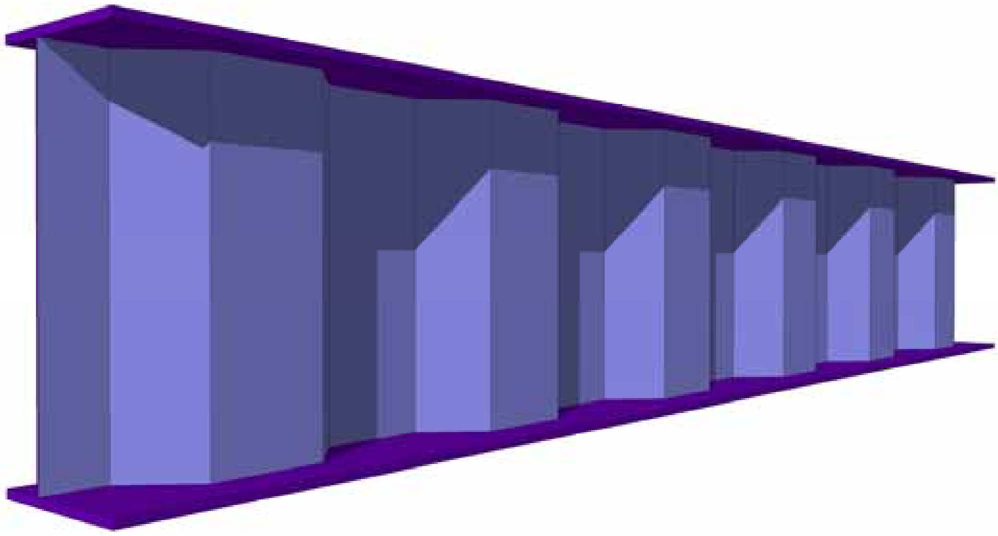


TECHNICAL DOCUMENTATION

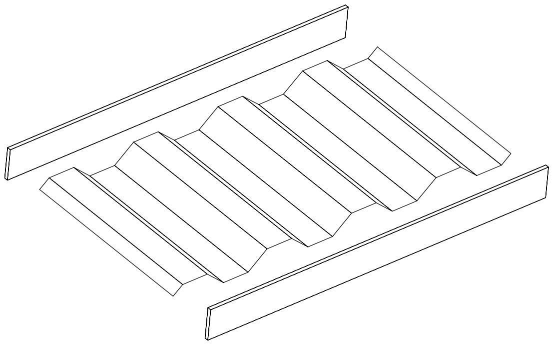
GLP®

www.LightweightBeam.com

Index

General description

A GLP LIGHTWEIGHT BEAM or trapezoidal corrugated web beam is a built-up girder with a thin-walled, trapezoidal shaped corrugated web and two plate flanges.



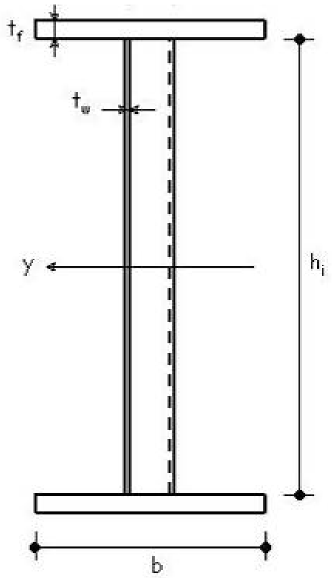
A GLP LIGHTWEIGHT BEAM consists of a trapezoidal folded plate and two plate flanges

The profiling of the web avoids failure of the beam due to loss of stability before the plastic limit loading of the web is reached. Corrugations in webs enormously increase their stability against buckling and can result in very economical designs. Therefore, GLP LIGHTWEIGHT BEAMs have the potential to eliminate many costly web stiffeners. In addition, the use of thinner webs results in less raw material cost with savings estimated at 10-30% compared with conventional stiffened built-up sections and more than 30% compared with standard I-beams.
Because of the high strength-to-weight ratio, the span lengths could be wider, so a less number of columns are needed. Furthermore there are costs savings possible at the erection, since the corrugation of the web provides higher resistance against bending about the weak axis, none of auxiliary lifting equipment normally needed is required.

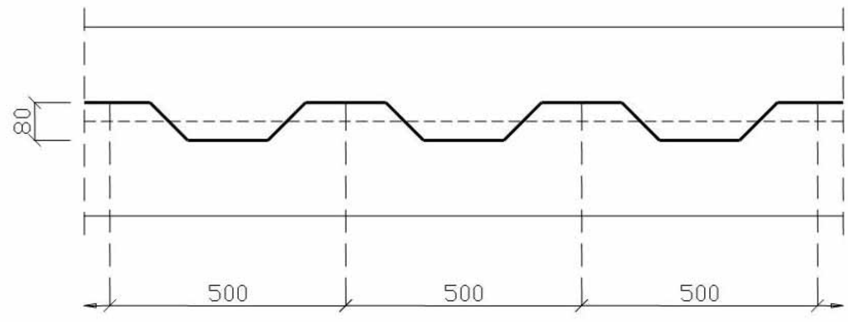
Corrugated web beams may be used as beams (roof or girders) or as components subject to normal forces (columns or frame columns) without structural limitations. The optimum area of application is in steel structural engineering wherever rolled profiles of structural depths greater than 400 mm or low lattice girders of structural height below approximately 1500 mm are used.

Product range and designation

The standard dimensions of GLP LIGHTWEIGHT BEAMS are presented in the next picture



h	=	516	–	2060 mm
h_i	=	500	–	2000 mm
b	=	120	–	400 mm
t_f	=	8	–	30 mm
t_w	=	3	–	8 mm

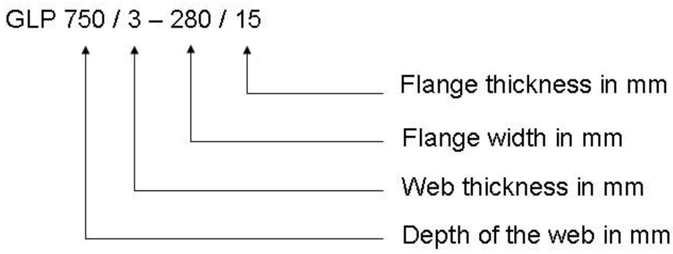


Product range dimensions of standard GLP LIGHTWEIGHT BEAMS

Flange width ranges from 120 mm to 400 mm and the flange thickness ranges from 10 mm to 30 mm. The trapezoidal webs depths ranges from 500 mm to 2000 mm and the thickness ranges from 3 till 8 mm.

Other dimensions and/or different sized (in width and thickness) top flange and bottom flange are available on request. The maximum depth of the web (h_i) is 4000 mm.

Designation of GLP LIGHTWEIGHT BEAMS



Special structural forms like different sized top and bottom flanges are designated as follows:
Example:

GLP 1250 / 3 – 280 / 15 – 250 / 12

Web	1250 mm x 3 mm
Top flange	280 mm x 15 mm
Bottom flange	250 mm x 12 mm

Also tapered GLP LIGHTWEIGHT BEAMS can be delivered. The designation is:
Example:

GLP 1500..1250 /3 – 280 / 15

Web	Tapered from 1500 mm till 1250 mm, thickness: 3 mm
Top flange	280 mm x 15 mm
Bottom flange	280 mm x 15 mm

Basis for design

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

In static terms, the girder with corrugated web acts like 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 is based on **EUROCODE 3** [G, H], or on any other national standard which contains rulings (such as **NEN 6770** [D] or **DAST-Ri. 015** [B]) in respect of lattice girders or open web columns and the transverse buckling of orthotropic plates.

Standards and guidelines:

[A] **StBK N5: Light-Gauge Metal Structures**, Sweden, 1982

[B] **DAST-Richtlinie 015: Träger mit schlanken Stegen**, Germany, 1990
(German recommendations for girders with slender web plates)

[C] **NEN 6702: Belastingen en vervormingen**, TBG 1990 Grondslagen bouwconstructies, Netherlands, 2001

[D] **NEN 6770: Staalconstructies**, TGB 1990 Grondslagen bouwconstructies Netherlands, 1997

[E] **NEN 6771: Stabiliteit**, TGB 1990 Grondslagen bouwconstructies, Netherlands, 1991

[F] **NEN 6772: Verbindingen**, TGB 1990 Grondslagen bouwconstructies, Netherlands, 1997

[G] **prEN 1993-1-1: General rules/ rules for buildings; EUROCODE 3**, Design of steel structures, Europe, May 2002

[H] **prEN 1993-1-5: Plated structural elements; EUROCODE 3**, Design of steel structures, Europe, February 2003

[I] **NAD-NVN-ENV 1993:** Richtlijnen voor gebruik van NVN-ENV 1993-1-1 Netherlands, August 1995

References

[2] Aschinger, R.: Tragverhalten von geschweiβten I-Trägern mit trapezförmig profilierten Stegen bei Torsion, Biegung, Biegedrillknicken und Normalkraft. TU Berlin, 1995.

[..] Hoop, H., Literature Study, Master thesis: Girders with trapezoidal corrugated webs, IV-Bouw & Industry Papendrecht, 2004

[18] Wierda, S.: Ontwerphandleiding – Plaatligger met geprofileerd lijf IV-Consult B.V. Papendrecht, 2002

Material

Standard product range:

Flanges:	Wide flat steel or cutted strips from heavy plates or cold rolled sheets S355 J2G3 according to EN 10 025
Web:	Cold rolled sheet or heavy plates S235 JR according to EN 10 025

Special qualities:

For the purpose of material purchasing, all other qualities of steel are regarded as special quantities

The use of higher strength material (S420 or S460) for the flanges is possible. Similarly, web material of higher yield strengths up to 355 (S355 J2G3) can also be processed. However, for reasons of material purchasing, longer delivery times and appropriate minimum order conditions apply

Corrosion protection

Corrosion protection by means of coatings:

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 phosphate primer is applied. With the above corrosion protection, the product can be classified in Corrosion Protection Class I an 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. This must be agreed separately with the factory.

Corrosion protection by hot galvanising:

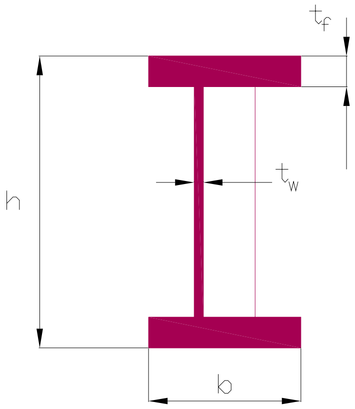
The GLP LIGHTWEIGHT BEAM can be hot-galvanised without difficulty.

Corrosion protection by powder coating:

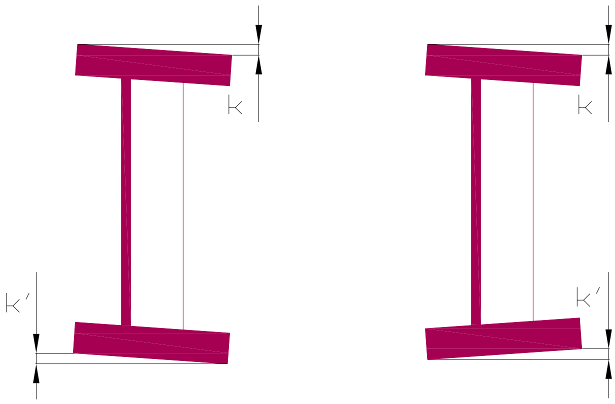
The GLP LIGHTWEIGHT BEAM can be powder coated without difficulty.

Tolerances

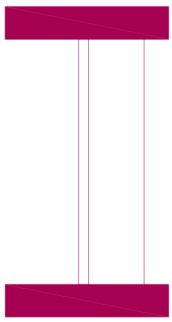
<u>For the blank beam:</u>



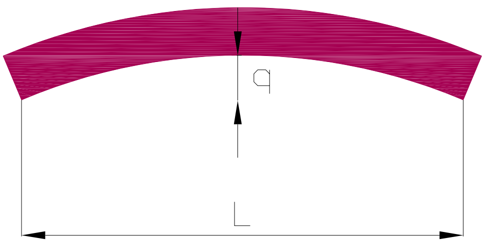
		(in mm)	(in mm)
Depth	h (mm)	400 < h ≤ 700	+5/-3
		h > 700	+5/-5
Flange width	b (mm)	120 < b ≤ 210	+4/-2
		210 < b < 325	+4/-4
		b>325	+6/-5
Web thickness	t_w		
Flange thickness	t_f		



Out of square	k+k' (mm)	b>110	0,01 b (max 4)



Web off-centre $e=(b_1- b_2)/2$	e (mm)	t_f < 40:	
		110 < b ≤ 325	3,5
		b > 325	5

		$t_f \geq 40$:	
		$110 < b \leq 325$	5
		$b > 325$	8
Straightness		q_{yy}/ q_{zz}	0.001 L

<u>For finished structures:</u>

EN 13920, level of accuracy B and F. Weld seams according to EN 25817, level C

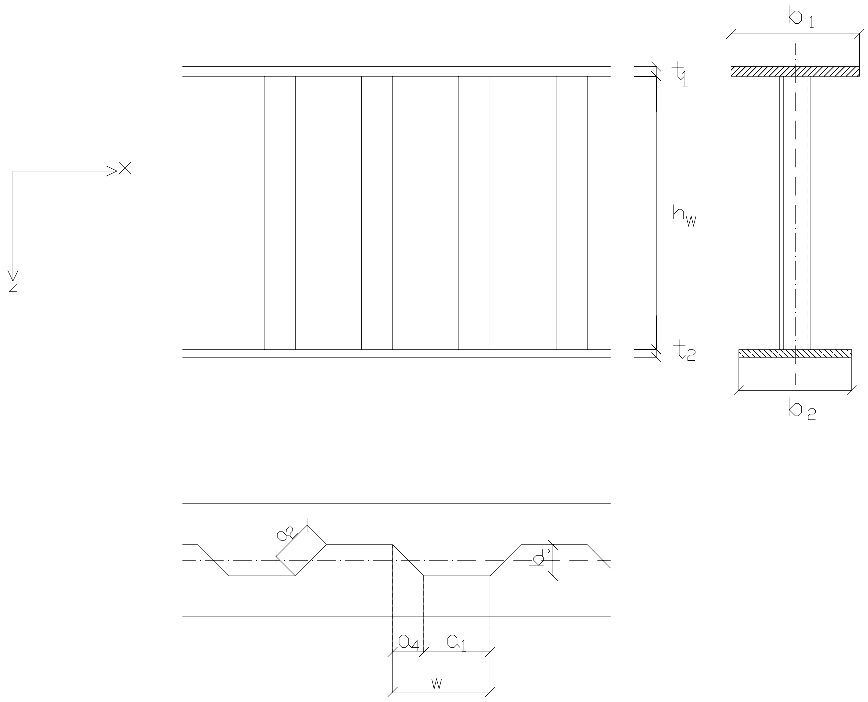
Quality monitoring

The production process is subject to constant, documented, internal monitoring.
Non-destructive testing by a notified body has to be agreed separately.

The quality of the starting material is on the basis of factory certificates according to EN 10204 clause 2.2 for S235JR and clause 3.1.B for S355J2G3. Any additional factory certificates must be agreed at the time of reserving the material.

Check-criteria

Below the design rules according to the Eurocode 3 are presented.



To check for the stability of the web, the local as well as the global stability has to be examined.

In the next table the formulas for determining the local and global buckling resistance are given. The minimum outcome of these two, is the designed buckling resistance

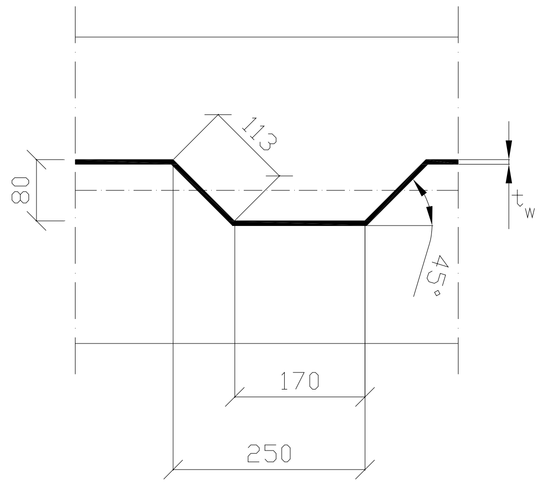


Table 1.: Checking of the shear force capacity of a corrugated web according to Annex D2.2 of prEN 1993-1-5

	Local web buckling	Global web buckling
Orthotropic plate Stiffness		$D_x = \frac{E \cdot t_w^3}{12(1-\upsilon^2)} \cdot \frac{w}{a_1 + a_2}$ $D_y = \frac{E \cdot t_w b_t^2 \cdot (3a_1 + a_2)}{12w}$ $a_1 = 170$; $a_2 = 113$; $w = 250$; $b_t = 80$ E is the elastic modulus
Critical buckling stress	$\tau_{cr,l} = 4{,}83 \cdot E \cdot \left[\frac{t_w}{a_{max}}\right]^2$ $a_{max} = 170$	$\tau_{cr,g} = \frac{32{,}4}{t_w \cdot h_i^2} \cdot \sqrt[4]{D_x \cdot D_y^3}$
Relative slenderness	$\bar{\lambda}_{c,l} = \sqrt{\frac{f_{y,w}}{\tau_{cr,l} \cdot \sqrt{3}}}$ $f_{y,w}$ = web yield strength	$\bar{\lambda}_{c,g} = \sqrt{\frac{f_{y,w}}{\tau_{cr,g} \cdot \sqrt{3}}}$
Buckling reduction factor	$\chi_{c,l} = \frac{1{,}15}{0{,}9 + \bar{\lambda}_{c,l}} \leq 1{,}0$	$\chi_{c,g} = \frac{1{,}5}{0{,}5 + \bar{\lambda}_{c,g}^2} \leq 1{,}0$
Shear resistance	$V_{R,d} = \chi_c \cdot \frac{f_{y,w}}{\sqrt{3} \cdot \gamma_{M1}} \cdot h_i \cdot t_w$, with $\gamma_{M1} = 1{,}0$ and $\chi_c = \min(\chi_{c,l}, \chi_{c,g})$	

Flange buckling

In determining the normal bearing force of the flanges, a distinction must be made between tensile and compressive stresses. In the context of compressive stresses, the stability of the flange must be taken into account.

Due to the transverse moments (M_Z) in the flanges a reduction of the yield strength occurs. Aschinger [2] proposed on basis of FEM analysis a design procedure to derive M_Z:

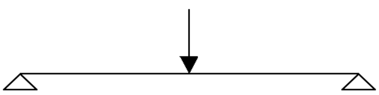
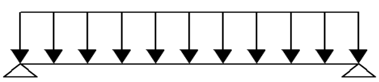
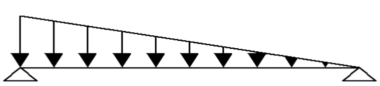
Table2.: Checking of the buckling resistance of the compression flange

Transverse moment	$M_z = f \cdot \max(F_y) + m \cdot \max(M_{z,1})$, where $\max(M_{z,1}) = \frac{a_1 \cdot b_t}{2 \cdot h_i} \cdot \max(V_z)$ $\max(F_y) = \frac{b_t}{h_i} \cdot \max(V_z)$ With $a_1 = 170$; $b_t = 80$. The factors f and m can be obtained from table 3	
Reduced yield strength	$f_{y,r} = f_y \cdot f_T$ and $f_T = 1 - 0{,}4\sqrt{\frac{\sigma_x(M_z)}{\frac{f_y}{\gamma_{M0}}}}$, where $\gamma_{M0} = 1{,}0$ and $\sigma_X = \frac{6 \cdot M_z}{t_1 \cdot b_1^2}$	
Buckling factor	Check a $k_{\sigma,a} = 0{,}43 + \left(\frac{b}{a}\right)^2$, with b the largest outstand from the web to the free edge and: $a = a_1 + 2 \cdot b_t$	Check b $k_{\sigma,b} = 0{,}60$ *and* $b = \frac{b_1}{2}$
Flange slenderness	$\bar{\lambda}_{p,a} = \frac{b_a / t}{28{,}4\varepsilon\sqrt{k_{\sigma,a}}}$ $\bar{\lambda}_{p,b} = \frac{b_b / t}{28{,}4\varepsilon\sqrt{k_{\sigma,b}}}$ where $\varepsilon = \sqrt{\frac{235}{f_{y,r}}}$	
Reduction factor for buckling	$\rho_a = \frac{\bar{\lambda}_{p,a} - 0{,}188}{\bar{\lambda}_{p,a}^2}$ $\rho_b = \frac{\bar{\lambda}_{p,b} - 0{,}188}{\bar{\lambda}_{p,b}^2}$ $\rho = \min(1, \rho_a, \rho_b)$	
Effective area compression flange	$A_{1,eff} = \rho \cdot A_c = \rho \cdot b_1 \cdot t_1$	

Buckling reduction factor	$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \qquad (\chi \leq 1{,}0)$$ Where, $$\Phi = 0{,}5\left[1 + \alpha(\bar{\lambda} - 0{,}2) + \bar{\lambda}^2\right]$$ $$\bar{\lambda} = \sqrt{\frac{A_{eff} \cdot f_y}{N_{cr}}} = \frac{L_{cr}}{i} \cdot \frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1}$$ L_{cr} is the buckling length i is the radius of gyration $\alpha = 0{,}49$ (imperfection factor, buckling curve c) $N_{cr} = b_1 \cdot t_1 \cdot f_y$ (the elastic critical force)
Buckling resistance of the compression flange	$N_{b,R,d} = \frac{b_1 \cdot t_1 \cdot \chi \cdot f_{y,r}}{\gamma_{M1}}$, where $\gamma_{M1} = 1{,}0$

Note

Table 3: Values for the factors f and m

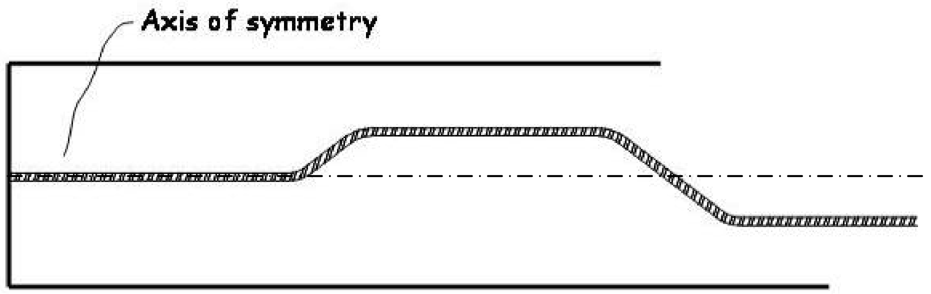
Load figuration	**Factor *f***	**Factor *m***
	0,130	1,50
	0,065	0,60
	0,065	0,50

Yield of the tension flange

Transverse moment	$M_z = f \cdot \max(F_y) + m \cdot \max(M_{z,1})$, where $\max(M_{z,1}) = \frac{a_1 \cdot b_t}{2 \cdot h_i} \cdot \max(V_z)$ $\max(F_y) = \frac{b_t}{h_i} \cdot \max(V_z)$ With $a_1 = 170$; $b_t = 80$. The factors f and m can be obtained from table 3
Reduced yield strength	$f_{y,r} = f_y \cdot f_T$ and $f_T = 1 - 0,4 \sqrt{\frac{\sigma_x(M_z)}{\frac{f_y}{\gamma_{M0}}}}$ and $\gamma_{M0} = 1,0$
Load carrying capacity	$N_{2,R,d} = b_2 \cdot t_2 \cdot f_{y,r}$

Structural Details

The corrugated web of a GLP LIGHTWEIGHT BEAM always ends in the middle of the flanges. In other words, the GLP LIGHTWEIGHT BEAM ends in the axis of symmetry.

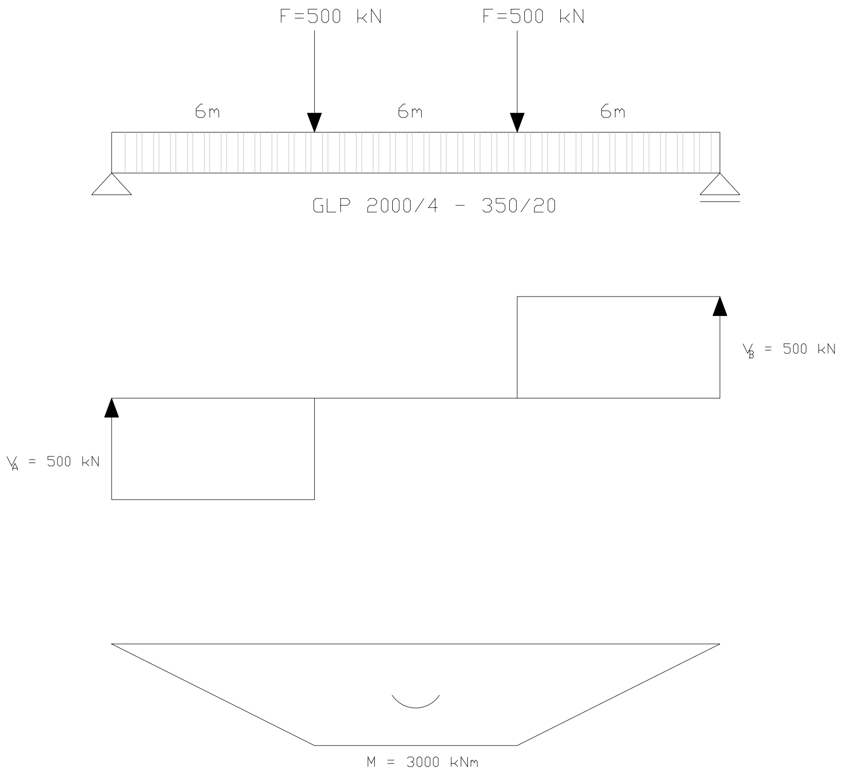


This is of great importance for the mutual connection of GLP LIGHTWEIGHT BEAMs and for the connection of a GLP LIGHTWEIGHT BEAM and a column.
Although research carried out in Germany demonstrate that a symmetrical ending is not necessary.
For GLP however, symmetrical endings are standard procedure.

The best way to indicate how the connections between several construction parts are established is by showing pictures and CAD drawings.

Calculation example

Following figure shows the load configuration of a standard GLP LIGHTWEIGHT BEAM. The applied GLP LIGHTWEIGHT BEAM is the GLP1000/4 – 350/20.



Check of web plate buckling

To check for the web stability, two main buckling modes are checked: local buckling and global buckling

Eurocode 3 (prEN 1993-1-5, Annex D)		
*Material factor (M0)**	*1*	-
*Material factor (M1)***	*1*	-

Local buckling of the corrugated web

a (max)	170	(mm)
Critical shear stress	561,6	(N/mm^2)
Slenderness	0,492	-
Reduction factor for local buckling	0,826	-
Used reduction factor (max = 1,0)	0,826	-
Shear resistance due to buckling*	897	(kN)
Design value shear force	500	(kN)
Unity check	**0,557**	**SATISFACTORY**

Global buckling of the corrugated web

I_y of one corrugation	1329359	(mm^4)
Plate stiffness D_y	1116661656	(Nmm)
Plate stiffness D_x	1086726	(Nmm)
Critical shear stress	399,4	(N/mm^2)
Slenderness	0,583	-
Reduction factor for local buckling	1,786	-
Used reduction factor (max = 1,0)	1,000	-
Shear resistance due to buckling**	1085	(kN)
Design value shear force	500	(kN)
Unity check	**0,461**	**SATISFACTORY**

Flange buckling

Below the flange buckling of the compression flange will be checked

Eurocode 3 (prEN 1993-1-5, Annex D)		
*Material factor (M0)**	*1*	-
*Material factor (M1)***	*1*	-
Maximum (F_y)	20	(kN)
Maximum ($M_{z,1}$)	1,70	(kNm)
Transverse moment in the flange	5,15	(kNm)
Longitudinal stresses in the flange	12,6	(N/mm²)
Reductionfactor yield strength*	0,925	-
Reduced yield strength C-flange	*328*	*(N/mm²)*

	Check (a)	**Check (b)**
Distance a	330	-
Appropriate width b	215	175
Buckling factor	0,85	0,6
Epsilon	0,846	0,846
Flange slenderness	0,484	0,470
Reductionfactor for buckling	1,264	1,277
Used reductionfactor (max = 1,0)	1,000	
Effective width	350,0	(mm)
Effective cross sectional area	*7000*	*(mm²)*

Epsilon	0,814	-
Lambda (1)	76,40	-
Radius of gyration	101,0	(mm)
Buckling length upper flange	6000	(mm)
Flange slenderness	0,78	-
Imperfection factor	0,49	(t<40mm)
Φ Factor	0,94	-
Buckling factor	*0,68*	-
Design buckling resistance**	1554	(kN)
Design value compression force	1485	(kN)
Unity check	**0,956**	**SATISFACTORY**

Check of the tension flange:

Eurocode 3 (prEN 1993-1-1, Section 6)		
*Material factor (M0)**	*1*	-
Maximum (F_y)	20	(kN)
Maximum ($M_{z,1}$)	1,70	(kNm)
Transverse moment in the flange	5,15	(kNm)
Longitudinal stresses in the flange	12,6	N/mm²
Reductionfactor yield strength*	0,925	-
Reduced yield strength T-flange	*328*	*(N/mm²)*
Design yield resistance*	2298	(kN)
Design value tension force	1485	(kN)
Unity check	**0,646**	**SATISFACTORY**

The next figure represents the set up of our spreadsheet program to design GLP LIGHTWEIGHT BEAMS

Reinaldstraat 6 - 6301 EC - Valkenburg a/d Geul, Netherlands
Tel. +31(0)433 653 835 - Fax +31(0)847 301580
www.cpi-glp.com - info@cpi-glp.com

Corrugated Plate Industry

Iv-Bouw & Industrie

INPUT

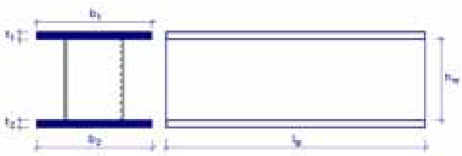
1. GIRDER PROPERTIES

LENGTH

Total length of the girder (l_g)	18	(m)
Buckling length upper flange ($l_{1,buc}$)	6	(m)
Buckling length lower flange ($l_{2,buc}$)	6	(m)

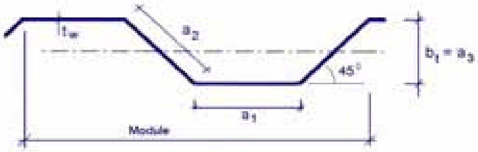
FLANGES

Width upper flange (b_1)	350	(mm)
Thickness upper flange (t_1)	20	(mm)
Width lower flange (b_2)	350	(mm)
Thickness lower flange (t_2)	20	(mm)
Yield strength flanges ($f_{y,f}$)	355	(N/mm²)



WEB

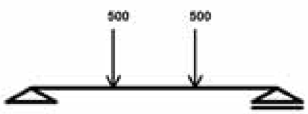
Height (h_w)	2000	(mm)
Thickness (t_w)	4	(mm)
Module	500	(mm)
Length parallel part (a_1)	170,0	(mm)
Length diagonal part (a_2)	113,1	(mm)
Depth of corrugation b_i (a_3)	80,0	(mm)
Yield strength web ($f_{y,w}$)	235	(N/mm²)

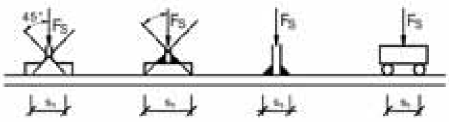


2. LOAD CONFIGURATION

TRANSVERSE LOADS

One local force	○	600	(kN)
Two local forces	●	500	(kN)
Constant transverse load	○	0	(kN/m)
No transverse loads	○		
Length of stiff bearing (S_s)		60	(mm)





EXTERNAL MOMENTS

Moment A (M_A)	(left)	0	(kNm)
Moment B (M_B)	(right)	0	(kNm)

OUTPUT

FAILURE MECHANISM	STANDARD	UNITY-CHECK	EVALUATION
Flange buckling upper flange	Eurocode 3 (prEN 1993-1-5, Annex D)	0,956	SATISFACTORY
Flange buckling lower flange	Eurocode 3 (prEN 1993-1-5, Annex D)	0,000	SATISFACTORY
Yield upper flange	Eurocode 3 (prEN 1993-1-1, Section 6)	0,000	SATISFACTORY
Yield lower flange	Eurocode 3 (prEN 1993-1-1, Section 6)	0,646	SATISFACTORY
Local web buckling	Eurocode 3 (prEN 1993-1-5, Annex D)	0,557	SATISFACTORY
Global web buckling	Eurocode 3 (prEN 1993-1-5, Annex D)	0,461	SATISFACTORY
Yield web plate	Eurocode 3 (prEN 1993-1-1, Section 6)	0,461	SATISFACTORY
Local forces (local web buckling)	Eurocode 3 (prEN 1993-1-5, Section 6)	0,866	SATISFACTORY

PROPERTIES: Girder with corrugated GLP-web		
Thickness of the corrugated web	4,0	(mm)
Weight of the flanges	109,9	(kg/m)
Weight of the corrugated web plate	71,1	(kg/m)
Weight of the girder	181,0	(kg/m)
Total weight of the girder	3258	(kg)