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Influence of Structural Connecting Details on the Load Carrying Capacity of Girders

Influence des assemblages sur la charge ultime des poutres

Der Einfluß von Anschluß-Details auf die Traglast von Biegeträgern

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SUMMARY
If the compression flange of a beam in bending is not supported laterally the beam may fail by lateral torsional buckling. Investigation of this stability problem usually assumes simple support. In reality often notched ends are used. By this real support condition the beam becomes weaker which is unfavourable especially with respect to the torsional rigidity. On the other hand a partial fixing in the lateral direction is given by the commonly used bolted connections. It is reported on tests which were carried out to investigate these two effects.

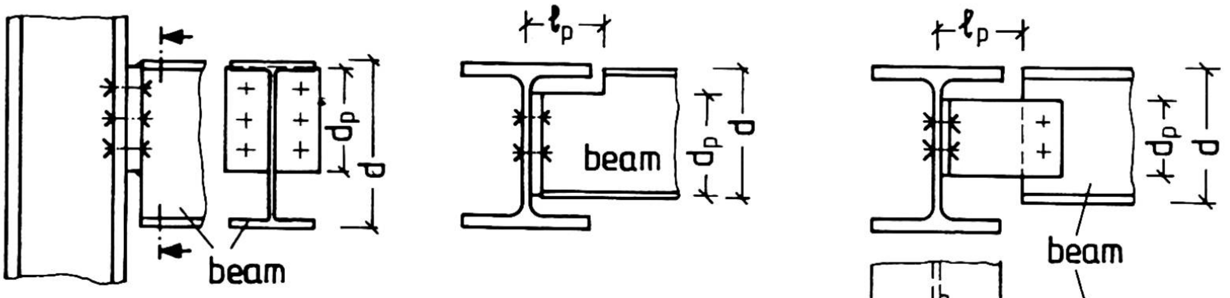
RÉSUMÉ
Au cas où la membrure comprimée d'une poutre fléchie n'est pas supportée latéralement, la ruine de la poutre peut se produire à cause du flambement par flexion-torsion. L'étude de ce problème de stabilité présuppose en général un appui simple. Mais il y a très souvent, des entailles, qui réduisent la rigidité de la poutre. D'autre part, les assemblages, conventionnels par boulons assurent une certaine rigidité latérale. Ces deux effets ont fait l'objet d'essais, présentés dans ce rapport.

ZUSAMMENFASSUNG
Wenn der Druckgurt eines Biegeträgers seitlich nicht gehalten ist, kann der Träger durch Biegedrillknicken (''Kippen'') versagen. Bei der Berechnung dieses Stabilitätsproblems wird üblicherweise eine Gabellagerung angenommen. Tatsächlich sind jedoch häufig Ausklinkungen vorhanden. Diese vermindern die Steifigkeit des Trägers, ergeben durch die Schrauben am Anschluß jedoch auch eine teilweise seitliche Einspannung. Es wird über Versuche zur Klärung dieser Effekte berichtet.

1. GENERAL

The theory of lateral torsional buckling was investigated by many researchers in the past. As the most appropriate method, the utilization of the theory of elasticity has been established. The plasticity of steel is then being incorporated by way of special design-procedure.

In building structures commonly connections are used which provide ease of design, fabrication and erection. Some typical configurations for beam to column and beam to beam connections are shown in Fig. 1.



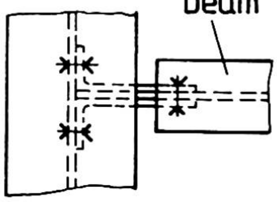


Fig. 1 Typical connections in building-structures

To clarify the influence of the structural details of the conncetions tests were carried out at the Technical University of Berlin, reported by Lindner/Schulze (1985), [1], [2].

2. TEST SPECIMEN

Single-span girders were chosen for the test-programme:
- IPE (UB) 160/St 37, beam length 2,20 and 3,80 m,
- IPE (UB) 300/St 37, beam length 3,80 and 5,60 m.

A concentrated load at mid-span was applied 10 mm above the top-flange. It was inserted with a lateral load eccentricity of L/1000 with respect to the web. This eccentricity was chosen in such way that the displacements summed up caused by the out-of-straigthness and the eccentricity.

Three different types of connections were investigated; Fig. 1: 1. end plates with reduced depth, 2. notched ends, 3. web cleats which result in a special type of notched ends. The connections mainly were chosen from a publication of the German Steel Association, [3]. The nomenclature in Table 3 followed [3]. The bolt grade was chosen as 4.6 and 10.9, in the latter case with a partial tightness of 50%. High strength bolts were used for tests A3, T4 (Table 1), ISH connection type (Table 2), all tests (Table 3).

The geometrical and material properties of each beam were measured as well as the out-of-straigthness.

The section properties differed slightly from the nominal values. The yield stress σ_y was higher than the nominal value:
- IPE 160: σ_y=253 .. 332 N/mm² (MPa), - IPE 300: σ_y:267 .. 286 N/mm² (MPa).

Using the measured section properties and the measured yield stresses the following full plastic moments M_p were calculated
- IPE 160: M_p=32,6 .. 40,3 kNm, - IPE 300: M_p:164,0 .. 174,2 kNm.

3. TEST RIG AND TESTING PROCEDURE

The test rig was described by Lindner (1977), [4]. The load was applied by a jack over a movable loading frame in such way that any restraining effect of the applied load was eliminated. The support construction of the jack moved by ball bearings on a small transverse beam in cases when the tested beam was twisting and deflecting. So the complete loading arrangement ensured that the applied

Test No.	Profil IPE	L [m]	Connection ℓ_p/d	Connection d_p/d	$\kappa = \frac{M_{test}}{M_p}$	Test No.	Profil IPE	L [m]	Connection ℓ_p/d	Connection d_p/d	$\kappa = \frac{M_{test}}{M_p}$
A1	160	2,2	0,67	0,67	0,538	T4	160	2,2	0,67	0,78	0,962
A2	160	2,2	0,67	0,67	0,604	T5	160	2,2	0,67	0,78	0,782
A3	160	2,2	0,67	0,67	0,521						

Table 1 Test results for notched beams
type A: both flanges notched, type T: upper flange notched

Test No.	Profil IPE	L [m]	Connection type	Connection d_p/d	$\kappa = \frac{M_{test}}{M_p}$	Test No.	Profil IPE	L [m]	Connection type	Connection d_p/d	$\kappa = \frac{M_{test}}{M_p}$
1	300	5,6	ISH 204	0,80	0,647	14	160	3,8	IS 164	0,75	0,651
2	300	5,6	ISH 204	0,80	0,576	15	160	3,8	IS 164	0,75	0,701
3	300	5,6	ISH 202	0,40	0,534	16	160	3,8	ISH 162	0,63	0,668
4	300	5,6	ISH 202	0,40	0,535	17	160	3,8	IS 162	0,44	0,596
5	300	5,6	IS 204	0,50	0,508	18	160	3,8	IS 164	0,75	0,658
6	300	5,6	IS 202	0,27	0,480	19	160	3,8	ISH 162	0,63	0,670
7	300	3,8	IS 204	0,50	0,659	20	160	2,2	ISH 162	0,63	0,708
8	300	3,8	ISH 202	0,40	0,712	21	160	2,2	ISH 162	0,63	0,727
9	300	3,8	ISH 202	0,40	0,699	22	160	2,2	IS 162	0,44	0,711
10	300	3,8	ISH 202	0,40	0,732	23	160	2,2	ISH 164	0,75	0,777
11	300	3,8	ISH 204	0,80	0,755	24	160	2,2	ISH 164	0,75	0,769
12	300	3,8	ISH 204	0,80	0,756	25	160	2,2	IS 164	0,75	0,765

Table 2 Test results for end plate connections with reduced depth

Test No.	Profil IPE	L [m]	Connection ℓ_p/d	Connection d_p/d	$\kappa = \frac{M_{test}}{M_{pl}}$	Test No.	Profil IPE	L [m]	Connection ℓ_p/d	Connection d_p/d	$\kappa = \frac{M_{test}}{M_p}$
W1	160	2,2	0,13	0,75	0,900	W13	300	3,8	0,50	0,77	0,676
W2	160	2,2	0,13	0,75	0,951	W14	300	3,8	0,50	0,77	0,659
W3	160	2,2	0,63	0,63	0,995	W15	300	3,8	0,33	0,77	0,687
W4	160	2,2	0,63	0,63	0,900	W16	300	3,8	0,33	0,77	0,667
W5	160	2,2	0,63	0,75	0,995	W17	300	3,8	0,33	0,53	0,619
W6	160	2,2	0,63	0,75	0,976	W18	300	3,8	0,33	0,53	0,702
W7	160	3,8	0,63	0,63	0,632	W19	300	5,6	0,33	0,77	0,516
W8	160	3,8	0,63	0,63	0,702	W20	300	5,6	0,33	0,77	0,502
W9	160	3,8	0,63	0,75	0,627	W21	300	5,6	0,33	0,53	0,472
W10	160	3,8	0,63	0,75	0,657	W22	300	5,6	0,33	0,53	0,452
W11	160	3,8	0,94	0,63	0,648	W23	300	5,6	0,50	0,77	0,494
W12	160	3,8	0,94	0,63	0,612	W24	300	5,6	0,50	0,77	0,482

Table 3 Test results for connections with web cleats (L 200•100•10)

load remained vertical.

The load on the specimens was held constant at convenient increments throughout the test so that the various data readings could be taken after the specimen -

had stabilized itself at that load level.

4. TEST RESULTS AND EVALUATION

The test results are given in Tables 1, 2, 3. In order t evaluate these results the design procedure of the European Recommendation (1978) by the ECCS was used.

$$\lambda_{eq} = \sqrt{M_p/M_E} \quad (1)$$

$$\kappa_M = \left[\frac{1}{1+\lambda_{eq}^{2n}}\right]^{1/n}, \quad n = 2,0, \quad M_u = \kappa_M \cdot M_p \quad (2)$$

where M_E = elastic critical lateral torsional buckling moment
n reduced system factor, following [5].

For each test specimen this evaluation was carried out using the individual section properties and yield stress. For calculation of the value M_E computer programms were used taking into account different assumptions:

E1. constant stiffness across the beam length, no cross section deformation, [6],

E2. reduced stiffness at the support due to the connection type, no cross section deformation, [6],

E3. reduced stiffness at the support due to the connection type, warping stiffness of the end plate and cross section deformations are considered, [7], [8], [9].

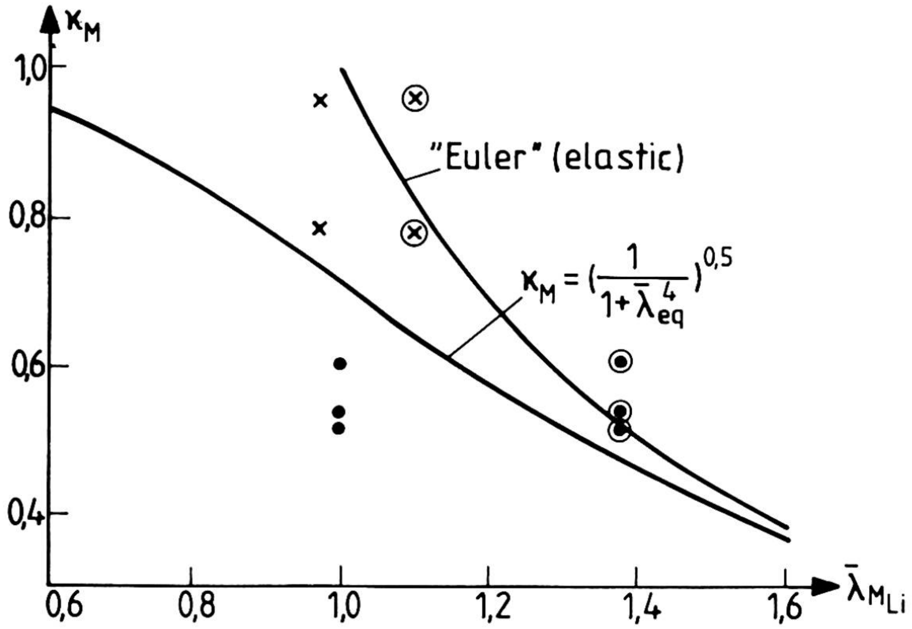


Fig. 2 Notched ends, evaluation of test results
•/x: assumption E1, •/x:assumption E3, [9]

Some of the results can be seen in Figs. 2 to 4, where the test results are plotted versus the equivalent slenderness λ_{eq} of equ. (1).

The following general conclusions can be drawn from these results:

1. Notched beams

1.1 The reduced stiffness and the cross section deformation in the notched region must be taken into consideration.

1.2 A significant effect of partial fixing with regard to the minor axis can be seen in the case of one flange notching.

2. End plate connections with reduced depth

2.1 The reduced stiffness due to the end plates is significant for beams of higher depth (here IPE 300).

2.2 A partial fixing with regard to the minor axis leads to a higher load carrying capacity especially for the smaller profiles (here IPE 160).

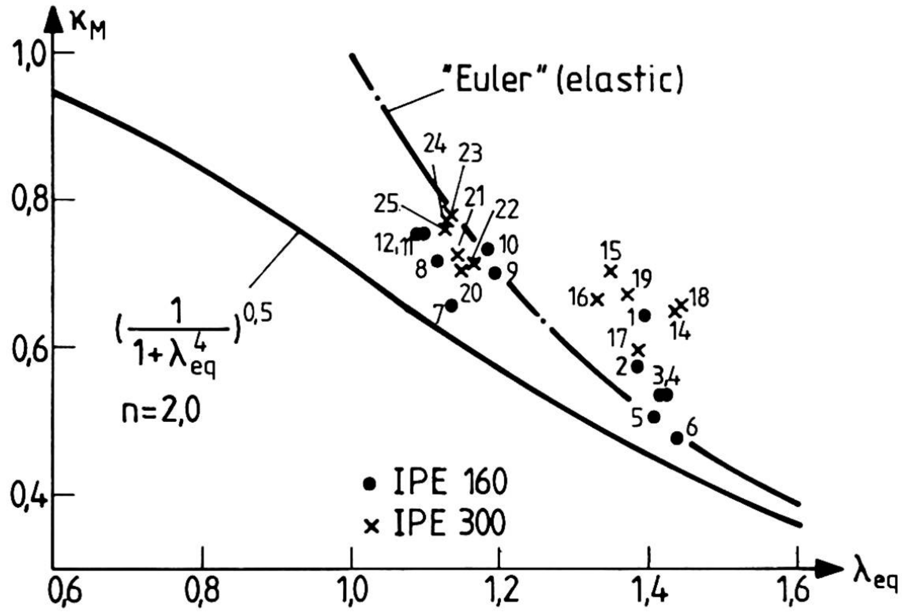


Fig. 3 Evaluation of test-results using assumption E3 - connection with end-plates

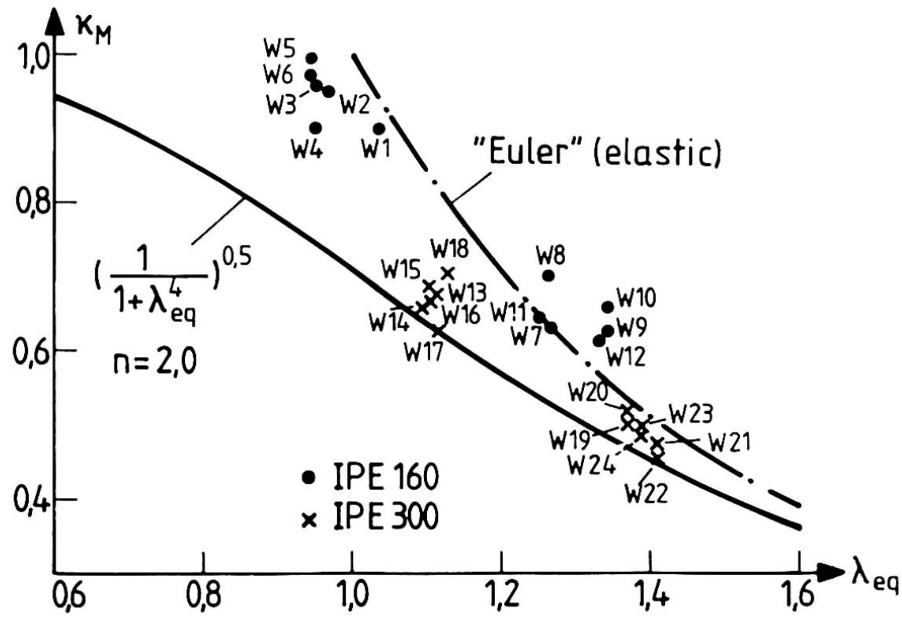


Fig. 4 Evaluation of test-results using assumption E2 - connection with web cleats

3. Connections with web cleats

3.1 The reduced stiffness in the support region is of minor influence. But this depends especially on the torsional stiffness of the cleats themselves which is relatively high in the cases tested here.

3.2 A partial fixing with regard to the minor axis leads to a higher load carrying capacity especially for the smaler profiles (here IPE 160).

The load deflection curves for the lateral displacement of the upper flange have shown to be very similar in all tests showing a satisfying rotation capacity. Bolt grade seems not to be a significant factor neither for the load carrying capacity nor for the flexible behaviour of the connections.

5. CONCLUSION

Further investigations under way concentrate on the influence of partial fixing with regard to minor axis. This effect depends especially on the type of cross section investigated.

6. ACKNOWLEDGEMENT

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