Study on Bracing under Seismic Design in Plant Construction

0. Contents

1. General

With steel structures in civil engineering, different types of seismic design are suggested in the relevant codes, e.g. EC8, DIN 4149, P100.

Dimensions are given in Millimeters [mm], Kilonewtons [kN], ...

On occasion of a OSB-forming station to be built in Romania this study has been conducted to evaluate the amount of steel needed for different methods of seismic design according to EC8 and P100.

2. Example

An example is given, which is taken from Brasov Forming Station:

Multi-storey vertical bracing between axes R11 and R16 in row

For simplification, the structure is modified as follows:

Height 5500 + 2 * 5850 = 17200 ... (4^{th} and 5^{th} storey not modelled)

original:

1^{st} storey (bottom) 5500

2^{nd} storey 12300 – 5500 = 6800

3^{rd} storey 17220 – 12300 = 4920

total 17220

Width 9000 (original 8950)

Design loads for seismic load combination +X-direction (amended 13.03.2011)

vertical loads

3rd storey (top): 260 left, 480 right

2nd storey:–360 (!) left, 350 right

1st storey (bottom): –50 left, –150 right

horizontal loads

3rd storey: 650 from left to right

2nd storey: 320 from left to right

Support reactions by hand for DCL (amended 13.03.2011):

horizontal: 650 + 320 = 970 q.e.d.

vertical right:

480 + 350 – 150 + 650 * 17,2 m / 9 m + 320 * 11,35 m / 9 m =

480 + 350 – 150 + 1242 + 404 = 2326 q.e.d.

Support reactions by hand for no seismic loads (amended 13.03.2011):

horizontal: 2330 * 1/200 = 12 (sway imperfection)

vertical right:

480 + 350 – 150 +480/200 * 17,2 m / 9 m + 350/200 * 11,35 m / 9 m =

480 + 350 – 150 + 5 + 2 = 687

Support reactions by hand for DCM (amended 13.03.2011):

horizontal loads as of DCL divided by four

horizontal: (650 + 320) / 4 = 243 (below it says 203 !!!)

vertical right:

480 + 350 – 150 + 650/4 * 17,2 m / 9 m + 320/4 * 11,35 m / 9 m =

480 + 350 – 150 + 311 + 101 = 1092 (below it says 1314/1,36=966)

Stress resultants (RSTAB):

Vertical per column:

1st storey (bottom) +1200 kN (R16) lift / –2330 kN (R11) compression

2nd storey +520 kN (R16) lift / –1880 kN (R11) compression

3rd storey –260 kN (R16) compression / –900 kN (R11) compression

support reactions +1800 / –2330

sum of support reactions: –530 kN

original:

1st storey (bottom) +1200 kN (R16) lift / –2330 kN (R11) compression

2nd storey +520 kN (R16) lift / –1880 kN (R11) compression

3rd storey –260 kN (R16) compression / –900 kN (R11) compression

support reactions +1830 / –2330

sum of support reactions: –550 kN

Horizontal design load in each storey:

1st storey (bottom) 970 kN

2nd storey 970 kN

3rd storey 650 kN

original:

1st storey (bottom) 970 kN

2nd storey app. 970 kN

3rd storey app. 650 kN

The structure is designed according to the regulations in EC8 / P100.

3. No seismic loads

column:

max N,d = –687 kN

design: HEA 220 – S235

utilisation in buckling check acc. DIN 18800-2: 0,98

g = 2 * 17,2 m * 50,5 kgs/m = 1,7 tons

walers 1+2:

max N,d = –12 kN

design: HEA 100 – S235

utilisation in buckling check acc. DIN 18800-2: 0,43

(without checking bending due to self-weight – so this seems to be OK)

g = 3 * 9 m * 16,7 kgs/m = 0,5 tons

waler 3:

max N,d = –8 kN

see walers 1+2

diagonals 1+2:

max N,d = +15 kN

design: L 60x6 – S235

no check required

g = 6 * 10,7 m * 5,4 kgs/m = 0,4 tons

diagonals 3:

see diagonals 1+2

theoretical weight: 2,6 metric tons

4. DC Low – elastic

Behaviour factor q = 1 (according to romanian regulations)

column:

max N,d = –2330 kN

design: HEA 450 – S235

utilisation in buckling check acc. DIN 18800-2: 0,92

walers 1+2:

max N,d = –970 kN

design: HEA 320 – S235

utilisation in buckling check acc. DIN 18800-2: 0,91

waler 3:

max N,d = –650 kN

design: HEA 280 – S235

utilisation in buckling check acc. DIN 18800-2: 0,86

diagonals 1+2:

max N,d = +1150 kN

design: L 180x18 – S235

A,net = 61,9 cm^2 – 1,8 cm * 1,8 cm = 58,7 cm^2

N,R,d = 5870 mm^2 * 218 N/mm^2 = 1280 kN

utilisation: 1150 kN / 1280 kN = 0,90

diagonals 3:

max N,d = +775 kN

design: L 150x15 – S235

A,net = 43,0 cm^2 – 1,8 cm * 1,5 cm = 40,3 cm^2

N,R,d = 4030 mm^2 * 218 N/mm^2 = 880 kN

utilisation: 775 kN / 880 kN = 0,88

theoretical weight: 10,04 metric tons

5. DC Medium – plastic – X-Bracing

Behaviour factor q = 4

Horizontal loads are divided by 4.

column:

loads for columns are determined such, that walers and diagonals have their capacity-top-longitudinal-forces (see below)

max N,d = –1314 kN

design: HEB 240 – S235

utilisation in buckling check acc. DIN 18800-2: 1,02 (HEB 260 gives 0,86)

walers 1+2:

max N,d = –203 kN

max N,d due to capacity of diagonals 1+2 (see below): max N,d,cap = –203 * 1,36 = 276 kN

design: HEB 200 – S235

utilisation in buckling check acc. DIN 18800-2: 0,76 (HEB 180 gives 1,09)

possible capacity in buckling: N,R,d,cap = 370 kN

factor in capacity design: 370 kN / 203 kN = 1,82

waler 3:

max N,d = –123 kN

max N,d due to capacity of diagonals 3 (see below): max N,d,cap = –123 * 1,66 = 204 kN

design: HEB 180 – S235

utilisation in buckling check acc. DIN 18800-2: 0,81 (HEB 160 gives 1,20)

possible capacity in buckling: N,R,d,cap = 258 kN

factor in capacity design: 258 kN / 123 kN = 2,10

diagonals 1+2:

max N,d = +238 kN

design: L 80x8 – S235

A,net = 12,3 cm^2 – 1,4 cm * 0,8 cm = 11,2 cm^2

N,R,d = 1120 mm^2 * 218 N/mm^2 = 244 kN

utilisation: 238 kN / 244 kN = 0,98

possible plastic tensile capacity: N,R,d,cap = 1120 mm^2 * 240 N/mm^2 *1,2 = 323 kN

factor in capacity design: 323 kN / 238 kN = 1,36

diagonals 3:

max N,d = +146 kN

design: L 70x7 – S235

A,net = 9,4 cm^2 – 1,4 cm * 0,7 cm = 8,42 cm^2

N,R,d = 842 mm^2 * 218 N/mm^2 = 184 kN

utilisation: 146 kN / 184 kN = 0,79

possible plastic tensile capacity: N,R,d,cap = 842 mm^2 * 240 N/mm^2 *1,2 = 242 kN

factor in capacity design: 242 kN / 146 kN = 1,66

theoretical weight: 5,00 metric tons

6. DC Medium – plastic – K-Bracing

Behaviour factor q = 2

Horizontal loads are divided by 2.

column:

loads for columns are determined such, that walers and diagonals have their capacity-top-longitudinal-forces (see below)

max N,d = –1650 kN

design: HEB 280 – S235

utilisation in buckling check acc. DIN 18800-2: 0,90 (HEB 260 gives 1,07)

walers 1+2:

max N,d = –322 kN

L,crit = 4500 mm

max N,d due to capacity of diagonals 1+2 (see below): max N,d,cap = –322 * 1,43 = 460 kN

design: HEB 160 – S235

utilisation in buckling check acc. DIN 18800-2: 0,89

possible capacity in buckling: N,R,d,cap = 600 kN

factor in capacity design: 600 kN / 322 kN = 1,86

waler 3:

max N,d = –325 kN

max N,d due to capacity of diagonals 3 (see below): max N,d,cap = –325 * 1,51 = 490 kN

design: HEB 160 – S235

utilisation in buckling check acc. DIN 18800-2: 0,95 possible capacity in buckling: N,R,d,cap = 600 kN

factor in capacity design: 600 kN / 325 kN = 1,85

diagonals 1+2:

max N,d = –400 kN

L = 7380 mm

design: HEB 200 – S235

utilisation in buckling check acc. DIN 18800-2: 0,80 (HEB 180 gives 1,13)

possible capacity in buckling: N,R,d,cap = 570 kN

factor in capacity design: 570 kN / 400 kN = 1,43

diagonals 3:

max N,d = –265 kN

L = 7380 mm

design: HEB 180 – S235

utilisation in buckling check acc. DIN 18800-2: 0,75 (HEB 160 gives 1,10)

possible capacity in buckling: N,R,d,cap = 401 kN

factor in capacity design: 401 kN / 265 kN = 1,51

theoretical weight: 7,22 metric tons

7. Summary

2,6	metric tons	no seismic loads	
10,0	metric tons	romanian DCL-design with	q = 1,0
7,2	metric tons	romanian DCM – K-bracing incl. capacity design	q = 2,0
5,0	metric tons	romanian DCM – X-bracing incl. capacity design	q = 4,0

It seems that capacity design requires a lot more tons than would be expected from the ratio of horizontal loads – because:

- the tension diagonal is chosen with a bigger cross section than is needed for the actual load;

- the waler is designed to match the oversized diagonal – and then rounded up to the next dimension of rolled section

- the colum is as well designed to match the oversized diagonal – and then rounded up to the next dimension of rolled section

Keep in mind:

These numbers are only for the structural parts, which participate in bracing fields – all the rest of the structure could remain unchanged. But as it is in plant construction, every part of equipment is supported on beams, which then receive seismic loads along their weak axes. Therefore a lot of additional tons are needed on every level of the building.

In such cases it would be sensible not to re-engineer the existing structure with respect to the newly added seismic horizontal loads, but to completely new-design a structure which can carry the loads from the masses (equipment) to the bracings.

8. References

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