FINITE ELEMENT MESH SIZING INFLUENCE ON MAT FOUNDATION REINFROCEMENT

The optimal mesh sizing in utilizing the Finite Element Method (FEM) for the design of foundation systems under concentrated loading is a frequently asked question by Structural Engineers.

A 48' x 48' x 2' deep mat foundation with a 400 kips point load at the center is used here to examine this important question. Multiple models with 8'-0", 4'-0", 2'-0", 1'-0", 0'-6", 0'-3" finite element mesh sizes respectively are used.

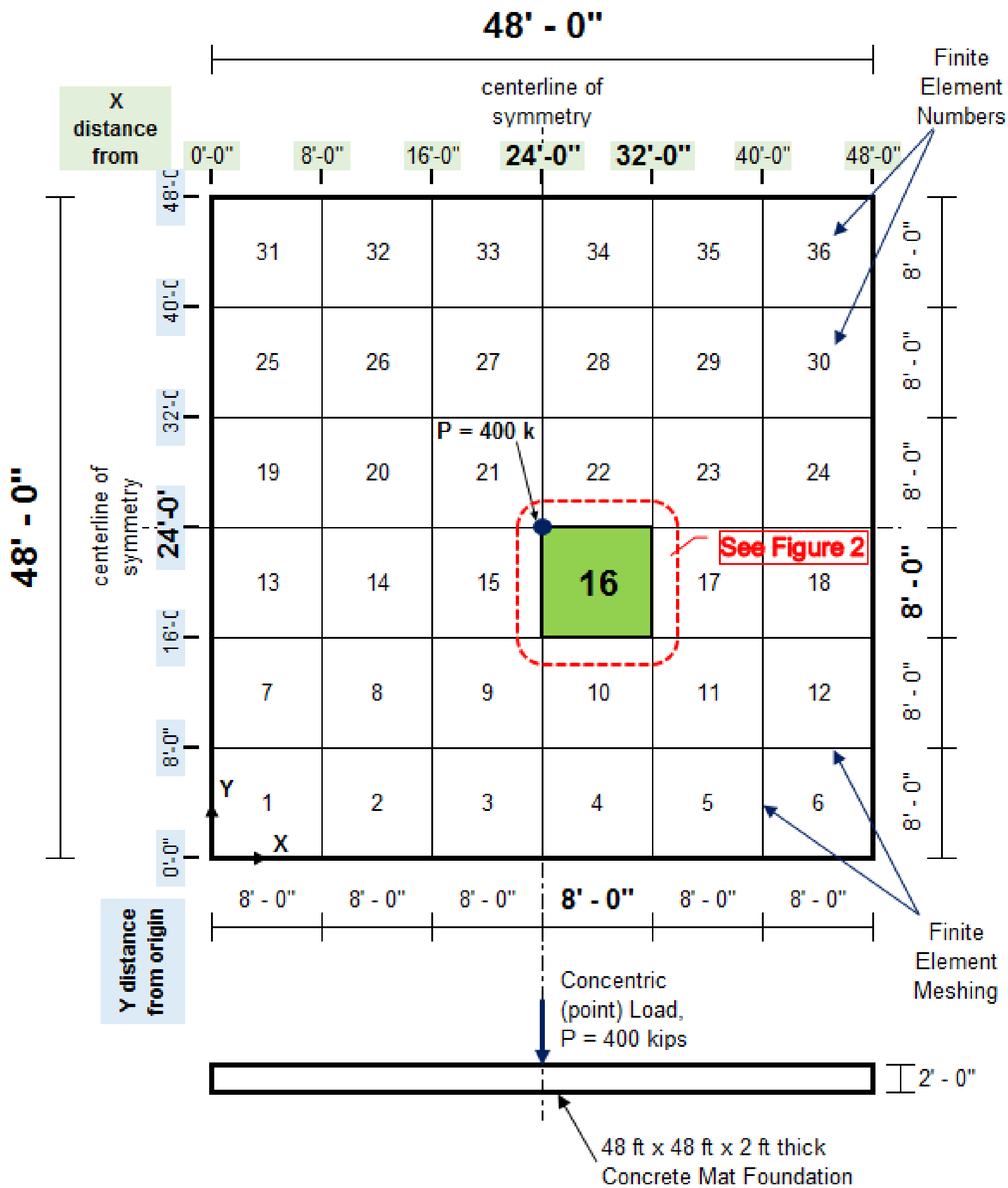

Figure 1 – Plan and Elevation View of the 48'-0" x 48'-0" x 2' deep Mat Foundation with 8 ft Finite Element Mesh

Since the foundation is symmetric in X and Y directions, only the Y-direction bottom design moment, M_{uy}, (along Y-axis) and corresponding required bottom reinforcement, A_{sy}, (along Y-axis) results will be demonstrated.
The comparison of results will also be limited to the 8 ft width [24'-0" ≤ X ≤ 32'-0"] adjacent to the concentric load at Y=24'-0" and X=24'-0" as it will suffice to show the mesh sizing influence on design moment and reinforcement.

Figure 2 below shows the blow-up plan view of this 8 ft width [i.e. 24’-0” ≤ X ≤ 32’-0”] at Y = 24’-0” for mesh sizes ranging from 8 ft to 0.25 ft. Within this 8 ft width, 8 ft meshing produces a single finite element (Elements 16), 4 ft meshing produces 2 finite elements (Elements 67 and 68), 2 ft meshing produces 4 finite elements (Elements 277 thru 280), 1 ft meshing produces 8 finite elements (Elements 1129 thru 1136), 0.50 ft meshing produces 16 finite elements (Elements 4561 thru 4576) and 0.25 ft meshing produces 32 finite elements (Elements 18337 thru 18368).

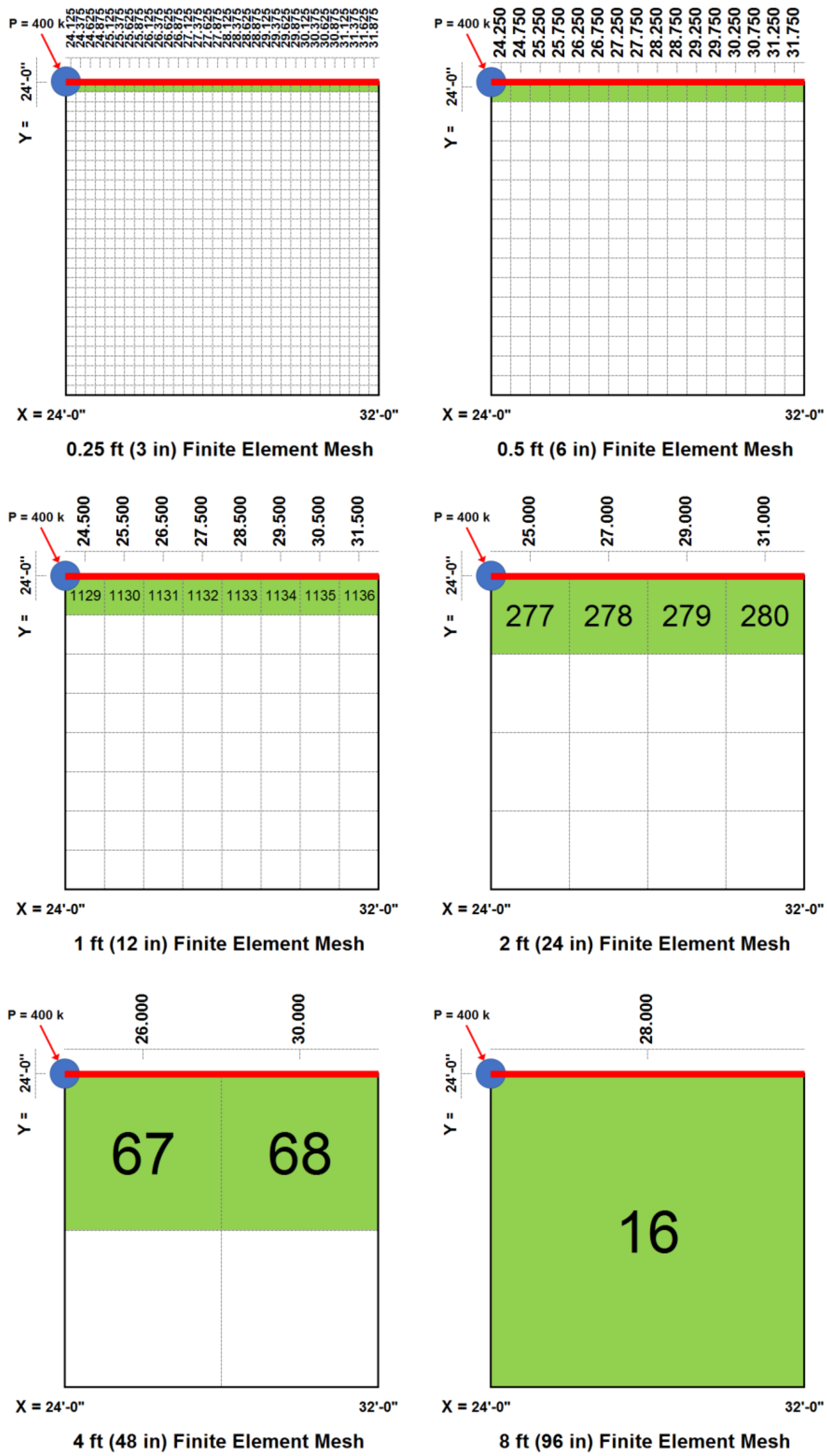

Figure 2 – Plan View the 8 ft width [24’-0” ≤ X ≤ 32’-0”] adjacent to the concentric load

Comparison of Bottom Design Moment, M_{uy}

From table and figure below it can be seen as the mesh size gets smaller, the design moment begins to peak near the concentrated load application point which is the true representation of the moment distribution in this 8 ft segment.

X = 24.000 ft

<table>
<tr><th colspan="3">8 ft Mesh [1 Finite Element]</th><th colspan="3">4 ft Mesh [2 Finite Elements]</th><th colspan="3">2 ft Mesh [4 Finite Elements]</th><th colspan="3">1 ft Mesh [8 Finite Elements]</th><th colspan="3">0.5 ft Mesh [16 Finite Elements]</th><th colspan="3">0.25 ft Mesh [32 Finite Elements]</th></tr>
<tr><th>Element No.</th><th>Element Centerline Coordinate (ft)</th><th>Design $M_{uy,bottom}$ (kip-ft/ft)</th><th>Element No.</th><th>Element Centerline Coordinate (ft)</th><th>Design $M_{uy,bottom}$ (kip-ft/ft)</th><th>Element No.</th><th>Element Centerline Coordinate (ft)</th><th>Design $M_{uy,bottom}$ (kip-ft/ft)</th><th>Element No.</th><th>Element Centerline Coordinate (ft)</th><th>Design $M_{uy,bottom}$ (kip-ft/ft)</th><th>Element No.</th><th>Element Centerline Coordinate (ft)</th><th>Design $M_{uy,bottom}$ (kip-ft/ft)</th><th>Element No.</th><th>Element Centerline Coordinate (ft)</th><th>Design $M_{uy,bottom}$ (kip-ft/ft)</th></tr>
<tr><td rowspan="32">16</td><td rowspan="32">28.000</td><td rowspan="32">-89.74</td><td rowspan="16">67</td><td rowspan="16">26.000</td><td rowspan="16">-120.11</td><td rowspan="8">277</td><td rowspan="8">25.000</td><td rowspan="8">-147.55</td><td rowspan="4">1129</td><td rowspan="4">24.500</td><td rowspan="4">-174.25</td><td rowspan="2">4561</td><td rowspan="2">24.25</td><td rowspan="2">-200.78</td><td>18337</td><td>24.125</td><td>-227.27</td></tr>
<tr><td>18338</td><td>24.375</td><td>-156.51</td></tr>
<tr><td rowspan="2">4562</td><td rowspan="2">24.75</td><td rowspan="2">-130.04</td><td>18339</td><td>24.625</td><td>-127.23</td></tr>
<tr><td>18340</td><td>24.875</td><td>-112.62</td></tr>
<tr><td rowspan="4">1130</td><td rowspan="4">25.500</td><td rowspan="4">-103.61</td><td rowspan="2">4563</td><td rowspan="2">25.25</td><td rowspan="2">-100.81</td><td>18341</td><td>25.125</td><td>-101.74</td></tr>
<tr><td>18342</td><td>25.375</td><td>-93.07</td></tr>
<tr><td rowspan="2">4564</td><td rowspan="2">25.75</td><td rowspan="2">-86.26</td><td>18343</td><td>25.625</td><td>-85.92</td></tr>
<tr><td>18344</td><td>25.875</td><td>-79.86</td></tr>
<tr><td rowspan="8">278</td><td rowspan="8">27.000</td><td rowspan="8">-77.32</td><td rowspan="4">1131</td><td rowspan="4">26.500</td><td rowspan="4">-74.53</td><td rowspan="2">4565</td><td rowspan="2">26.25</td><td rowspan="2">-75.48</td><td>18345</td><td>26.125</td><td>-74.62</td></tr>
<tr><td>18346</td><td>26.375</td><td>-70.03</td></tr>
<tr><td rowspan="2">4566</td><td rowspan="2">26.75</td><td rowspan="2">-66.94</td><td>18347</td><td>26.625</td><td>-65.94</td></tr>
<tr><td>18348</td><td>26.875</td><td>-62.26</td></tr>
<tr><td rowspan="4">1132</td><td rowspan="4">27.500</td><td rowspan="4">-60.26</td><td rowspan="2">4567</td><td rowspan="2">27.25</td><td rowspan="2">-59.95</td><td>18349</td><td>27.125</td><td>-58.93</td></tr>
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<tr><td>18352</td><td>27.875</td><td>-50.53</td></tr>
<tr><td rowspan="16">68</td><td rowspan="16">30.000</td><td rowspan="16">-51.51</td><td rowspan="8">279</td><td rowspan="8">29.000</td><td rowspan="8">-48.88</td><td rowspan="4">1133</td><td rowspan="4">28.500</td><td rowspan="4">-49.85</td><td rowspan="2">4569</td><td rowspan="2">28.25</td><td rowspan="2">-49.07</td><td>18353</td><td>28.125</td><td>-48.14</td></tr>
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<tr><td>18356</td><td>28.875</td><td>-41.92</td></tr>
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<tr><td>18358</td><td>29.375</td><td>-38.40</td></tr>
<tr><td rowspan="2">4572</td><td rowspan="2">29.75</td><td rowspan="2">-37.53</td><td>18359</td><td>29.625</td><td>-36.79</td></tr>
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<tr><td rowspan="8">280</td><td rowspan="8">31.000</td><td rowspan="8">-35.58</td><td rowspan="4">1135</td><td rowspan="4">30.500</td><td rowspan="4">-35.42</td><td rowspan="2">4573</td><td rowspan="2">30.25</td><td rowspan="2">-34.53</td><td>18361</td><td>30.125</td><td>-33.83</td></tr>
<tr><td>18362</td><td>30.375</td><td>-32.48</td></tr>
<tr><td rowspan="2">4574</td><td rowspan="2">30.75</td><td rowspan="2">-31.83</td><td>18363</td><td>30.625</td><td>-31.19</td></tr>
<tr><td>18364</td><td>30.875</td><td>-29.97</td></tr>
<tr><td rowspan="4">1136</td><td rowspan="4">31.500</td><td rowspan="4">-30.24</td><td rowspan="2">4575</td><td rowspan="2">31.25</td><td rowspan="2">-29.41</td><td>18365</td><td>31.125</td><td>-28.81</td></tr>
<tr><td>18366</td><td>31.375</td><td>-27.71</td></tr>
<tr><td rowspan="2">4576</td><td rowspan="2">31.75</td><td rowspan="2">-27.22</td><td>18367</td><td>31.625</td><td>-26.67</td></tr>
<tr><td>18368</td><td>31.875</td><td>-25.67</td></tr>
</table>

X = 32.000 ft

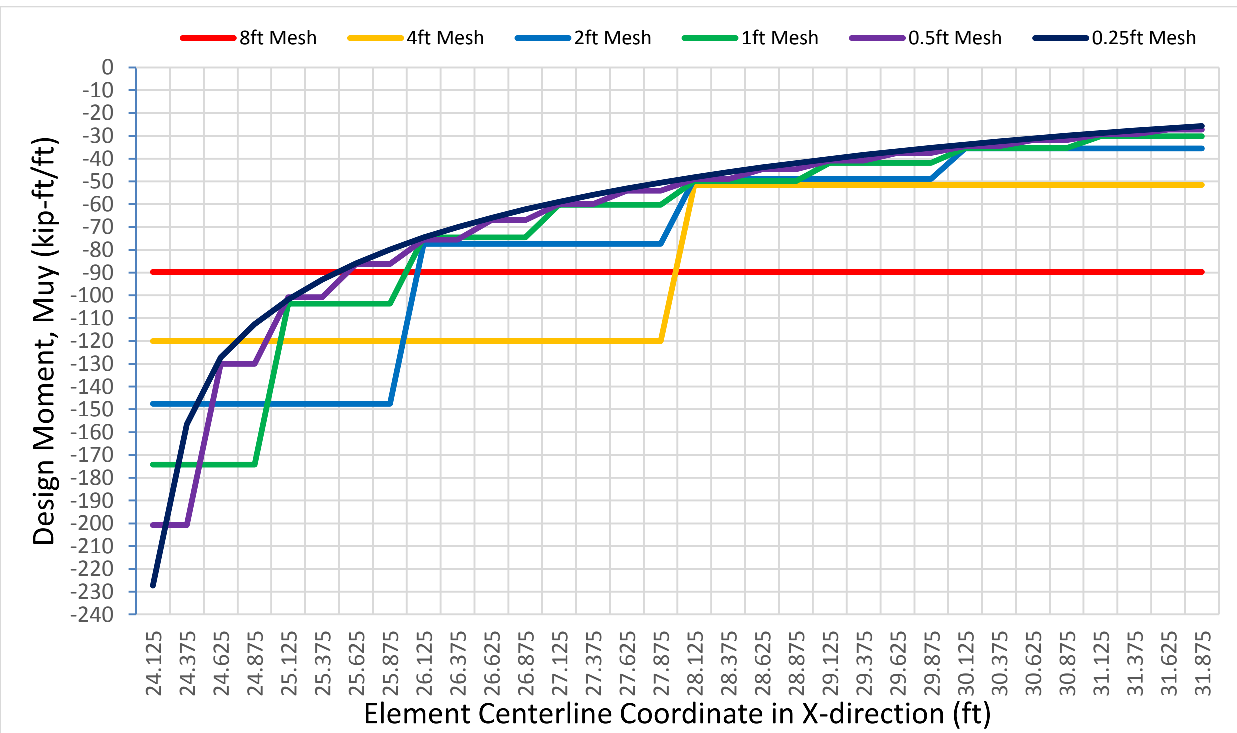


Figure 3 - Design Bottom Moment, Muy (ft-kip) @ Y=24'-0" between X=24'-0" and X=32'-0"

Similarly, the Figure 4 below shows that as the mesh size gets smaller, the reinforcement requirement peaks near the concentrated load application point

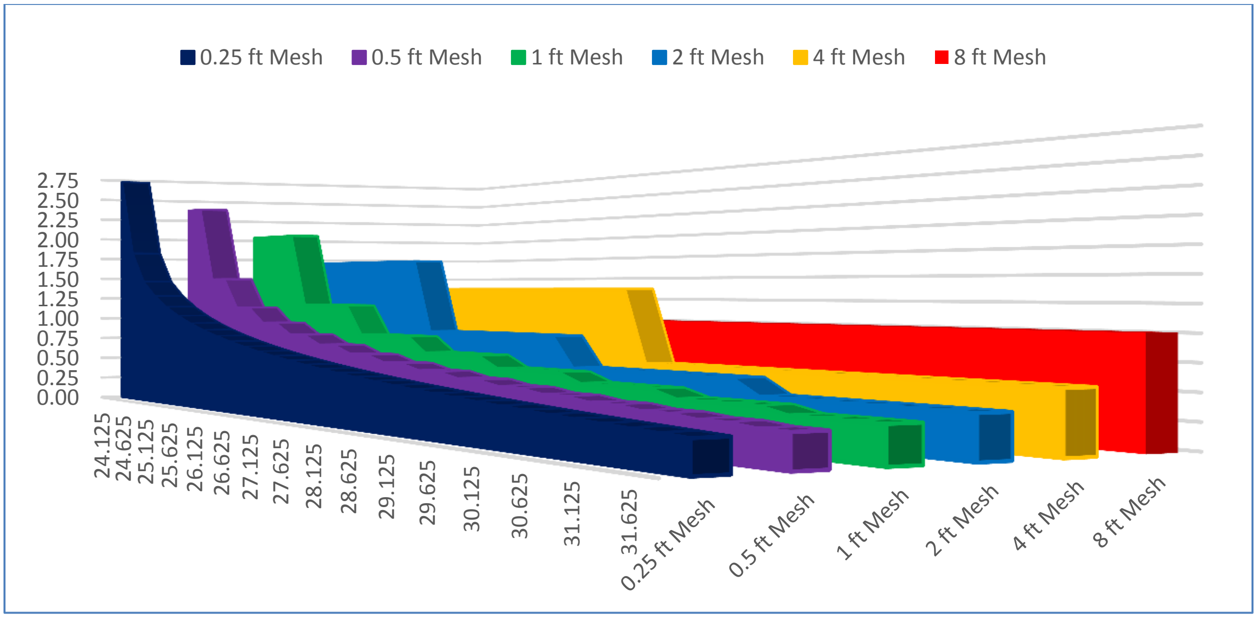
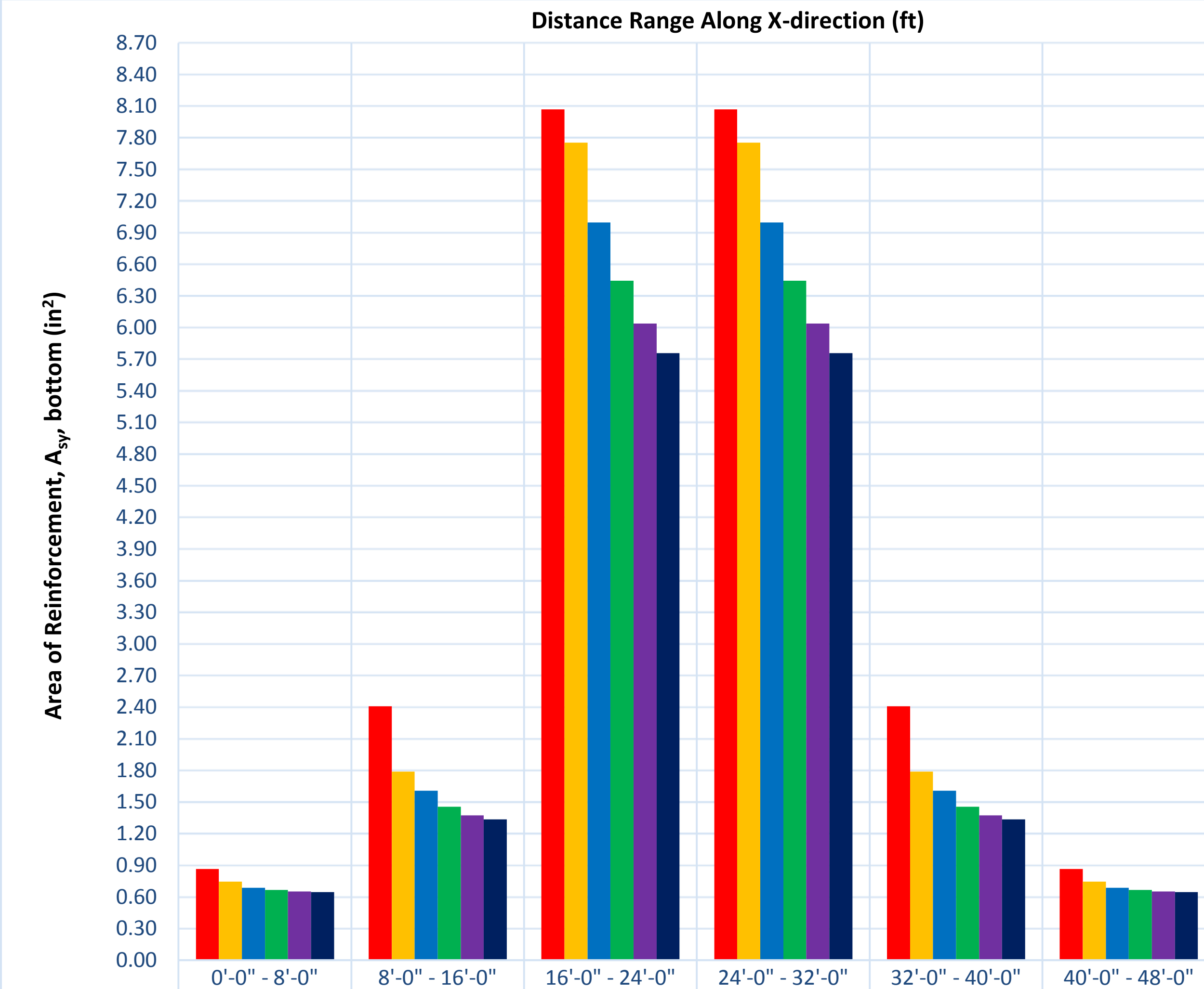


Figure 4 - Bottom Reinforcement Along Y-direction , Asy (in^2) @ Y=24'-0" between X=24'-0" and X=32'-0".

Nevertheless, the total amount of reinforcement required within the given range (i.e. 24'-0" ≤ X ≤ 32'-0") is actually less in finer mesh models as compared to coarser mesh models desipt the pronounced peak near the concentrated load.

Figure 5 below shows that for the range 24'-0" ≤ X ≤ 32'-0" at Y=24'-0", 0.25 ft mesh ($A_{sy,}$ bottom= 5.76 in^2) model results in approximately 30% less Y-direction bottom reinforcement requirement as compared to 8 ft mesh model ($A_{sy.}$ bottom= 8.07 in^2). For the entire width of the mat foundation, 0'-0" ≤ X ≤ 48'-0" at Y=24'0", the Y-direction bottom reinforcements are 15.5 in^2 and 22.68 in^2 for 0.25 ft mesh and 8 ft mesh respectively.



	0'-0" - 8'-0"	8'-0" - 16'-0"	16'-0" - 24'-0"	24'-0" - 32'-0"	32'-0" - 40'-0"	40'-0" - 48'-0"
8ft Mesh	0.86	2.41	8.07	8.07	2.41	0.86
4ft Mesh	0.74	1.79	7.76	7.76	1.79	0.74
2ft Mesh	0.69	1.61	7.00	7.00	1.61	0.69
1ft Mesh	0.67	1.46	6.45	6.45	1.46	0.67
0.5ft Mesh	0.65	1.37	6.04	6.04	1.37	0.65
0.25ft Mesh	0.65	1.34	5.76	5.76	1.34	0.65

Figure 4 - Bottom Reinforcement Along Y-direction , Asy (in^2) @ Y=24'-0" between X=24'-0" and X=32'-0".

In FEA models for mat foundation systems with concentrated load reactions of columns or pedestals at the top of mat slab, the spMats Program provides the user to determine the required reinforcement based on the average moment within an element as compared to default option of calculating the required reinforcement based on the maximum moment within the element. The averaging of moment within the element alleviates the moment and reinforcement concentration in the proximity of applied concentrated load and can be justified due to the uniform nature of application of such a reaction within the footprint of the column or pedestal. Another modeling option in spMats for this loading condition is to apply the reaction as a surface area load within the footprint of the column or pedestal.

Conclusions

Based on the study above the following can be concluded:

1. As the mesh size decreases, the required area of reinforcement near the applied concentrated load peaks as compared to coarser mesh models. However, the overall amount of required reinforcement area tends to be smaller as the mesh sizes decrease (fine mesh models).
2. Additional factors that may be considered are:
    a. The amount of output required to interpret results increases as mesh size gets finer.
    b. The savings in the amount of reinforcement required may also be reduced by the increase in complexity in laying out of the different reinforcement spacings on site based on sharp changes in moments (reinforcement demand) in finer mesh models.
3. For typical size concrete column or pedestal applications, the utilization of concentrated loads with average moment solver option in spMats may yield smearing of stress concentration effects around the point load application which has a similar effect as the surface load application of the concentrated load within the footprint of concrete column or pedestal.

In general FEA programs such as spMats should be used carefully by the engineer when it comes making choices of element size, density and aspect ratio. The choices can be predicated on the importance of the structure, cost considerations, detailing and construction options, prevailing minimum reifemcement especially in massive structural elements, and finally constructability and schedule.

References

[1] spMats v8.12 – Analysis and Design of Foundation Mats, Combined Footings, and Slabs on Grade, STRUCTUREPOINT 2016