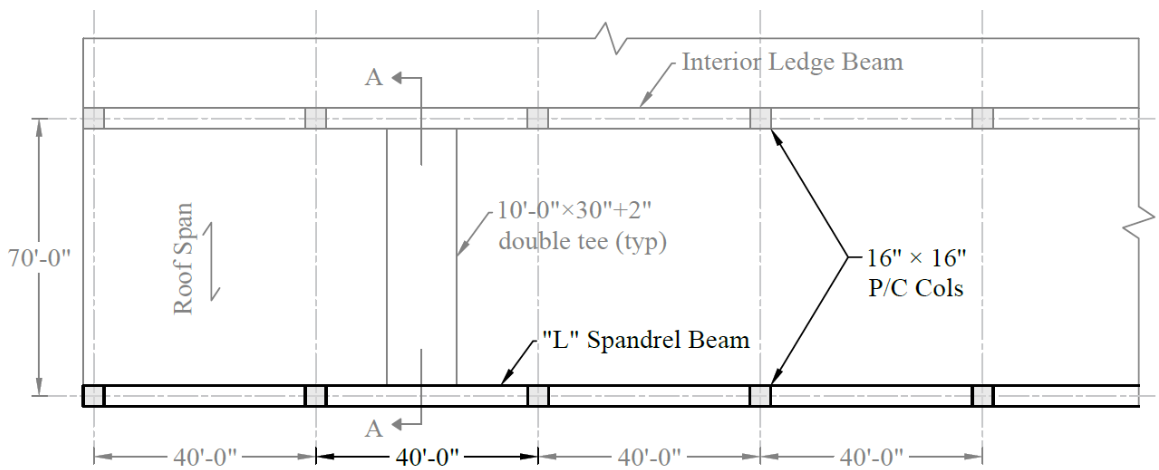
17. Results can be printed or exported in different formats by selecting the **Reporter** command from the **Ribbon.**



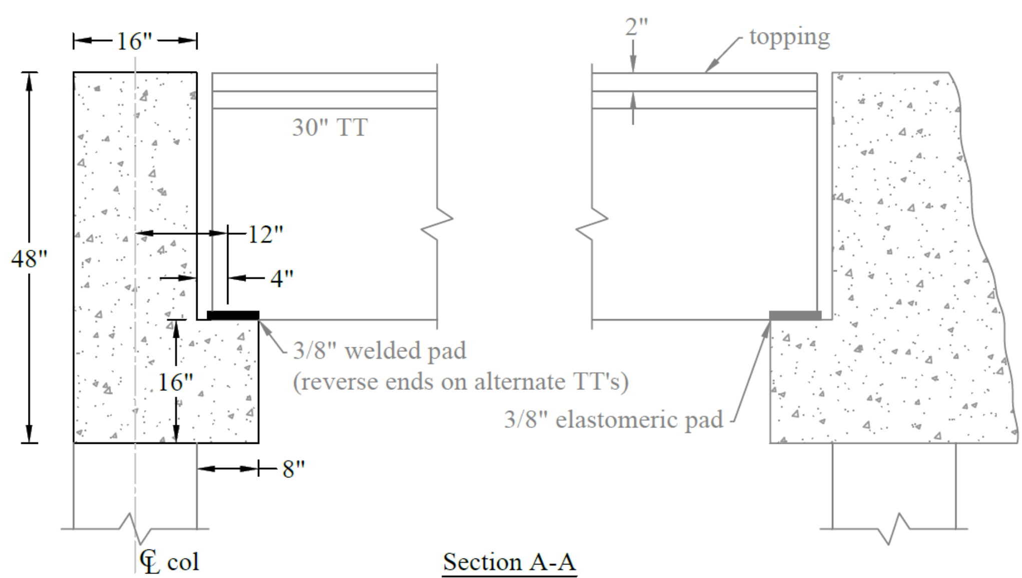
# 8.2. Example 2 – Spandrel Beam with Torsion

## 8.2.1. Problem Formulation

Design a precast, nonprestressed concrete spandrel beam for combined shear and torsion. Roof members are simply supported on spandrel ledge. Spandrel beams are connected to columns to transfer torsion. Continuity between spandrel beams is not provided.[2]




Partial Plan of Precast Roof System




Section A-A

[2] *Notes on ACI 318-11 Building Code Requirements for Structural Concrete*, Twelfth Edition, 2013 Portland Cement Association, Example 13-1

**Design data**

Dead load = 90 lb/ft$^2$ (double tee + topping + insulation + roofing)

Live load = 30 lb/ft$^2$

$f_c'$ = 5,000 psi ($w_c$ = 150 pcf)

$f_y$ = 60,000 psi

Roof members are 10 ft wide double tee units, 30 in. deep with 2 in. topping. Design of these units is not included in this design example. For lateral support, alternate ends of roof members are fixed to supporting beams.

### 8.2.2. Preparing the Input

1. From the Start screen, select **New Project**.

2. From the **Main Program Window**, select **Project** from the **Ribbon**.

   - In the **General** section, select the DESIGN CODE, UNIT SYSTEM, and BAR SET.

   - In the **Materials** section, input the following:

     f'c (SLABS & BEAMS): 5.00 ksi

     f'c (COLUMNS): 5.00 ksi

     fy: 60.00 ksi

     Alternatively, detailed material properties for **Concrete** and **Reinforcement Steel** can be entered using **Definitions** dialog box (see Steps 4 and 5).

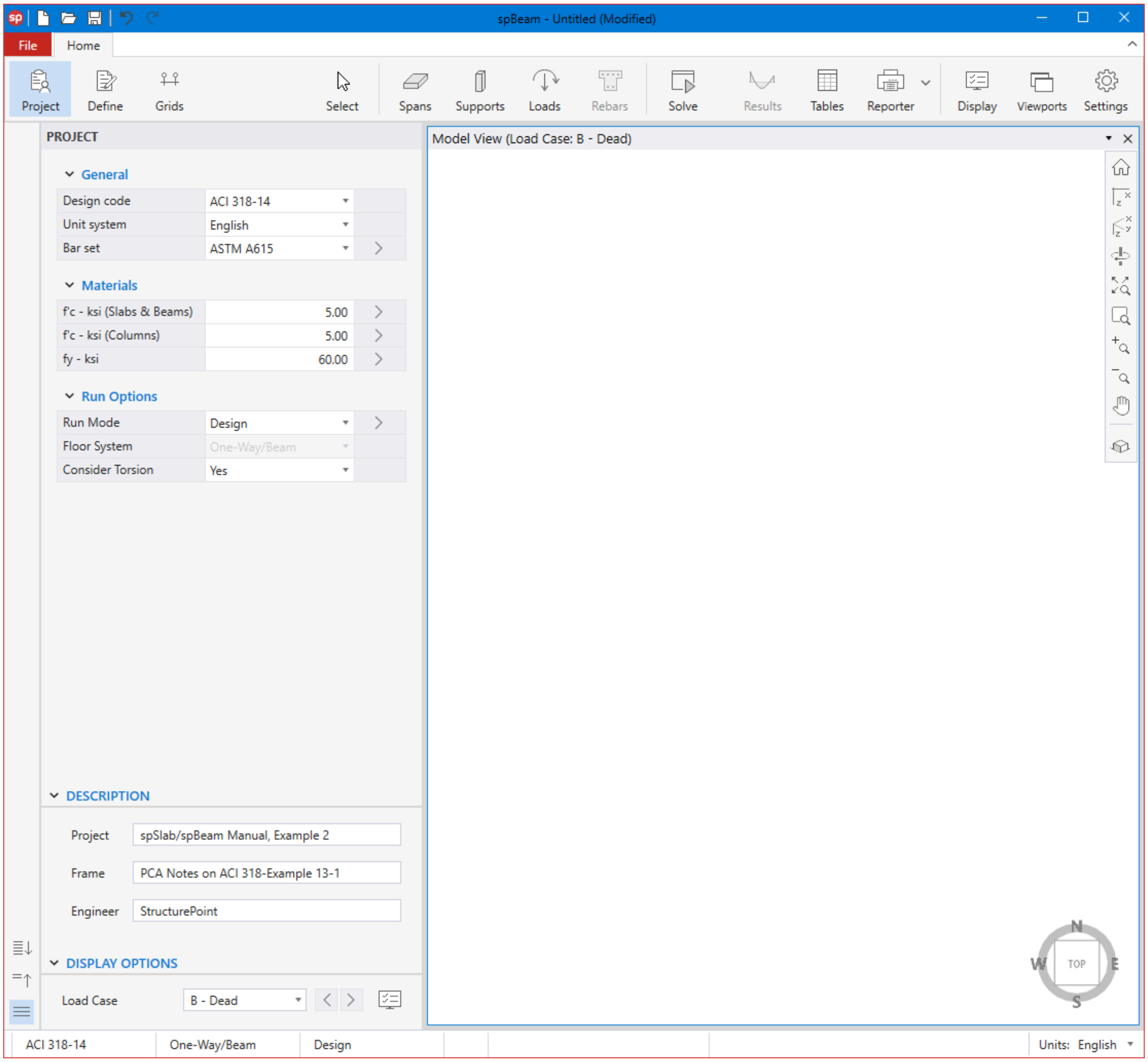
   - In the **Run Options** section, select the following:

     RUN MODE: Design

     FLOOR SYSTEM: One-Way/Beam

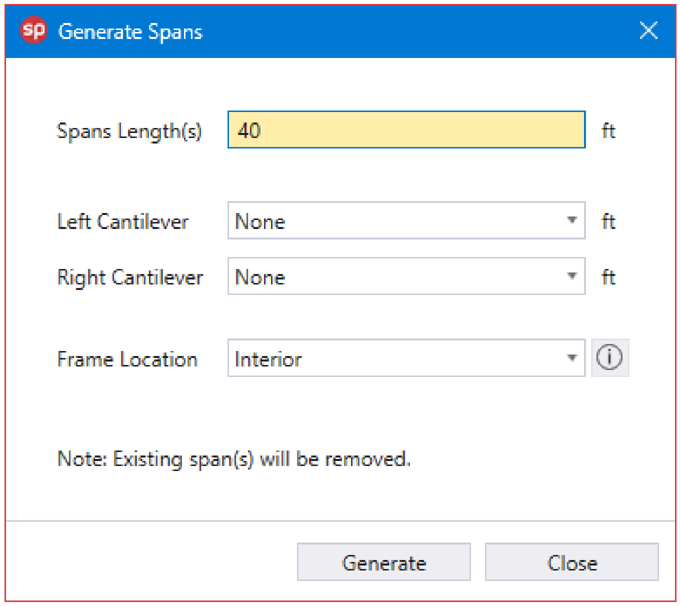
     CONSIDER TORSION: Yes

   - In the **Description** section, enter the PROJECT, FRAME, and ENGINEER.


spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
PROJECT
General
Design code
ACI 318-14
Unit system
English
Bar set
ASTM A615
Materials
f'c - ksi (Slabs & Beams)
5.00
f'c - ksi (Columns)
5.00
fy - ksi
60.00
Run Options
Run Mode
Design
Floor System
One-Way/Beam
Consider Torsion
Yes
DESCRIPTION
Project
spSlab/spBeam Manual, Example 2
Frame
PCA Notes on ACI 318-Example 13-1
Engineer
StructurePoint
DISPLAY OPTIONS
Load Case
B - Dead
Model View (Load Case: B - Dead)
N
W
TOP
E
S
ACI 318-14
One-Way/Beam
Design
Units: English

3. From the **Ribbon**, select **Grids**.

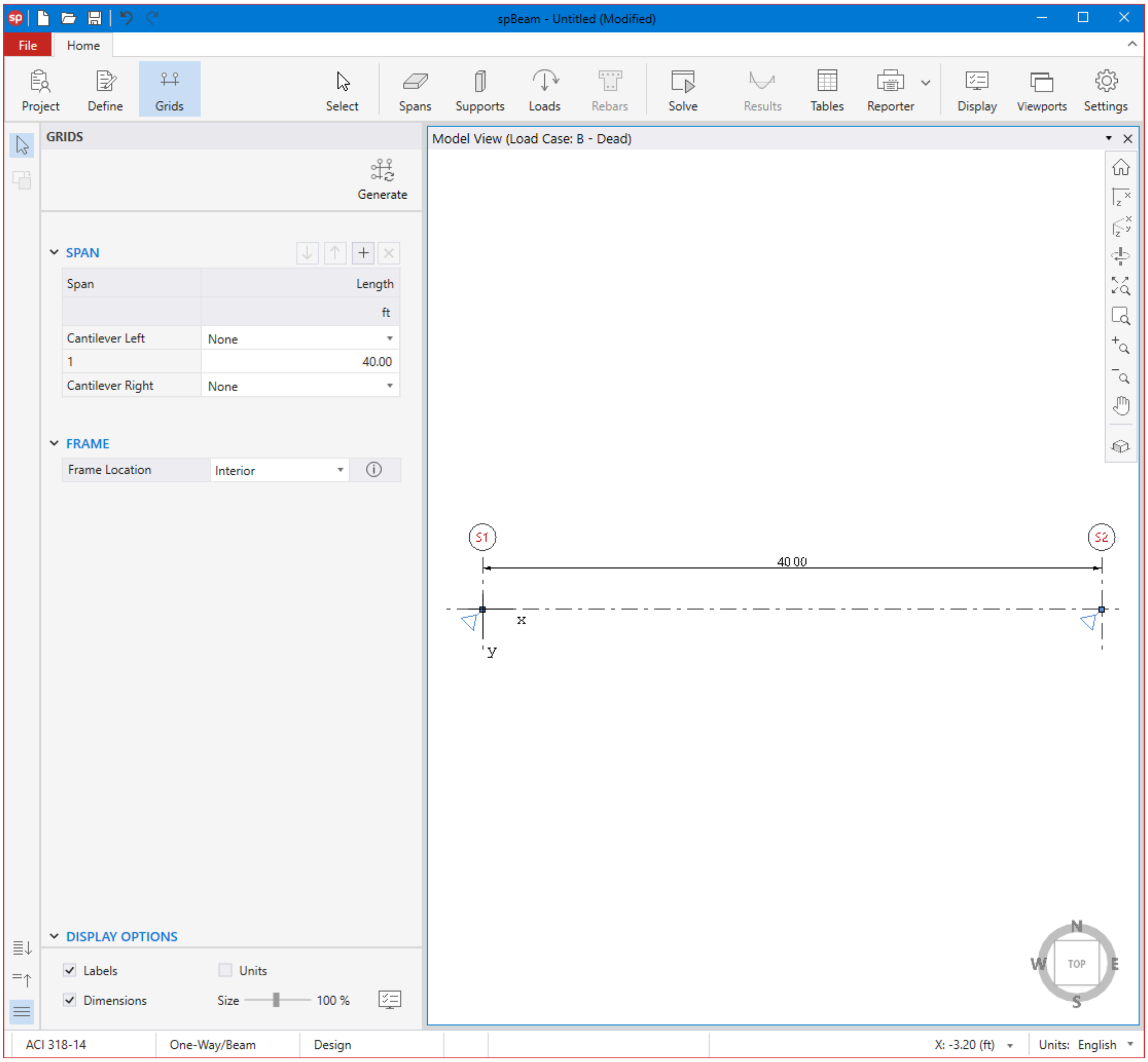
- Click on the **Generate** in the left panel to have the program surface the following:




- Enter the following values in the corresponding text boxes:

| | |
|---|---|
| SPANS LENGTH(S): | 40 |
| LEFT CANTILEVER: | None |
| RIGHT CANTILEVER: | None |
| FRAME LOCATION: | Interior |

- Click on the GENERATE button to return to the main window. Notice how the grid lines now appear in the VIEWPORT.

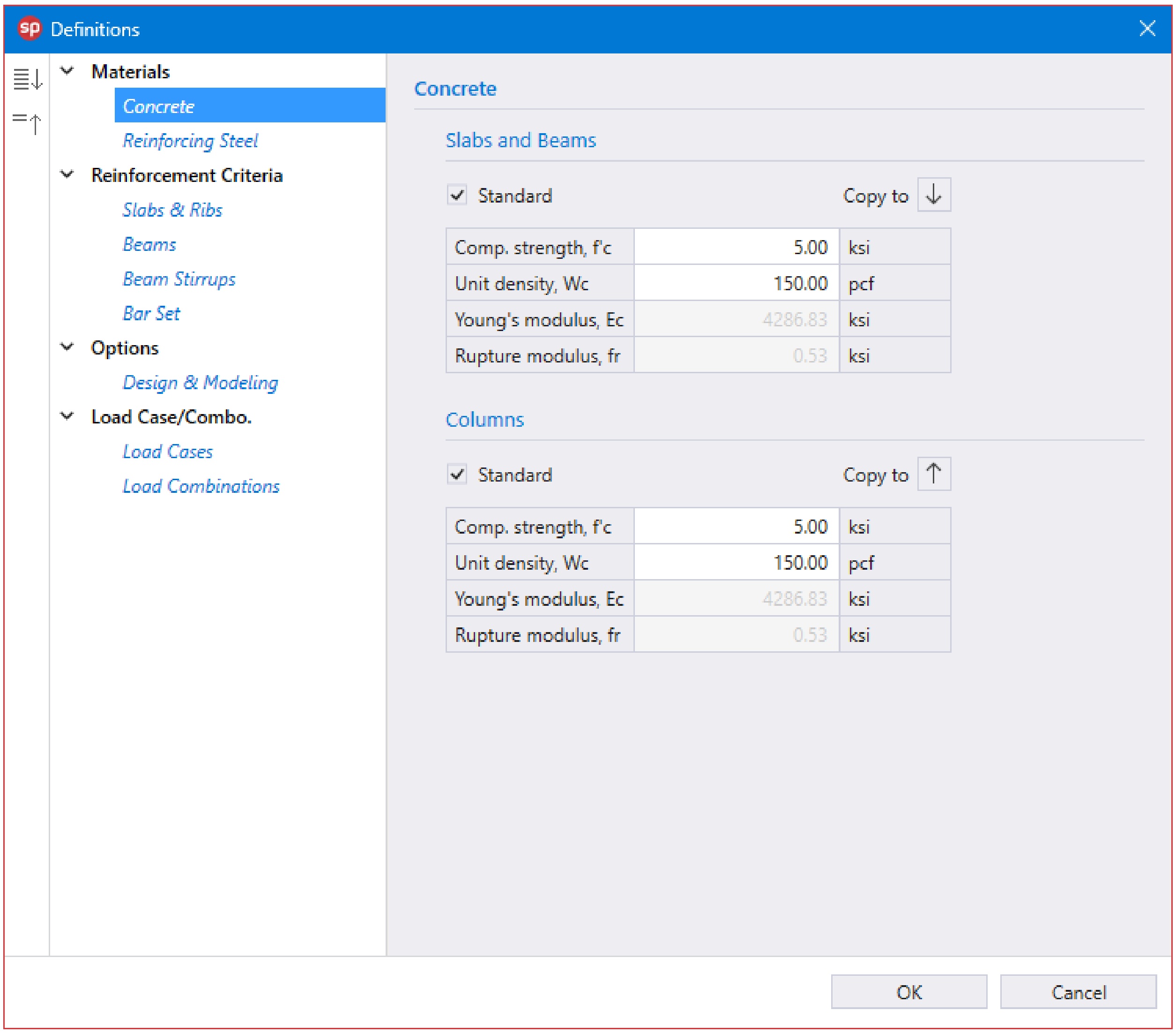

spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
GRIDS
Generate
SPAN
Span
Length
ft
Cantilever Left
None
1
40.00
Cantilever Right
None
FRAME
Frame Location
Interior
DISPLAY OPTIONS
Labels
Units
Dimensions
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
40.00
x
y
N
W
TOP
E
S
ACI 318-14
One-Way/Beam
Design
X: -3.20 (ft)
Units: English

4. From the **Ribbon**, select **Define,** then choose **Concrete** from **Materials** to display the **Concrete** dialog box.

- Check STANDARD for SLABS AND BEAMS and COLUMNS.
- Enter the following for SLABS AND BEAMS and COLUMNS:

COMPRESSIVE STRENGTH, f'c: `5.00` ksi

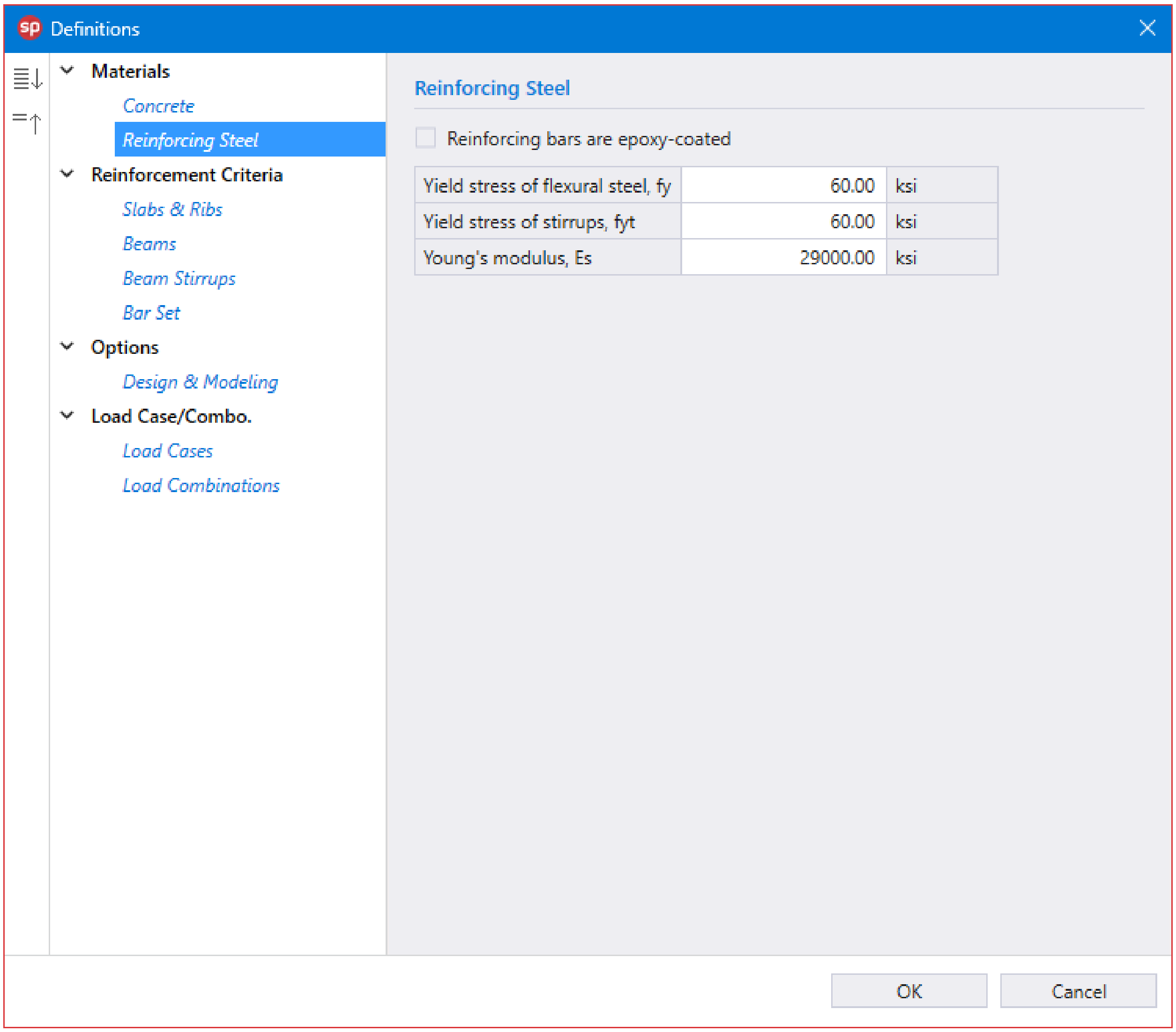
UNIT DENSITY, Wc: `150.00` pcf



5. Click on **Reinforcing Steel** from **Materials** to display the **Reinforcing Steel** dialog box.

- Enter the following:

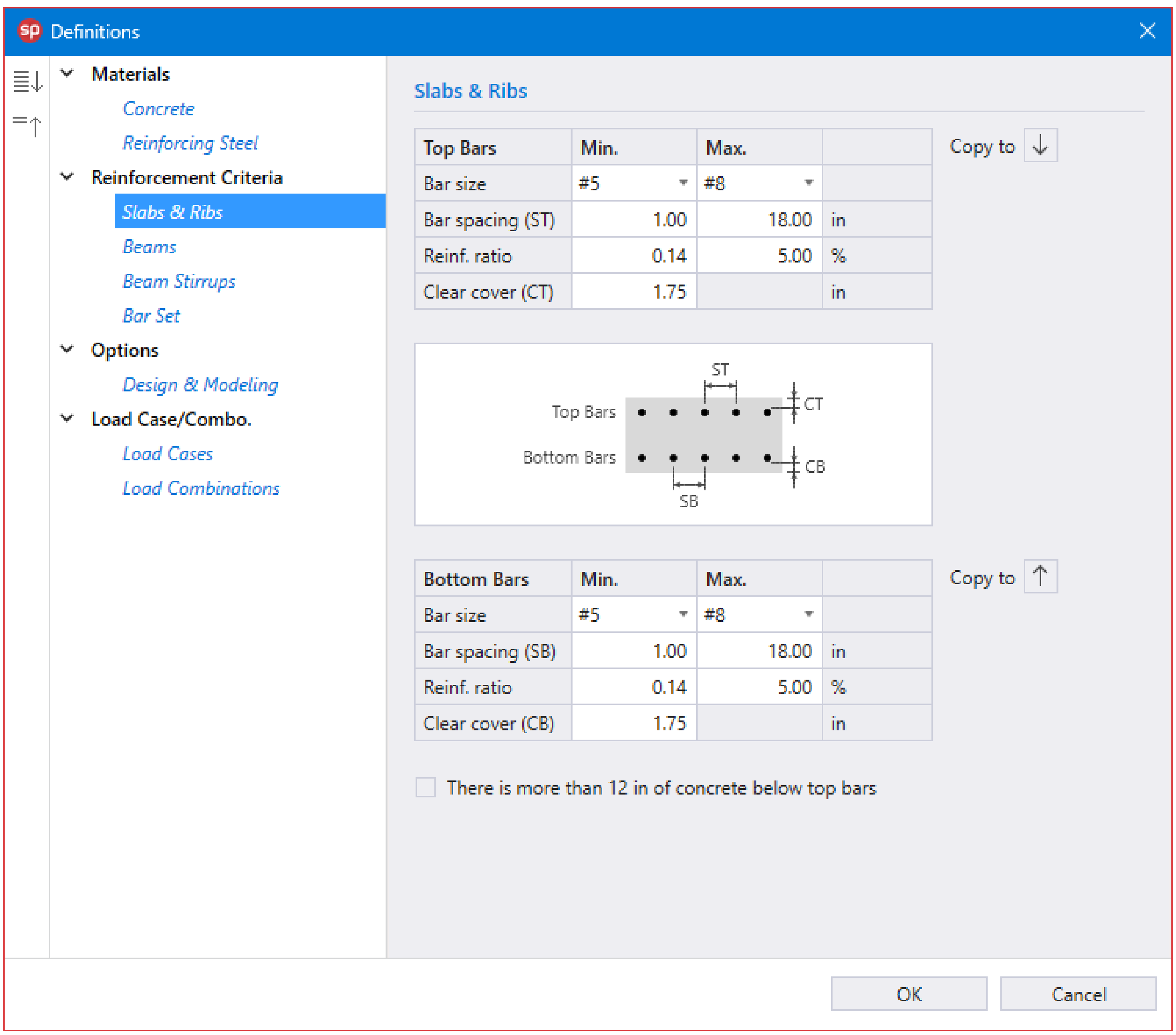
| | |
|---|---|
| YIELD STRESS OF FLEXURAL STEEL, fy: | 60.00 ksi |
| YIELD STRESS OF STIRRUP, fyt: | 60.00 ksi |
| YOUNG'S MODULUS, Es: | 29000.00 ksi |



6. Click on **Slabs & Ribs** from **Reinforcement Criteria** to display the **Slabs & Ribs** dialog box.

   - Enter the following for TOP BARS and BOTTOM BARS:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #5 | #8 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.75 in | |



7. Click on **Beams** from **Reinforcement Criteria** to display the **Beams** dialog box.

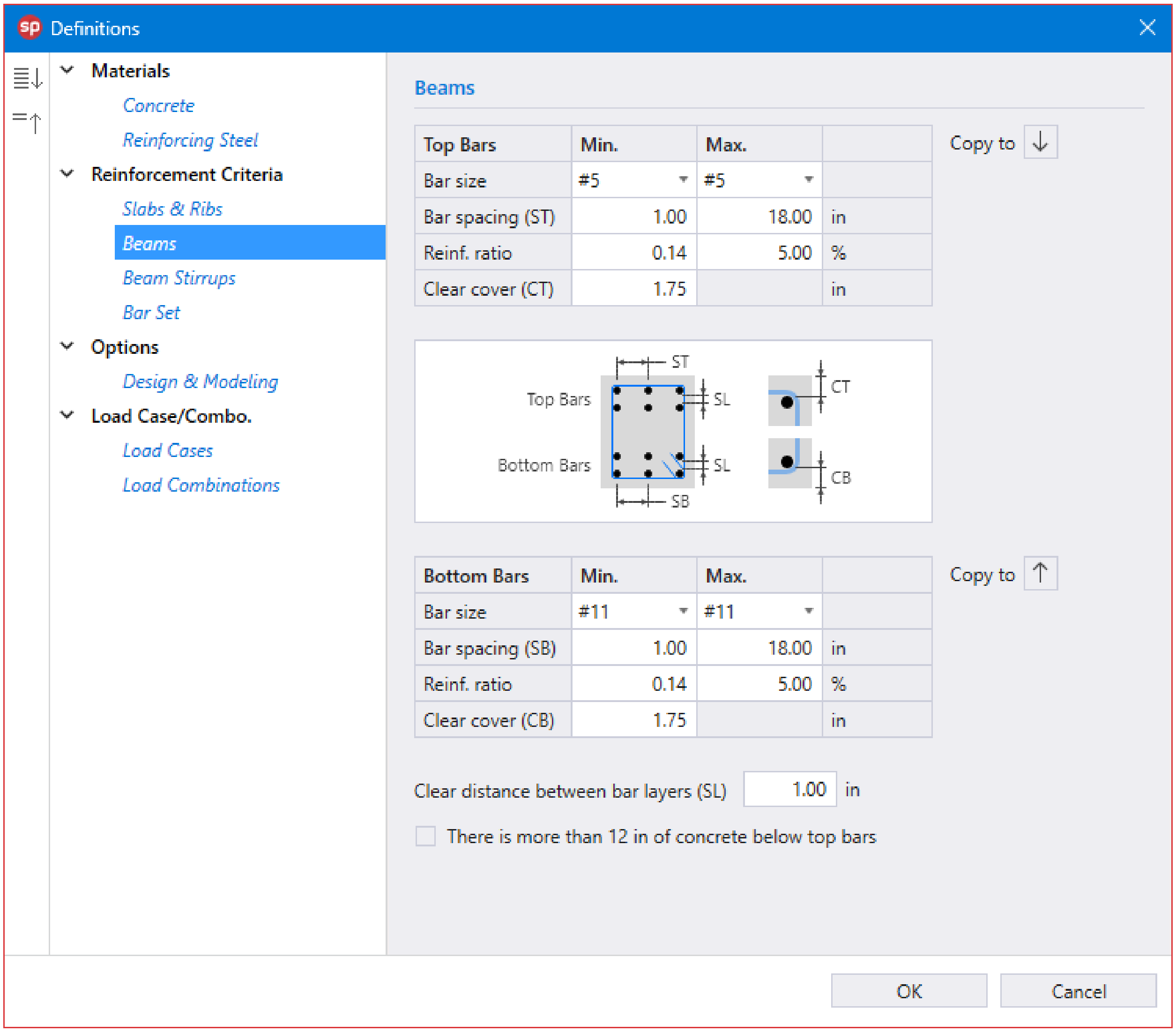
- Enter the following for TOP BARS:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #5 | #5 |
| BAR SPACING (ST): | `1.00` in | `18.00` in |
| REINFORCEMENT RATIO: | `0.14` % | `5.00` % |
| CLEAR COVER (CT): | `1.75` in | |

- Enter the following for BOTTOM BARS:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #11 | #11 |
| BAR SPACING (ST): | `1.00` in | `18.00` in |
| REINFORCEMENT RATIO: | `0.14` % | `5.00` % |
| CLEAR COVER (CT): | `1.75` in | |

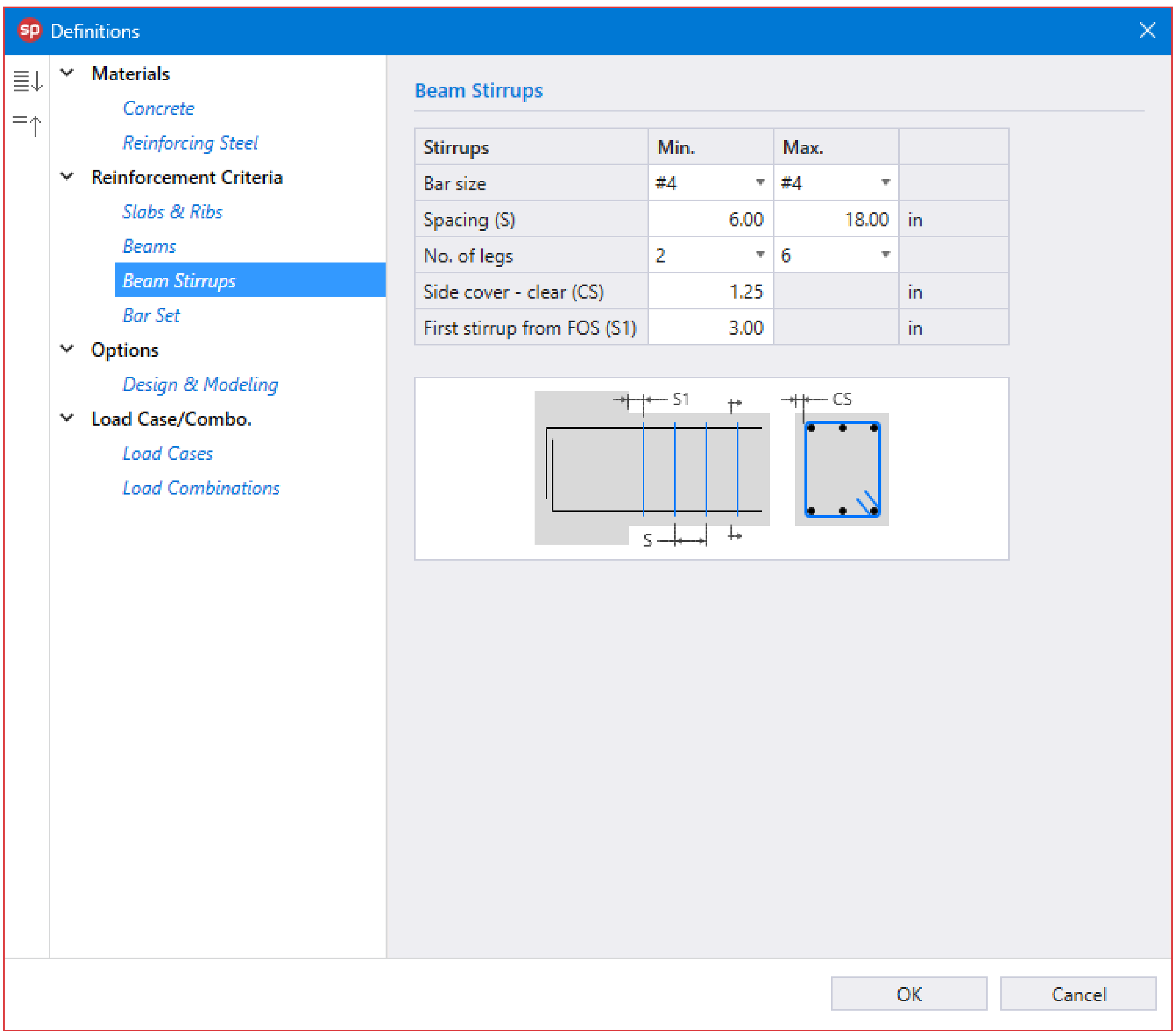
CLEAR DISTANCE BETWEEN BAR LAYERS (SL): `1.00` in


Definitions
Materials
Concrete
Reinforcing Steel
Reinforcement Criteria
Slabs & Ribs
Beams
Beam Stirrups
Bar Set
Options
Design & Modeling
Load Case/Combo.
Load Cases
Load Combinations
Beams
Top Bars | Min. | Max.
Bar size | #5 | #5
Bar spacing (ST) | 1.00 | 18.00 | in
Reinf. ratio | 0.14 | 5.00 | %
Clear cover (CT) | 1.75 | in
Copy to
ST
Top Bars
SL
CT
Bottom Bars
SL
CB
SB
Bottom Bars | Min. | Max.
Bar size | #11 | #11
Bar spacing (SB) | 1.00 | 18.00 | in
Reinf. ratio | 0.14 | 5.00 | %
Clear cover (CB) | 1.75 | in
Copy to
Clear distance between bar layers (SL) 1.00 in
There is more than 12 in of concrete below top bars
OK
Cancel

8. Click on **Beam Stirrups** from **Reinforcement Criteria** to display the **Beam Stirrups** dialog box.

   - Enter the following:

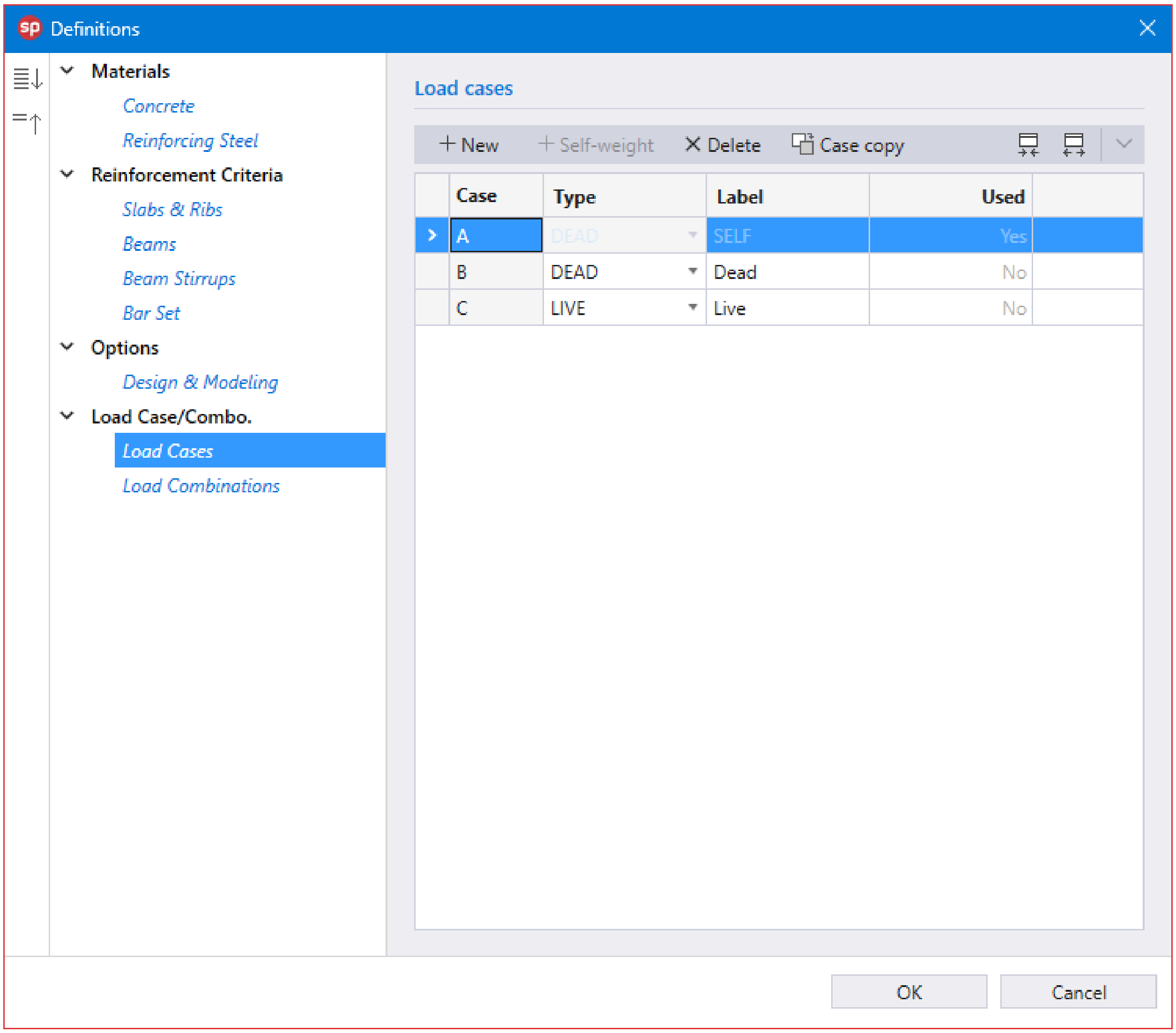
| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #4 | #4 |
| BAR SPACING (S): | 6.00 in | 18.00 in |
| NUMBER OF LEGS: | 2 | 6 |
| SIDE COVER – CLEAR (CS): | 1.25 in | |
| FIRST STIRRUP FROM FOS (S1): | 3.00 in | |



9. Click on **Load Cases** from **Load Case/Combo.** to display the **Load Cases** dialog box.

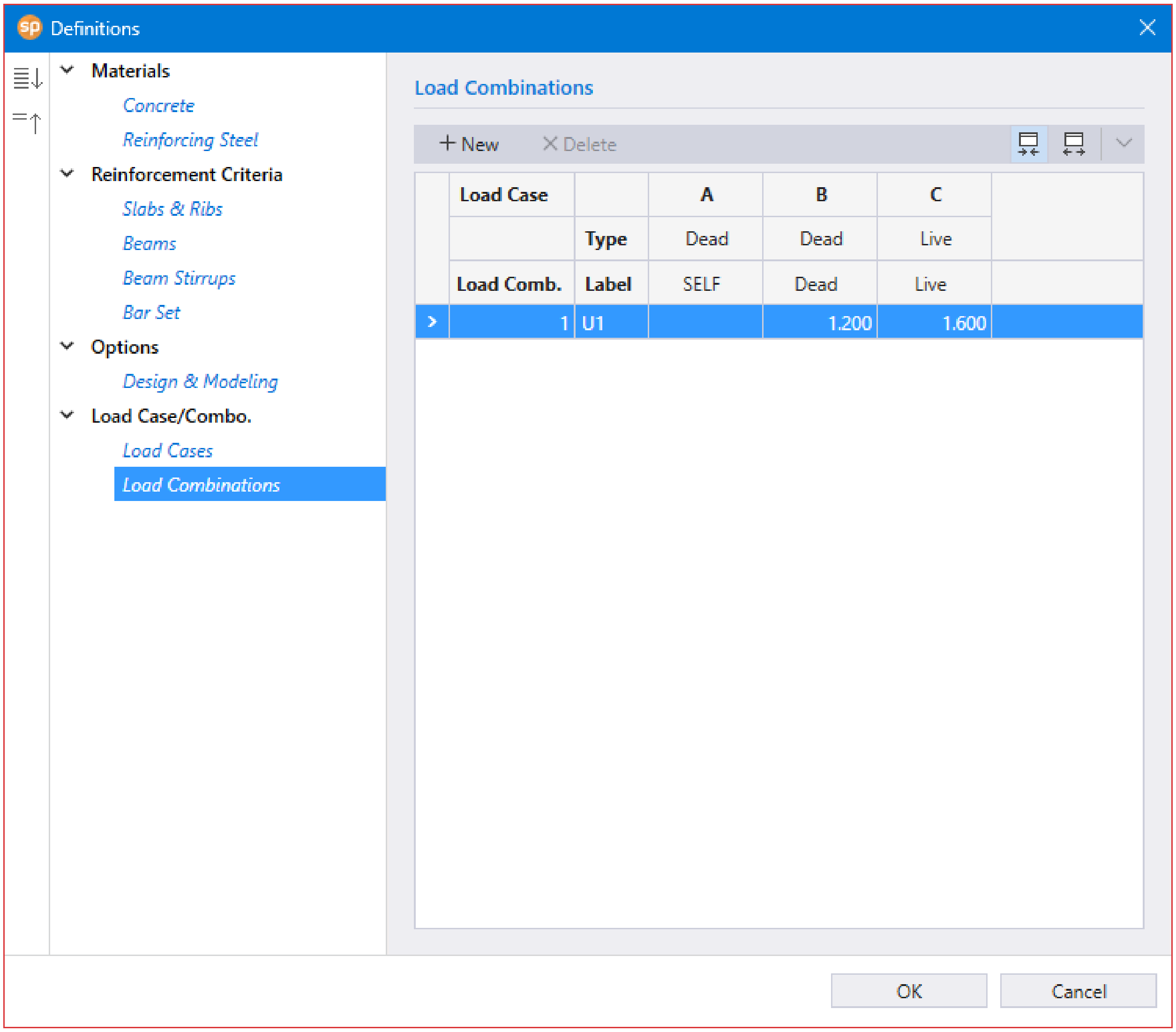
- Add SELF-WEIGHT for CASE A.
- Enter the following:

| | |
|---|---|
| CASE B: | `Dead` |
| CASE C: | `Live` |



10. Click on **Load Combinations** from **Load Case/Combo.** to display the **Load Combinations** dialog box.

- Enter the following load combination shown in the figure below:



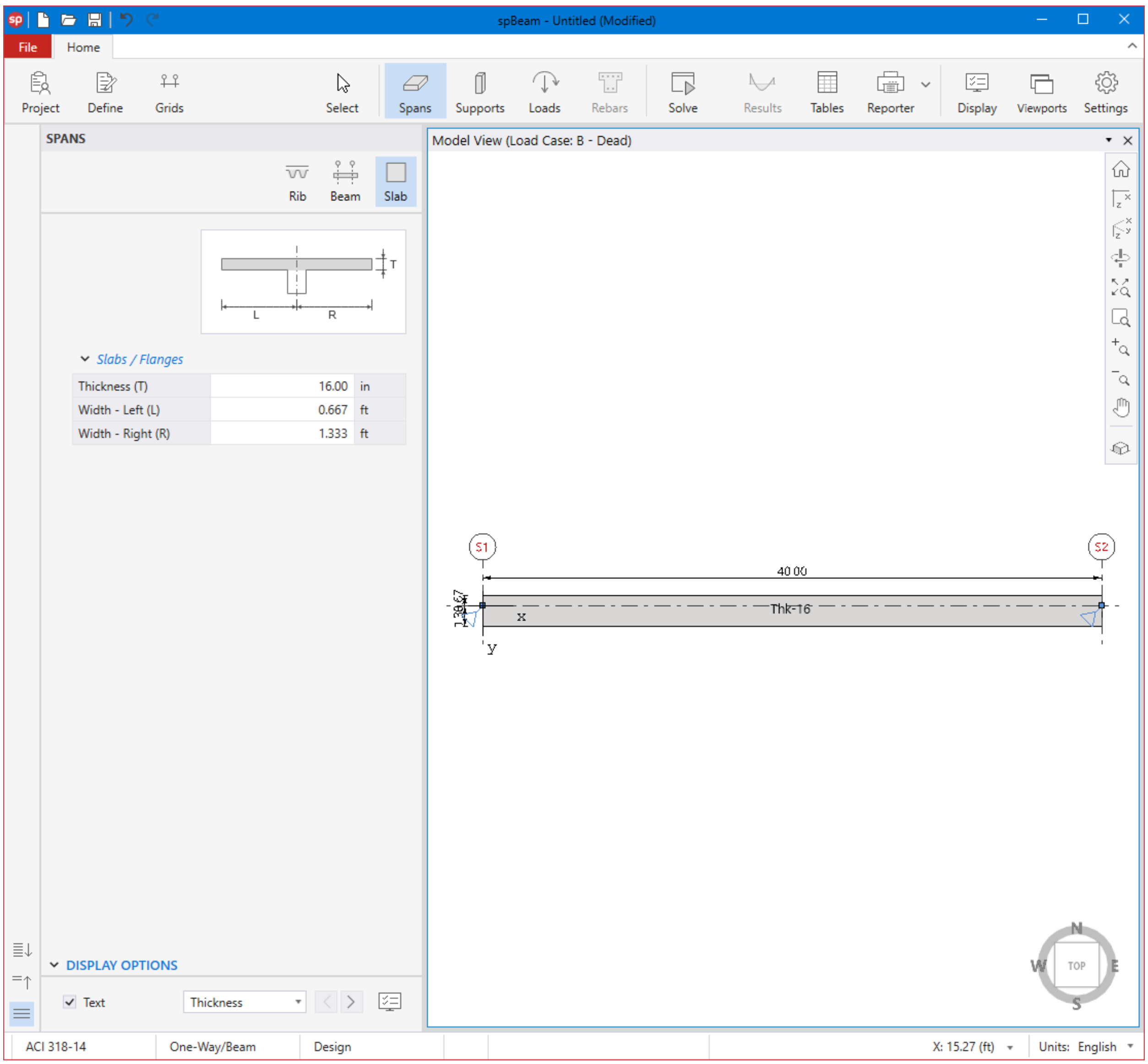
### 8.2.3. Assigning Spans

11. From the **Ribbon**, select **Spans** command.

- In the left panel, select **Slab** and enter the following:

| | |
|---|---|
| THICKNESS (T): | 16.00 in |
| WIDTH – LEFT (L): | 0.667 ft |
| WIDTH – RIGHT (R): | 1.333 ft |

- Apply to the span as shown in the figure below.

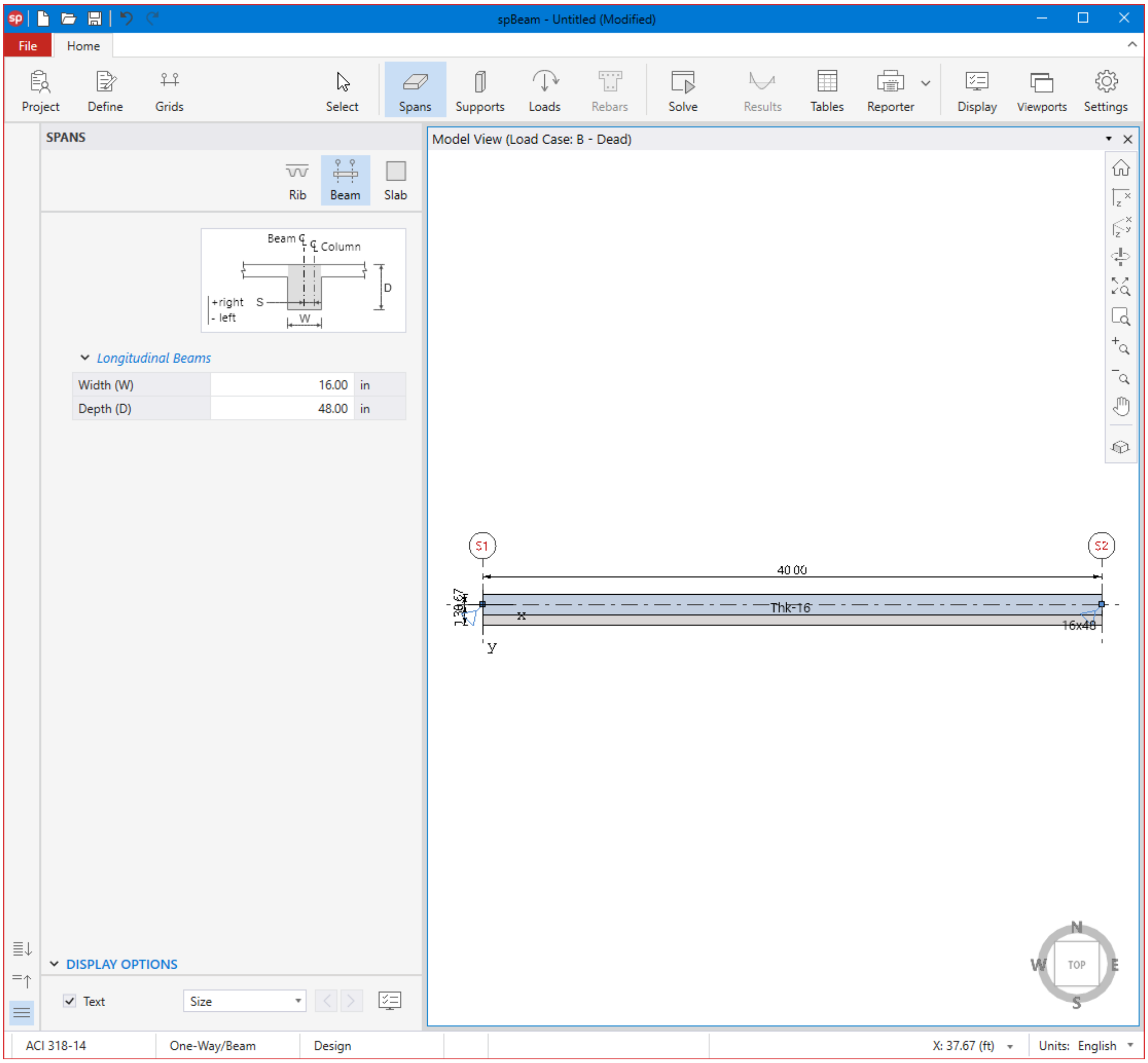


- In the left panel, select **Beam** and enter the following:

WIDTH (W): 16.00 in

DEPTH (D): 48.00 in

- Apply to the span as shown in the figure below.



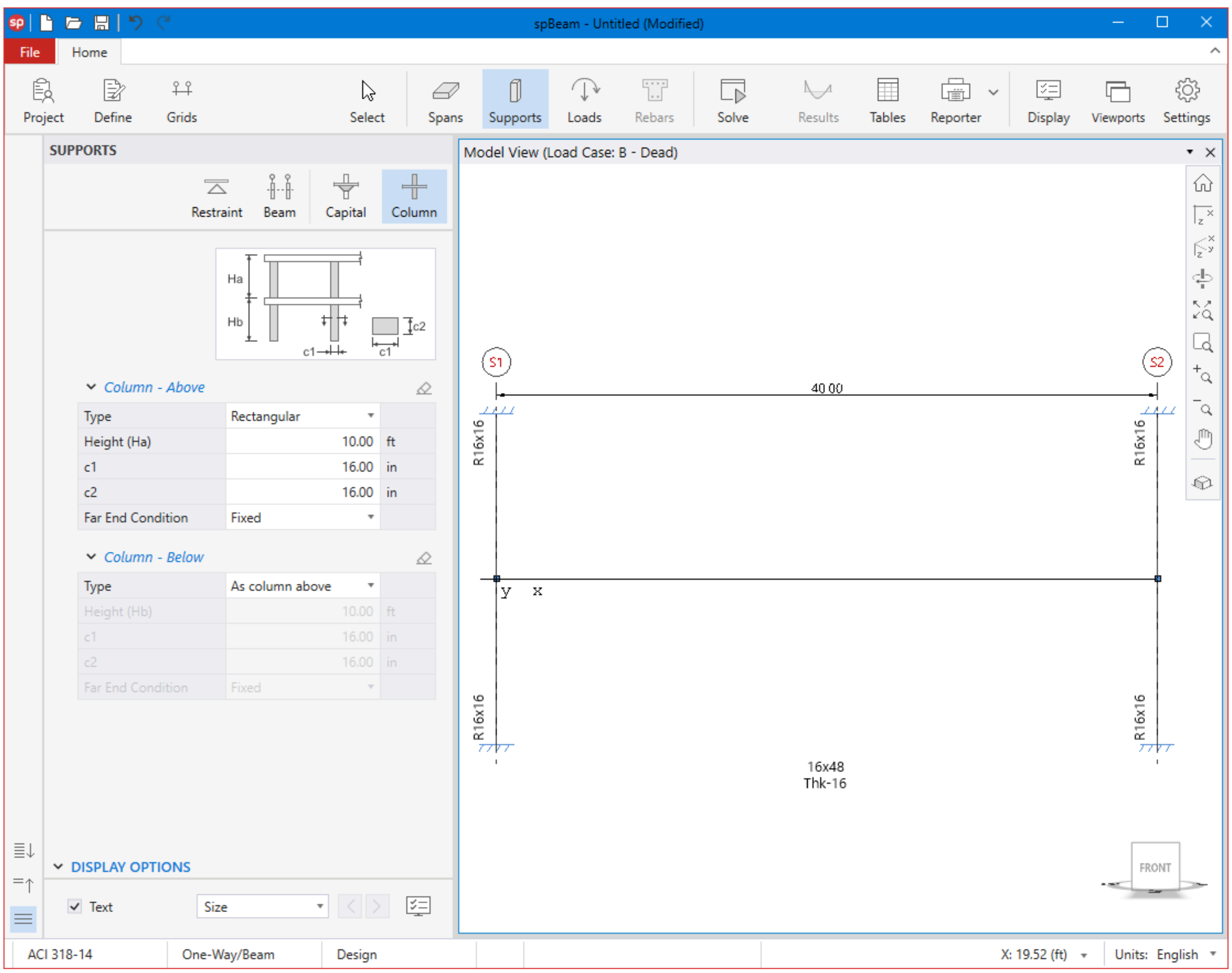
## 8.2.4. Assigning Supports

12. From the **Ribbon**, select **Supports** command.

    - In the left panel, select **Column** and enter the following for COLUMN – ABOVE and COLUMN – BELOW:

| | |
|---|---|
| TYPE: | Rectangular |
| HEIGHT: | 10.00 ft |
| c1: | 16.00 in |
| c2: | 16.00 in |
| FAR END CONDITION: | Fixed |

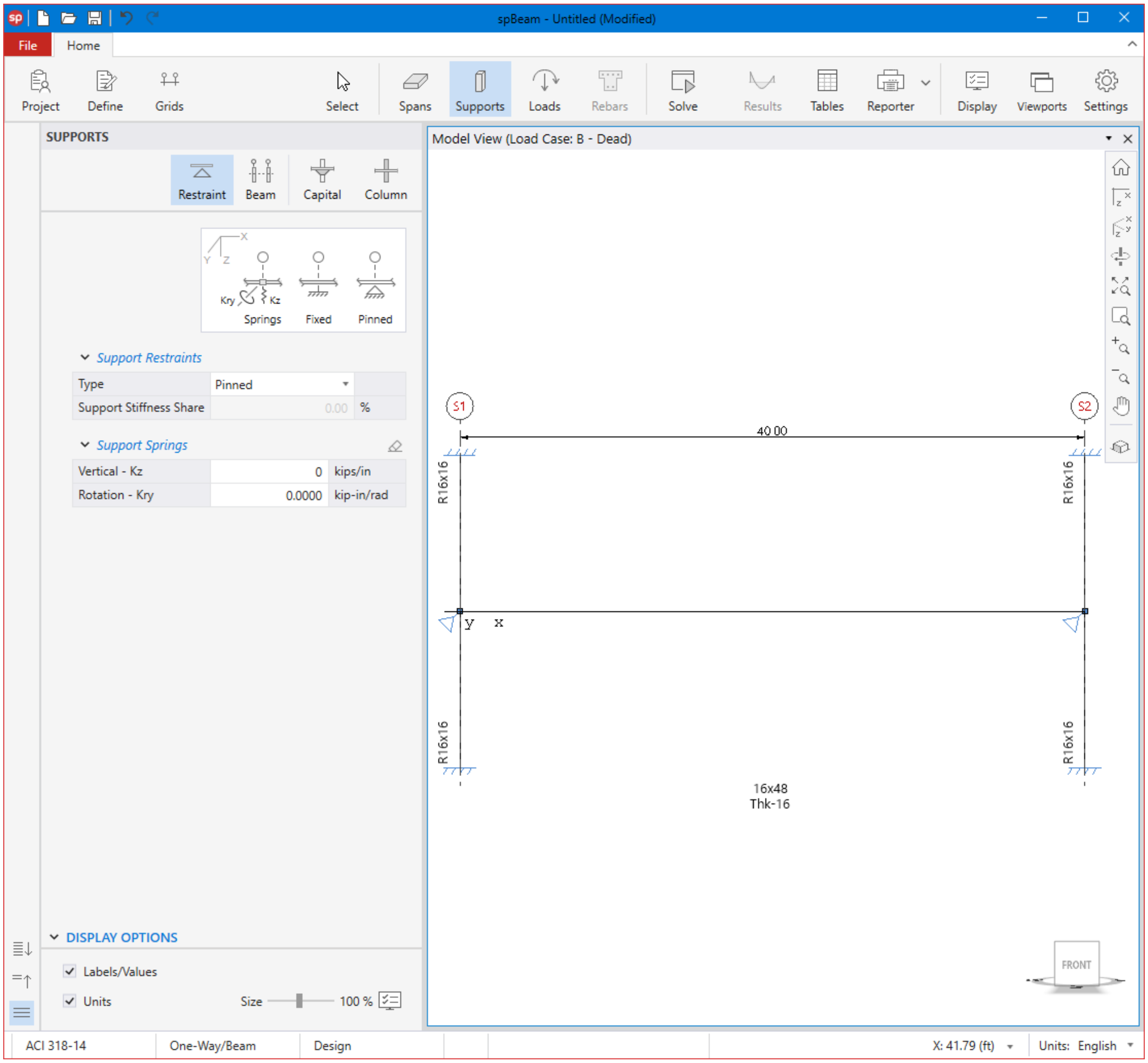
    - Apply to all supports as shown in the figure below.



- In the left panel, select **Restraint** and select the following for SUPPORT RESTRAINTS.

TYPE: Pinned

- Apply to all supports as shown in the figure below.



## 8.2.5. Assigning Loads

13. From the **Ribbon**, select **Loads** command.

- In the left panel, select **Uniform Line Loads** then select B-DEAD from LOAD CASE and enter the following:

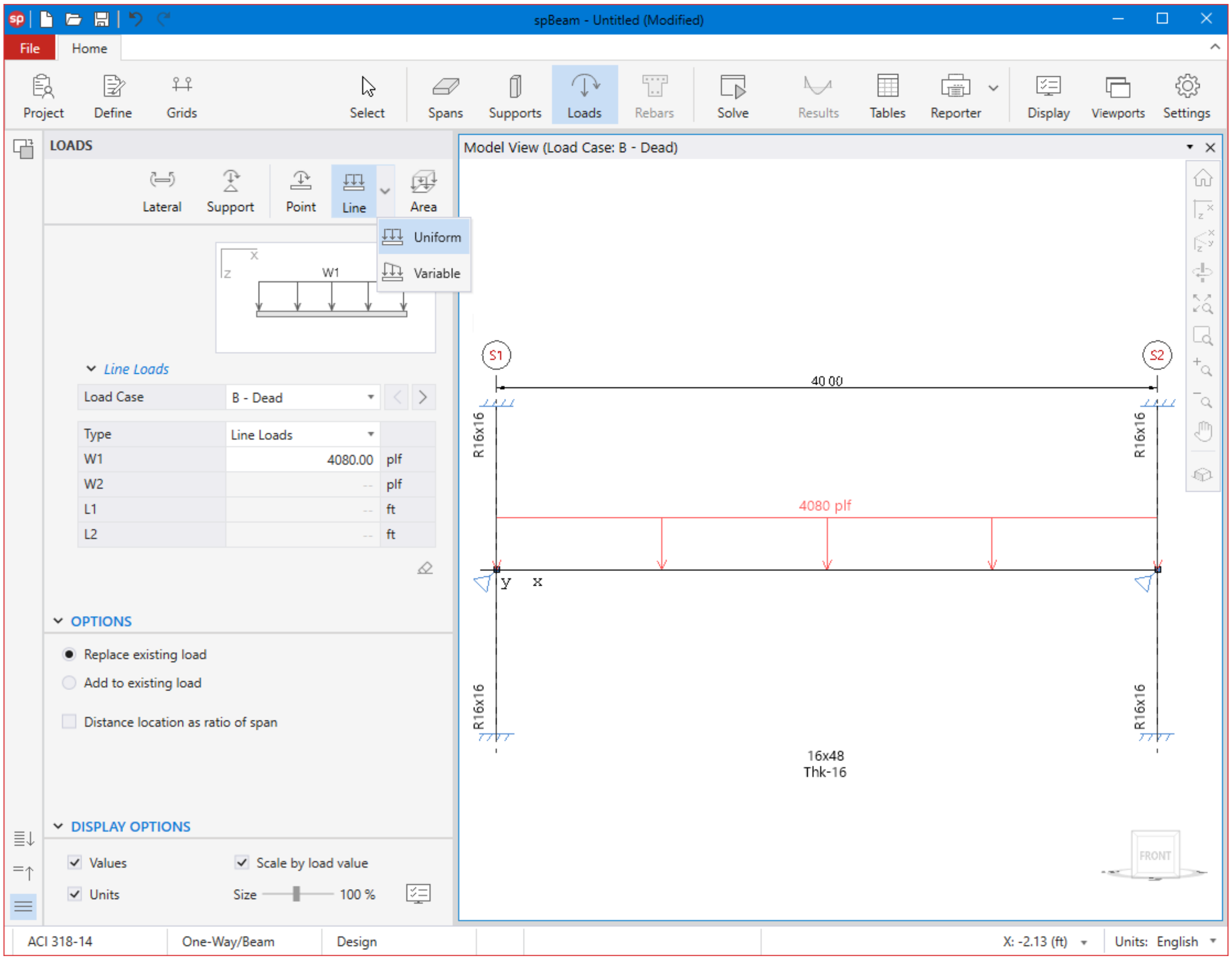
  $w_1$: `4080.00` plf

  (Note: this value was obtained by converting the area loads on the roof and the beam's self weight into line loads.)

  Dead Load = Superimposed Load + Self Weight of Spandrel Beam =

  $$\left(90 \text{ psf} \times \frac{70 \text{ ft}}{2}\right) + \left[(1.33 \text{ ft} \times 4.00 \text{ ft}) + (1.33 \text{ ft} \times 0.67 \text{ ft})\right] \times 150 \text{ pcf} = 4.080 \text{ kip/ft}$$

- Apply to the span as shown in the figure below.


spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
LOADS
Lateral
Support
Point
Line
Area
Uniform
Variable
W1
Line Loads
Load Case
B - Dead
Type
Line Loads
W1
4080.00
plf
W2
plf
L1
ft
L2
ft
OPTIONS
Replace existing load
Add to existing load
Distance location as ratio of span
DISPLAY OPTIONS
Values
Scale by load value
Units
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
40.00
R16x16
4080 plf
16x48
Thk-16
FRONT
ACI 318-14
One-Way/Beam
Design
X: -2.13 (ft)
Units: English

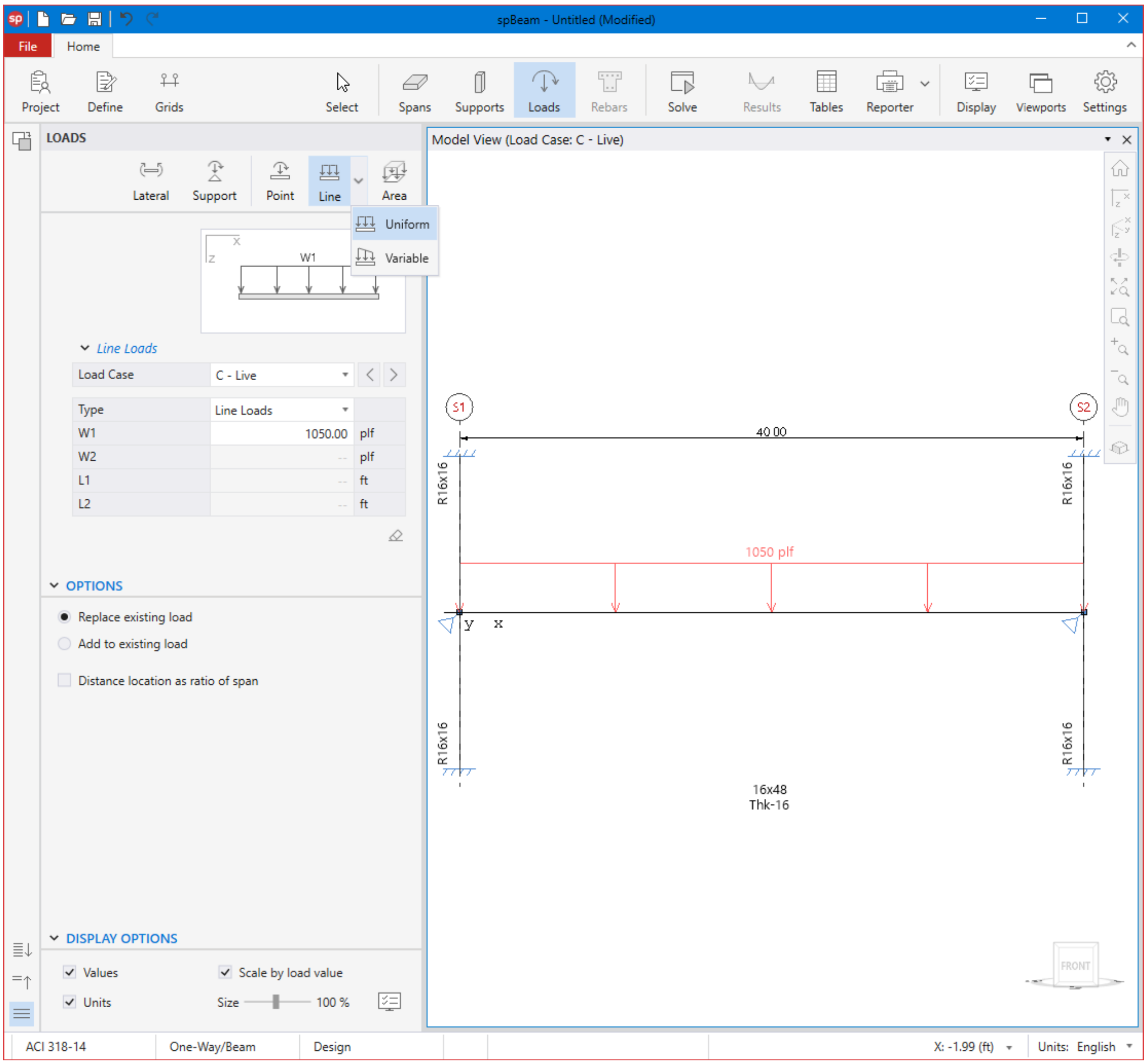
- Select C-LIVE from LOAD CASE and enter the following:

W1: 1050.00 plf

(Note: this value was obtained by converting the area loads on the roof to line loads on the beam.)

$$\text{Live Load} = 30 \text{ psf} \times \left(\frac{70 \text{ ft}}{2}\right) = 1{,}050 \text{ lb/ft}$$

- Apply to the span as shown in the figure below.



- In the left panel, select **Uniform Line Torques** then select B-DEAD from LOAD CASE and enter the following:

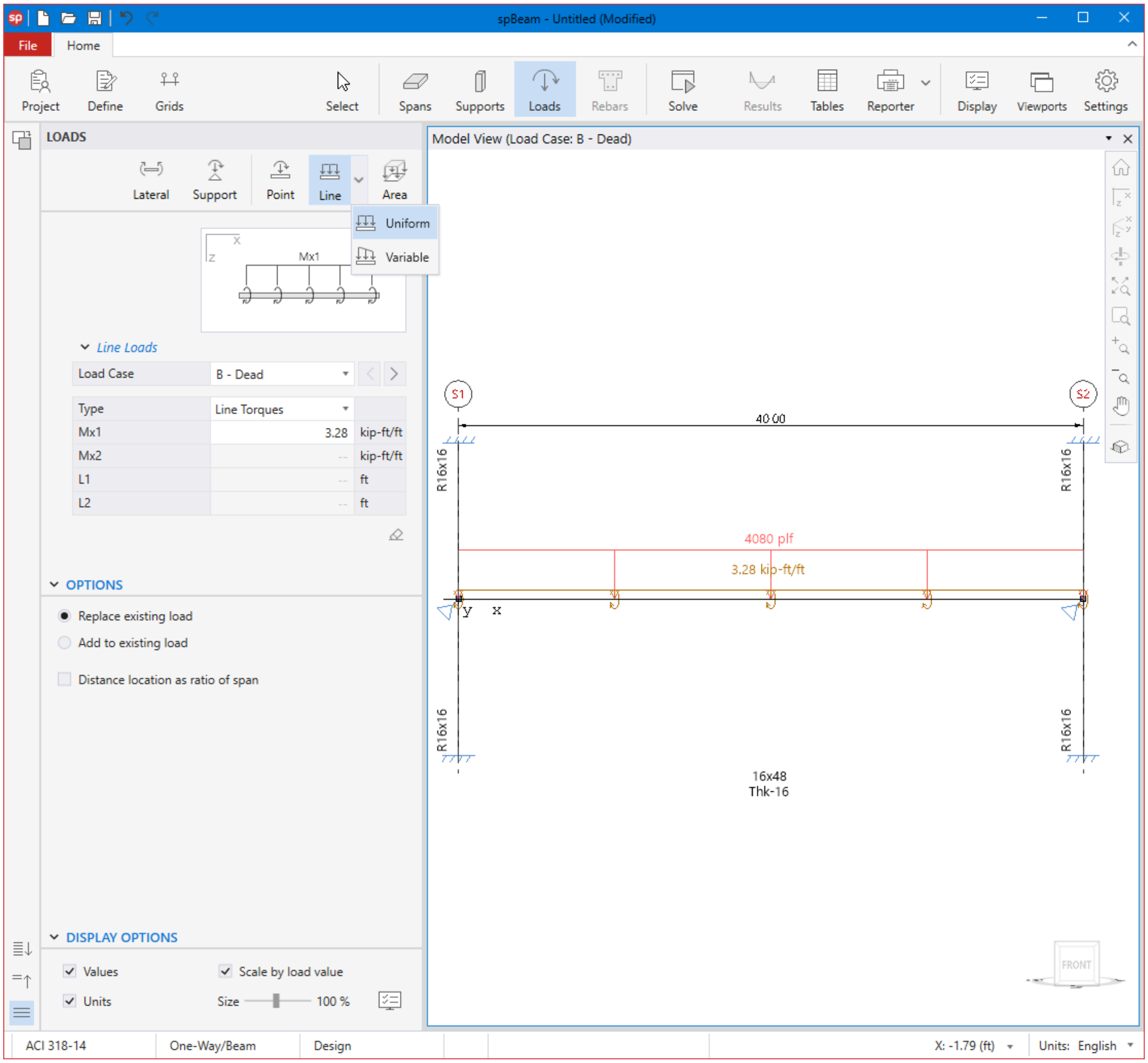
  $M_{x1}$: 3.28 kip-ft/ft

  (Note: this value was obtained by multiplying the superimposed line load by the moment arm of 12 in.)

  Torsion Line Load (Dead) =

  $$\left(90\text{ psf}\times\frac{70\text{ ft}}{2}+\frac{16\times 8}{12}\text{ft}^2\times 150\text{ pcf}\right)\times\frac{12\text{ in.}}{12\text{ in./ft}}=3.28\text{ kip-ft/ft}$$

- Apply to the span as shown in the figure below.


spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
LOADS
Lateral
Support
Point
Line
Area
Uniform
Variable
Mx1
Line Loads
Load Case
B - Dead
Type
Line Torques
Mx1
3.28
kip-ft/ft
Mx2
kip-ft/ft
L1
ft
L2
ft
OPTIONS
Replace existing load
Add to existing load
Distance location as ratio of span
DISPLAY OPTIONS
Values
Scale by load value
Units
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
40.00
R16x16
4080 plf
3.28 kip-ft/ft
16x48
Thk-16
FRONT
ACI 318-14
One-Way/Beam
Design
X: -1.79 (ft)
Units: English

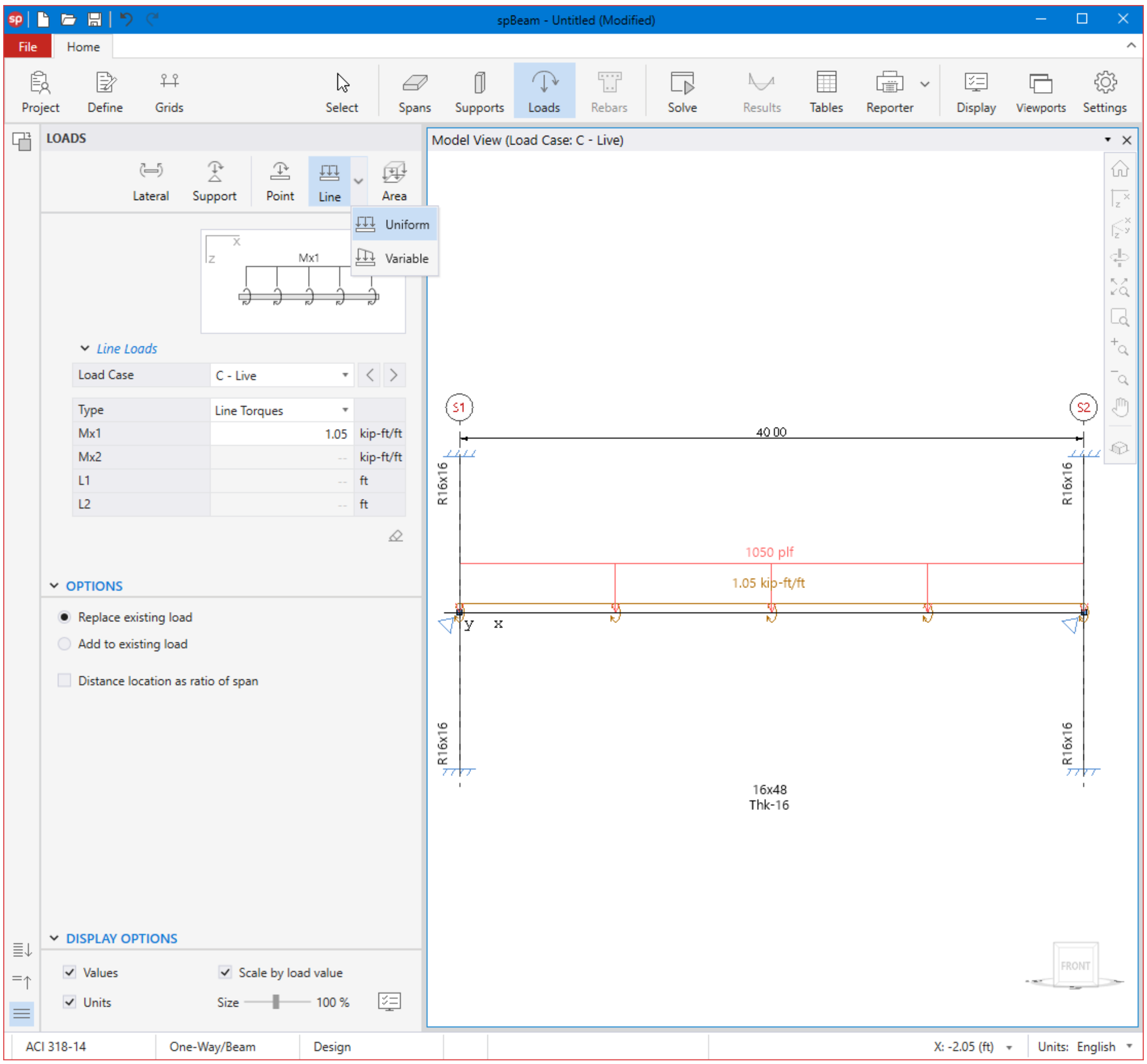
- Select C-LIVE from LOAD CASE and enter the following:

$M_{x1}$: 1.05 kip-ft/ft

(Note: this value was obtained by multiplying the live line load by the moment arm of 12 in.)

$$\left[30\text{ psf}\times\left(\frac{70\text{ ft}}{2}\right)\right]\times\frac{12\text{ in.}}{12\text{ in./ft}}=1.05\text{ kip-ft/ft}$$

- Apply to the span as shown in the figure below.



- In the left panel, select **Point Loads** then select B-DEAD from LOAD CASE and enter the following:

$F_z$: `0.001` kips

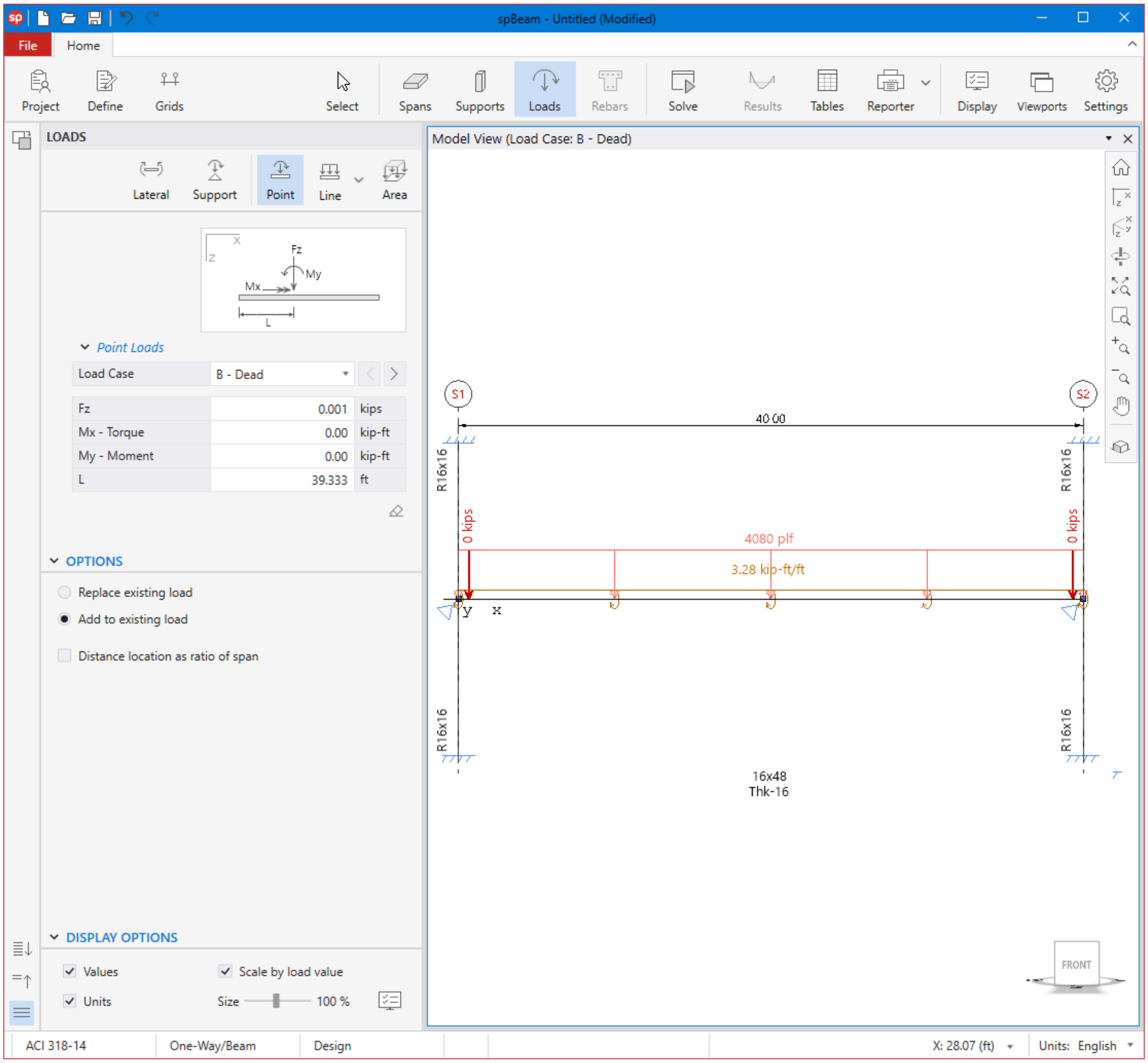
L: `0.667` ft

- Apply to the span as shown in the figure below.
- Select ADD TO EXISTING LOAD from OPTIONS and enter the following:

$F_z$: `0.001` kips

L: `39.333` ft

- Apply to the span as shown in the figure below.
- Critical section for torsion is at the face of the support because of concentrated torques applied by the double tee stems at a distance less than *d* from the face of the support. The critical section for shear is also at the face of support because the load on the spandrel beam is not applied close to the top of the member and because the concentrated forces transferred by the double tee stems are at a distance less than *d* from the face of support. A small dummy load of 0.001 kips at the face of support is therefore introduced in order to move the critical section for shear from the default location of *d* away from the support to the face of the support.

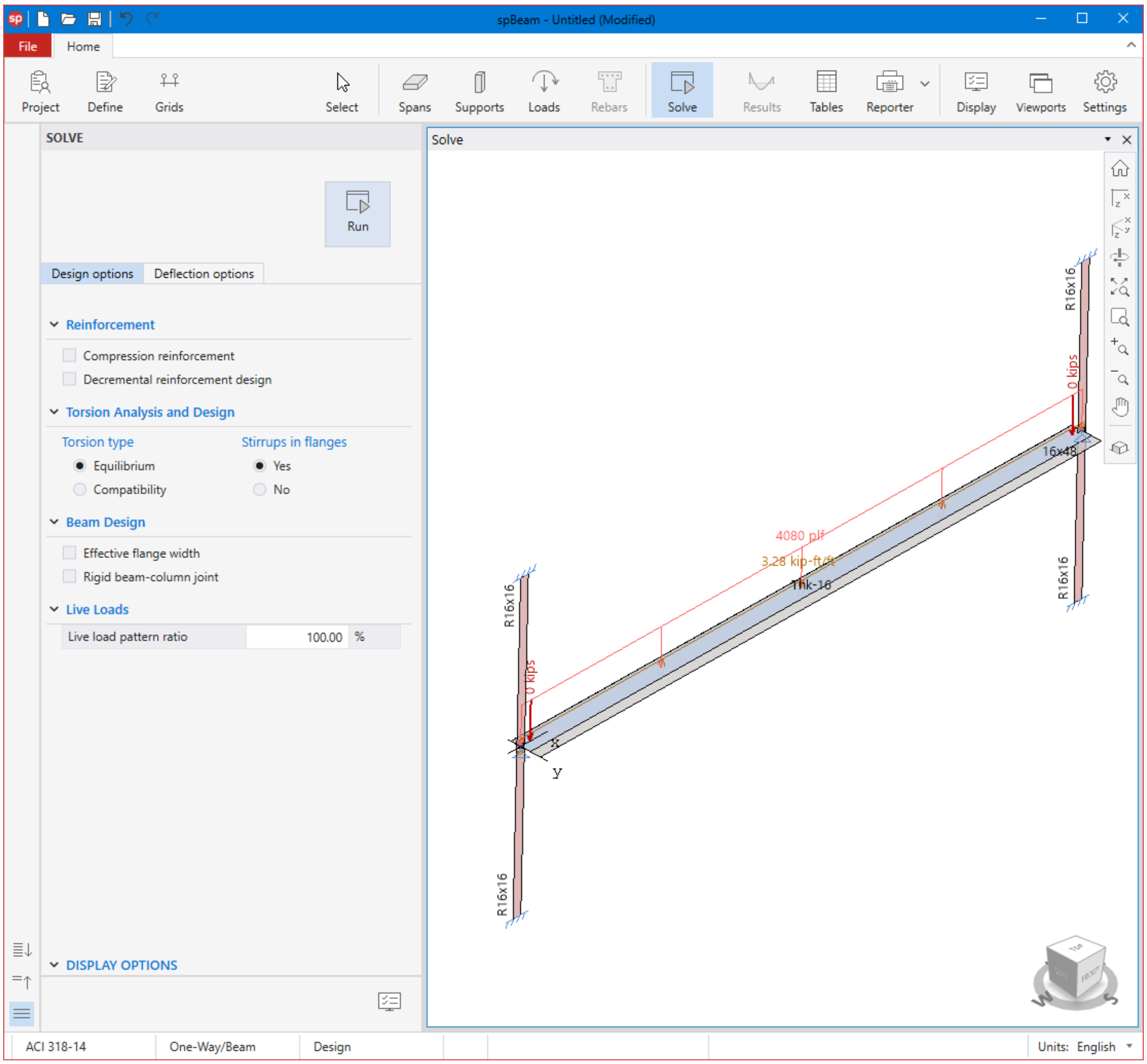

spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
LOADS
Lateral
Support
Point
Line
Area
Point Loads
Load Case
B - Dead
Fz
0.001
kips
Mx - Torque
0.00
kip-ft
My - Moment
0.00
kip-ft
L
39.333
ft
OPTIONS
Replace existing load
Add to existing load
Distance location as ratio of span
DISPLAY OPTIONS
Values
Scale by load value
Units
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
40.00
R16x16
0 kips
4080 plf
3.28 kip-ft/ft
16x48
Thk-16
FRONT
ACI 318-14
One-Way/Beam
Design
X: 28.07 (ft)
Units: English

## 8.2.6. Solving

14. From the **Ribbon**, select **Solve** command.

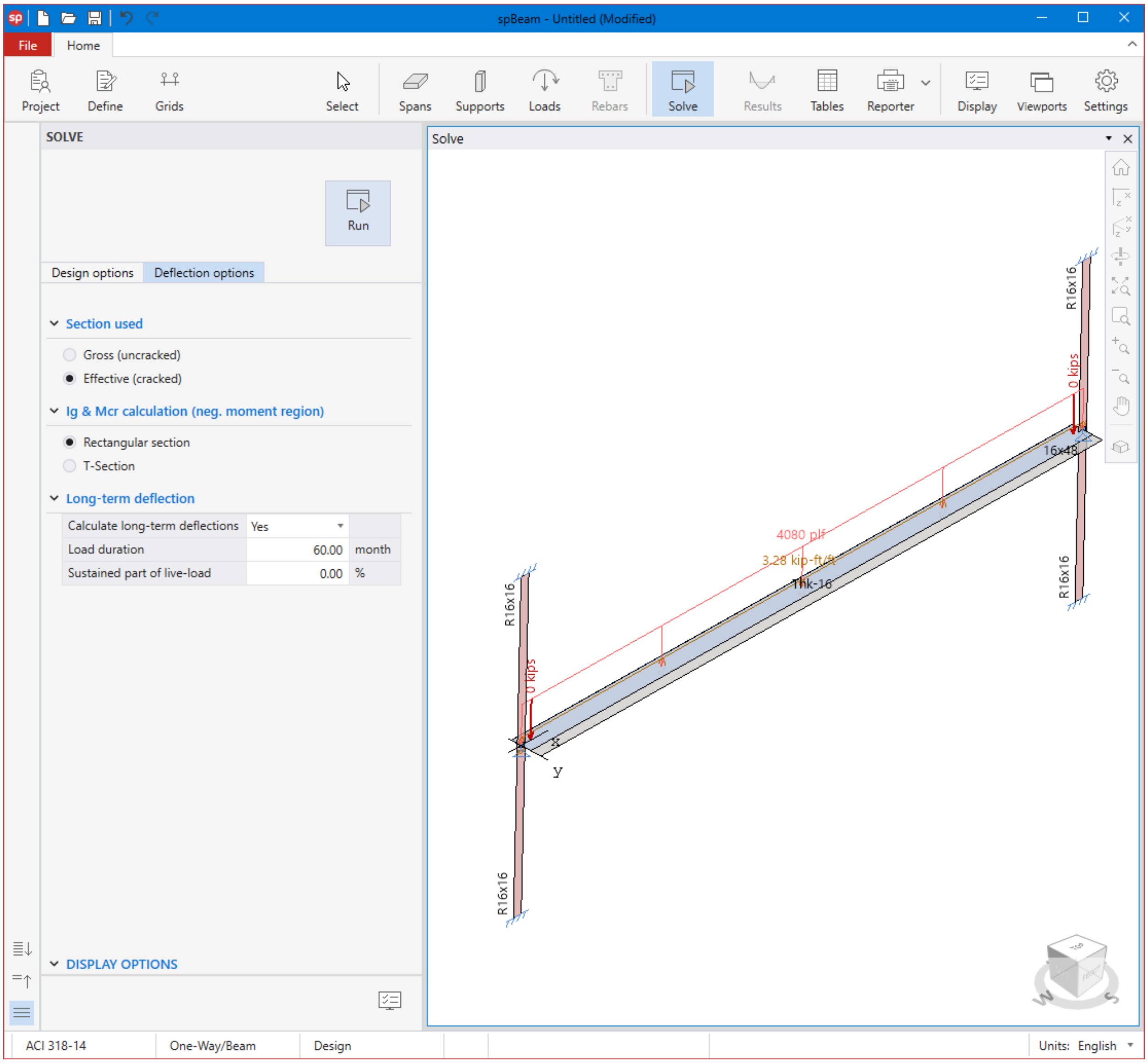
    For **Design Options**:

    - Select EQUILIBRIUM for TORSION TYPE, and YES for STIRRUPS IN FLANGES in TORSION ANALYSIS AND DESIGN section.
    - Uncheck EFFECTIVE FLANGE WIDTH for BEAM DESIGN section.



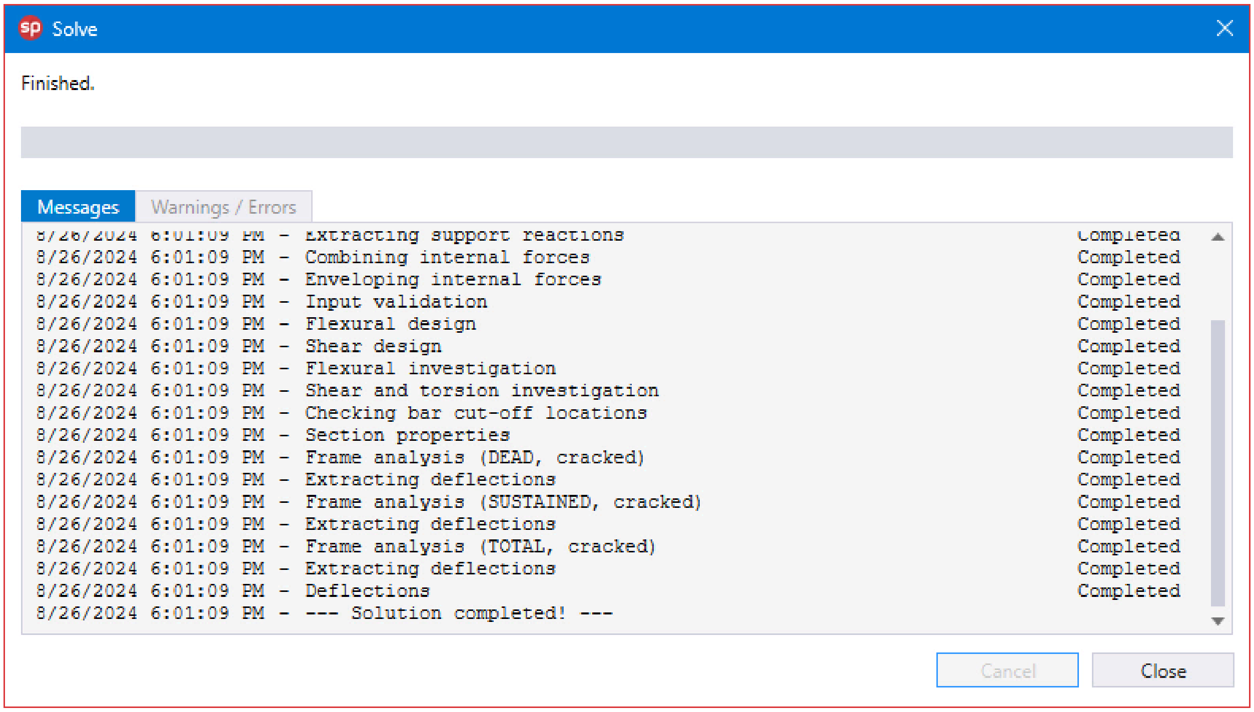
For **Deflection Options**:

- Leave all **Design Options** to their default settings.



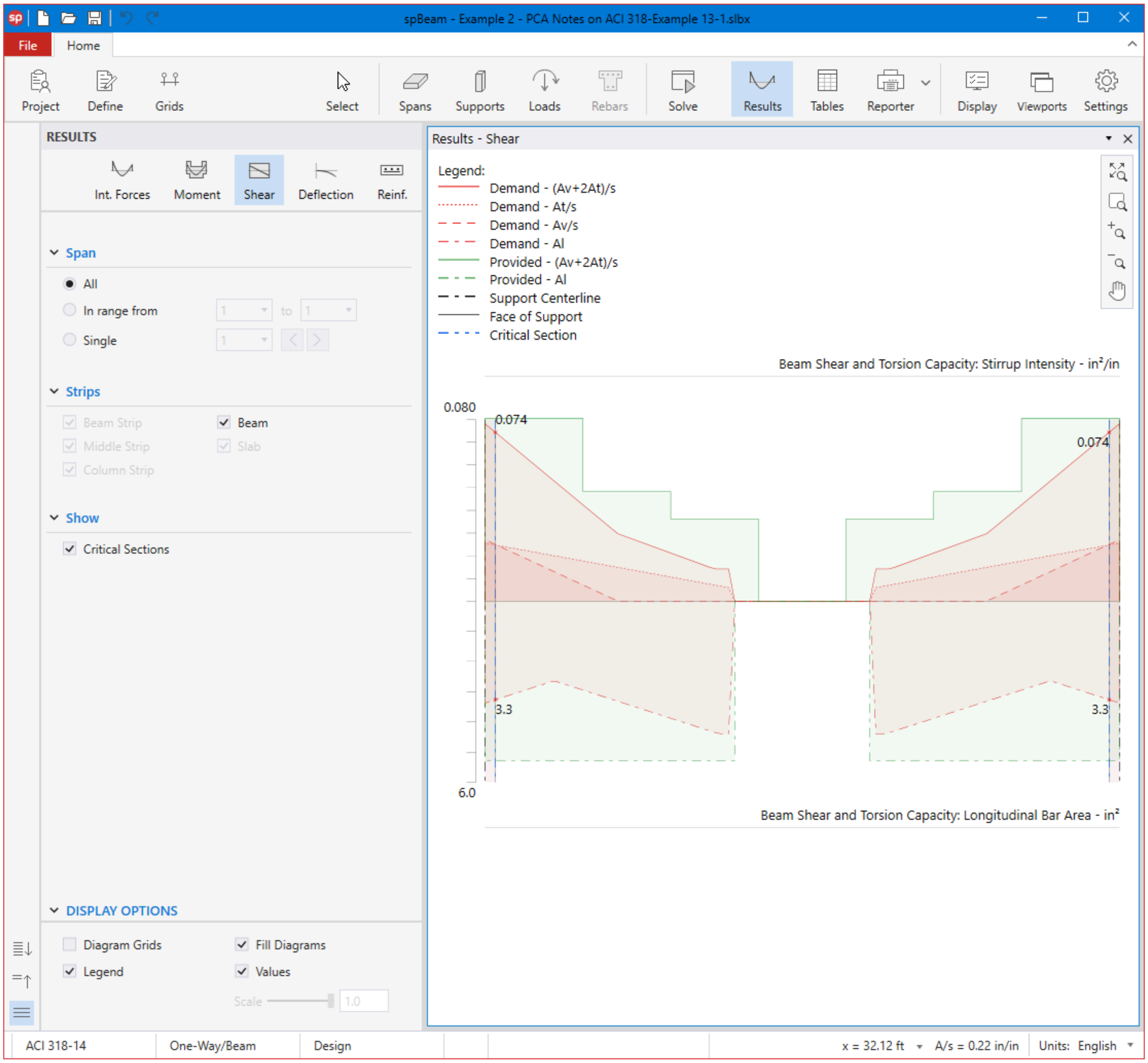
- Click on the **Run** button.

- The spBeam **Solver** window is displayed and the solver messages are listed. After the solution is done, the design will be performed and then the focus will immediately be passed to the **Results** scope.

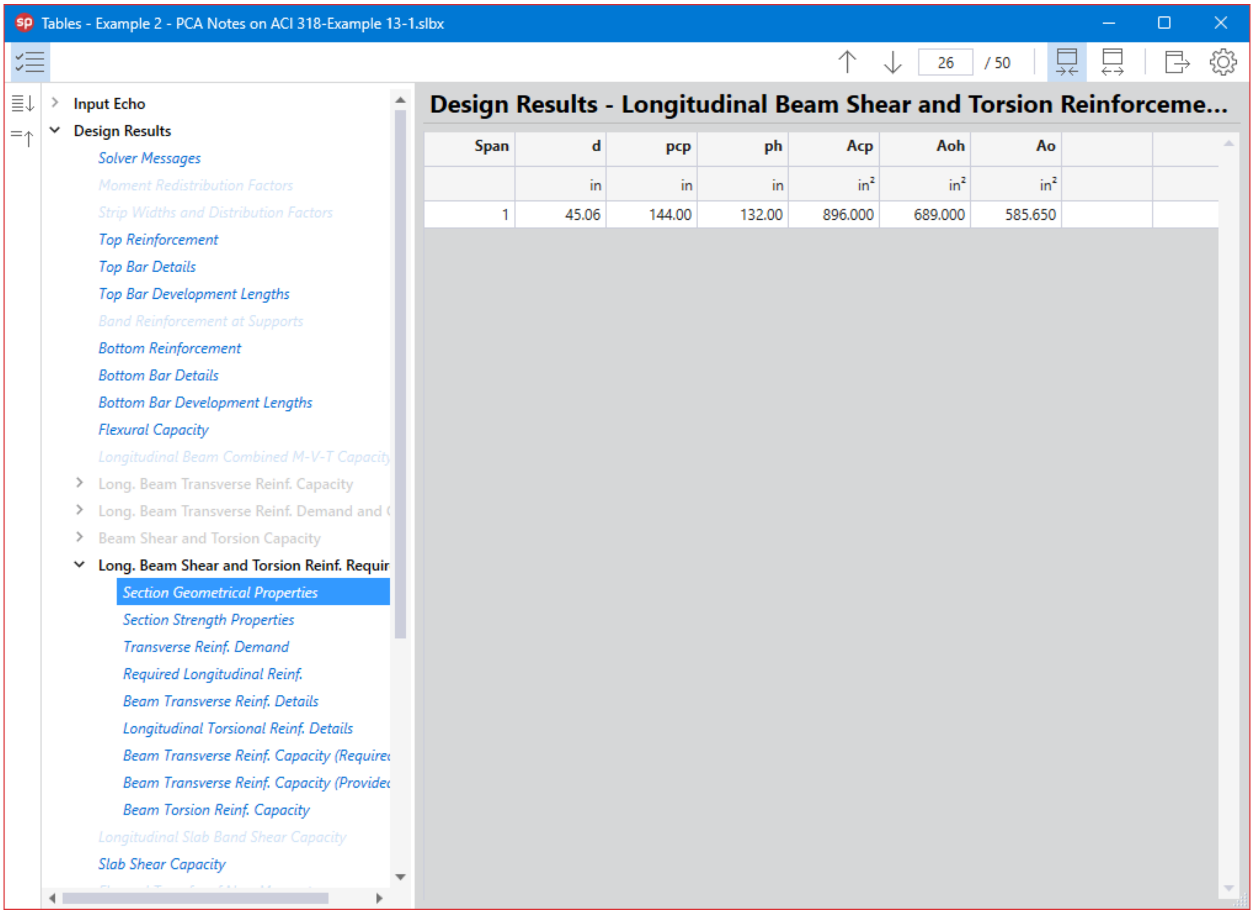


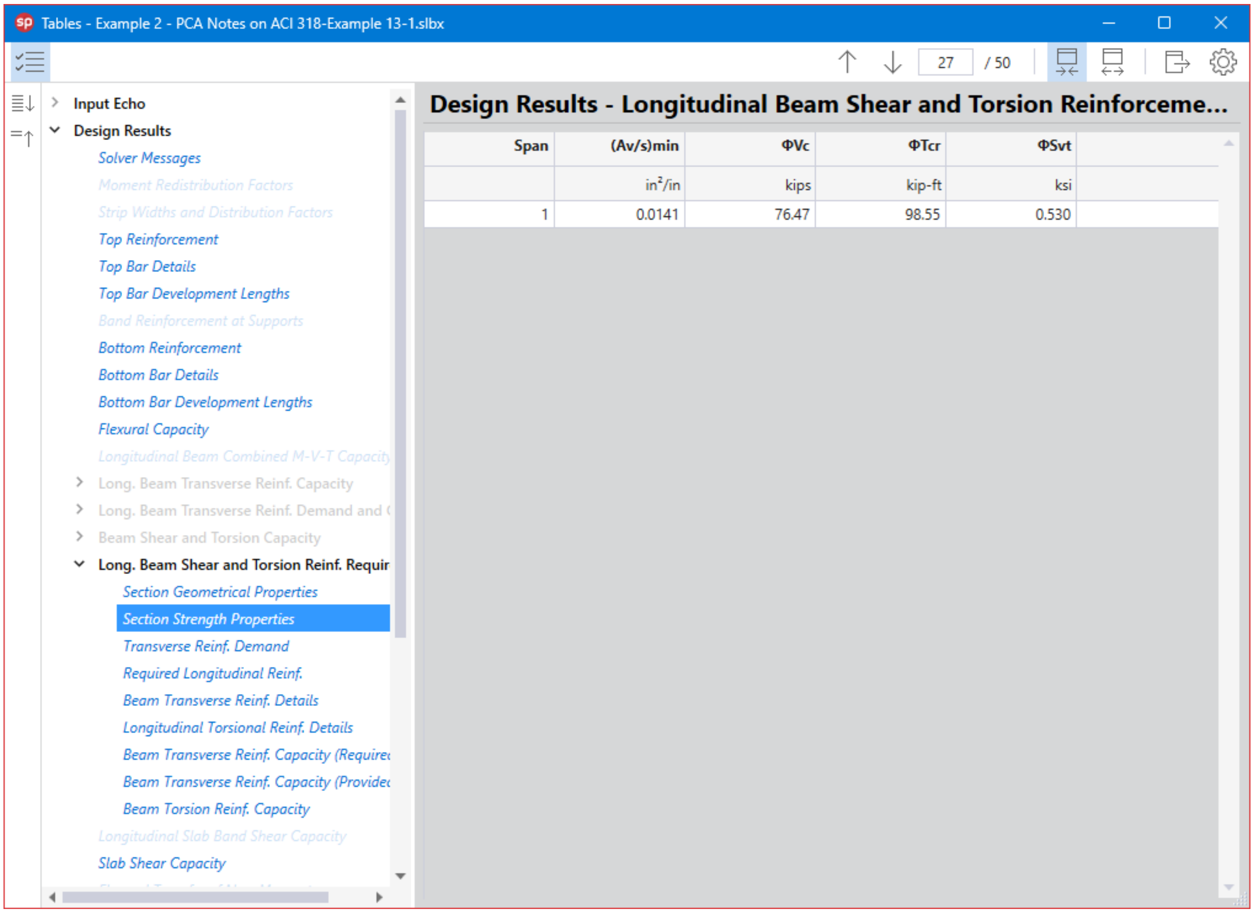
### 8.2.7. Viewing and Printing Results

15. After a successful run, results can be viewed by selecting **Internal Forces**, **Moment Capacity**, **Shear Capacity**, **Deflection**, or **Reinforcement** from the left panel.



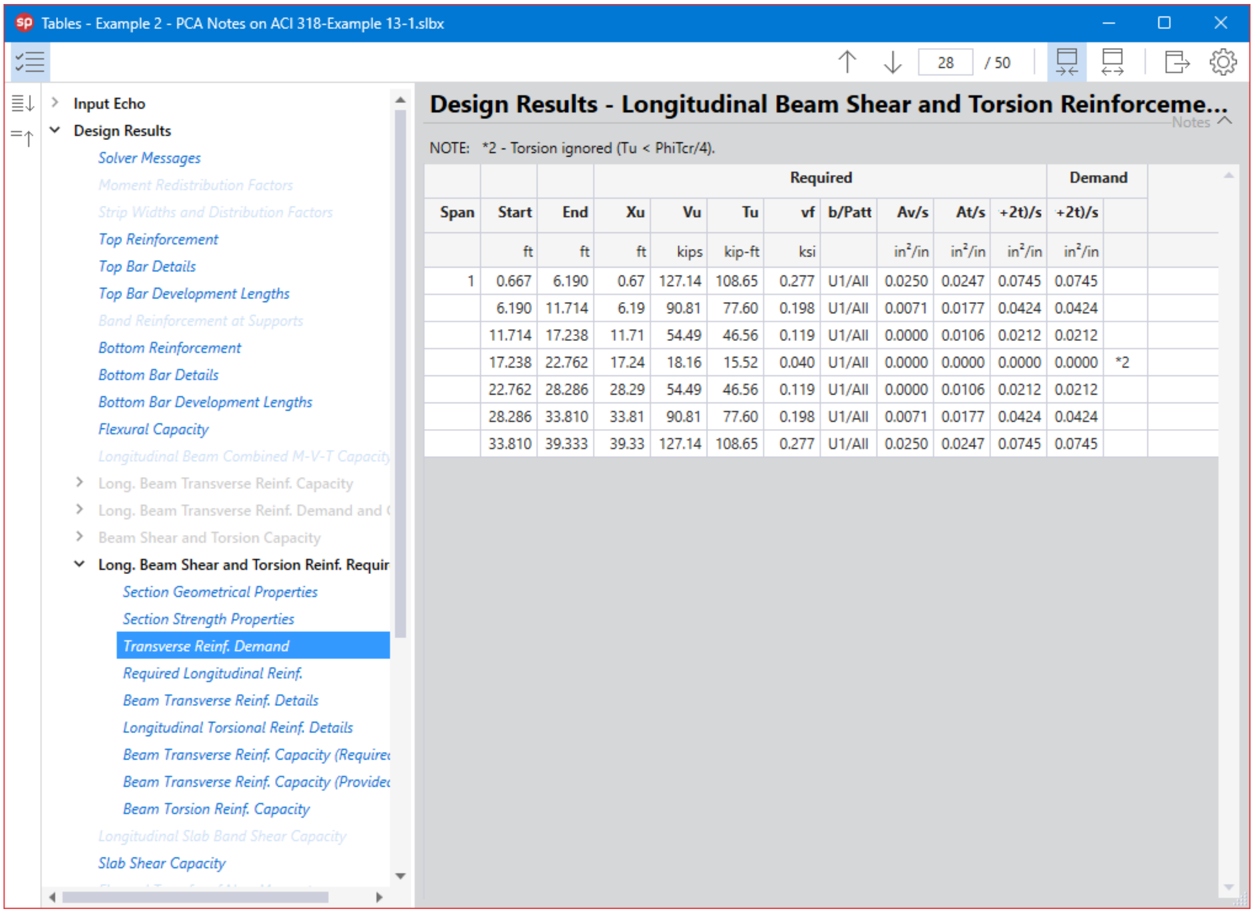
16. Results can be also viewed in table format by selecting the **Tables** command from the **Ribbon.**



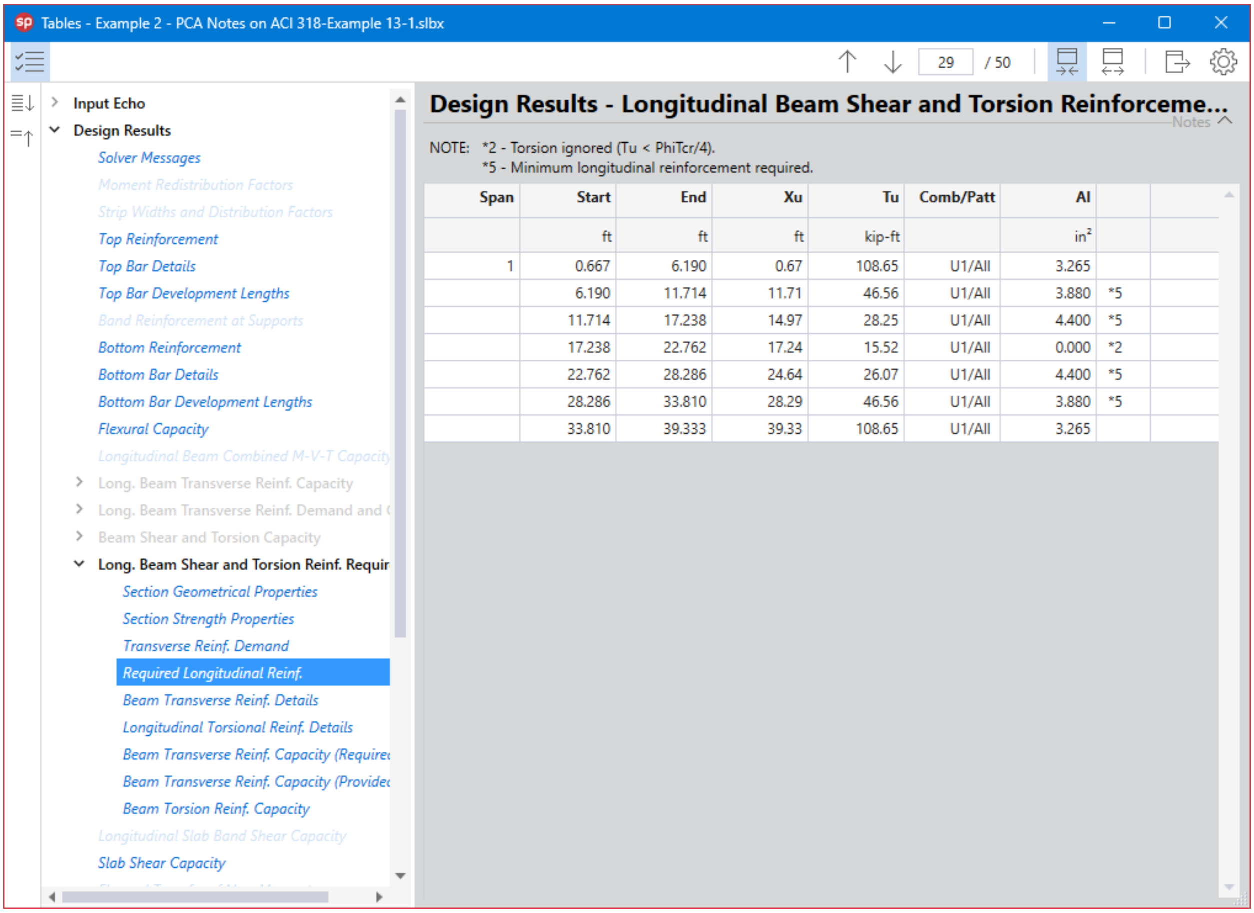



Design Results - Longitudinal Beam Shear and Torsion Reinforceme...

| Span | (Av/s)min | ΦVc | ΦTcr | ΦSvt |
|---|---|---|---|---|
| | $in^2$/in | kips | kip-ft | ksi |
| 1 | 0.0141 | 76.47 | 98.55 | 0.530 |



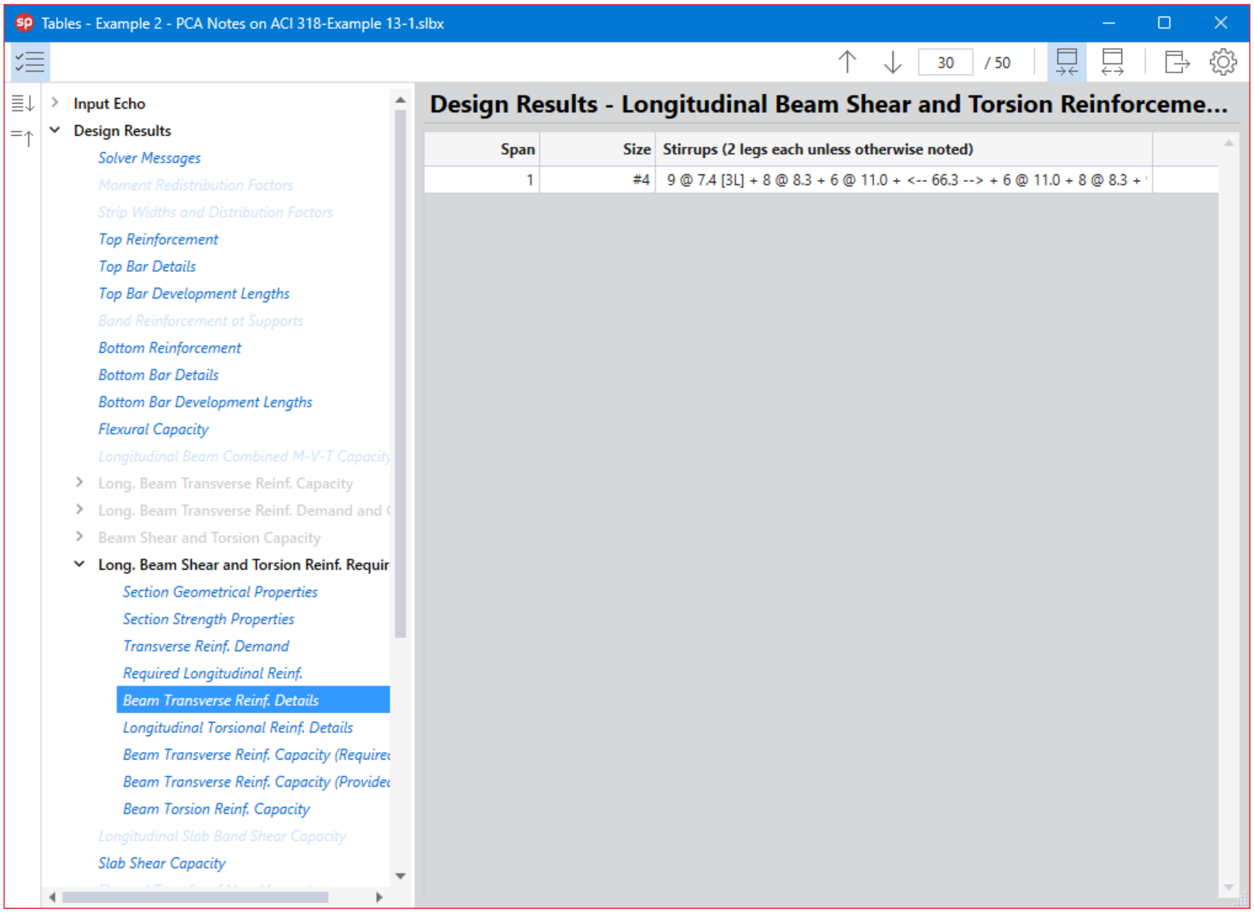

| | | | Required | | | | | | | | Demand | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Span | Start | End | Xu | Vu | Tu | vf | b/Patt | Av/s | At/s | +2t)/s | +2t)/s | |
| | ft | ft | ft | kips | kip-ft | ksi | | in²/in | in²/in | in²/in | in²/in | |
| 1 | 0.667 | 6.190 | 0.67 | 127.14 | 108.65 | 0.277 | U1/All | 0.0250 | 0.0247 | 0.0745 | 0.0745 | |
| | 6.190 | 11.714 | 6.19 | 90.81 | 77.60 | 0.198 | U1/All | 0.0071 | 0.0177 | 0.0424 | 0.0424 | |
| | 11.714 | 17.238 | 11.71 | 54.49 | 46.56 | 0.119 | U1/All | 0.0000 | 0.0106 | 0.0212 | 0.0212 | |
| | 17.238 | 22.762 | 17.24 | 18.16 | 15.52 | 0.040 | U1/All | 0.0000 | 0.0000 | 0.0000 | 0.0000 | *2 |
| | 22.762 | 28.286 | 28.29 | 54.49 | 46.56 | 0.119 | U1/All | 0.0000 | 0.0106 | 0.0212 | 0.0212 | |
| | 28.286 | 33.810 | 33.81 | 90.81 | 77.60 | 0.198 | U1/All | 0.0071 | 0.0177 | 0.0424 | 0.0424 | |
| | 33.810 | 39.333 | 39.33 | 127.14 | 108.65 | 0.277 | U1/All | 0.0250 | 0.0247 | 0.0745 | 0.0745 | |

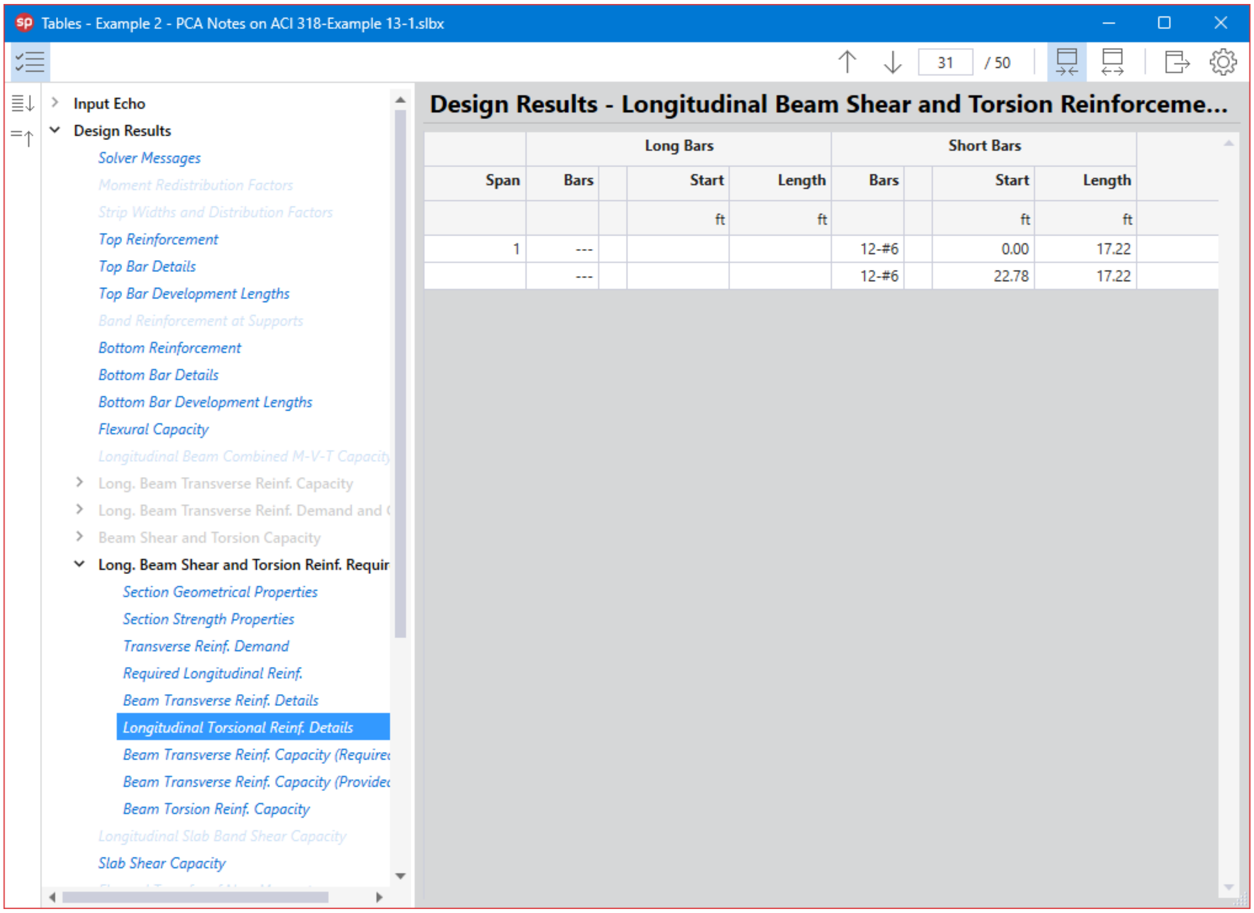


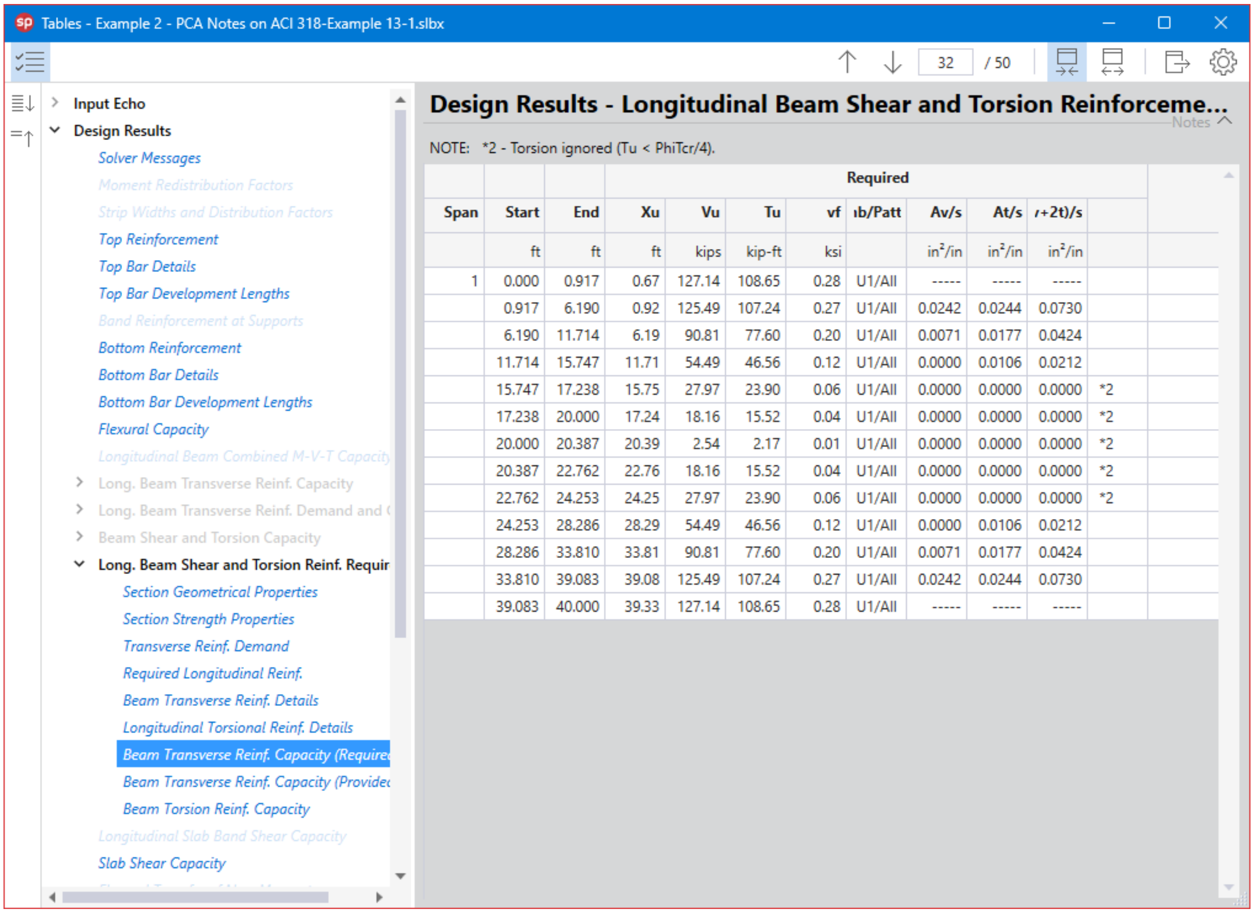

Design Results - Longitudinal Beam Shear and Torsion Reinforceme...

NOTE: *2 - Torsion ignored (Tu < PhiTcr/4).
*5 - Minimum longitudinal reinforcement required.

| Span | Start | End | Xu | Tu | Comb/Patt | Al | |
|---|---|---|---|---|---|---|---|
| | ft | ft | ft | kip-ft | | in² | |
| 1 | 0.667 | 6.190 | 0.67 | 108.65 | U1/All | 3.265 | |
| | 6.190 | 11.714 | 11.71 | 46.56 | U1/All | 3.880 | *5 |
| | 11.714 | 17.238 | 14.97 | 28.25 | U1/All | 4.400 | *5 |
| | 17.238 | 22.762 | 17.24 | 15.52 | U1/All | 0.000 | *2 |
| | 22.762 | 28.286 | 24.64 | 26.07 | U1/All | 4.400 | *5 |
| | 28.286 | 33.810 | 28.29 | 46.56 | U1/All | 3.880 | *5 |
| | 33.810 | 39.333 | 39.33 | 108.65 | U1/All | 3.265 | |


Tables - Example 2 - PCA Notes on ACI 318-Example 13-1.slbx
30
/ 50
Input Echo
Design Results
Solver Messages
Moment Redistribution Factors
Strip Widths and Distribution Factors
Top Reinforcement
Top Bar Details
Top Bar Development Lengths
Band Reinforcement at Supports
Bottom Reinforcement
Bottom Bar Details
Bottom Bar Development Lengths
Flexural Capacity
Longitudinal Beam Combined M-V-T Capacity
Long. Beam Transverse Reinf. Capacity
Long. Beam Transverse Reinf. Demand and (
Beam Shear and Torsion Capacity
Long. Beam Shear and Torsion Reinf. Requir
Section Geometrical Properties
Section Strength Properties
Transverse Reinf. Demand
Required Longitudinal Reinf.
Beam Transverse Reinf. Details
Longitudinal Torsional Reinf. Details
Beam Transverse Reinf. Capacity (Requirec
Beam Transverse Reinf. Capacity (Providec
Beam Torsion Reinf. Capacity
Longitudinal Slab Band Shear Capacity
Slab Shear Capacity
Design Results - Longitudinal Beam Shear and Torsion Reinforceme...
Span | Size | Stirrups (2 legs each unless otherwise noted)
1 | #4 | 9 @ 7.4 [3L] + 8 @ 8.3 + 6 @ 11.0 + <-- 66.3 --> + 6 @ 11.0 + 8 @ 8.3 +


Tables - Example 2 - PCA Notes on ACI 318-Example 13-1.slbx
31
/ 50
Input Echo
Design Results
Solver Messages
Moment Redistribution Factors
Strip Widths and Distribution Factors
Top Reinforcement
Top Bar Details
Top Bar Development Lengths
Band Reinforcement at Supports
Bottom Reinforcement
Bottom Bar Details
Bottom Bar Development Lengths
Flexural Capacity
Longitudinal Beam Combined M-V-T Capacity
Long. Beam Transverse Reinf. Capacity
Long. Beam Transverse Reinf. Demand and
Beam Shear and Torsion Capacity
Long. Beam Shear and Torsion Reinf. Requir
Section Geometrical Properties
Section Strength Properties
Transverse Reinf. Demand
Required Longitudinal Reinf.
Beam Transverse Reinf. Details
Longitudinal Torsional Reinf. Details
Beam Transverse Reinf. Capacity (Require
Beam Transverse Reinf. Capacity (Provide
Beam Torsion Reinf. Capacity
Longitudinal Slab Band Shear Capacity
Slab Shear Capacity
Design Results - Longitudinal Beam Shear and Torsion Reinforceme...
Long Bars
Short Bars
Span
Bars
Start
Length
Bars
Start
Length
ft
ft
ft
ft
1
---
12-#6
0.00
17.22
---
12-#6
22.78
17.22




**Design Results - Longitudinal Beam Shear and Torsion Reinforceme...**

NOTE: *2 - Torsion ignored (Tu < PhiTcr/4).

| | | | | | | | | Required | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Span | Start | End | Xu | Vu | Tu | vf | ıb/Patt | Av/s | At/s | ı+2t)/s | |
| | ft | ft | ft | kips | kip-ft | ksi | | $in^2/in$ | $in^2/in$ | $in^2/in$ | |
| 1 | 0.000 | 0.917 | 0.67 | 127.14 | 108.65 | 0.28 | U1/All | ----- | ----- | ----- | |
| | 0.917 | 6.190 | 0.92 | 125.49 | 107.24 | 0.27 | U1/All | 0.0242 | 0.0244 | 0.0730 | |
| | 6.190 | 11.714 | 6.19 | 90.81 | 77.60 | 0.20 | U1/All | 0.0071 | 0.0177 | 0.0424 | |
| | 11.714 | 15.747 | 11.71 | 54.49 | 46.56 | 0.12 | U1/All | 0.0000 | 0.0106 | 0.0212 | |
| | 15.747 | 17.238 | 15.75 | 27.97 | 23.90 | 0.06 | U1/All | 0.0000 | 0.0000 | 0.0000 | *2 |
| | 17.238 | 20.000 | 17.24 | 18.16 | 15.52 | 0.04 | U1/All | 0.0000 | 0.0000 | 0.0000 | *2 |
| | 20.000 | 20.387 | 20.39 | 2.54 | 2.17 | 0.01 | U1/All | 0.0000 | 0.0000 | 0.0000 | *2 |
| | 20.387 | 22.762 | 22.76 | 18.16 | 15.52 | 0.04 | U1/All | 0.0000 | 0.0000 | 0.0000 | *2 |
| | 22.762 | 24.253 | 24.25 | 27.97 | 23.90 | 0.06 | U1/All | 0.0000 | 0.0000 | 0.0000 | *2 |
| | 24.253 | 28.286 | 28.29 | 54.49 | 46.56 | 0.12 | U1/All | 0.0000 | 0.0106 | 0.0212 | |
| | 28.286 | 33.810 | 33.81 | 90.81 | 77.60 | 0.20 | U1/All | 0.0071 | 0.0177 | 0.0424 | |
| | 33.810 | 39.083 | 39.08 | 125.49 | 107.24 | 0.27 | U1/All | 0.0242 | 0.0244 | 0.0730 | |
| | 39.083 | 40.000 | 39.33 | 127.14 | 108.65 | 0.28 | U1/All | ----- | ----- | ----- | |

Tables - Example 2 - PCA Notes on ACI 318-Example 13-1.slbx

33 / 50

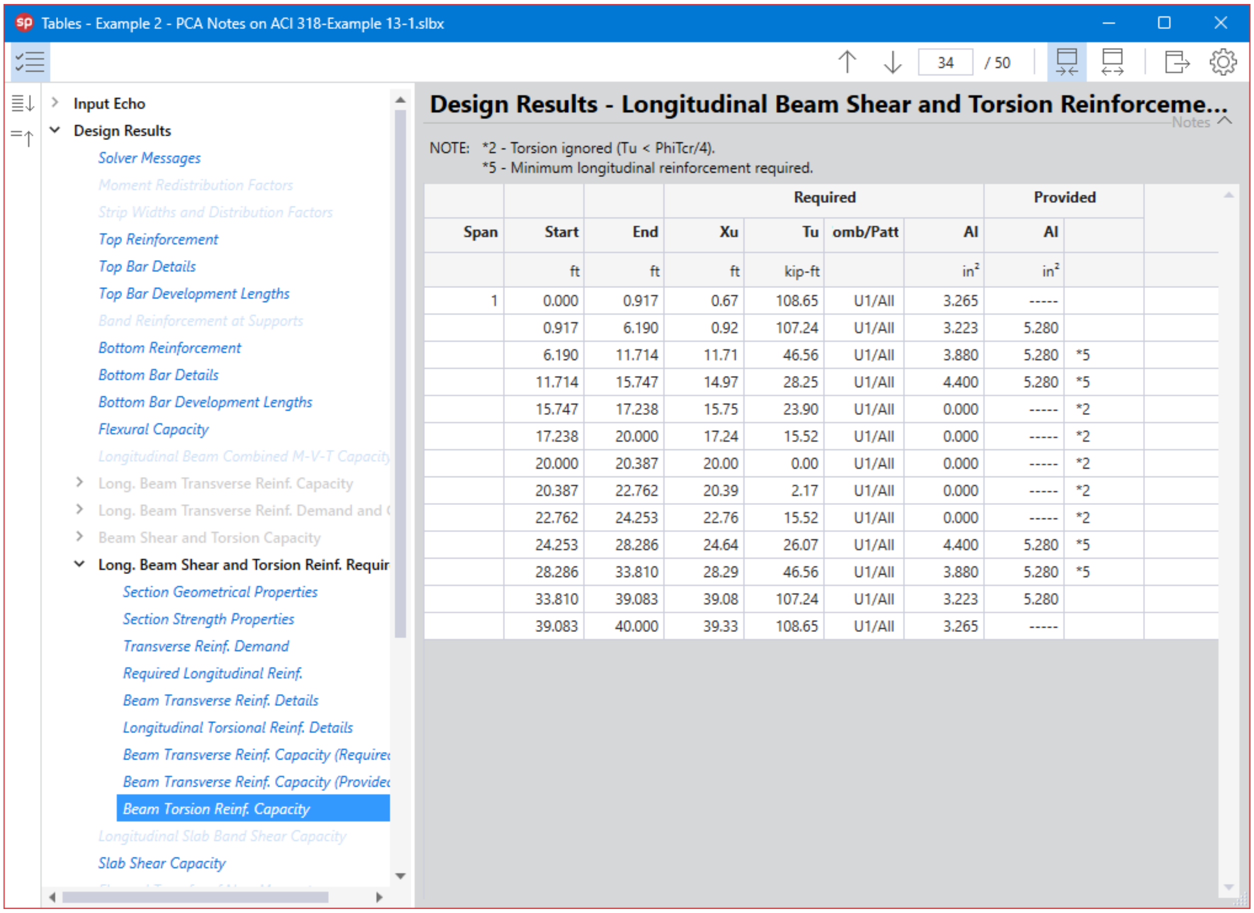
Input Echo
Design Results
Solver Messages
Moment Redistribution Factors
Strip Widths and Distribution Factors
Top Reinforcement
Top Bar Details
Top Bar Development Lengths
Band Reinforcement at Supports
Bottom Reinforcement
Bottom Bar Details
Bottom Bar Development Lengths
Flexural Capacity
Longitudinal Beam Combined M-V-T Capacity
Long. Beam Transverse Reinf. Capacity
Long. Beam Transverse Reinf. Demand and (
Beam Shear and Torsion Capacity
Long. Beam Shear and Torsion Reinf. Requir
Section Geometrical Properties
Section Strength Properties
Transverse Reinf. Demand
Required Longitudinal Reinf.
Beam Transverse Reinf. Details
Longitudinal Torsional Reinf. Details
Beam Transverse Reinf. Capacity (Requirec
Beam Transverse Reinf. Capacity (Providec
Beam Torsion Reinf. Capacity
Longitudinal Slab Band Shear Capacity
Slab Shear Capacity

## Design Results - Longitudinal Beam Shear and Torsion Reinforceme...

Notes

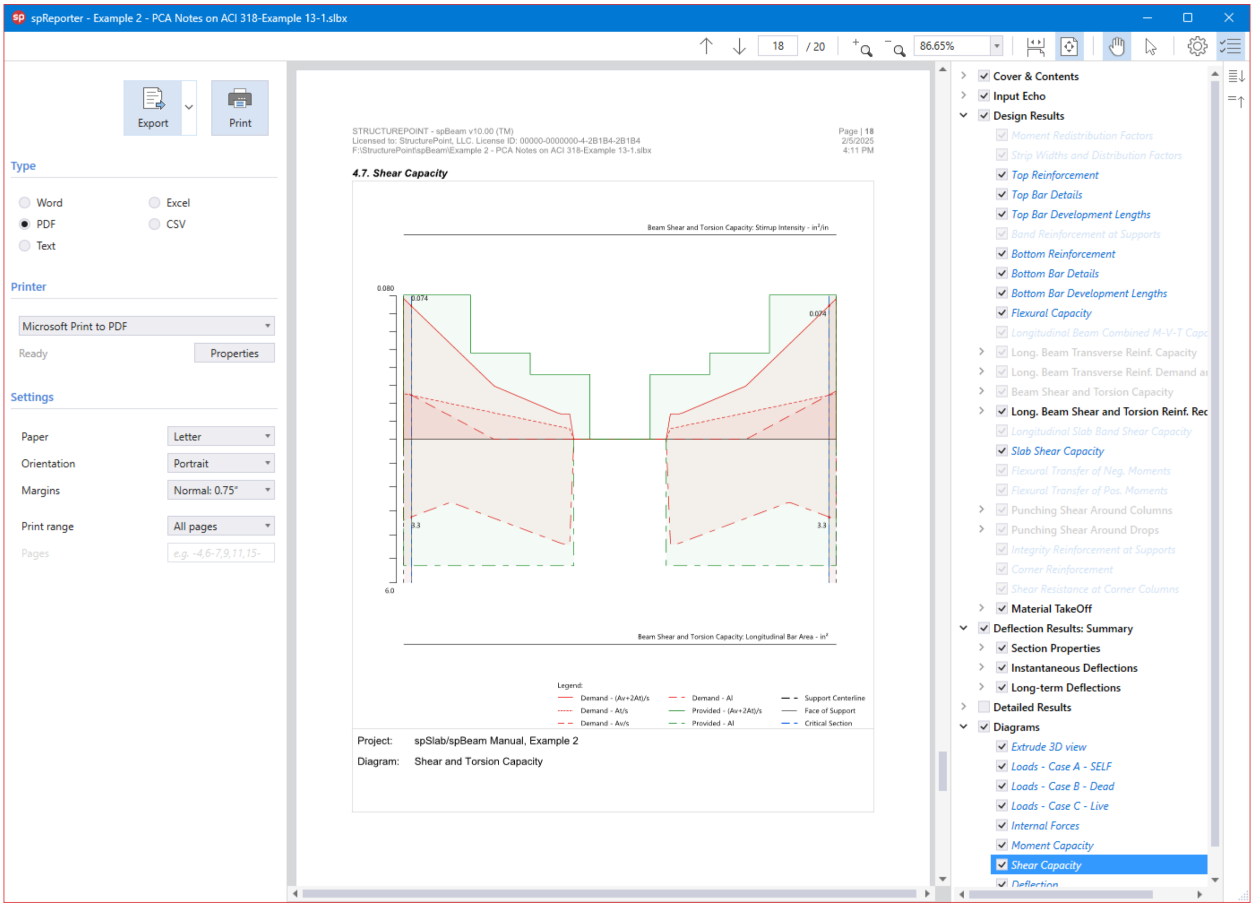
NOTE: *2 - Torsion ignored (Tu < PhiTcr/4).

| | | | Provided | | | |
|---|---|---|---|---|---|---|
| Span | Start | End | A(v+2t) | Sp | A(v+2t)/s | |
| | ft | ft | in² | in | in²/in | |
| 1 | 0.000 | 0.917 | ----- | ----- | ------ | |
| | 0.917 | 6.190 | 0.600 | 7.45 | 0.0806 | |
| | 6.190 | 11.714 | 0.400 | 8.29 | 0.0483 | |
| | 11.714 | 15.747 | 0.400 | 11.05 | 0.0362 | |
| | 15.747 | 17.238 | 0.400 | 11.05 | 0.0362 | *2 |
| | 17.238 | 20.000 | ----- | ----- | ------ | *2 |
| | 20.000 | 20.387 | ----- | ----- | ------ | *2 |
| | 20.387 | 22.762 | ----- | ----- | ------ | *2 |
| | 22.762 | 24.253 | 0.400 | 11.05 | 0.0362 | *2 |
| | 24.253 | 28.286 | 0.400 | 11.05 | 0.0362 | |
| | 28.286 | 33.810 | 0.400 | 8.29 | 0.0483 | |
| | 33.810 | 39.083 | 0.600 | 7.45 | 0.0806 | |
| | 39.083 | 40.000 | ----- | ----- | ------ | |




| | | | | | | Required | Provided | |
|---|---|---|---|---|---|---|---|---|
| Span | Start | End | Xu | Tu | omb/Patt | Al | Al | |
| | ft | ft | ft | kip-ft | | $in^2$ | $in^2$ | |
| 1 | 0.000 | 0.917 | 0.67 | 108.65 | U1/All | 3.265 | ----- | |
| | 0.917 | 6.190 | 0.92 | 107.24 | U1/All | 3.223 | 5.280 | |
| | 6.190 | 11.714 | 11.71 | 46.56 | U1/All | 3.880 | 5.280 | *5 |
| | 11.714 | 15.747 | 14.97 | 28.25 | U1/All | 4.400 | 5.280 | *5 |
| | 15.747 | 17.238 | 15.75 | 23.90 | U1/All | 0.000 | ----- | *2 |
| | 17.238 | 20.000 | 17.24 | 15.52 | U1/All | 0.000 | ----- | *2 |
| | 20.000 | 20.387 | 20.00 | 0.00 | U1/All | 0.000 | ----- | *2 |
| | 20.387 | 22.762 | 20.39 | 2.17 | U1/All | 0.000 | ----- | *2 |
| | 22.762 | 24.253 | 22.76 | 15.52 | U1/All | 0.000 | ----- | *2 |
| | 24.253 | 28.286 | 24.64 | 26.07 | U1/All | 4.400 | 5.280 | *5 |
| | 28.286 | 33.810 | 28.29 | 46.56 | U1/All | 3.880 | 5.280 | *5 |
| | 33.810 | 39.083 | 39.08 | 107.24 | U1/All | 3.223 | 5.280 | |
| | 39.083 | 40.000 | 39.33 | 108.65 | U1/All | 3.265 | ----- | |

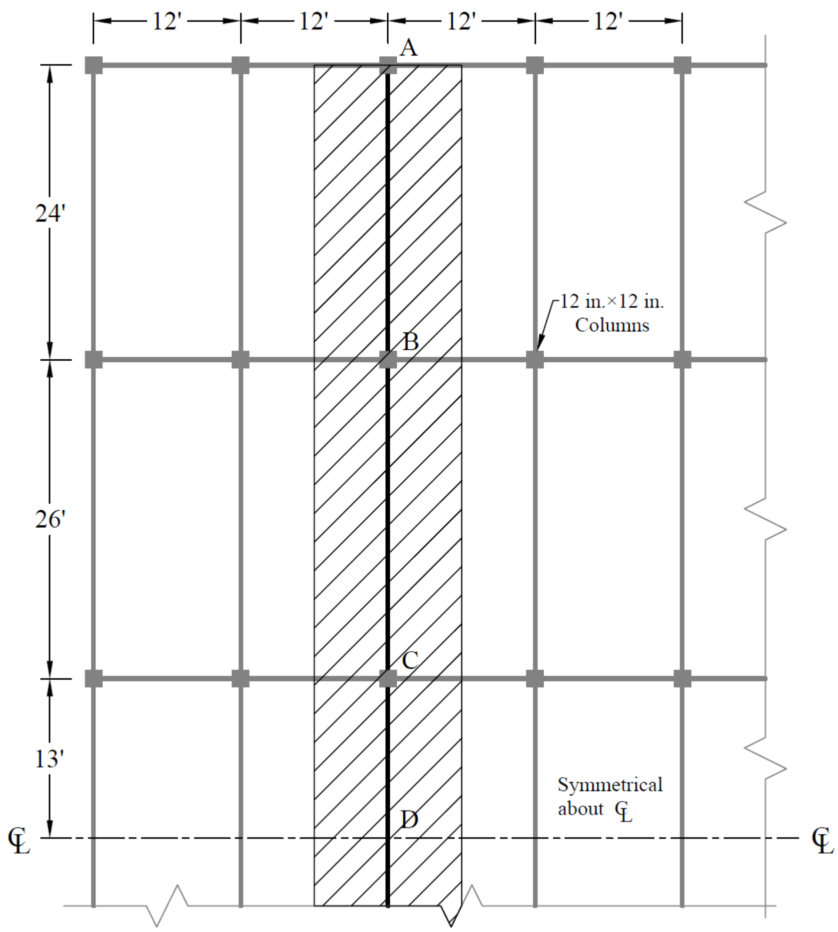
17. Results can be printed or exported in different formats by selecting the **Reporter** command from the **Ribbon.**



# 8.3. Example 3 – Design of a Continuous Beam

## 8.3.1. Problem Formulation

The system shown in the following figure consists of five spans symmetric about the centerline. We will be designing beam ABCD assuming that the other half of the beam will be loaded and designed the same way. All beams have a width of 12 in. and a depth of 22 in. – including the 5 in. thick deck. Span length and widths are shown in the figure. Columns have a 12 in. × 12 in. cross-section and a length equal to a typical story height of 13 ft. The system will be analyzed and designed under a uniform live load of 130 psf and a dead load that consists of the slab system's own weight plus 80 psf. Use $f'_c$ = 4 ksi, $f_y$ = 60 ksi, and $\gamma_{concrete}$ = 150 pcf.[3]




[3] M. N. Hassoun and A. Al-Manaseer, *Structural Concrete: Theory and Design*, John Wiley & Sons, Inc., Sixth Edition, 2015, Example 16.1

**Design data**

DL = 80 psf

LL = 130 lb/ft

$f_c'$ = 4,000 psi

$f_y$ = 60,000 psi

$\gamma_{concrete}$ = 150 pcf

Beams: 12 × 22 in.

Columns: 12 × 12 in.

Story height: 13 ft

## 8.3.2. Preparing the Input

1. From the Start screen, select **New Project**.

2. From the **Main Program Window**, select **Project** from the **Ribbon**.

- In the **General** section, select the DESIGN CODE, UNIT SYSTEM, and BAR SET.

- In the **Materials** section, input the following:

  f'c (SLABS & BEAMS): 4.00 ksi

  f'c (COLUMNS): 4.00 ksi

  fy: 60.00 ksi

  Alternatively, detailed material properties for **Concrete** and **Reinforcement Steel** can be entered using **Definitions** dialog box (see Steps 4 and 5).

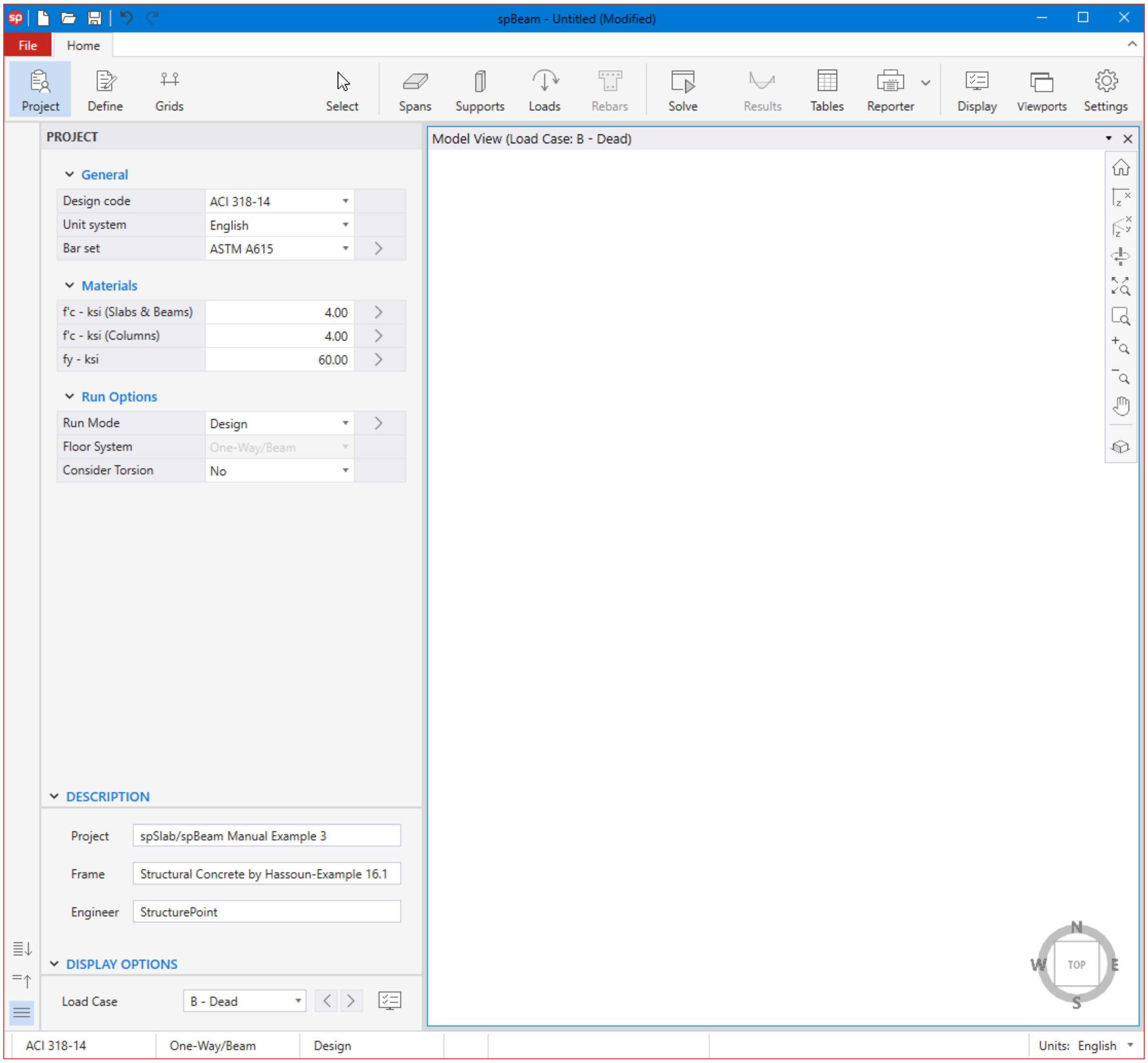
- In the **Run Options** section, select the following:

  RUN MODE: Design

  FLOOR SYSTEM: One-Way/Beam

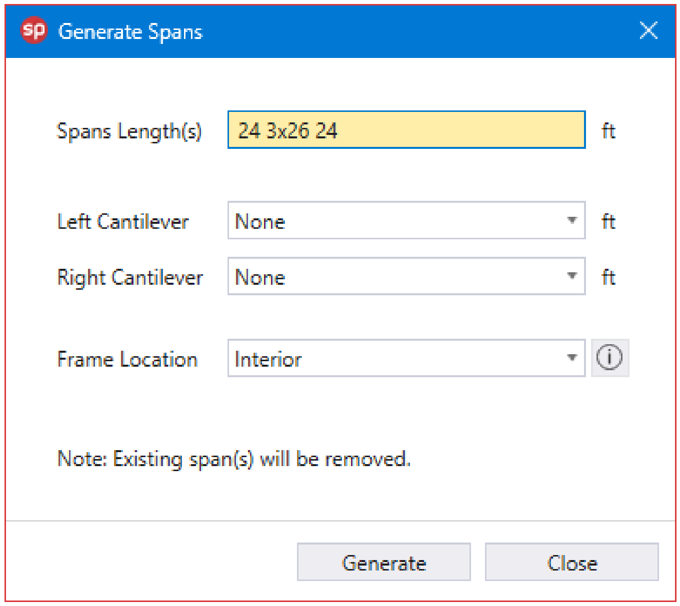
  CONSIDER TORSION: No

- In the **Description** section, enter the PROJECT, FRAME, and ENGINEER.


spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
PROJECT
General
Design code ACI 318-14
Unit system English
Bar set ASTM A615
Materials
f'c - ksi (Slabs & Beams) 4.00
f'c - ksi (Columns) 4.00
fy - ksi 60.00
Run Options
Run Mode Design
Floor System One-Way/Beam
Consider Torsion No
DESCRIPTION
Project spSlab/spBeam Manual Example 3
Frame Structural Concrete by Hassoun-Example 16.1
Engineer StructurePoint
DISPLAY OPTIONS
Load Case B - Dead
Model View (Load Case: B - Dead)
N
W
TOP
E
S
ACI 318-14
One-Way/Beam
Design
Units: English

3. From the **Ribbon**, select **Grids**.

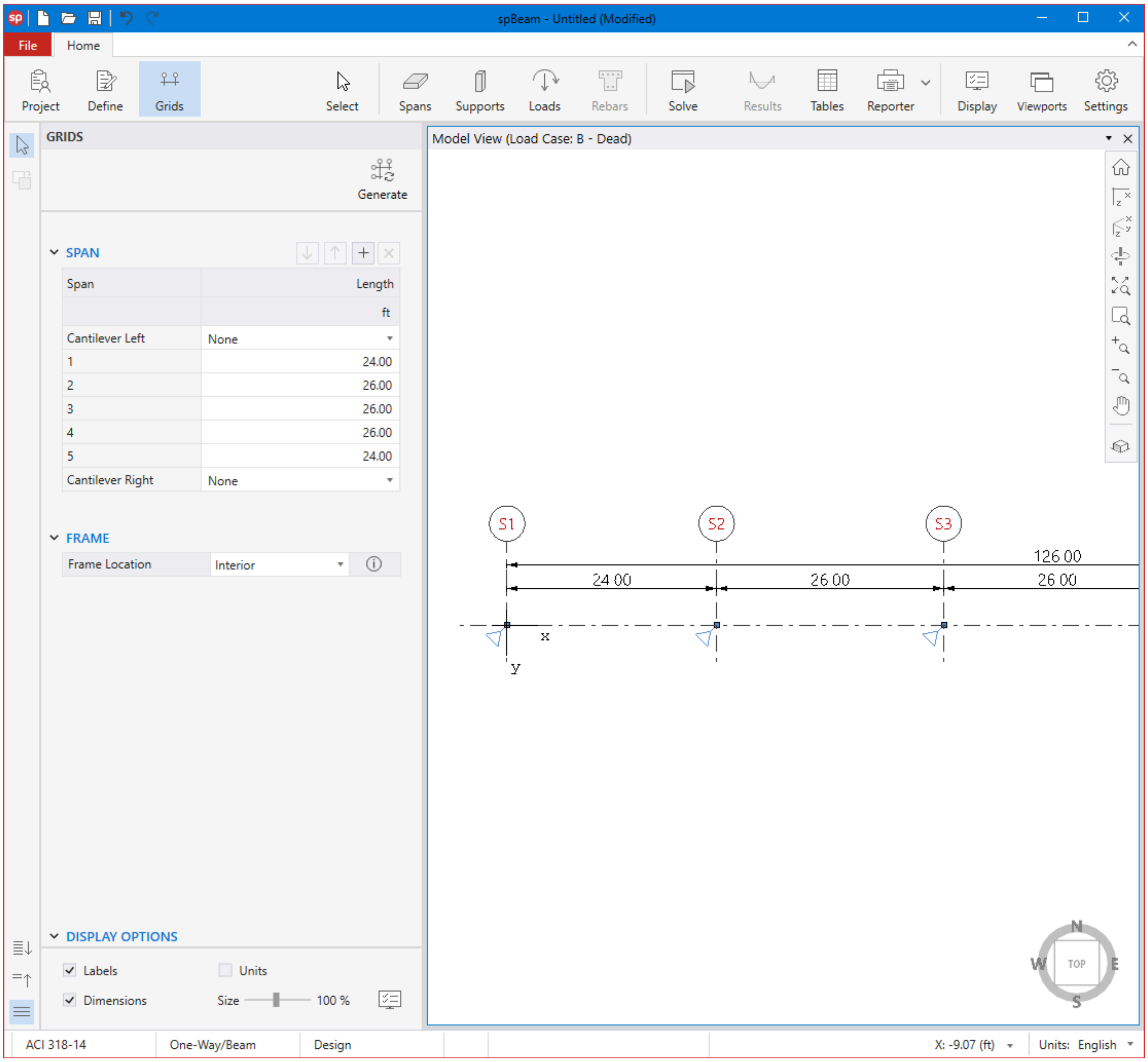
- Click on the **Generate** in the left panel to have the program surface the following:




- Enter the following values in the corresponding text boxes:

| | |
|---|---|
| SPANS LENGTH(S): | `24 3x26 24` |
| LEFT CANTILEVER: | None |
| RIGHT CANTILEVER: | None |
| FRAME LOCATION: | Interior |

- Click on the GENERATE button to return to the main window. Notice how the grid lines now appear in the VIEWPORT.

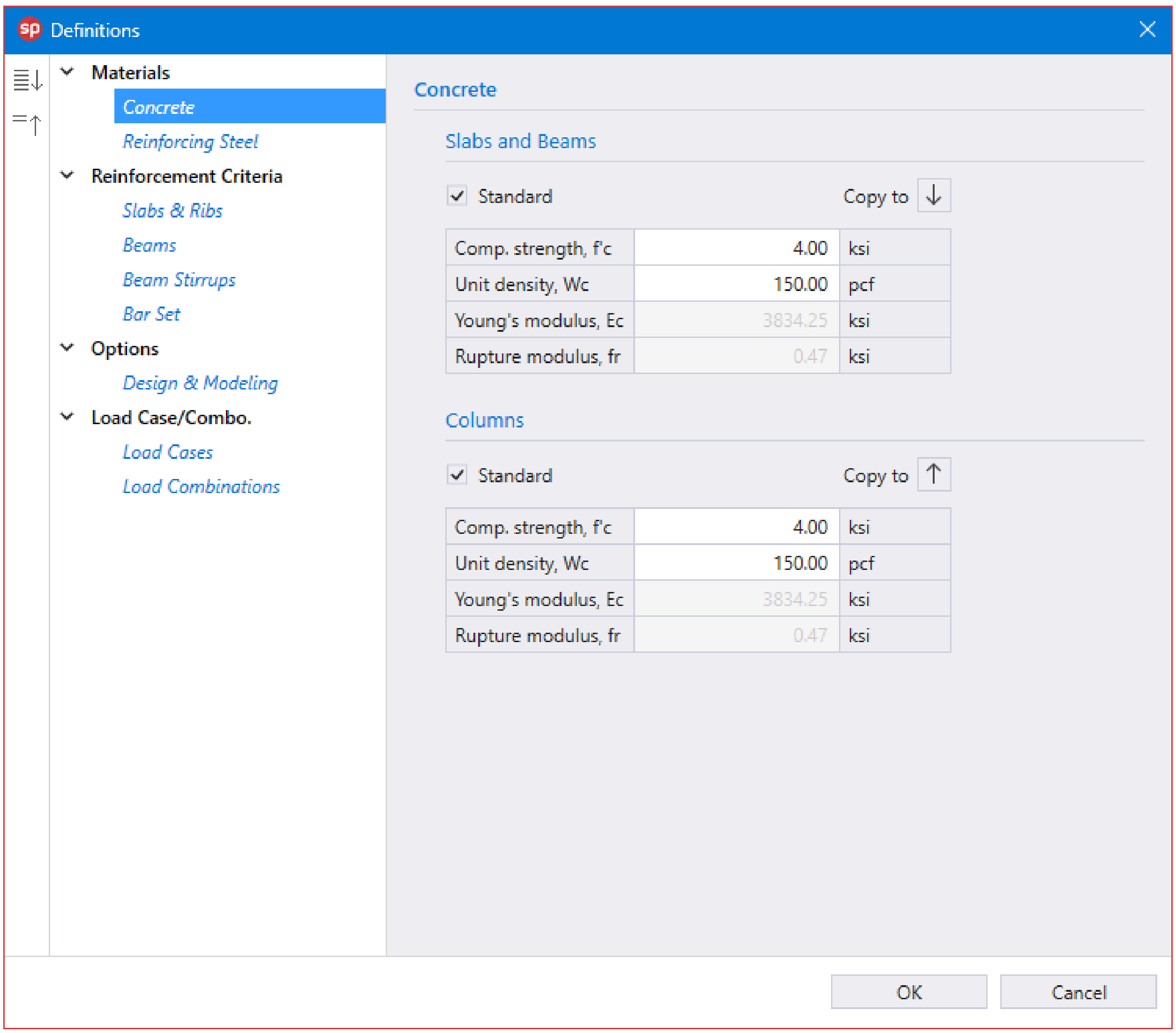

spBeam - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
GRIDS
Generate
SPAN
Span
Length
ft
Cantilever Left
None
1
24.00
2
26.00
3
26.00
4
26.00
5
24.00
Cantilever Right
None
FRAME
Frame Location
Interior
DISPLAY OPTIONS
Labels
Units
Dimensions
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
S3
126.00
24.00
26.00
26.00
x
y
N
W
TOP
E
S
ACI 318-14
One-Way/Beam
Design
X: -9.07 (ft)
Units: English

4. From the **Ribbon**, select **Define,** then choose **Concrete** from **Materials** to display the **Concrete** dialog box.

   - Check STANDARD for SLABS AND BEAMS and COLUMNS.
   - Enter the following for SLABS AND BEAMS and COLUMNS:

   COMPRESSIVE STRENGTH, f'c: `4.00` ksi

   UNIT DENSITY, Wc: `150.00` pcf



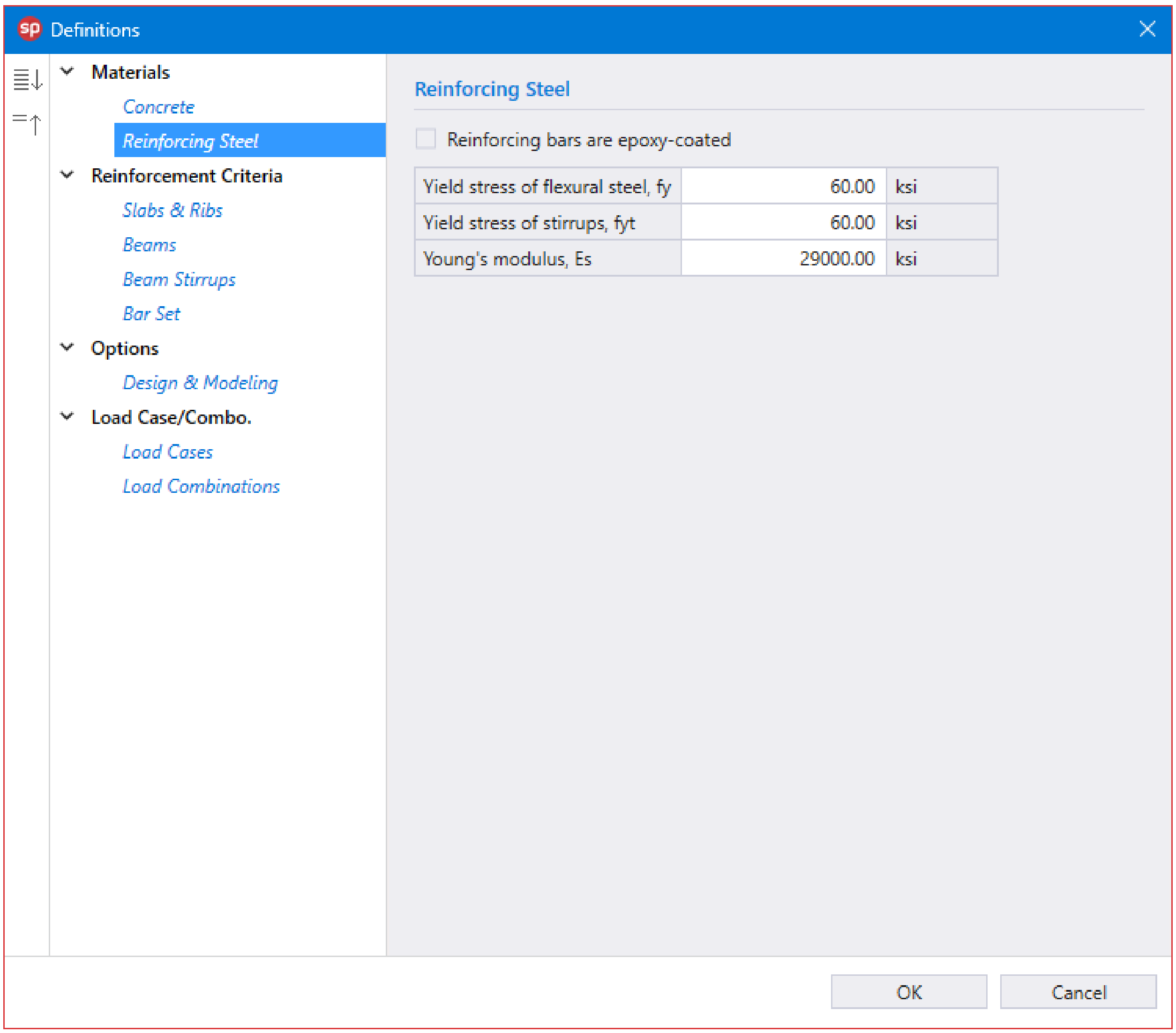
5. Click on **Reinforcing Steel** from **Materials** to display the **Reinforcing Steel** dialog box.

   - Enter the following:

     YIELD STRESS OF FLEXURAL STEEL, fy: 60.00 ksi

     YIELD STRESS OF STIRRUP, fyt: 60.00 ksi

     YOUNG'S MODULUS, Es: 29000.00 ksi



6. Click on **Beams** from **Reinforcement Criteria** to display the **Beams** dialog box.

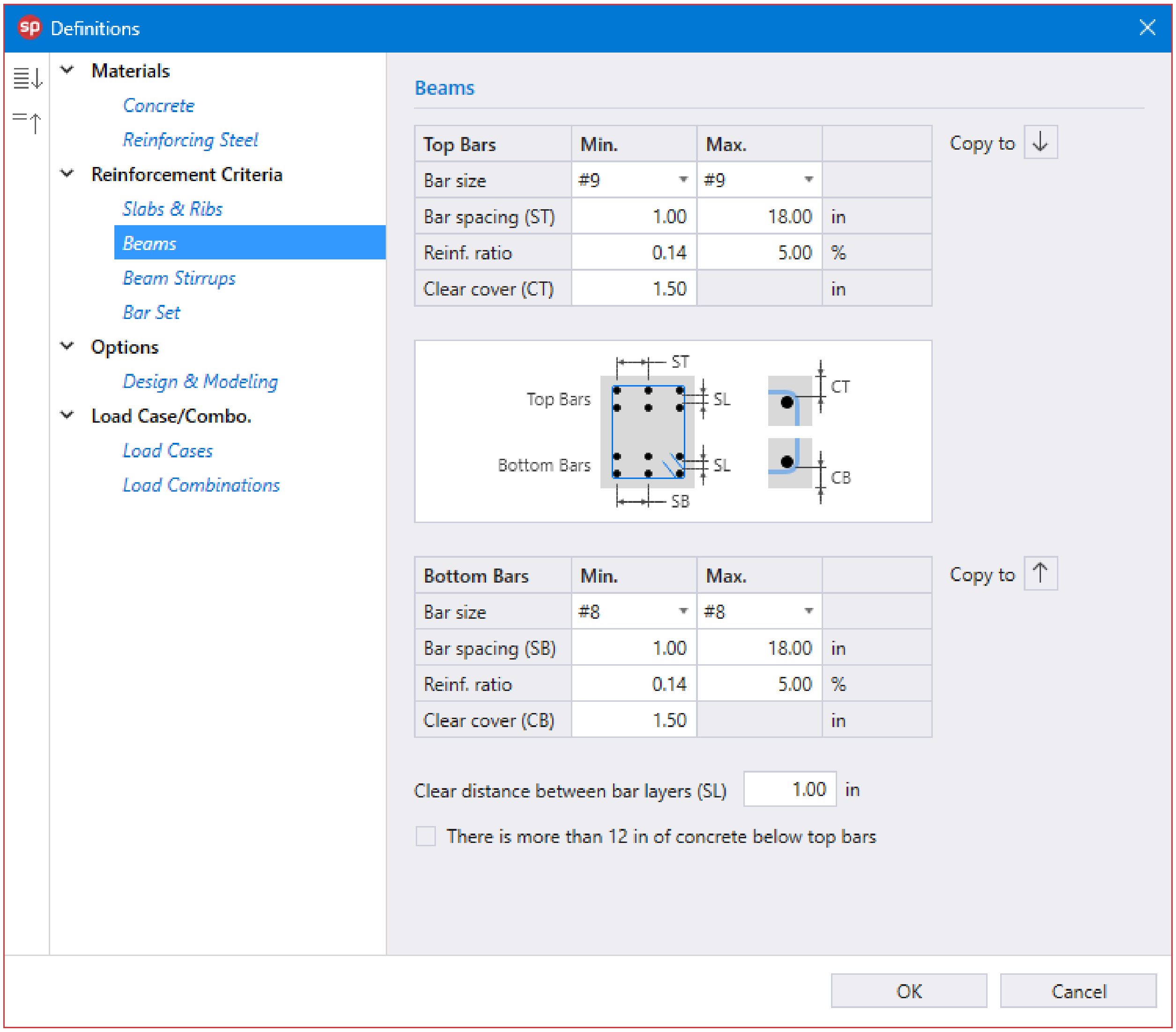
- Enter the following for TOP BARS:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #9 | #9 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.50 in | |

- Enter the following for BOTTOM BARS:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #8 | #8 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.50 in | |

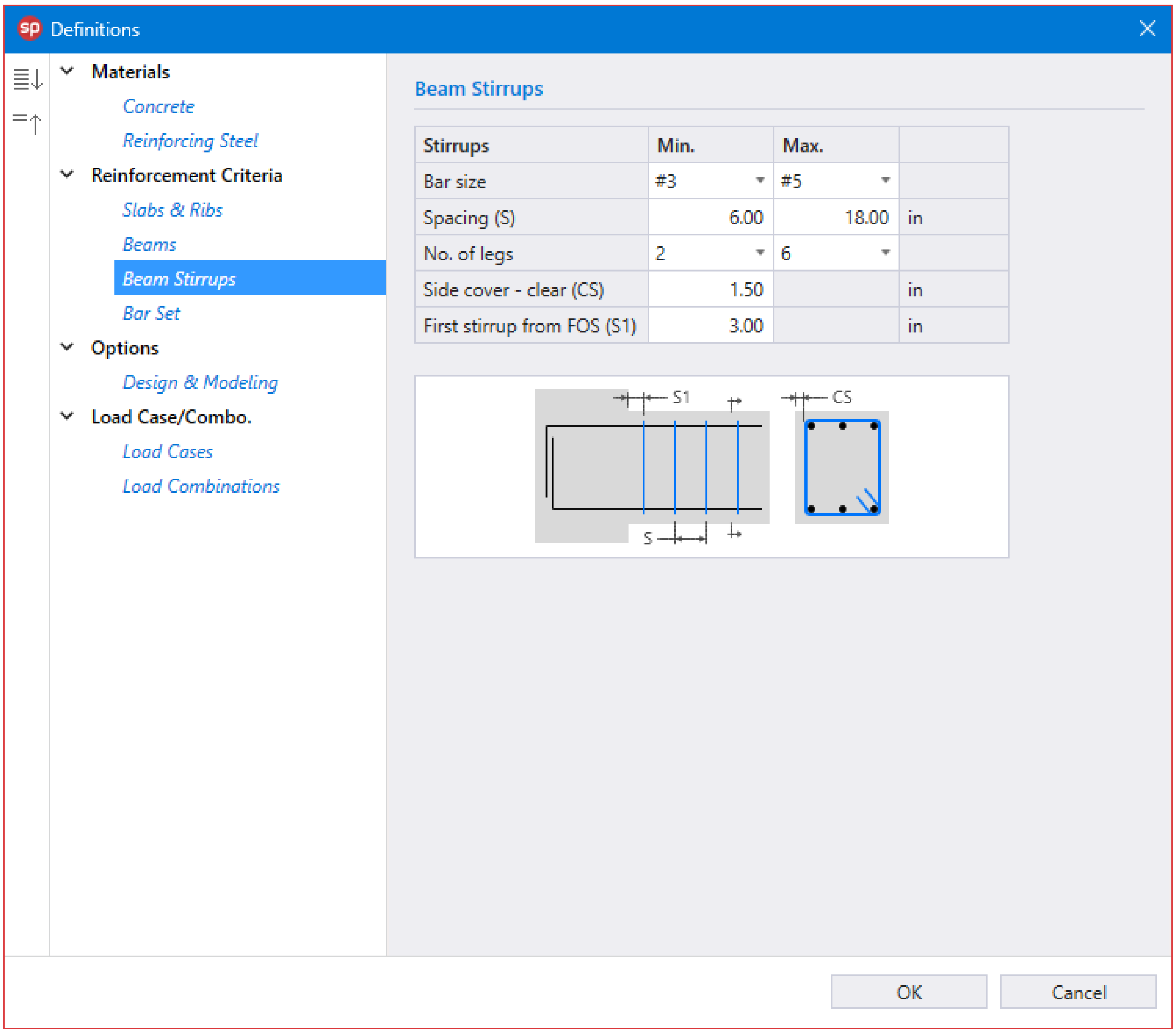
CLEAR DISTANCE BETWEEN BAR LAYERS (SL): 1.00 in


Definitions
Materials
Concrete
Reinforcing Steel
Reinforcement Criteria
Slabs & Ribs
Beams
Beam Stirrups
Bar Set
Options
Design & Modeling
Load Case/Combo.
Load Cases
Load Combinations
Beams
Top Bars | Min. | Max.
Bar size | #9 | #9
Bar spacing (ST) | 1.00 | 18.00 | in
Reinf. ratio | 0.14 | 5.00 | %
Clear cover (CT) | 1.50 | in
Copy to
Top Bars
Bottom Bars
ST
SL
SB
CT
CB
Bottom Bars | Min. | Max.
Bar size | #8 | #8
Bar spacing (SB) | 1.00 | 18.00 | in
Reinf. ratio | 0.14 | 5.00 | %
Clear cover (CB) | 1.50 | in
Copy to
Clear distance between bar layers (SL) 1.00 in
There is more than 12 in of concrete below top bars
OK
Cancel

7. Click on **Beam Stirrups** from **Reinforcement Criteria** to display the **Beam Stirrups** dialog box.

    - Enter the following:

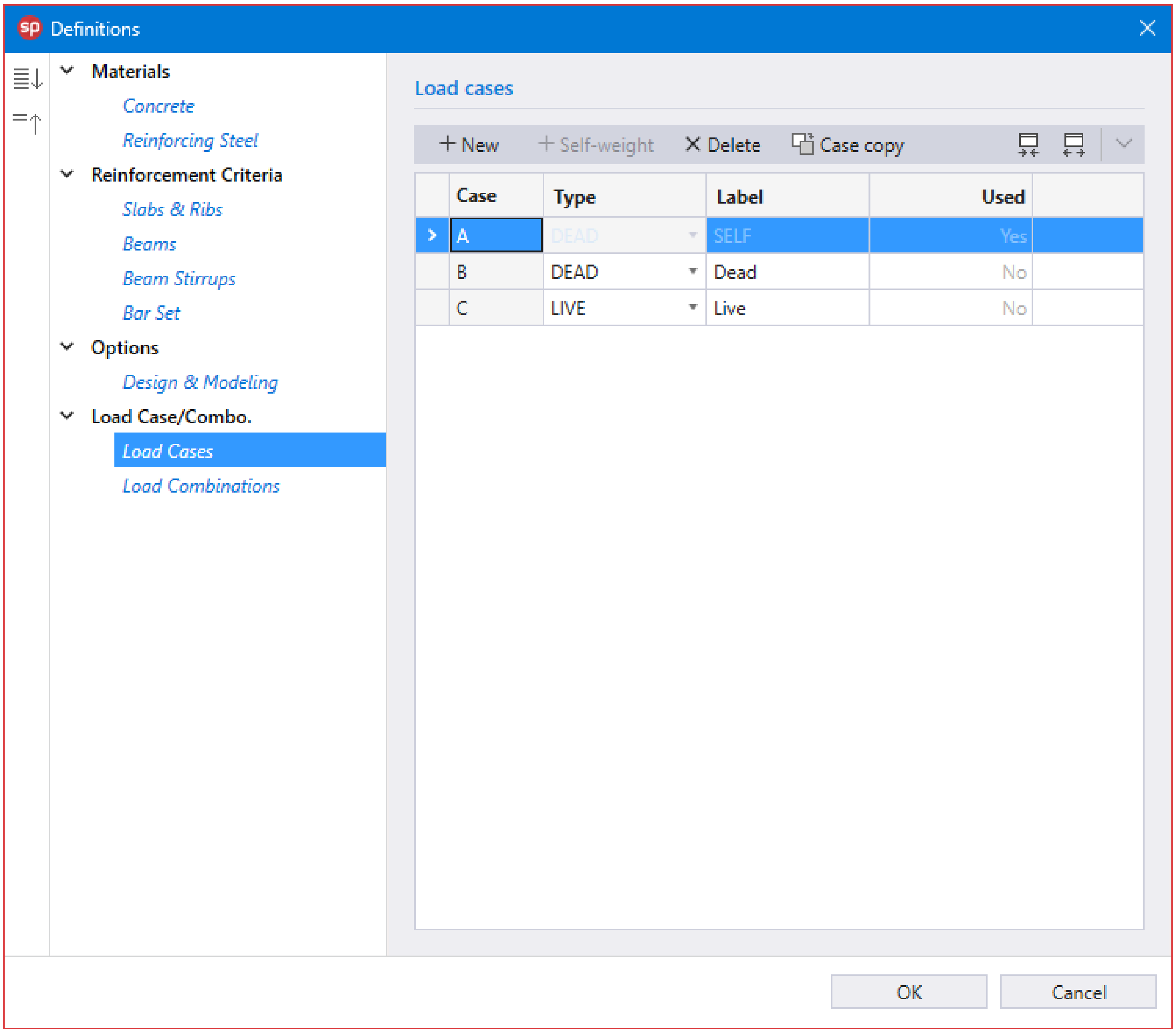
| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #3 | #5 |
| BAR SPACING (S): | 6.00 in | 18.00 in |
| NUMBER OF LEGS: | 2 | 6 |
| SIDE COVER – CLEAR (CS): | 1.50 in | |
| FIRST STIRRUP FROM FOS (S1): | 3.00 in | |



8. Click on **Load Cases** from **Load Case/Combo.** to display the **Load Cases** dialog box.

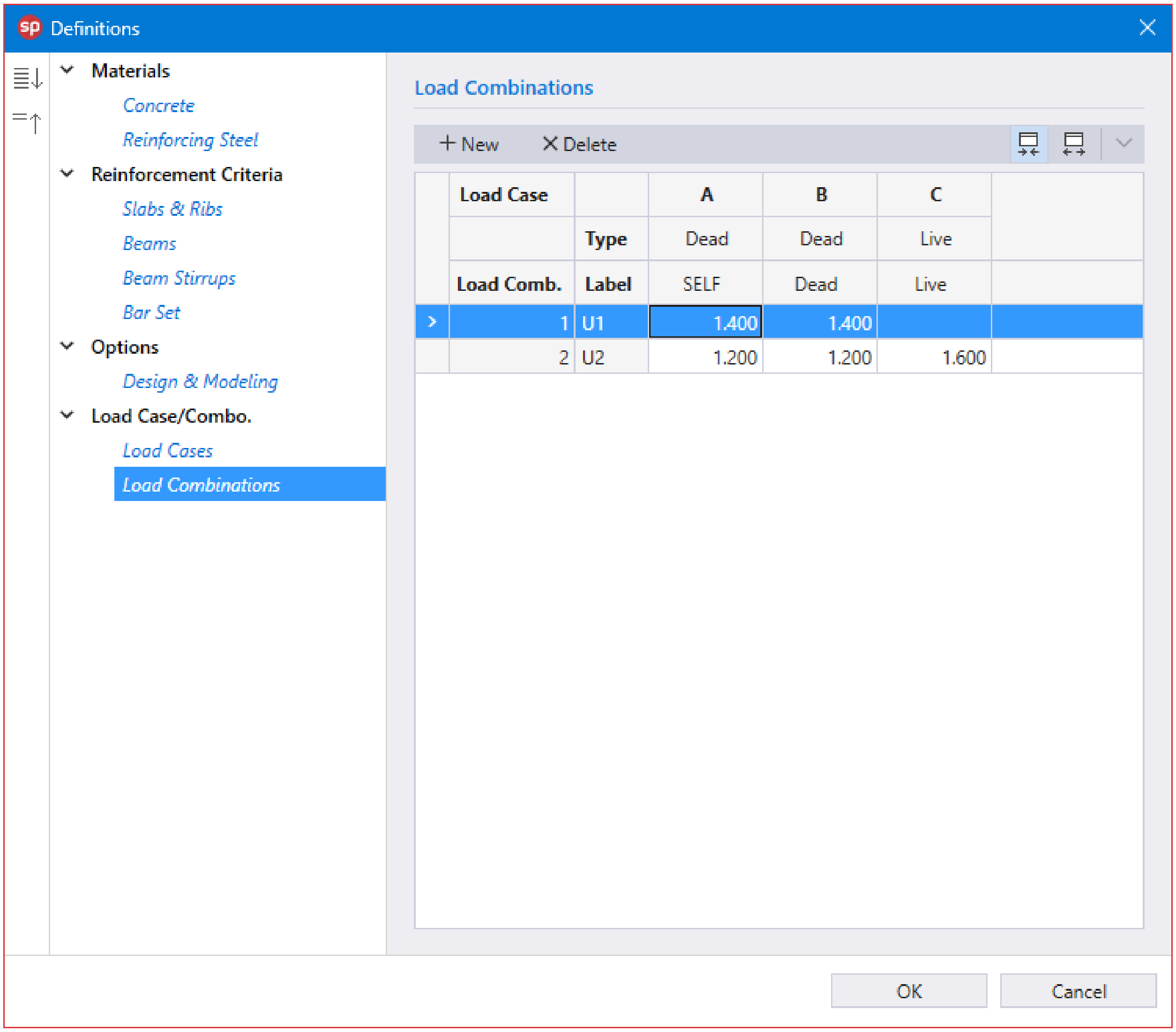
    - Add SELF-WEIGHT for CASE A.
    - Enter the following:

| | |
|---|---|
| CASE B: | `Dead` |
| CASE C: | `Live` |



9. Click on **Load Combinations** from **Load Case/Combo.** to display the **Load Combinations** dialog box.

- Enter the following load combination shown in the figure below:



### 8.3.3. Assigning Spans

10. From the **Ribbon**, select **Spans** command.

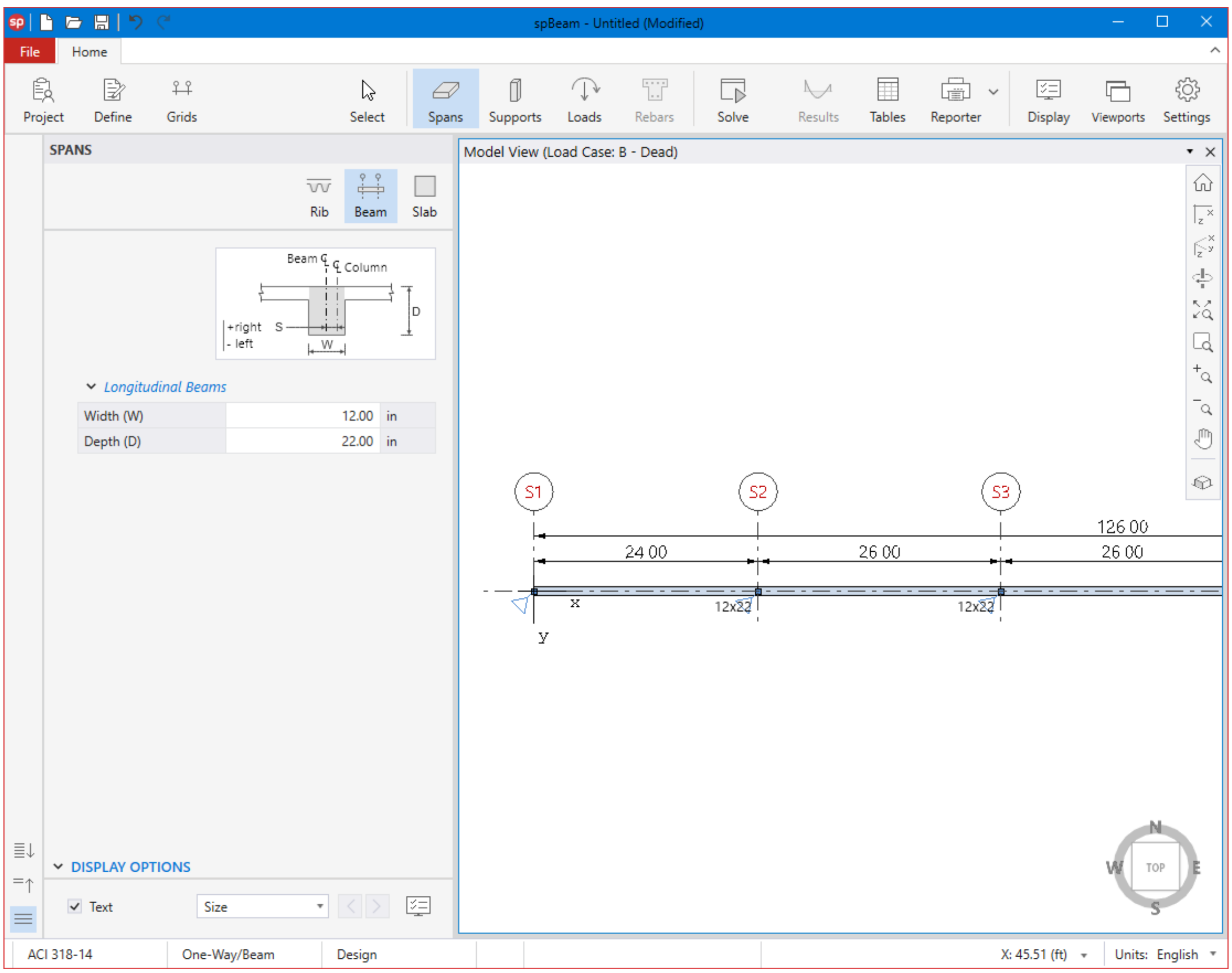
- In the left panel, select **Beam** and enter the following:

WIDTH (W): `12.00` in

DEPTH (D): `22.00` in

(Note: Since there will be no slab assigned, we must convert the area loads to line loads along the beam and also add the self-weight of the slab to the dead load. This calculation will be shown in Step 12.)

- Apply to all spans as shown in the figure below.



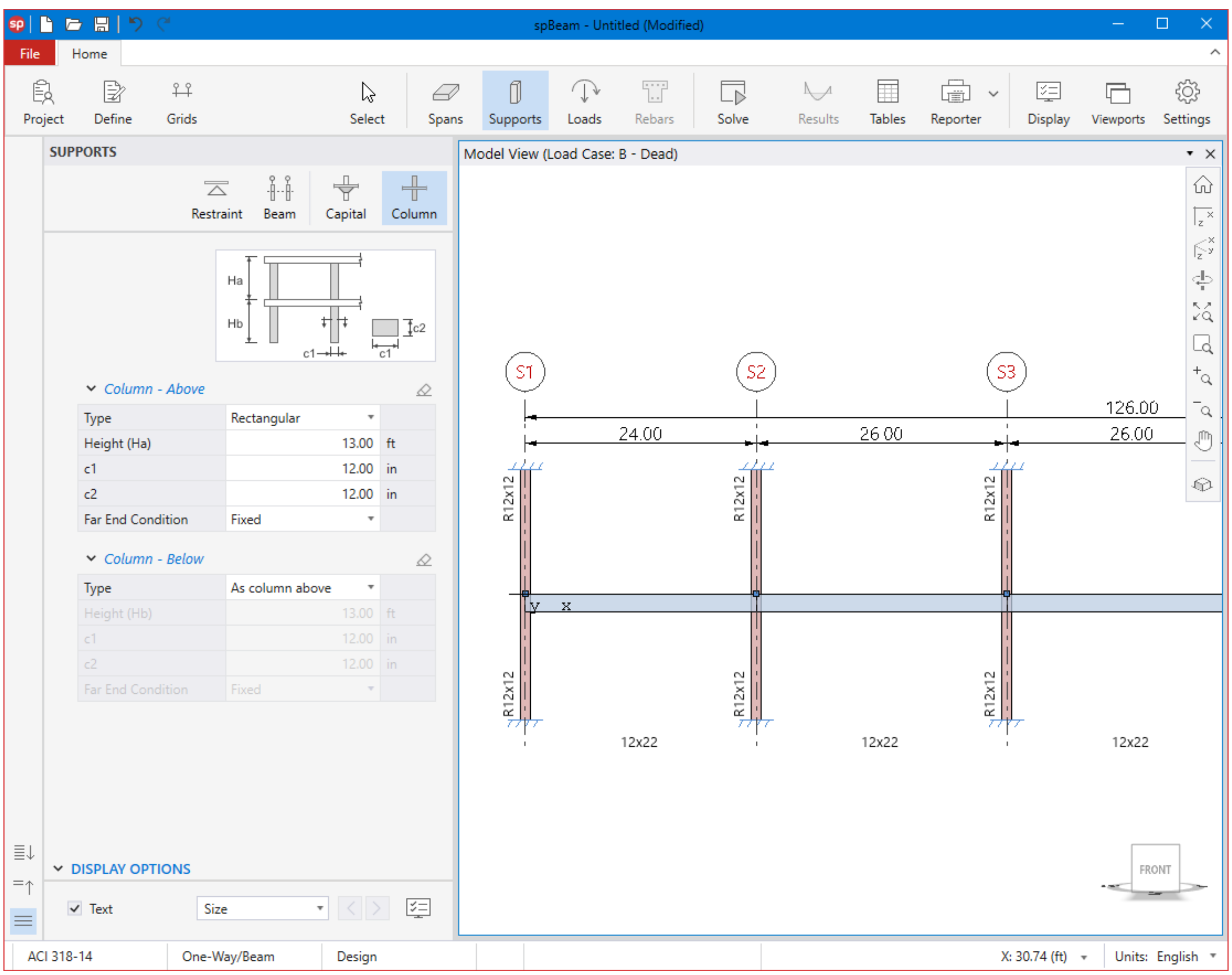
## 8.3.4. Assigning Supports

11. From the **Ribbon**, select **Supports** command.

- In the left panel, select **Column** and enter the following for COLUMN – ABOVE and COLUMN – BELOW:

| | |
|---|---|
| TYPE: | Rectangular |
| HEIGHT: | 13.00 ft |
| c1: | 12.00 in |
| c2: | 12.00 in |
| FAR END CONDITION: | Fixed |

- Apply to all supports as shown in the figure below.



### 8.3.5. Assigning Loads

12. From the **Ribbon**, select **Loads** command.

- In the left panel, select **Uniform Line Loads** then select B-DEAD from LOAD CASE and enter the following:

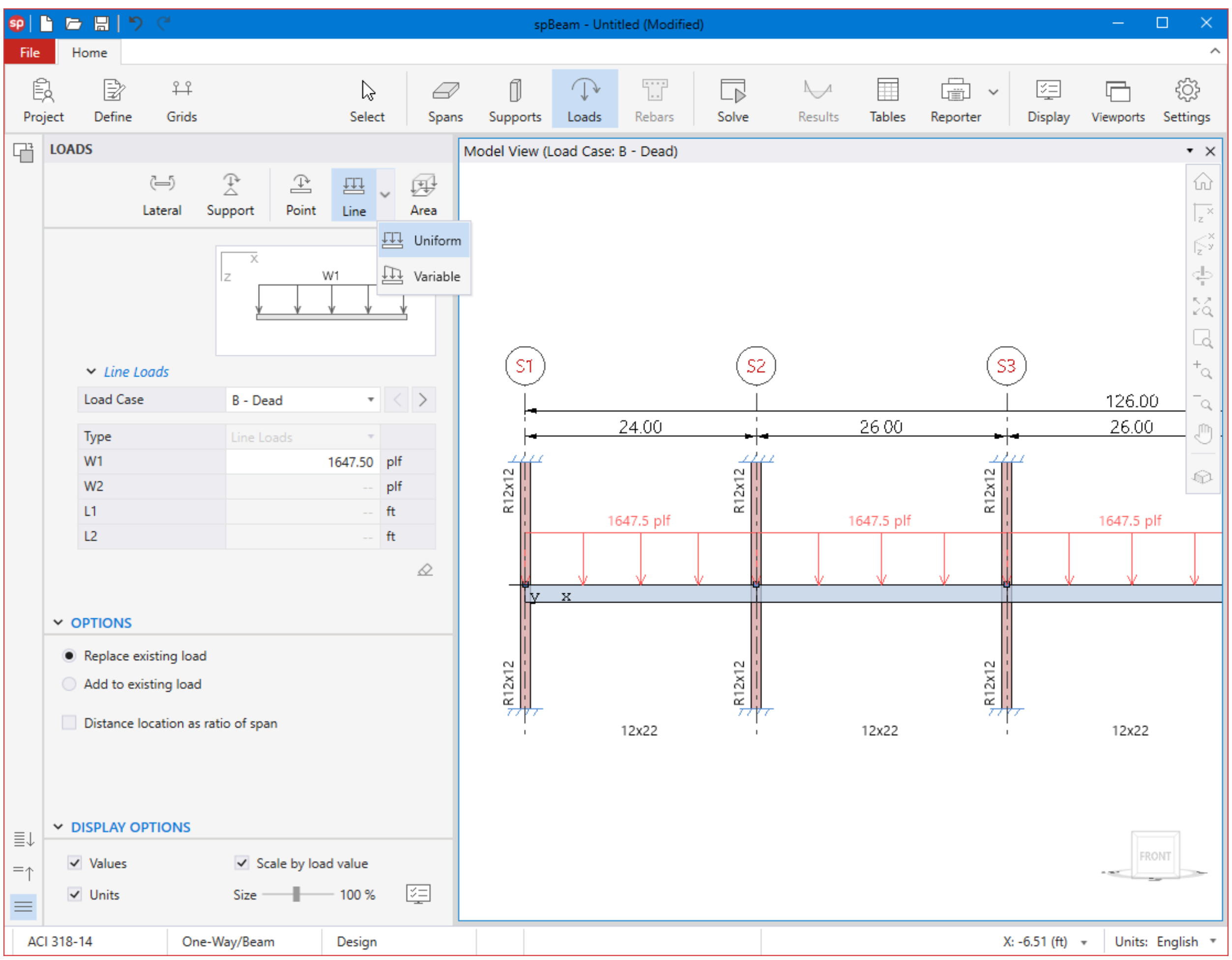
  W1: 1647.50 plf

  (Note: This value was obtained by converting the area loads of the slab's self weight (without the beam) and superimposed dead load into a line load)

$$\text{Dead Load} = \left(\frac{5}{12}\ \text{ft} \times 150\ \text{pcf} \times 12\ \text{ft}\right) + (80\ \text{psf} \times 12\ \text{ft}) - \left(\frac{5\ \text{in.} \times 12\ \text{in.}}{144\ \text{in.}^2/\text{ft}^2} \times 150\ \text{pcf}\right)$$

$$= 1647.50\ \text{lb/ft}$$

- Apply to all spans as shown in the figure below.

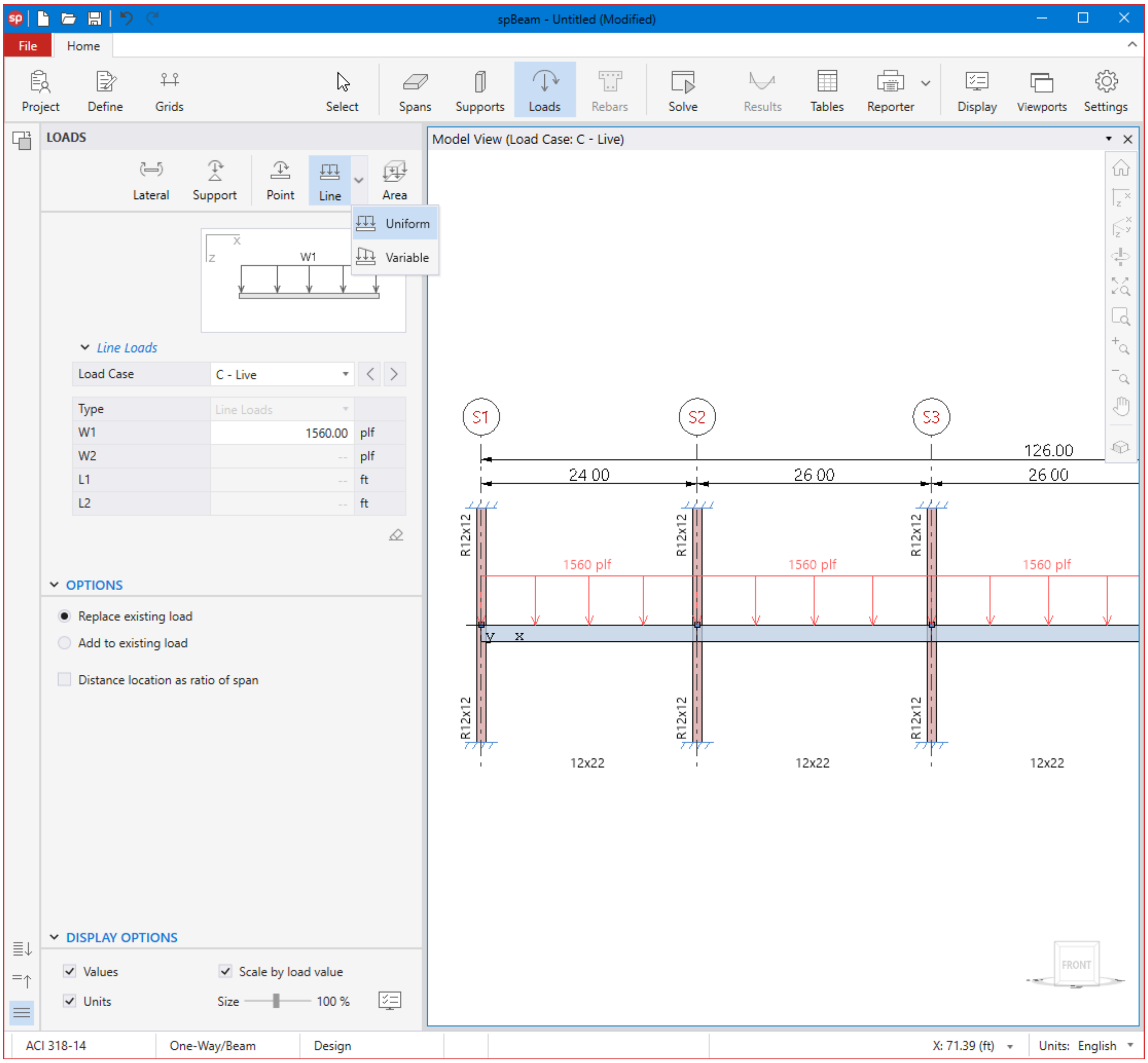


- Select C-LIVE from LOAD CASE and enter the following:

  $W_1$: `1560.00` plf

  Live Load = (130 psf × 12 ft) = 1560 lb/ft

- Apply to all spans as shown in the figure below.

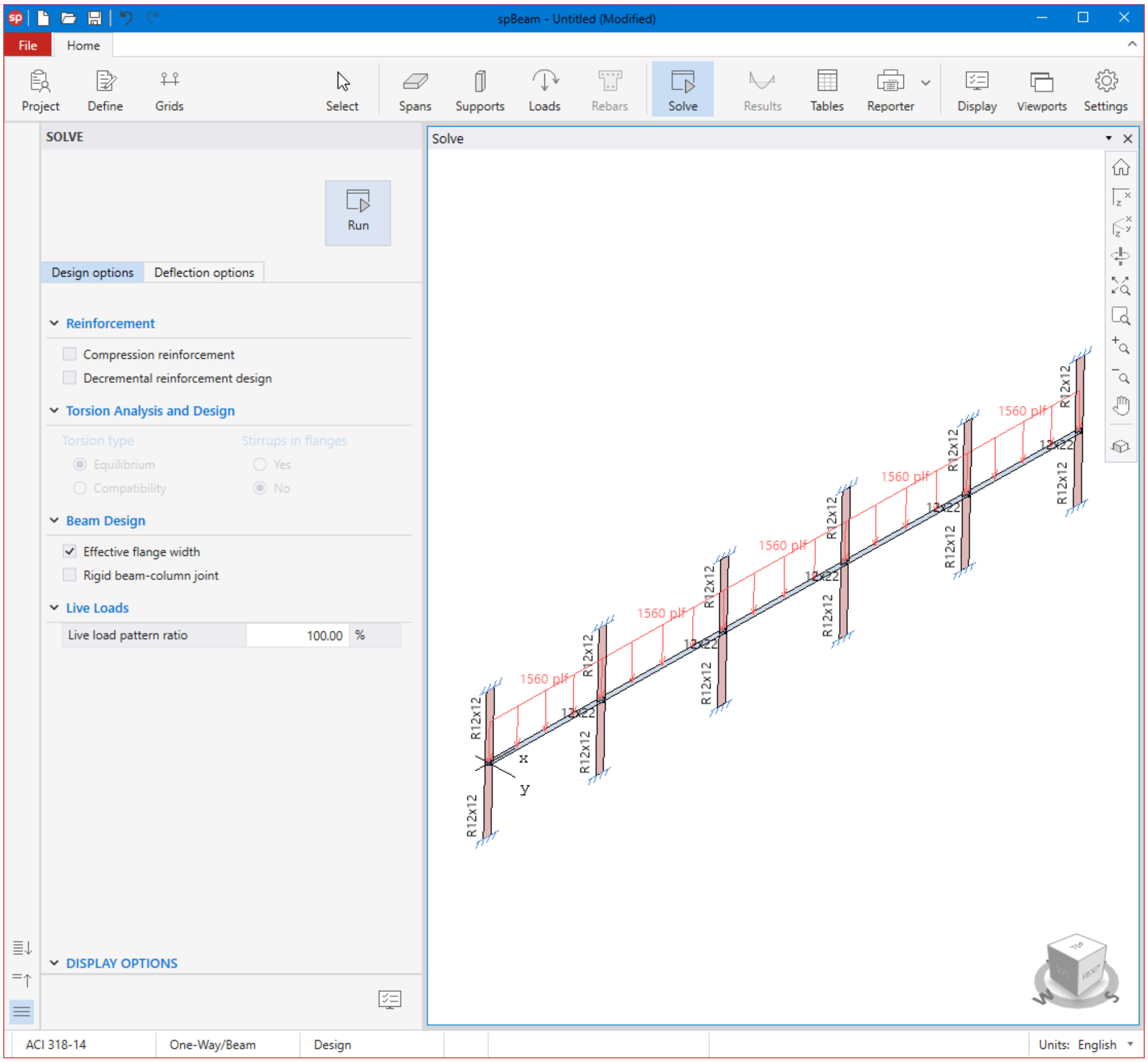


### 8.3.6. Solving

13. From the **Ribbon**, select **Solve** command.

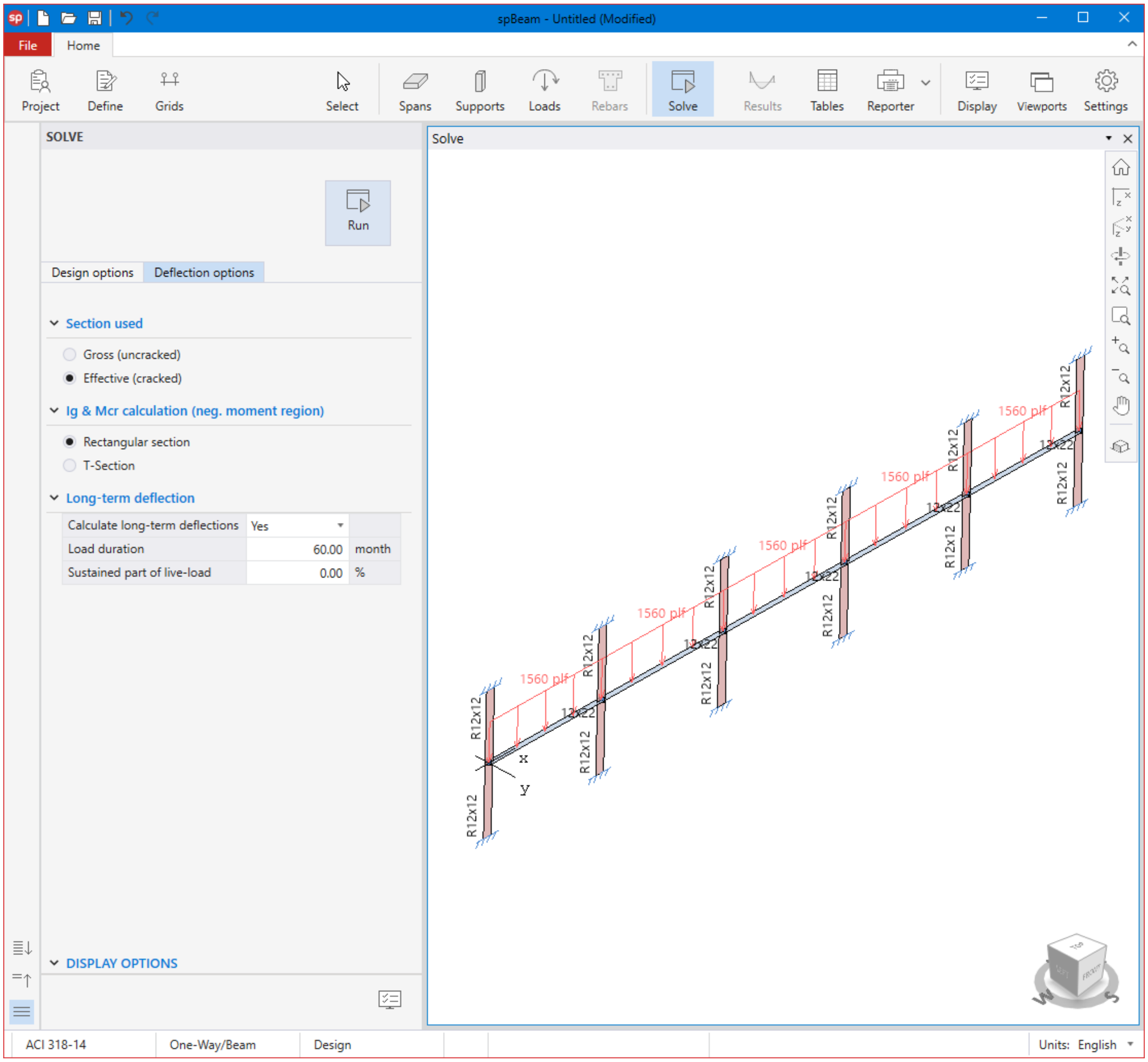
    For **Design Options**:

    - Leave all **Design Options** to their default settings.

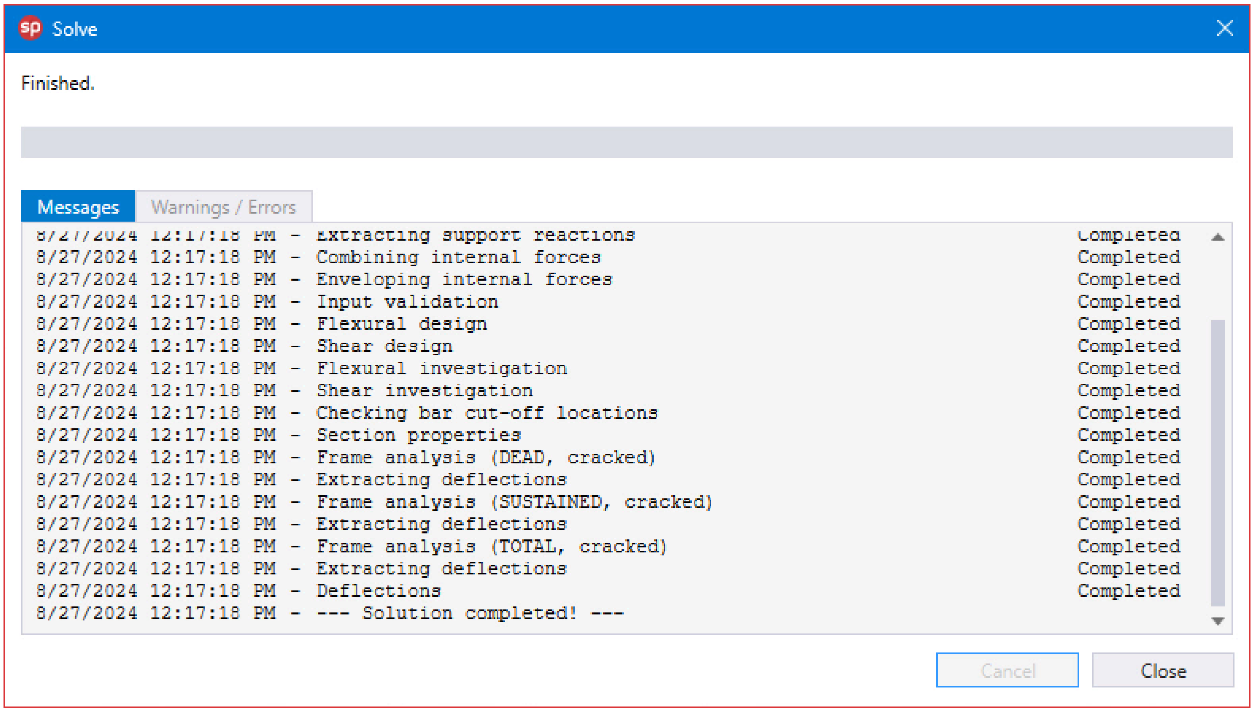


For **Deflection Options**:

- Leave all **Design Options** to their default settings.

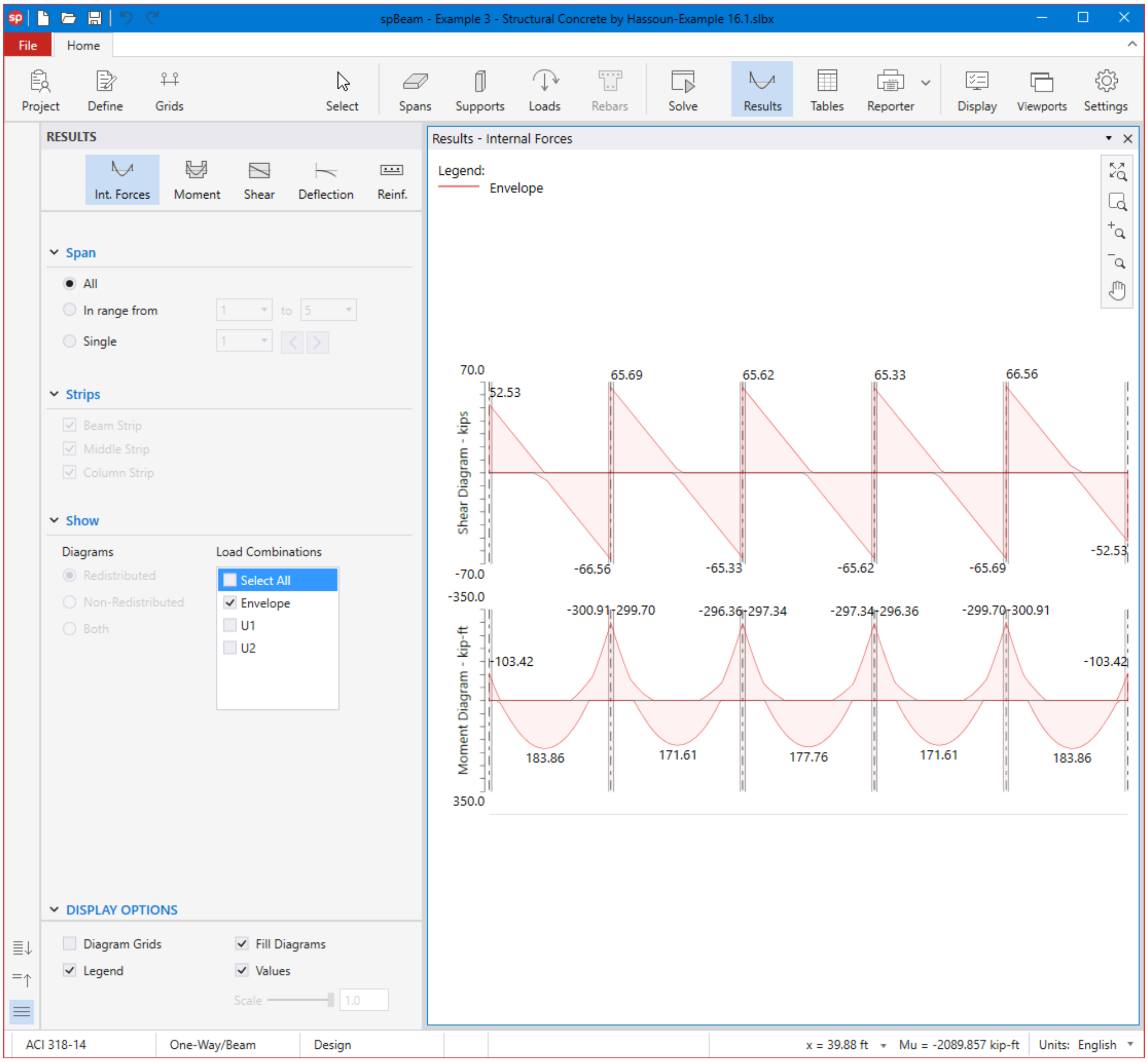


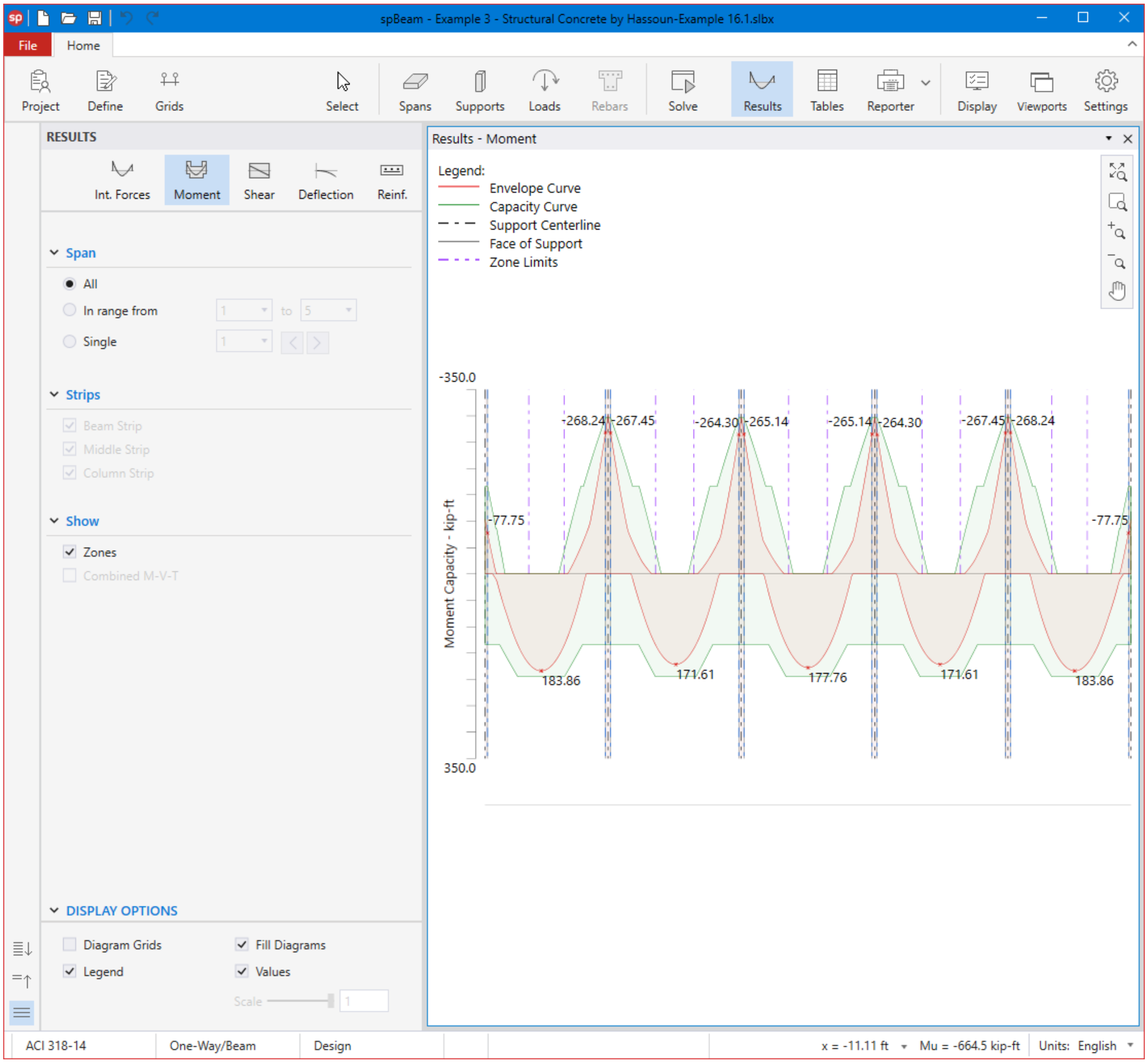
- Click on the **Run** button.
- The spBeam **Solver** window is displayed and the solver messages are listed. After the solution is done, the design will be performed and then the focus will immediately be passed to the **Results** scope.

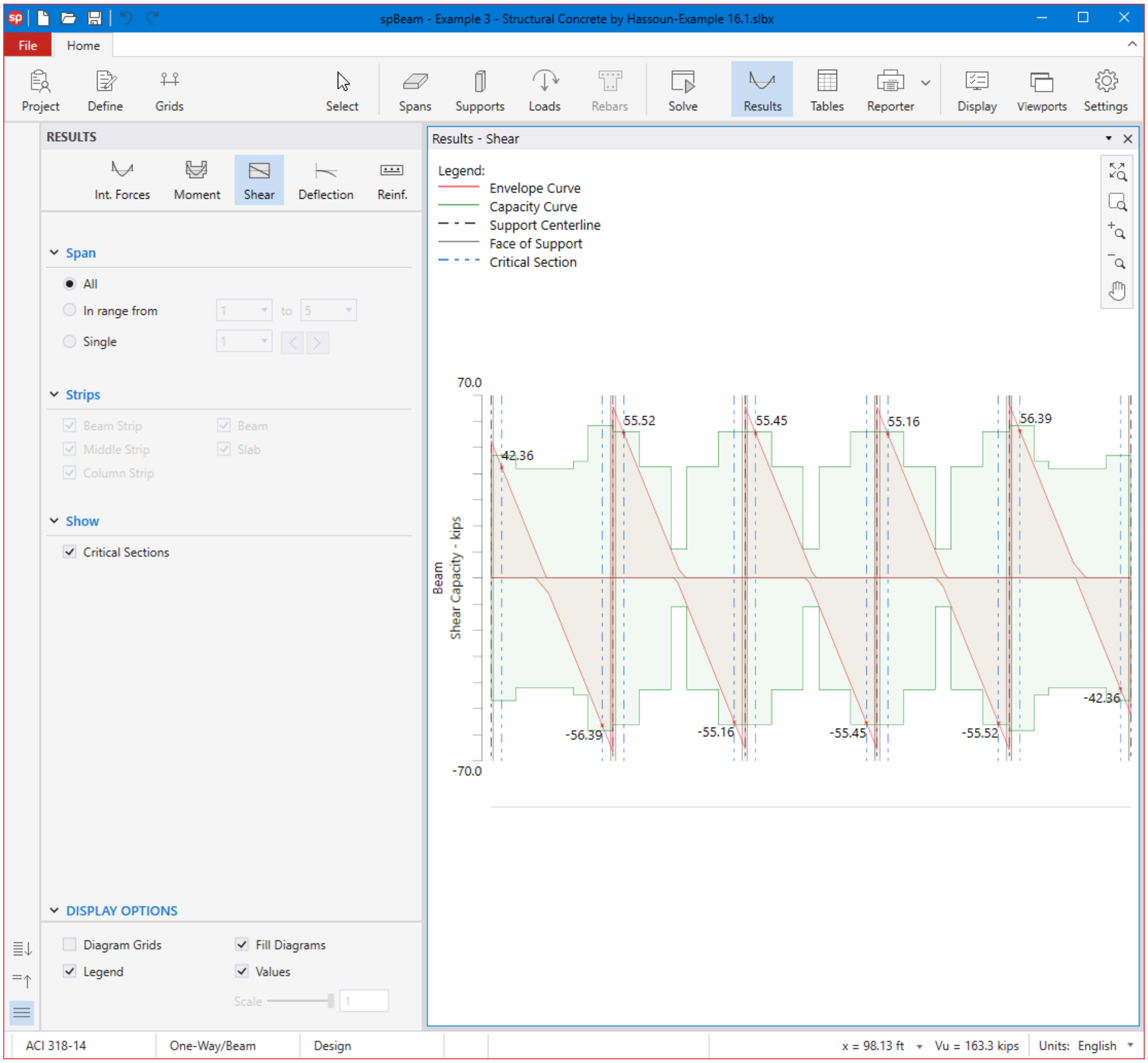


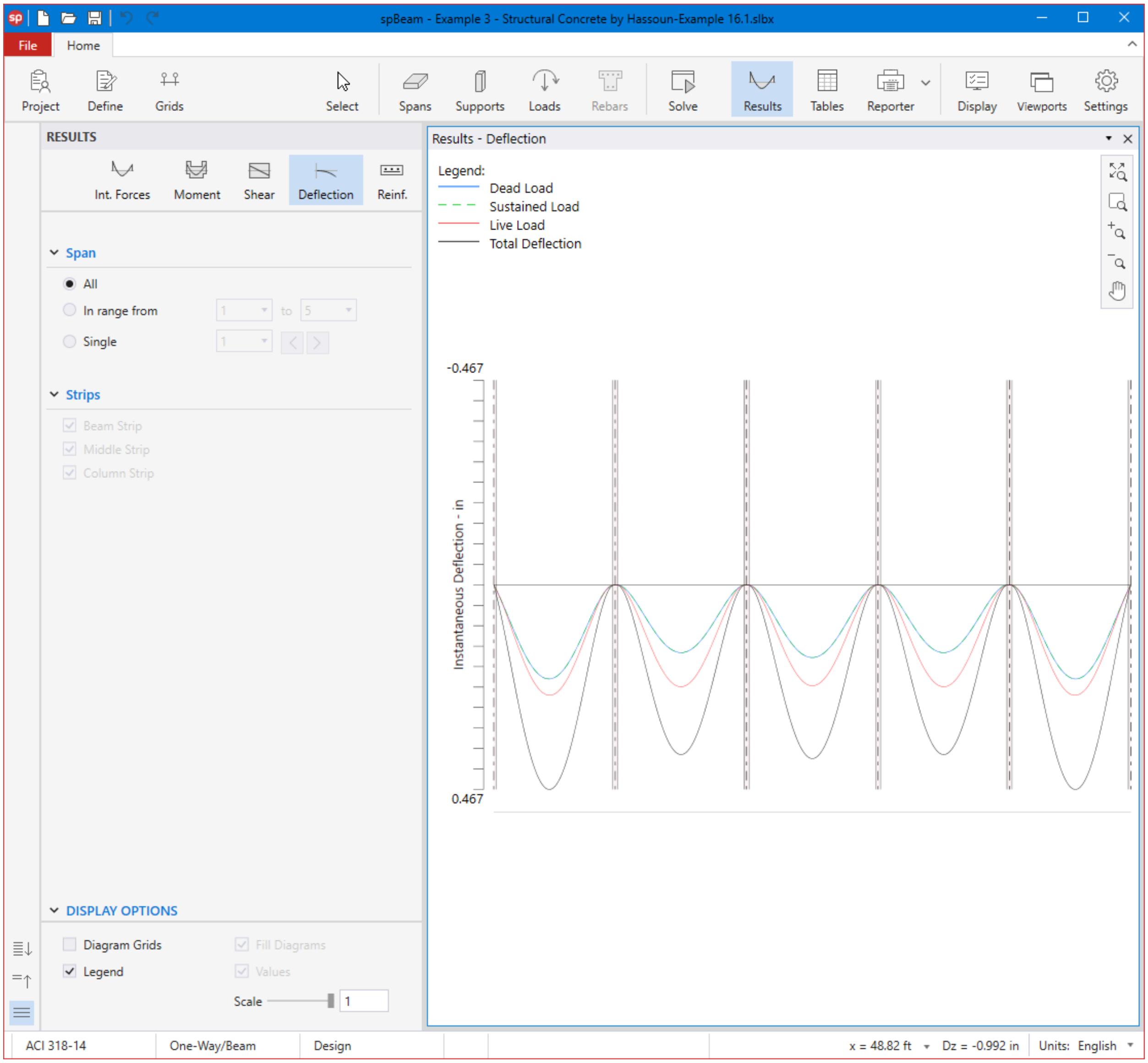
## 8.3.7. Viewing and Printing Results

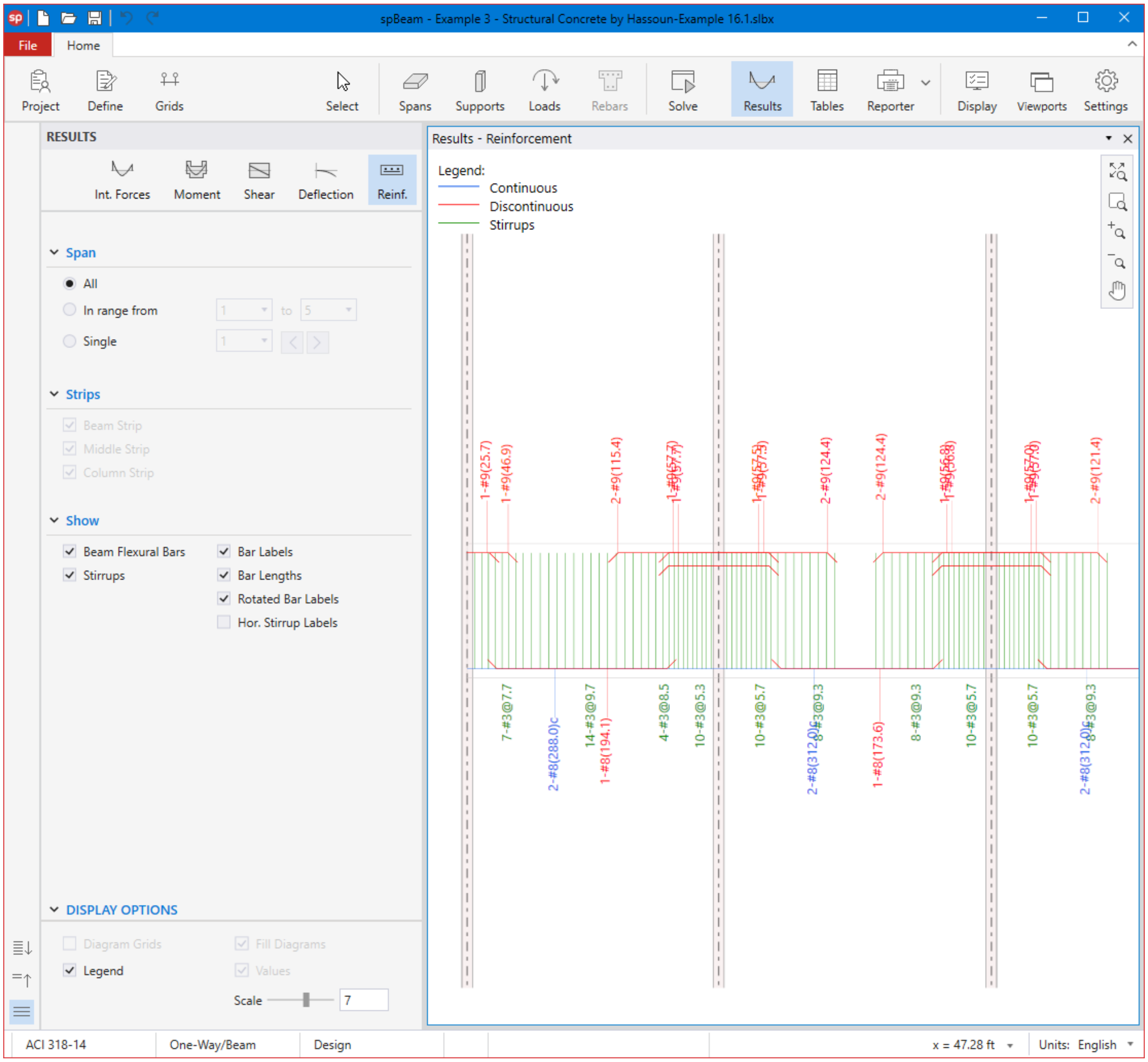
14. After a successful run, results can be viewed by selecting **Internal Forces**, **Moment Capacity**, **Shear Capacity**, **Deflection**, or **Reinforcement** from the left panel.



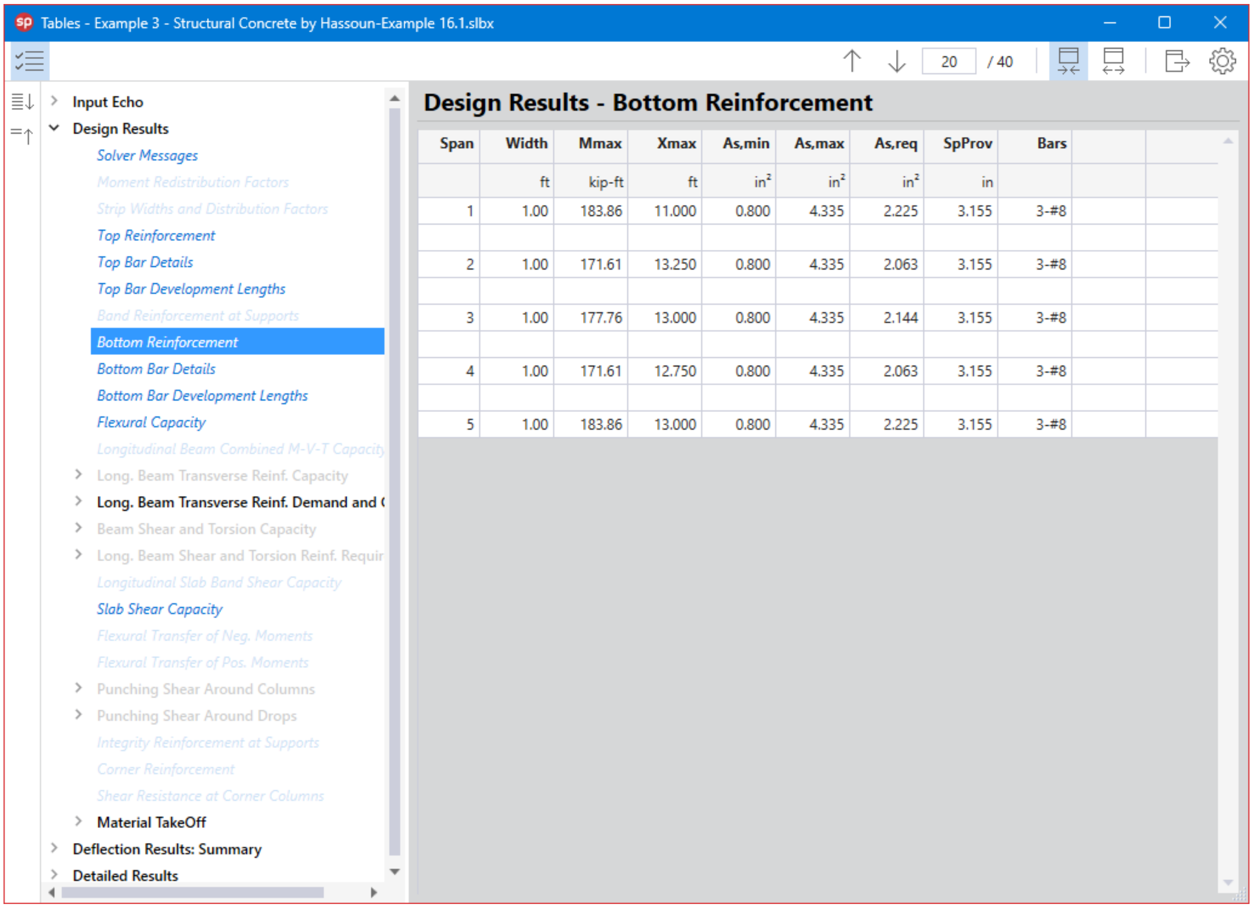

spBeam - Example 3 - Structural Concrete by Hassoun-Example 16.1.slbx
Results - Moment
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Zone Limits
-350.0
350.0
Moment Capacity - kip-ft
-268.24
-267.45
-264.30
-265.14
-265.14
-264.30
-267.45
-268.24
-77.75
-77.75
183.86
171.61
177.76
171.61
183.86
ACI 318-14
One-Way/Beam
Design
x = -11.11 ft
Mu = -664.5 kip-ft
Units: English


spBeam - Example 3 - Structural Concrete by Hassoun-Example 16.1.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Beam
Middle Strip
Slab
Column Strip
Show
Critical Sections
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Shear
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Critical Section
70.0
-70.0
Beam
Shear Capacity - kips
42.36
55.52
55.45
55.16
56.39
-56.39
-55.16
-55.45
-55.52
-42.36
ACI 318-14
One-Way/Beam
Design
x = 98.13 ft
Vu = 163.3 kips
Units: English


spBeam - Example 3 - Structural Concrete by Hassoun-Example 16.1.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
DISPLAY OPTIONS
Diagram Grids
Legend
Fill Diagrams
Values
Scale
Results - Deflection
Legend:
Dead Load
Sustained Load
Live Load
Total Deflection
-0.467
Instantaneous Deflection - in
0.467
ACI 318-14
One-Way/Beam
Design
x = 48.82 ft
Dz = -0.992 in
Units: English

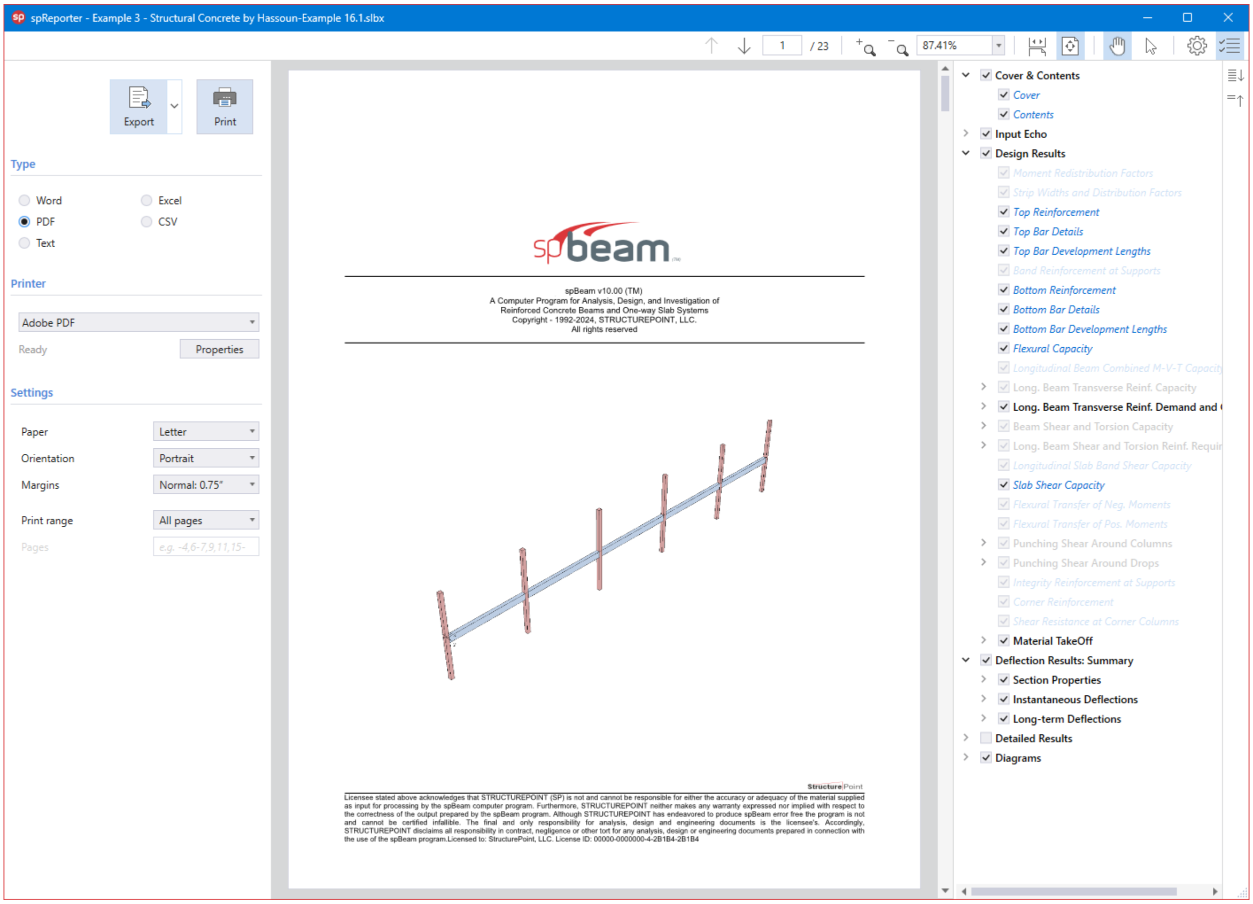

spBeam - Example 3 - Structural Concrete by Hassoun-Example 16.1.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
Show
Beam Flexural Bars
Stirrups
Bar Labels
Bar Lengths
Rotated Bar Labels
Hor. Stirrup Labels
DISPLAY OPTIONS
Diagram Grids
Legend
Fill Diagrams
Values
Scale
Results - Reinforcement
Legend:
Continuous
Discontinuous
Stirrups
1-#9(25.7)
1-#9(46.9)
2-#9(115.4)
2-#9(124.4)
2-#9(124.4)
2-#9(121.4)
7-#3@7.7
2-#8(288.0)c
14-#3@9.7
1-#8(194.1)
4-#3@8.5
10-#3@5.3
10-#3@5.7
8-#3@9.3
1-#8(173.6)
8-#3@9.3
10-#3@5.7
10-#3@5.7
8-#3@9.3
ACI 318-14
One-Way/Beam
Design
x = 47.28 ft
Units: English

15. Results can be also viewed in table format by selecting the **Tables** command from the **Ribbon.**




| Span | Width | Mmax | Xmax | As,min | As,max | As,req | SpProv | Bars |
|---|---|---|---|---|---|---|---|---|
| | ft | kip-ft | ft | in² | in² | in² | in | |
| 1 | 1.00 | 183.86 | 11.000 | 0.800 | 4.335 | 2.225 | 3.155 | 3-#8 |
| 2 | 1.00 | 171.61 | 13.250 | 0.800 | 4.335 | 2.063 | 3.155 | 3-#8 |
| 3 | 1.00 | 177.76 | 13.000 | 0.800 | 4.335 | 2.144 | 3.155 | 3-#8 |
| 4 | 1.00 | 171.61 | 12.750 | 0.800 | 4.335 | 2.063 | 3.155 | 3-#8 |
| 5 | 1.00 | 183.86 | 13.000 | 0.800 | 4.335 | 2.225 | 3.155 | 3-#8 |

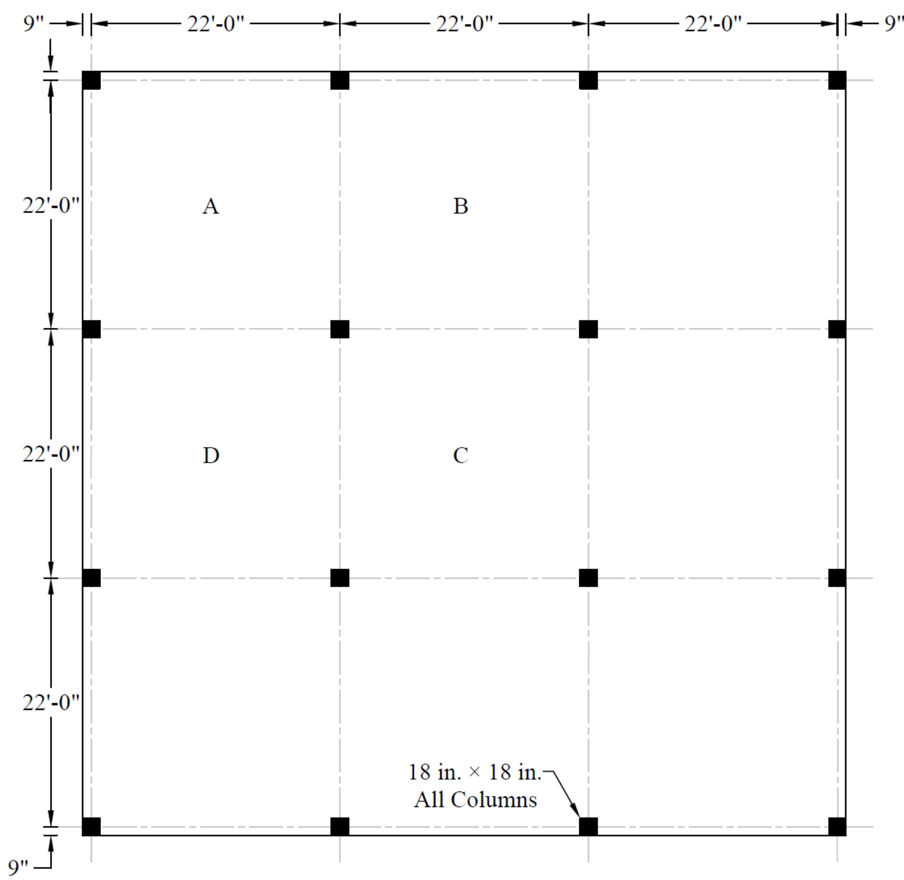
16. Results can be printed or exported in different formats by selecting the **Reporter** command from the **Ribbon.**



# 8.4. Example 4 – Flat Plate Floor System

## 8.4.1. Problem Formulation

An office building is planned using a flat plate floor system with the column layout as shown in figure below. No beams, drop panels, or column capitals are permitted. Specified live load is 100 psf and dead load will include the weight of the slab plus an allowance of 20 psf for finish floor plus suspended loads. The columns will be 18 in. square, and the floor-to-floor height of the structure will be 12 ft. The slab thickness will be 8.50 in. according to ACI Code. Design the interior panel *C*, using material strengths $f_y$ = 60,000 psi and $f'_c$ = 4,000 psi. Straight-bar reinforcement will be used.[1]




[1] A. H. Nilson, D. Darwin, and C. W. Dolan, *Design of Concrete Structures*, Fifteenth Edition, 2016 McGraw-Hill Education, Example 13-2

**Design data**

Dead load = 20 psf

Live load = 100 psf

$f_c'$ = 4,000 psi ($w_c$ = 150 pcf)

$f_y$ = 60,000 psi

Columns: 18 × 18 in.

Story height: 12 ft

Slab thickness: 8.50 in.

### 8.4.2. Preparing the Input

1. From the Start screen, select **New Project**.

2. From the **Main Program Window**, select **Project** from the **Ribbon**.

    - In the **General** section, select the DESIGN CODE, UNIT SYSTEM, and BAR SET.

    - In the **Materials** section, input the following:

      f'c (SLABS & BEAMS): `4.00` ksi

      f'c (COLUMNS): `4.00` ksi

      fy: `60.00` ksi

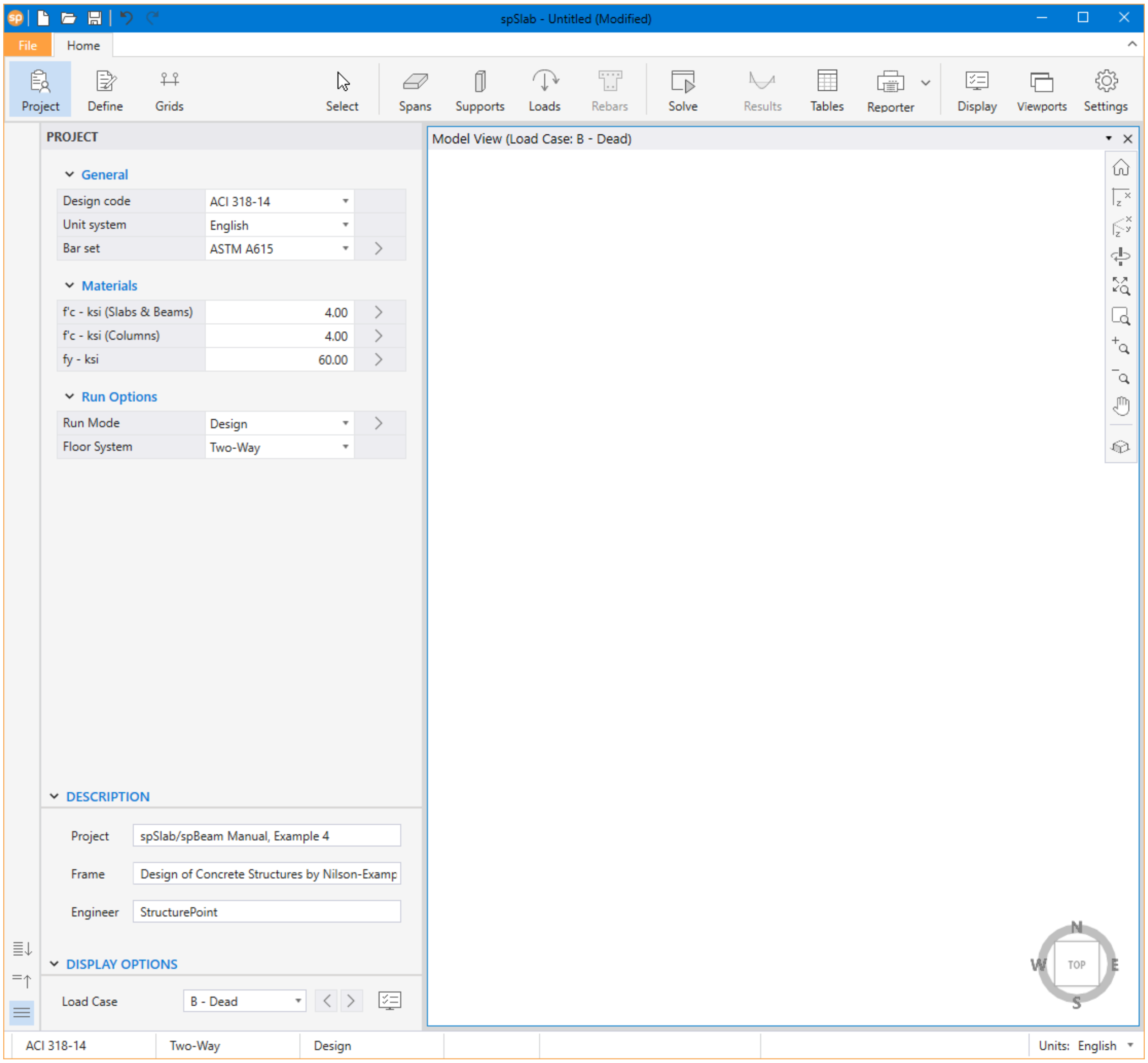
      Alternatively, detailed material properties for **Concrete** and **Reinforcement Steel** can be entered using **Definitions** dialog box (see Steps 4 and 5).

    - In the **Run Options** section, select the following:

      RUN MODE: Design

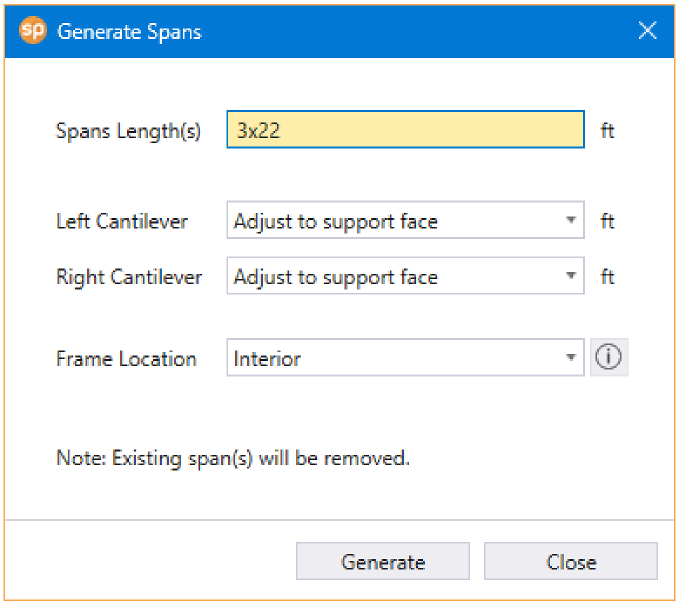
      FLOOR SYSTEM: Two-Way

    - In the **Description** section, enter the PROJECT, FRAME, and ENGINEER.


spSlab - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
PROJECT
General
Design code
ACI 318-14
Unit system
English
Bar set
ASTM A615
Materials
f'c - ksi (Slabs & Beams)
4.00
f'c - ksi (Columns)
4.00
fy - ksi
60.00
Run Options
Run Mode
Design
Floor System
Two-Way
DESCRIPTION
Project
spSlab/spBeam Manual, Example 4
Frame
Design of Concrete Structures by Nilson-Examp
Engineer
StructurePoint
DISPLAY OPTIONS
Load Case
B - Dead
Model View (Load Case: B - Dead)
N
W
TOP
E
S
ACI 318-14
Two-Way
Design
Units: English

3. From the **Ribbon**, select **Grids**.

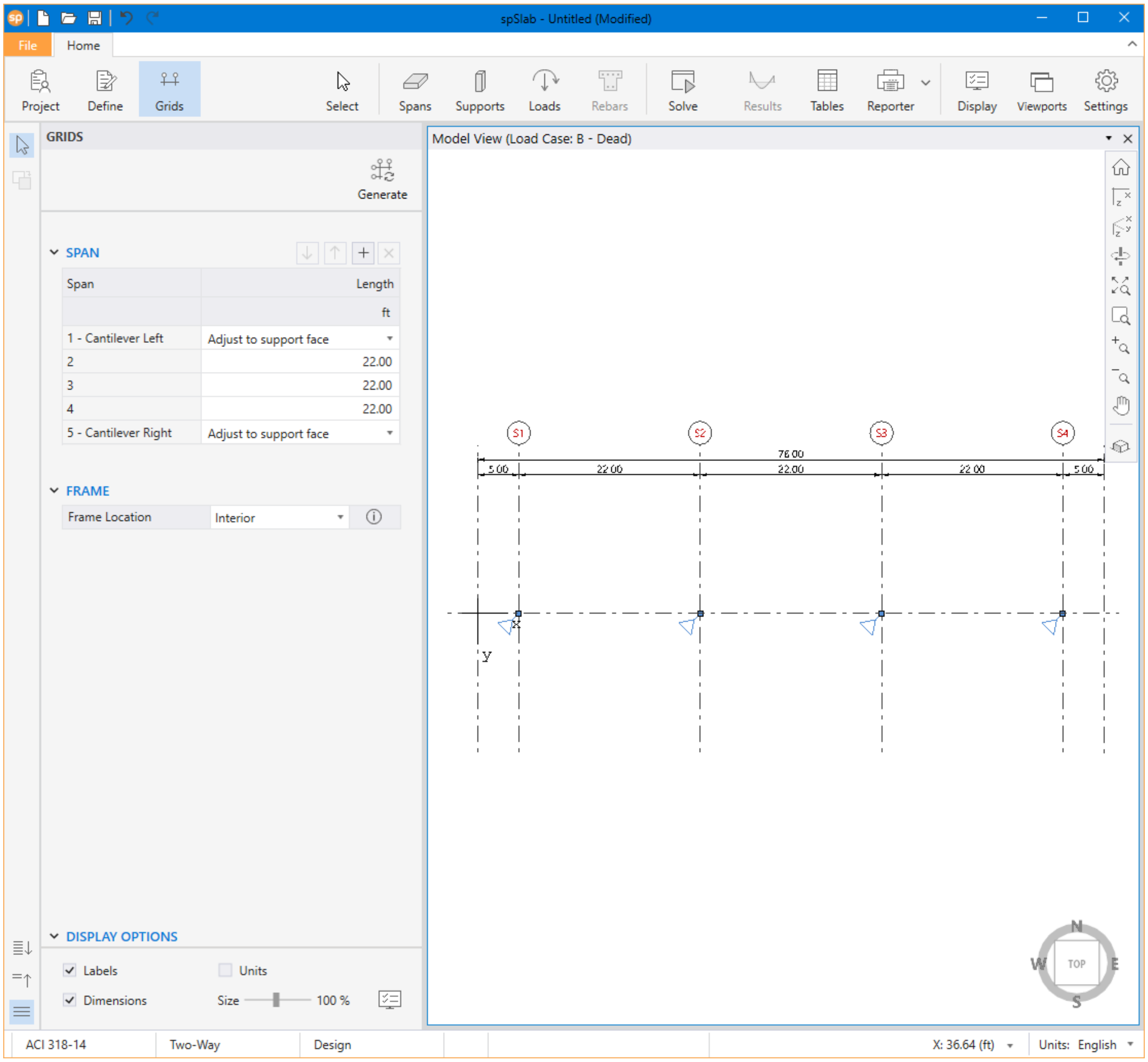
- Click on the **Generate** in the left panel to have the program surface the following:




- Enter the following values in the corresponding text boxes:

| | |
|---|---|
| SPANS LENGTH(S): | 3x22 |
| LEFT CANTILEVER: | Adjusted to support face |
| RIGHT CANTILEVER: | Adjusted to support face |
| FRAME LOCATION: | Interior |

- Click on the GENERATE button to return to the main window. Notice how the grid lines now appear in the VIEWPORT.

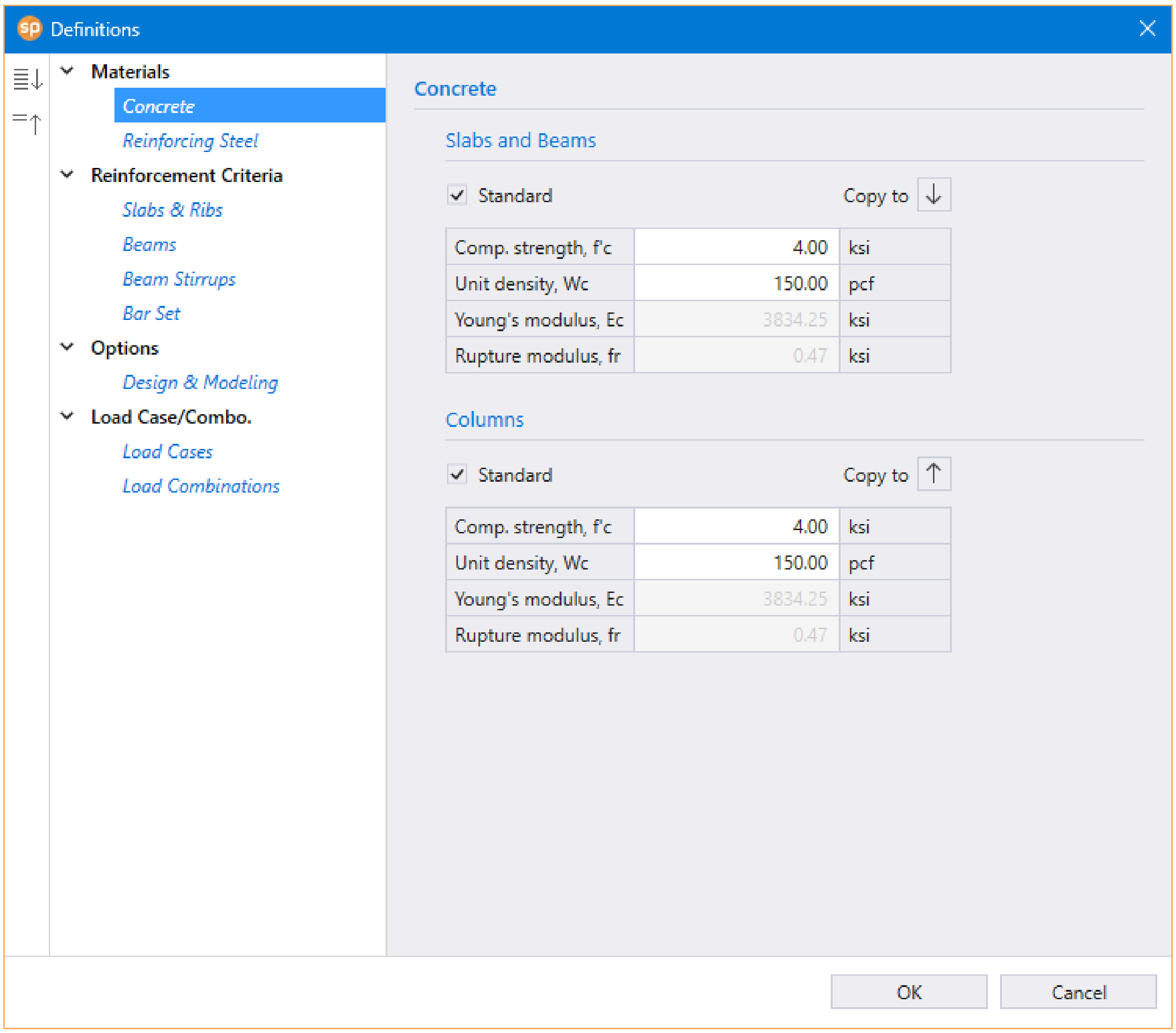

spSlab - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
GRIDS
Generate
SPAN
Span
Length
ft
1 - Cantilever Left
Adjust to support face
2
22.00
3
22.00
4
22.00
5 - Cantilever Right
Adjust to support face
FRAME
Frame Location
Interior
DISPLAY OPTIONS
Labels
Units
Dimensions
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
S3
S4
76.00
5.00
22.00
22.00
22.00
5.00
ACI 318-14
Two-Way
Design
X: 36.64 (ft)
Units: English

4. From the **Ribbon**, select **Define,** then choose **Concrete** from **Materials** to display the **Concrete** dialog box.

 - Check STANDARD for SLABS AND BEAMS and COLUMNS.
 - Enter the following for SLABS AND BEAMS and COLUMNS:

 COMPRESSIVE STRENGTH, f'c: `4.00` ksi

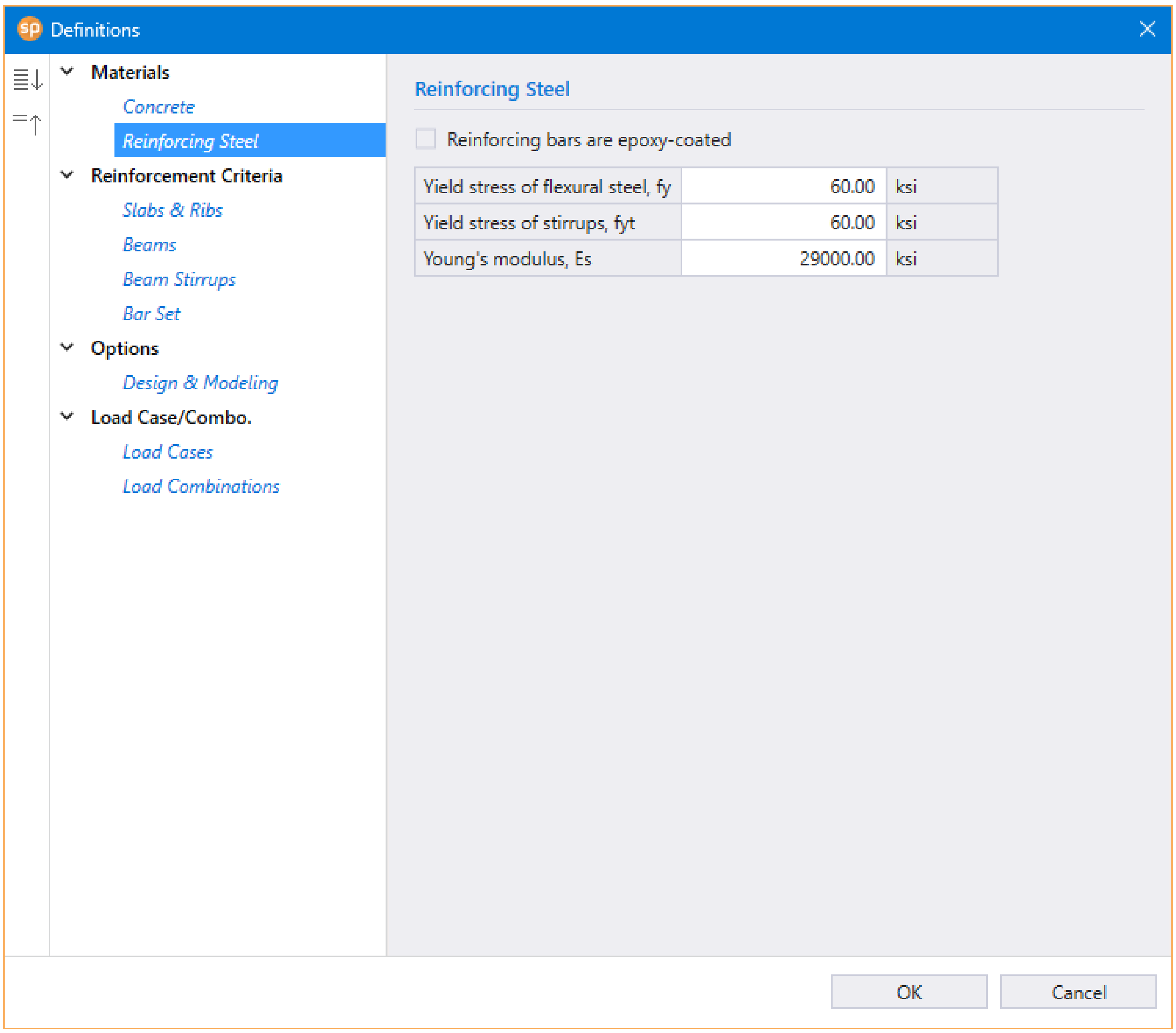
 UNIT DENSITY, Wc: `150.00` pcf



5. Click on **Reinforcing Steel** from **Materials** to display the **Reinforcing Steel** dialog box.

   - Enter the following:

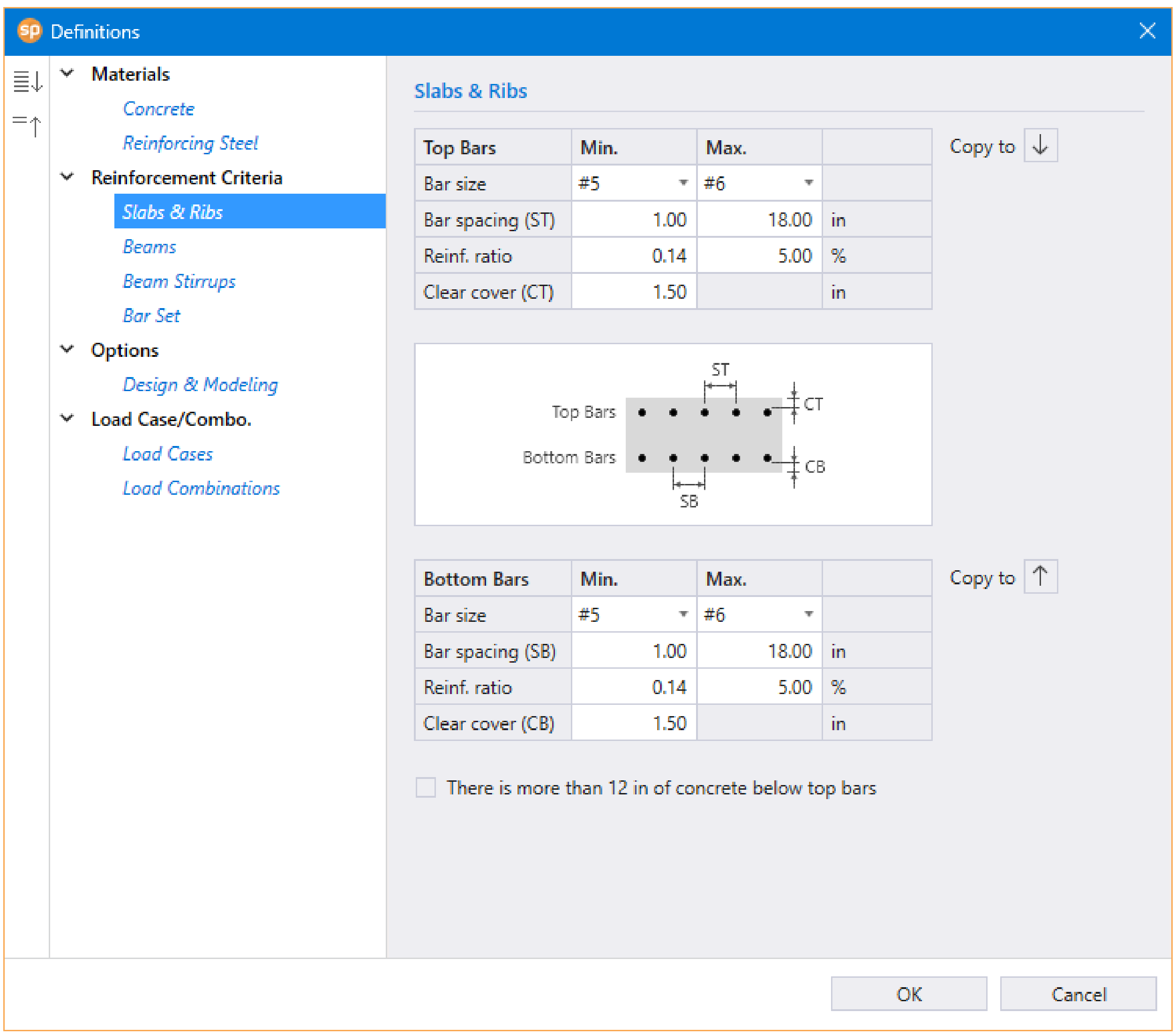
| | |
|---|---|
| YIELD STRESS OF FLEXURAL STEEL, fy: | 60.00 ksi |
| YIELD STRESS OF STIRRUP, fyt: | 60.00 ksi |
| YOUNG'S MODULUS, Es: | 29000.00 ksi |



6. Click on **Slabs & Ribs** from **Reinforcement Criteria** to display the **Slabs & Ribs** dialog box.

- Enter the following for TOP BARS and BOTTOM BARS:

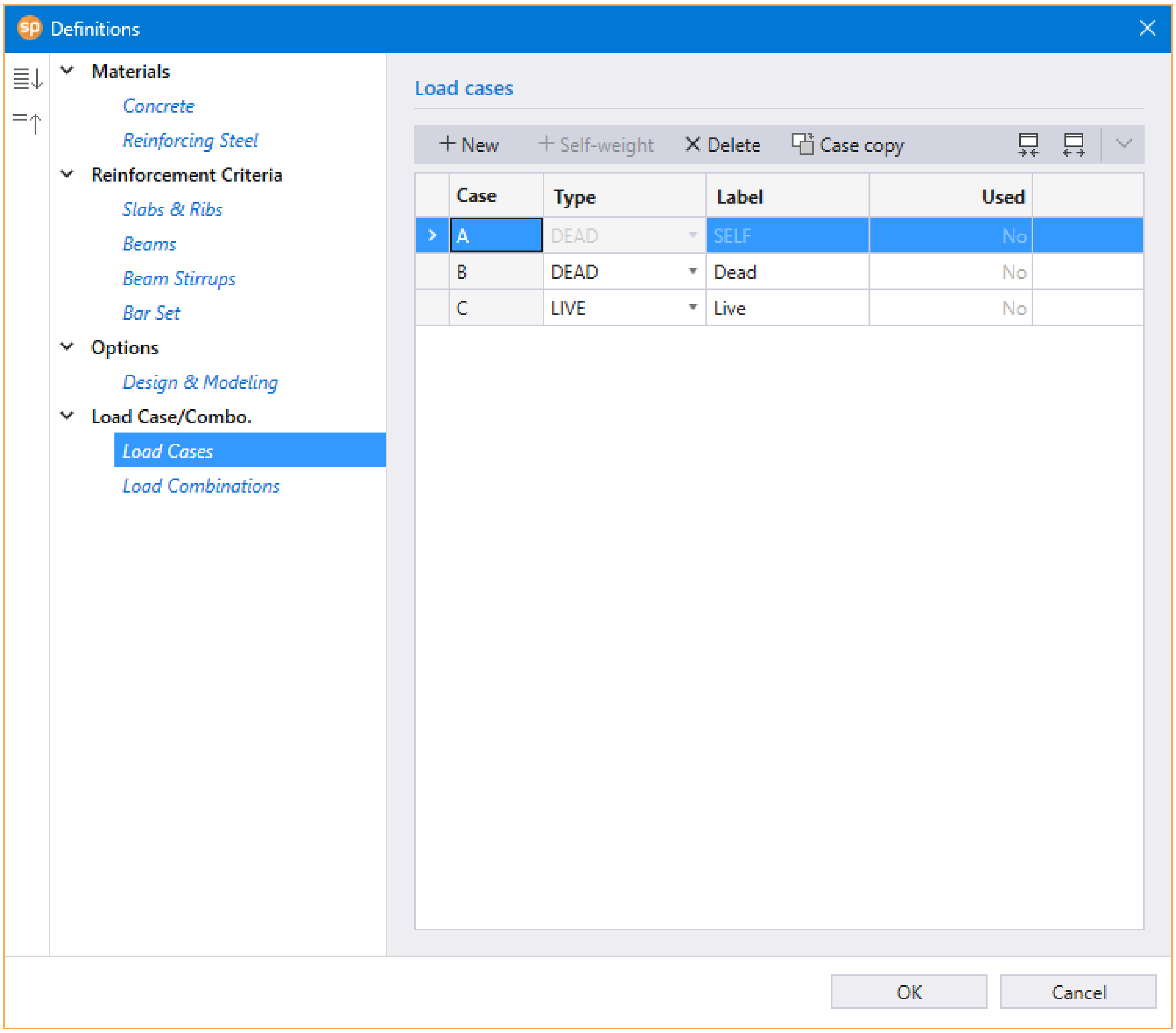
| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #5 | #6 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.50 in | |



7. Click on **Load Cases** from **Load Case/Combo.** to display the **Load Cases** dialog box.

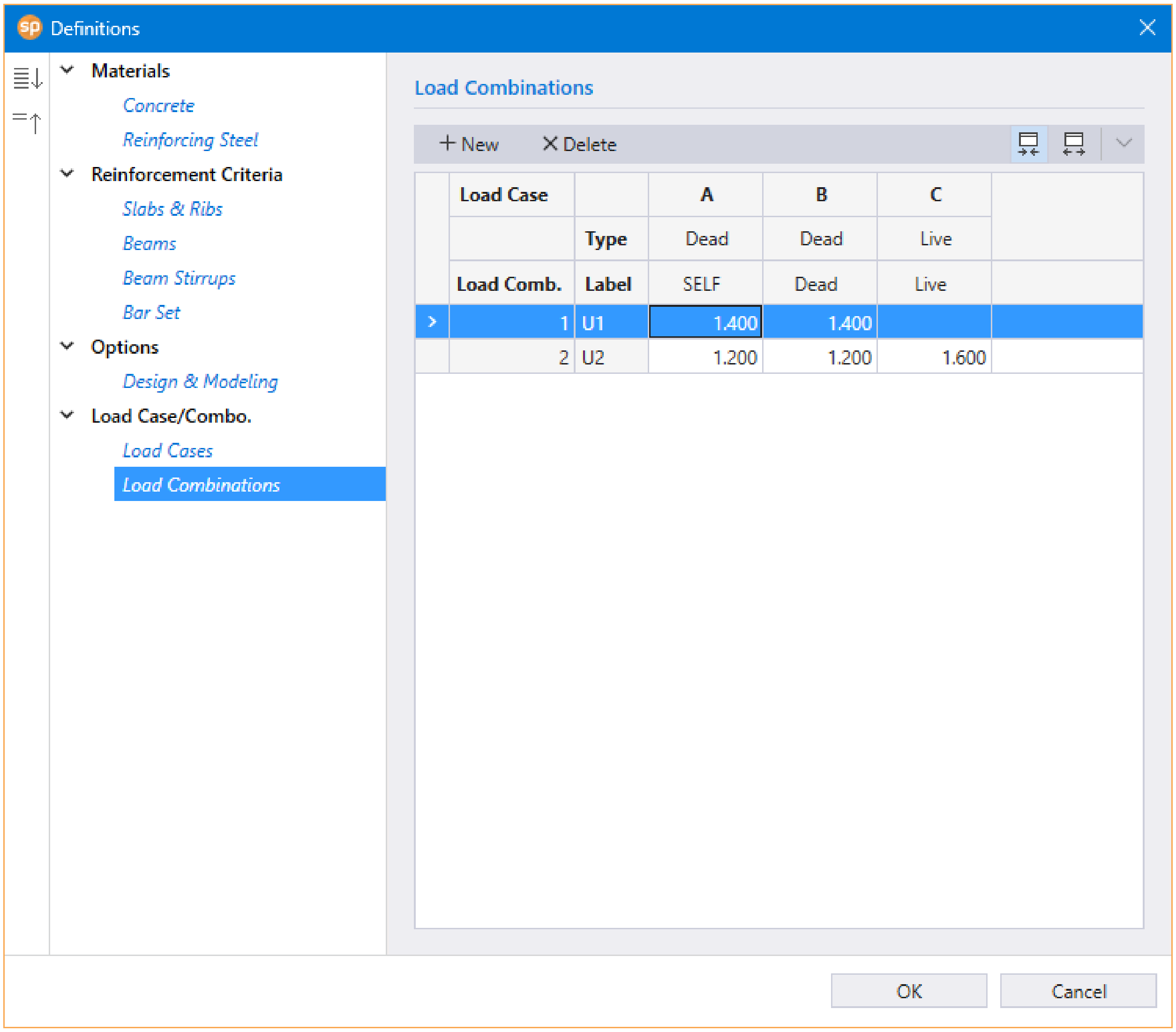
- Add SELF-WEIGHT for CASE A.
- Enter the following:

| | |
|---|---|
| CASE B: | `Dead` |
| CASE C: | `Live` |



8. Click on **Load Combinations** from **Load Case/Combo.** to display the **Load Combinations** dialog box.

   - Enter the following load combination shown in the figure below:



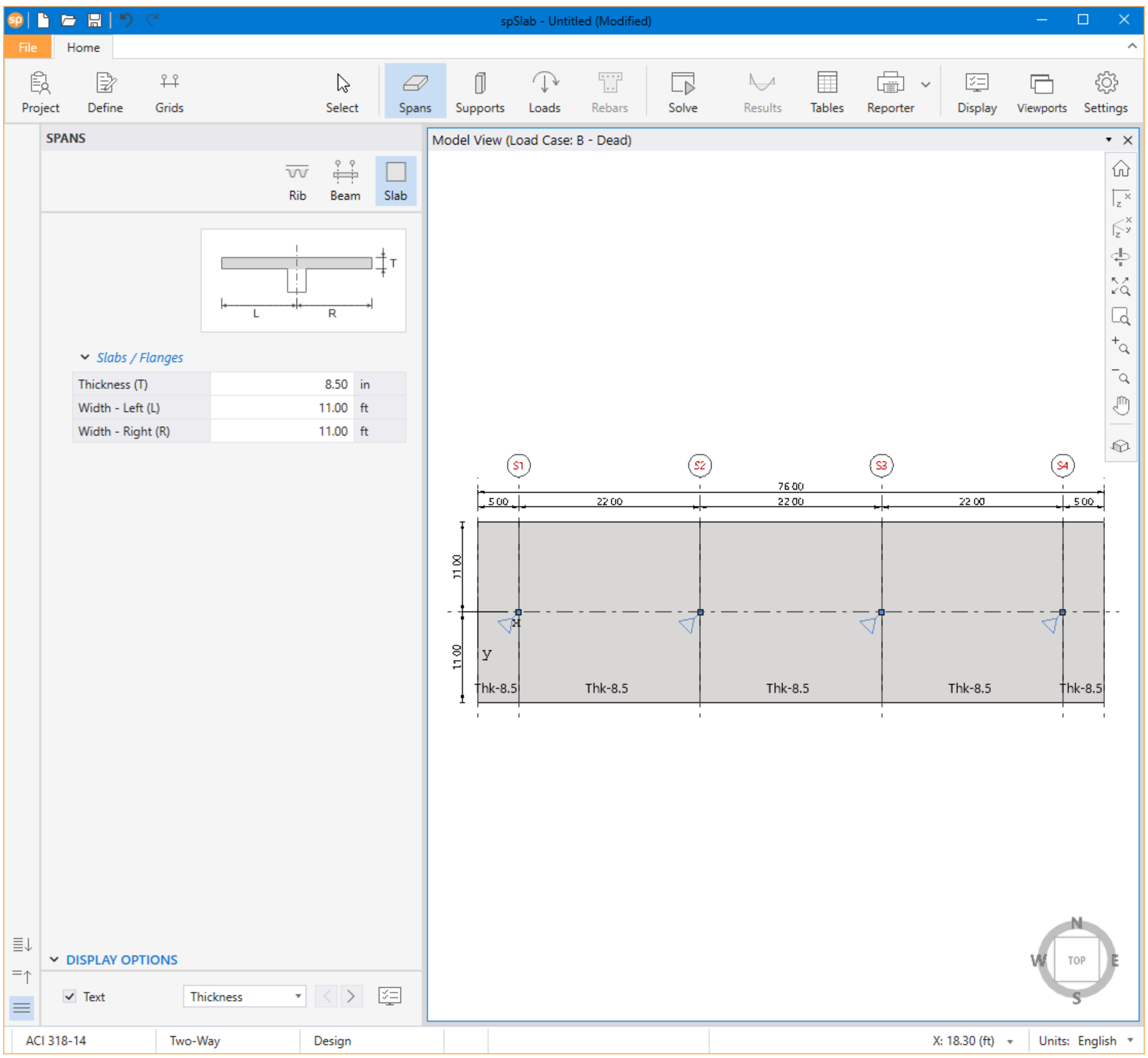
### 8.4.3. Assigning Spans

9. From the **Ribbon**, select **Spans** command.

- In the left panel, select **Slab** and enter the following:

| | |
|---|---|
| THICKNESS (T): | 8.50 in |
| WIDTH – LEFT (L): | 11.00 ft |
| WIDTH – RIGHT (R): | 11.00 ft |

- Apply to all spans as shown in the figure below.



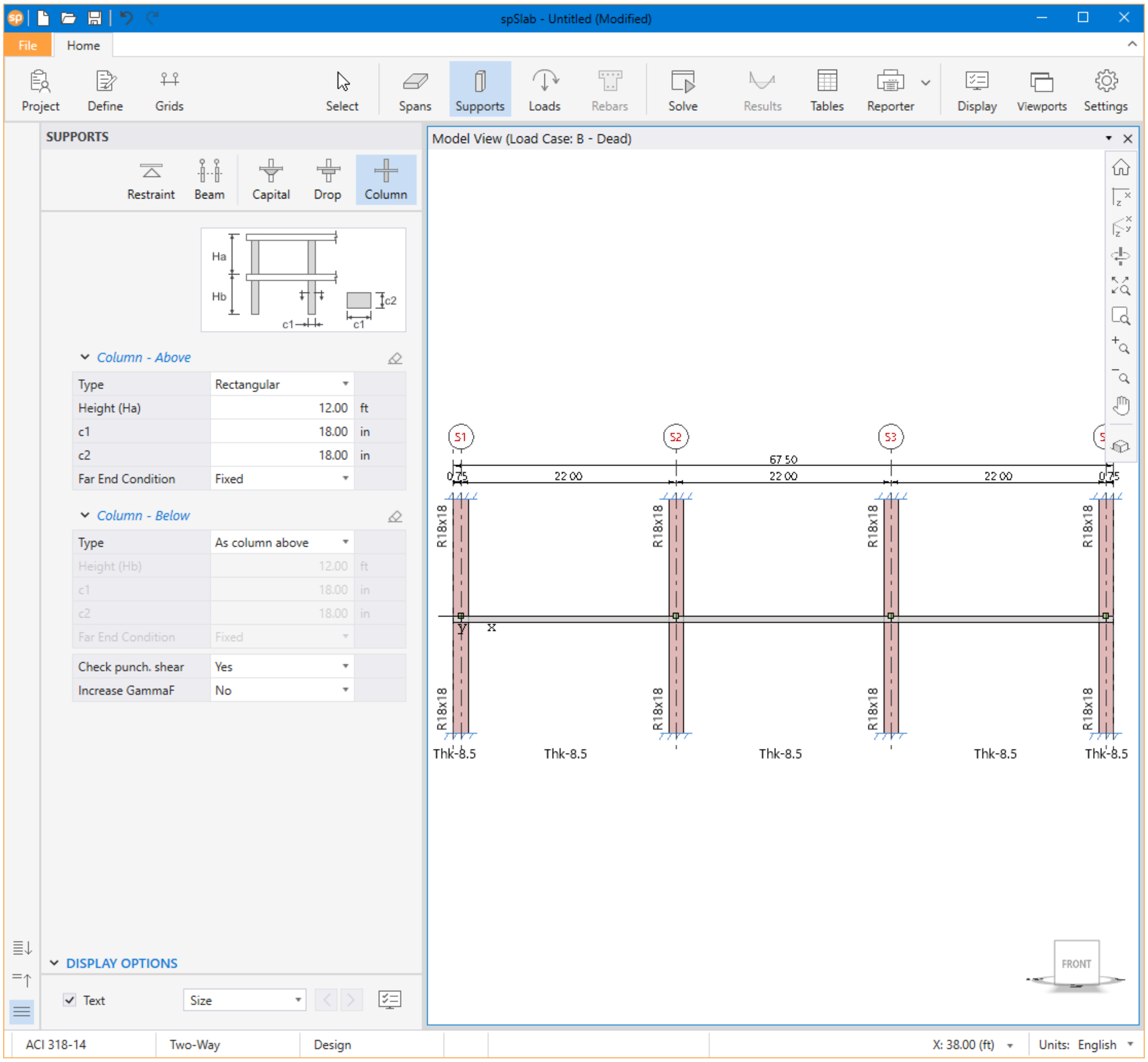
### 8.4.4. Assigning Supports

10. From the **Ribbon**, select **Supports** command.

- In the left panel, select **Column** and enter the following for COLUMN – ABOVE and COLUMN – BELOW:

| | |
|---|---|
| TYPE: | Rectangular |
| HEIGHT: | `12.00` ft |
| c1: | `18.00` in |
| c2: | `18.00` in |
| FAR END CONDITION: | Fixed |
| CHECK PUNCHING SHEAR: | Yes |
| INCREASE GAMMAF: | No |

- Apply to all supports as shown in the figure below.
- Notice how the cantilevers adjusted to the column faces when the exterior columns are assigned.



spSlab - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
SUPPORTS
Restraint
Beam
Capital
Drop
Column
Column - Above
Type
Rectangular
Height (Ha)
12.00
ft
c1
18.00
in
c2
18.00
in
Far End Condition
Fixed
Column - Below
Type
As column above
Height (Hb)
12.00
ft
c1
18.00
in
c2
18.00
in
Far End Condition
Fixed
Check punch. shear
Yes
Increase GammaF
No
DISPLAY OPTIONS
Text
Size
Model View (Load Case: B - Dead)
S1
S2
S3
67.50
22.00
22.00
22.00
R18x18
Thk-8.5
FRONT
ACI 318-14
Two-Way
Design
X: 38.00 (ft)
Units: English

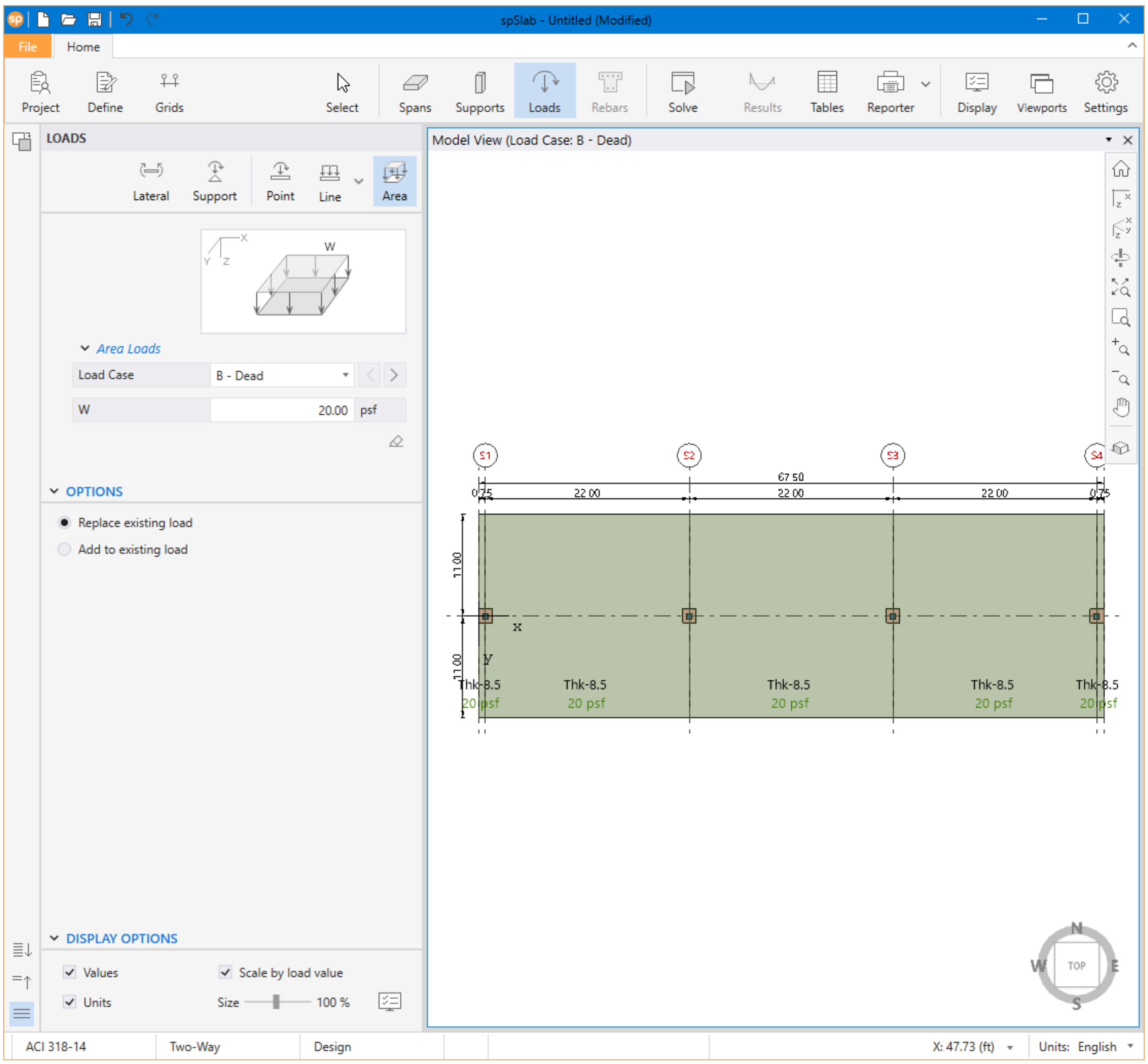
## 8.4.5. Assigning Loads

11. From the **Ribbon**, select **Loads** command.

- In the left panel, select **Area Load** then select B-DEAD from LOAD CASE and enter the following:

  w: 20.00 psf

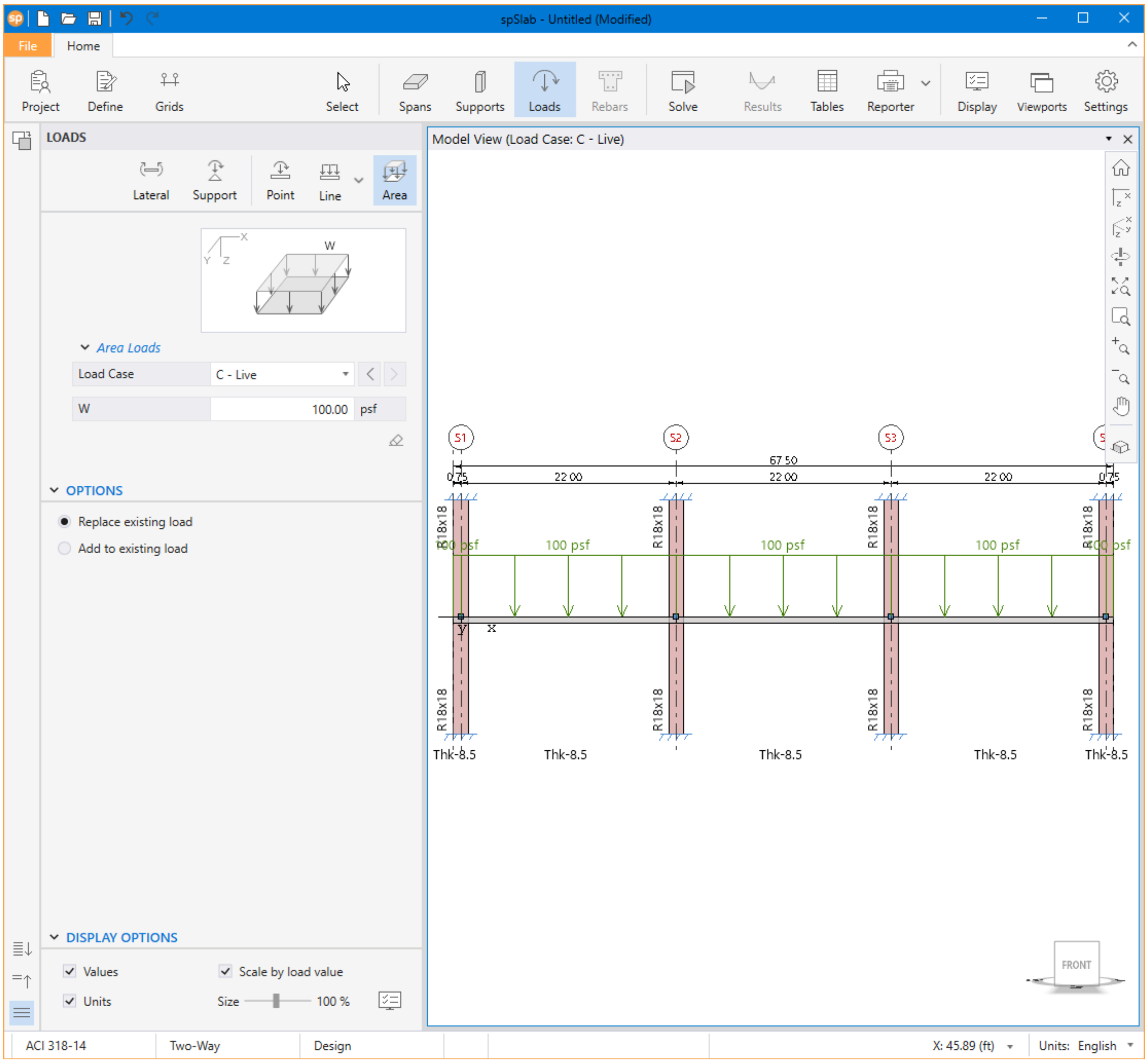
- Apply to all spans as shown in the figure below.



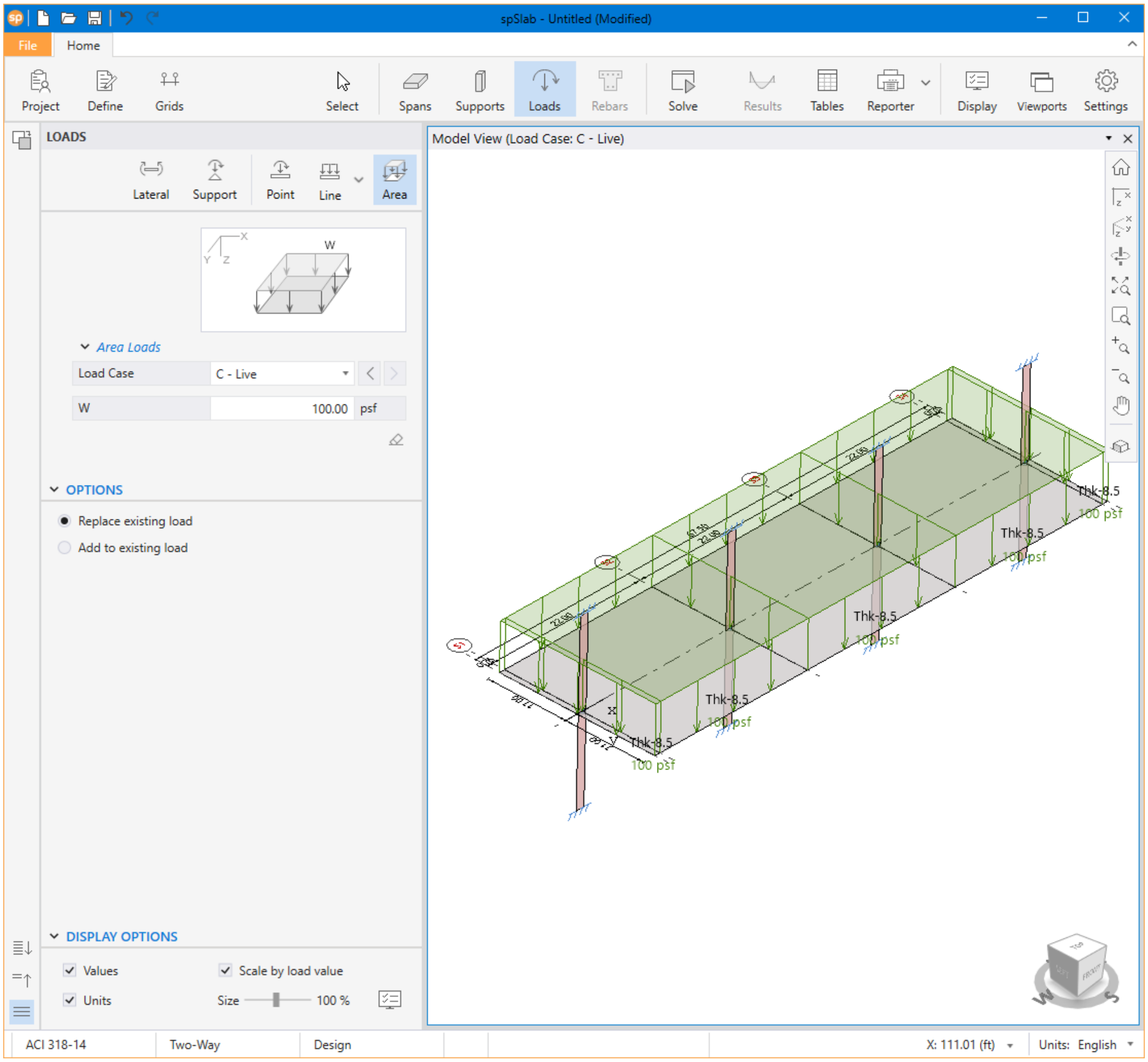
- Select C-LIVE from LOAD CASE and enter the following:

  w: 100.00 psf

- Apply to all spans as shown in the figure below.



- Also, you can click on the VIEW 3D icon from **View Controls** (top right of the active viewport) to get a better view of the applied loads.

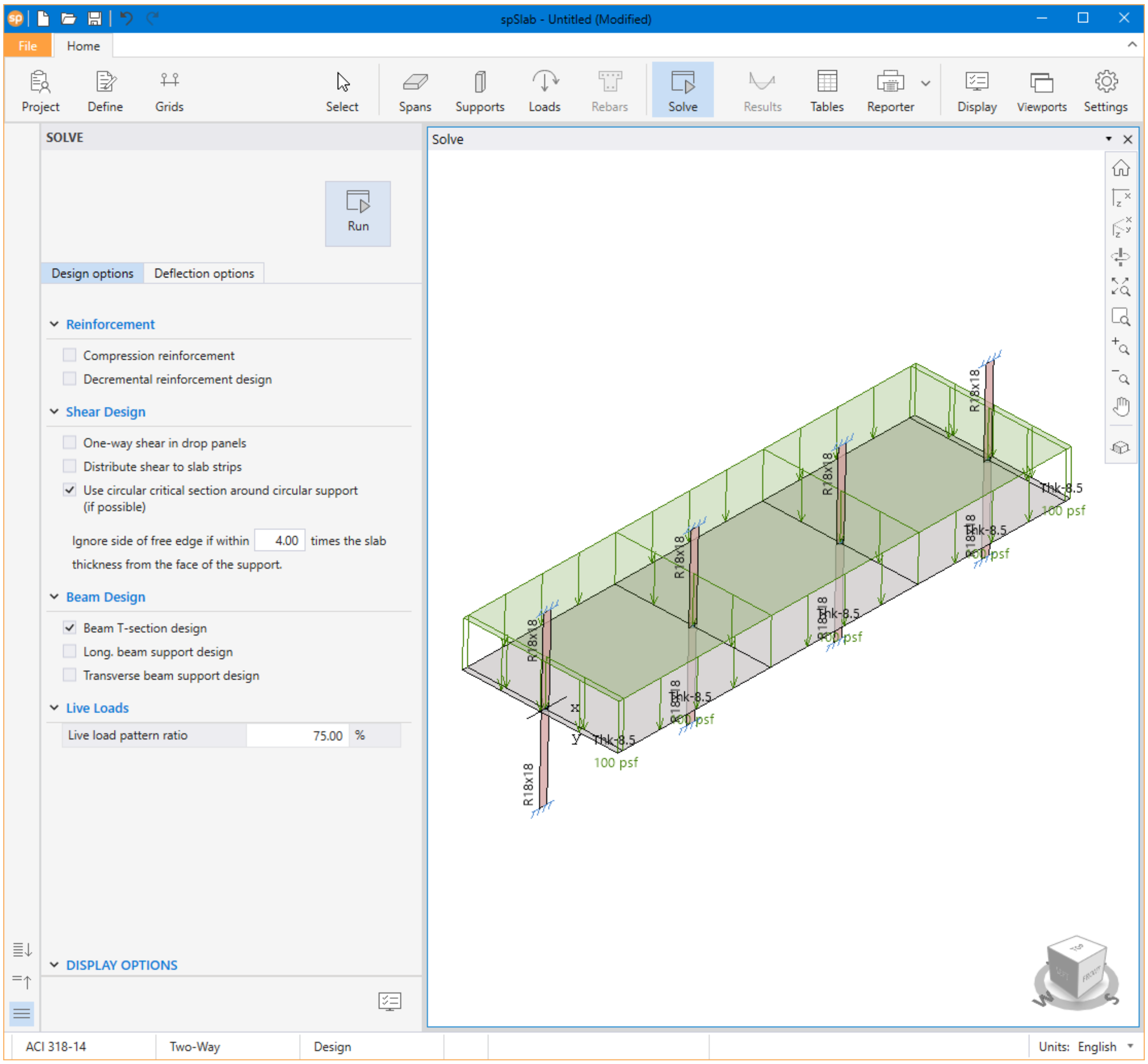


### 8.4.6. Solving

12. From the **Ribbon**, select **Solve** command.

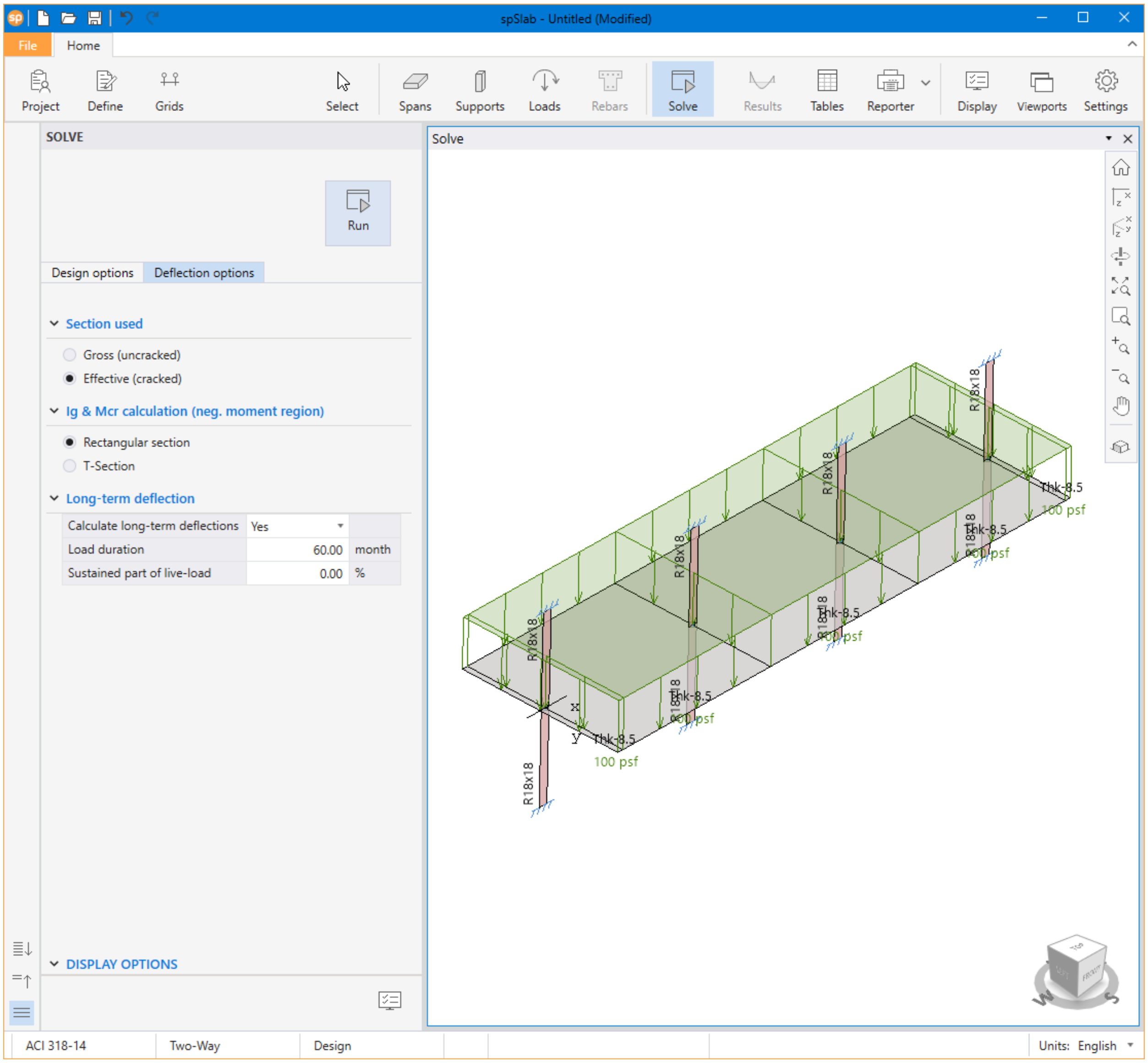
    For **Design Options**:

    - Uncheck DISTRIBUTE SHEAR TO SLAB STRIPS for SHEAR DESIGN section.
    - Leave all the other **Design Options** to their default settings.

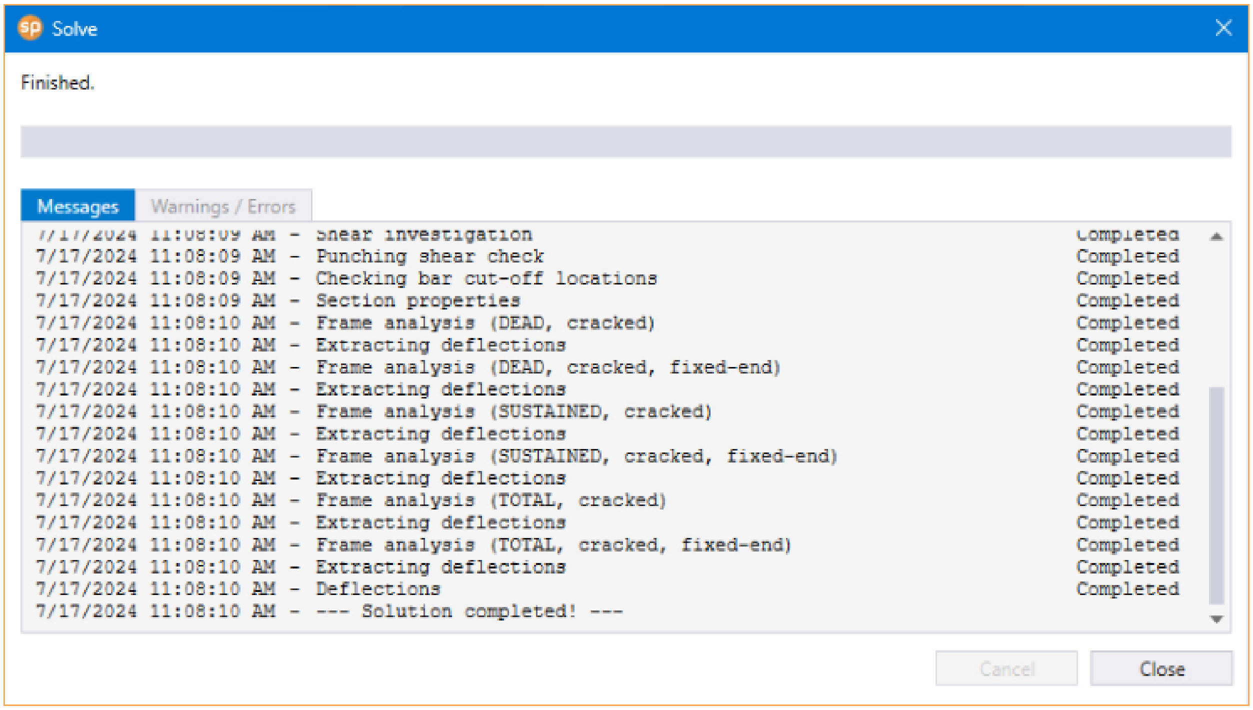


For **Deflection Options**:

- Leave all **Design Options** to their default settings.

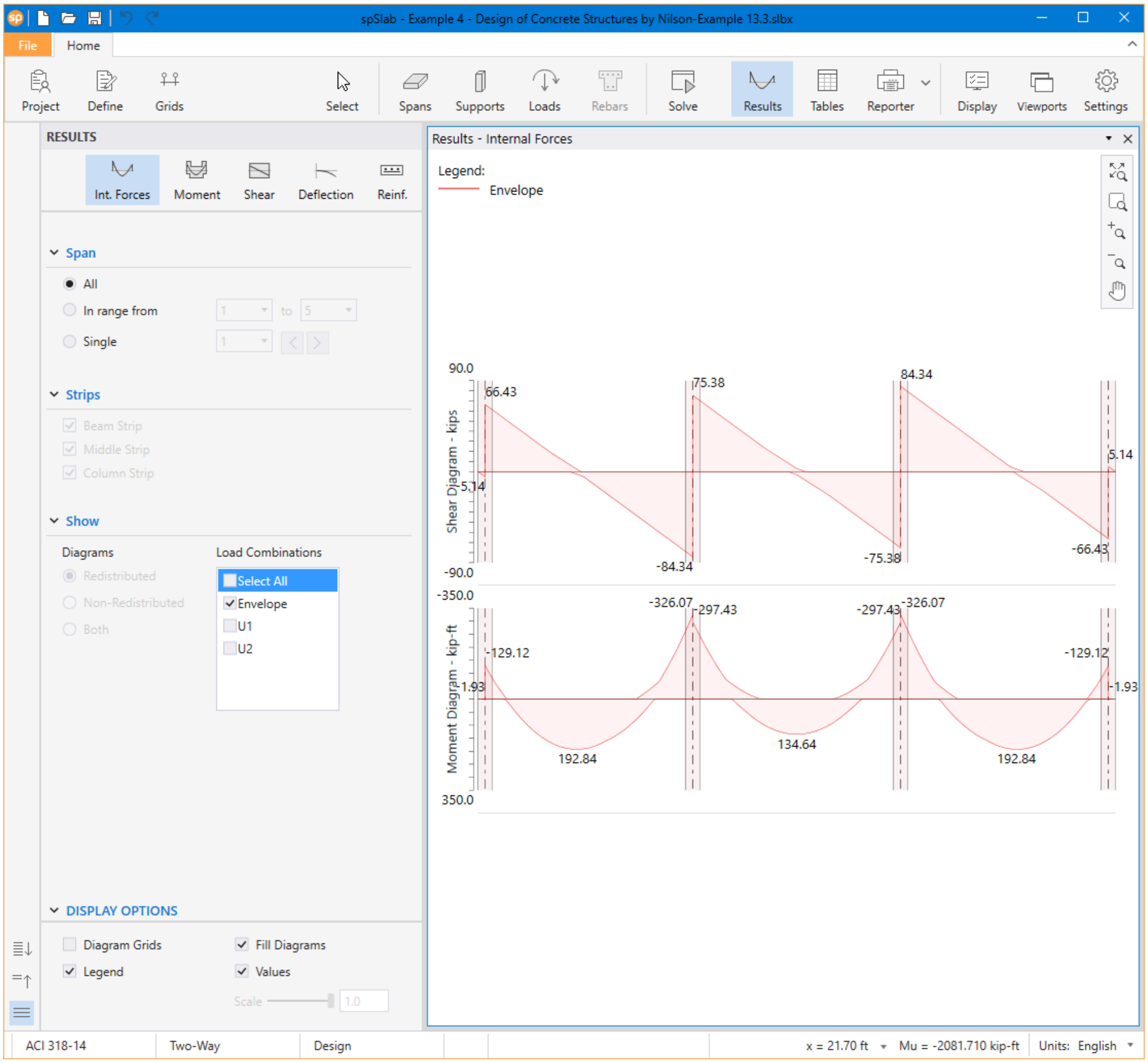


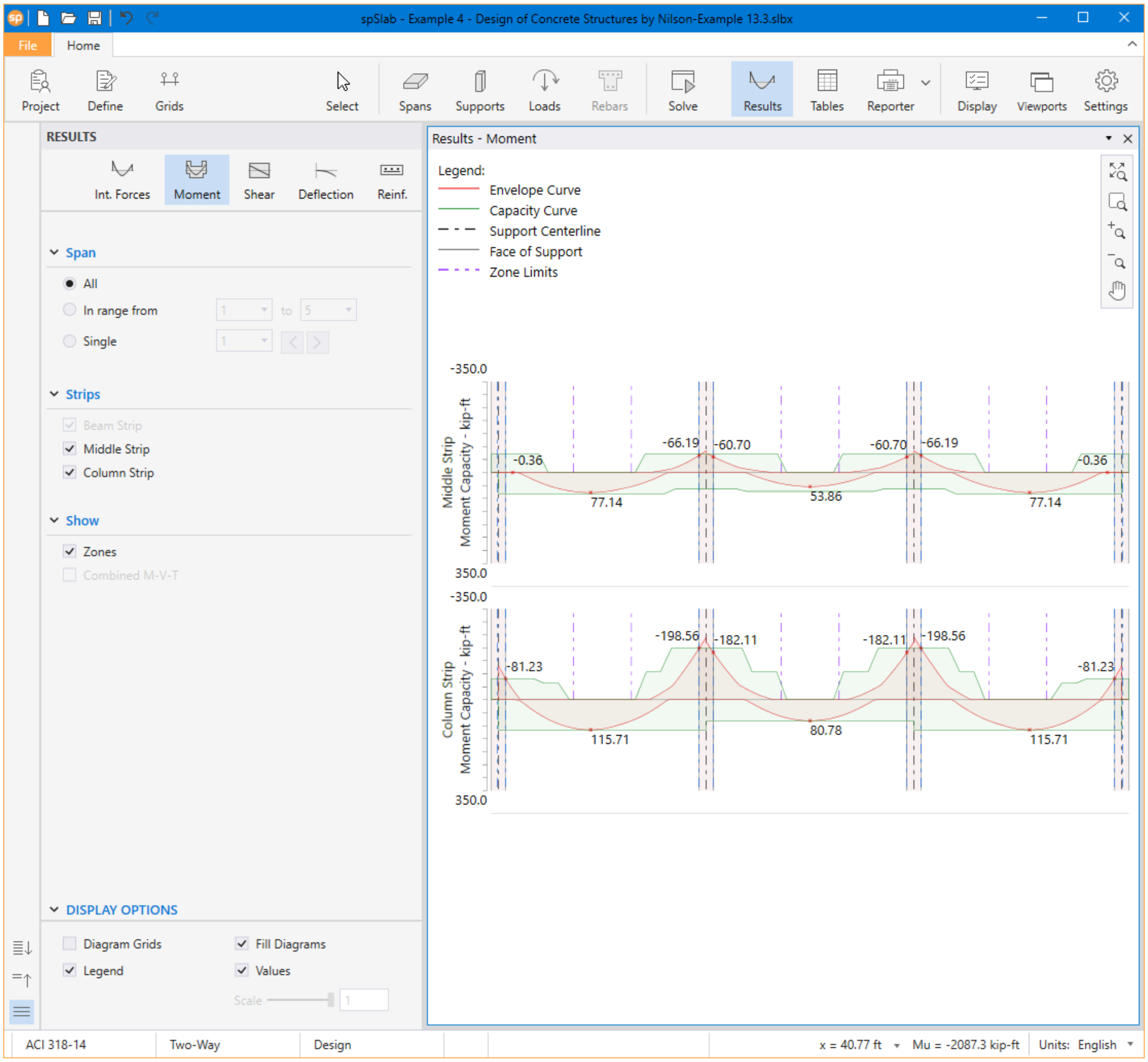
- Click on the **Run** button.
- The spSlab **Solver** window is displayed and the solver messages are listed. After the solution is done, the design will be performed and then the focus will immediately be passed to the **Results** scope.

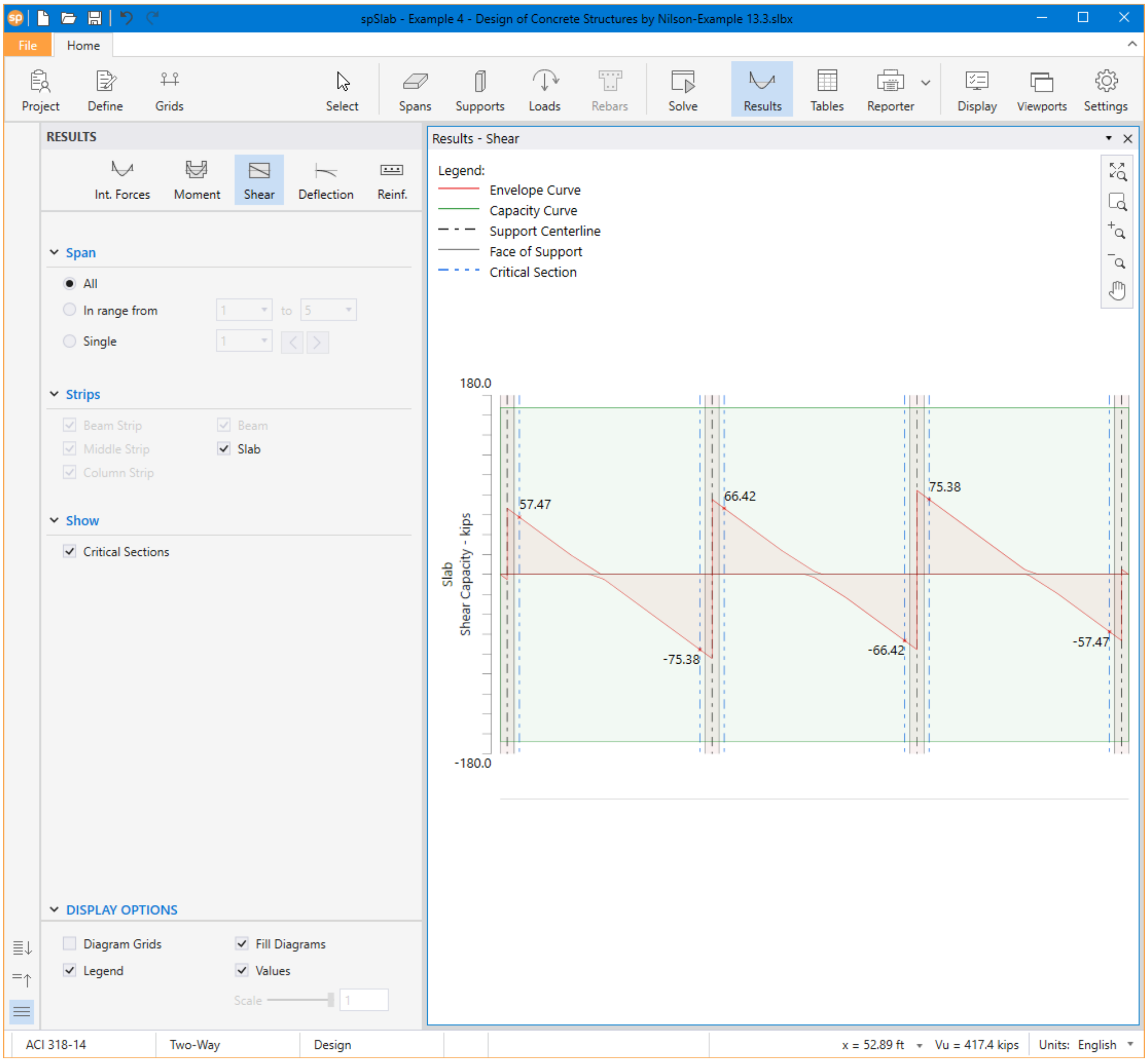


### 8.4.7. Viewing and Printing Results

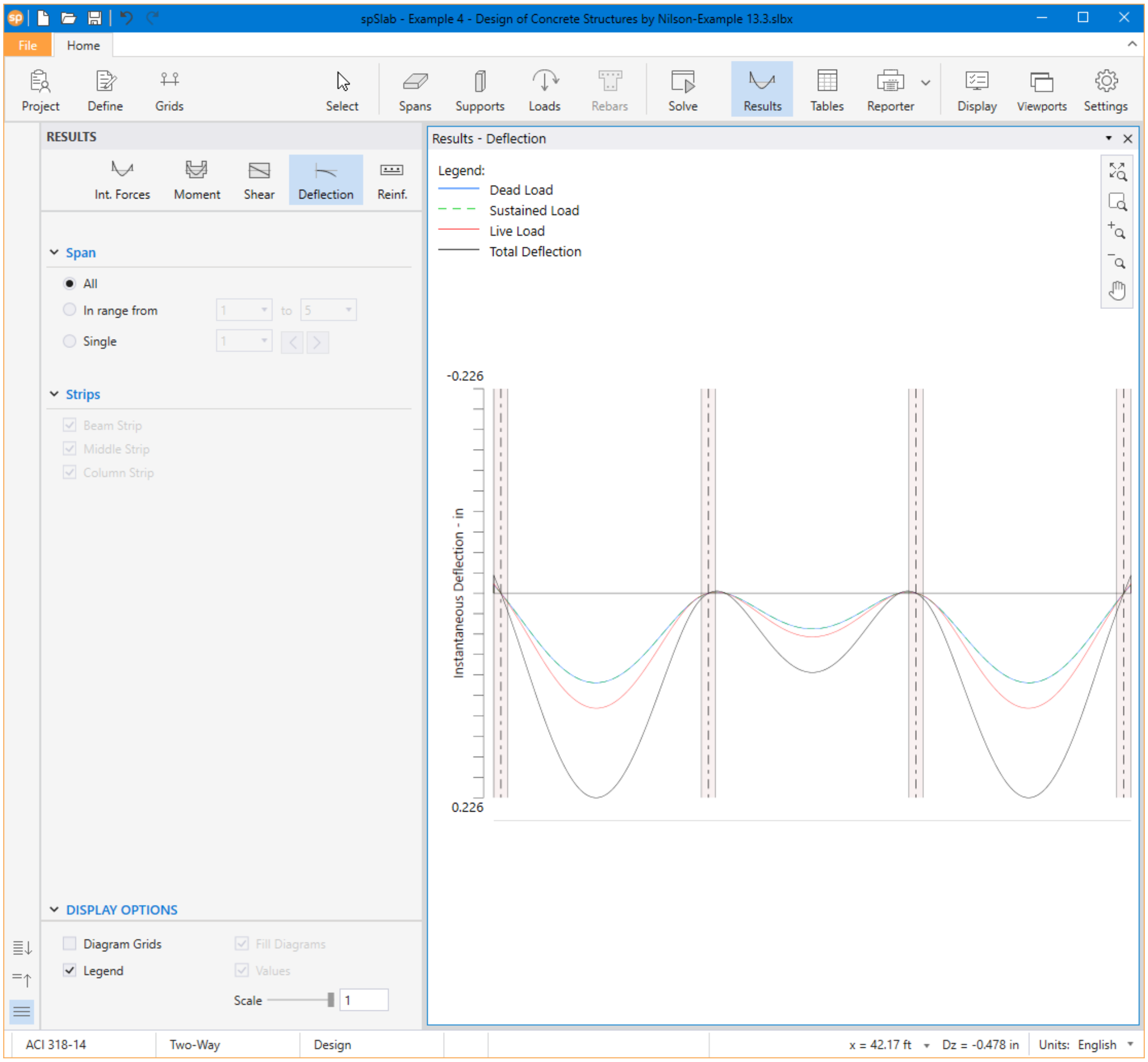
13. After a successful run, results can be viewed by selecting **Internal Forces**, **Moment Capacity**, **Shear Capacity**, **Deflection**, or **Reinforcement** from the left panel.

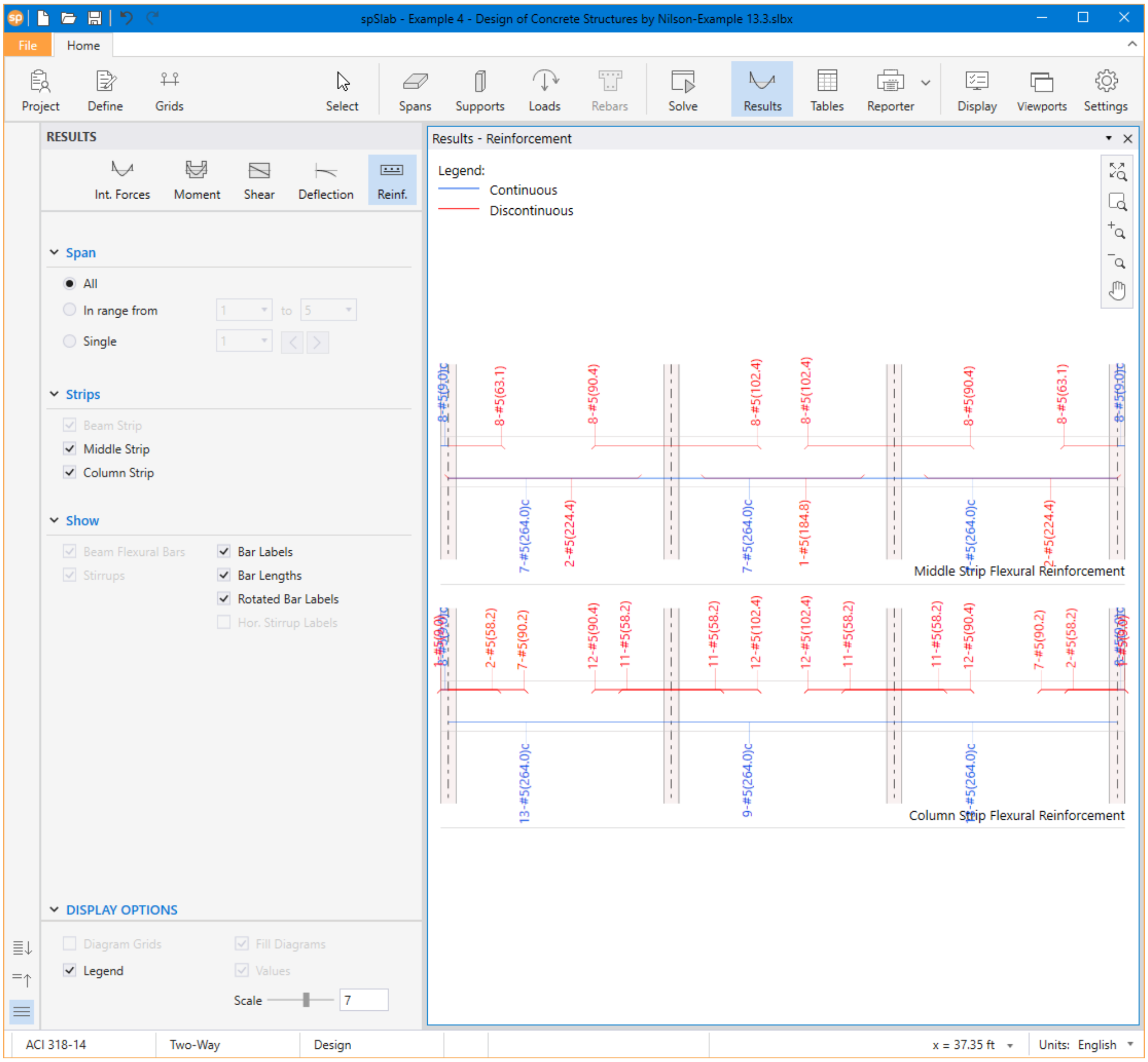



spSlab - Example 4 - Design of Concrete Structures by Nilson-Example 13.3.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
Show
Zones
Combined M-V-T
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Moment
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Zone Limits
Middle Strip Moment Capacity - kip-ft
-350.0
-0.36
-66.19
-60.70
-60.70
-66.19
-0.36
77.14
53.86
77.14
350.0
Column Strip Moment Capacity - kip-ft
-350.0
-81.23
-198.56
-182.11
-182.11
-198.56
-81.23
115.71
80.78
115.71
350.0
ACI 318-14
Two-Way
Design
x = 40.77 ft
Mu = -2087.3 kip-ft
Units: English

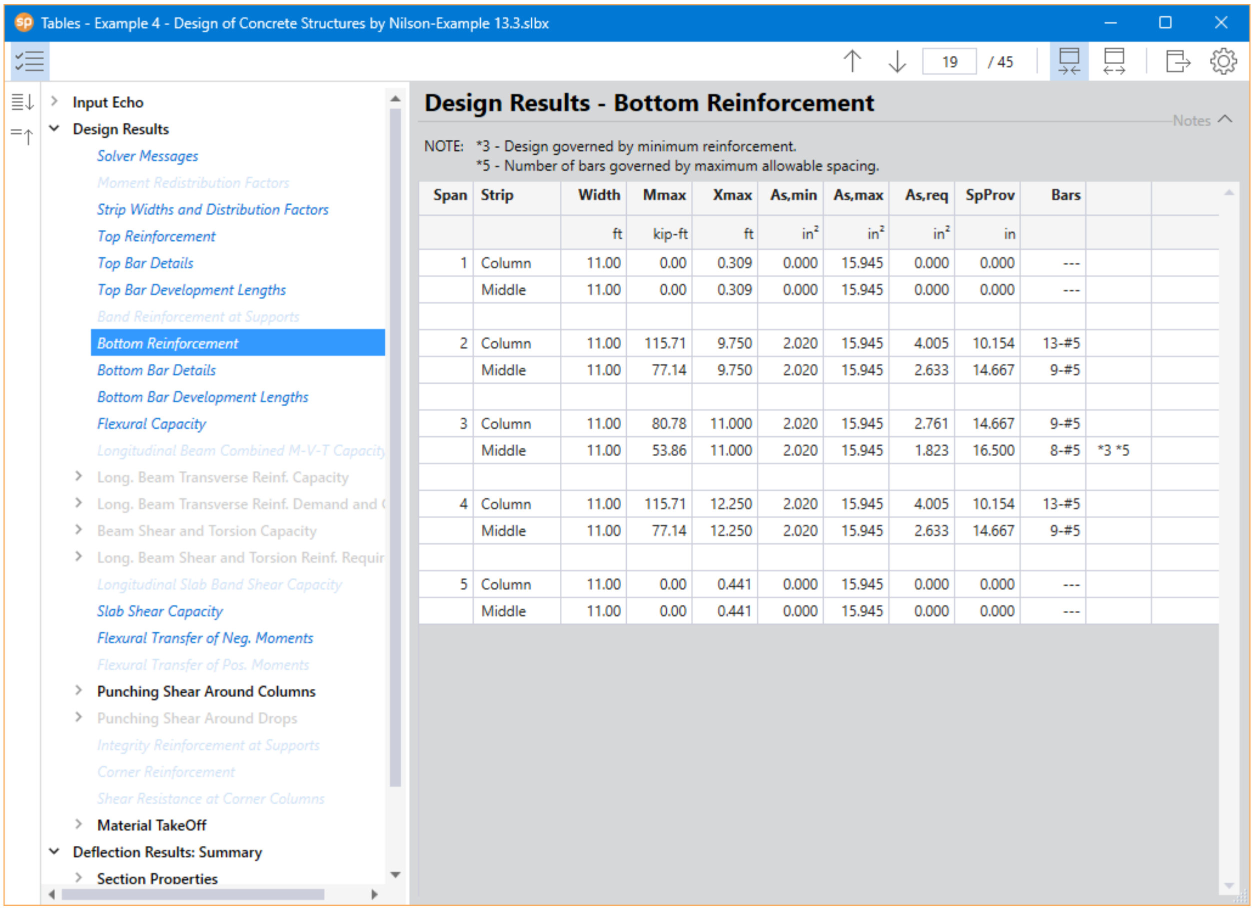


spSlab - Example 4 - Design of Concrete Structures by Nilson-Example 13.3.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Beam
Middle Strip
Slab
Column Strip
Show
Critical Sections
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Shear
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Critical Section
180.0
-180.0
Slab
Shear Capacity - kips
57.47
66.42
75.38
-75.38
-66.42
-57.47
ACI 318-14
Two-Way
Design
x = 52.89 ft
Vu = 417.4 kips
Units: English


spSlab - Example 4 - Design of Concrete Structures by Nilson-Example 13.3.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Deflection
Legend:
Dead Load
Sustained Load
Live Load
Total Deflection
-0.226
Instantaneous Deflection - in
0.226
ACI 318-14
Two-Way
Design
x = 42.17 ft
Dz = -0.478 in
Units: English

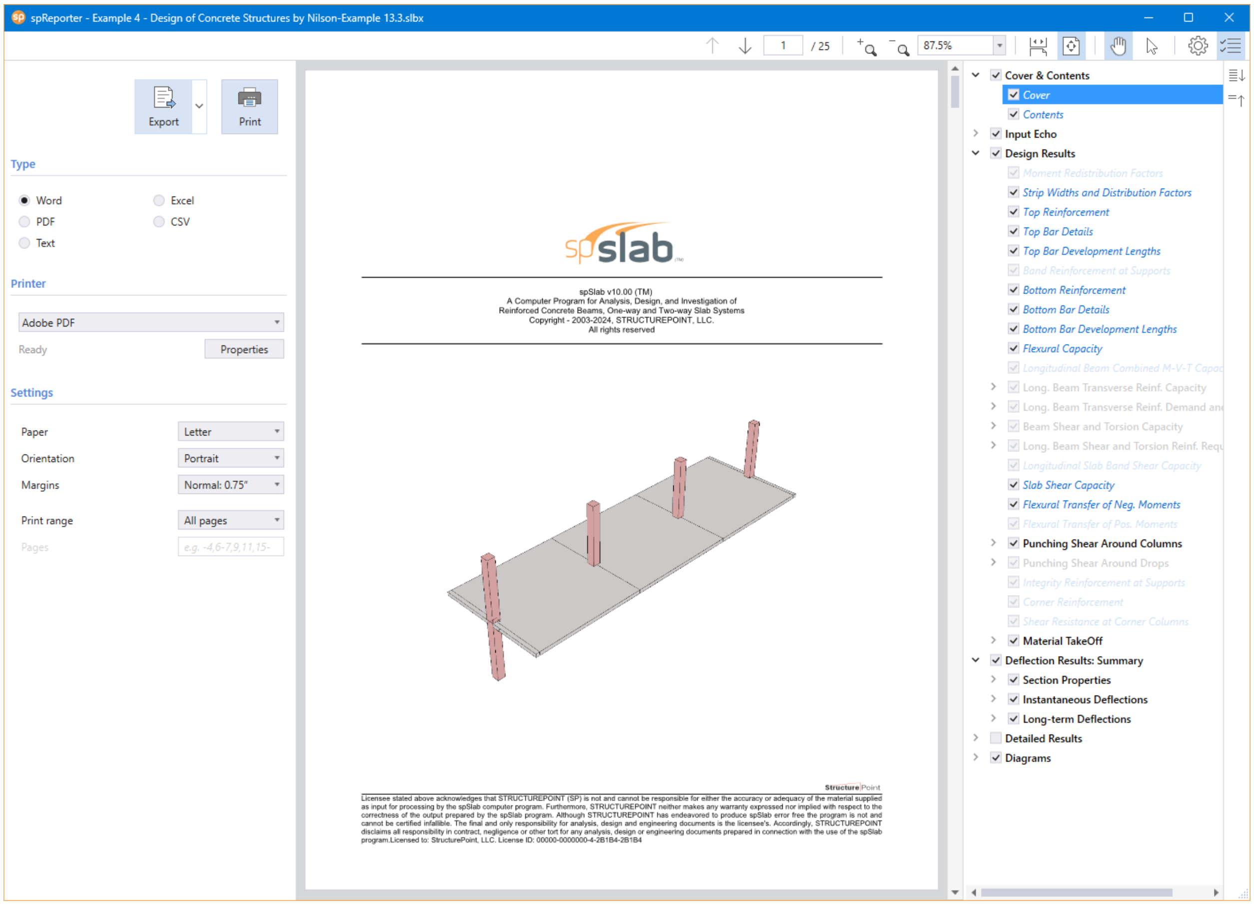

spSlab - Example 4 - Design of Concrete Structures by Nilson-Example 13.3.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
Show
Beam Flexural Bars
Stirrups
Bar Labels
Bar Lengths
Rotated Bar Labels
Hor. Stirrup Labels
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Reinforcement
Legend:
Continuous
Discontinuous
Middle Strip Flexural Reinforcement
Column Strip Flexural Reinforcement
ACI 318-14
Two-Way
Design
x = 37.35 ft
Units: English

14. Results can be also viewed in table format by selecting the **Tables** command from the **Ribbon**.




| Span | Strip | Width | Mmax | Xmax | As,min | As,max | As,req | SpProv | Bars | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ft | kip-ft | ft | in² | in² | in² | in | | |
| 1 | Column | 11.00 | 0.00 | 0.309 | 0.000 | 15.945 | 0.000 | 0.000 | --- | |
| | Middle | 11.00 | 0.00 | 0.309 | 0.000 | 15.945 | 0.000 | 0.000 | --- | |
| 2 | Column | 11.00 | 115.71 | 9.750 | 2.020 | 15.945 | 4.005 | 10.154 | 13-#5 | |
| | Middle | 11.00 | 77.14 | 9.750 | 2.020 | 15.945 | 2.633 | 14.667 | 9-#5 | |
| 3 | Column | 11.00 | 80.78 | 11.000 | 2.020 | 15.945 | 2.761 | 14.667 | 9-#5 | |
| | Middle | 11.00 | 53.86 | 11.000 | 2.020 | 15.945 | 1.823 | 16.500 | 8-#5 | *3 *5 |
| 4 | Column | 11.00 | 115.71 | 12.250 | 2.020 | 15.945 | 4.005 | 10.154 | 13-#5 | |
| | Middle | 11.00 | 77.14 | 12.250 | 2.020 | 15.945 | 2.633 | 14.667 | 9-#5 | |
| 5 | Column | 11.00 | 0.00 | 0.441 | 0.000 | 15.945 | 0.000 | 0.000 | --- | |
| | Middle | 11.00 | 0.00 | 0.441 | 0.000 | 15.945 | 0.000 | 0.000 | --- | |

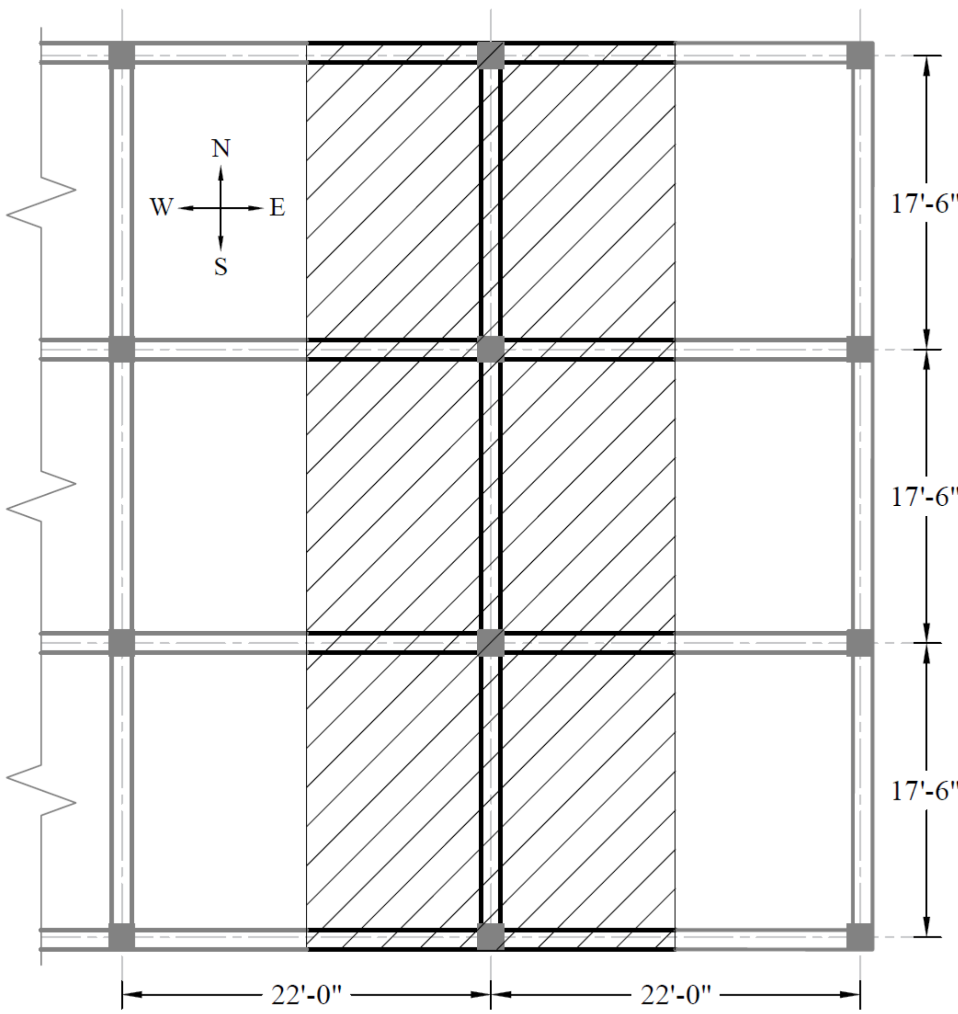
15. Results can be printed or exported in different formats by selecting the **Reporter** command from the **Ribbon.**



# 8.5. Example 5 – Two-way Slab System

## 8.5.1. Problem Formulation

Using the Equivalent Frame Method, determine design moments for the slab system in the direction shown, for an intermediate floor.[2]




2 *Notes on ACI 318-11 Building Code Requirements for Structural Concrete*, Twelfth Edition, 2013 Portland Cement Association, Example 20-2

**Design data**

Dead load = Self-weight

Service live load = 100 psf

$f_c'$ = 4,000 psi (for all members), normal weight concrete

$f_y$ = 60,000 psi

Column dimensions = 18 × 18 in.

Story height = 12 ft

Edge beam dimensions = 14 × 27 in.

Interior beam dimensions = 14 × 20 in.

### 8.5.2. Preparing the Input

1. From the Start screen, select **New Project**.

2. From the Main Program Window, select **Project** from the **Ribbon**.

- In the **General** section, select the DESIGN CODE, UNIT SYSTEM, and BAR SET.

- In the **Materials** section, input the following:

  f'c (SLABS & BEAMS): `4.00` ksi

  f'c (COLUMNS): `4.00` ksi

  fy: `60.00` ksi

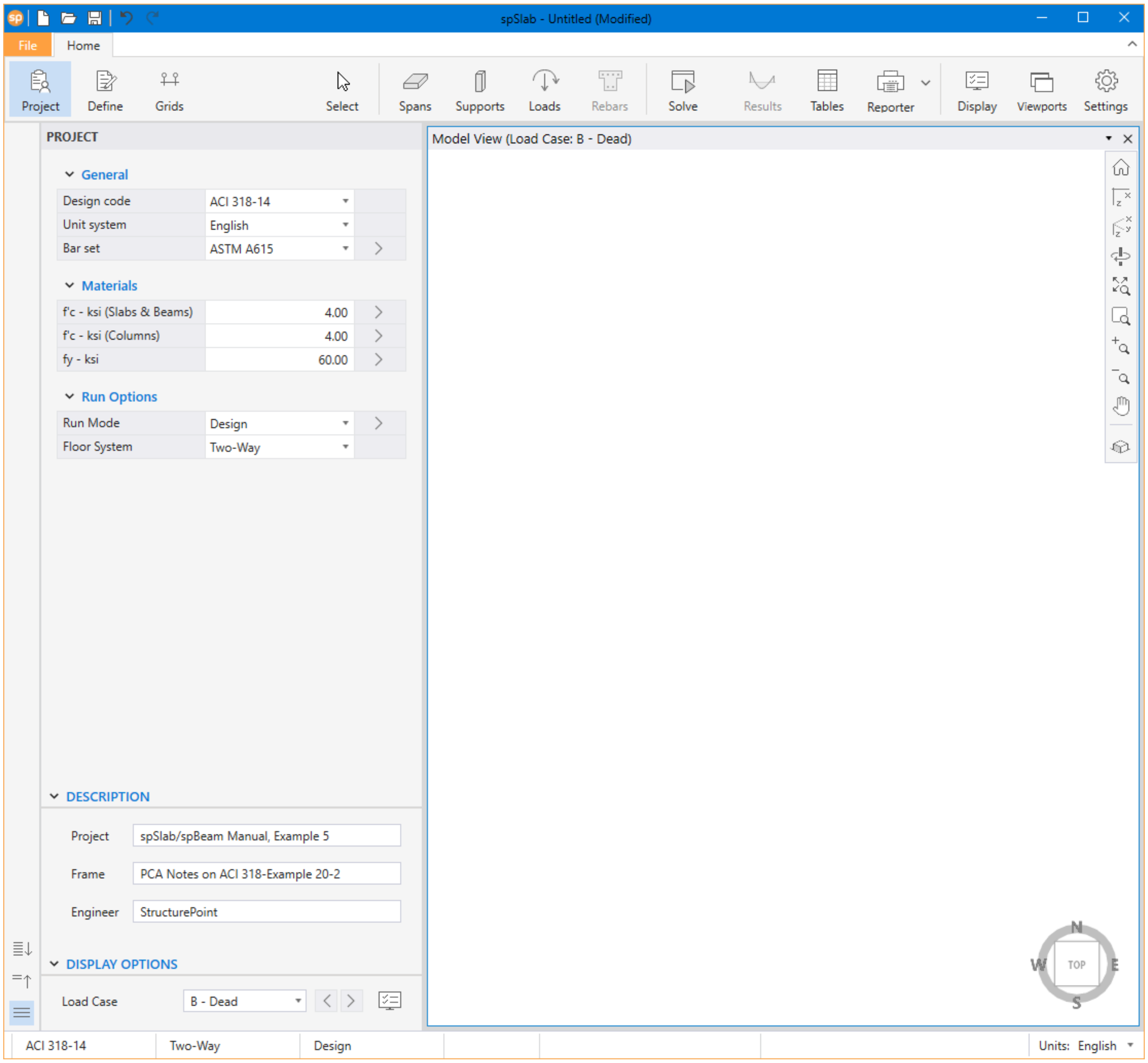
  Alternatively, detailed material properties for **Concrete** and **Reinforcement Steel** can be entered using **Definitions** dialog box (see Steps 4 and 5).

- In the **Run Options** section, select the following:

  RUN MODE: Design

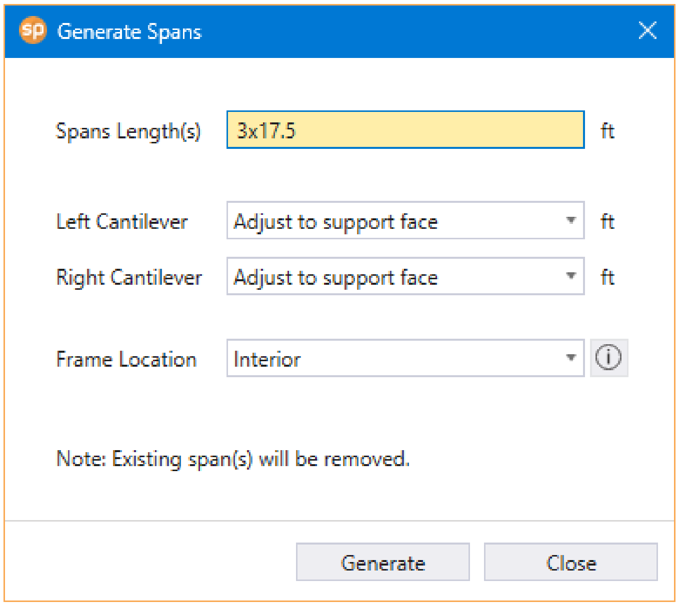
  FLOOR SYSTEM: Two-Way

- In the **Description** section, enter the PROJECT, FRAME, and ENGINEER.


spSlab - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
PROJECT
General
Design code
ACI 318-14
Unit system
English
Bar set
ASTM A615
Materials
f'c - ksi (Slabs & Beams)
4.00
f'c - ksi (Columns)
4.00
fy - ksi
60.00
Run Options
Run Mode
Design
Floor System
Two-Way
DESCRIPTION
Project
spSlab/spBeam Manual, Example 5
Frame
PCA Notes on ACI 318-Example 20-2
Engineer
StructurePoint
DISPLAY OPTIONS
Load Case
B - Dead
Model View (Load Case: B - Dead)
N
W
TOP
E
S
ACI 318-14
Two-Way
Design
Units: English

3. From the **Ribbon**, select **Grids**.

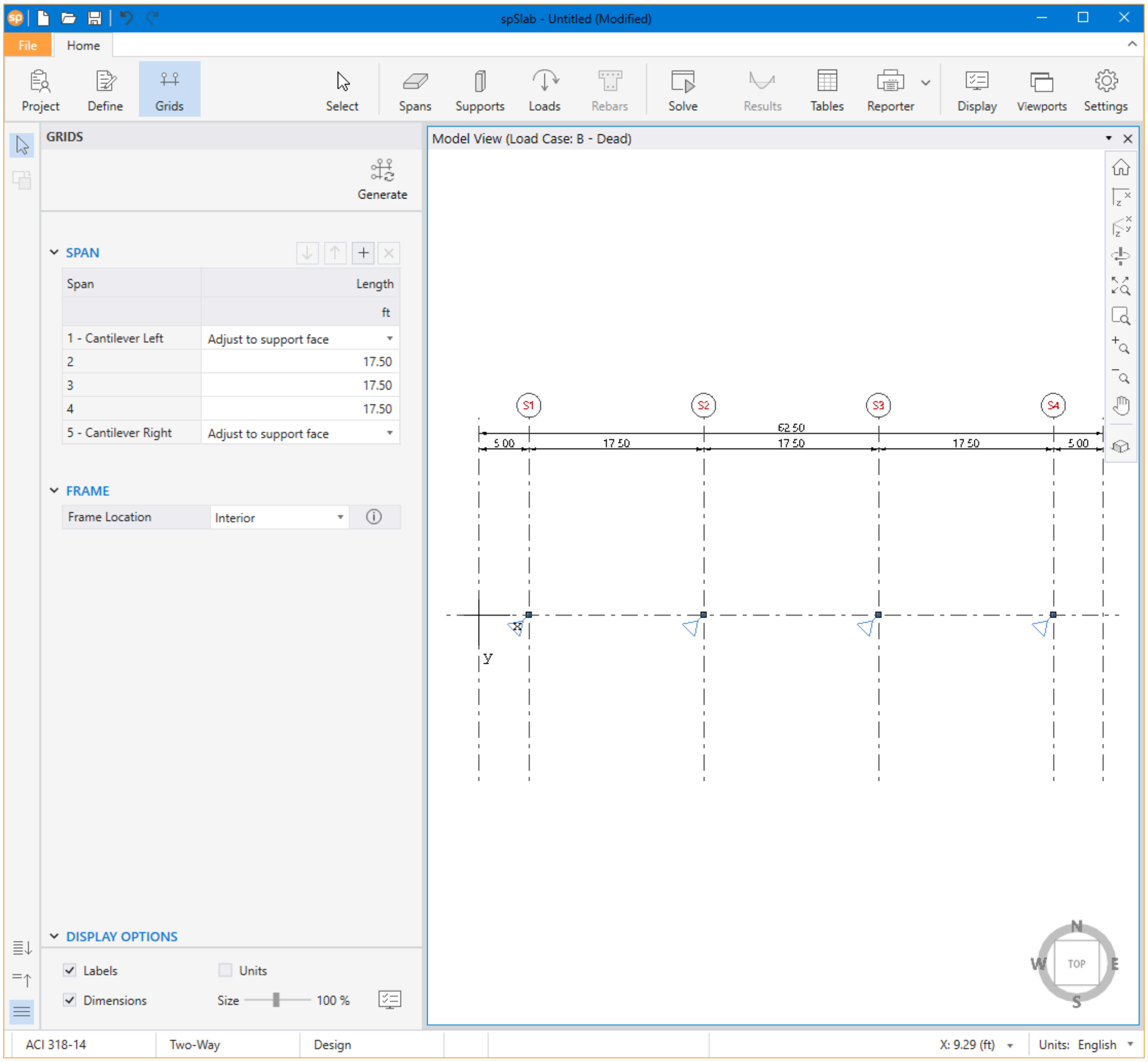
- Click on the **Generate** in the left panel to have the program surface the following:




- Enter the following values in the corresponding text boxes:

| | |
|---|---|
| SPANS LENGTH(S): | `3x17.5` |
| LEFT CANTILEVER: | Adjusted to support face |
| RIGHT CANTILEVER: | Adjusted to support face |
| FRAME LOCATION: | Interior |

- Click on the GENERATE button to return to the main window. Notice how the grid lines now appear in the VIEWPORT.

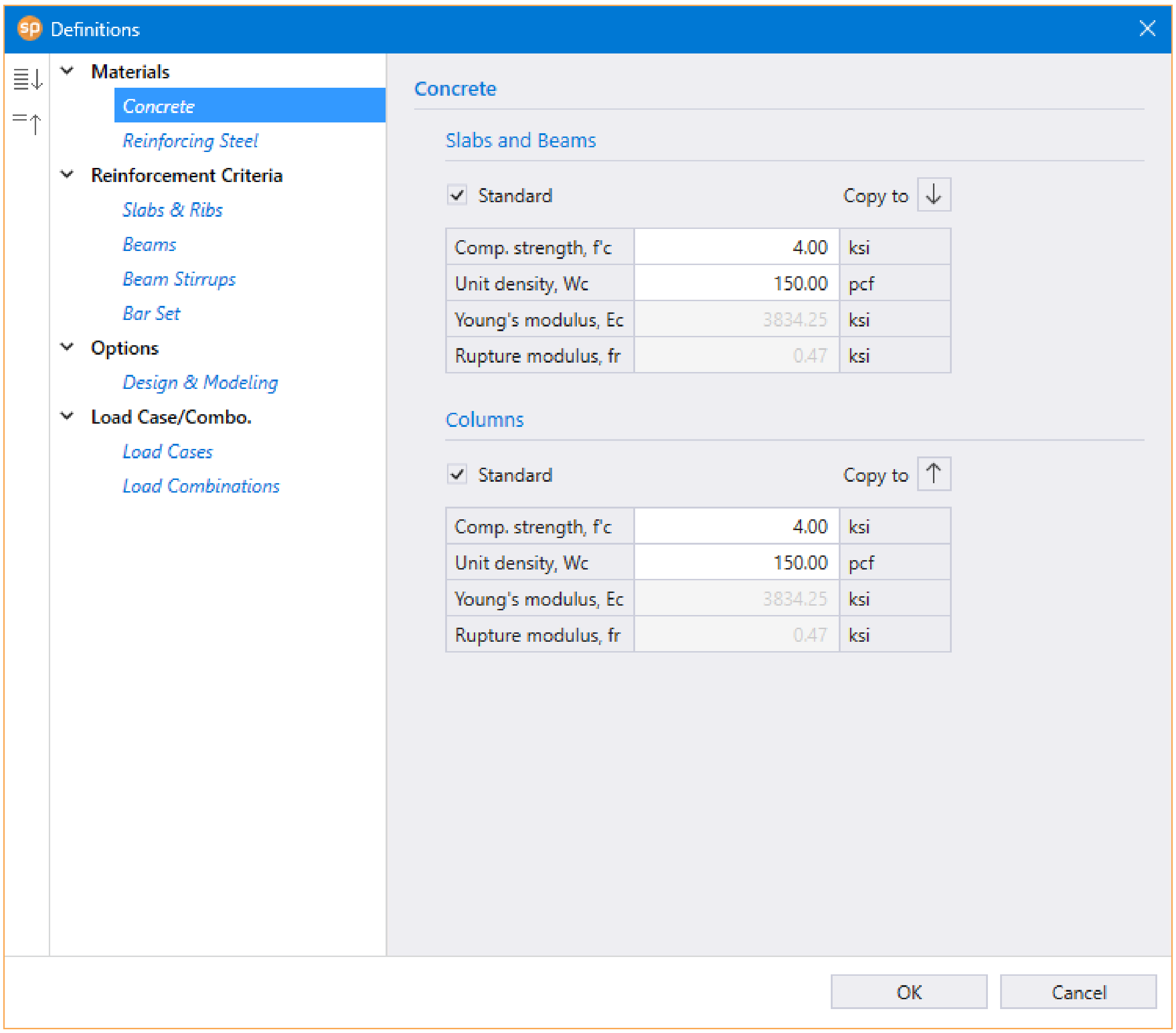

spSlab - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
GRIDS
Generate
SPAN
Span
Length
ft
1 - Cantilever Left
Adjust to support face
2
17.50
3
17.50
4
17.50
5 - Cantilever Right
Adjust to support face
FRAME
Frame Location
Interior
DISPLAY OPTIONS
Labels
Units
Dimensions
Size
100 %
Model View (Load Case: B - Dead)
S1
S2
S3
S4
62.50
5.00
17.50
17.50
17.50
5.00
N
W
TOP
E
S
ACI 318-14
Two-Way
Design
X: 9.29 (ft)
Units: English

4. From the **Ribbon**, select **Define,** then choose **Concrete** from **Materials** to display the **Concrete** dialog box.

   - Check STANDARD for SLABS AND BEAMS and COLUMNS.
   - Enter the following for SLABS AND BEAMS and COLUMNS:

   COMPRESSIVE STRENGTH, f'c: `4.00` ksi

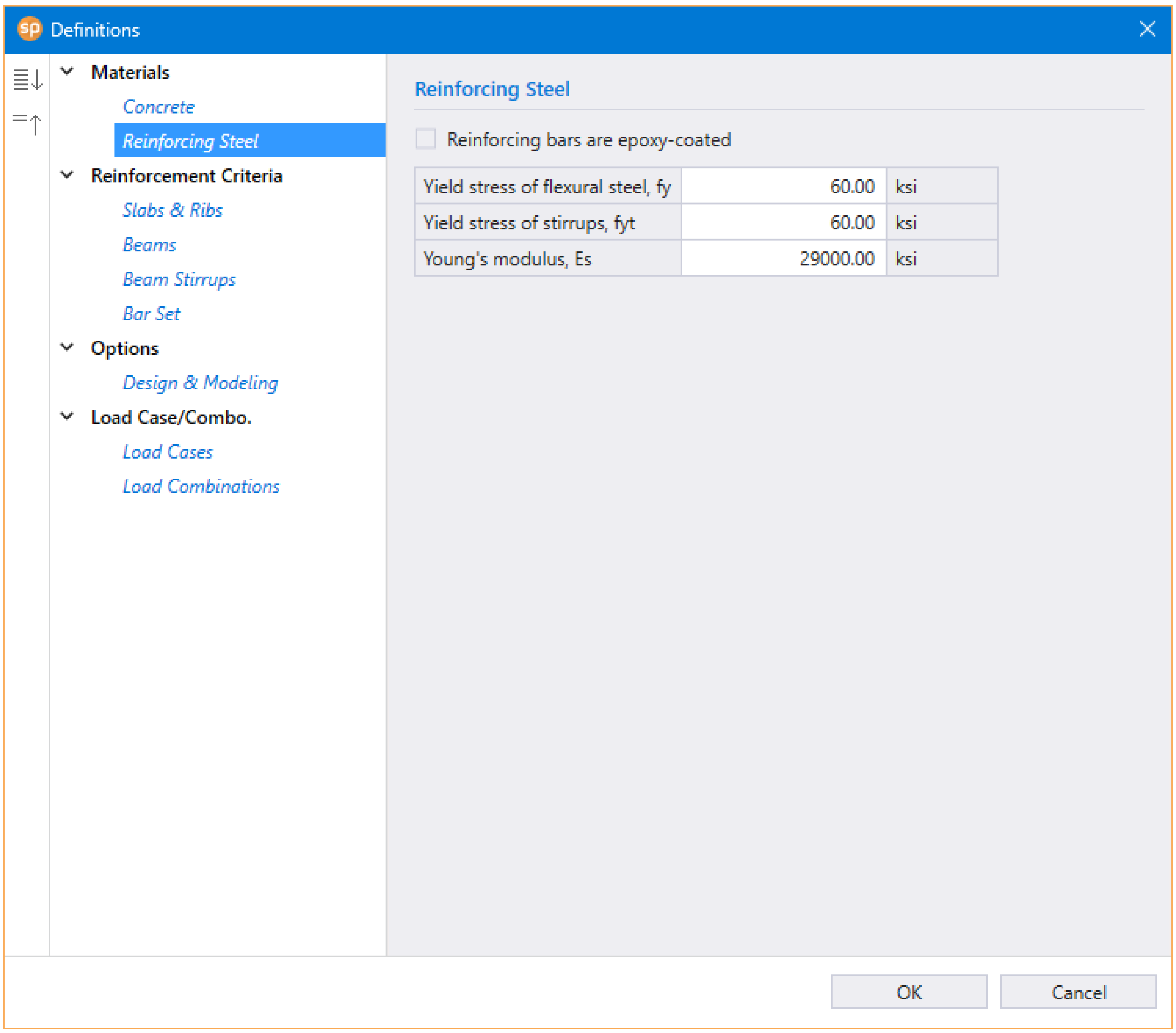
   UNIT DENSITY, Wc: `150.00` pcf



5. Click on **Reinforcing Steel** from **Materials** to display the **Reinforcing Steel** dialog box.

- Enter the following:

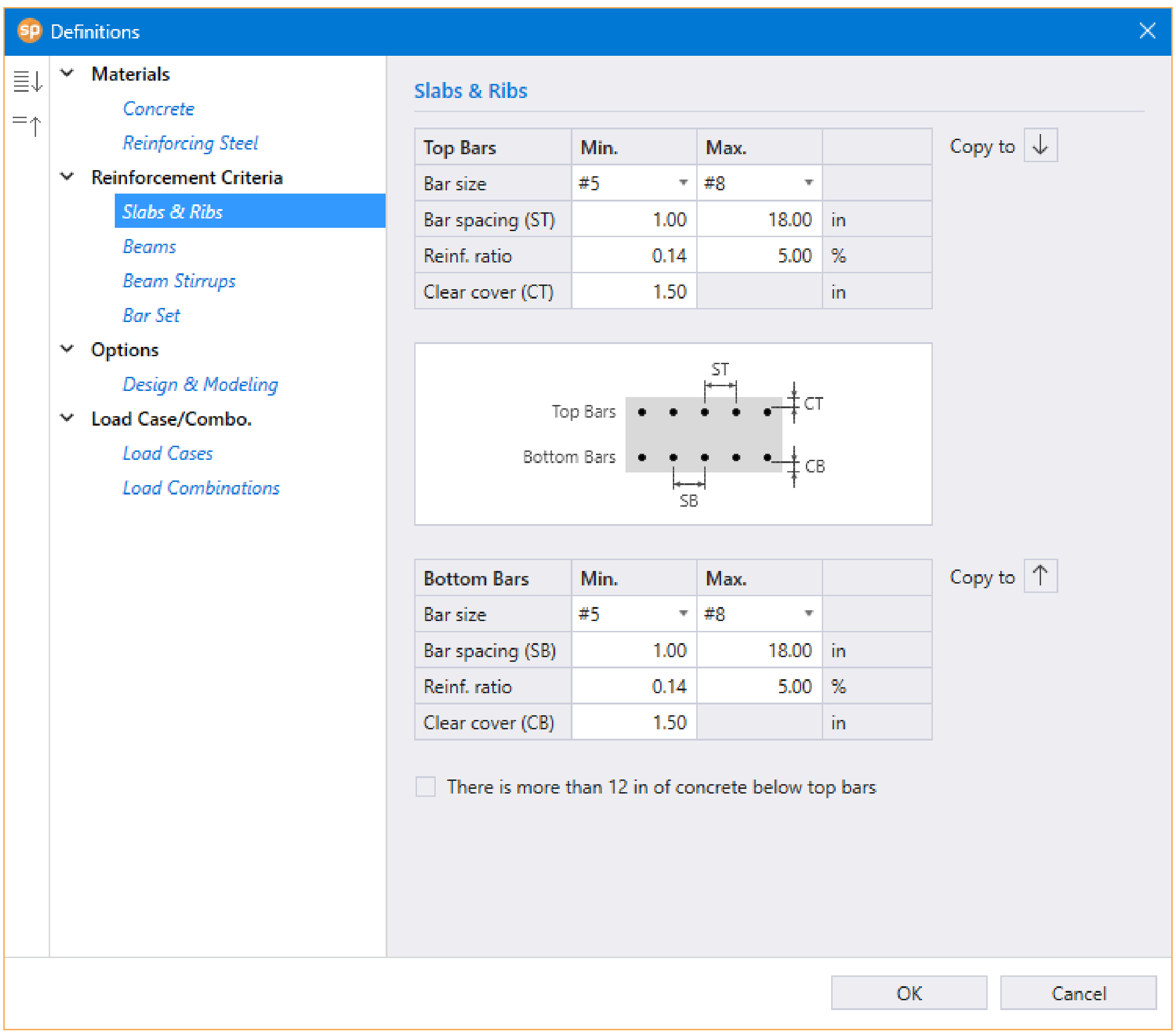
| | |
|---|---|
| YIELD STRESS OF FLEXURAL STEEL, fy: | 60.00 ksi |
| YIELD STRESS OF STIRRUP, fyt: | 60.00 ksi |
| YOUNG'S MODULUS, Es: | 29000.00 ksi |



6. Click on **Slabs & Ribs** from **Reinforcement Criteria** to display the **Slabs & Ribs** dialog box.

   - Enter the following for TOP BARS and BOTTOM BARS:

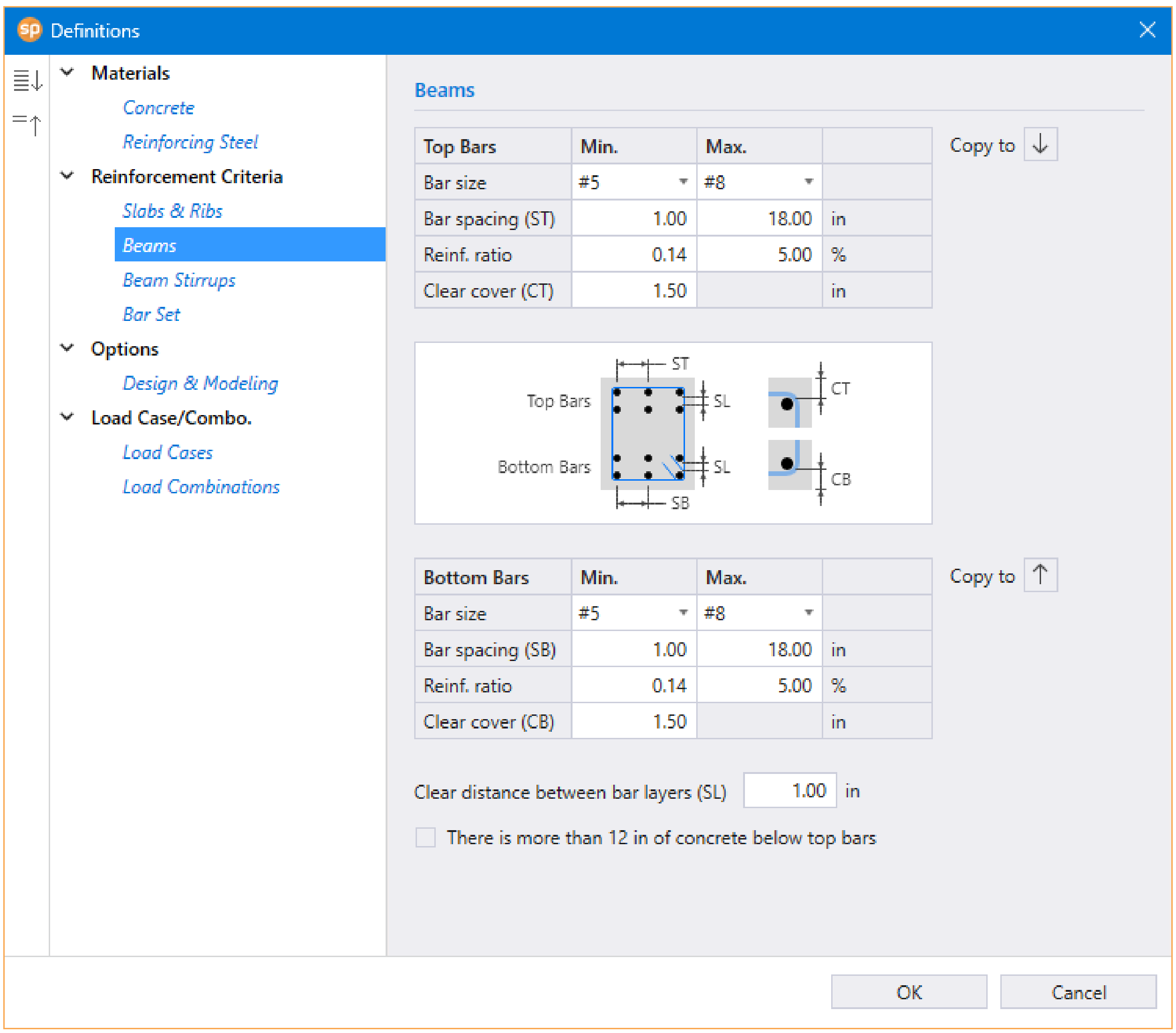
| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #5 | #8 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.50 in | |



7. Click on **Beams** from **Reinforcement Criteria** to display the **Beams** dialog box.

- Enter the following for TOP BARS and BOTTOM BARS:

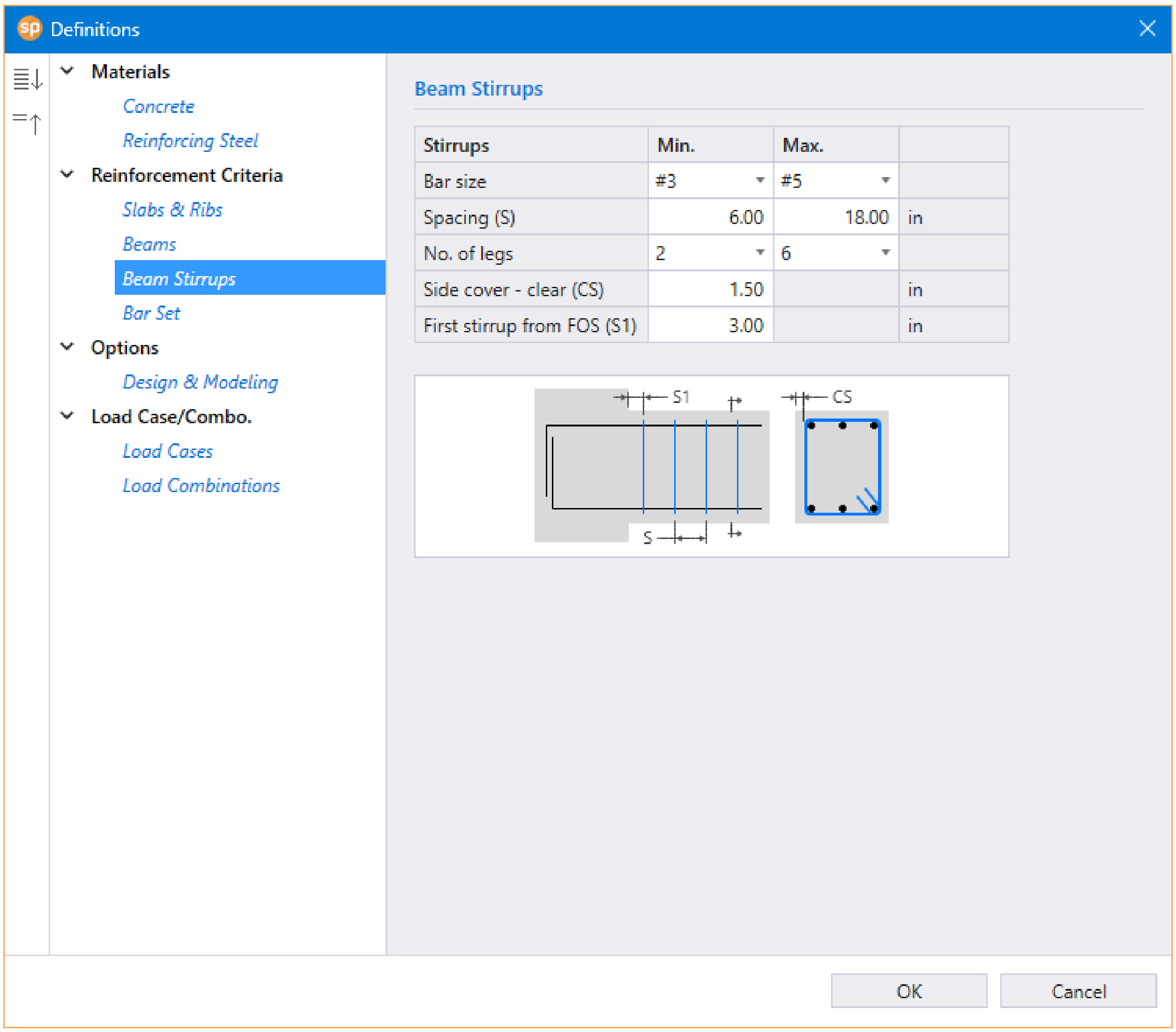
| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #5 | #8 |
| BAR SPACING (ST): | 1.00 in | 18.00 in |
| REINFORCEMENT RATIO: | 0.14 % | 5.00 % |
| CLEAR COVER (CT): | 1.50 in | |
| CLEAR DISTANCE BETWEEN BAR LAYERS (SL): | 1.00 in | |



8. Click on **Beam Stirrups** from **Reinforcement Criteria** to display the **Beam Stirrups** dialog box.

- Enter the following:

| | Min. | Max. |
|---|---|---|
| BAR SIZE: | #3 | #5 |
| BAR SPACING (S): | 6.00 in | 18.00 in |
| NUMBER OF LEGS: | 2 | 6 |
| SIDE COVER – CLEAR (CS): | 1.50 in | |
| FIRST STIRRUP FROM FOS (S1): | 3.00 in | |

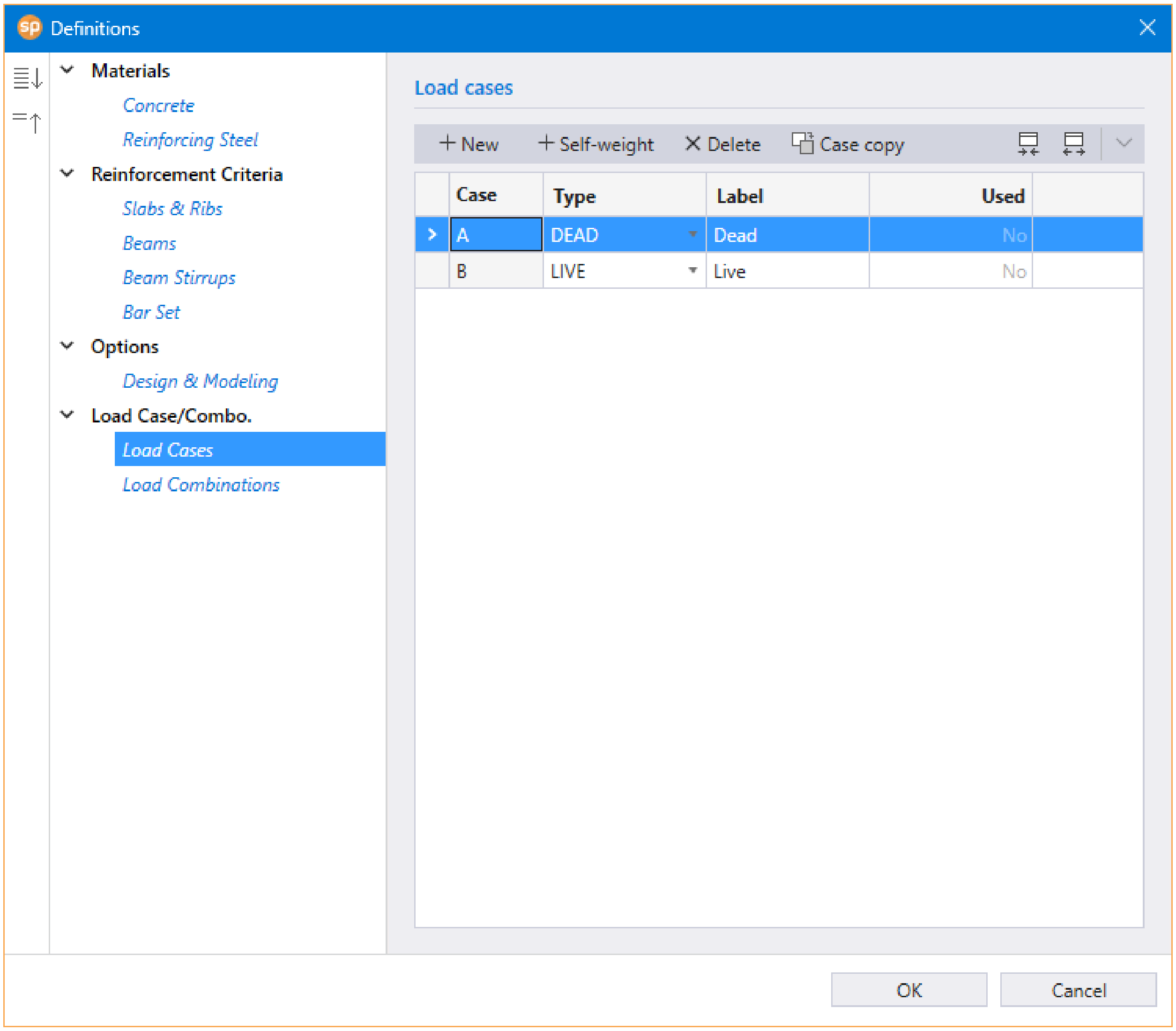


9. Click on **Load Cases** from **Load Case/Combo.** to display the **Load Cases** dialog box.

- Enter the following:

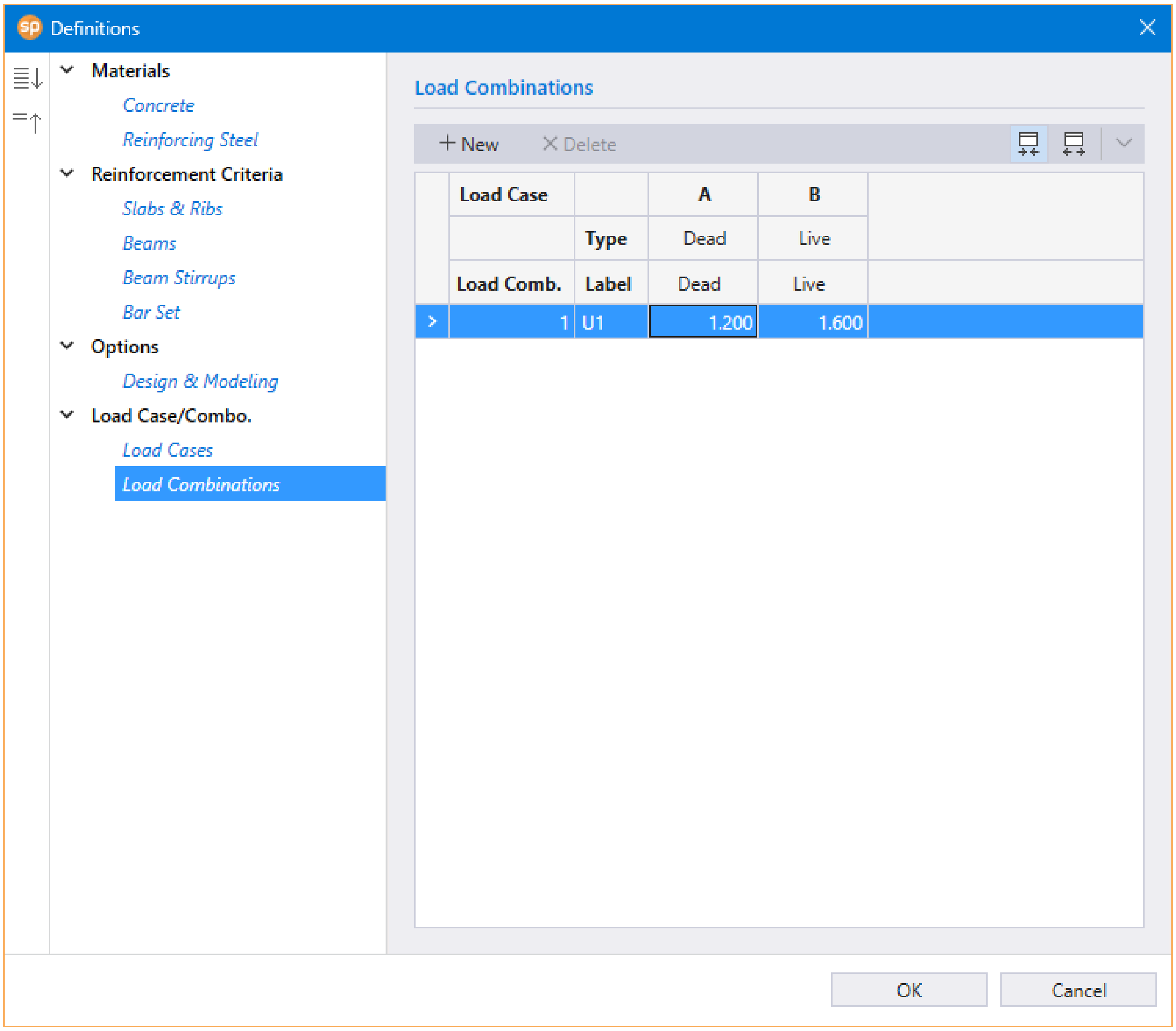
CASE A: `Dead`

CASE B: `Live`



10. Click on **Load Combinations** from **Load Case/Combo.** to display the **Load Combinations** dialog box.

- Enter the following load combination shown in the figure below:



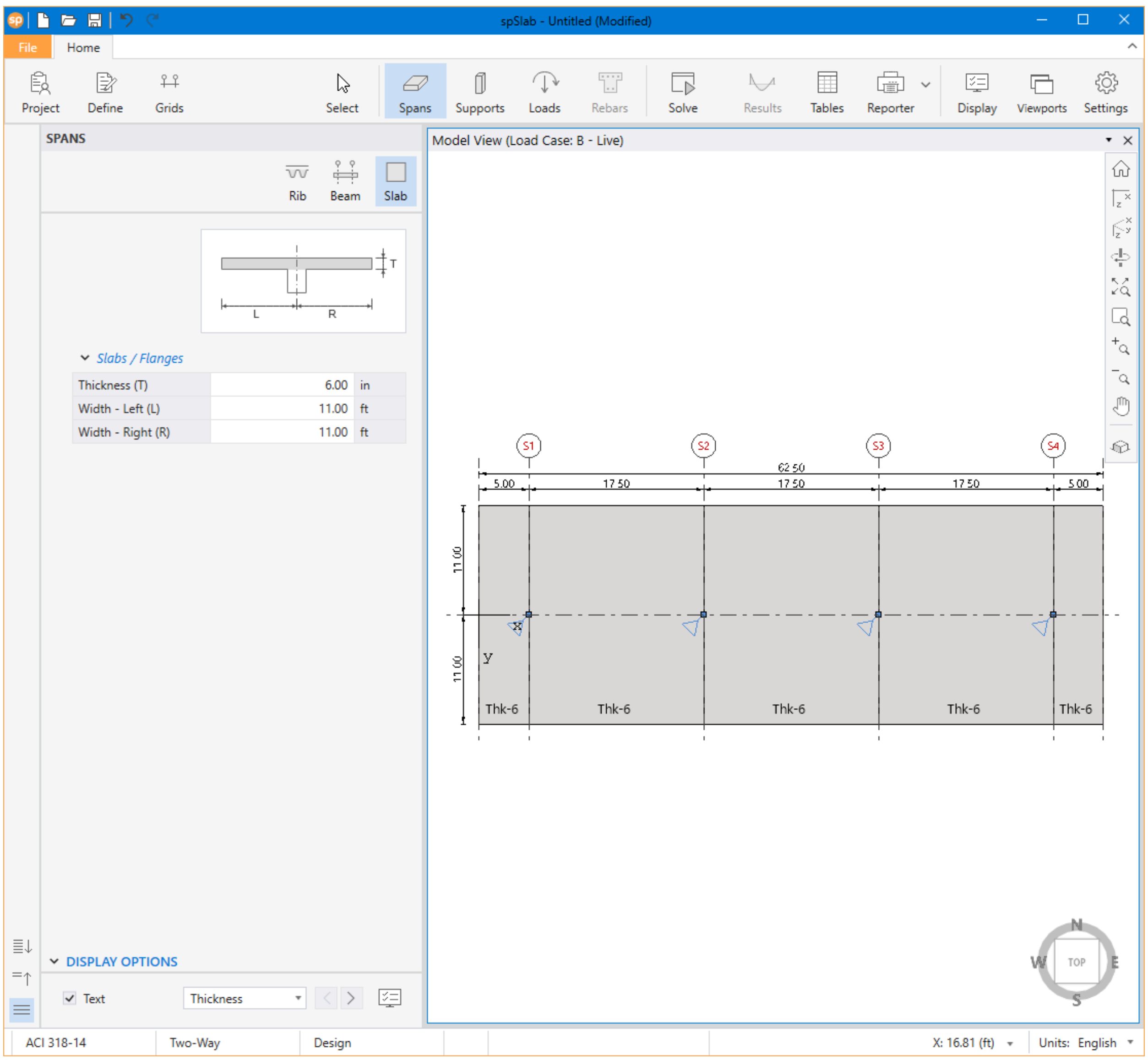
### 8.5.3. Assigning Spans

11. From the **Ribbon**, select **Spans** command.

- In the left panel, select **Slab** and enter the following:

| | |
|---|---|
| THICKNESS (T): | 6.00 in |
| WIDTH – LEFT (L): | 11.00 ft |
| WIDTH – RIGHT (R): | 11.00 ft |

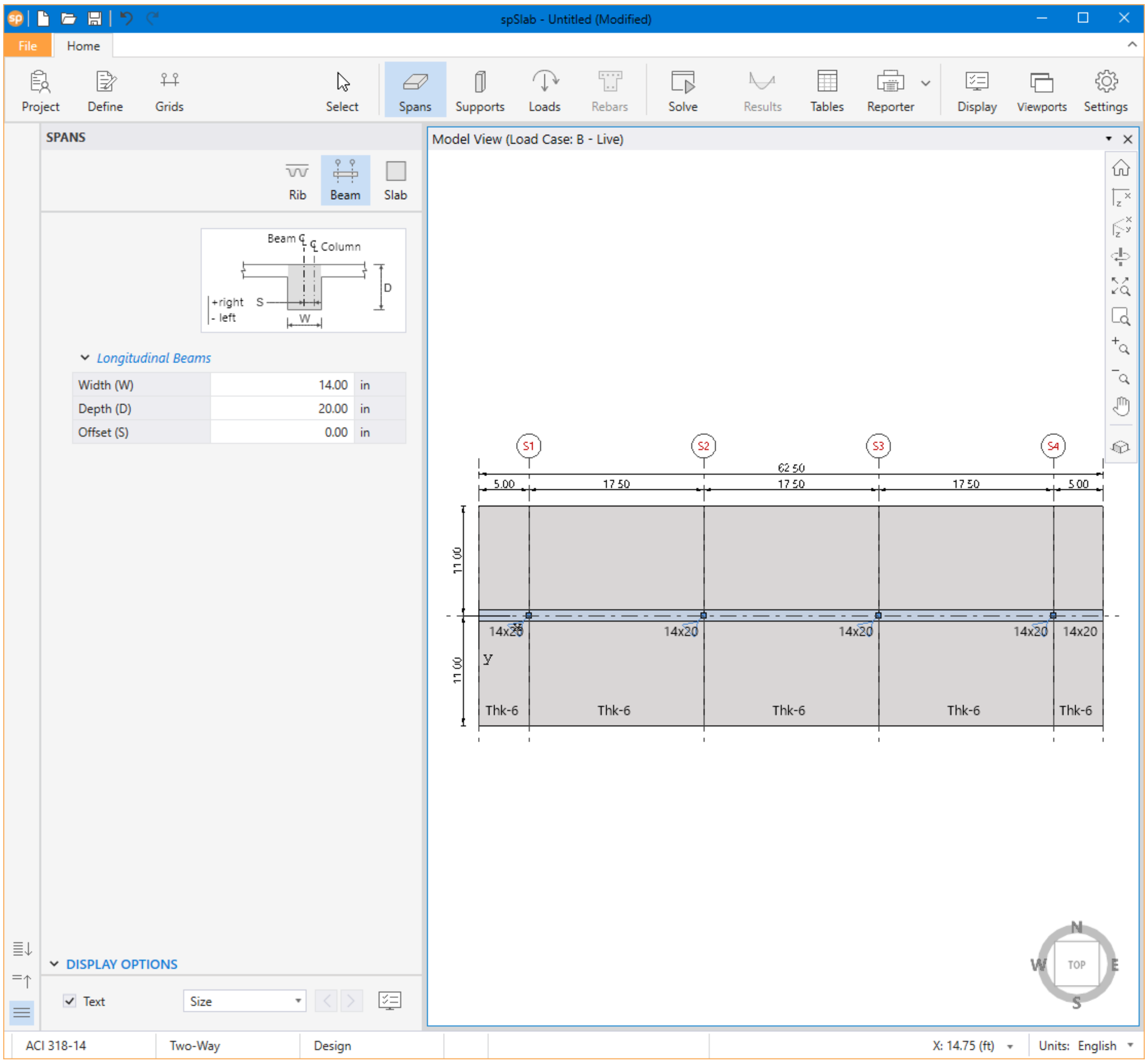
- Apply to all spans as shown in the figure below.



- In the left panel, select **Beam** and enter the following:

| | |
|---|---|
| WIDTH (W): | 14.00 in |
| DEPTH (D): | 20.00 in |
| OFFSET (S): | 0.00 in |

- Apply to all spans as shown in the figure below.



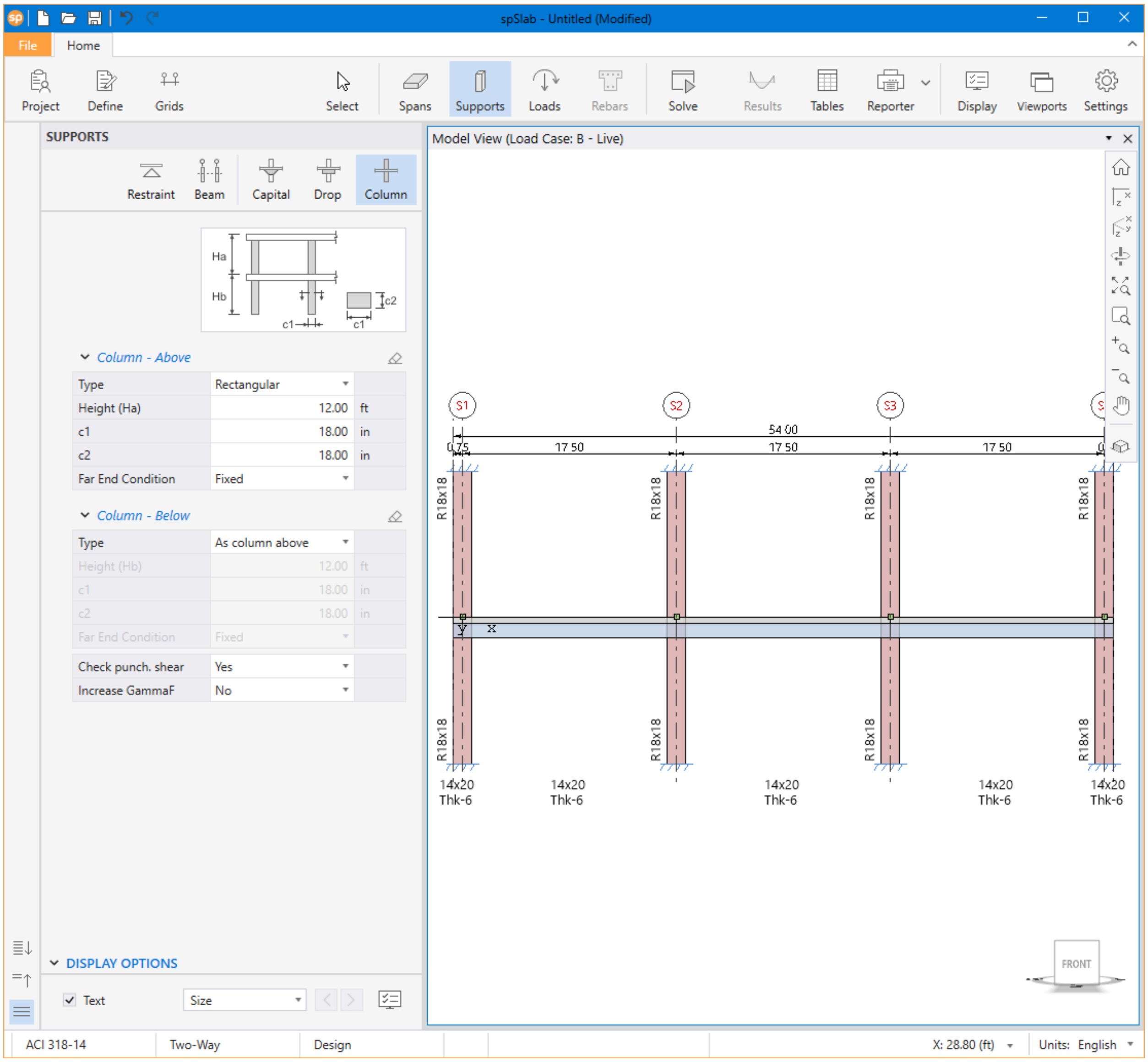
### 8.5.4. Assigning Supports

12. From the **Ribbon**, select **Supports** command.

- In the left panel, select **Column** and enter the following for COLUMN – ABOVE and COLUMN – BELOW:

| | |
|---|---|
| TYPE: | Rectangular |
| HEIGHT: | `12.00` ft |
| c1: | `18.00` in |
| c2: | `18.00` in |
| FAR END CONDITION: | Fixed |
| CHECK PUNCHING SHEAR: | Yes |
| INCREASE GAMMAF: | No |

- Apply to all supports as shown in the figure below.
- Notice how the cantilevers adjusted to the column faces when the exterior columns are assigned.

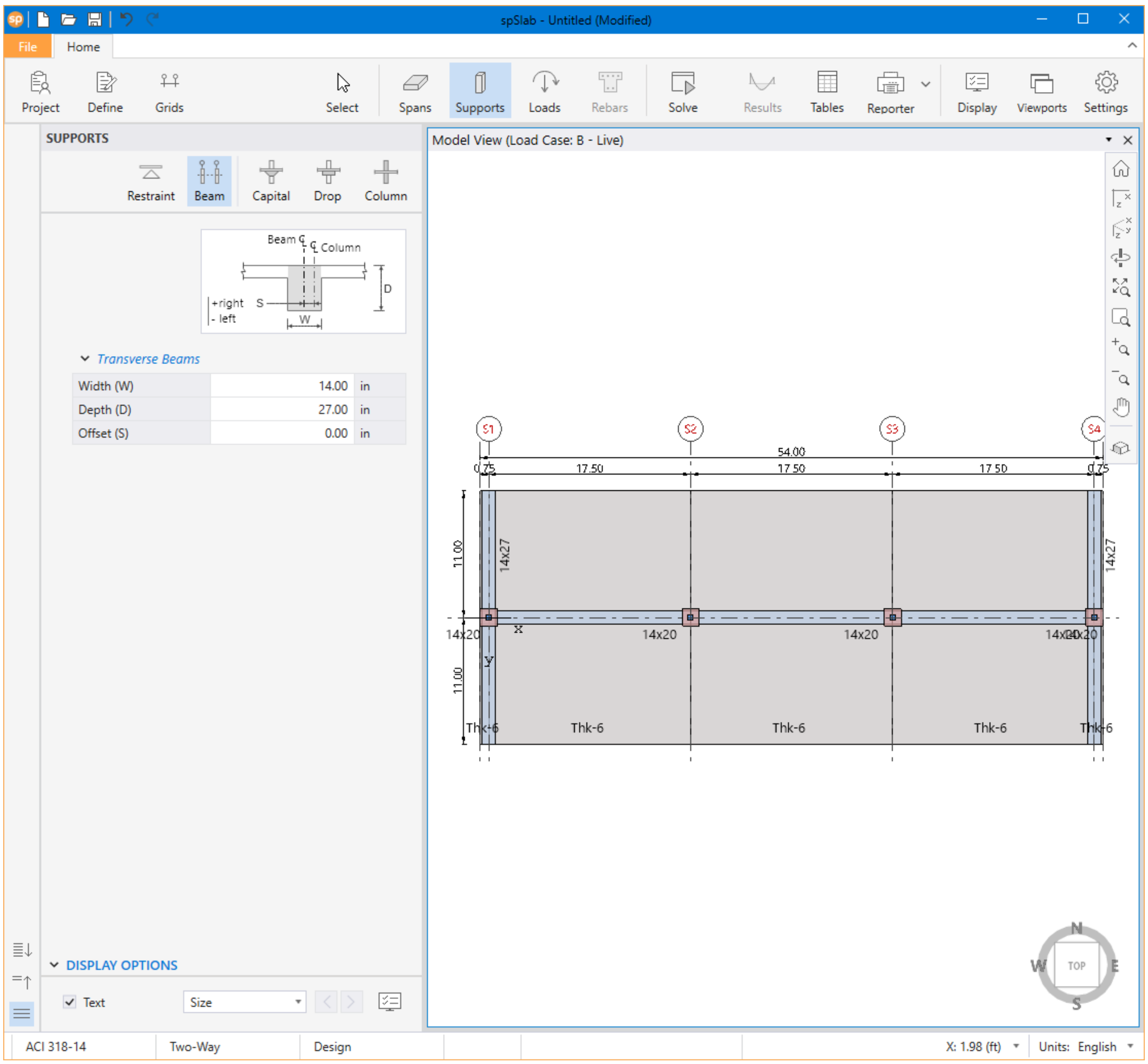

spSlab - Untitled (Modified)
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
SUPPORTS
Restraint
Beam
Capital
Drop
Column
Column - Above
Type
Rectangular
Height (Ha)
12.00
ft
c1
18.00
in
c2
18.00
in
Far End Condition
Fixed
Column - Below
Type
As column above
Height (Hb)
12.00
c1
18.00
c2
18.00
Far End Condition
Fixed
Check punch. shear
Yes
Increase GammaF
No
DISPLAY OPTIONS
Text
Size
Model View (Load Case: B - Live)
S1
S2
S3
54.00
17.50
17.50
17.50
R18x18
14x20
Thk-6
FRONT
ACI 318-14
Two-Way
Design
X: 28.80 (ft)
Units: English

For exterior transverse beams:

- In the left panel, select **Beam** and enter the following:

| | |
|---|---|
| WIDTH (W): | 14.00 in |
| DEPTH (D): | 27.00 in |
| OFFSET (S): | 0.00 in |

- Apply to all exterior supports as shown in the figure below.

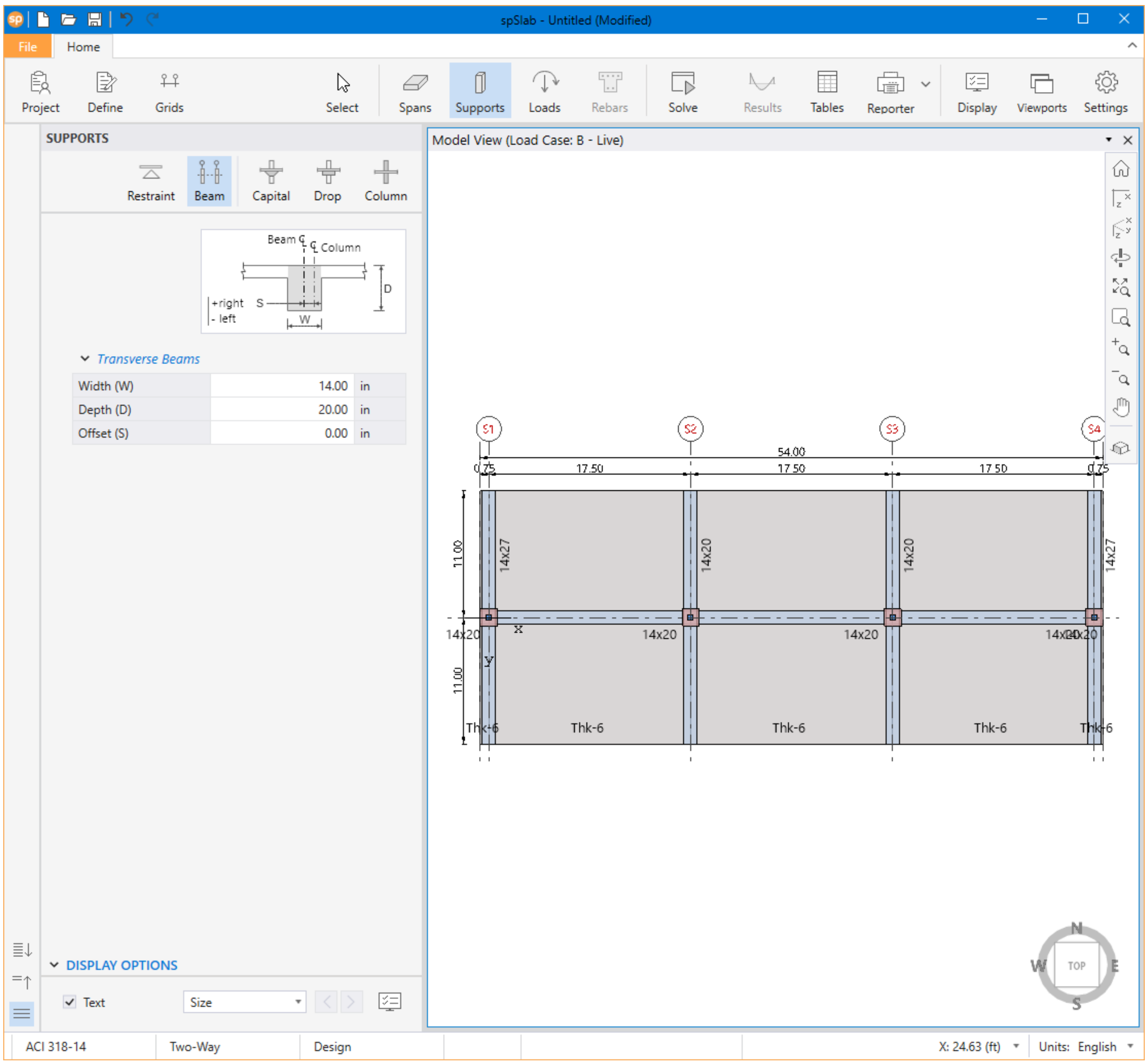


For interior transverse beams:

- In the left panel, select **Beam** and enter the following:

| | |
|---|---|
| WIDTH (W): | 14.00 in |
| DEPTH (D): | 20.00 in |
| OFFSET (S): | 0.00 in |

- Apply to all interior supports as shown in the figure below.



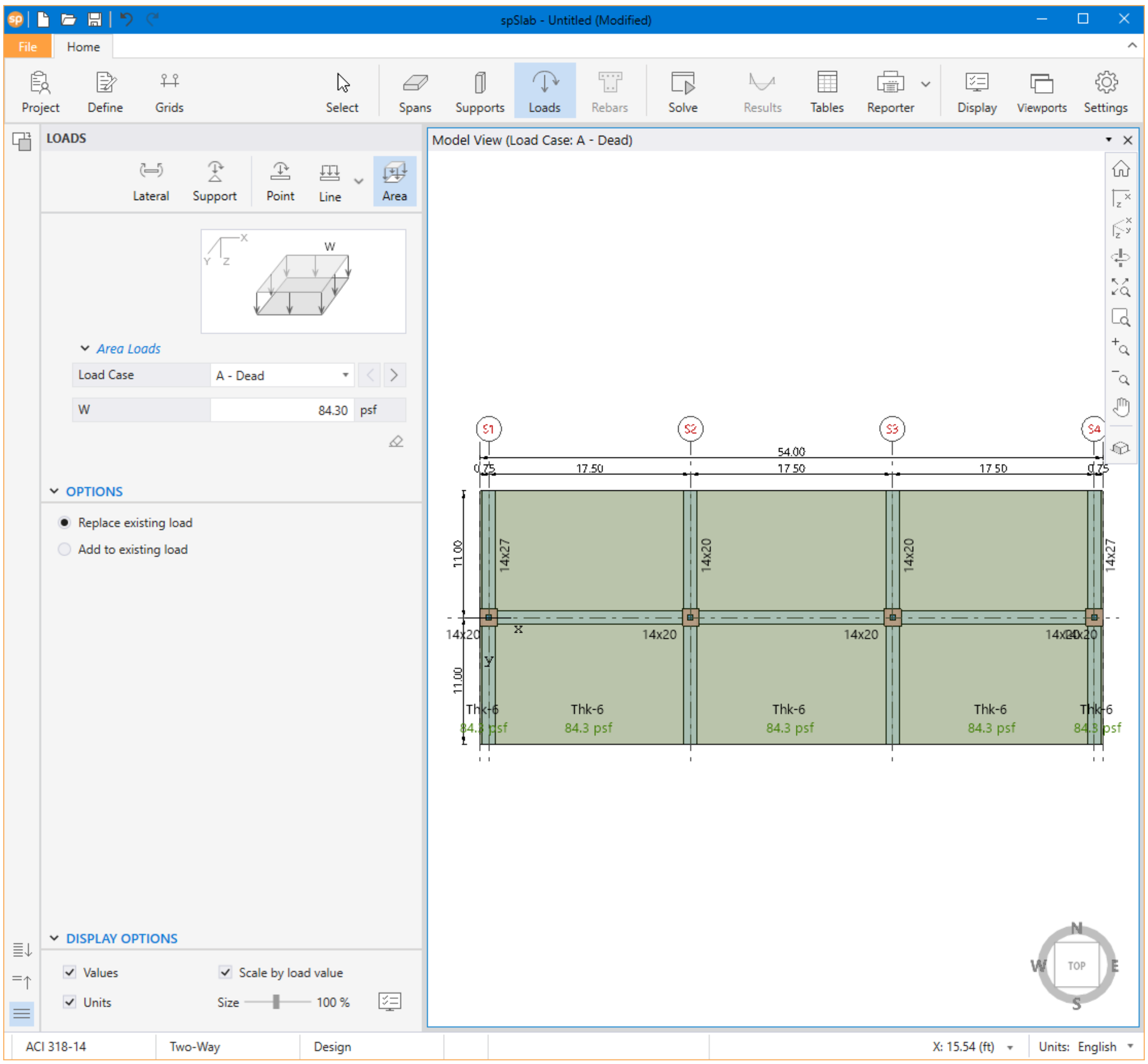
## 8.5.5. Assigning Loads

13. From the **Ribbon**, select **Loads** command.

- In the left panel, select **Area Load** then select A-DEAD from LOAD CASE and enter the following:

  w: 84.30 psf

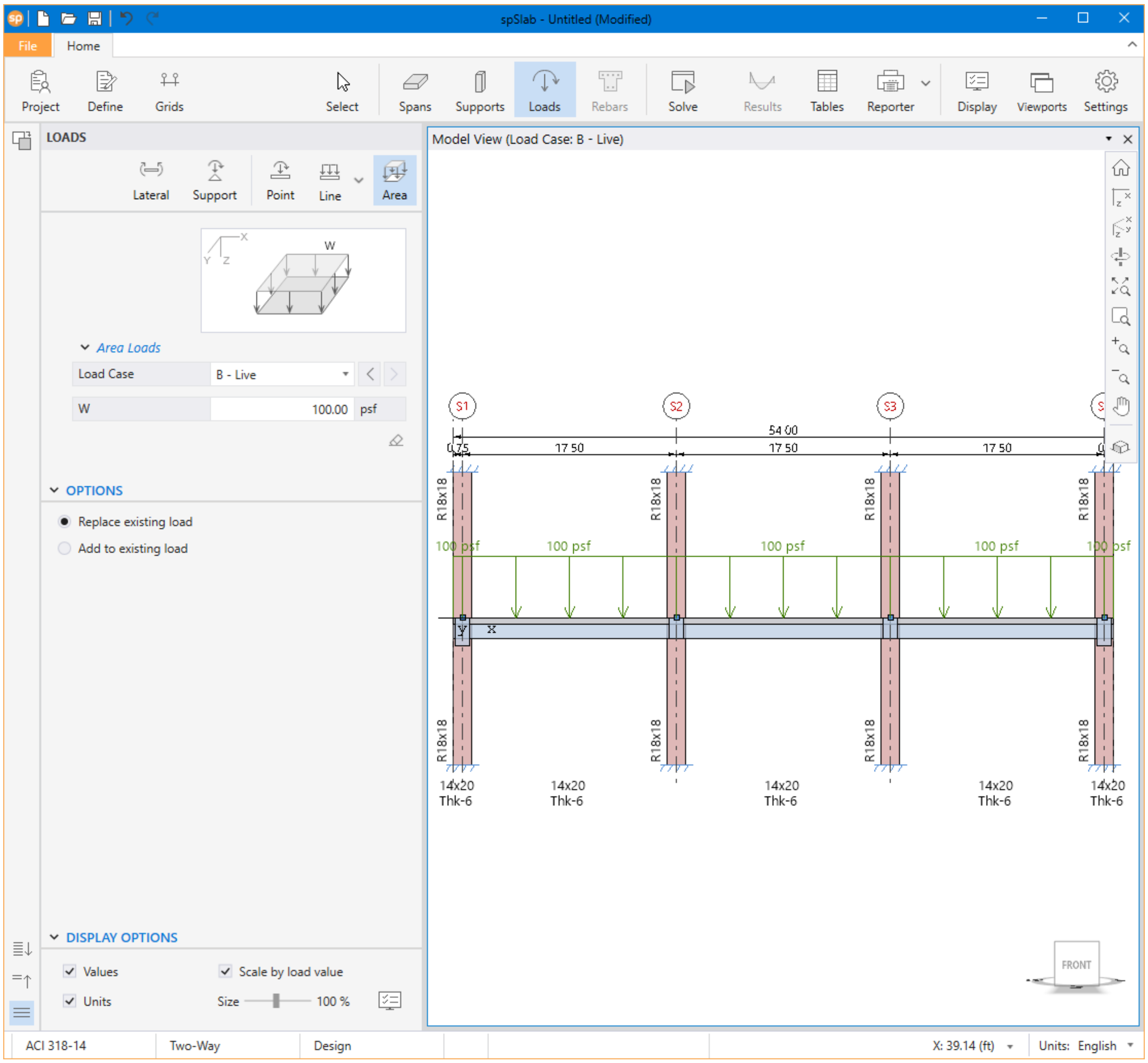
- Apply to all spans as shown in the figure below.



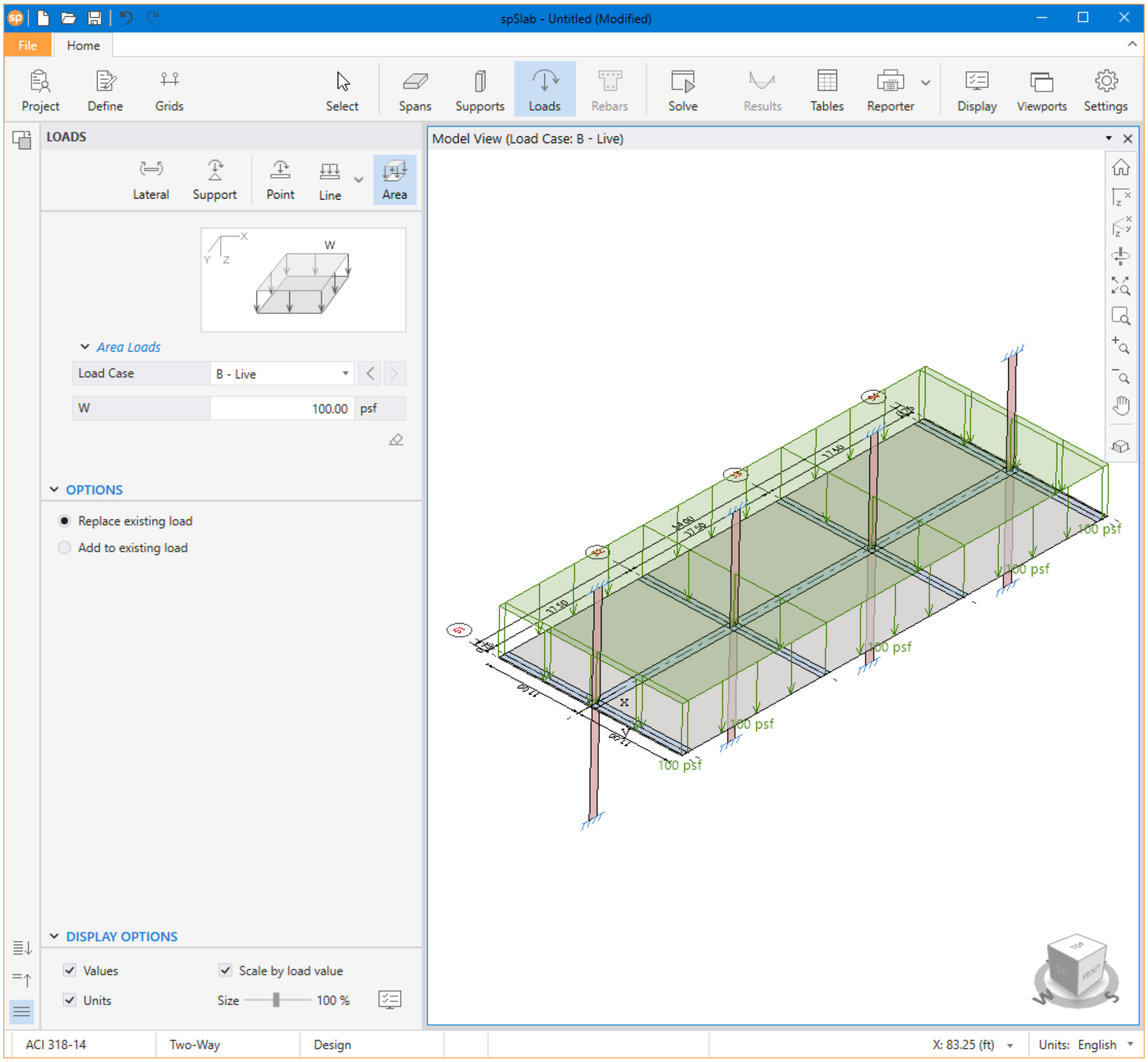
- Select B-LIVE from LOAD CASE and enter the following:

  w: `100.00` psf

- Apply to all spans as shown in the figure below.



- Also, you can click on the VIEW 3D icon from **View Controls** (top right of the active viewport) to get a better view of the applied loads.

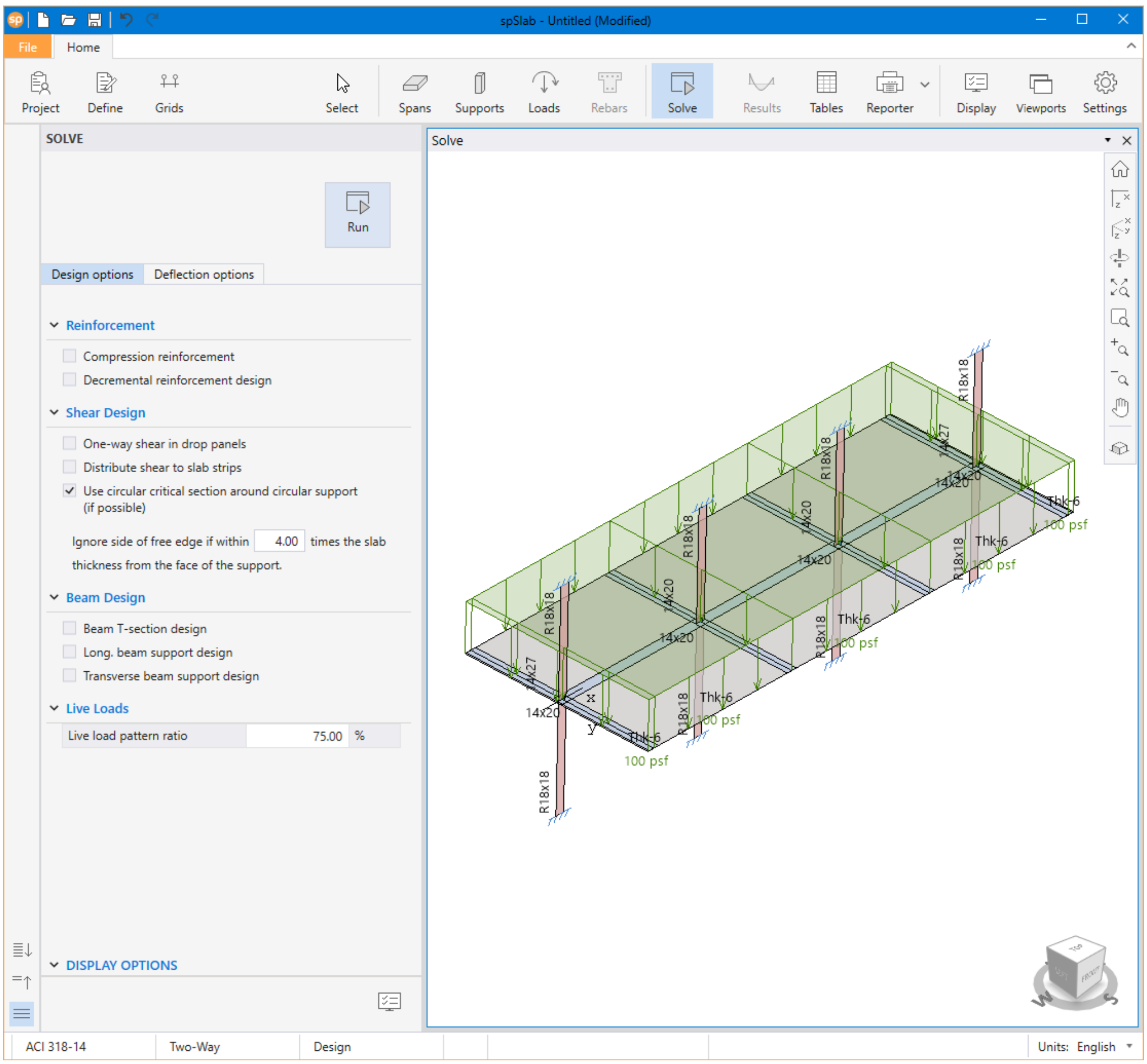


## 8.5.6. Solving

14. From the **Ribbon**, select **Solve** command.

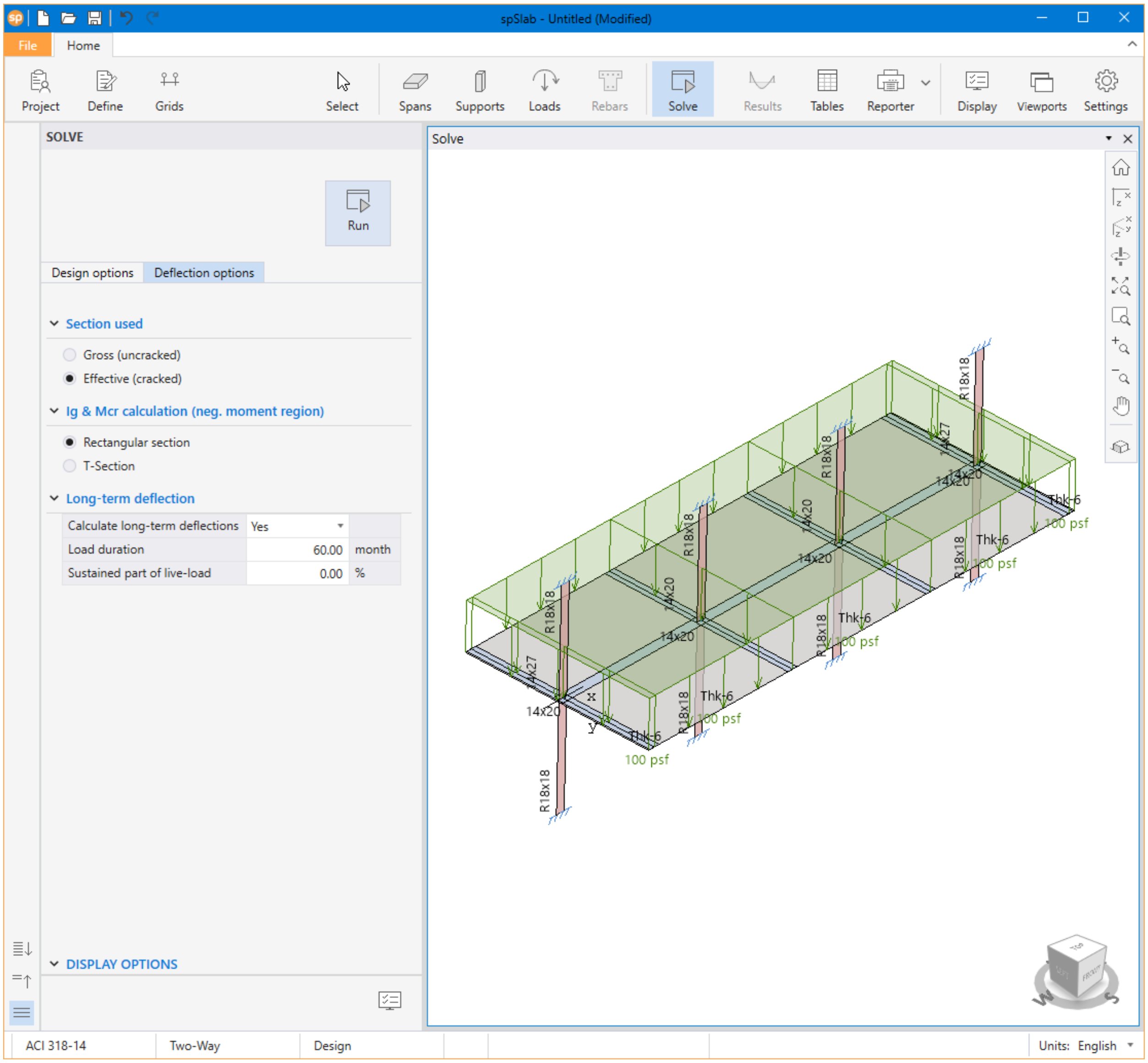
For **Design Options**:

- Uncheck DISTRIBUTE SHEAR TO SLAB STRIPS for SHEAR DESIGN section.
- Uncheck BEAM T-SECTION DESIGN for BEAM DESIGN section.
- Leave all the other **Design Options** to their default settings.

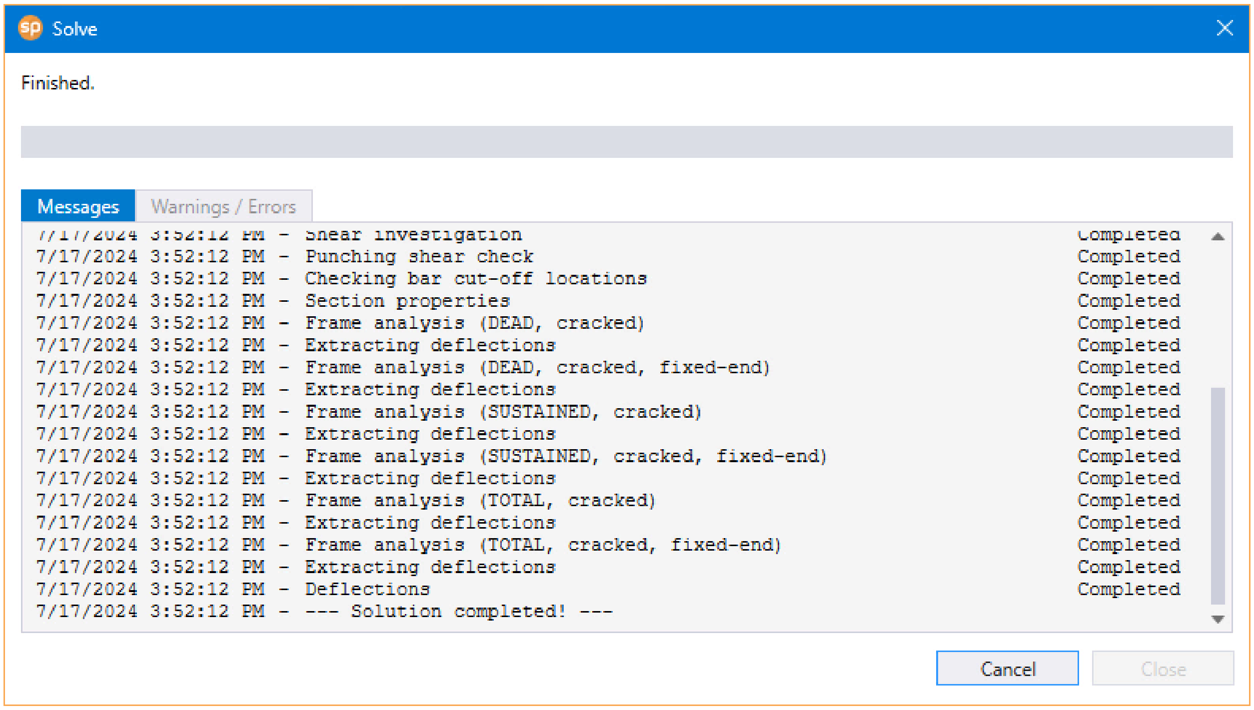


For **Deflection Options**:

- Leave all **Design Options** to their default settings.

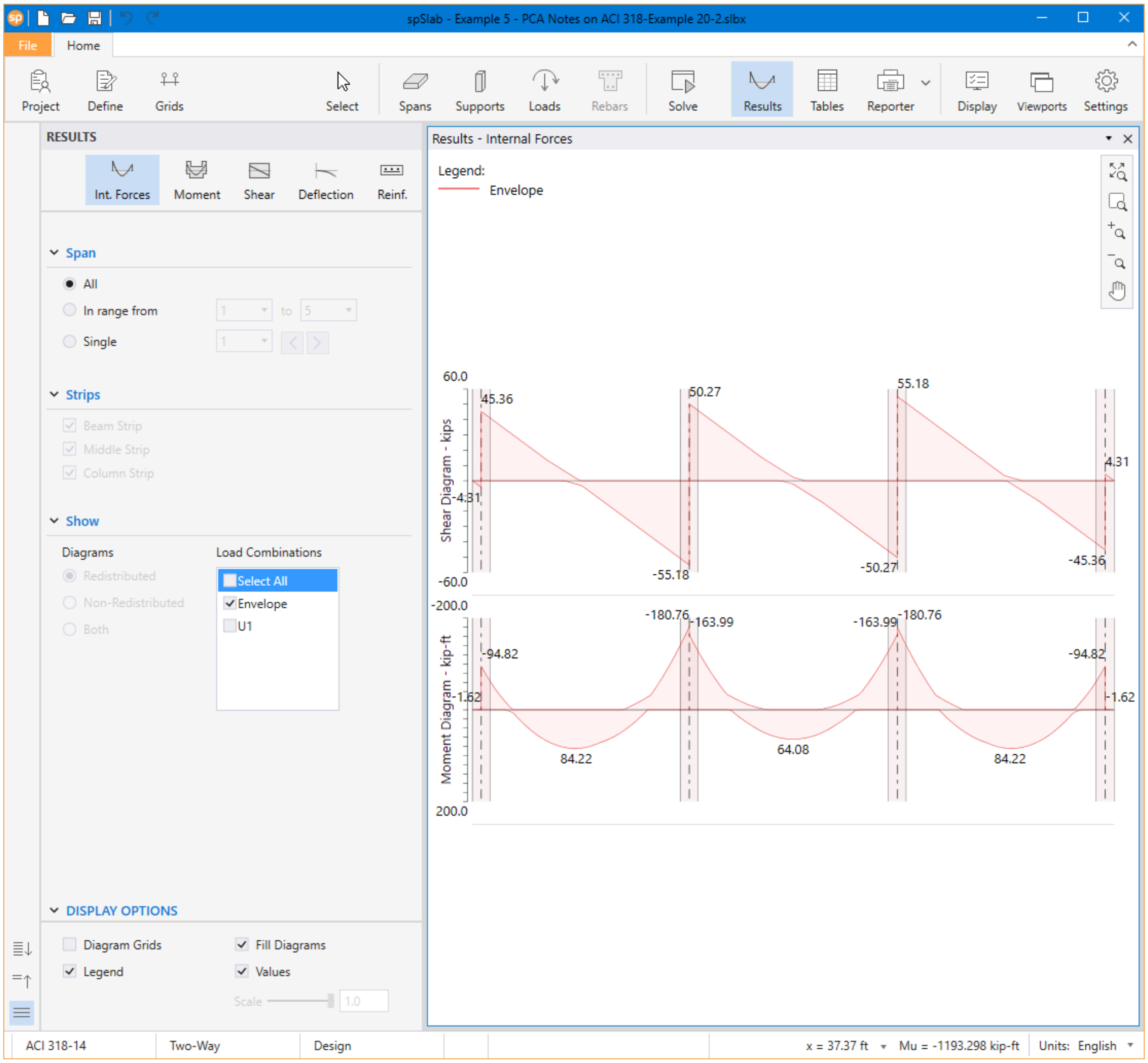


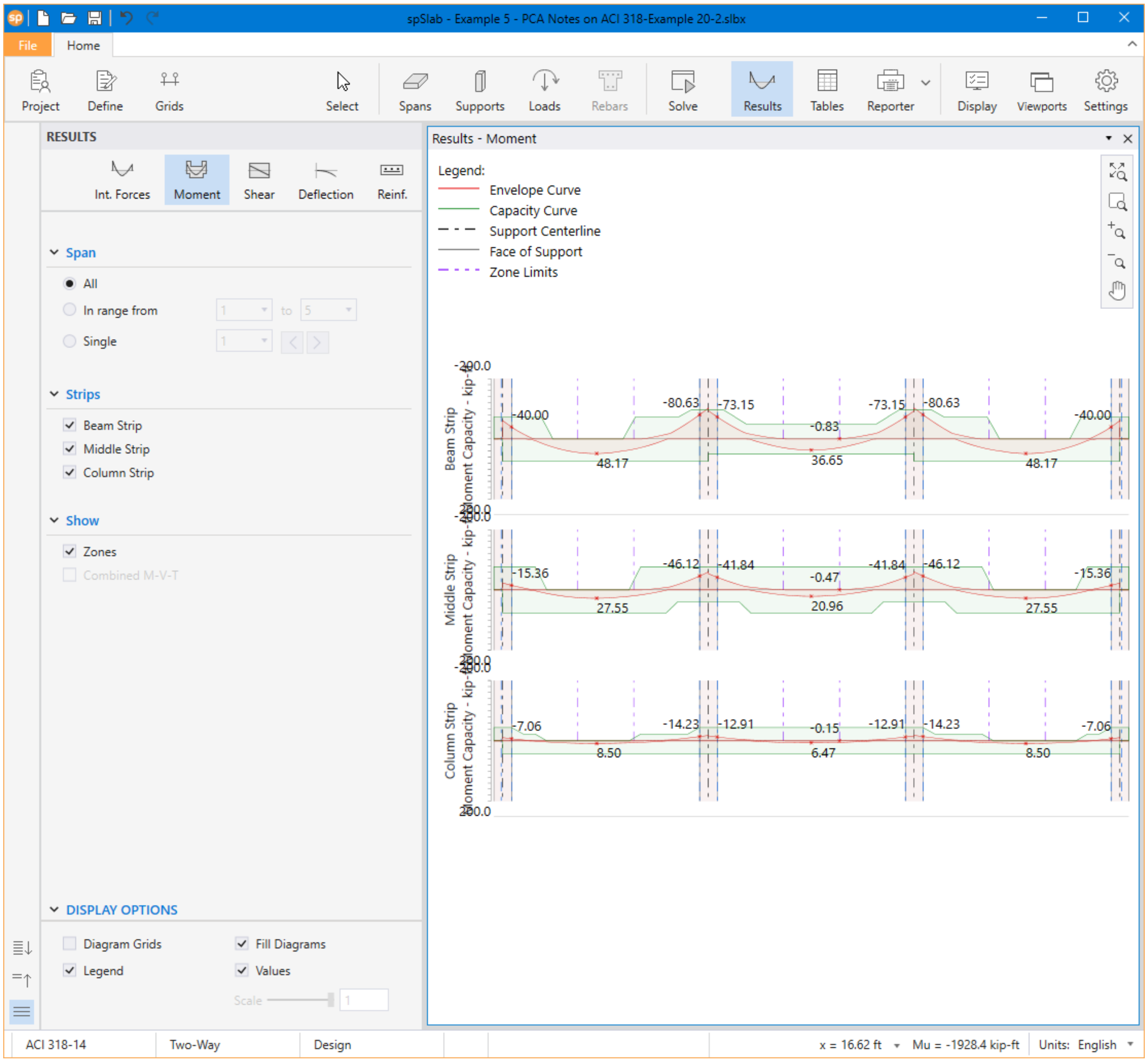
- Click on the **Run** button.
- The spSlab **Solver** window is displayed and the solver messages are listed. After the solution is done, the design will be performed and then the focus will immediately be passed to the **Results** scope.

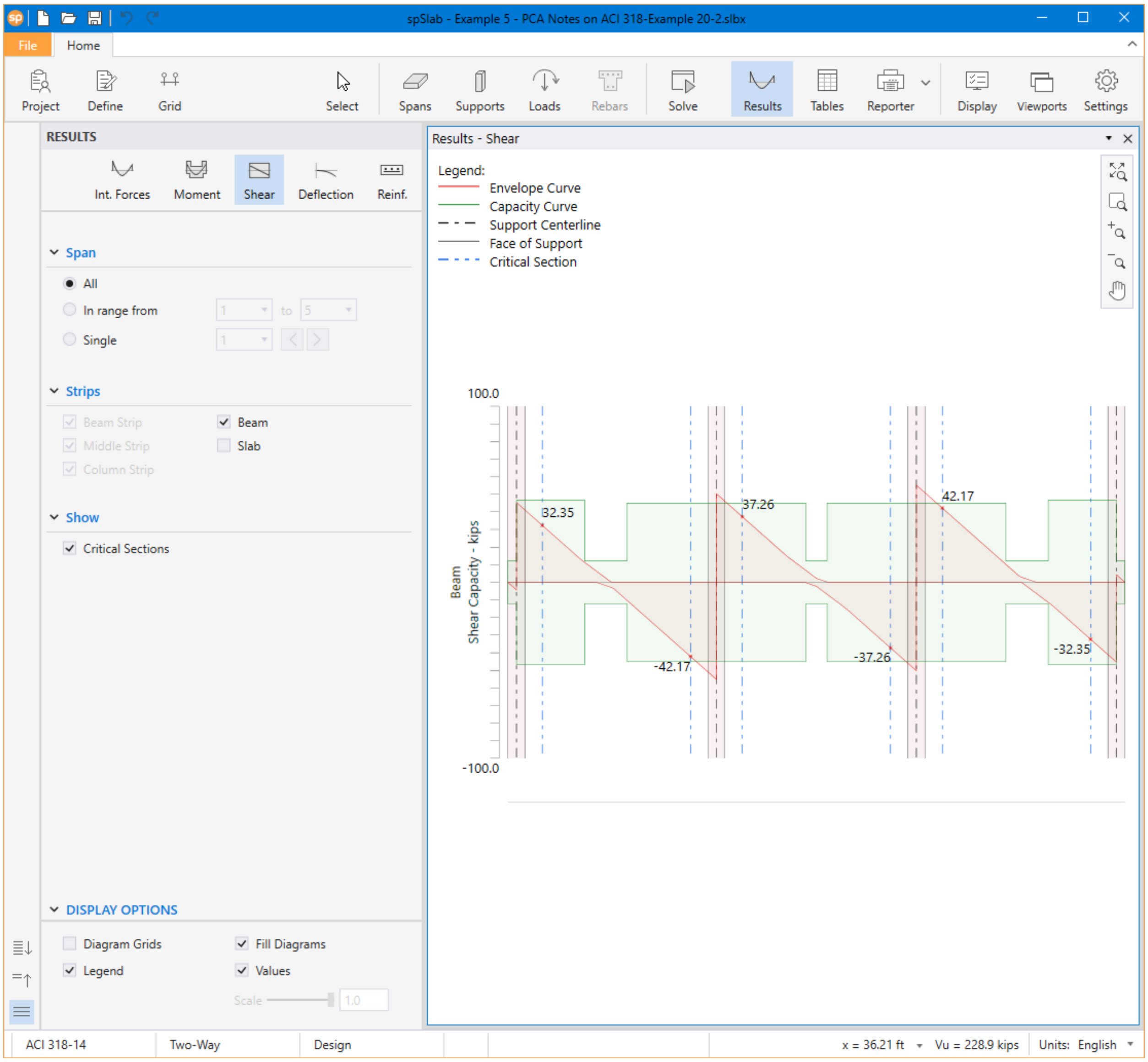


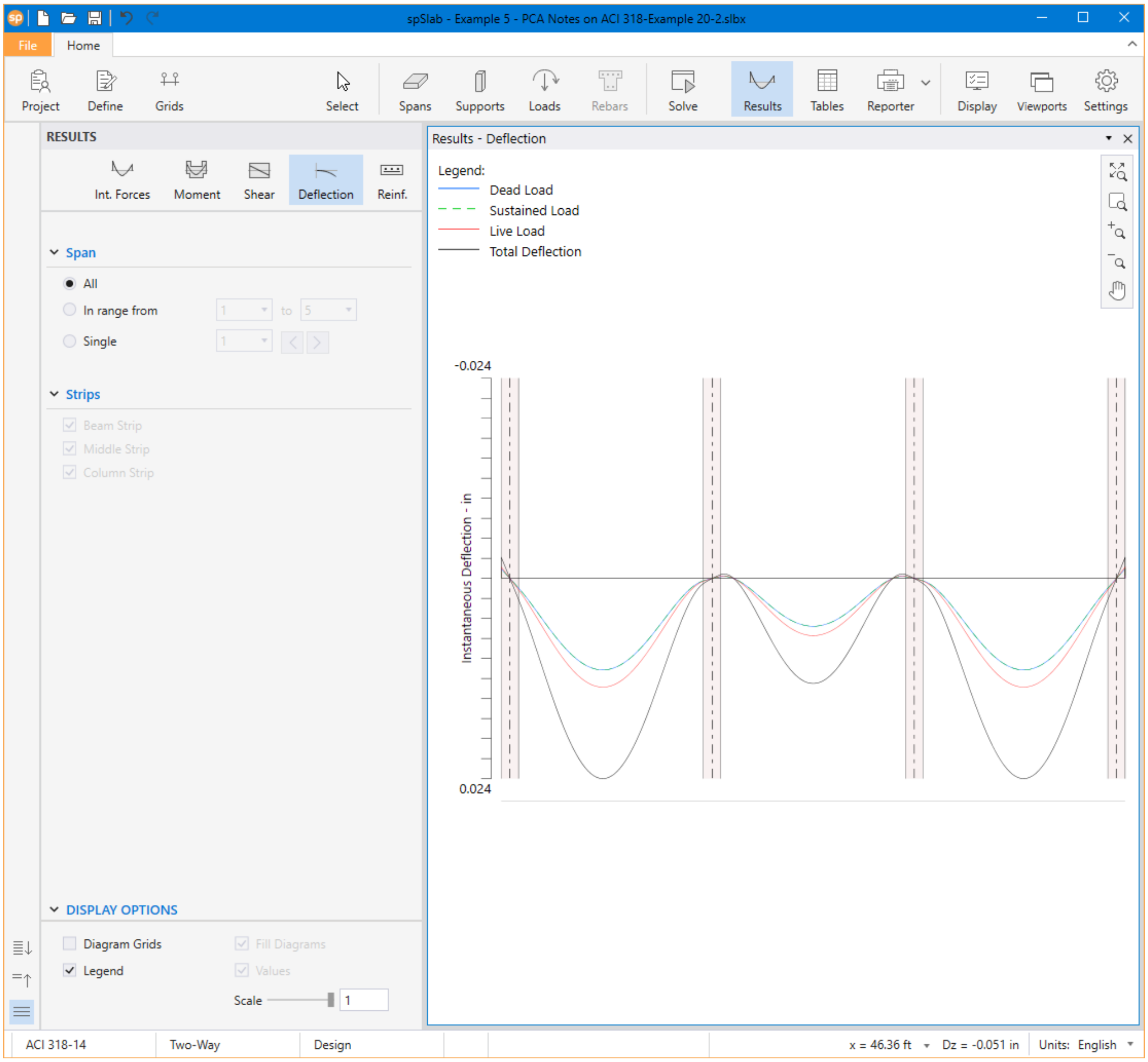
### 8.5.7. Viewing and Printing Results

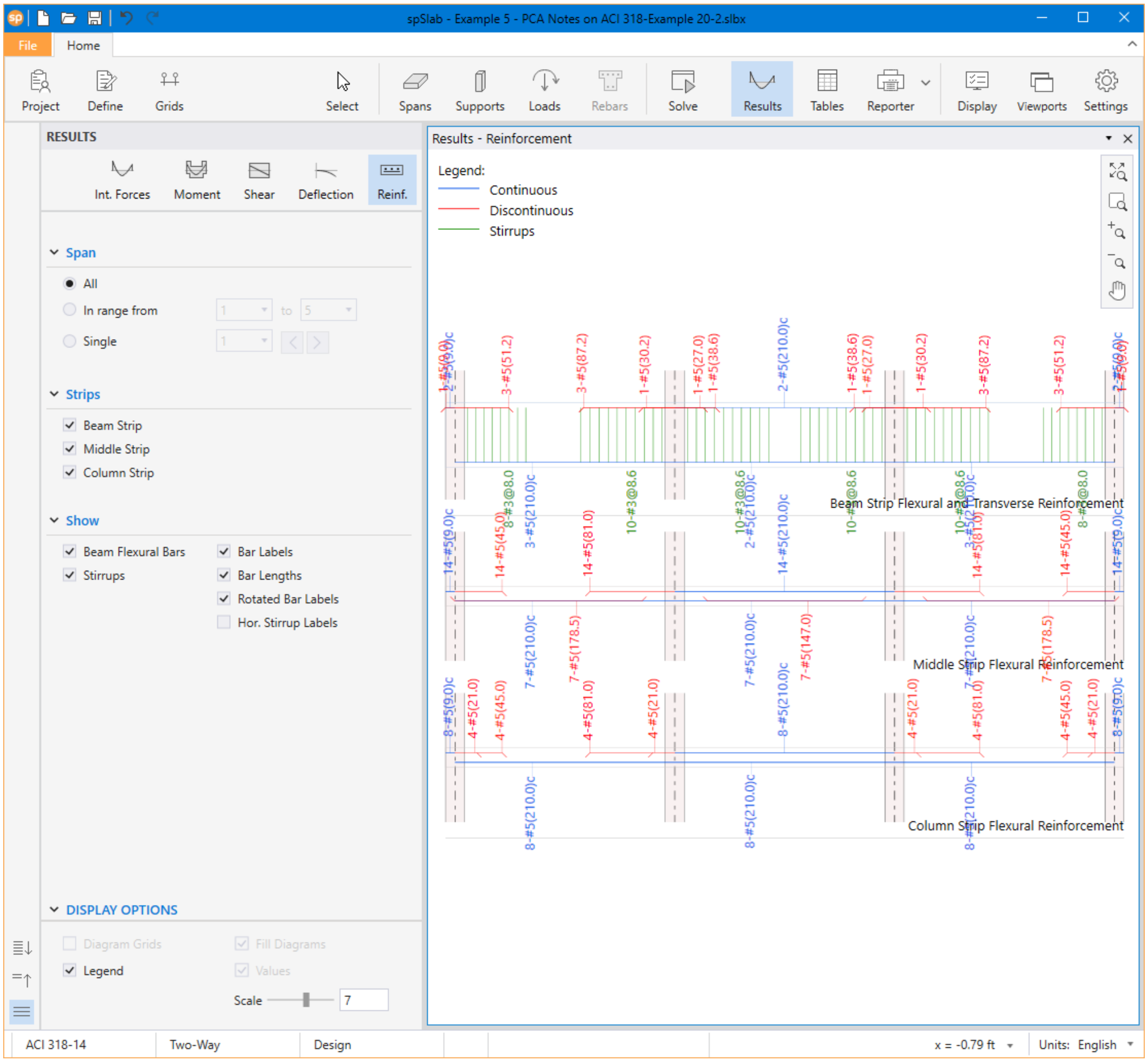
15. After a successful run, results can be viewed by selecting **Internal Forces**, **Moment Capacity**, **Shear Capacity**, **Deflection**, or **Reinforcement** from the left panel.



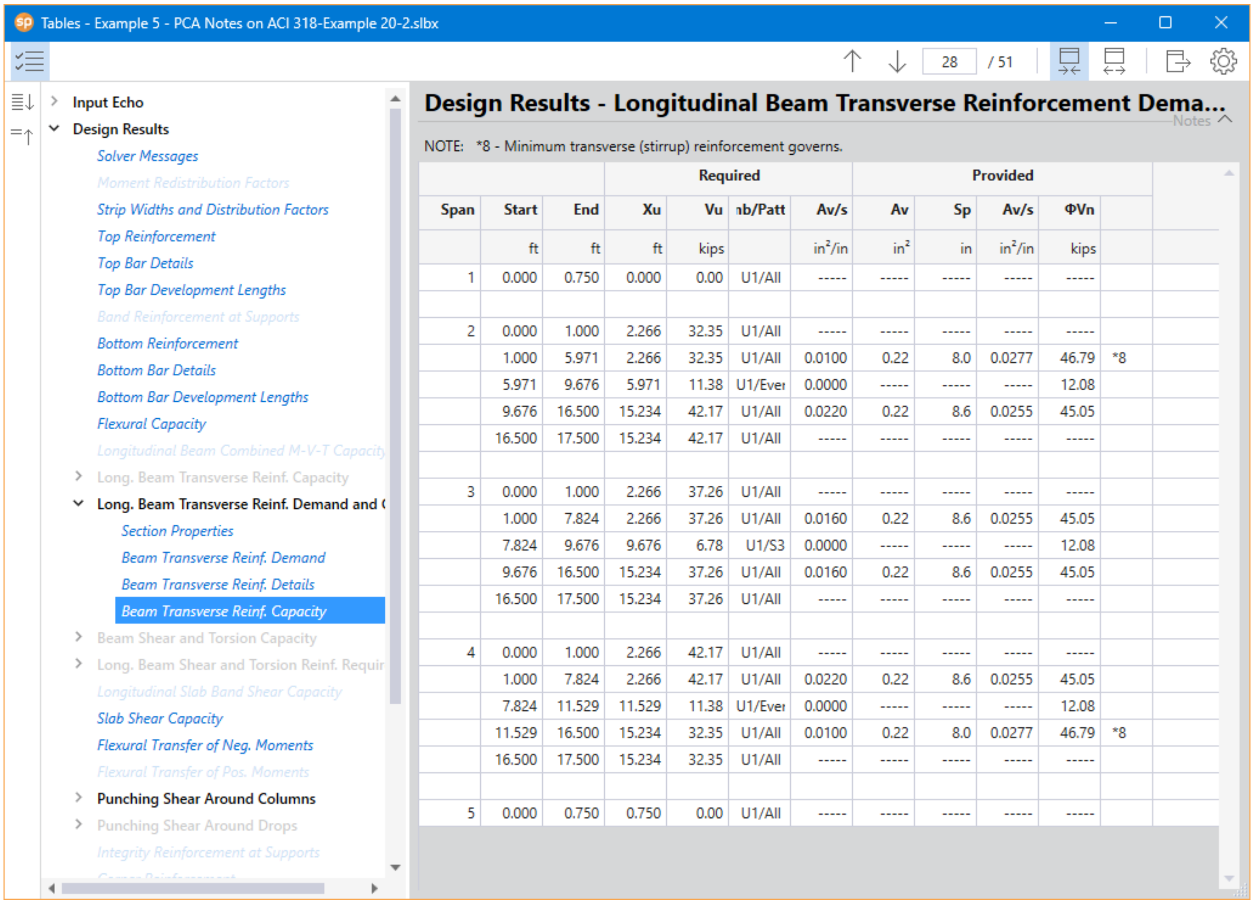

spSlab - Example 5 - PCA Notes on ACI 318-Example 20-2.slbx
Results - Moment
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Zone Limits
Beam Strip
Middle Strip
Column Strip
ACI 318-14
Two-Way
Design
x = 16.62 ft
Mu = -1928.4 kip-ft
Units: English


spSlab - Example 5 - PCA Notes on ACI 318-Example 20-2.slbx
File
Home
Project
Define
Grid
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
Beam
Slab
Show
Critical Sections
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Shear
Legend:
Envelope Curve
Capacity Curve
Support Centerline
Face of Support
Critical Section
100.0
-100.0
Beam
Shear Capacity - kips
32.35
37.26
42.17
-42.17
-37.26
-32.35
ACI 318-14
Two-Way
Design
x = 36.21 ft
Vu = 228.9 kips
Units: English


spSlab - Example 5 - PCA Notes on ACI 318-Example 20-2.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
DISPLAY OPTIONS
Diagram Grids
Fill Diagrams
Legend
Values
Scale
Results - Deflection
Legend:
Dead Load
Sustained Load
Live Load
Total Deflection
-0.024
Instantaneous Deflection - in
0.024
ACI 318-14
Two-Way
Design
x = 46.36 ft
Dz = -0.051 in
Units: English

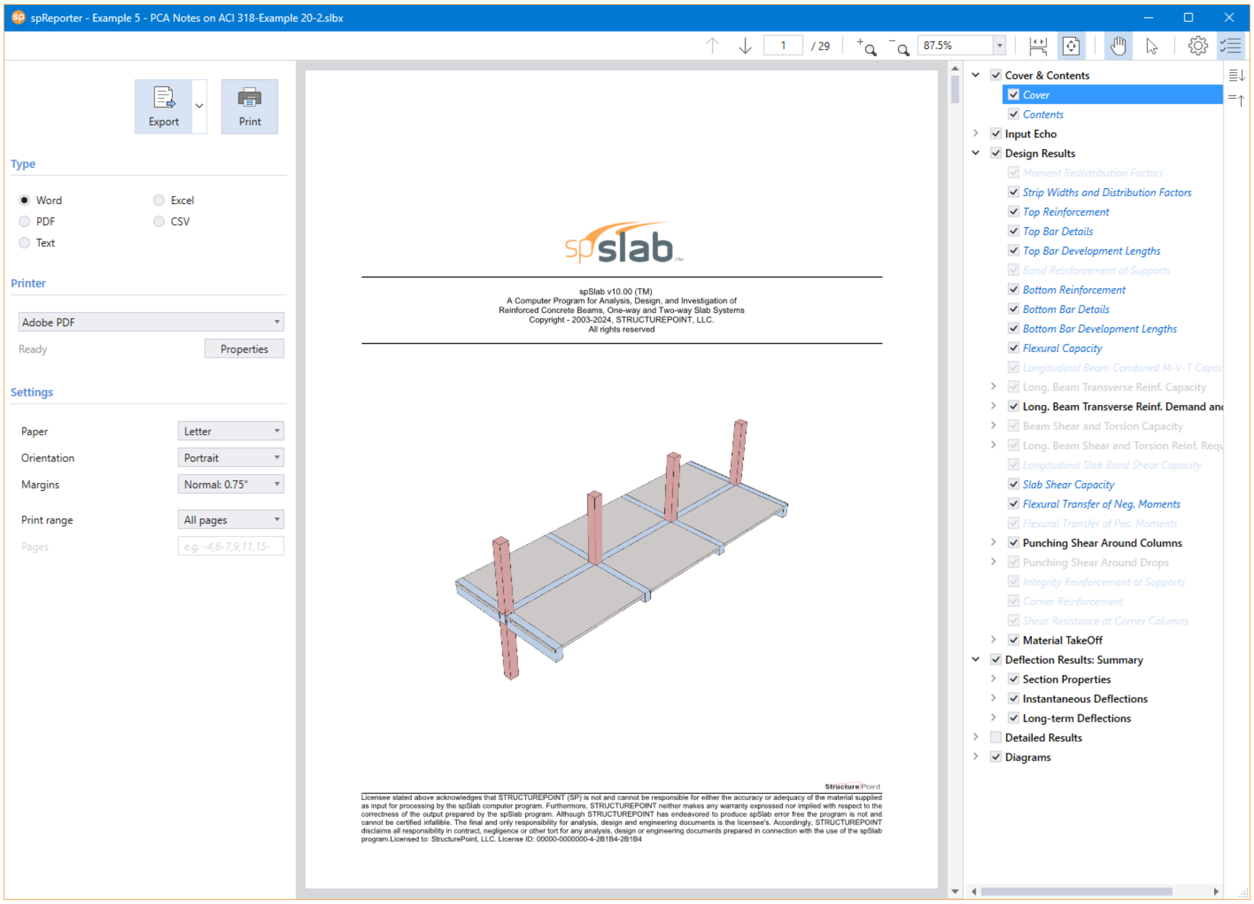

spSlab - Example 5 - PCA Notes on ACI 318-Example 20-2.slbx
File
Home
Project
Define
Grids
Select
Spans
Supports
Loads
Rebars
Solve
Results
Tables
Reporter
Display
Viewports
Settings
RESULTS
Int. Forces
Moment
Shear
Deflection
Reinf.
Span
All
In range from
to
Single
Strips
Beam Strip
Middle Strip
Column Strip
Show
Beam Flexural Bars
Stirrups
Bar Labels
Bar Lengths
Rotated Bar Labels
Hor. Stirrup Labels
DISPLAY OPTIONS
Diagram Grids
Legend
Fill Diagrams
Values
Scale
Results - Reinforcement
Legend:
Continuous
Discontinuous
Stirrups
Beam Strip Flexural and Transverse Reinforcement
Middle Strip Flexural Reinforcement
Column Strip Flexural Reinforcement
ACI 318-14
Two-Way
Design
x = -0.79 ft
Units: English

16. Results can be also viewed in table format by selecting the **Tables** command from the **Ribbon**.




| | | | | Required | | | Provided | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Span | Start | End | Xu | Vu | ıb/Patt | Av/s | Av | Sp | Av/s | ΦVn | |
| | ft | ft | ft | kips | | in²/in | in² | in | in²/in | kips | |
| 1 | 0.000 | 0.750 | 0.000 | 0.00 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | | | | | | | | | | | |
| 2 | 0.000 | 1.000 | 2.266 | 32.35 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | 1.000 | 5.971 | 2.266 | 32.35 | U1/All | 0.0100 | 0.22 | 8.0 | 0.0277 | 46.79 | *8 |
| | 5.971 | 9.676 | 5.971 | 11.38 | U1/Ever | 0.0000 | ----- | ----- | ----- | 12.08 | |
| | 9.676 | 16.500 | 15.234 | 42.17 | U1/All | 0.0220 | 0.22 | 8.6 | 0.0255 | 45.05 | |
| | 16.500 | 17.500 | 15.234 | 42.17 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | | | | | | | | | | | |
| 3 | 0.000 | 1.000 | 2.266 | 37.26 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | 1.000 | 7.824 | 2.266 | 37.26 | U1/All | 0.0160 | 0.22 | 8.6 | 0.0255 | 45.05 | |
| | 7.824 | 9.676 | 9.676 | 6.78 | U1/S3 | 0.0000 | ----- | ----- | ----- | 12.08 | |
| | 9.676 | 16.500 | 15.234 | 37.26 | U1/All | 0.0160 | 0.22 | 8.6 | 0.0255 | 45.05 | |
| | 16.500 | 17.500 | 15.234 | 37.26 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | | | | | | | | | | | |
| 4 | 0.000 | 1.000 | 2.266 | 42.17 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | 1.000 | 7.824 | 2.266 | 42.17 | U1/All | 0.0220 | 0.22 | 8.6 | 0.0255 | 45.05 | |
| | 7.824 | 11.529 | 11.529 | 11.38 | U1/Ever | 0.0000 | ----- | ----- | ----- | 12.08 | |
| | 11.529 | 16.500 | 15.234 | 32.35 | U1/All | 0.0100 | 0.22 | 8.0 | 0.0277 | 46.79 | *8 |
| | 16.500 | 17.500 | 15.234 | 32.35 | U1/All | ----- | ----- | ----- | ----- | ----- | |
| | | | | | | | | | | | |
| 5 | 0.000 | 0.750 | 0.750 | 0.00 | U1/All | ----- | ----- | ----- | ----- | ----- | |

17. Results can be printed or exported in different formats by selecting the **Reporter** command from the **Ribbon.**



CHAPTER

# A

# APPENDIX

# A.1. Default Load Case and Combination Factors

The program allows defining up to 50 load combinations. The user has full control over the combinations. The program contains predefined (built into the program) default primary load combinations for the supported codes. These default combinations are created when starting a new project.

### A.1.1. For ACI 318-14/11

For the ACI 318-14 and ACI 318-11 codes, the default combinations of the Self-weight (SW), Dead (D), Live (L), Snow (S), Wind (W) and Earthquake (E) loads considered by the program are[1]:

| Ultimate Load Combinations – ACI 318 – 14 / 11 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load Combo | Self-weight SW | Dead D | Live L | Snow S | Wind W | EQ E | Principal Loads | Companion Loads |
| U1 | 1.40 | 1.40 | | | | | SW, D | - |
| U2 | 1.20 | 1.20 | 1.60 | 0.50 | | | SW, D, L | S |
| U3 | 1.20 | 1.20 | 1.00 | 1.60 | | | SW, D, S | L |
| U4 | 1.20 | 1.20 | | 1.60 | 0.50 | | SW, D, S | W |
| U5 | 1.20 | 1.20 | | 1.60 | -0.50 | | SW, D, S | W |
| U6 | 1.20 | 1.20 | 1.00 | 0.50 | 1.00 | | SW, D, W | L, S |
| U7 | 1.20 | 1.20 | 1.00 | 0.50 | -1.00 | | SW, D, W | L, S |
| U8 | 1.20 | 1.20 | 1.00 | 0.20 | | 1.00 | SW, D, E | L, S |
| U9 | 1.20 | 1.20 | 1.00 | 0.20 | | -1.00 | SW, D, E | L, S |
| U10 | 0.90 | 0.90 | | | 1.00 | | SW, D, W | - |
| U11 | 0.90 | 0.90 | | | -1.00 | | SW, D, W | - |
| U12 | 0.90 | 0.90 | | | | 1.00 | SW, D, E | - |
| U13 | 0.90 | 0.90 | | | | -1.00 | SW, D, E | - |

1 ACI 318-14, 5.3.1; ACI 318-11, 9.2; (assuming W and E based on ultimate-level forces)

## A.1.2. For ACI 318-08/05/02

For the ACI 318-08, ACI 318-05, and ACI 318-02 codes, the default combinations of the Self-weight (SW), Dead (D), Live (L), Snow (S), Wind (W) and Earthquake (E) loads considered by the program are[2]:

| Ultimate Load Combinations – ACI 318 – 08 / 05 / 02 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load Combo | Self-weight SW | Dead D | Live L | Snow S | Wind W | EQ E | Principal Loads | Companion Loads |
| U1 | 1.40 | 1.40 | | | | | SW, D | - |
| U2 | 1.20 | 1.20 | 1.60 | 0.50 | | | SW, D, L | S |
| U3 | 1.20 | 1.20 | 1.00 | 1.60 | | | SW, D, S | L |
| U4 | 1.20 | 1.20 | | 1.60 | 0.80 | | SW, D, S | W |
| U5 | 1.20 | 1.20 | | 1.60 | -0.80 | | SW, D, S | W |
| U6 | 1.20 | 1.20 | 1.00 | 0.50 | 1.60 | | SW, D, W | L, S |
| U7 | 1.20 | 1.20 | 1.00 | 0.50 | -1.60 | | SW, D, W | L, S |
| U8 | 1.20 | 1.20 | 1.00 | 0.20 | | 1.00 | SW, D, E | L, S |
| U9 | 1.20 | 1.20 | 1.00 | 0.20 | | -1.00 | SW, D, E | L, S |
| U10 | 0.90 | 0.90 | | | 1.60 | | SW, D, W | - |
| U11 | 0.90 | 0.90 | | | -1.60 | | SW, D, W | - |
| U12 | 0.90 | 0.90 | | | | 1.00 | SW, D, E | - |
| U13 | 0.90 | 0.90 | | | | -1.00 | SW, D, E | - |

[2] ACI 318-08, 9.2; ACI 318-05, 9.2; ACI 318-02, 9.2 (assuming W based on service-level wind load and E based on ultimate-level forces)

### A.1.3. For ACI 318-99

For the ACI 318-99 code, the default combinations of the Self-weight (SW), Dead (D), Live (L), Wind (W) and Earthquake (E) loads considered by the program are[3]:

| Ultimate Load Combinations – ACI 318 – 99 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load Combo | Self-weight SW | Dead D | Live L | Snow S | Wind W | EQ E | Principal Loads | Companion Loads |
| U1 | 1.400 | 1.400 | 1.700 | | | | SW, D, L | - |
| U2 | 1.050 | 1.050 | 1.275 | | 1.275 | | SW, D, L, W | - |
| U3 | 1.050 | 1.050 | 1.275 | | -1.275 | | SW, D, L, W | - |
| U4 | 1.050 | 1.050 | | | 1.275 | | SW, D, W | - |
| U5 | 1.050 | 1.050 | | | -1.275 | | SW, D, W | - |
| U6 | 1.050 | 1.050 | 1.275 | | | 1.430 | SW, D, L, E | - |
| U7 | 1.050 | 1.050 | 1.275 | | | -1.430 | SW, D, L, E | - |
| U8 | 1.050 | 1.050 | | | | 1.430 | SW, D, E | - |
| U9 | 1.050 | 1.050 | | | | -1.430 | SW, D, E | - |
| U10 | 0.900 | 0.900 | | | 1.300 | | SW, D, W | - |
| U11 | 0.900 | 0.900 | | | -1.300 | | SW, D, W | - |
| U12 | 0.900 | 0.900 | | | | 1.430 | SW, D, E | - |
| U13 | 0.900 | 0.900 | | | | -1.430 | SW, D, E | - |

[3] ACI 318-99, 9.2

## A.1.4. For CSA A23.3-14

For the CSA A23.3-14 code load combinations are compliant with 2015 NBCC. The default combinations of the Self-weight (SW), Dead (D), Live (L), Snow (S), Wind (W) and Earthquake (E) loads considered by the program are[4]:

| Ultimate Load Combinations – CSA A23.3 – 14 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load Combo | Self-weight SW | Dead D | Live L | Snow S | Wind W | EQ E | Principal Loads | Companion Loads |
| U1 | 1.40 | 1.40 | | | | | SW, D | - |
| U2 | 1.25 | 1.25 | 1.50 | 1.00 | | | SW, D, L | S |
| U3 | 0.90 | 0.90 | 1.50 | 1.00 | | | SW, D, L | S |
| U4 | 1.25 | 1.25 | 1.50 | | 0.40 | | SW, D, L | W |
| U5 | 1.25 | 1.25 | 1.50 | | -0.40 | | SW, D, L | W |
| U6 | 0.90 | 0.90 | 1.50 | | 0.40 | | SW, D, L | W |
| U7 | 0.90 | 0.90 | 1.50 | | -0.40 | | SW, D, L | W |
| U8 | 1.25 | 1.25 | 1.00 | 1.50 | | | SW, D, S | L |
| U9 | 0.90 | 0.90 | 1.00 | 1.50 | | | SW, D, S | L |
| U10 | 1.25 | 1.25 | | 1.50 | 0.40 | | SW, D, S | W |
| U11 | 1.25 | 1.25 | | 1.50 | -0.40 | | SW, D, S | W |
| U12 | 0.90 | 0.90 | | 1.50 | 0.40 | | SW, D, S | W |
| U13 | 0.90 | 0.90 | | 1.50 | -0.40 | | SW, D, S | W |
| U14 | 1.25 | 1.25 | 0.50 | | 1.40 | | SW, D, W | L |
| U15 | 1.25 | 1.25 | 0.50 | | -1.40 | | SW, D, W | L |
| U16 | 1.25 | 1.25 | | 0.50 | 1.40 | | SW, D, W | S |
| U17 | 1.25 | 1.25 | | 0.50 | -1.40 | | SW, D, W | S |
| U18 | 0.90 | 0.90 | 0.50 | | 1.40 | | SW, D, W | L |
| U19 | 0.90 | 0.90 | 0.50 | | -1.40 | | SW, D, W | L |
| U20 | 0.90 | 0.90 | | 0.50 | 1.40 | | SW, D, W | S |
| U21 | 0.90 | 0.90 | | 0.50 | -1.40 | | SW, D, W | S |
| U22 | 1.00 | 1.00 | 0.50 | 0.25 | | 1.00 | SW, D, E | L, S |
| U23 | 1.00 | 1.00 | 0.50 | 0.25 | | -1.00 | SW, D, E | L, S |

[4] CSA A23.3-14, 8.3.2, Annex C, Table C1 a); NBCC 2015, Table 4.1.3.2.-A

## A.1.5. For CSA A23.3-04

For the CSA A23.3-04 code load combinations are compliant with 2005 NBCC. The default combinations of the Self-weight (SW), Dead (D), Live (L), Snow (S), Wind (W) and Earthquake (E) loads considered by the program are[5]:

| Ultimate Load Combinations – CSA A23.3 – 04 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load Combo | Self-weight SW | Dead D | Live L | Snow S | Wind W | EQ E | Principal Loads | Companion Loads |
| U1 | 1.40 | 1.40 | | | | | SW, D | - |
| U2 | 1.25 | 1.25 | 1.50 | 0.50 | | | SW, D, L | S |
| U3 | 0.90 | 0.90 | 1.50 | 0.50 | | | SW, D, L | S |
| U4 | 1.25 | 1.25 | 1.50 | | 0.40 | | SW, D, L | W |
| U5 | 1.25 | 1.25 | 1.50 | | -0.40 | | SW, D, L | W |
| U6 | 0.90 | 0.90 | 1.50 | | 0.40 | | SW, D, L | W |
| U7 | 0.90 | 0.90 | 1.50 | | -0.40 | | SW, D, L | W |
| U8 | 1.25 | 1.25 | 0.50 | 1.50 | | | SW, D, S | L |
| U9 | 0.90 | 0.90 | 0.50 | 1.50 | | | SW, D, S | L |
| U10 | 1.25 | 1.25 | | 1.50 | 0.40 | | SW, D, S | W |
| U11 | 1.25 | 1.25 | | 1.50 | -0.40 | | SW, D, S | W |
| U12 | 0.90 | 0.90 | | 1.50 | 0.40 | | SW, D, S | W |
| U13 | 0.90 | 0.90 | | 1.50 | -0.40 | | SW, D, S | W |
| U14 | 1.25 | 1.25 | 0.50 | | 1.40 | | SW, D, W | L |
| U15 | 1.25 | 1.25 | 0.50 | | -1.40 | | SW, D, W | L |
| U16 | 1.25 | 1.25 | | 0.50 | 1.40 | | SW, D, W | S |
| U17 | 1.25 | 1.25 | | 0.50 | -1.40 | | SW, D, W | S |
| U18 | 0.90 | 0.90 | 0.50 | | 1.40 | | SW, D, W | L |
| U19 | 0.90 | 0.90 | 0.50 | | -1.40 | | SW, D, W | L |
| U20 | 0.90 | 0.90 | | 0.50 | 1.40 | | SW, D, W | S |
| U21 | 0.90 | 0.90 | | 0.50 | -1.40 | | SW, D, W | S |
| U22 | 1.00 | 1.00 | 0.50 | 0.25 | | 1.00 | SW, D, E | L, S |
| U23 | 1.00 | 1.00 | 0.50 | 0.25 | | -1.00 | SW, D, E | L, S |

[5] CSA A23.3-04, 8.3.2, Annex C, Table C1 a); NBCC 2005, Table 4.1.3.2.-A

## A.1.6. For CSA A23.3-94

For the CSA A23.3-94 code, the default combinations of the Self-weight (SW), Dead (D), Live (L), Wind (W), Earthquake (E), and Snow (S) loads considered by the program are[6]:

| Ultimate Load Combinations – CSA A23.3 – 94 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load Combo | Self-weight SW | Dead D | Live L | Snow S | Wind W | EQ E | Principal Loads | Companion Loads |
| U1 | 1.25 | 1.25 | | | | | SW, D | - |
| U2 | 1.25 | 1.25 | 1.50 | 1.50 | | | SW, D, L | S |
| | 1.25 | 1.25 | 1.50 | 1.50 | | | SW, D, S | L |
| U3 | 0.85 | 0.85 | 1.50 | 1.50 | | | SW, D, L | S |
| | 0.85 | 0.85 | 1.50 | 1.50 | | | SW, D, S | L |
| U4 | 1.25 | 1.25 | 1.05 | 1.05 | 1.05 | | SW, D, L, W | S |
| | 1.25 | 1.25 | 1.05 | 1.05 | 1.05 | | SW, D, S, W | L |
| U5 | 1.25 | 1.25 | 1.05 | 1.05 | -1.05 | | SW, D, L, W | S |
| | 1.25 | 1.25 | 1.05 | 1.05 | -1.05 | | SW, D, S, W | L |
| U6 | 0.85 | 0.85 | 1.05 | 1.05 | 1.05 | | SW, D, L, W | S |
| | 0.85 | 0.85 | 1.05 | 1.05 | 1.05 | | SW, D, S, W | L |
| U7 | 0.85 | 0.85 | 1.05 | 1.05 | -1.05 | | SW, D, L, W | S |
| | 0.85 | 0.85 | 1.05 | 1.05 | -1.05 | | SW, D, S, W | L |
| U8 | 1.25 | 1.25 | | | 1.50 | | SW, D, W | - |
| U9 | 1.25 | 1.25 | | | -1.50 | | SW, D, W | - |
| U10 | 0.85 | 0.85 | | | 1.50 | | SW, D, W | - |
| U11 | 0.85 | 0.85 | | | -1.50 | | SW, D, W | - |
| U12 | 1.00 | 1.00 | | | | 1.00 | SW, D, E | - |
| U13 | 1.00 | 1.00 | | | | -1.00 | SW, D, E | - |
| U14 | 1.00 | 1.00 | 0.50 | 0.50 | | 1.00 | SW, D, L, E | S |
| | 1.00 | 1.00 | 0.50 | 0.50 | | 1.00 | SW, D, S, E | L |
| U15 | 1.00 | 1.00 | 0.50 | 0.50 | | -1.00 | SW, D, L, E | S |
| | 1.00 | 1.00 | 0.50 | 0.50 | | -1.00 | SW, D, S, E | L |

6 CSA A23.3-94, 8.3.2 (assuming occupancies other than storage and assembly); NBCC 1995, 4.1.3.2

# A.2. Conversion Factors – English to SI

| To convert from | To | Multiply by |
|---|---|---|
| in. | m (1,000 mm) | 0.025400 |
| ft | m | 0.304800 |
| lb | N (0.001 kN) | 4.448222 |
| kip (1,000 lbs) | kN | 4.448222 |
| plf (lb/ft) | N/m | 14.593904 |
| psi (lb/in.$^2$) | kPa | 6.894757 |
| ksi (kips/in.$^2$) | MPa | 6.894757 |
| psf (lb/ft$^2$) | N/m$^2$ (Pa) | 47.88026 |
| pcf (lb/ft$^3$) | kg/m$^3$ | 16.018460 |
| ft-kips | kN × m | 1.355818 |

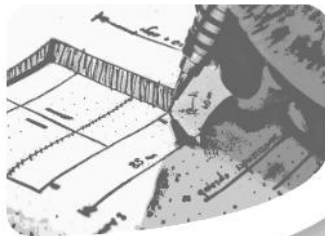
# A.3. Conversion Factors – SI to English

| To convert from | To | Multiply by |
|---|---|---|
| m (1,000 mm) | in. | 39.37008 |
| m | ft | 3.28084 |
| N (0.001 kN) | lb | 0.224809 |
| kN | kip (1,000 lbs) | 0.224809 |
| kN/m | plf (lb/ft) | 68.52601 |
| MPa | psi (lb/in.$^2$) | 145.0377 |
| MPa | ksi (kips/in.$^2$) | 0.145038 |
| kN/m$^2$ (kPa) | psf (lb/ft$^2$) | 20.88555 |
| kg/m$^3$ | pcf (lb/ft$^3$) | 0.062428 |
| kN × m | ft-kips | 0.737562 |

# A.4. Technical Resources

Bookstore

Technical Articles



Design Examples

Case Studies

StructurePoint Wiki

Video Tutorials


Web Applications


Technical Manuals

## A.5. Contact Information

| | |
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