# Benchmarks for beams under elevated temperature

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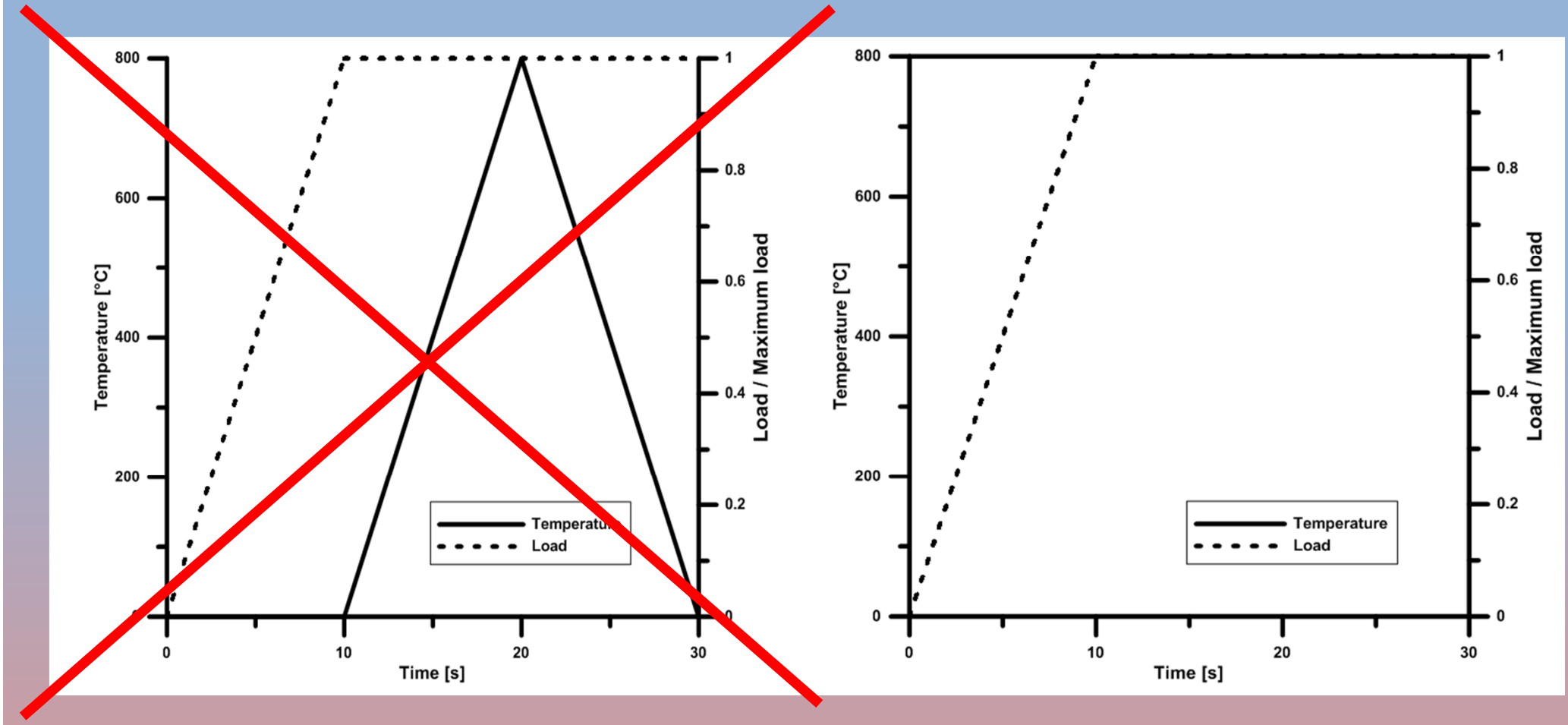
# Previous assumptions – temperature variaton

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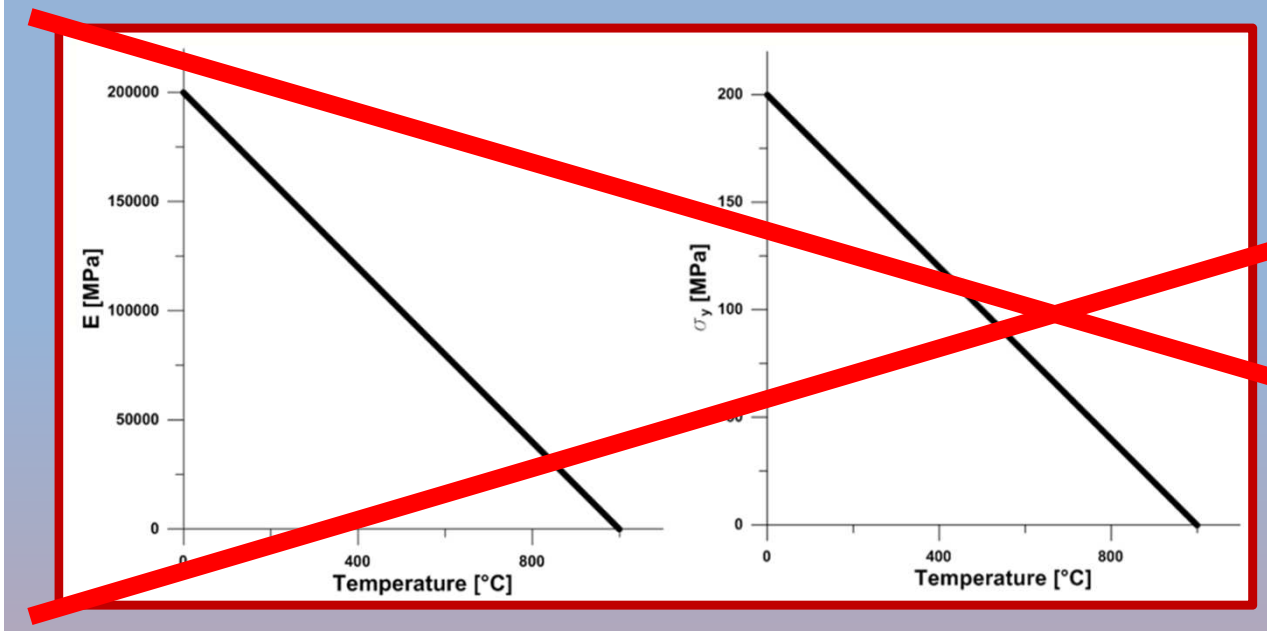
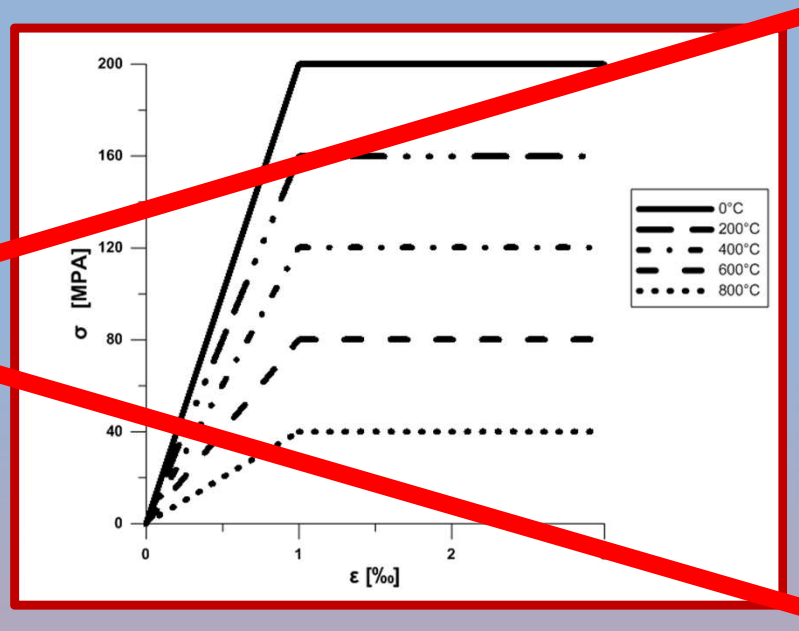
# Previous assumptions – material properties

Yield stress and Young modulus are linearly temperature dependent




Change of material properties under elevated temperature

$E=40GPa$

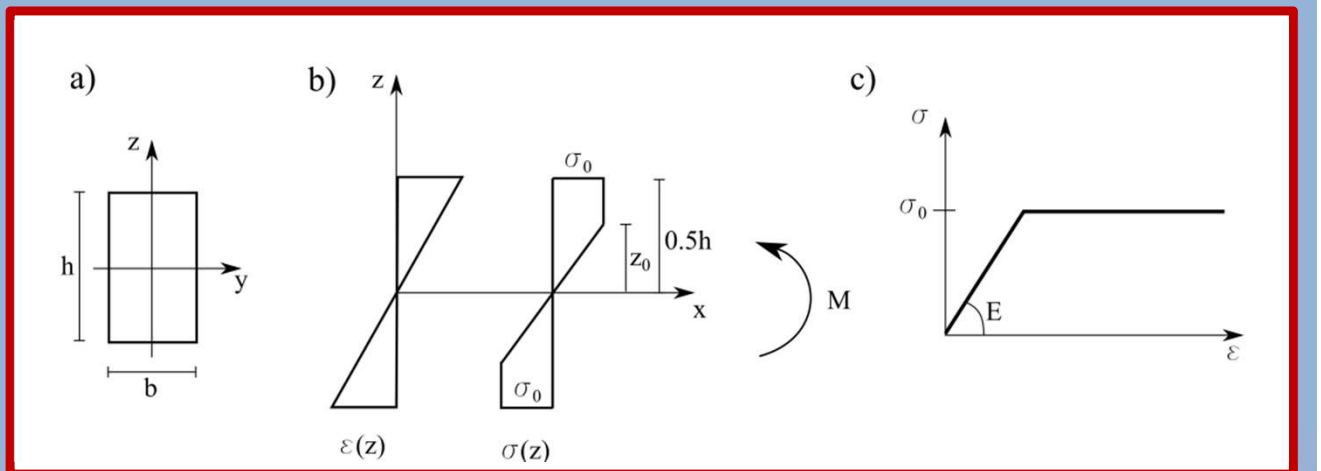
Stress-strain curves at chosen temperatures

$f_y=40MPa$

# Main assumptions of analytical solutions

Assumptions:

- cross sections stay planar,
- the effect of shear is neglected,
- the approximate formula (second derivative) for the curvature can be applied to find beam deflection.

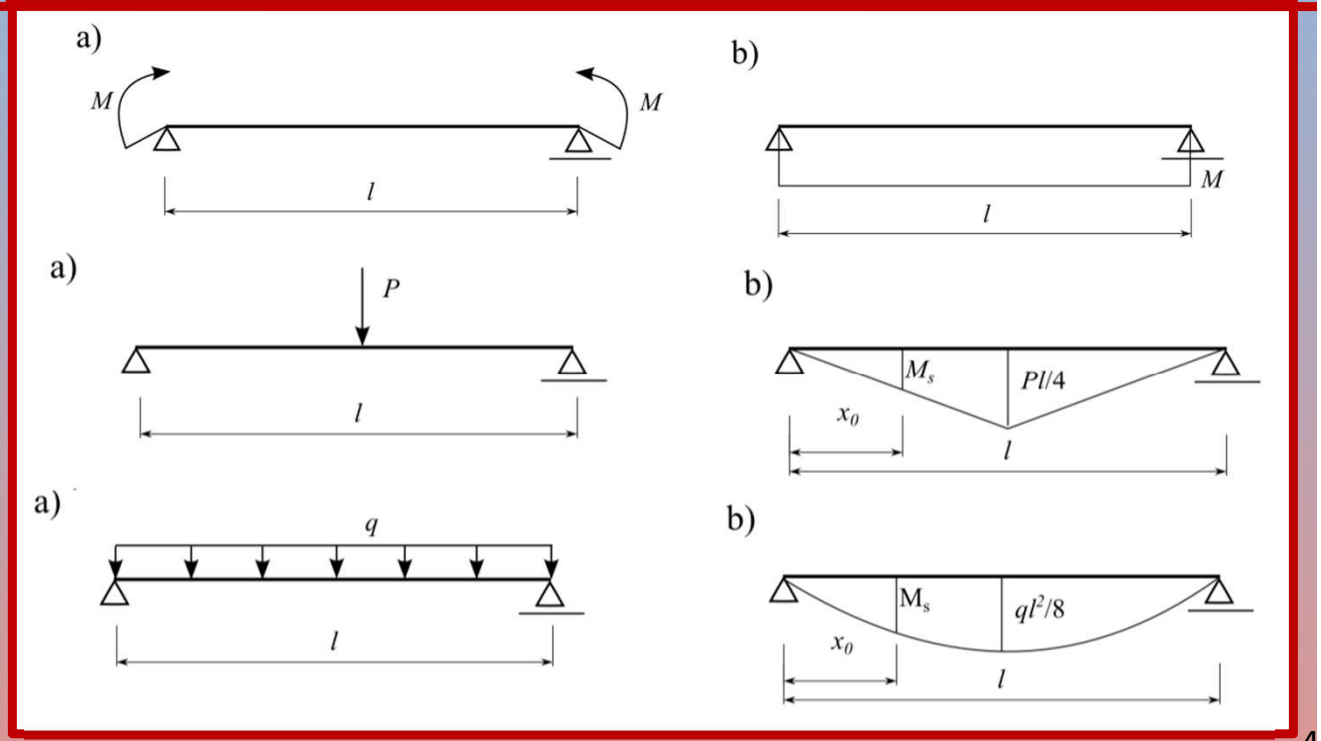



$$f = \frac{1}{8\sqrt{3}} \frac{\sigma_y l^2}{Eh} \left( \frac{1}{4} - \frac{1}{6}\mu \right)^{-1/2}$$

$$\mu = \frac{M}{\sigma_y \frac{bh^2}{6}}$$

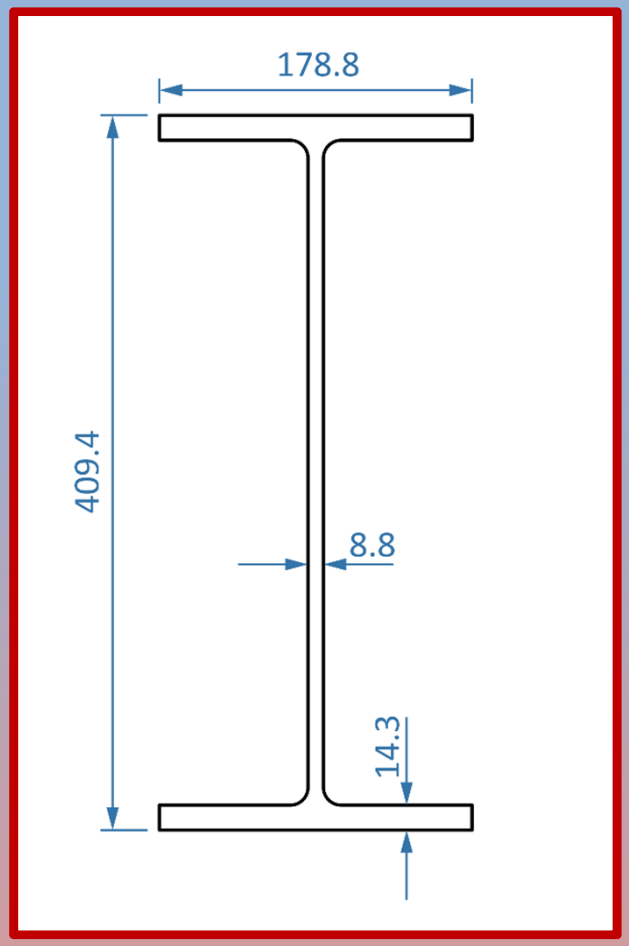
$$f = \frac{1}{6} \frac{\sigma_y l^2}{Eh} \frac{3\sqrt{3-2\psi} + \psi\sqrt{3-2\psi} - 5}{\psi^2}$$

$$\psi = \frac{P}{\frac{2}{3}\frac{\sigma_y bh^2}{l}}$$

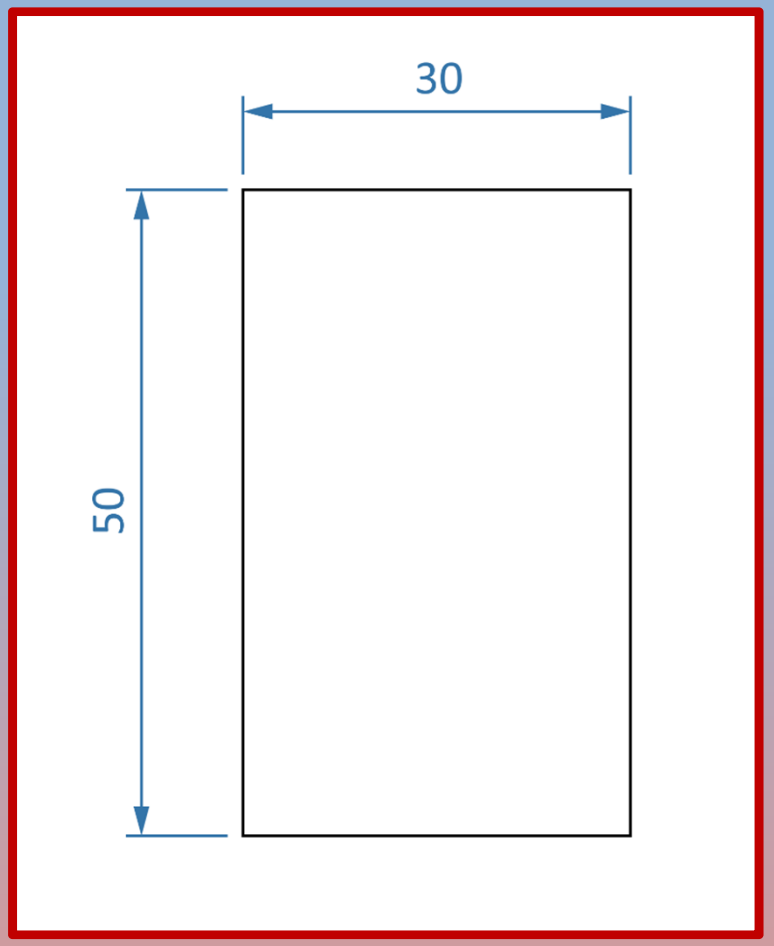


# Cross-sections

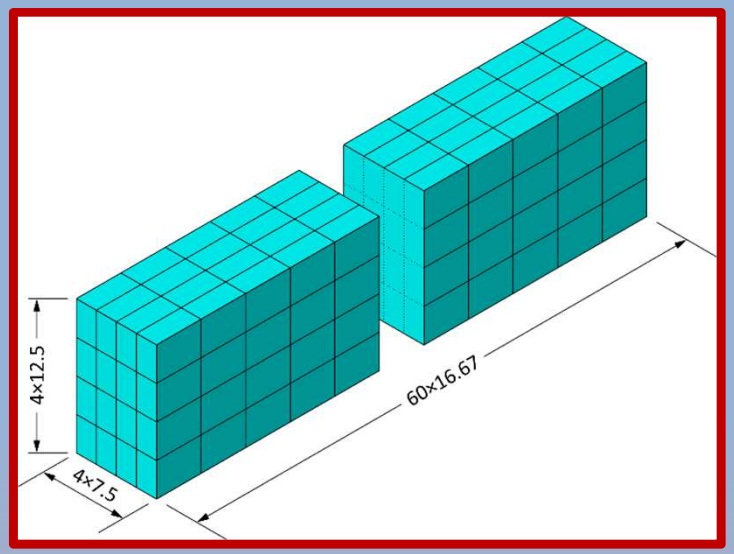
**UB 406×178×67 profile**

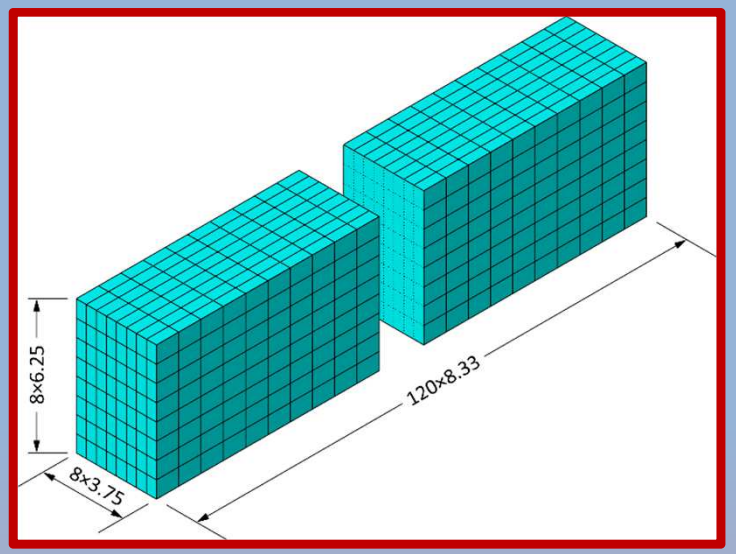


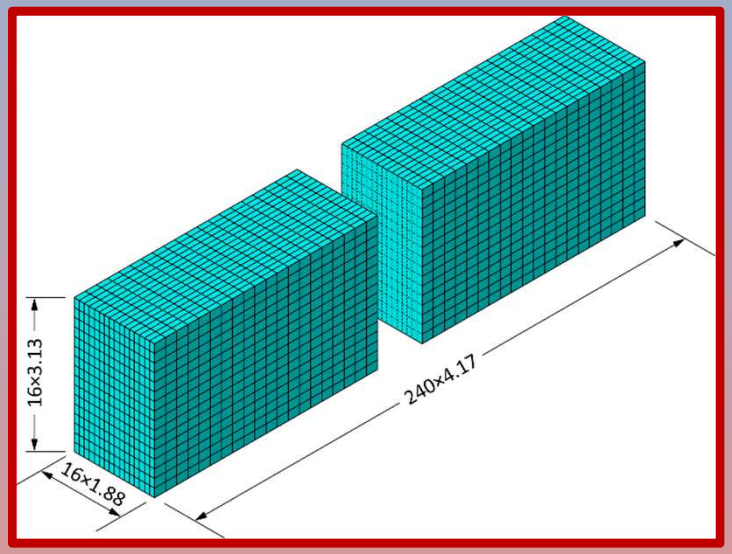

**Rectangular cross-section 30×50**



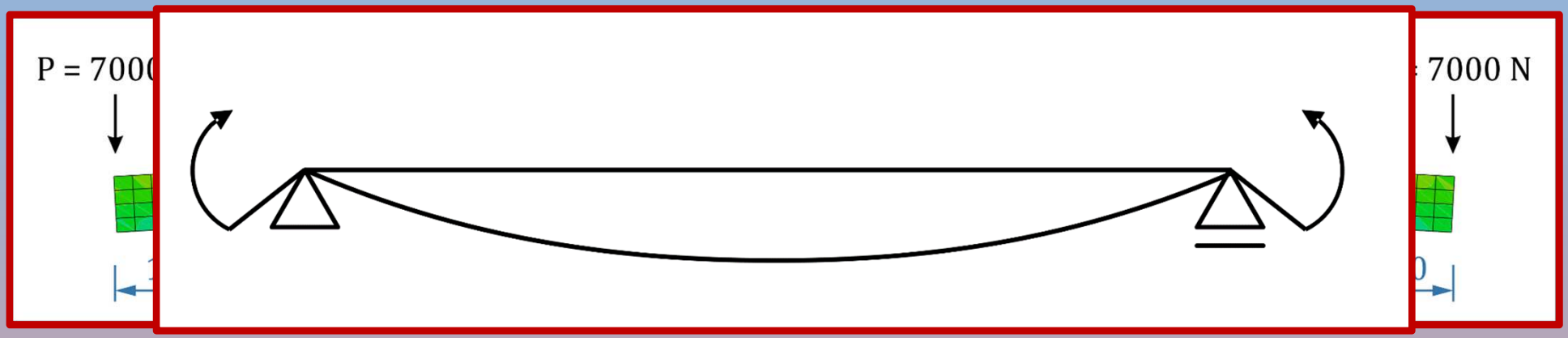
# Mesh densities



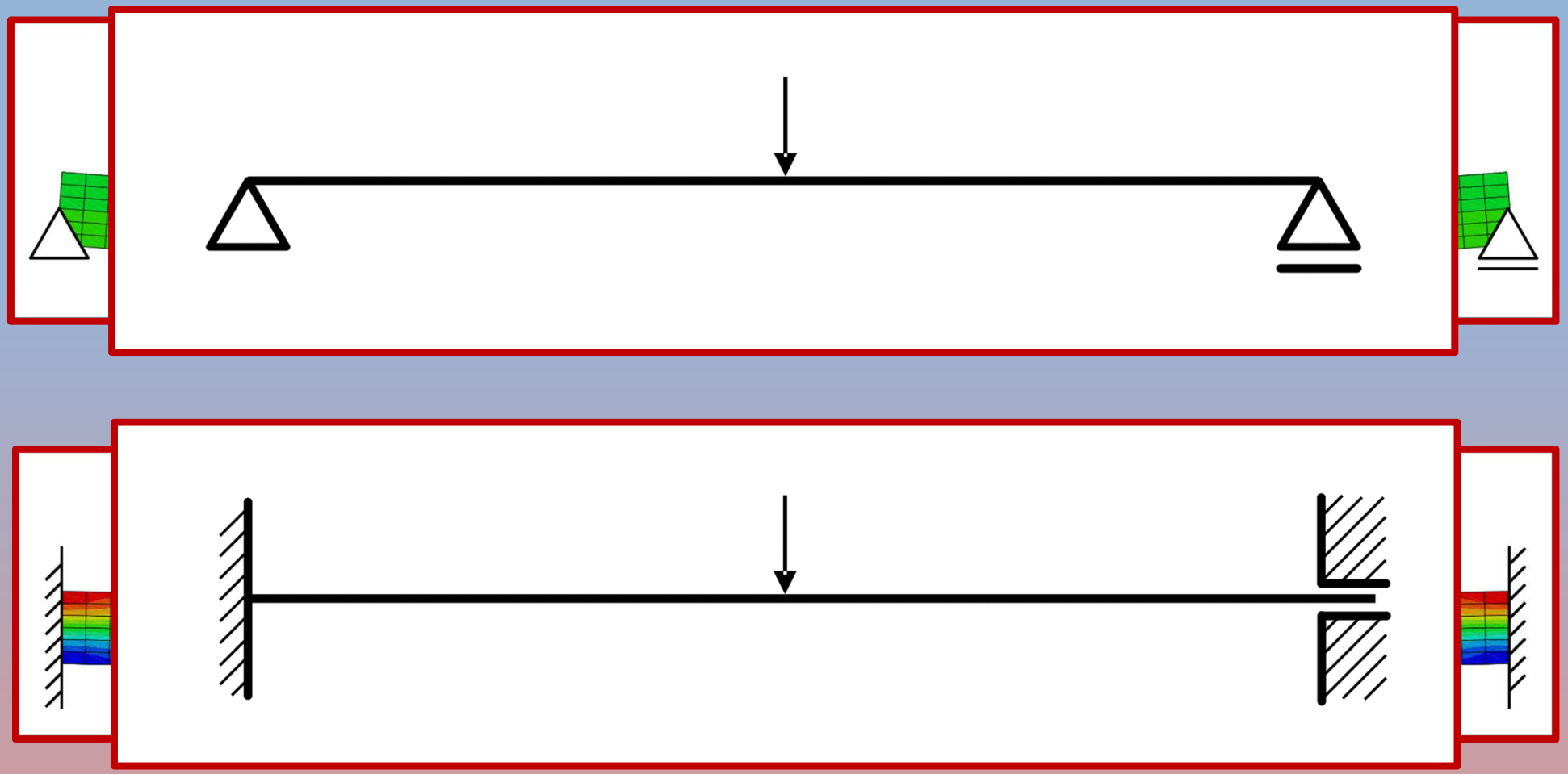



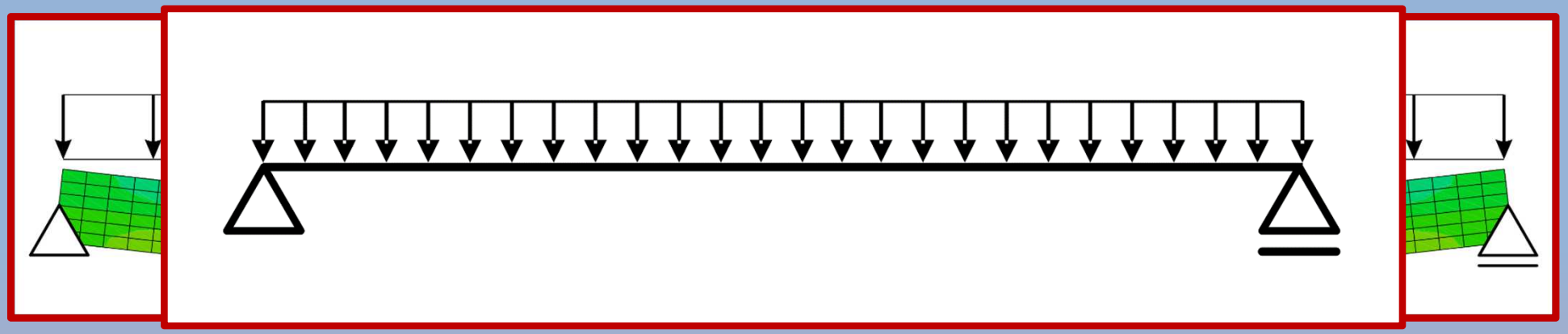
# Loading case 1 – pure bending

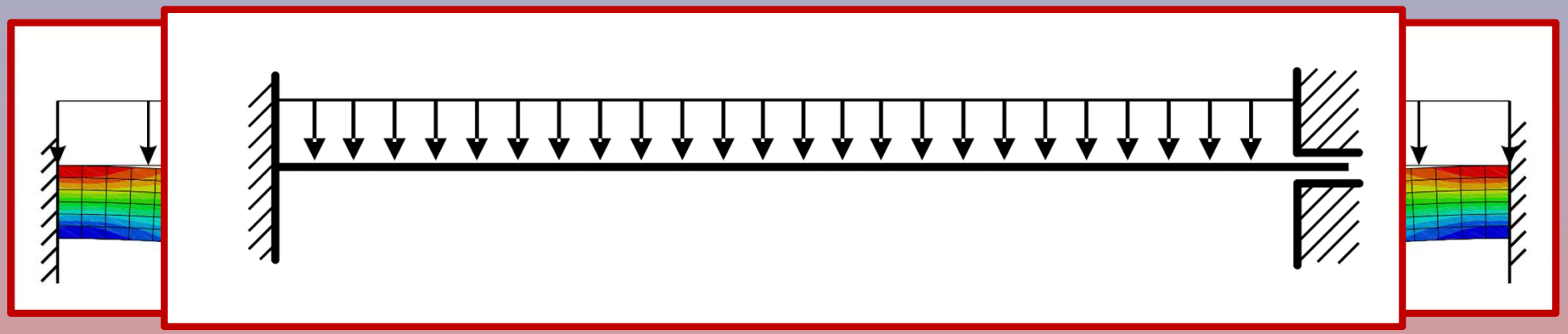


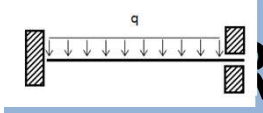
# Loading case 2 & 3 – point load



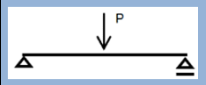
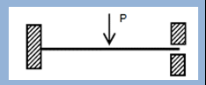
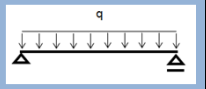
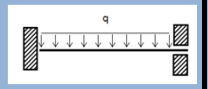
# Loading case 4 & 5 – distributed load

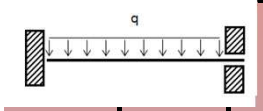




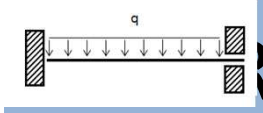


# Results – rectangular cross-section, k=0.80

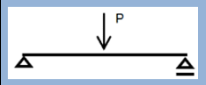
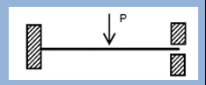
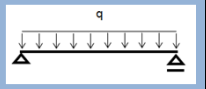
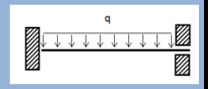
| RECTANGULAR CROSS-SECTION (l×h×b) 1000×50×30mm, E=40GPa, $\sigma_y$=40MPa, N=0 (no longitudinal constraints)<br>J=312500mm$^4$, $M_{el}$= 500000Nmm, $M_u$=750000Nmm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | # | 1 | 2 | 3 | 4 | 5 |
| | | | BC |  |  |  |  |  |
| | | | **$M=M_{el}+0.8\cdot(M_u-M_{el})$** | M=700000 Nmm | P=2800 N | P=5600 N | q=5.6 N/mm | q=8.4 N/mm |
| Analytical | | | $f_{el}$ [mm] | 7.0000<br>$\frac{Ml^2}{8EJ}$ | 4.6667<br>$\frac{Pl^3}{48EJ}$ | 2.3333<br>$\frac{Pl^3}{192EJ}$ | 5.8333<br>$\frac{5ql^4}{384EJ}$ | 1.7500<br>$\frac{ql^4}{384EJ}$ |
| | | | f [mm] | 11.1803 | 5.1569 | 2.5785 | 7.4301 | 1.8216 |
| LS-DYNA | Solid | Mesh 3 (16.65×12.5×7.5) | $f_{el}$ [mm] | 6.8753 | 4.5870 | 2.3270 | 5.7232 | 1.7425 |
| | | | f [mm] | 9.6829 | 4.8339 | 2.4212 | 6.5639 | 1.7631 |
| | | Mesh 2 (8.3×6.3×3.7) | $f_{el}$ [mm] | 6.9970 | 4.6697 | 2.3722 | 5.8112 | 1.7768 |
| | | | f [mm] | 11.0130 | 5.0932 | 2.5523 | 7.0554 | 1.8193 |
| | | Mesh 1 (4.2×3.2×1.9) | $f_{el}$ [mm] | 7.0303 | 4.6923 | 2.3848 | 5.8563 | 1.7866 |
| | | | f [mm] | 11.8070 | 5.1690 | 2.5905 | 7.3645 | 1.8354 |
| | Shell | Mesh 3 (16.65×7.5) | $f_{el}$ [mm] | 6.9959 | 4.6944 | 2.3823 | 5.8587 | 1.7850 |
| | | | f [mm] | 10.6410 | 5.1699 | 2.5705 | 7.3691 | 1.8272 |
| | | Mesh 2 (8.3×3.7) | $f_{el}$ [mm] | 6.9960 | 4.6955 | 2.3862 | 5.8608 | 1.7883 |
| | | | f [mm] | 10.6410 | 5.1758 | 2.5947 | 7.3755 | 1.8377 |
| | | Mesh 1 (4.2×1.9) | $f_{el}$ [mm] | 6.9962 | 4.6958 | 2.3874 | 5.8613 | 1.7894 |
| | | | f [mm] | 10.6420 | 5.1780 | 2.6024 | 7.3776 | 1.8431 |

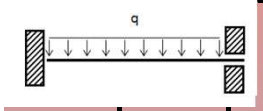


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| VULCAN | | Mesh 3 (33.3× 5.5× 3.3) | $f_{el}$ [mm] | 7.0841 | 4.7610 | 2.4352 | 5.9416 | 1.8264 |
| | | | f [mm] | 10.9827 | 5.2611 | 2.6955 | 7.5532 | 1.9033 |
| | | Mesh 2 (33.3× 2.5× 1.5) | $f_{el}$ [mm] | 7.0143 | 4.7143 | 2.4119 | 5.8833 | 1.8090 |
| | | | f [mm] | 11.0547 | 5.2081 | 2.6591 | 7.4779 | 1.8805 |
| | | Mesh 1 (33.3× 2.0× 1.2) | $f_{el}$ [mm] | 7.0080 | 4.7101 | 2.4098 | 5.8781 | 1.8074 |
| | | | f [mm] | 11.1824 | 5.2000 | 2.6559 | 7.4825 | 1.8783 |
| ABAQUS | Solid | Mesh 3 (16.65× 12.5× 7.5) | $f_{el}$ [mm] | 7.4579 | 4.8383 | 2.4625 | 6.0337 | 1.8398 |
| | | | f [mm] | 14.3010 | 5.3121 | 2.6736 | 7.5906 | 1.8879 |
| | | Mesh 2 (8.3× 6.3× 3.7) | $f_{el}$ [mm] | 7.1071 | 4.7820 | 2.4365 | 5.9638 | 1.8195 |
| | | | f [mm] | 11.5924 | 5.3089 | 2.6659 | 7.6962 | 1.8690 |
| | | Mesh 1 (4.2× 3.2× 1.9) | $f_{el}$ [mm] | 7.0245 | 4.7279 | 2.4104 | 5.8963 | 1.7996 |
| | | | f [mm] | 11.0694 | 5.2339 | 2.6330 | 7.4909 | 1.8527 |
| | Shell | Mesh 3 (16.65 ×7.5) | $f_{el}$ [mm] | 6.9960 | 4.7006 | 2.3973 | 5.8649 | 1.7969 |
| | | | f [mm] | 10.6423 | 5.1738 | 2.5901 | 7.3749 | 1.8398 |
| | | Mesh 2 (8.3x 3.7) | $f_{el}$ [mm] | 6.9961 | 4.7017 | 2.3994 | 5.8669 | 1.7984 |
| | | | f [mm] | 10.6416 | 5.1790 | 2.6051 | 7.3802 | 1.8476 |
| | | Mesh 1 (4.2× 1.9) | $f_{el}$ [mm] | 6.9961 | 4.7019 | 2.4000 | 5.8674 | 1.7988 |
| | | | f [mm] | 10.6416 | 5.1799 | 2.6095 | 7.3820 | 1.8502 |
| | Beam | Mesh 3 (16.7) | $f_{el}$ [mm] | 6.9968 | 4.7016 | 2.4040 | 5.8664 | 1.8031 |
| | | | f [mm] | 8.9900 | 5.2169 | 2.6609 | 7.0034 | 1.8866 |
| | | Mesh 2 (8.3) | $f_{el}$ [mm] | 6.9968 | 4.7019 | 2.4045 | 5.8676 | 1.8034 |
| | | | f [mm] | 8.9900 | 5.2184 | 2.6623 | 7.0056 | 1.8872 |
| | | Mesh 1 (4.2) | $f_{el}$ [mm] | 6.9968 | 4.7019 | 2.4046 | 5.8679 | 1.8035 |
| | | | f [mm] | 8.9900 | 5.2186 | 2.6630 | 7.0062 | 1.8874 |

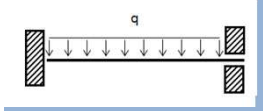


# Results – rectangular cross-section, k=0.95

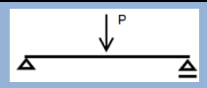
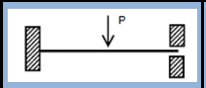
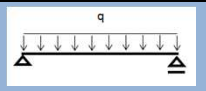
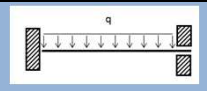
| RECTANGULAR CROSS-SECTION (l×h×b) 1000×50×30mm, E=40GPa, $\sigma_y$=40MPa, N=0 (no longitudinal constraints) J=312500mm$^4$, $M_{el}$= 500000Nmm, $M_u$=750000Nmm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | # | 1 | 2 | 3 | 4 | 5 |
| | | | BC |  |  |  |  |  |
| | | | **$M=M_{el}+0.95(M_u-M_{el})$** | M=737500 Nmm | P=2950 N | P=5900 N | q=5.9 N/mm | q=8.85 N/mm |
| Analytical | | | $f_{el}$ [mm] | 7.3750 $\frac{Ml^2}{8EJ}$ | 4.9167 $\frac{Pl^3}{48EJ}$ | 2.4583 $\frac{Pl^3}{192EJ}$ | 6.1458 $\frac{5ql^4}{384EJ}$ | 1.8437 $\frac{ql^4}{384EJ}$ |
| | | | f [mm] | 22.3607 | 6.1275 | 3.0638 | 10.7171 | 1.9832 |
| LS-DYNA | Solid | Mesh 3 (16.65×12.5×7.5) | $f_{el}$ [mm] | 7.2467 | 4.8329 | 2.4517 | 6.0298 | 1.8359 |
| | | | f [mm] | 12.8190 | 5.4056 | 2.6726 | 7.8911 | 1.8782 |
| | | Mesh 2 (8.3×6.3×3.7) | $f_{el}$ [mm] | 7.3748 | 4.9205 | 2.8765 | 6.1124 | 1.8720 |
| | | | f [mm] | 23.4980 | 5.8757 | 2.5523 | 9.1407 | 1.9493 |
| | | Mesh 1 (4.2×3.2×1.9) | $f_{el}$ [mm] | 7.4087 | 4.9442 | 2.5129 | 6.1699 | 1.8823 |
| | | | f [mm] | 23.3990 | 6.0624 | 2.9454 | 10.2480 | 1.9716 |
| | Shell | Mesh 3 (16.65×7.5) | $f_{el}$ [mm] | 7.3711 | 4.9460 | 2.5100 | 6.1752 | 1.8806 |
| | | | f [mm] | 22.3510 | 6.0048 | 2.8973 | 11.0570 | 1.9598 |
| | | Mesh 2 (8.3×3.7) | $f_{el}$ [mm] | 7.3706 | 4.9477 | 2.5141 | 6.1747 | 1.8841 |
| | | | f [mm] | 22.3180 | 6.1508 | 2.9485 | 11.1080 | 1.9825 |
| | | Mesh 1 (4.2×1.9) | $f_{el}$ [mm] | 7.3700 | 4.9480 | 2.5157 | 6.1752 | 1.8852 |
| | | | f [mm] | 22.3530 | 6.1627 | 2.9780 | 11.1240 | 1.9888 |

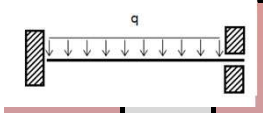


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| VULCAN | | Mesh 3 (33.3× 5.5× 3.3) | $f_{el}$ [mm] | 7.4633 | 5.0160 | 2.5657 | 6.2598 | 1.9243 |
| | | | f [mm] | 20.7379 | 6.3268 | 3.2396 | 11.0557 | 2.0593 |
| | | Mesh 2 (33.3× 2.5× 1.5) | $f_{el}$ [mm] | 7.3897 | 4.9668 | 2.5411 | 6.1984 | 1.9059 |
| | | | f [mm] | 20.1379 | 6.1889 | 3.1211 | 10.8031 | 2.0413 |
| | | Mesh 1 (33.3× 2.0× 1.2) | $f_{el}$ [mm] | 7.3830 | 4.9624 | 2.5389 | 6.1928 | 1.9042 |
| | | | f [mm] | 20.3720 | 6.1732 | 3.1243 | 10.7609 | 2.0376 |
| ABAQUS | Solid | Mesh 3 (16.65× 12.5× 7.5) | $f_{el}$ [mm] | 7.8570 | 5.0975 | 2.5944 | 6.3569 | 1.9384 |
| | | | f [mm] | 18.1445 | 6.6285 | 3.0713 | 12.0794 | 2.0319 |
| | | Mesh 2 (8.3× 6.3× 3.7) | $f_{el}$ [mm] | 7.4875 | 5.0381 | 2.5670 | 6.2832 | 1.9170 |
| | | | f [mm] | 25.3703 | 6.3609 | 3.0458 | 11.9572 | 2.0126 |
| | | Mesh 1 (4.2× 3.2× 1.9) | $f_{el}$ [mm] | 7.4005 | 4.9811 | 2.5395 | 6.2121 | 1.8960 |
| | | | f [mm] | 21.3933 | 6.1998 | 3.0122 | 10.8401 | 1.9913 |
| | Shell | Mesh 3 (16.65 ×7.5) | $f_{el}$ [mm] | 7.3704 | 4.9524 | 2.5258 | 6.1790 | 1.8931 |
| | | | f [mm] | 22.3227 | 6.0595 | 2.9243 | 11.0846 | 1.9769 |
| | | Mesh 2 (8.3x 3.7) | $f_{el}$ [mm] | 7.3705 | 4.9535 | 2.5279 | 6.1811 | 1.8948 |
| | | | f [mm] | 22.3196 | 6.1197 | 2.9549 | 11.1126 | 1.9911 |
| | | Mesh 1 (4.2× 1.9) | $f_{el}$ [mm] | 7.3705 | 4.9538 | 2.5285 | 6.1816 | 1.8952 |
| | | | f [mm] | 22.3194 | 6.1339 | 2.9644 | 11.1207 | 1.9940 |
| | Beam | Mesh 3 (16.7) | $f_{el}$ [mm] | 7.3713 | 4.9535 | 2.5328 | 6.1806 | 1.8996 |
| | | | f [mm] | 9.7376 | 5.6347 | 2.8729 | 7.5919 | 2.0096 |
| | | Mesh 2 (8.3) | $f_{el}$ [mm] | 7.3713 | 4.9537 | 2.5333 | 6.1818 | 1.9000 |
| | | | f [mm] | 9.7376 | 5.6357 | 2.8741 | 7.5943 | 2.0102 |
| | | Mesh 1 (4.2) | $f_{el}$ [mm] | 7.3713 | 4.9538 | 2.5334 | 6.1822 | 1.9001 |
| | | | f [mm] | 9.7376 | 5.6360 | 2.8746 | 7.5949 | 2.0108 |

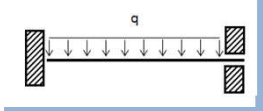


# Results – I-beam, k=0.80

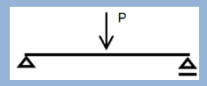
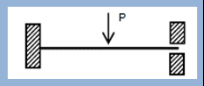
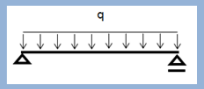
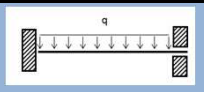
| UB 406×178×67 cross-section, l=8000mm, E=40GPa, $\sigma_y$ =40MPa, N=0 (no longitudinal constraints)<br>J=2.4015×10⁸ mm⁴, $M_{el}$=4.6927×10⁷ Nmm, $M_f$=4.8915×10⁷ Nmm, $M_u$=5.3169×10⁷ Nmm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | # | 1 | 2 | 3 | 4 | 5 |
| | | | BC |  |  |  |  |  |
| | | | $M=M_{el}+0.8\cdot(M_u-M_{el})$ | M=5.1921×10⁷ Nmm | P=25960.3 N | P=51920.6 N | q=6.49008 N/mm | q=9.73511 N/mm |
| Analytical | | | $f_{el}$ [mm] | 7.0000<br>$\frac{Ml^2}{8EJ}$ | 4.6667<br>$\frac{Pl^3}{48EJ}$ | 2.3333<br>$\frac{Pl^3}{192EJ}$ | 5.8333<br>$\frac{5ql^4}{384EJ}$ | 1.7500<br>$\frac{ql^4}{384EJ}$ |
| | | | f [mm] | 11.1803 | 5.1569 | 2.5785 | 7.4301 | 1.8216 |
| LS-DYNA | Shell | Mesh 3 (133×100×45) | $f_{el}$ [mm] | 42.5210 | 29.3000 | 16.0730 | 36.9340 | 12.2290 |
| | | | f [mm] | 61.6370 | 29.8120 | 16.1580 | 43.6440 | 12.2550 |
| | | Mesh 2 (66×50×23) | $f_{el}$ [mm] | 42.5210 | 29.3100 | 16.1050 | 36.9490 | 12.2540 |
| | | | f [mm] | 61.2590 | 29.9480 | 16.3230 | 44.1600 | 12.3320 |
| | | Mesh 1 (33×25×11) | $f_{el}$ [mm] | 42.5210 | 29.3140 | 16.1190 | 36.9520 | 12.2620 |
| | | | f [mm] | 61.4380 | 30.0060 | 16.4400 | 44.1820 | 12.3920 |
| VULCAN | | Mesh 3 (133.3×34×15) | $f_{el}$ [mm] | 43.3154 | 29.3631 | 15.3998 | 36.5825 | 11.5499 |
| | | | f [mm] | 77.6325 | 30.8757 | 16.1075 | 45.2064 | 11.7563 |
| | | Mesh 2 (133.3×20×9) | $f_{el}$ [mm] | 43.2670 | 29.3294 | 15.3829 | 36.5404 | 11.5373 |
| | | | f [mm] | 77.1231 | 30.7664 | 16.1002 | 44.9249 | 11.7369 |
| | | Mesh 1 (133.3×17×17.5) | $f_{el}$ [mm] | 43.2595 | 29.3244 | 15.3804 | 36.5342 | 11.5354 |
| | | | f [mm] | 76.8991 | 30.7611 | 16.0814 | 44.8710 | 11.7310 |

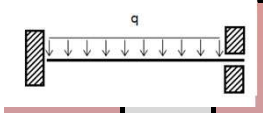



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ABAQUS | Shell | Mesh 3 (133.3×100×45) | $f_{el}$ [mm] | 43.0331 | 29.646 | 16.2621 | 37.4070 | 12.3754 |
| | | | f [mm] | 72.4345 | 30.2998 | 16.4472 | 48.4766 | 12.4048 |
| | | Mesh 2 (66×50×23) | $f_{el}$ [mm] | 42.6592 | 29.4112 | 16.1583 | 37.1111 | 12.2921 |
| | | | f [mm] | 62.3708 | 30.2167 | 16.4490 | 45.0364 | 12.3911 |
| | | Mesh 1 (33×25×11) | $f_{el}$ [mm] | 42.5674 | 29.3562 | 16.1344 | 37.0413 | 12.2720 |
| | | | f [mm] | 62.7691 | 30.1374 | 16.5224 | 44.6249 | 12.4236 |
| | Beam | Mesh 3 (133.3) | $f_{el}$ [mm] | 43.2761 | 29.7669 | 16.2490 | 36.9713 | 12.1868 |
| | | | f [mm] | 69.8233 | 31.4506 | 17.0838 | 45.1008 | 12.3395 |
| | | Mesh 2 (66.6) | $f_{el}$ [mm] | 43.2761 | 29.7640 | 16.2432 | 36.9745 | 12.1825 |
| | | | f [mm] | 69.8232 | 31.4515 | 17.0858 | 45.1594 | 12.4153 |
| | | Mesh 1 (33.3) | $f_{el}$ [mm] | 43.2761 | 29.7633 | 16.2418 | 36.9753 | 12.1814 |
| | | | f [mm] | 69.8232 | 31.4518 | 17.0863 | 45.1674 | 12.4150 |

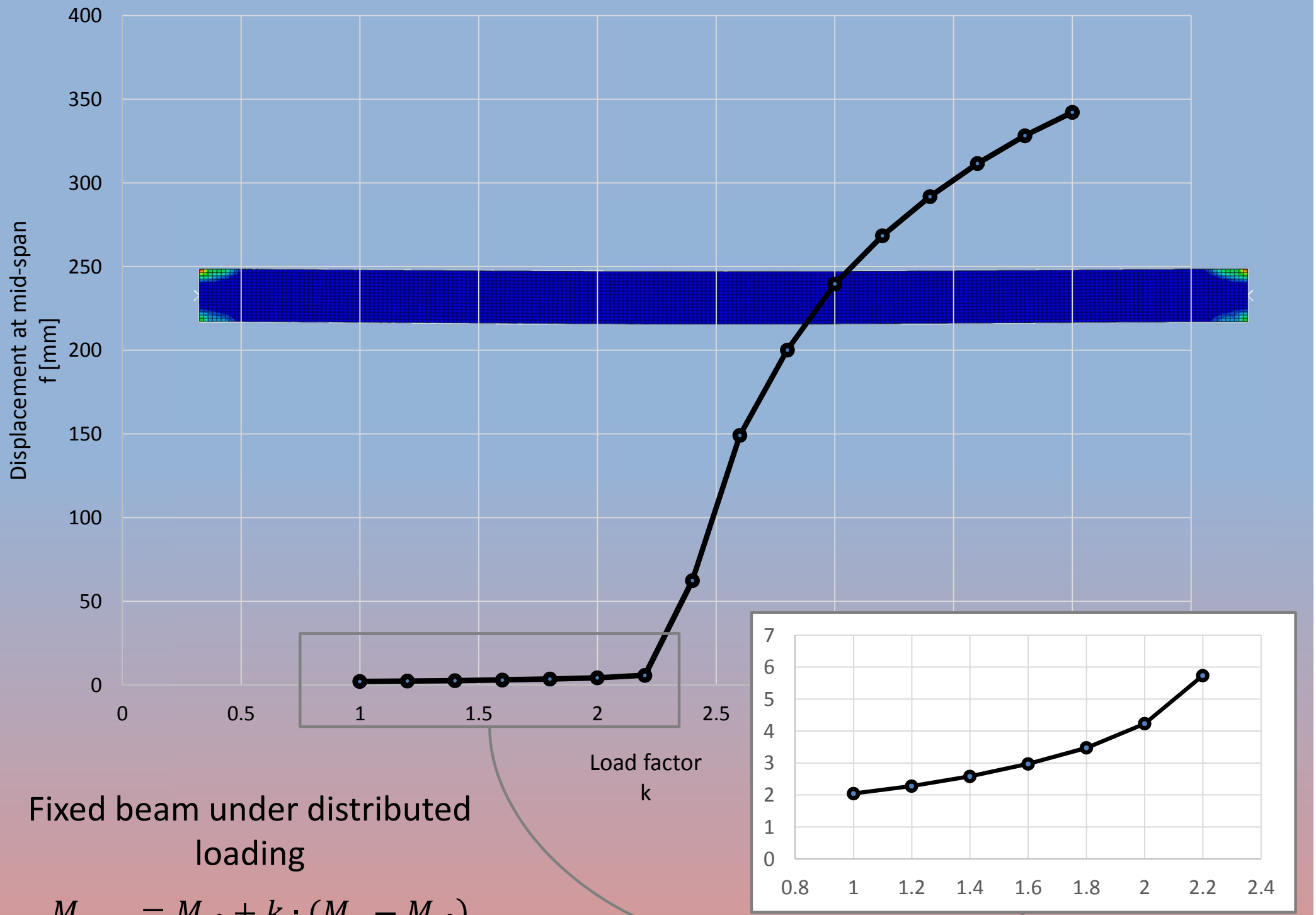


# Results – I-beam, k=0.95

| UB 406×178×67 cross-section, l=8000mm, E=40GPa, $\sigma_y$ =40MPa, N=0 (no longitudinal constraints)<br>J=2.4015×10$^8$ mm$^4$, $M_{el}$=4.6927×10$^7$ Nmm, $M_f$=4.8915×10$^7$ Nmm, $M_u$=5.3169×10$^7$ Nmm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | # | 1 | 2 | 3 | 4 | 5 |
| | | | BC |  |  |  |  |  |
| | | | **$M=M_{el}+0.95(M_u-M_{el})$** | M=5.28569×10$^7$ Nmm | P=26428.5 N | P=52856.9 N | q=6.6071 N/mm | q=9.910668 N/mm |
| Analytical | | | $f_{el}$ [mm] | 44.0203<br>$\frac{Ml^2}{8EJ}$ | 29.3469<br>$\frac{Pl^3}{48EJ}$ | 14.6733<br>$\frac{Pl^3}{192EJ}$ | 36.683<br>$\frac{5ql^4}{384EJ}$ | 11.0050<br>$\frac{ql^4}{384EJ}$ |
| | | | f [mm] | 155.111 | 31.5555 | 16.7100 | 57.0720 | 11.3768 |
| LS-DYNA | Shell | Mesh 3 (133×100×45) | $f_{el}$ [mm] | 43.3010 | 29.8310 | 16.3670 | 37.6000 | 12.4520 |
| | | | f [mm] | 87.9010 | 31.1390 | 16.6170 | 52.4430 | 12.4990 |
| | | Mesh 2 (66×50×23) | $f_{el}$ [mm] | 43.3010 | 29.8410 | 16.4000 | 37.6150 | 12.4780 |
| | | | f [mm] | 89.6360 | 31.2260 | 16.8950 | 55.0960 | 12.6280 |
| | | Mesh 1 (33×25×11) | $f_{el}$ [mm] | 43.3010 | 29.8450 | 16.4140 | 37.6190 | 12.4860 |
| | | | f [mm] | 88.2980 | 31.3030 | 17.1040 | 55.1600 | 12.7250 |
| VULCAN | | Mesh 3 (133.3×34×15) | $f_{el}$ [mm] | 44.0960 | 29.8926 | 15.6775 | 37.2420 | 11.7582 |
| | | | f [mm] | 133.3375 | 33.6005 | 17.2481 | 60.5958 | 12.1158 |
| | | Mesh 2 (133.3×20×9) | $f_{el}$ [mm] | 43.6569 | 29.8583 | 15.5800 | 37.1991 | 11.7453 |
| | | | f [mm] | 135.9685 | 33.2939 | 17.2415 | -- | 12.0991 |
| | | Mesh 1 (133.3×17×17.5) | $f_{el}$ [mm] | 44.0392 | 29.8532 | 15.6578 | 37.1928 | 11.7434 |
| | | | f [mm] | -- | 33.2742 | 17.2419 | -- | 12.0944 |



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ABAQUS | Shell | Mesh 3 (133.3×100×45) | $f_{el}$ [mm] | 43.8114 | 30.1812 | 16.5554 | 38.0912 | 12.6014 |
| | | | f [mm] | 126.1600 | 31.4241 | 16.9272 | 63.0917 | 12.6622 |
| | | Mesh 2 (66×50×23) | $f_{el}$ [mm] | 43.4307 | 29.9422 | 16.4497 | 37.7899 | 12.5165 |
| | | | f [mm] | 97.2991 | 31.4816 | 17.1062 | 59.3565 | 12.7171 |
| | | Mesh 1 (33×25×11) | $f_{el}$ [mm] | 43.3370 | 29.8862 | 16.4253 | 37.7188 | 12.4961 |
| | | | f [mm] | 92.6288 | 31.5062 | 17.2266 | 57.2381 | 12.7714 |
| | Beam | Mesh 3 (133.3) | $f_{el}$ [mm] | 44.0561 | 30.3037 | 16.5420 | 37.6379 | 12.4066 |
| | | | f [mm] | 78.0258 | 32.9218 | 17.8441 | 49.1606 | 12.7333 |
| | | Mesh 2 (66.6) | $f_{el}$ [mm] | 44.0561 | 30.3008 | 16.5362 | 37.6411 | 12.4022 |
| | | | f [mm] | 78.0258 | 33.0015 | 17.8461 | 49.2409 | 12.7383 |
| | | Mesh 1 (33.3) | $f_{el}$ [mm] | 44.0561 | 30.3001 | 16.5347 | 37.6419 | 12.4011 |
| | | | f [mm] | 78.0258 | 33.0020 | 17.8861 | 49.2501 | 12.7691 |




Fixed beam under distributed loading

$$M_{max} = M_{el} + k \cdot (M_u - M_{el})$$

# Fixed beam under distributed loading

$$M_{max} = M_{el} + k \cdot (M_u - M_{el})$$