

CORRUGATED WEB BEAM



TECHNICAL DOCUMENTATION

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A. GENERAL

1. General description and application

Corrugated web beams are built-up girders with a thin-walled, corrugated web and wide plate flanges (Fig 1).

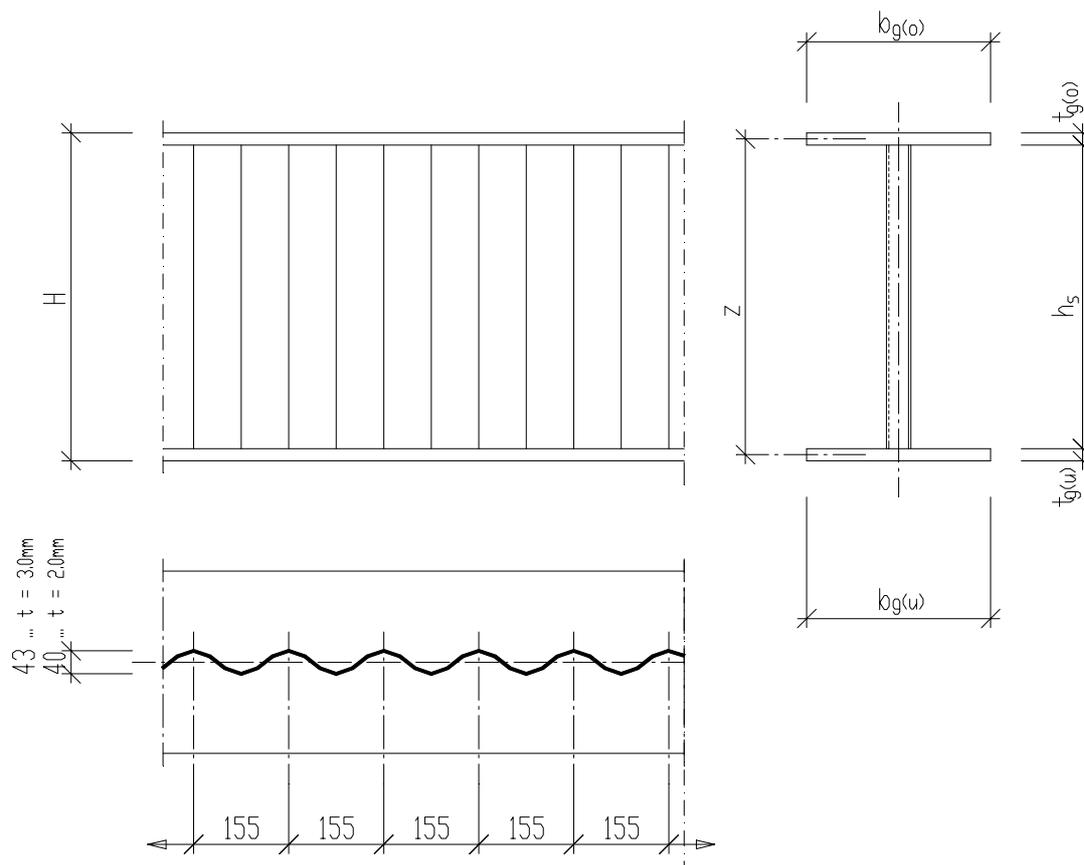


Fig. 1. Corrugated web beam - dimensions, designation

The profiling of the web generally avoids failure of the beam due to loss of stability before the plastic limit-loading for the web is reached. In addition to benefits in production technology, the sinusoidal corrugation has the advantage over trapezoidal profiling of eliminating local buckling of the flat plate strips.

Corrugated web beams may be used as beams (roof or slab beams, structural beams) or as components subject to normal forces (columns or frame columns) virtually without structural limitations. The optimum area of application is in steel structural engineering wherever rolled profiles of structural height greater than 450 mm or low lattice girders of structural height below approximately 1,800 mm were formerly used.

For sample applications see Appendix A.

2. Basis for calculation

As a result of its profiling, the web does not participate in the transfer of longitudinal normal stresses from bending. This means that

in static terms, the corrugated web beam corresponds to a lattice girder

in which the bending moments and the normal forces are transferred only via the flanges, while the transverse forces are only transferred through the diagonals and verticals of the lattice girder - in this case the corrugated web.

On the basis of this static model, dimensioning and testing is implemented in accordance with **DIN 18 800** ([1]-[3]) or **DAST-Ri. 015**, ([4], Sections 4 and 6) according to the E-P (E-E) method. Accordingly, the verification of the load carrying capacity is ideally provided at the level of internal forces and the cross-sectional resistance of the individual cross-sectional components - flange and web.

Alternatively, calculations may also be based on **EUROCODE 3** [5], or any other national standard which contains rulings in respect of lattice girders or open web columns and the transverse buckling of orthotropic plates.

Ascertaining the parameters for the resistance of the corrugated web beam is described in detail in Section 7. This is essentially based on the expertises [6] and [7]^{*)}. The procedure is additionally verified by means of experimental results ([8]...[10]).

Standards and Expert Opinions:

- [1] DIN 18 800 Teil 1 (1990), Stahlbauten; Bemessung und Konstruktion.
- [2] DIN 18 800 Teil 2 (1990), Stahlbauten; Stabilitätsfälle, Knicken von Stäben und Stabwerken.
- [3] DIN 18 800 Teil 3 (1990), Stahlbauten; Stabilitätsfälle, Plattenbeulen.
- [4] DAST - Richtlinie 015 (1990); Träger mit schlanken Stegen.
(German recommendations for girders with slender web plates.)
- [5] DIN V ENV 1993-1-1 (1993); EUROCODE 3: Design of steel structures; Part 1-1: General rules and rules for buildings.
- [6] O.Univ. Prof. D.I. Dr. Günter Ramberger, Gutachten über die Berechnung von geschweißten I-Trägern mit Stegen aus gewellten Blechen, Wien 20.12.1989.
(Expert opinion on the calculation of welded I-beams with corrugated webs, in German)
- [7] O.Univ. Prof. D.I. Dr. Günter Ramberger, 2. Gutachten über die Berechnung von geschweißten I-Trägern mit Stegen aus gewellten Blechen, Wien 16.11.1990.
(2nd Expert opinion on the calculation of welded I-beams with corrugated webs).

^{*)} Since these expert opinions were written before the appearance of DIN 18 800 and DAST-Ri. 015, the formulae for bearing loads of the flanges (Section 4) do not agree exactly with those of the above named standard. However, comparative calculations have shown that the results in the relevant areas of design and application do agree well.

- [8] Test report on experiments carried out on I-beams with corrugated web plates, Vienna University of Technology, Institute for Steel Construction, Department of Applied Model Statics in Steel Construction, August 1990. (in German)
- [9] Report No. 943040: Untersuchung zur Einleitung dynamischer Lasten in Wellstegträger WTB 750 - 300x12, Versuchsanstalt für Stahl, Holz und Steine (Amtl. Materialprüfanstalt) Universität Karlsruhe, 1995. (Investigation into the introduction of dynamic loads into corrugated web beams WTB 750 - 300x12).
- [10] Fire tests on corrugated web beams, Institute for Fire Prevention Technology and Safety Research (Officially Authorised Testing and Experimental Institute) Linz 1995. (in German).
- [11] Final Report on the Bearing Performance of Corrugated Web Beams; Brandenburgische Technische Universität, Lehrstuhl für Stahlbau, Cottbus 1996. (in German).
- [12] Gutachterliche Stellungnahme zur Querkrafttragfähigkeit von Wellstegträgern; Univ. Prof. Dr.-Ing. habil. Hartmut Pasternak, Braunschweig/Cottbus 1996. (Expert statement on the transverse force load carrying capacity of corrugated web beams).

References:

- [13] Easley: Buckling Formulas for Corrugated Metal Shear Diaphragms. Journal of the Structural Division, ASCE, No. ST 7, July 1975, pp. 1403-1417.
- [14] Kähönen, Zur Einleitung von Einzellasten in I-Träger mit trapezförmig profilierten Stegen. Stahlbau 57, 1988, Heft 8, S. 250. (On the Introduction of Individual Loads into I-Beams with Trapezoidal Profiled Web Plates).
- [15] Lindner, Aschinger: Grenzschertragfähigkeit von I-Trägern mit trapezförmig profilierten Stegen. Stahlbau 57, 1988, Heft 12, S. 377. (The limit shear load capacity of I-beams with trapezoidal profiled web plates).
- [16] Lindner, Aschinger: Zur Torsionssteifigkeit von Trapezstegträgern. Stahlbau 59, 1990, Heft 4, S. 113. (On the torsional stiffness of trapezoidal web girders).
- [17] Aschinger, Beljaev, Mikhailova: Zur Querkrafttragfähigkeit von I-Trägern mit verschiedenen Stegprofilierungen. Stahlbau 60, 1991, Heft 10, S. 314. (On the shearing force loading capacity of I-beams with various web-profiles).
- [18] Lindner: Zur Bemessung von Trapezstegträgern. Stahlbau 61, 1992, Heft 10, S. 311. (On the dimensioning of trapezoidal web girders).
- [19] Aumayr: Verformungs- und Beulverhalten von Wellblechen unter reiner Schubbelastung, Diplomarbeit, Inst. für Stahlbau, Technische Universität Wien, 1992. (Deformation and buckling behaviour of corrugated plates under pure transverse loading, Master thesis).

3. Product range and designation

Standard girders consist of selected webs and steel plate flanges with identical dimensions for the upper flange (OG) and lower flange (UG).

Web dimensions:

Web heights: 500, 625, 750, 1 000, 1 250, 1 500 mm
 Web thickness: 2.0; 2.5; 3.0 mm.

Flanges:

min. w = 200 mm max. w = 430 mm
 min. t = 10 mm max. t = 30 mm

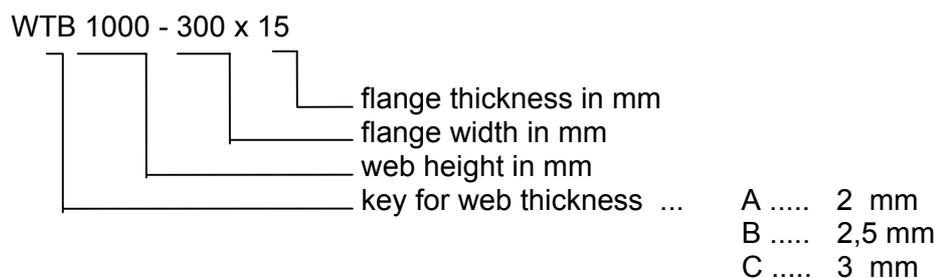
Lengths supplied:

min. 6,000 mm , surcharge for short lengths
 max. 20,000 mm

Maximum dimensions for construction elements:

See construction details, Sheets 1.3 and 1.4 (Appendix C).

Designation of girders:



Special structural forms with any intermediate heights and/or different sized upper flange (OG) and lower flange (UG) are available on request. For reasons of production technology, the width of the flanges should be the same.

$$b_{OG} = b_{UG} ; \quad t_{OG} \neq t_{UG}$$

In exceptional cases, however, $b_{OG} = b_{UG} \pm 50$ mm is possible with the same flange thickness.

Designation is as a **WTS** - girder.

For example: WTS 1250 - 300 x 15 / 300 x 12

4. Material

Standard product range:

- Flanges: Wide flat steel or steel lamellas
S235JRG2 in accordance with EN 10 025
(RSt 37.2 in accordance with DIN 17 100)
- Web: Cold rolled sheet
St 37-2G in accordance with DIN 1623, Part 2
with a guaranteed yield strength $R_{H,min} = 215 \text{ N/mm}^2$

Special qualities:

For the purposes of material purchasing, all other qualities of steel are regarded as special qualities.

The use of higher strength material (S355J2G3 = St52.3 N) for the flanges is possible, but in terms of statics, this is only meaningful in exceptional cases. Similarly, web material of higher yield strength up to 320 N/mm^2 (StE 320) can also be processed for the web. However, for reasons of material purchasing, longer delivery times and appropriate minimum order conditions apply.

5. Corrosion protection

Corrosion protection by means of coatings:

The finished beam is given a factory coating of approximately $40 \mu\text{m}$. Any other coatings, variant primer coats or top coatings which may be required must be agreed separately in the order. Standard colours are indicated in the currently applicable price list.

In the standard design, the web is connected to the flanges with a continuous fillet weld. On the non-welded side of the web, in the neck region, an additional coating of zinc primer is applied. With the above corrosion protection, the product can be classified in Corrosion Protection Class I and II in accordance with DIN 55 928 Part 8.

To achieve Corrosion Protection Class III, further measures may be necessary on the non-welded side of the web-flange connection. These must be agreed separately with the factory.

Corrosion protection by hot galvanising:

The corrugated web beam can be hot-galvanised without difficulty.

6. Tolerances

For the blank beam:

Flanges:	According to tolerances for plate and wide flat steel
Web :	Corrugation division: + 2.0 mm
	Corrugation height: ± 2.0 mm
Structural height of beam:	± 5.0 mm
Parallelism of flanges:	0.5 % of flange width
Longitudinal tolerance:	- 0 mm; + 5 mm
Straightness of beam:	0.1 % of beam length

For the finished structure:

DIN 8570 Teil 1, Level of Accuracy **B** or. DIN 8570 Teil 3, Level of Accuracy **F**.
Weld seams in accordance with EN 25 817, Group C (middle).

7. Quality monitoring

The production process is subject to constant, documented, internal monitoring.

The quality of the starting material is demonstrated on the basis of factory certificates in accordance with EN 10 204 clause 2.2. Any additional factory certificates must be agreed at the time of reserving the material.

The manufacturer's factory has the „Großen Eignungsnachweis“ in accordance with DIN 18 800, Teil 7, Section 6.2, DIN 4132 and DIN 8563 Teil 10 (Issued by SLV, Berlin) for welding techniques (E) and (MAG). Furthermore, procedural tests are available for welding the flanges in accordance with the T.I.M.E. protective gas welding method and for stud welding. All tests apply in respect of basic materials of quality classes S235 and S355. Current certificates can be presented on request.

B. TECHNICAL

8. Load carrying capacity of webs and flanges

Transverse force load carrying capacity of webs

It is possible to calculate the transverse force load carrying capacity of corrugated web beams in accordance with DAST-Ri.015 [4] by substituting a trapezoidal form for the actual corrugated form. However, this leads to inappropriately conservative results. The reason for this is that the interaction between global and local buckling upon which [4] is based does not occur with the corrugated web and the buckling coefficients κ_τ are set too low.

On the basis of tests [8, 11] and finite element calculations, the following design procedure has been suggested by Pasternak in [12]:

The corrugated web is regarded as an orthotropic plate with rigidities D_x and D_y . According to [13], the following formula therefore applies to the corrugated web:

$$D_x = \frac{E \cdot t^3}{12} \cdot \frac{w}{s} \quad ; \quad D_y = \frac{E \cdot I_y}{w} \quad \text{for } D_x \ll D_y$$

w ... length of corrugation = 155 mm
s ... uncoiled length
I_y ... moment of inertia of one corrugation

s and I_y are determined by numerical integration of the actual shape of the corrugation.

With transverse buckling stress $\tau_{pi,g} = \frac{32,4}{t \cdot h^2} \sqrt[4]{D_x \cdot D_y^3}$ in accordance with DAST-Ri.015 ([4], Eq.

415) the resulting specific slenderness parameter is $\bar{\lambda}_p = \sqrt{\frac{f_{yk}}{\sqrt{3} \cdot \tau_{pi,g}}}$.

With the buckling coefficient κ_τ in accordance with [12]

$$\kappa_\tau = \frac{1}{\bar{\lambda}_p^{1,5}}$$

the transverse force load carrying capacity for the corrugated web finally results in:

$$V_{Rk} = \kappa_\tau \cdot \frac{f_{yk}}{\sqrt{3}} \cdot h \cdot t = 0,58 \cdot \kappa_\tau \cdot f_{yk} \cdot h \cdot t \quad ; \quad V_{Rd} = V_{Rk} / \gamma_M$$

The evaluation for the current geometrical dimensions and strength values of the corrugated web is summarized in Table 1.

Normal force load carrying capacity of flanges

In determining the normal bearing force of the flanges, a distinction must be made between tensile and compressive stresses.

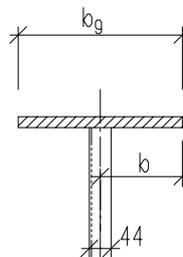
In the case of **tensile stress**, the load carrying capacity of the flange is derived as follows:

$$N_{gRk} = f_{yk} \cdot b_g \cdot t_g \quad ; \quad N_{gRd} = N_{gRk} / \gamma_M$$

In the context of **compressive stress**, the stability of the flange must be taken into account. A distinction must be made here between local buckling of the flange and its global stability (buckling transverse to the axis of the girder = torsional-flexural buckling).

Local buckling is demonstrated via the limit values **lim(b/t)** in accordance with DIN 18 800 Teil 1, Table.13. In order to take into account the elastic restraining effect of the web, the flange width, reduced by half the height of the web, is used for the width of the plate strip b.

$$b = \frac{b_g}{2} - 11 \text{ mm}$$



Reformulation of the expression for $\psi = 1$ (Table 13, line 4) leads to the following elastic limit stress:

$$\sigma_1 = \frac{4000}{(b_g/t_g)^2} \quad [\text{kN} / \text{cm}^2]$$

and therefore the reduced normal force on the flange:

$$N_{gRk,l} = \sigma_1 \cdot b_g \cdot t_g \quad \text{if} \quad \begin{aligned} & b > 12.9 \cdot t_g \text{ for } f_{yk} = 240 \text{ N/mm}^2 \\ & b > 10.5 \cdot t_g \text{ for } f_{yk} = 355 \text{ N/mm}^2 \end{aligned}$$

Global failure of stability - lateral buckling of the flange - is equivalent to the verification against **torsional-flexural buckling**. If the restraining effect of the web is ignored, the torsional-flexural verification is carried out as the **buckling verification for the "isolated" flange** in accordance with DIN 18 800 Teil 2, clause 3.3.3, EI (310).

By reformulating eqs. (12) and (13), the following condition for the distance between lateral supports is obtained:

$$N_{gRk,g} = \frac{0,5 \cdot \pi}{\sqrt{12}} \sqrt{E \cdot f_{yk}} \frac{b_g^2 \cdot t_g}{k_c \cdot c}$$

k_c ... Compressive force factor in accordance with Table 8, DIN 18 800 Teil 2

c Distance between lateral mountings

or

$$N_{gRk,g} = 65,7 \cdot \sqrt{f_{yk}} \frac{b_g^2 \cdot t_g}{k_c \cdot c} \quad \text{with } f_{yk} \text{ in } [\text{kN/cm}^2] \text{ and } b_g, t_g \text{ and } c \text{ in } [\text{cm}].$$

In the case of compressive stress, the load bearing capacity of the flange is therefore

$$N_{gRk} = \min (N_{gRk} ; N_{gRk,l} ; N_{gRk,g}) \quad ; \quad N_{gRd} = N_{gRk} / \gamma_M$$

Table 2 lists the load bearing capacities of the flanges for steel quality S235 (St 37), related to the distance of lateral supports for a constant normal force ($\psi = 1$).

For the mentioned flange cross sections act. $(b/t) < \text{lim. } (b/t)$ in accordance with DIN 18 800 Teil 1, Table 13 applies. The application limits are elaborated as follows:

- c_{lim} the distance between lateral supports up to which the compressed flange can be calculated without reduction due to buckling with the full elastic limit load N_{gRk}
- c_{max} maximum distance between lateral supports which is determined by the maximum slenderness (transverse to the girder axis) of 250.

By way of deviation from DAST-Ri. 015, an additional transverse bending stress on the flanges, resulting from the misalignment moments of the shearing forces, does not need to be taken into account (cf. [19]) because of the “small corrugation” of the web profile.

The cross-sectional tables in section 12 show the bearing moments and bearing transverse forces for all of the flange-web combinations.

9. Dimensioning of beams

For the calculation model, it is assumed by way of simplification that the normal forces and bending moments are only taken up by the flanges (whereby the bending rigidity of the flange is ignored) and transverse forces are allocated only to the web. This corresponds to the similar procedure applied when calculating parallel plate lattice girders. The design and verification of corrugated web beams should be implemented analogously.

- **Selecting the construction height** by the slenderness of the beam

$$h_s = L_{St}/15 \text{ to } L_{St}/25$$

(single-span girders continuous girders or horizontal beams of frames)

- **Selecting the web thickness or verification of the web**

via the transverse force load carrying capacity V_{Rd} .

$$V_d = \gamma_F \cdot V < V_{Rd} = V_{Rk}/\gamma_M \quad V_{Rk} \text{ in accordance with Section 8 or Table 1}$$

- **Selecting or verification of the flanges**

via the normal force loading capacity N_{Rd} .

$$N_g = N \frac{A_g}{A} \pm \frac{M}{z}$$

A ... Cross-sectional area of both flanges

z Spacing of centres of gravity of flanges

$N_{g,d} = \gamma_F \cdot N_g < N_{g,Rd} = N_{g,Rk}/\gamma_M$ N_{Rk} in accordance with Section 8 or Table 2 for tensile or compressive stresses, taking into account lateral stability.

As an alternative to verification of the flanges, it is possible to verify the bearing moment $M_{Rd} = M_{Rk} / \gamma_M$ of the total cross section directly. However, this presupposes that the stability of the compressed flange is guaranteed by constructional measures (eg. directly laid trapezoidal sheeting or purlins at a distance of $e < c_{lim}$).

- **Verification of serviceability**

This is provided by verification of deflections. Shear deformation must be taken into account. The tables in Section 12 with the section properties give details of the "transverse force area" A_Q , and/or the ratio A/A_Q , required as an input for many computation programs to allow the shear flexibility to be taken into account when determining deformations and cross section forces.

- **Verification of the load initiation points**

See Section 11 or Table 3.

10. Dimensioning of columns

When dimensioning columns, the static model of a multi-part compression member of the lattice or frame-stanchion type is assumed. As with bending girders, the normal force is distributed only to the flanges. The corrugated web serves only to transfer shear forces between the flanges. Allowance must therefore be made for the shear flexibility of the web when verifying buckling in the direction of the “strong” axis (equivalent to the non-material axis in the case of multi-part compression members), eg. by introducing ideal slenderness.

$$\lambda_{id} = \sqrt{\lambda_y^2 + \lambda_1^2} \quad \text{with} \quad \lambda_y = \frac{S_{ky}}{i_y} \quad \text{and}$$

$$\lambda_1^2 = \frac{\pi^2 \cdot E \cdot A}{G_s \cdot t_s \cdot h_s} = \frac{\pi^2 \cdot E \cdot A}{G_s \cdot A_Q} = 25,9 \cdot \frac{A}{A_Q}$$

The buckling test at the “weak axis” and the torsional-flexural buckling verification may be carried out, to be on the safe side, on the „isolatet“ flange resorting to Table 2.

11. Verification of local load initiation

By profiling the web, the application of stiffeners can largely be dispensed with when initiating individual loads - eg. by means of purlins or secondary beams. Ascertaining the load bearing capacity by introducing stiffener-free loads in accordance with the principles of DIN ([1], clause 744) or according to the procedure suggested in [6] and [7] ensures that

- no local buckling (web crippling) occurs and
- deformation in the flange is kept sufficiently low.

The bearing load in the case of stiffener-free load initiation to the web is determined in accordance with [6].

$$P_{Rk} = t_s (a + 5t_g) \cdot f_{yk}$$

a ... load distribution width
t_s ... web plate thickness

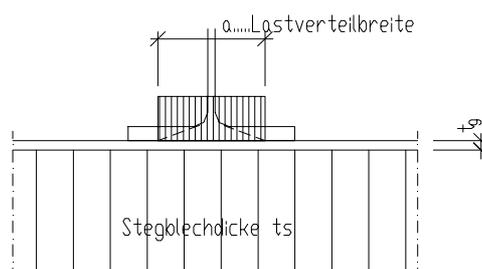


Fig. 2: Stiffener-free load initiation onto the corrugated web.

If rolled profiles are supported directly, the load distribution widths “a” can be taken from dimensioning guides for profile constructions.

The bearing loads for the web thicknesses contained in the production range and various load distribution widths “a” are summarized in Table 3.

12. Section properties for corrugated web beams

Notations and Remarks:

Steel grades for flanges: $f_{yk} = 240 \text{ N/mm}^2$
 for web: $f_{yk} = 215 \text{ N/mm}^2$

$b_g \times t_g$... flange dimensions
 H overall height of the beam
 U painting surface per meter
 $2A_g$ sectional area of both flanges
 $A_{go} = b_{go} \cdot t_{go}$; $A_{gu} = b_{gu} \cdot t_{gu}$; $2A_g = A_{go} + A_{gu}$
 A_Q transverse force cross section of the web
 for taking shear stiffness into account

$$G^* = G \cdot \frac{w}{s} = 80\,000 \cdot \frac{155}{178} \approx 69\,700 \text{ N / mm}^2 ,$$

$$A_Q = h_s \cdot t_s \cdot \frac{G^*}{G} = h_s \cdot t_s \cdot \frac{w}{s}$$

I_y, I_z moment of inertia

$$I_y = \frac{A_{go} \cdot A_{gu}}{A_{go} + A_{gu}} \cdot z^2 ; \quad I_z = \frac{1}{12} \cdot (t_{go} \cdot b_{go}^3 + t_{gu} \cdot b_{gu}^3)$$

i_y, i_z radius of gyration

I_t torsional constant (for beams with equal flanges)

$$I_t = \frac{2}{3} \cdot b_g \cdot t_g^3 + \frac{1}{3} \cdot h_s \cdot t_s^3$$

I_w warping constant (for beams with equal flanges)

$$I_w = \frac{A_g}{24} \cdot b_g^2 \cdot z^2 \quad \text{with } A_g \dots \text{ cross section of one flange}$$

c_{lim} maximum distance of lateral supports to avoid lateral buckling

$$c_{lim} = 0,5 \cdot \frac{i_{z,g} \cdot \lambda_a}{k_c}$$

V_{RK} transverse force load bearing capacity according to chapter 8.

N_{RK} plastic normal force (for the total cross section)

M_{RK} plastic moment

For evaluation of bearing capacities N_{RK} and M_{RK} a constant compression force distribution ($k_c = 1$) and lateral supports in a distance of 1.5 m (to avoid lateral instability) were assumed.