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Investigation of the Eurocode 3 Method for Computing the Buckling Resistance of Plate Girders with Web Stiffeners

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***Abstract:** Tall steel beams, like plate-girders, are susceptible to local web-buckling when loaded by a point load. To prevent this, transverse stiffeners are often installed in the area below the point load to transfer the load into the girder web. The method described in Eurocode 3 NS-EN 1993-1-5 on how to compute the local web buckling resistance of a girder is investigated by executing both FEM-analyses and practical laboratory experiments with point-loaded girders without and with transverse web-stiffeners of various configurations, and comparing these results with the capacities obtained from the code-method, which implies that the point-load capacity decreases when the distance between stiffeners becomes small, i.e. approaches 20 mm. This seems unreasonable, particularly as only one single stiffener at each side of the web is commonly utilized in engineering design. The conclusion of this investigation is that the code-method is not valid for stiffener-distances below a limit.*

Keywords: **Steel girder; web buckling; stiffeners; point-load capacity.**

I. INTRODUCTION

A plategirder is a type of beam constructed from plates of steel that are either bolted or welded together. The purpose is to obtain a beam that is larger than anything that can be built by a steel mill or factory. This type of girder is usually used to make certain types of bridges, and the girders themselves are very often in the shape of an I-beam. The size and shape of the girder allows builders to construct bridges that are much longer and heavier duty than bridges constructed with other designs. Web-stiffeners are commonly required to prevent local web-buckling at the points of application of concentrated loads. One single transverse stiffener areoften sufficient at each side of the web, but a pair of stiffeners are required in other cases when the point-load is larger. The validity, for smaller stiffener spacing, of a method described in EUR NS-EN 1993-1-5:2006 (Design of Steel Structures – Plated Structural Elements) was investigated [1, 2].

The purpose of the stiffeners is to transfer the point-load through the stiffeners and into the girder-web via the vertical welds between stiffeners and web, Figure 1 and 2. This takes place through compressive stress between the underside of the girder flange and the top edge contact area of the stiffeners. This pressure is then transferred as shear stress through the stiffener to and through the stiffener/web-weldment, Figure 1.

The structural steel design code, NS-EN 1993-1-5 Section 6 – Transverse Loading Capacity, describes a computational method for stiffener configurations as shown in Figure 1. Previous preliminary computations at the University of Life Sciences has indicated that the method yields too conservative results, and more so when stiffeners are closely spaced, as the capacity than becomes unreasonably low. Later on, 2 Master Degree theses have supported these findings [2, 3, 4, 5].

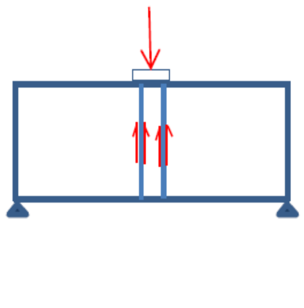

Fig 1. Transfer of point-load through web-stiffener to girder-web

Practical experiments with shop-fabricated, short, but tall, girders, Figure 2, loaded by utilizing a hydraulic press, in addition to extensive FEM-analyses, were executed for the purpose of resolving the matter. The configurations utilized in this research are visualized in Figures 3 through 6.

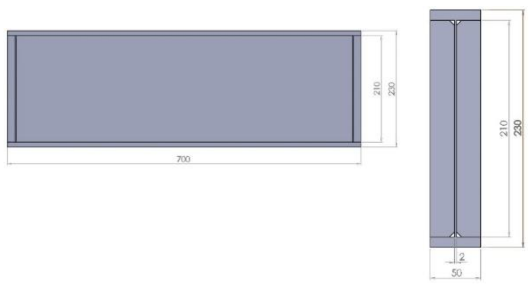

Fig 2. Elevation and section of Plate Girder

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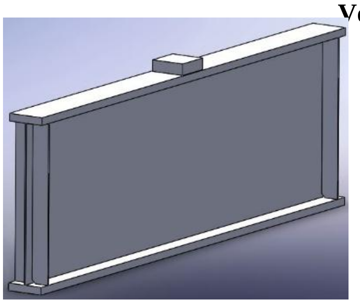

Fig 3. Plate Girder without stiffeners at point of load application

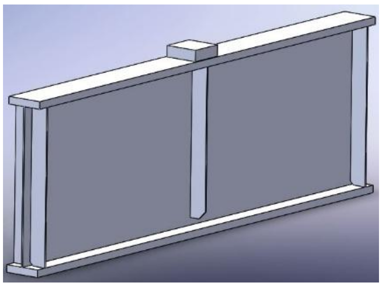

Fig 4. Plate Girder with one stiffener at ea. side of point of load application

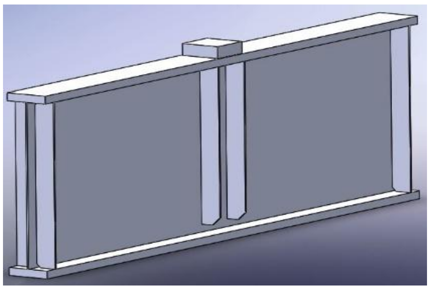

Fig 5. Plate Girder with two stiffeners spaced at 50 mm ea. side of load application

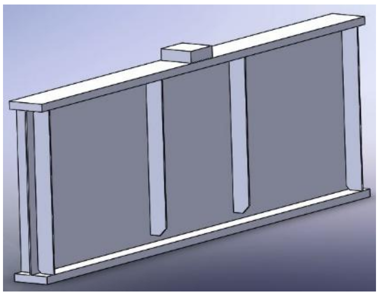

Fig 6. Plate Girder with two stiffeners spaced at 182 mm each side of web and centered om point of load application

The plate girders were continuously supported laterally at the top flange. Web buckling underneat the point of load application occurred, both in the practical lab-tests and in the FEM-models,with no internal stiffeners, Figure 3, as expected. The stiffener configurations illustrated in Figures 4 and 5 effectively prevented web buckling below the point load, and eventual failure took place as shear buckling of the web, Figure 7, in the areas adjacent to the stiffened part of the web. The stiffeners were placed too far apart in the configuration visualized in Figure 6, to prevent the web from buckling directly beneath the load, i.e. "ordinary" Euler web-buckling took place.

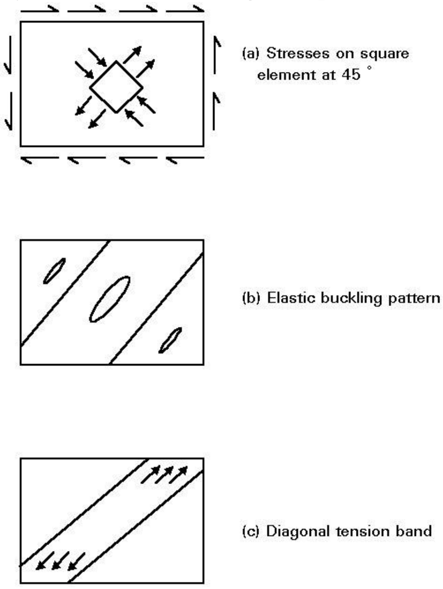

Figure 7 Plate buckling in shear

II. CAPACITY VALUES OBTAINED FROM EUR NS-EN 1993-1-5:2006

According to EUR NS-EN 1993-1-5:2006 the point load capacity with respect to web failure may be computed from

$F_{Rd} = \dfrac{f_{yw} L_{eff} t_w}{\gamma_{M1}}$ where

$f_{yw}$is the yield strength of the web
$t_w$is the web thickness
γ_{M1} = materialsfactor
$L_{eff}$is the effective length for resistance to transverse forces which should be determined from $L_{eff} = \chi_F \cdot \ell_y$

where ℓ_y is the effective loaded length appropriate to the length of the *stiff bearing*,s_s, Figure 8.The reduction factor, χ_F , should be obtained from

$$\chi_F = \frac{0,5}{\lambda_F} \leq 1,0$$

Where

$$\lambda_F = \sqrt{\frac{l_y t_w f_{yw}}{F_{cr}}}$$

Effective loaded length

$$\ell_y = s_s + 2t_f \left(1 + \sqrt{m_1 + m_2}\right)$$

where

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$m_1 = \frac{f_{yf} b_f}{f_{yw} t_w}$ and $m_2 = 0{,}02 \left(\frac{h_w}{t_f}\right)^2$ if $\lambda_F > 0{,}5$

and $m_2 = 0$ if $\lambda_F \leq 0{,}5$

f_{yf} = yield strength of the flange
t_f = flange thickness
b_f = flange width
h_w = web height,i.e. distance between flanges

$$F_{cr} = 0{,}9 k_F E \frac{t_w^{\,3}}{h_w}$$

where

$$k_F = 6 + 2\left(\frac{h_w}{a}\right)^2$$

"a" being the distance between the transverse stiffeners, Figure 8.

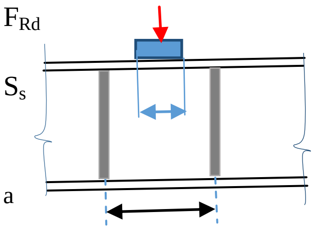

Fig 8. Distance between stiffeners = a. Length of stiff bearing = S_s

The point load capacity increases from approximately 38 kN to 45 kN with decreasing distance "a" between stiffeners from 300 mm to 70 mm. With further reducing values of "a", the point load capacity decreases steeply down to approximately 7 kN when at stiffener distance 20 mm [2]. This corresponds closely to the findings of Hansen [4]. Computational results for the configurations in Figures 3 through 6 are listed in Table 1.

Table 1. Results computed from EUR NS-EN 1993-1-5:2006

TYPE	STIFFENER CONFIGURATION	a-value (mm)	Max.loadF_{Rd} (kN)
I	No interior stiffeners, only end stiffeners	670	**22.0**
I	As above	∞	**21.6**
II	One interior stiffener ea. s. of web centered on point load in addition to end stiffeners	0	**25.5**
III	Two stiffeners ea. side of web, centered on point load in addition to end stiffeners	50	**33.8**
IV	Two stiffeners ea. side of web, centered on point load in addition to end stiffeners	182	**42.8**

The capacity of 25.5 kN, obtained with a single stiffener ea. s. of the web, ought to be considerably higher than the capacity of 22 kN with no interior stiffeners, Table 1. Further, it does not seem reasonable that the capacity is greater with stiffeners @ 182 mm than when spaced @ 50 mm.

III. LABORATORY WORK

The types of weld-fabricated beam, support, and loading configuration as in Figure 9 were utilized, with and without transverse stiffeners inserted by welding under the point load (stiffeners are not shown in Figure 9).

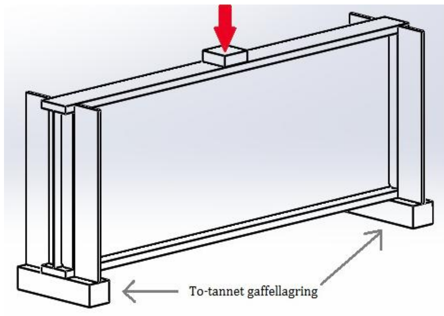

Fig 9. Simply supported, end-fork stabilized plate-girder All steel: S355

Modulus of Elasticity: 210000 N/mm^2.

The distances between stiffeners were as given in Table 1. Refer to Figures 10 through 13 for photographies of the girders. The photo of a beam without interior stiffeners in Fig. 10 was taken subsequent to initial web buckling failure, and illustrates the test setup as well.

Fig 10. Beam with no internal stiffeners, Configuration I, after web buckling

Fig 11. Stiffener configuration II

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Fig 12. Stiffener configuration III

Fig 13. Stiffener configuration IV

Table 2. Results from laboratory tests

TYPE	STIFFENER CONFIGURATION	Max.load F_{Rd} (kN)
I	No interior stiffeners, only end stiffeners	**38**
II	One interior stiffener ea. s. of web centered on point load in addition to end stiffeners	**78**
III	Two stiffeners ea. side of web, centered on point load in addition to end stiffeners, a = 50 mm	**81**
IV	Two stiffeners ea. side of web, centered on point load in addition to end stiffeners, a = 182 mm	**58**

The test results obtained from the laboratory experiments, listed in Table 2, are in agreement with common engineering experience. One stiffener ea. s. of web beneath the point load, doubles the capacity, while two stiffeners, spaced 50 mm, ea. s. of web, yields approximately the same capacity. With stiffeners 182 mm apart, the capacity decreases to about 70% of the capacity of the beam with one stiffener ea. s. of the web or with two stiffeners @ 50 mm ea.s. of the web.

IV. FEM – ANALYSES

The same type of fine mesh was utilized in all areas of the model, Figure 14. Imperfections in shape, residual stress and eccentricities were not accounted for in this FEM-analysis. Accordingly, it was expected that the critical buckling loads would be considerably higher than the maximum loads obtained for the real beams in the laboratory experiments. The FEM-model support conditions are visualized in Figure 15. The modeling was intended to simulate the support conditions in the practical laboratory experiments. The loading block is fixed against lateral movements, but free to move vertically, which was achieved with roller supports around the edges of the block. The girder-ends are fork-supported, i.e. free to rotate laterally, and vertically, but fixed against linear horizontal movement.

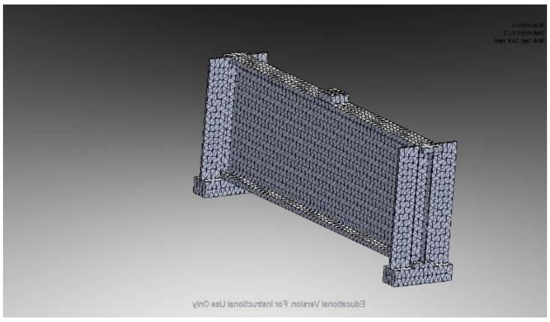

Fig 14. Fine-meshed FEM-model

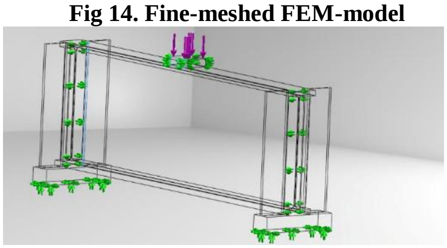

Fig 15. FEM-model support conditions

Non-linear analyzes yielded critical buckling loads which occurred at initial buckling of the web when no internal stiffeners were installed and also in the case when internal stiffeners were spaced far apart, 182 mm, and corresponds to the Euler-column initial buckling load, i.e. a perfectly ideal structure. When one single stiffener pair was inserted, and also when two stiffener pairs, spaced at 50 mm, were installed, shear buckling, Fig. 7, occurred, Figures 17 and 18.

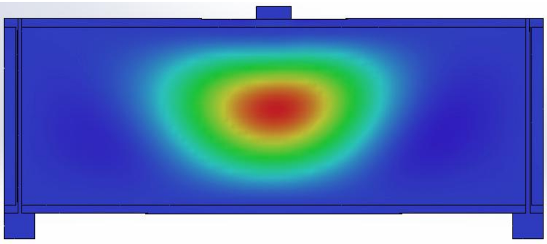

Fig 16. Initial buckling without interior stiffeners

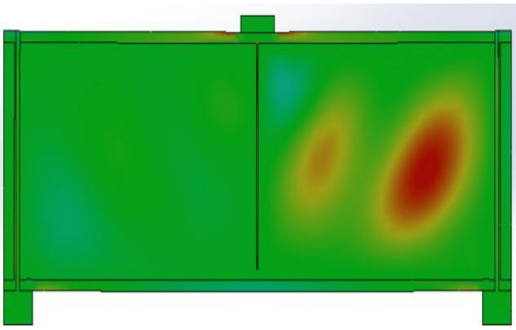

Fig 17.Initial buckling with one interior stiffener ea.s. of the web

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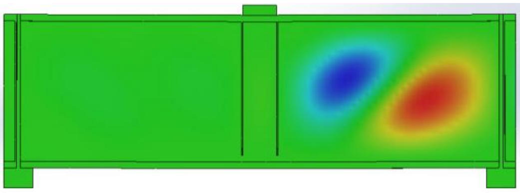

Fig 18. Initial buckling with two interior stiffeners, spaced @50 mm, ea. s. of web

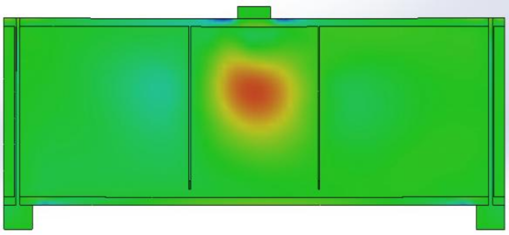

Fig 19. Initial buckling with two interior stiffeners, spaced @ 182 mm, ea. s. of web

Areas of no lateral deflection of the web is indicated by blue color in Figure 16 and by green color in Figures 17, 18 and 19,while the red color in all four figures indicates web-areas of maximum lateral deflection. The blue colored area in Figure 18 deflected in the opposite direction of the red colored area.

Table 3. Results from FEM-analysis

TYPE	STIFFENER CONFIGURATION	Max.load F_{Rd} (kN)
I	No interior stiffeners, only end stiffeners	**62**
II	One interior stiffener ea. s. of web centered on point load in addition to end stiffeners	**173**
III	Two stiffeners ea. side of web, centered on point load in addition to end stiffeners, a = 50 mm	**181**
IV	Two stiffeners ea. side of web, centered on point load in addition to end stiffeners, a = 182 mm	**105**

As expected, considering the idealized Euler-column-type conditions provided, by the FEM-method, the failure loads are considerably higher than those obtained from the laboratory experimental series. However, relative to each other, the max.loads for the different configurations, follow the same pattern as in the laboratory series.

V. DISCUSSION OF RESULTS

The Code-method apparently is based upon that only evenly distributed vertical stress occurs in the girder web, and that vertical local buckling will be the failure mode.

Table 4. Comparison of results, loads are in kN

TYPE	STIFFENERS	CODE	LAB	FEM
I	None	**21.6-22**	**38**	**62**
II	One	**25.5**	**78**	**173**
III	Two @50 mm	**33.8**	**81**	**181**
IV	Two @ 182	**42.8**	**58**	**105**

By installing one stiffener pair, i.e. one ea. s. of web, or two pairs at close spacing, beneath the point load, vertical buckling is prevented. However, it seems unreasonable that the failure load is larger when stiffeners are spaced at 182 mm than at 50 mm, as the possibility for web buckling taking place below the point load would be higher for the larger stiffener spacing. Both the lab-tests and the FEM-analysis support this. The code-method only yields a slight increase in load capacity from no stiffener to one stiffener pair, or 22 kN to 26 kN, which seems unreasonable. Both the lab-tests and the FEM-analysis yields substantial increases in load-capacity when one stiffener pair is inserted, compared to no stiffeners, and a limitedfurther increase when 2 pairs are installed, 50 mm apart. A larger spacing, 182 mm, results in a substantially reduced capacity, although still considerably higher than without interior stiffeners.

VI. CONCLUSION

The lab-test results and the FEM-analysis results are in agreement with respect to the load capacities relative to each other, and the results seems logical. The code-results are not in line with the above, and the results are ratherunreasonable, based on common engineering knowledge and practice.

It may safely be concluded that the code-method is in need of revision.Limits on stiffener spacing are required, and the method should include the case with only one stiffener pair placed beneath the point load, as this is commonly used in practice.

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