StructurePoint
CONCRETE SOFTWARE SOLUTIONS

Column Design with High-Strength Reinforcing Bars per ACI 318-19

ACI 318-19 introduced new provisions for high-strength reinforcing bars (HSRB) with 80 ksi and 100 ksi strengths. These provisions are as follows:

- Generalization of the strain reduction limit on ε_t: Table 21.2.2 in ACI 318-19 defines the strength reduction factor ϕ, for tension-controlled sections as an expression of f_y, for all reinforcement grades. Therefore, beginning with the 2019 Code, the expression, ε_{ty} + 0.003, defines the lower limit on ε_t for tension-controlled behavior.

- Upper limit for f_y is introduced for maximum axial compressive strength, $P_{n,max,}$ calculations: ACI 318-19, 22.4.2.1 states that *"the value of f_y shall be limited to a maximum of 80,000 psi"* when calculating the maximum axial compressive strength, $P_{n,max,}$ for nonprestressed and prestressed members with f_y exceeding 80,000 psi.

The impact of these new ACI 318-19 provisions are discussed and evaluated further by utilizing the design example titled "Interaction Diagram - Tied Reinforced Concrete Column (ACI 318-14)".

Using the spColumn engineering software program, tables below summarize the comparison of key control points for the nominal and the factored P-M interaction diagrams when using 60 ksi, 80 ksi, and 100 ksi steel bar strengths.

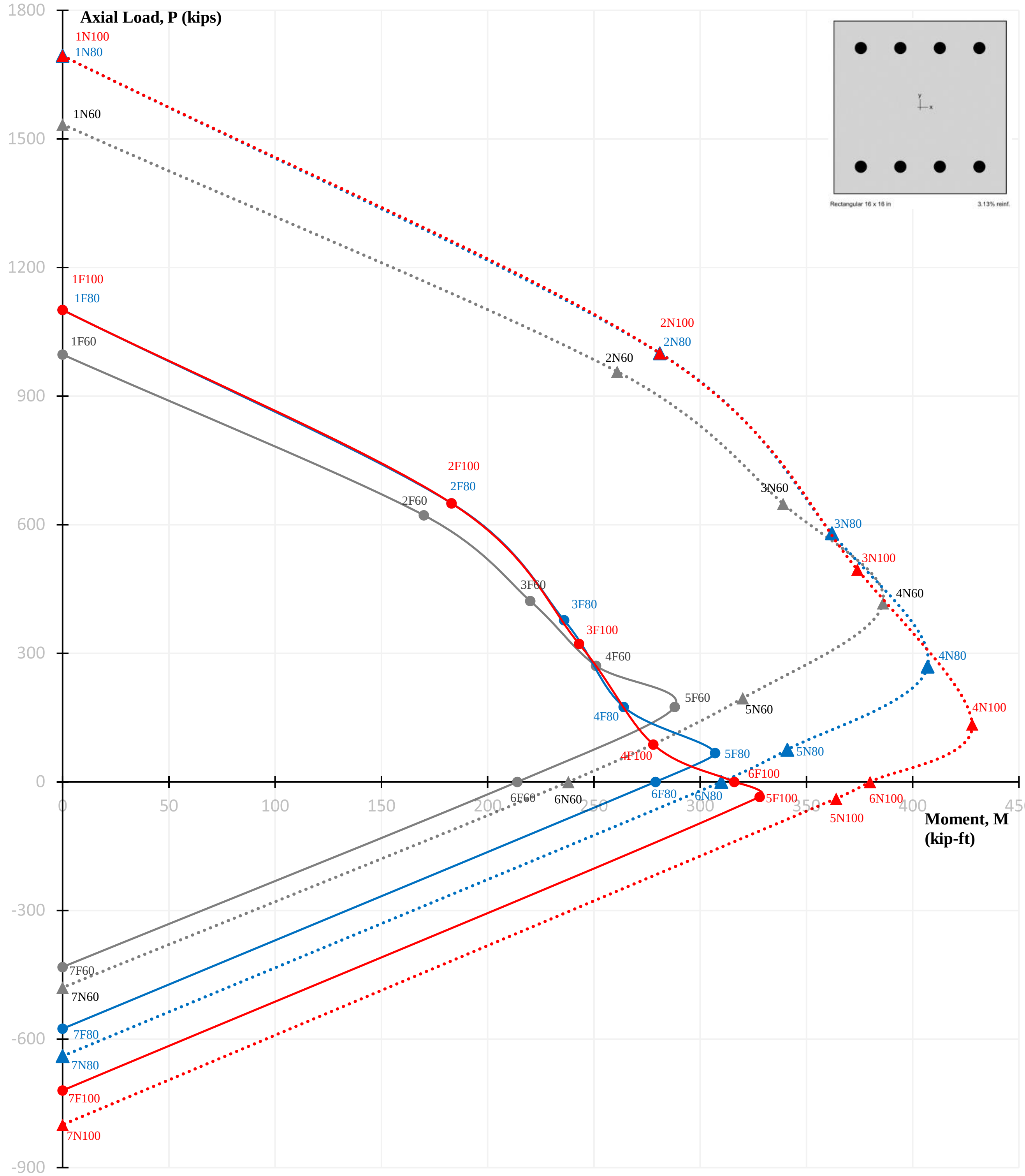
Table 1 – Nominal P-M Interaction Diagram Control Points per ACI 318-19

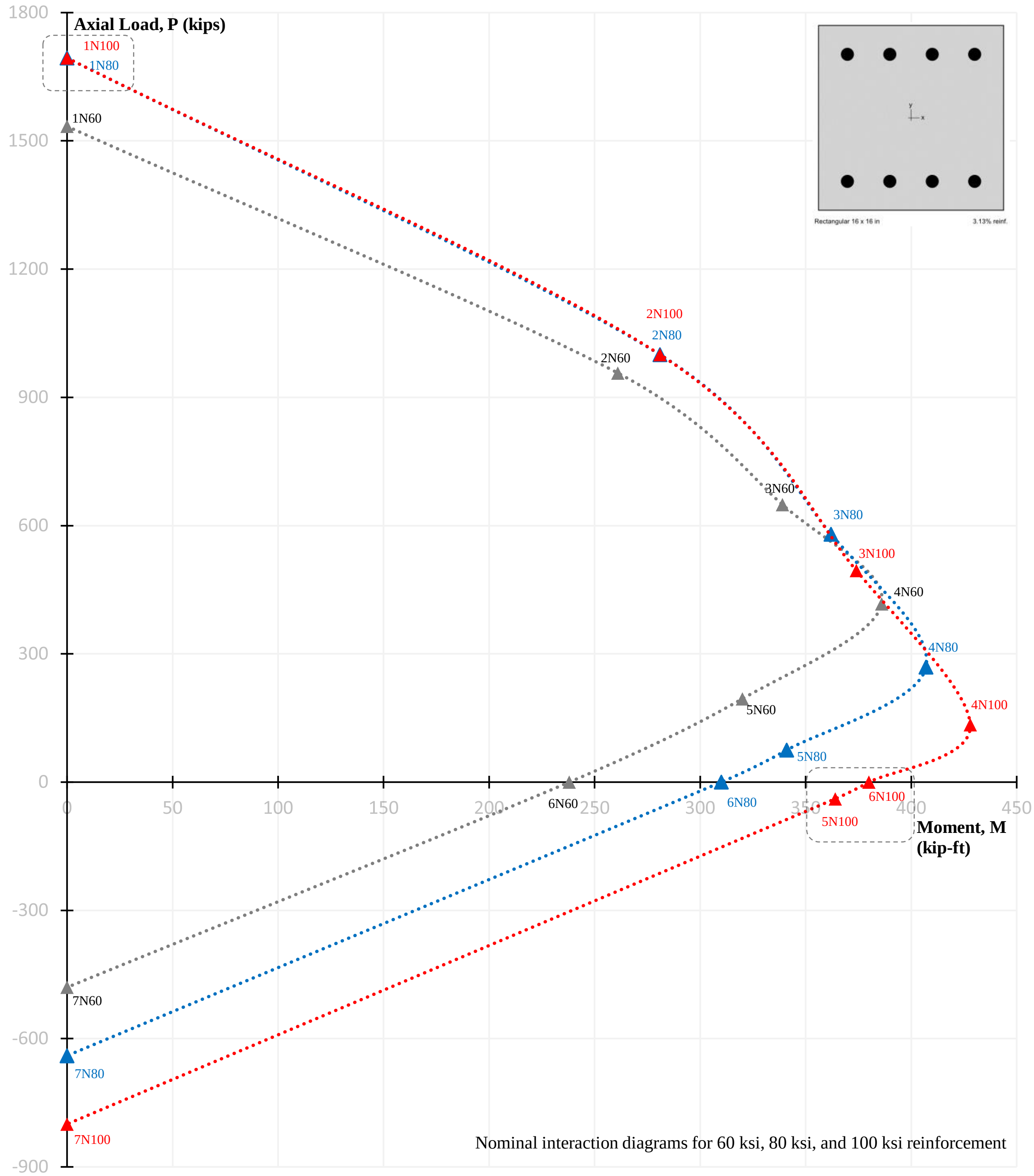
Control Points	Labels	P_n, kips			M_n, kip-ft		
Reinforcing bar strength		60 ksi	80 ksi	100 ksi	60 ksi	80 ksi	100 ksi
Max compression, P_0	1N	1534	1694	1694	0	0	0
$\varepsilon_s = 0.0$	2N	957	1000	1000	261	281	281
$\varepsilon_s = 0.5\ \varepsilon_{ty}$	3N	649	580	495	339	362	374
$\varepsilon_s = \varepsilon_{ty}$ [Compression-controlled limit]	4N	417	269	134	386	407	428
$\varepsilon_s = \varepsilon_{ty} + 0.003$ [Tension-controlled limit]	5N	195	75	-39	320	341	380
Pure bending	6N	0	0	0	238	310	364
Max tension	7N	-480	-640	-800	0	0	0

Table 2 – Factored P-M Interaction Diagram Control Points per ACI 318-19

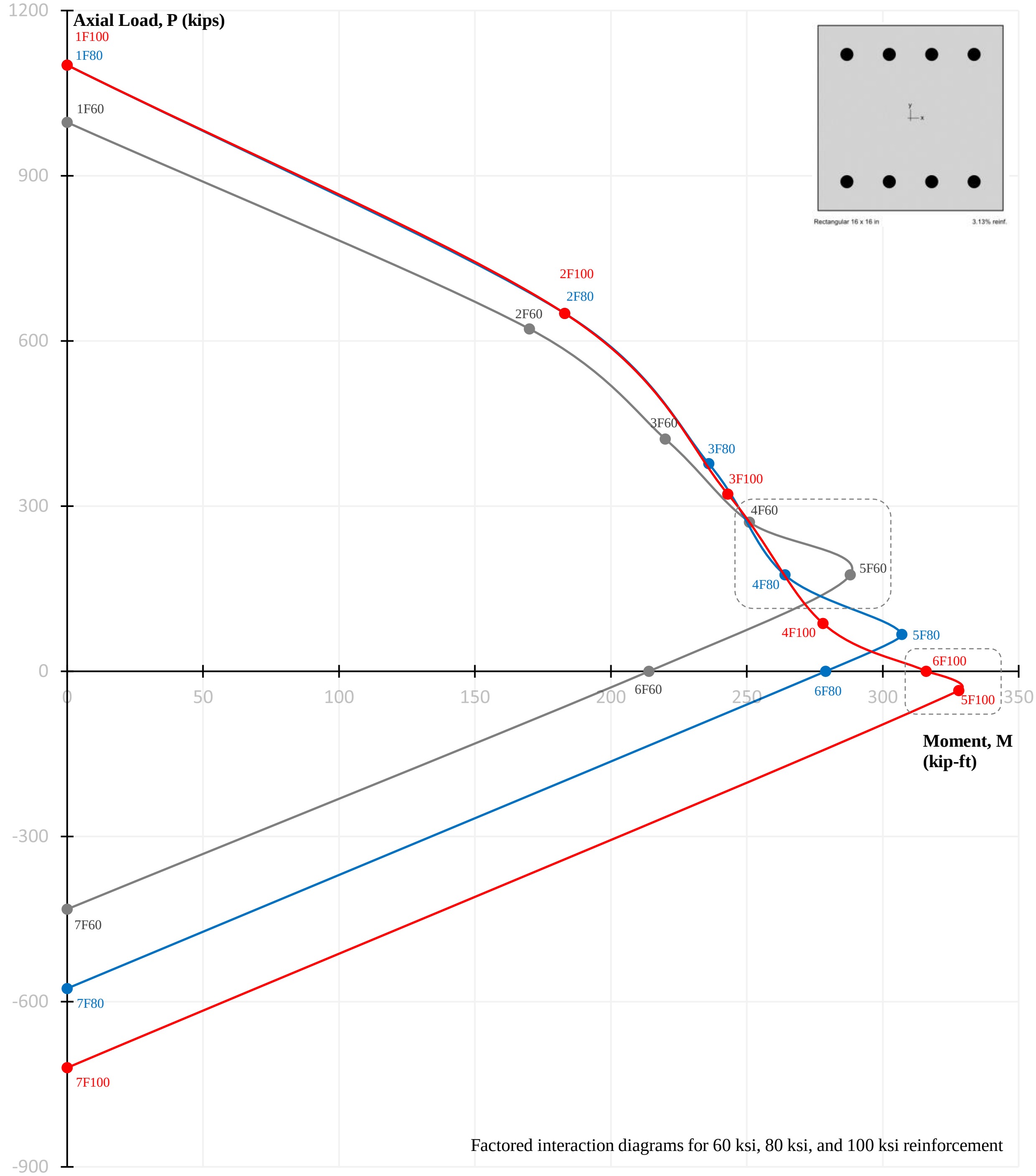
Control Points	Labels	$\phi\ P_n$, kips			$\phi\ M_n$, kip-ft		
Reinforcing bar strength		60 ksi	80 ksi	100 ksi	60 ksi	80 ksi	100 ksi
Max compression, ϕP_0	1F	997	1101	1101	0	0	0
$\varepsilon_s = 0.0$	2F	622	650	650	170	183	183
$\varepsilon_s = 0.5\ \varepsilon_{ty}$	3F	422	377	322	220	236	243
$\varepsilon_s = \varepsilon_{ty}$ [Compression-controlled limit]	4F	271	175	87	251	264	278
$\varepsilon_s = \varepsilon_{ty} + 0.003$ [Tension-controlled limit]	5F	175	67*	-35*	288	307*	316*
Pure bending	6F	0	0	0	214	279	328
Max tension	7F	-432	-576	-720	0	0	0
* Modified manually to reflect new tension-controlled limit in ACI 318-19							

The figure shows nominal and factored interaction diagrams for a column section with Gr 60, Gr 80, and Gr 100 reinforcement. Each point is labeled such as 4F80 indicate 4 = control point 4, F = Factored, 80 = 80 ksi strength.





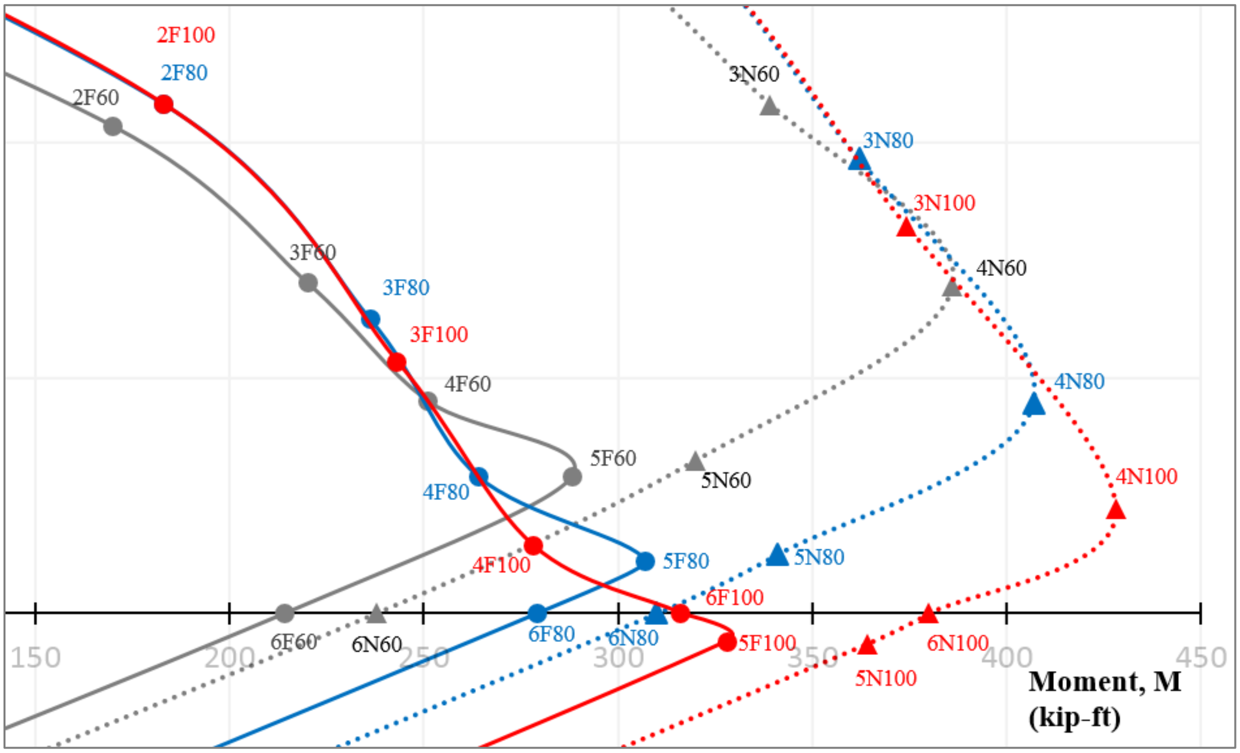
Notes:
1. The nominal axial strength at zero eccentricity for Gr 100 reinforcement [1N100] is calculated by limiting its yield strength, f_y, to 80 ksi. Therefore, control points 1 and 2 have same values for Gr 80 and Gr 100 reinforcement.
2. Lower reinforcement grade yields consistently lower factored moment capacity at all axial load levels.
3. Column with Gr 100 reinforcement reaches the tension-controlled limit [5N100] at axial tension loads.
4. Column with Gr 100 reinforcement reaches the pure bending [6N100] at the transition zone.



Factored interaction diagrams for 60 ksi, 80 ksi, and 100 ksi reinforcement

Notes:

1. The lower reinforcement grade has a higher factored moment capacity at some axial load levels.
2. Gr 80 and Gr 100 reinforcement have identical factored capacities from point 1F to 2F. Beyond point 2F where the strain in rebar is greater than zero ($\varepsilon_s > 0.0$), the factored capacities starts to differ.
3. Column with Gr 100 reaches pure bending at transition zone prior to tension-controlled limit.
4. The factored moment capacity at a given strain level (i.e. 5F - $\varepsilon_s = \varepsilon_{ty}$) increases as reinforcement grade increases.



The figure above shows nominal and factored interaction diagrams for a column section with 60 ksi, 80 ksi, and 100 ksi reinforcement.

Note 1:
Factored interaction diagram control points (e.g. 3F100) are obtained by multiplying Nominal interaction diagram control points (e.g. 3N100) by the strength reduction factor, ϕ, per ACI 318-19, Table 21.2.2.

Control points 4F80 and 5F60 have the same factored axial load capacity, ϕP_n of 175 kips. However, at this same axial load capacity, the factored moment capacity of higher grade, Gr 80, is smaller than the factored moment capacity of the lower grade, Gr 60. This can be explained as follows:

The control point 4N80 is at compression-controlled limit where reinforcement strain, ε_s, equals to ε_{ty} and the strength reduction factor, ϕ, equals to 0.65. Therefore, 4F80 equals to 65% of 4N80. On the other hand, the control point 5N60 is at tension-controlled limit where reinforcement strain, ε_s, equals to ε_{ty} + 0.003 and the strength reduction factor, ϕ, equals to 0.90. Therefore, 5F60 equals to 90% of 5N60.

Even though the nominal moment capacity at 4N80 is much greater than that of 5N60, the strength reduction of 0.65 for 4N80 lowers the factored axial and moment capacities for 4F80 so significantly that Gr 60 reinforcement provides higher factored moment capacity.

Note 2:
For Gr 100 reinforcement, the tension-controlled strain limit is 0.00645 per ACI 318-19, Table 21.2.2. For this example, at the control point 5N100 (tension-controlled strain limit), the cross-section has a nominal axial load capacity that is negative (tension). This implies that a cross-section still does not satisfy the tension-controlled section criteria with no axial load as in the case of pure bending condition and the control point 6N100 (pure bending) is located in the transition zone.