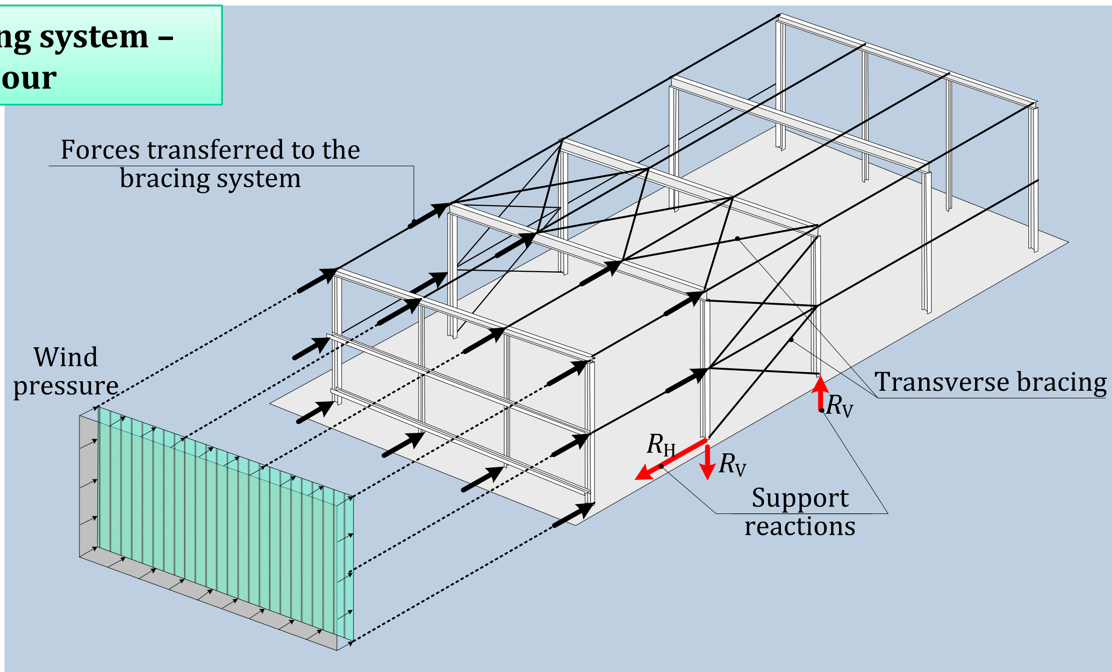
STEEL STRUCTURES – BRACING SYSTEMS

Transverse bracing system – Structural behaviour



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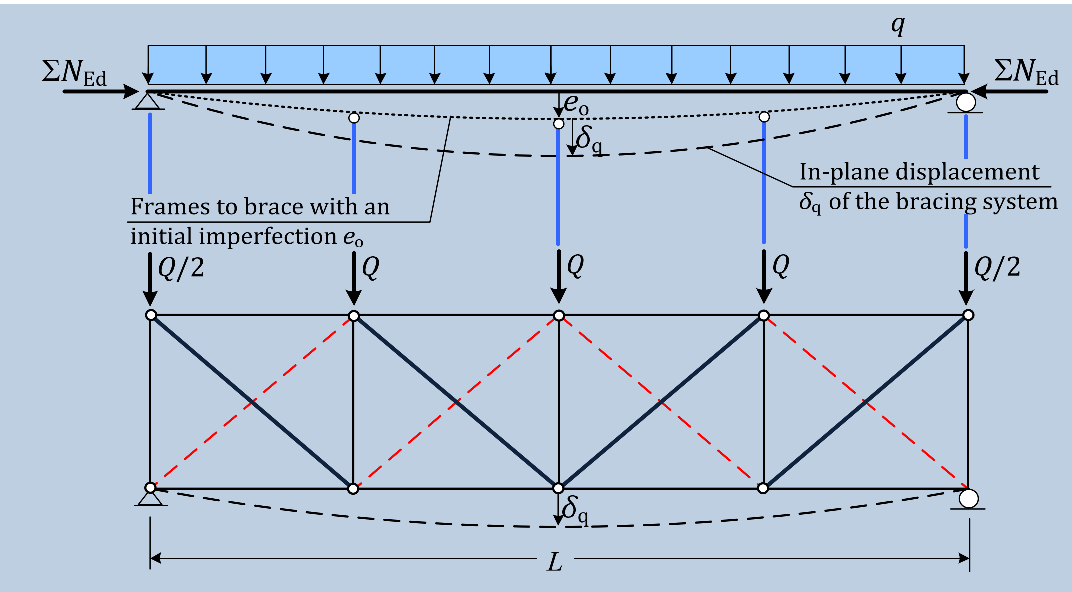

The design of the transverse bracing system must take into account:

- the actions directly applied to the bracing system,
- the horizontal actions applied to the typical frames,
- the action equivalent to the stabilizing effect of frames by the bracing system.

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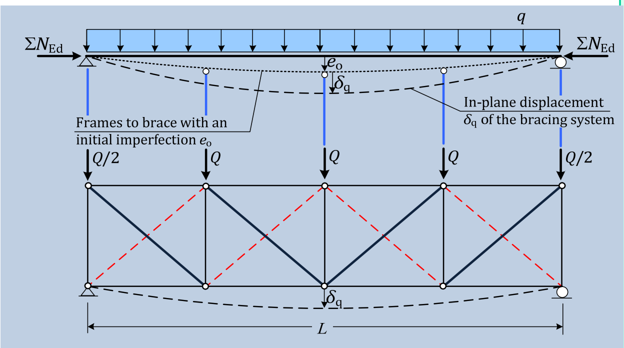

Equivalent force for the bracing system design

This equivalent load is defined by equalizing the bending moment obtained by this uniform load at mid-span ($= q \cdot L^2/8$) with the 2º order bending moment at this section produced by the compression installed at the beam on its deformed position, i.e.,

$$\frac{q \cdot L^2}{8} = (\Sigma\, N_{\mathrm{Ed}}) \cdot (e_0 + \delta_{\mathrm{q}})$$

with:

δ_{q} – displacement of the bracing system, in its plane, due to the load q and possible external loads (wind action, for example), calculated with a first order analysis,

e_0 – amplitude of an initial equivalent geometric imperfection defined for the elements to be braced.

EC3-1-1 provides the amplitude of this geometric imperfection is calculated according to the span of the bracing system, L, and the number of elements to be braced, m, for

$$e_0 = \frac{L}{500} \cdot \sqrt{0{,}5 \cdot \left(1 + \frac{1}{m}\right)}$$

The load q will be given by:

$$q = \frac{8 \cdot (\Sigma\, N_{\mathrm{Ed}})}{L^2} \cdot (e_0 + \delta_{\mathrm{q}}) = \varphi \cdot \frac{(\Sigma\, N_{\mathrm{Ed}})}{L} \qquad \text{with} \qquad \varphi = \frac{8 \cdot (e_0 + \delta_{\mathrm{q}})}{L}$$

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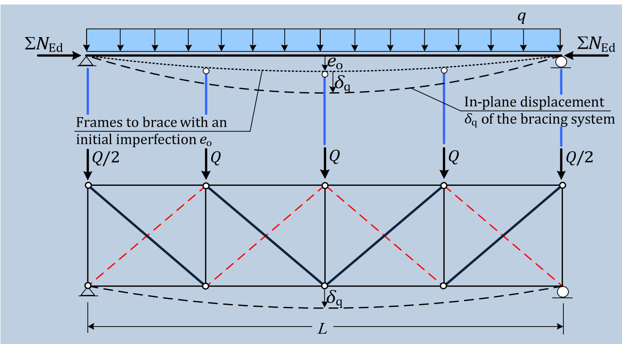

Factor φ as a function of the mumber of franes (m) and the maximum admissible displacement of the bracing system (δ_{q})

m	α_{m}	e_0	φ for $\delta_{\mathrm{q}} = L/1000$	φ for $\delta_{\mathrm{q}} = L/2500$
1	1,00	$L/500$	1/41,7	1/52,1
2	0,866	$L/577$	1/45,8	1/56,0
3	0,816	$L/612$	1/47,5	1/58,6
4	0,791	$L/632$	1/48,4	1/60,1
5	0,775	$L/645$	1/49,0	1/61,0

Equivalent force for the bracing system design

- Factor φ has values in the order of $1/50$;
- Therefore, the equivalent total force loading the bracing system ($q \cdot L$) is a small percentage of the compression force installed on the braced elements;
- Order of 2% $\sum N_{\mathrm{Ed}}$

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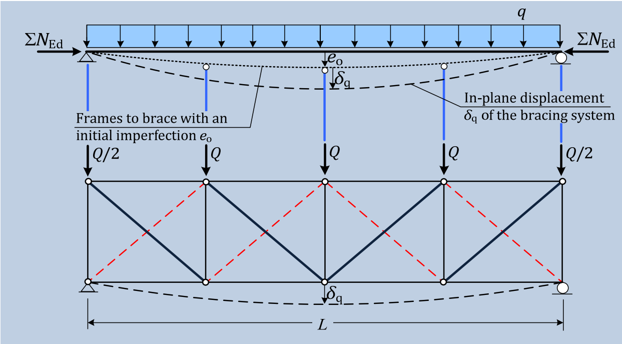
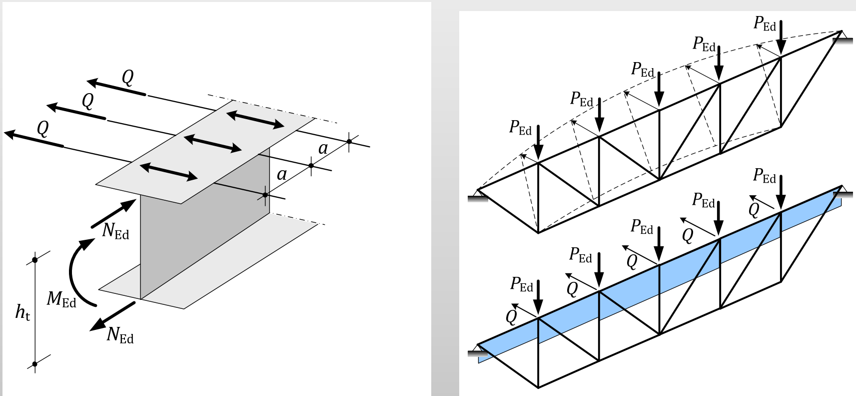
$$q = \frac{8 \cdot (\Sigma N_{Ed})}{L^2} \cdot (e_0 + \delta_q) = \varphi \cdot \frac{(\Sigma N_{Ed})}{L} \quad \text{with} \quad \varphi = \frac{8 \cdot (e_0 + \delta_q)}{L}$$





a) $N_{Ed} = M_{Ed}/h_t$ (or $N_{Ed} = A_f \cdot f_y$) b) $N_{Ed} = N_{Ed,f,max}$ (or $N_{Ed} = A_f \cdot f_y$)

Design forces of the bracing system: a) a laminated beam profile, b) a truss

Equivalent force for the bracing system design

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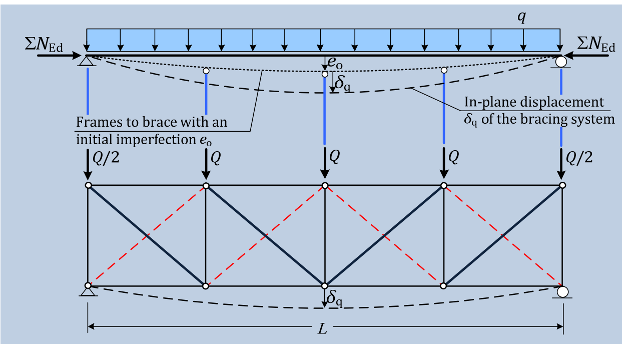


The design of the bracing system is an iterative process, with the following sequence of steps:

1) Set up the maximum admissible displacement δ_q (example, $L/2000$);

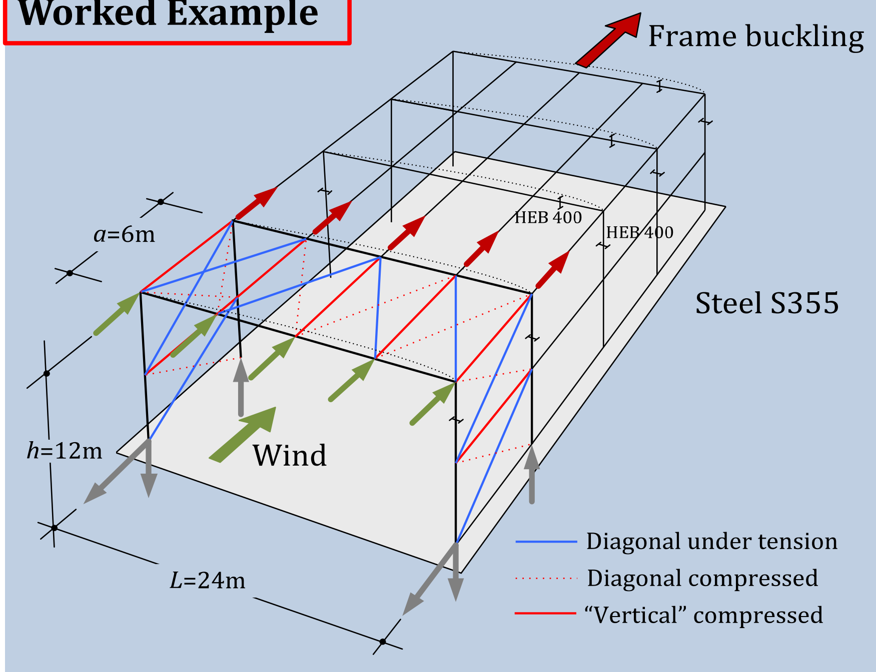
2) Evaluate the uniform load q to be applied to the bracing system, together, where appropriate, with external forces transmitted or directly applied to the system (in particular, wind forces);

3) Design the bracing system sections (truss diagonals and verticals) based on the internal forces obtained, and then check if maximum displacement of the bracing is less than that considered in 1);

4) Depending on the solution obtained, "close" the design or return to 1), assuming a different value for the displacement limit (for current situations, δ_q is usually between $L/1000$ and $L/2500$).

Equivalent force for the bracing system design

Worked Example



1) Equivalent stabilizing force

Wind > $v_{Ed} \approx 1.2\ \text{kN/m}^2 \cdot h/2 = 7.20\ \text{kN/m}$

Assume > $\delta_q \le L/2000$

Nº frames > $m = 5$

Initial imperfection >

$$e_0 = \frac{L}{500}\cdot\sqrt{0{,}5\cdot\left(1+\frac{1}{m}\right)} = L/645.5$$

Factor > $\varphi = \frac{8\cdot(e_0+\delta_q)}{L} = 1.64\%$ (=1/61)

Maximum force at the beam's compressed flanges >
$\Sigma N_{Ed} \approx m\cdot A_{flange}\cdot f_y = 12\,780\ \text{kN}$

Equiv. force > $q_{Ed} = \varphi\cdot\frac{(\Sigma N_{Ed})}{L} = 8.73\ \text{kN/m}$

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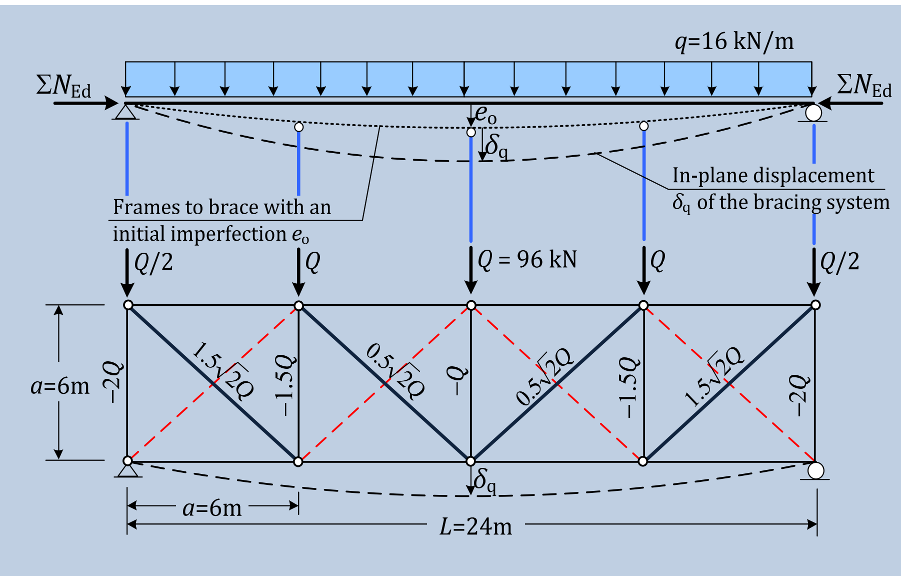
Worked Example



2) Equivalent internal forces

$Q = (q_{Ed} + v_{Ed})\cdot a \approx 16\ \text{kN/m}\cdot L/4 = 96\ \text{kN}$

3) Design of the bracing member sections

Diagonals: $N_{Ed} = 1.5\sqrt{2}Q = 203.6\ \text{kN}$
$Area \ge 203.6/35.5 = 5.74\ \text{cm}^2$

Choose SHS 80x80x3.6 > $Area = 10.9\ \text{cm}^2$

"Verticals": $N_{Ed} = -2Q = -192\ \text{kN}$
$Area \ge N_{Ed}/(\chi f_y) = 192/(0.3\cdot 35.5) = 18\ \text{cm}^2$

Choose SHS 80x80x6.3
c/ $Area = 18.1\text{cm}^2$; $i = 2.99$ cm
$\bar{\lambda} = 600/2.99/76.4 = 2.63 \rightarrow \chi_a \approx 0.13$ ✗

Choose SHS 120x120x5.0

c/ $Area = 22.7\text{cm}^2$; $i = 4.68$ cm
$\bar{\lambda} = 600/4.68/76.4 = 1.68 \rightarrow \chi_a \approx 0.30$ ✓

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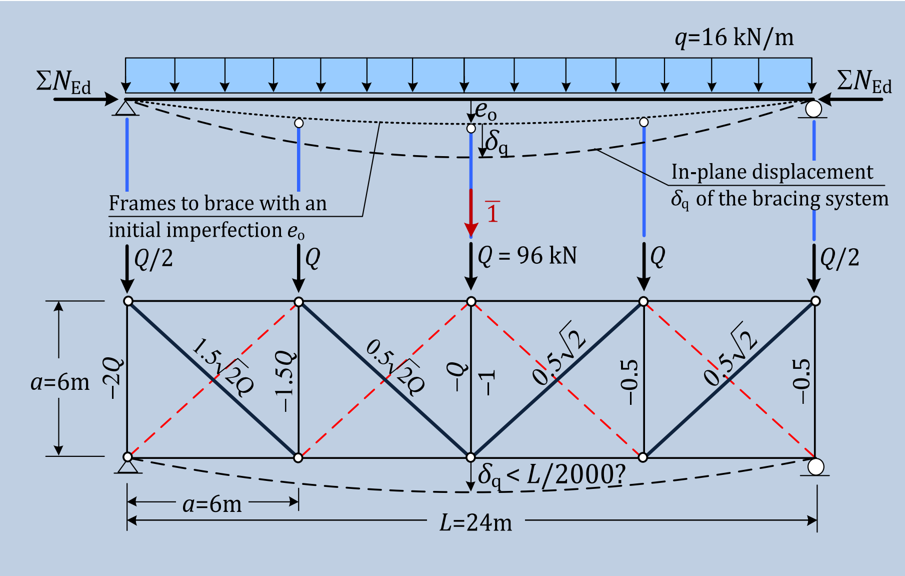
Worked Example



4) Deformability assessment

$\delta_q = \Sigma(N_{Ed,i} \cdot \overline{N}_i \cdot L_i)/(E \cdot A_i) = \delta_{chords} + \delta_{diag} + \delta_{vert}$ ($\delta_{chords} \approx 0$)

$\delta_{diag} = 33.94\ Q/(E \cdot A_{diag}) = 14.2$ mm

$\delta_{vert} = 27.0\ Q/(E \cdot A_{vert}) = 5.4$ mm

$\delta_q = 14.2+5.4 = 19.6 \text{ mm} > L/2000 = 12 \text{ mm}$

So, it doesn't check the initial hypothesis!

Solution → Change the diagonals to SHS 120x120x5.0 – similar to "verticals"

$\delta_q = 6.8+5.4 = 12.2 \text{ mm} > L/2000 = 12 \text{ mm}$

Still it doesn't check the initial hypothesis!

So, what is a better solution ??

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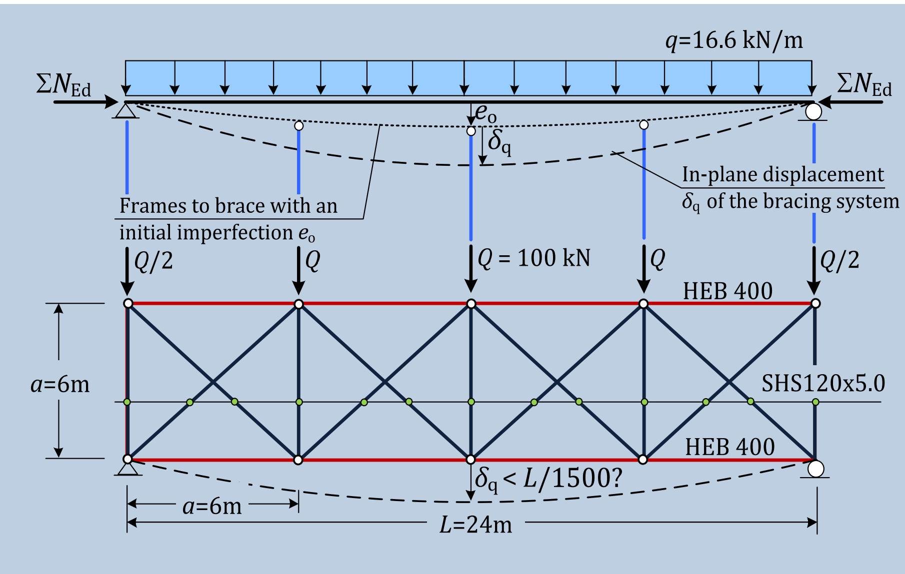
Worked Example



4) Deformability assessment

Better solution → Assume a greater bracing deformability, $\delta_q \leq L/1500$ (for example),

Continuing using SHS 120x120x5.0 for diagonals and "verticals", one obtains

$\varphi = 1.77\%$

$q_{Ed} = 9.44$ kN/m

$Q = (q_{Ed} + v_{Ed}) \cdot a \approx 100$ kN

Diagonals: $N_{Ed} = 212 \text{ kN} << N_{Rd} = 806 \text{ kN}$

"Verticals": $N_{Ed} = -200 \text{ kN} < N_{Rd} = -242 \text{ kN}$

$\delta_{diag} = 33.94\ Q/(E \cdot A_{diag}) = 7.1$ mm

$\delta_{vert} = 27.00\ Q/(E \cdot A_{vert}) = 5.7$ mm

$\delta_q = 7.1+5.7 = 12.8 \text{ mm} < L/1500 = 16 \text{ mm}$

Already verifies the initial hypothesis!

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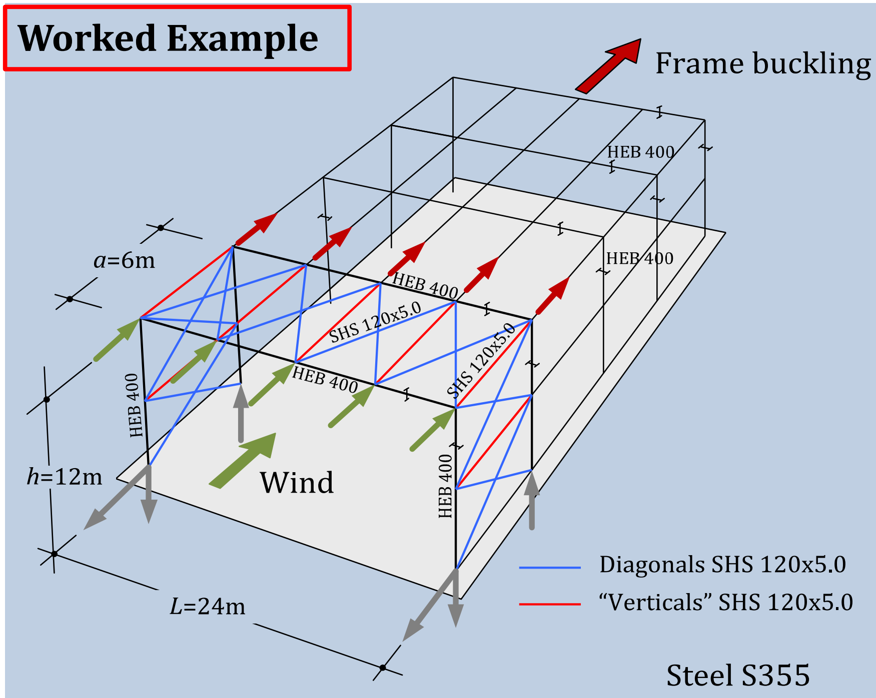

4) Adopted solution

Solution → Assume bracing deformability $\delta_q \leq L/1500$ (for example),

and adopt for the bracing system the following sections, in S355:

Diagonals >> SHS 120x120x5.0

"Verticals" >> SHS 120x120x5.0

STEEL STRUCTURES – BRACING SYSTEMS

Summary:

1) The longitudinal bracing system is useful, but not absolutely required (in most steel structures)

2) If adopted, it must have a minimum stiffness to be efficient, contributing to reduce the buckling length of the columns in the plane of the frames

3) The transverse bracing system is required to transfer the wind actions of top facades to the foundations and to "stabilize" the out-of-plane buckling of the frames

4) The total design force of this system corresponds to about 2% of the force installed in the compressed flange of the beams – or 2% of their plastic resistance

5) However, the most important requirement of the transverse bracing system is to have the necessary stiffness to minimize the out-of-plane movements of the frames, as thus supplying rigid out-of-plane supports to the frames.