Zeman

CORRUGATED WEB BEAM

SIN TECHNOLOGY EXPLAINED

KING STEEL

sin

Introduction:

Corrugated web beams may be used as beams (roof or slab beams, frame transoms) or as components subjected to axial forces (columns or frame stanchions) virtually without limitations in terms of construction. The optimal area of application is in steel structural engineering wherever rolled profiles with greater than 300 mm structural height or low lattice girders of structural height below approx. 1800 mm were formerly used.

The Corrugated Web I-Beam is a built-up girder consisting of wide plate flanges which are welded to a corrugated web (Fig.1 & Fig.2). The corrugation of the web increases the stability of the web against buckling which results in considerable savings in raw material cost in a magnitude of app. 10-30% versus welded I-beams and way above 30% versus Hot-Rolled.

Compared with trapezoidal profiling of webs the Corrugated Web I-Beam has in addition to benefits in production methods, also the advantage of preventing local buckling of flat plate sections; which is largely eliminated.

The Corrugated Web I-Beam is being applied to a broad variety of structural framing. It adds significantly to the competitiveness of the pre-engineered steel building business when approaching the multi-story market by offering an extremely competitive substructure for 2 - and 3 - story office buildings or condominiums.

The rigidity of the webs makes the Corrugated Web I-Beam feasible for the crane beam and even the bridge crane market. It may also help the steel bridge companies in gaining back a significant portion of the short span bridge business which they lost during the past years.

All national codes, such as DIN, BS, SNIP, Eurocode are applicable for the SIN Beam!

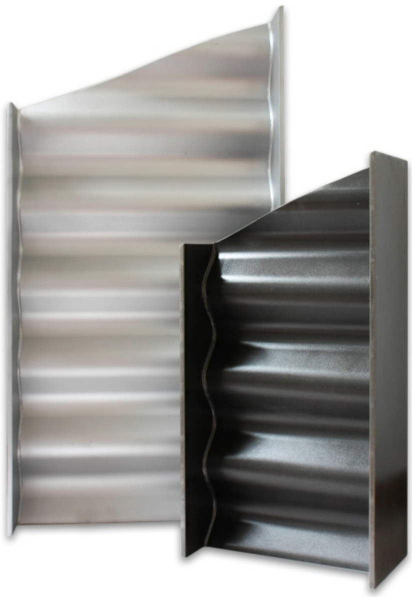


Fig.1 Fig.2

Advantages of SIN Beam over traditional steel structures:

Advantages of SIN Beam compared to Hot rolled Profiles (Fig.3):

- Saving of construction weight respectively saving on raw materials above 30%
- More stiffness with increased web height
- Increase of bearing capacity
- Fewer handling steps
- Aesthetical appearance

Advantages of SIN Beam compared to Welded Profile (Fig.3):

- Saving of construction weight respectively saving on raw materials up to 10-30%
- Quick and efficient automated fabrication
- More stiffness with increased web height
- Increase of bearing capacity
- Fewer handling steps
- Aesthetical appearance

Advantages of SIN Beam compared to Lattice Work:

- Quick and efficient automated fabrication

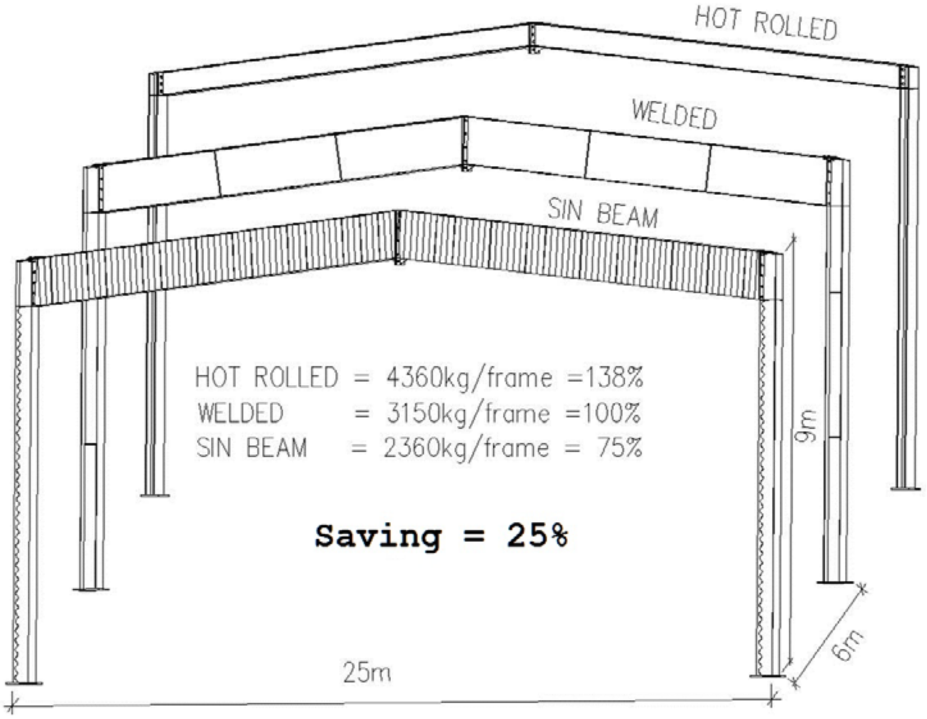


Fig.3

Fabrication (SIN Beam Line Fig.4):

The Corrugated Web I-Beam is being assembled in the course of a continuous and highly automated manufacturing process. At the beginning of the assembly line a decoiler feeds the thin web material into a stretch leveler for stress reduction before the flat material is being fed into the corrugating unit. After the corrugation has been implemented and after the desired length of the web has been reached the web is being cut off by means of a flying shear.

While the finished web is being transported through the assembly line continuously both flanges which were preassembled in a separate process are put in place and fixed to the web by means of a hydraulic device. Together they pass the welding unit where the flanges and the web are welded together under submerged arch. Speed and angle of the welding pistol are automatically controlled in order to achieve a secure and high quality of the one side welding. The entire manufacturing process takes place at a speed of **2 m/minute**.

The finished beam will then be completed by splice plates or other accessories before it will receive it‘s corrosion protection.

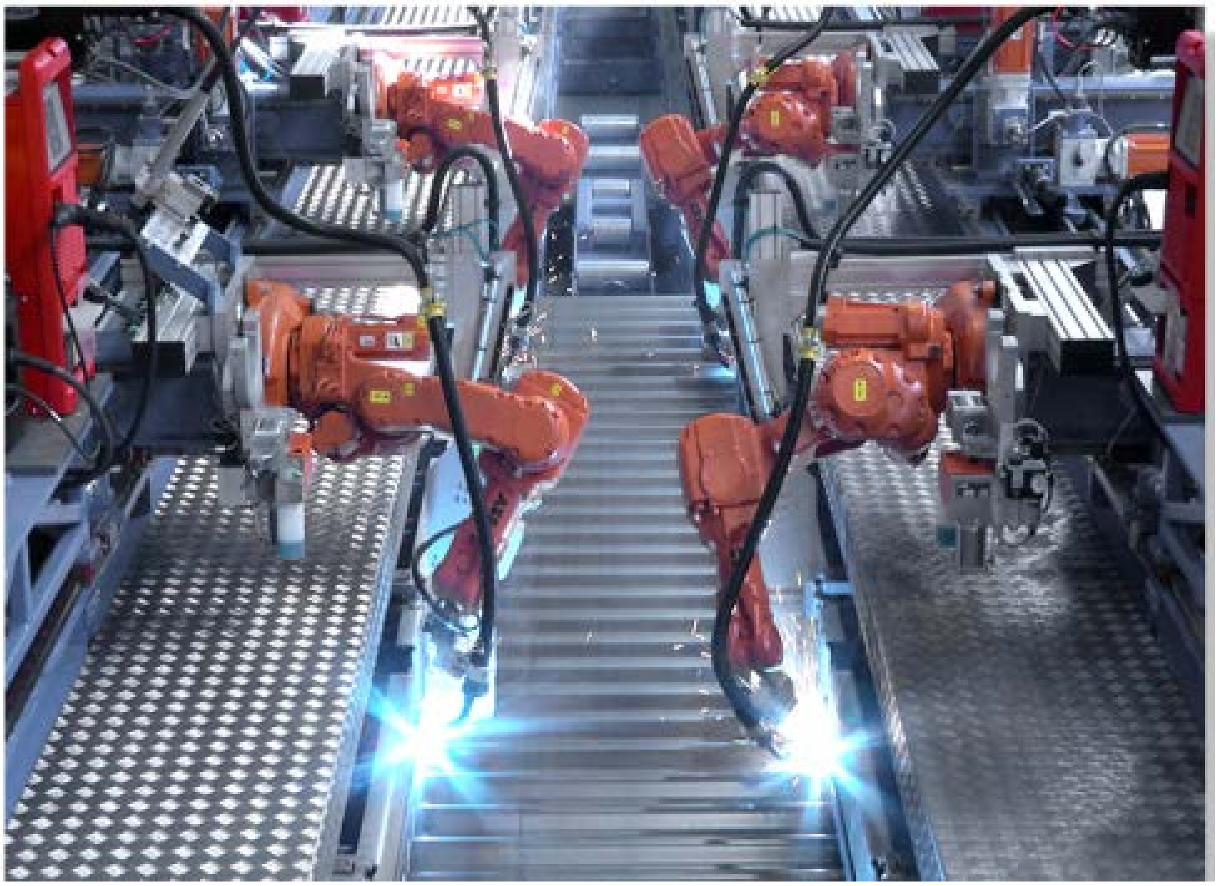


Fig.4 (SIN Fabrication Line)

Fields of application:

Production- and Storage Hangars (Fig5 – Fig10)

Fig.5

Fig.6

Fig.7

Fig.8

Fig.9

Fig.10

Parking Facilities (Fig.11– Fig.12)

Fig.11

Fig.12

Sales Centers (Fig.13)

Fig.13

Event- and Exhibitionhalls (Fig.14)

Fig.14

Sports Facilities (Fig.15)

Fig.15

Load Carrying Capacity & Dimensioning of Corrugated Web Beams

Premises - The corrugation of the web generally avoids failure of the beam due to loss of web stability before the plastic limit-loading is reached. However as a result of the corrugation the web does not participate in the transfer of longitudinal normal forces from bending. This means that the Corrugated Web I-Beam behaves like a **Lattice Girder** in which the bending moments and the normal forces are transferred via the flanges, while the transverse forces are transferred through the diagonals and verticals of the lattice girder – here: the corrugated web.

On the basis of this static analogy dimensioning and testing is performed 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 section properties of the individual cross section 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 I-Beam is essentially based on the expertises [6] and [7]. In addition the procedure is verified on the bases of experimental results [8], [9], [10].

Corrugated web beam – dimensions and attributes

<u>Production Programme:</u>

Web thickness in mm:	1,5; 2,0; 2,5; 3,0
Web height in mm:	333; 500; 625; 750; 1000; 1250; 1500
Beam length in m:	4 – 16
Flange width in mm:	120 – 450
Flange thickness in mm:	6 - 30

<u>Material for Standard Product Range:</u>

Flange: wide flat steel or steel lamellas
S235J0 or JR in accordance with EN 10 025-2
S355J2 in accordance with EN 10 025-2
Web: cold- or hot-rolled sheet in accordance with EN 10 025-2

Load carrying Capacity of Webs and Flanges - The transverse force load carrying capacity of Corrugated Web I-Beams can be calculated in accordance with DASt-Ri.015 [4] by substituting a trapezoidal shape by the actual corrugated shape. This however leads to inappropriate conservative results. The reason is the fact that the interaction between global and local buckling according to [4] does not occur with corrugated webs. Therefore the buckling coefficients κ_τ are set too low. On the basis of tests [8, 11] and finite element calculations, the following design procedure was suggested by Pasternak [12]:

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

$$D_x = E*t^3/12 * w/s; \qquad D_y = E*l_y/w \qquad \text{for } D_x << D_y$$

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

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

With the transverse buckling stress $\tau_{pi,g} = 32,4/(t*h^2) * \sqrt[4]{D_x * D_y^3}$

and in accordance with DASt-Ri.015 ([4], Eq. 415)

the resulting specific slenderness parameter is $\lambda_p = \sqrt{f_{yk} / (\sqrt{3} * \tau_{pi,g})}$

With the buckling coefficient κ_τ in accordance with [12] $\kappa_\tau = 1 / \lambda_p^{1,5}$

The transverse force loading capacity for the corrugated web finally results in:

$$V_{Rk} = \kappa_\tau * (f_{yk}/\sqrt{3})*h*t = 0.58 * \kappa_\tau * f_{yk}*h*t \ ; \ V_{Rd} = V_{Rk} / \gamma_M$$

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 derives as follows:

$$N_{gRk} = f_{yk}*b_g*t_g\ ; \qquad N_{gRd} = N_{gRk} / \gamma_M$$

In the context of **compression stresses** the stability of the flange must be taken into account. A distinction must be made 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 , Part 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 corrugation – is used for the width of the plate strip ***b***.

$$B = (b_g / 2) - 11 \text{ mm}$$

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

$$\sigma_1 = 4000 /(b_g/t_g)^2 \ [kN/cm^2]$$

and therefore the reduced normal force on the flange:

$$N_{gRk,l} = \sigma_1*b_g*t_g \qquad \text{if} \qquad b > 12.9*t_g \text{ for } f_{yk} = 240 \text{ N/mm}^2$$

$b > 10.5*t_g$ for $f_{yk} = 355$ N/mm²

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, Part 2, clause 3.3.3, El (310).

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

$$N_{gRk,g} = (0.5*\pi / \sqrt{12}) * \sqrt{E*f_{yk}} * (b_g^2*t_g/(k_c*c))$$

kc... Compressive force factor in accordance with Table 8, DIN 18 800, Part 2

c..... Distance between lateral mountings.

Or $$N_{gRk,g} = 65,7* \sqrt{f_{yk}} * (b_g^2*t_g / k_c*c))$$

with f_{yk} in [kN/cm²] and b_g, t_g and c in [cm].

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

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

For the above mentioned flange cross sections act. **(b/t) < lim. (b/t)** according to DIN 18 800, Part 1, Table 13 is applicable. The limits of application are elaborated as follows:

c_{lim}.... the distance between lateral supports up to which the compression flange can be calculated without reduction due to buckling with the entire 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 deviating 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.

Dimensioning of the Beams

For the calculation model it is assumed by way of simplification that the normal forces and bending moments are only taken 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.

Bay Spacing 10 m

- **Selection of the construction height** - by the slenderness of the beam.
  $H_s = L_{St}/15$ to $L_{St}/25$
  (single-span girders .... continuous girders or frame girders)

- **Selection of the web thickness or verification of the web** - via the transverse force load carrying capacity **V_{Rd}**.

  $V_d = \gamma_F * V < V_{Rd} = V_{Rk} / \gamma_M$

- **Selection or verification of the flanges** - via the normal force loading capacity N_{Rd}.

$$\mathbf{N_g = N*A_g/A + M/z} \qquad \mathbf{N_{g,d} = \gamma_F*N_g < N_{g,Rd} = N_{g,Rk}/\gamma_M}$$

A ... Cross-sectional area of both flanges.
Z ... Spacing of centers of gravity of flanges
N_{Rk} for tensile or compressive stresses taking into account lateral stability.

As an alternative to the verification of the flanges it is possible to verify the bearing moment $\mathbf{M_{Rd} = M_{Rk} / \gamma_M}$ of the total cross section directly. However, this presupposes that the stability of the compressed flange is guaranteed by structural measures (e.g. Directly applied trapezoidal profiles or purlins at distances $\mathbf{e < c_{lim}}$).

The Verification of the Serviceability - is provided by the verification of deflections. Shear deformation must be taken into account.

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

$$\lambda_{1d} = \sqrt{\lambda_y^2 + \lambda_1^2} \text{ with } \qquad \lambda_y = s_{ky} / i_y \qquad \text{and}$$

$$\lambda_1^2 = (\pi^2*E*A/G_s*t_s*h_s) = (\pi^2*E*A/G_s*A_Q) = 25.9 *A/A_Q$$

Verification of Local Load Initiation – By corrugating the web the application of stiffeners can largely be eliminated when spot loads are initiated.- e.g. Purlins or secondary beams. Ascertaining the load bearing capacity by introducing stiffener-free loads in accordance with the principles of the DIN ([1], clause 744) or according to the procedure suggested in [6] and [7] ensures that

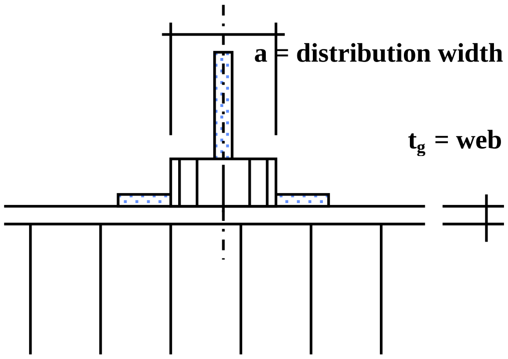
- No local buckling (web crippling) occurs and
- Deformation in the flange is kept sufficiently low.

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

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

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

If rolled profiles are supported directly the load distribution width "a" can be taken from dimensioning guides for steel structures.



Section Properties for Corrugated Web I-Beams:

Steel Grades: Flanges f_{yk} = 240 N/mm²

Webs f_{yk} = 215 N/mm²

b_g*t_g	flangedimensions
H	overall height of beam
$2A_g$	sectional area of both flanges
A_Q	transverse force cross section of the web for taking shear stiffeners into account
I_y, I_z	moment of inertia
i_y, i_z	radius of gyration
I_t	torsional constant
I_w	warping constant
c_{lim}	maximum distance of lateral supports to avoid lateral buckling
V_{Rk}	transverse force load bearing capacity
N_{Rk}	plastic normal force (for the total cross section)
M_{Rk}	plastic Moment

For the evaluation of bearing capacities $\mathbf{N_{Rk}}$ and $\mathbf{M_{Rk}}$ it was assumed that a constant force distribution **(k_c = 1)** takes place with a spacing of **1.50 m** of the lateral supports (to avoid lateral instability).

Standards and Expert Opinions:

[1] DIN 18 800 Part 1 (1990), Steel Construction, Design and Detailing.

[2] DIN 18 800 Part 2 (1990), Steel Construction, Stability, Buckling of Members.

[3] DIN 18 800 Part 3 (1990), Steel Construction, Stability, Buckling of Plates.

[4] DAST – Regulation 015 (1990), Beams with Slender Webs.

[5] DIN V ENV 1993-1-1 (1993), EUROCODE 3, Design of Steel Structures, Part 1-1: General rules and rules for buildings.

[6] Prof.D.I.Dr. Günter Ramberger: Vienna 12.20.1989
Expert opinion on the design of welded I-beams with corrugated webs.

[7] Prof.D.I.Dr. Günter Ramberger: Vienna-Austria 11.16.1990
2nd Expert opinion about the design of welded I-beams with corrugated webs.

[8] Test report on experiments carried out with I-beams with corrugated web plates, Vienna University of technology, Institute for Steel Construction, department of Applied Structural Analogies in Steel Construction, Austria, August 1990.

[9] Report Nr. 943040: Investigation into the introduction of dynamic loads into Corrugated Web I-Beams WTB 750-300*12, Testing Laboratory for Steel, Timber and Brick, University of Karlsruhe-Germany, 1995.

[10] Fire testing of Corrugated Web Beams, Institute for Fire Prevention Technology and Safety Research, Linz-Austria 1995.

[11] Final Report on the Bearing Performance of Corrugated Web Beams. Brandenburgische Technische Universität, Department for Steel Construction,
Cottbus-Germany 1996.

[12] Expert Statement on the Transverse Force Load Carrying Capacity of Corrugated Web Beams. Prof. Dr. Hartmut Pasternak, Brauschweig/Cottbus-Germany 1996.

[13] Easly: Buckling Formulas for Corrugated Metal Shear Diaphragms. Journal of the Structural Division, ASCE, No. ST 7, July 1975, pp.1403-1417.

[14] Kaehoenen: On the Introduction of Individual Loads into I-Beams with Trapezoidal Profiled Web Plates. Germany-Der Stahlbau 57, 1988, Heft 8, page 250.

[15] Lindner, Aschinger: The Limit Shear Load Capacity of I-Beams with Trapezoidal Profiled Web Plates. Germany-Der Stahlbau 57, 1988, Heft 12, page 377.

[16] Lindner, Aschinger: On the Torsional Stiffness of Trapezoidal Web Girders.
Germany-Der Stahlbau 59, 1990, Heft 4, page 113.

[17] Aschinger, Beljaev, Mikhailova: On the Shearing Force Loading Capacity of I-Beams with Various Web-Profiles. Germany-Der Stahlbau 60, 1991, Heft 10, page 314.

[18] Lindner: On the Dimensioning of Trapezoidal Web Girders.
Germany – Der Stahlbau 61, Heft 10, page 311.

[19] Aumeyr: Deformation and Buckling Behaviour of Corrugated Plates under Pure Transverse Loading, Master Thesis. Technical University of Vienna-Austria, 1992.