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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).

![Diagram of corrugated web beam]

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]¹. 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.
[3] DIN 18 800 Teil 3 (1990), Stahlbauten; Stabilitätsfälle, Plattenbeulen.
[4] DAST - Richtlinie 015 (1990); Träger mit schlanken Stegen. (German recomendations for girders with slender web plates.)

¹) 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)


References:


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:**

```
WTB 1000 - 300 x 15
     | flange thickness in mm
     | flange width in mm
     | web height in mm
     +-------+   +-------+   +-------+
     |   A   |   B   |   C   |
     |  2 mm  |  2.5 mm|  3 mm |

**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\text{OG} = b\text{UG}  ;  \ t\text{OG} \neq t\text{UG}

In exceptional cases, however, b\text{OG} = b\text{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
*St235JRG2 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/mm² (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 $\mu$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:

<table>
<thead>
<tr>
<th>Component</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flanges</td>
<td>According to tolerances for plate and wide flat steel</td>
</tr>
<tr>
<td>Web</td>
<td>Corrugation division: + 2.0 mm</td>
</tr>
<tr>
<td></td>
<td>Corrugation height: ± 2.0 mm</td>
</tr>
<tr>
<td>Structural height</td>
<td>± 5.0 mm</td>
</tr>
<tr>
<td>Parallelism of flanges</td>
<td>0.5 % of flange width</td>
</tr>
<tr>
<td>Longitudinal tolerance</td>
<td>- 0 mm; + 5 mm</td>
</tr>
<tr>
<td>Straightness of beam</td>
<td>0.1 % of beam length</td>
</tr>
</tbody>
</table>

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 $\kappa_\tau$ 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:

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

for $D_x << D_y$

where:

- $w$ ... 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 $\tau_{pi,g} = \frac{32 \cdot 4}{l \cdot h^2} \sqrt{D_x \cdot D_y}$ in accordance with DASt-Ri.015 ([4], Eq. 415) the resulting specific slenderness parameter is

$$\frac{\lambda_p}{\tau} = \sqrt{3 \cdot \tau_{pi,g}}$$

With the buckling coefficient $\kappa_\tau$ in accordance with [12]

$$\kappa_\tau = \frac{1}{\frac{15}{\lambda_p}}$$

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:

\[
N_{gRk} = f_{yk} b_g t_g ; \quad N_{gRd} = N_{gRk} / \gamma_M
\]

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 \( \text{lim}(b/t) \) 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:

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

and therefore the reduced normal force on the flange:

\[
N_{gRk} = \sigma_1 b_g t_g \quad \text{ if } \quad b > 12.9 t_g \text{ for } f_{yk} = 240 \text{ N/mm}^2
\]

\[
> 10.5 t_g \text{ for } f_{yk} = 355 \text{ N/mm}^2
\]

**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, El (310).

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

\[
N_{gRk,g} = \frac{0.5 \cdot \pi}{\sqrt{12}} \sqrt{E \cdot f_{yk}} \frac{b_g^2 t_g}{k_c \cdot c}
\]

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

\( c \) ..... Distance between lateral mountings

or

\[
N_{gRk,g} = 65.7 \sqrt{f_{yk}} \frac{b_g^2 t_g}{k_c \cdot c}
\]

with \( f_{yk} \) in [kN/cm²] and \( b_g \), \( t_g \) and \( c \) in [cm].
In the case of compressive stress, the load bearing capacity of the flange is therefore

\[
N_{gRk} = \min \left( N_{gRk,1}, N_{gRk,2}, N_{gRk,3} \right) \quad ; \quad N_{gRd} = N_{gRk} / \gamma_M
\]

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) < lim. (b/t) in accordance with DIN 18 800 Teil 1, Table 13 applies. The application limits are elaborated as follows:

- \( c_{\text{lim}} \) .... 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 \( N_{gRk} \)
- \( c_{\text{max}} \) .... 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
  \[ h_s = \frac{L_{Sl}}{15} \text{ to } \frac{L_{Sl}}{25} \]
  (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 \( V_{Rd} \).
  \[ V_d = \gamma_f V < V_{Rd} = \frac{V_{Rk}}{M} \]
  \( V_{Rk} \) in accordance with Section 8 or Table 1

- **Selecting or verification of the flanges**
  via the normal force loading capacity \( N_{Rd} \).
  \[ N_g = N \frac{A_g}{A} \pm \frac{M}{z} \]
  \( A \text{ ... Cross-sectional area of both flanges} \)
  \( z \text{ ... Spacing of centres of gravity of flanges} \)

  \[ N_{g,d} = \gamma_f N_g < N_{g,Rd} = \frac{N_{g,Rk}}{M} \]
  \( N_{Rk} \) 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 \( M_{Rd} = \frac{M_{Rk}}{\gamma_M} \) 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.

\[ \lambda_{yd} = \sqrt{\lambda_y^2 + \lambda_i^2} \quad \text{with} \quad \lambda_y = \frac{S_{ny}}{I_y} \quad \text{and} \quad \lambda_i = \frac{\pi^2 E A}{G_s t_s h_s} = \frac{\pi^2 E A}{G_s A_Q} = 25.9 \frac{A}{A_Q} \]

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 "isolated" 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].

\[ P_{rk} = t_s \left( a + 5t_s \right) f_{yk} \]

\( a \) ... 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: \( f_{yk} = 215 \text{ N/mm}^2 \)

- \( b_g \times t_g \ldots \) flange dimensions
- \( H \ldots \ldots \) overall height of the beam
- \( U \ldots \ldots \) painting surface per meter
- \( 2A_g \ldots \ldots \) sectional area of both flanges
- \( A_g = b_g \cdot t_g \); \( A_{gu} = b_{gu} \cdot t_{gu} \); \( 2A_g = A_{go} + A_{gu} \)
- \( A_Q \ldots \ldots \) transverse force cross section of the web

for taking shear stiffness into account

\[
G' = G \cdot \frac{w}{s} = 80000 \cdot \frac{155}{178} = 69700 \text{ N / mm}^2
\]

- \( l_y, l_z \ldots \ldots \) moment of inertia

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

- \( i_y, i_z \ldots \ldots \) radius of gyration

- \( I_t \ldots \ldots \) torsional constant (for beams with equal flanges)

\[
I_t = \frac{2}{3} b_g t_g^3 + \frac{1}{3} h_l t_s^3
\]

- \( l_w \ldots \ldots \) warping constant (for beams with equal flanges)

\[
I_w = \frac{A_g}{24} b_g^2 z^2 \quad \text{with} \quad A_g \ldots \ldots \text{cross section of one flange}
\]

- \( c_{lim} \ldots \ldots \) maximum distance of lateral supports to avoid lateral buckling

\[
c_{lim} = 0.5 \cdot \frac{i_{z,g} \cdot \lambda_{x,a}}{K_c}
\]

- \( V_{rk} \ldots \ldots \) transverse force load bearing capacity according to chapter 8.
- \( N_{rk} \ldots \ldots \) plastic normal force (for the total cross section)
- \( M_{rk} \ldots \ldots \) plastic moment

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