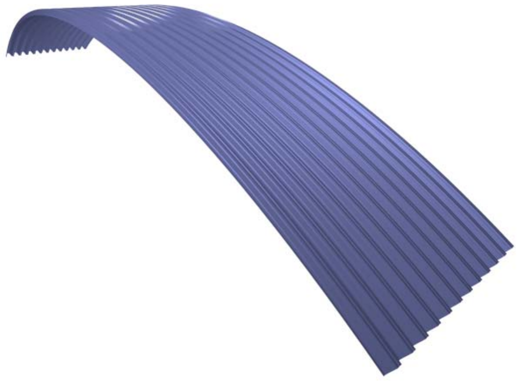
LEGATO-ARCH SYSTEM



TECHNICAL DOCUMENTATION

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A. General Part:

1. General description and application

The arch elements of System Legato consist of trapezoidal sections that are bent to a circular arc in a subsequent production process, i.e. starting with the coiling material some profile shapes can be shaped and curved in one production process.

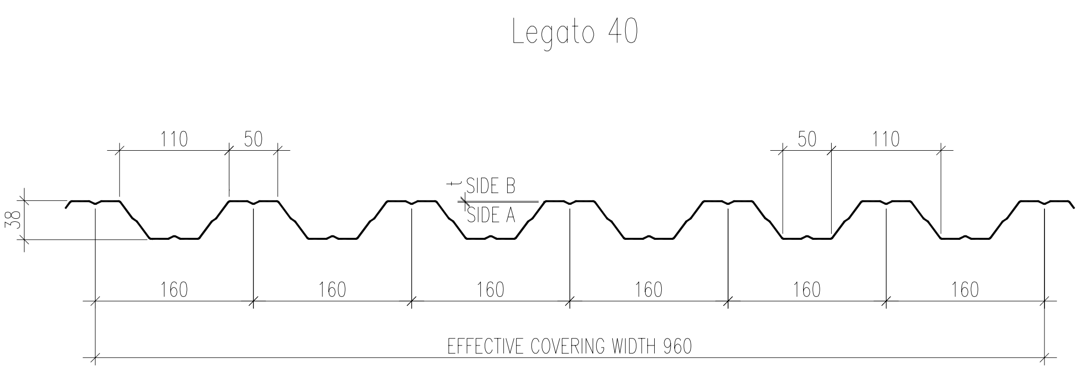


Figure 1: Example Trapezoidal sheet panel

In its static functionality the resulting system is equivalent to a two-hinged arch. Hence spans can be bridged that significantly exceed those of the flat trapezoidal panel in its conventional structural shape.

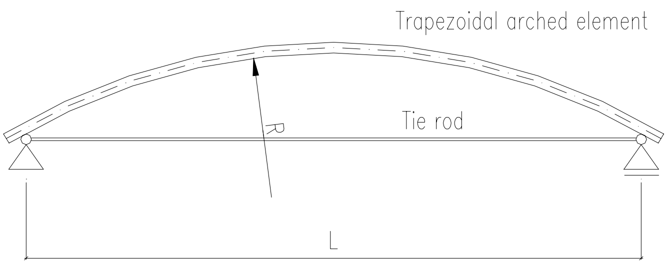


Figure 2: Static system single-skin arch

By means of appropriate spacer profiles double-skin systems can be produced, that may occur with an intermediate heat-insulating layer. The application of double-skin systems has the advantage of increasing the span width and achieving fire resistant structures with a stability of up to 90 minutes.

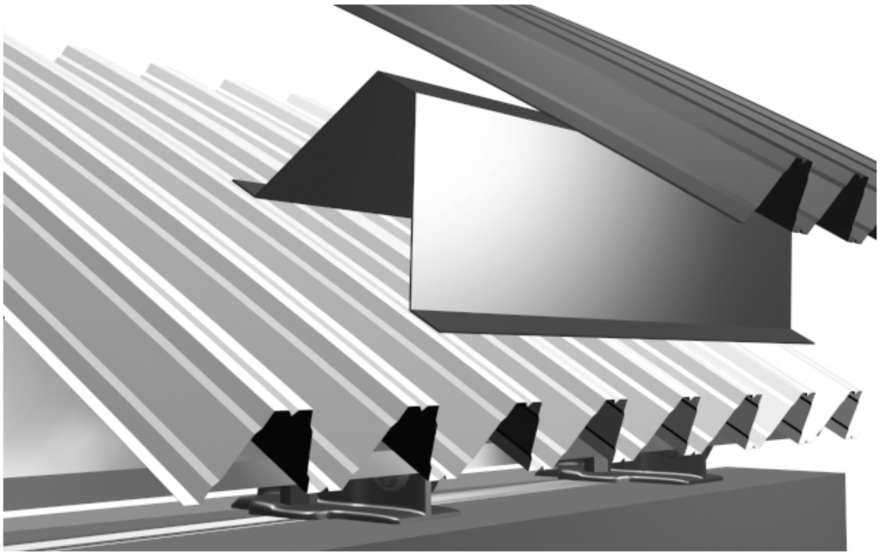


Figure 3: Arch with spacer profile

A characteristic feature of all arches is that tabular recording of allowable loads in case of given span width, as is commonly carried out with trapezoidal sections, is not practicable as the internal forces and moments also depend on the span to arch ratio and, in case of the double-skin arch, on the combination of profiles. Therefore a static calculation has to be carried out in each case of application. Approximate values for maximum span width can be found in Section D.

System Legato allows unsupported spans of up to approx. 20 m. From a static point of view even wider span widths would be possible, however, conditions at transportation result in a restriction to this span width.

The arch action produces high normal forces in the profile and thus high horizontal loads acting on the supports. These should be compensated by the substructure. Therefore System Legato is usually executed with tie rods spaced at 2-3m. These compensate the horizontal arch forces from surcharges so that the substructure is merely loaded vertically, not taking into account wind suction load. In case the horizontal forces of the surcharge are considered in the overall concept of the building and the substructure was calculated to compensate the loads, tie rods are not necessary.

It has to be considered that decreasing arch rise is accompanied by increasing horizontal supporting reaction on the substructure. So-called flat arches with a ratio of Radius : Span = 2 : 1 should not exceed spans of approx. 10m.

Besides static aspects also minimum radii determined by the production process have to be considered when determining sheet thickness. From a static point of view a radius / span ratio of 1:1 is favorable (“normal arch”), yet, larger radii may be chosen as well.

Legato-Arch System is applied as self-supporting or purlin-supported roof element but also as curved wall element.
The structural shape may be concave (arch as tension member) or convex (arch as pressure member.)

Single-skin arches may be applied as permanent shuttering for composite floors as well.

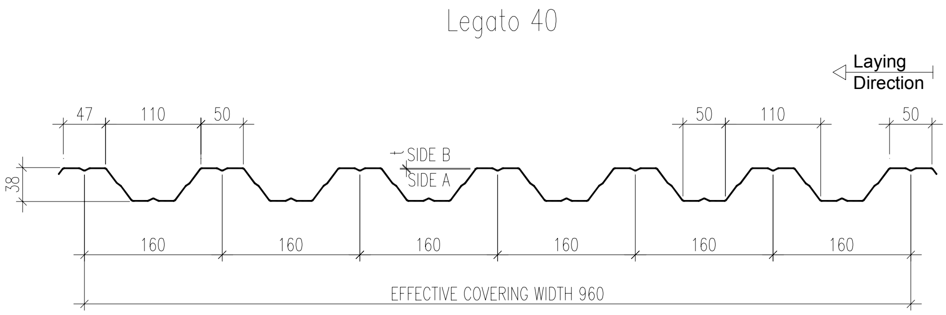
Please refer to the Zeman & Co GmbH Arch Prospectus for a detailed typology of the Legato-Arch System.

2. Description of Legato system elements – delivery program

Currently System Legato offers three different profile shapes. Each profile shape can be supplied in various sheet thickness.

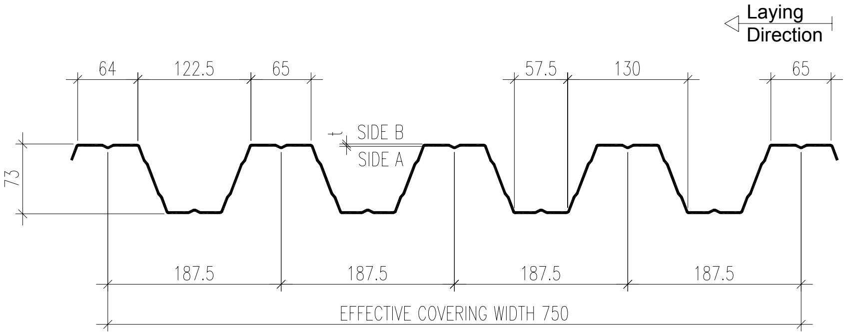
Due to reasons related to production a minimum radius has to be observed, which is determined by depth of section, sheet thickness, quality of material and the geometrical possibilities of the bending machine.

By combining depth and thickness of section System Legato can perfectly be adjusted to loading and span width.



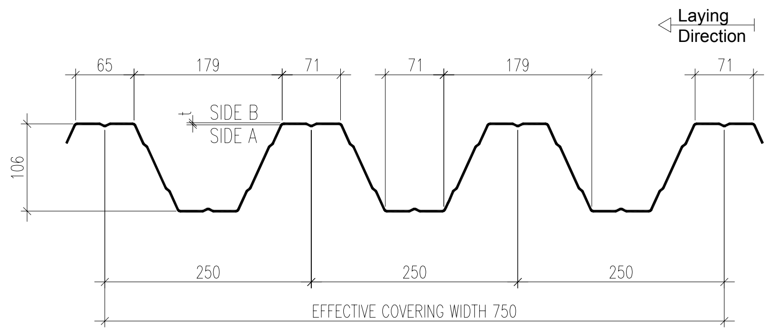
Profile type	Steel quality	Material thickness [mm]	Minimum radius [m]
Legato 40 **Coil width 1250 mm**	**Fe E 280 G**	0.75	8.00
		0.88	6.00
		1.00	4.50
		1.25	4.00
		1.50	4.00
	(Fe E 250 G) not included in standard delivery program	0.75	5.00
		0.88	3.00
		1.00	2.50

Legato 70



Profile type	Steel quality	Material thickness [mm]	Minimum radius [m]
Legato 70 Coil width 1250 mm	Fe E 320 G	0.75	12.0
		0.88	10.0
		1.00	8.0
		1.25	8.0
		1.50	8.0

Legato 107



Profile type	Steel quality	Material thickness [mm]	Minimum radius [m]
Legato 107 Coil width 1250 mm	Fe E 280 G	0.75	50.0
		0.88	28.0
		1.00	15.0
		1.25	11.0
		1.50	10.0
	Fe E 250 G	0.75	20.0
		0.88	13.0
		1.00	12.0

The above mentioned values of the minimum radii depend on the height of the profile, on the steel quality and the material thickness. Additional the radius should not be smaller than 75% of the span due to the geometrical possibilities of the bending machine.

Apart from the actual arch elements additional system elements are necessary, which ensure flawless structural and static fitness of purpose.

-) Clamping plates

Clamping plates, which are adjusted with bolts M12 resp. M16 bolt grade 8.8, are used to connect the arch elements to the abutments. Due to the applied tightening torque the connection serves as slip resistance connection.

The tightness of the connection is guaranteed by an insulating layer.

In exceptional cases (very low arch forces) the connection may be established with self-drilling bolts.

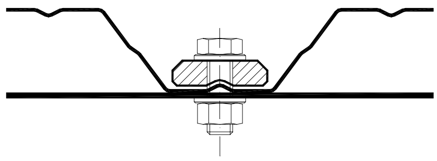


Figure 4: clamping plate, diagrammatic

-) Abutment

It is recommendable to form the substructure already in the angle of the arch tangent rise. In this case the arch elements can directly be attached to the substructure. If this is not possible or large allowable variations of the substructure must be balanced, adjustable abutment supports with an attached abutment section must be provided.

Horizontal forces emerging from the surcharge are compensated by tie rods. The suction loads emerging from lifting load must either be taken by a superstructure or by pressure profiles.

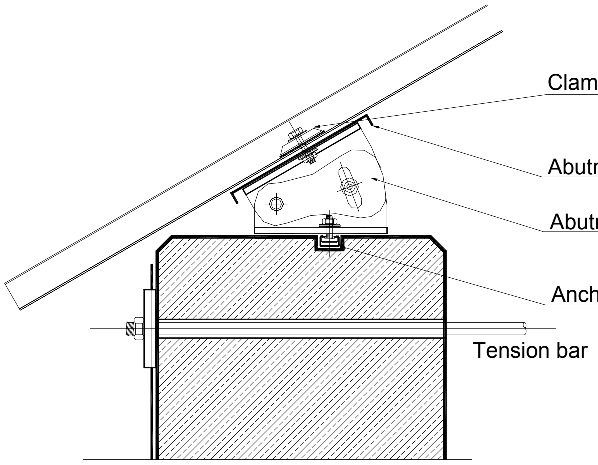


Figure 5: bearing support

-) Hat profiles

Buckled sheets with a height determined by the thickness of the thermal insulation (mostly 130 mm, greater heights possible as well) and a sheet thickness of 1.00 mm are used as connection between the skins of the double-skin arch. The buckled elements are usually bolted to the upper skin and riveted to the lower skin.

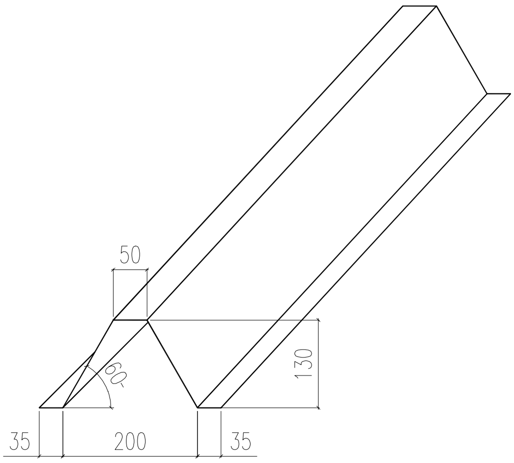


Figure 6: hat profile

If the thermal insulation has to meet higher demands, the standard hat profiles are replaced by isolated stirrups with a longitudinal profile placed on top (e.g. plastic slat).

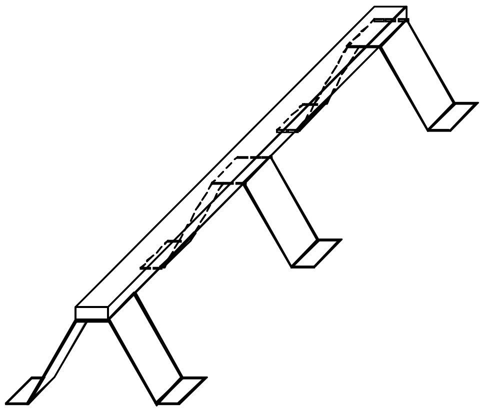


Figure 7: Isolated stirrup with plastic slat

Choosing lower continuous buckled sheets with a plastic slat placed on top represents an alternative to the spacer structures described above.

-) Tie rods

Round steel bars with turnbuckles, ISTOR tension bars or equivalent products may be used as tie rods.

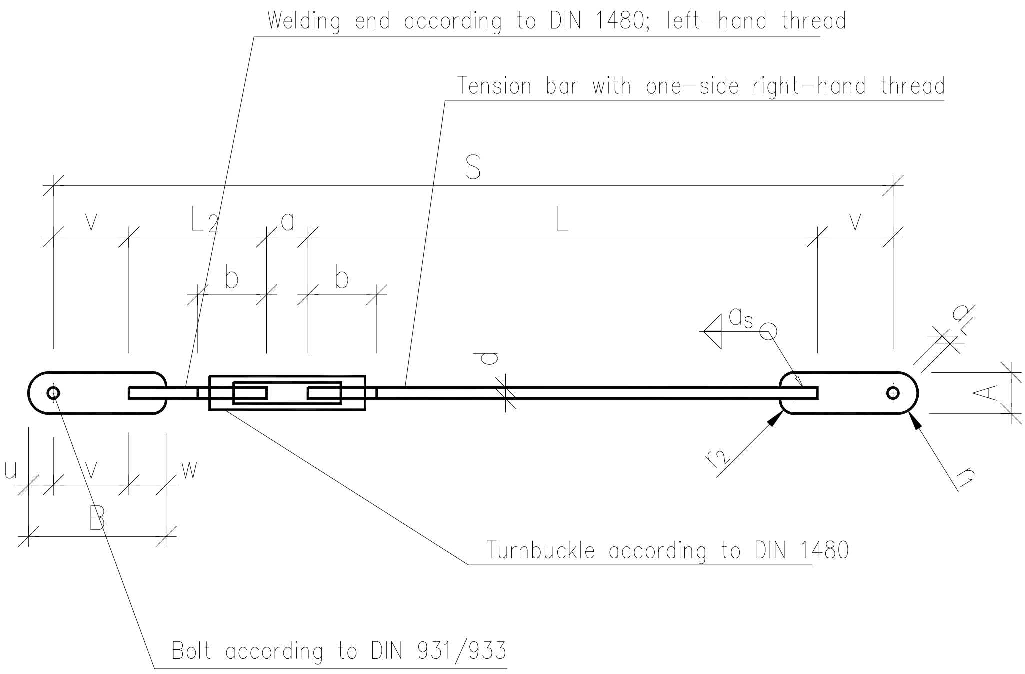


Figure 8: example of tension bar with turnbuckle

-) Verge profiled sheets

For covering the verge edges of a double-skin arch system verge profiled sheets embossed with notch folds are required. The radius is determined by the spacing of the folds in the vertical leg.

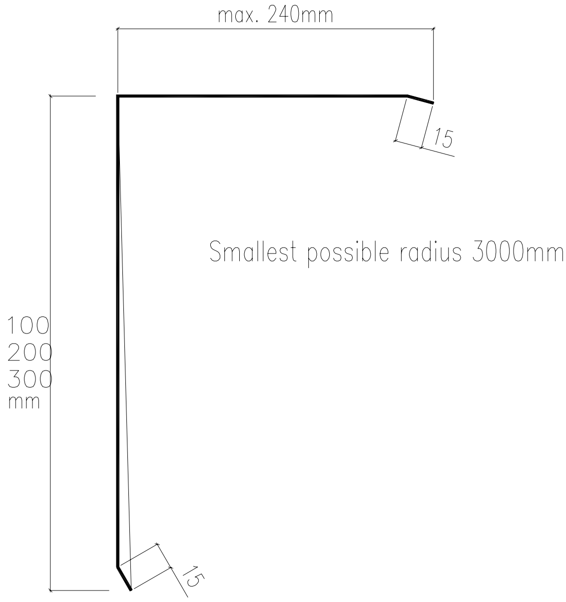


Figure 9: verge profiled sheets

In case of the single-skin arch system verge profiled sheets may be used. In any case the first two corrugation tops have to be connected by means of a curved sheet along the verge in order to avoid a dangling arch end.

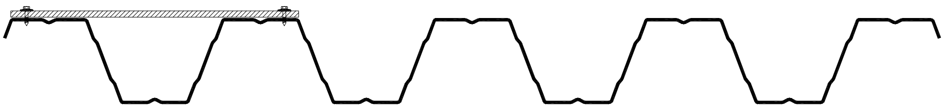


Figure 10: bracing of single-skin arch

-) Strip-line lights

Strip-line lights, which usually show the same width as the laying width of the legato profiles, are executed with poly-carbonate double web plates of a minimum thickness of 10 mm.

Likewise domed roof lights or smoke vents with framing structures can be executed with the Legato arch system.

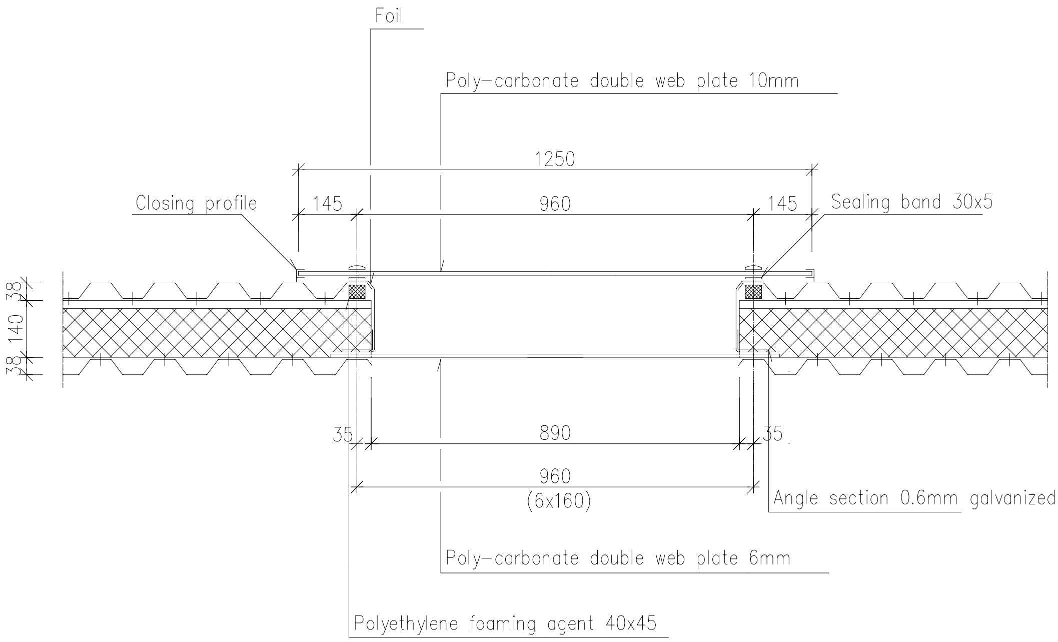


Figure 11: Standard-strip-line light formation, double-skin arch

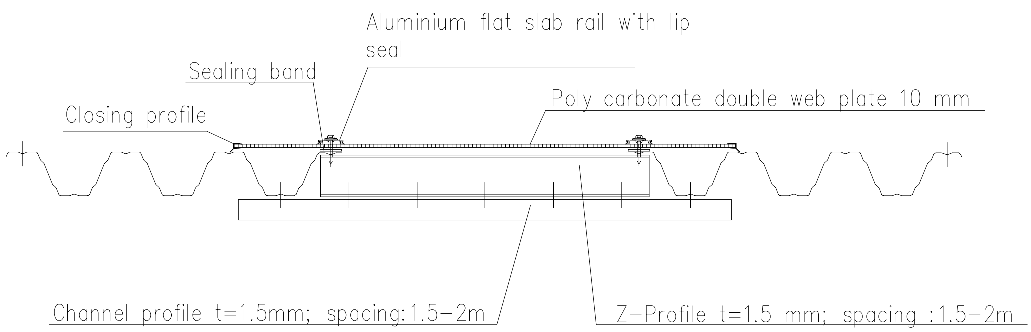


Figure 12: Standard-strip-line light, single-skin arch

3. Construction physics

-) Thermal insulating characteristics

Under conditions complying with standards an authorized testing station (TGM in Vienna) measured and documented in test reports the coefficients of heat transfer of different double-skin arched roof superstructures.

For a superstructure with Legato 40 as internal and external skin with a continuous hat profile as shown in figure 6 a coefficient of heat transfer of

k = 0.51 W/(m^2*K) was measured.

A significant improvement of the results can be achieved by the use of hat profiles with plastic slat as shown in figure 7. The resulting values are

k = 0.39 W/(m^2*K) (without ventilation) respectively k = 0.38 W/(m^2*K) (with ventilation).

All tests were carried out with a thermal insulation of 100mm.

-) Sound insulating characteristics

According to tests carried out by the TGM Vienna the “assessed sound reduction index” R_w of the double-skinned arch systems was stated as 38 dB.

This test was carried out with a superstructure of Legato 40 as internal and external skin, an insulation of 100mm and continuous hat profiles.

4. Corrosion protection

Usually all sheets are galvanized with a zinc layer of 275 g/m^2. This corresponds to group Z275 of DIN EN 10 147 (Table 4).

Furthermore, plastic coatings are applied by means of coil coating. The required coating thickness, which depends on the intended use, is specified in DIN 18807, Part 1. The coating properties and quality control are fixed by DIN 55928-8, - corrosion protection of supporting thin-walled construction elements.

Generally corrosion class III applies for the outside of sheets, which is strained by rain and humidity (e.g. 25 my Polyester), for the inside of the building corrosion class II applies (10 my protective varnish resp. 15 my thin coating in case of strain due to humidity).

Standard coatings of the double-skin arch system:

-) Internal skin	Side A:	10 my protective varnish
	Side B:	15 my thin coating
-) External skin	Side A:	10 my protective varnish
	Side B:	25 my polyester

Standard coatings of single-skin arch systems:

-) Load-bearing skin Side A: 10 my protective varnish
Side B: 25 my Polyester

Further coating options are :

25 my PVDF
25 my siliconpolyester
100my plastisole

The sheets for a building project should originate from the same coiling material as otherwise differences in color may occur.

5. Fire resistance

Self-supporting double-skin arch structures can be executed as fire resistance class F30 (fire inhibiting) construction elements with a structural safety of up to 90 min. according to ÖNORM B3800/2.

Contrary to the standard double-skin arch superstructure, whose internal skin is supported to the substructure, a fire inhibiting structure requires the external skin alone to be able to show load-bearing capacity in case of fire. The internal skin fails as load-bearing element and merely prevents the insulating material from falling down. The insulating layer prevents excessive high temperature of construction elements of the external skin.

As fire is considered an accidental event, the static calculation may be carried out with reduced partial safety factors and reduced loads in accordance with Eurocode 1. Verification of the load-bearing capacity has to be made with resistance values (Young´s modulus and allowable stress) that correspond with the temperature of the construction elements .

An authorized testing institute (IBS – Institut für Brandschutztechnik und Sicherheitsforschung) has classified the different double-skin arch system superstructures by means of tests.

The superstructure with continuous hat profiles can be attributed to fire resistance class
-) F30 showing structural safety of up to 90 min.

Isolated stirrups with a plastic slat on top reach
-) F30.

In order to reach the required fire resistance class all secondary elements (tie rod, bearing formation) of this class have to be formed accordingly.

6. Expert reports and lists of standards

Expert reports on construction physics:

[1] Physikalisch-Technische Versuchsanstalt am TGM Wien : Gutachten 6881/WS; Wärmeschutz einer zweischaligen Konstruktion aus Trapezprofilen; TGM ZL.: 1384/1/87; 23.10.1987

[2] Physikalisch-Technische Versuchsanstalt am TGM Wien : Gutachten 9260/WS; Wärmeschutz einer zweischaligen Konstruktion aus Trapezprofil Stahlblech; TGM ZL.: 1301/95; 22.1.1996

[3] Physikalisch-Technische Versuchsanstalt am TGM Wien : Gutachten 9880/WS; Luftschallschutz einer Dachkonstruktion aus Trapezblechen; TGM ZL.: 1348/87; 6.10.1987

Expert reports on fire resistance and standards:

[4] Institut für Brandschutztechnik und Sicherheitsforschung: BV-Zahl 3612/96; Untersuchung des zweischaligen Bogendaches mit Einzelbügel und darüberliegender Kunststoffleiste; 8.7.96

[5] Institut für Brandschutztechnik und Sicherheitsforschung: BV-Zahl 2749/87; Untersuchung des zweischaligen Bogendaches mit durchlaufenden Hutprofilen; 10.7.87

[6] ÖNORM B3800 Teil 2:Brandverhalten von Baustoffen und Bauteilen

Corrosion protection:

[7] DIN EN 10 147; Kontinuierlich feuerverzinktes Blech und Band aus Baustählen

[8] DIN 18 807, Teil 1; Stahltrapezprofile, Allgemeine Anforderungen, Ermittlung der Tragfähigkeitswerte durch Berechnung

[9] DIN 55928-8; Korrosionsschutz von tragenden dünnwandigen Bauteilen

B. Static Part:

7. Static scheme:

As already mentioned in part A, from a static point of view the Legato arch system is equivalent to a two-hinged arch with fixed supports.

For the calculation of the single-skin arch the system is represented as two-dimensional traverse bar with one meter influence width.

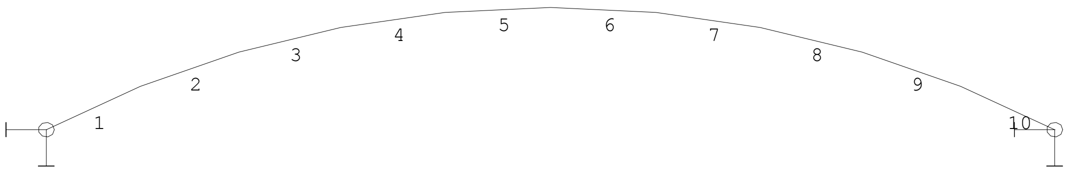


Figure 13 single-skin arch

The section properties of the different section types can be found in part D and chapter 11.

The static scheme of the double-skin arch shows a system of two concentrically situated traverses with radial bars as spacers. The modular lines represent the centroid axes of the trapezoidal sections. The scope of internal forces and moments and their distribution significantly depend on the ratio of skin rigidity, the rigidity of the radial bars and on the shear softness of the connection.

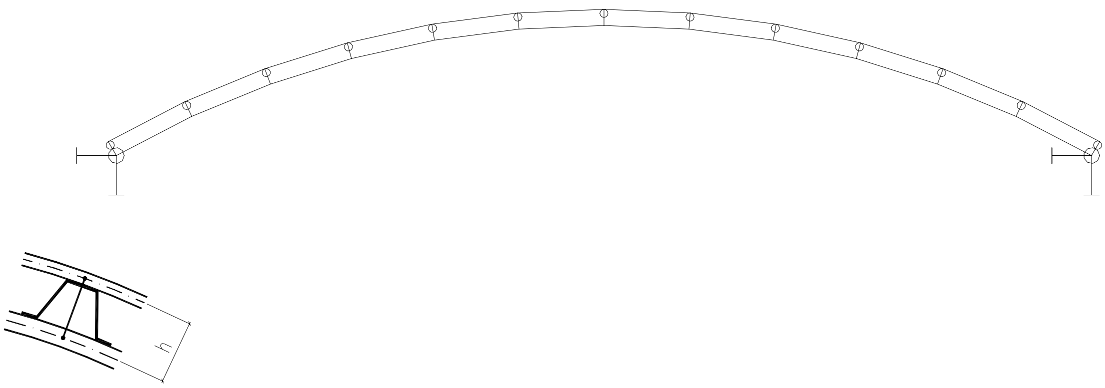


Figure 14 double-skin arch

The radial bars simulate the hat profiles, whose section properties are determined by means of tests in consideration of connecting devices. In shear tests deflections were measured at various section combinations, from which fictitious moments of inertia for the static scheme were deduced.

Due to the form of the hat profiles the connection to the upper skin is hinged, whereas that to the lower sheet is rigid.

It has to be pointed out that trapezoidal arches are statically sensitive systems whose calculation requires accuracy and careful dimensioning.
Displacements of supports or geometrical imperfections become effective as rise reduction resp. increase and thereby in the internal forces and moments.

Therefore the resilience of the substructure must be considered and the displacement of support must be kept low, so that the assumption of solid supports for the arch system is justified.
Otherwise this assumption in the static system for the design of the substructure may be considered safe, as it involves overestimation of the horizontal forces.

The horizontal forces emerging from surcharge must be compensated by tie rods. Normally they are arranged along the longitudinal profile of the supports, with a spacing of 2-3 m. Together with the longitudinal profile of the support and the tie rods the arch forms a closed system that does not produce external horizontal forces in case of vertical surcharge.

The horizontal loads emerging from suction loads may be taken by pressure profiles or by the substructure.

8. Basics of calculation

-) Loading:

In case of loads the respective country norms are applied. Most norms state values for arched roof formations for wind as well as snow loads.
Alternatively the load values may also be calculated according to the “Eurocodes”, provided this is permitted in the respective country.

-) Snow

ÖNORM B4013 as well as ENV 1991-2-3 state the numerical values of the applicable shape coefficient μ.
At canopy arches the possibility of snow accumulations has to be taken into account. In case of multi-bay arches drifting of the snow into the valley must be considered.
In any case asymmetric snow load cases have to be examined, as these result in larger bending moments.

-) Wind

ÖNORM B4014 and ENV 1991-2-4 contain c_{pe}-values for cylindrical roof areas. Neither norm gives details on wind loading of free-standing arched roofs. These can be found in an expertise of “Bundesversuchs- und Forschungsanstalt Arsenal” , which was specially prepared for Zeman & Co GmbH.

-) Imposed load

Details on whether the imposed load on the roof has to be considered can be found in the respective country norms. Mostly, as is the case with ENV 1991-2-1, it must not be applied together with snow and wind. In Austria a decision of the standards committee 176 stipulates that imposed load must only be applied for areas of roof pitches up to 5°.

In any case the erecting state must be examined with a single load of 1.50 kN applied at the most unfavorable place.

-) Imperfections

If a calculation is made according to second-order theory, imperfections have to be taken into account, e.g. by assuming an equivalent load. It has proven useful to apply the equivalent load according to DIN 18 800, Part 2, Table 23 (buckling curve c, l/400).

-) Fire

If a fireproof design is required, it has to be kept in mind that the internal skin fails as load bearing element. The external skin must be capable of compensating the loads on its own.
In this case calculations may be carried out with reduced loading and partial safety factors γ_F=1.0 and γ_M=1.0. ENV 1991-2-2 may be referred to for the assumption of loading. The case of fire load is regarded as accidental event. The characteristic values of material have to be adjusted to the temperature.

-) Structural analysis:

The determination of the significant combinations of loads and partial safety factors is carried out in accordance with the country norms or ENV 1991-1.

For the single-skin arch both, calculations in accordance with first-order theory and second-order theory are acceptable. For the double skin arch calculations are appropriately carried out in accordance with second-order theory, as simultaneous recording of system stability and the stability of single bars has not proven successful. Therefore merely imperfections of the overall system are considered in initial imperfections, and the verification of stability of the single bars is taken into account by means of the fictitious bar method.

-) Design:

Trapezoidal sections may be designed in accordance with DIN 18 807 or ENV 1993-1-3. Expert reports of TU Karlsruhe [21] and TU Graz [20] prove that DIN 18 807, which actually applies to straight trapezoidal sections, is also valid for arched sections.

The carrying capacity of special construction elements, such as hat profiles, clamping plates and bearing shoes, were established in tests and are documented in expert reports [22]-[26] and [29] and in part D.

If verification is carried out in accordance with DIN 18 807 Part 3, 3.3.3.6.1, the “Anpassungsrichtlinie Stahlbau” has to be complied with.

The verification process in accordance with DIN 18 807 Part 3 will be introduced in chapter 10.

9. Material

Different steel qualities, which are regulated in DIN EN 10 147, are being used. The applied material does not only effect the load-bearing capacity but also the minimal radius of the arch. Generally higher-grade sheets require a larger minimal radius.

The fabrication process has resulted in observable minimal radii for various profile shapes, qualities of material and grades of sheet thickness in order to avoid buckling resp. folding of the web. These can be found in part D.

According to DIN EN 10 147 the following steel grades are used for the Legato-arch system

Fe E 320 G (yield point $f_{y,k}$=320 N/mm^2) for Legato 70,
Fe E 280 G (yield point $f_{y,k}$=280 N/mm^2) for Legato 40 and 107
Respectively Fe E 250 G (yield point $f_{y,k}$=250 N/mm^2) for thinner sheets of Legato 107

All profile shapes can be delivered in different grades of sheet thickness, namely
0.75; 0.88; 1.00; 1.25 and 1.50 mm.

10. Verification process

Once the significant internal forces and moments are known from static calculation, the load-bearing capacity of the trapezoidal sections and special construction elements can be verified.

-) Trapezoidal sections

As mentioned above, the internal forces and moments of a single-skin arch may either be calculated according to first-order theory or to second-order theory. Various verification processes result from each calculation method. They may be conducted in accordance with DIN 18 807 or ENV 1993-1-3. As an example we introduce verification in accordance with DIN 18 807 Part 3, 3.3.3.6.1. The “Anpassungsrichtlinie Stahlbau”, Point 4.13 (May 1996) must be observed, which adapts DIN 18 807 to the partial factor method.

If the internal forces and moments were determined in accordance with first-order theory, verification must be carried out following the fictitious bar method.

In case of compressive force the following is applied

$$\frac{N_D}{N_{dD}} \cdot \left[1 + 0,5 \cdot \alpha \cdot \left(1 - \frac{N_D}{N_{dD}}\right)\right] + \frac{M}{M_d} \leq 1 \qquad \text{(DIN 18 807 Part 3; 3.3.3.6.1; Eq.(1))},$$

in case of tensile force

$$\frac{N_Z}{N_{dZ}} + \frac{M}{M_d} \leq 1 \qquad \text{(DIN 18 807 Part 3; 3.3.3.6.1; Eq.(2))},$$

is applied with

N_Z design value of tensile force,
N_D design value of compressive force,
M design value of bending moment,
M_d design resistance for bending moment,
N_{dZ} design resistance for tensile force,
N_{dD} design resistance for compressive force,
α factor dependent on section resp. system geometry,

$$\alpha = \sqrt{\frac{f_{y,k}}{\sigma_{el}}} = \frac{s_k}{i_{ef} \cdot \pi} \cdot \sqrt{\frac{f_{y,k}}{E}} \qquad \text{(DIN 18 807 Part 1; 4.2.8.2; } \alpha \leq 1\text{; Eq.(3))}$$

with

s_k buckling length according to DIN 18800 part 2; 6.1.1.1,
i_{ef} radius of inertia of the effective cross section and
σ_{el} buckling stress of the effective cross section.

If the internal forces and moments are determined in accordance with second-order theory, verification of the cross section under compressive force simply needs to be carried out, with

$$\frac{N_D}{N_{dD}} + \frac{M}{M_d} \leq 1 \qquad \text{Eq.(4)}$$

Verification remains unchanged as regards tensile forces, cf. Eq.(2).

Double-skin arches are calculated according to second-order theory. By applying a load case 'deformation similar to the buckling line' system stability has already been accounted for. Yet the individual bars have not been examined in terms of their failure in a sway mode.

Therefore verification has to be carried out according to Eq.(1) and with the buckling length corresponding to that of the individual bars.

All types of profiles necessary for static calculation are listed in chapter 11 resp. part D. The minimal radii can be found in part A resp. D.

-) Special construction elements

Tables with bearing capacity values established by testing exist for clamping plates, bearing shoes and hat profiles. These can be found in part D.

Arch substructures such as tie rods, bearing profiles or domed roof light framing beams have to be verified in compliance with valid norms.

11. Profile characteristics

All profile characteristics in the following tables were determined in accordance with DIN 18 807 Part 1-3.

-) Legato 40:

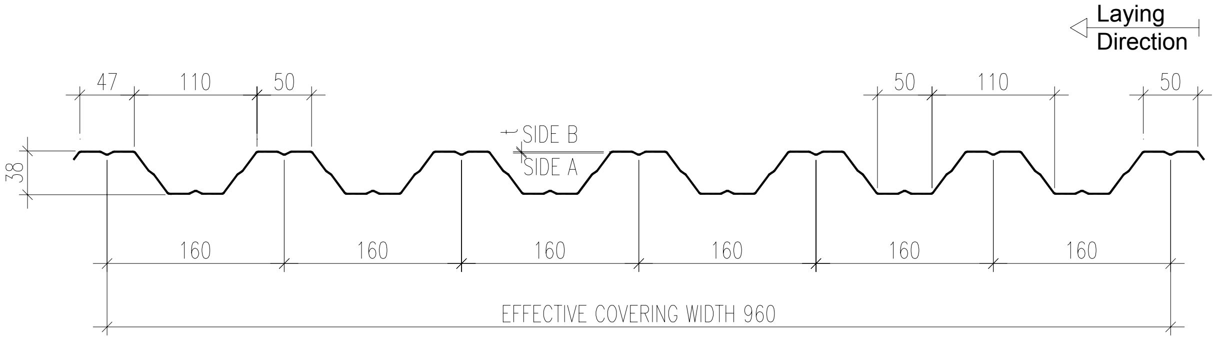


Table 1: Section properties (all Fe E 280 G)

Sheet thickness mm	Rigidity and tension					Pressure and bending				
	A_g cm^2/m	I_g cm^4/m	i_g cm	e_o cm	e_u cm	A_{ef} cm^2/m	i_{ef} cm	I_{ef} cm^4/m	$W_{o,ef}$ cm^3/m	$W_{u,ef}$ cm^3/m
0.75	8.87	20.49	1.52	1.88	1.88	7.78	1.53	20.36	10.83	10.83
0.88	10.49	24.24	1.52	1.88	1.88	9.55	1.53	24.09	12.81	12.81
1.00	11.99	27.70	1.52	1.88	1.88	11.20	1.52	27.53	14.64	14.64
1.25	15.11	34.91	1.52	1.88	1.88	14.69	1.52	34.69	18.45	18.45
1.50	18.23	42.12	1.52	1.88	1.88	18.23	1.52	41.89	22.26	22.26

Table 2: Characteristic resistance forces

Steel grade	Sheet thickness t[mm]	Resistance for axial force [kN/m]		Resistance for bending moment $M_{R,k}$ [kNm/m]
		$N_{R,k\ tension}$	$N_{R,k\ pressure}$	
Fe E 280 G $f_{y,k}$ = 280 N/mm²	0.75	248.36	217.84	2.94
	0.88	293.72	267.40	3.54
	1.00	335.72	313.60	4.10
	1.25	423.08	411.32	5.16
	1.50	510.44	510.44	6.23

-) Legato 70:

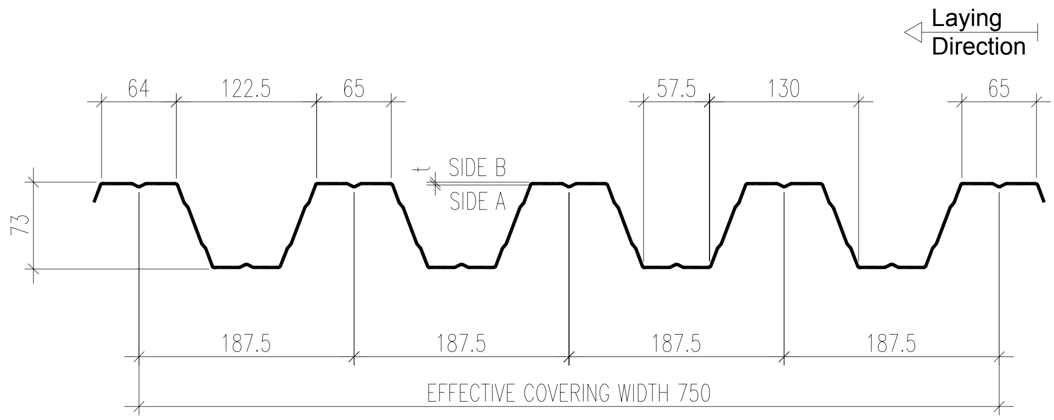


Table 1: Section properties (all Fe E 320 G)

Sheet thickness mm	Rigidity and tension					Pressure and bending				
	A_g cm²/m	I_g cm⁴/m	i_g cm	e_o cm	e_u cm	A_{ef} cm²/m	i_{ef} cm	I_{ef} cm⁴/m	$W_{o,ef}$ cm³/m	$W_{u,ef}$ cm³/m
0.75	10.98	86.08	2.80	3.65	3.65	6.95	2.97	85.97	23.44	23.23
0.88	12.99	101.84	2.80	3.65	3.65	8.96	2.92	101.72	28.19	27.48
1.00	14.84	116.35	2.80	3.65	3.65	10.89	2.89	116.25	32.63	31.41
1.25	18.71	146.69	2.80	3.65	3.65	14.99	2.86	146.52	41.80	39.58
1.50	22.57	176.95	2.80	3.65	3.65	19.20	2.84	176.79	50.63	47.76

Table 2: Characteristic resistance forces

Steel grade	Sheet thickness t[mm]	Resistance for axial force [kN/m]		Resistance for bending moment $M_{R,k}$ [kNm/m]
		$N_{R,k\ tension}$	$N_{R,k\ pressure}$	
Fe E 320 G $f_{y,k}$ = 320 N/mm²	0.75	309.40	219.80	6.57
	0.88	365.96	279.72	7.78
	1.00	418.04	336.00	8.89
	1.25	526.96	455.00	11.20
	1.50	635.88	576.52	13.52

-) Legato 107:

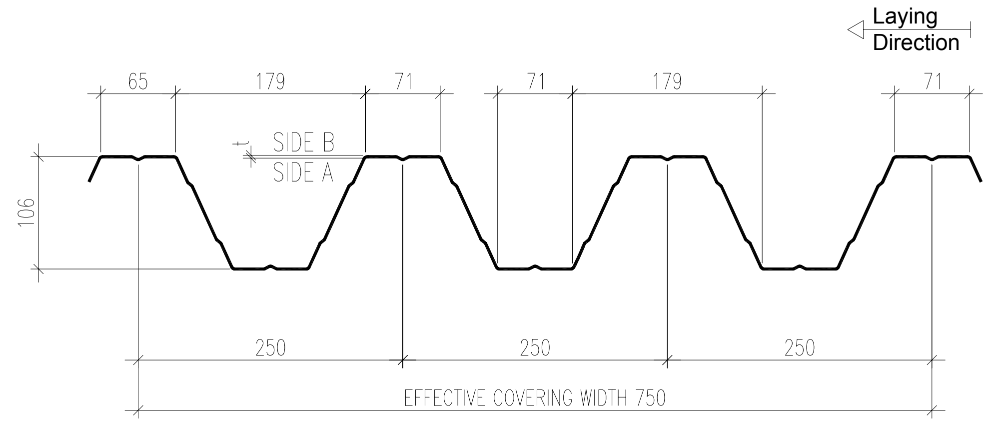


Table 1: Section properties (0.75 and 0.88 mm Fe E 250 G, all others Fe E 280 G)

Sheet thickness mm	Rigidity and tension					Pressure and bending				
	A_g cm^2/m	I_g cm^4/m	i_g cm	e_o cm	e_u cm	A_{ef} cm^2/m	i_{ef} cm	I_{ef} cm^4/m	$W_{o,ef}$ cm^3/m	$W_{u,ef}$ cm^3/m
0.75	11.81	182.7	4.00	5.30	5.30	9.01	4.20	182.4	34.43	34.43
0.88	13.12	209.9	4.00	5.30	5.30	9.35	4.31	209.6	39.55	39.55
1.00	14.99	239.8	4.00	5.30	5.30	10.83	4.28	239.5	45.19	45.19
1.25	18.90	302.4	4.00	5.30	5.30	15.01	4.18	301.9	56.96	56.96
1.50	22.80	364.8	4.00	5.30	5.30	19.47	4.10	364.3	68.74	67.74

Table 2: Characteristic resistance forces

Steel grade	Sheet thickness t[mm]	Resistance for axial force [kN/m]		Resistance for bending moment $M_{R,k}$ [kNm/m]
		$N_{R,k\ tension}$	$N_{R,k\ pressure}$	
Fe E 250 G $f_{y,k}$ = 250 N/mm²	0.75	212.62	162.21	6.17
	0.88	328.00	233.75	9.55
Fe E 280 G $f_{y,k}$ = 280 N/mm²	1.00	419.72	303.24	12.23
	1.25	529.20	420.28	15.87
	1.50	638.40	545.16	19.25

12. Expert reports and lists of standards

Loading and Structural analysis:

[10] ENV 1991: Grundlagen der Tragwerksplanung und Einwirkungen auf Tragwerke

[11] ÖNORM B 4012: Belastungsannahmen im Bauwesen, Veränderliche Einwirkungen, Nutzlasten

[12] ÖNORM B 4013: Belastungsannahmen im Bauwesen, Schnee- und Eislasten

[13] ÖNORM B 4014-1: Belastungsannahmen im Bauwesen, Statische Windwirkungen (nicht schwingungsanfällige Bauwerke)

[14] Bundesversuchs- und Forschungsanstalt Arsenal: Bericht über Windkanalversuche an Modellen von Flugdächern; 1987

[15] Österreichisches Normungsinstitut, FNA 176 (Belastungsannahmen im Bauwesen): Interpretation der Lastnorm B 4012; 1996

[16] DIN 18 800 Teil 2 (11.90): Stabilitätsfälle, Knicken von Stäben und Stabwerken

Design:

[17] DIN 18 807 Teil 1-3: Stahltrapezprofile

[18] Mitteilungen des Deutschen Instituts für Bautechnik; Anpassungsrichtlinie Stahlbau; Mai 1996

[19] ENV 1993-1-3: Bemessung und Konstruktion von Stahlbauten, Allgemeine Bemessungsregeln- Ergänzende Regeln für kaltgeformte dünnwandige Bauteile und Bleche

[20] o.Univ.Prof.DI.Dr.techn. F. Resinger, ao.Univ.Prof.DI.Dr.techn. R. Greiner: Bericht über die Tragfähigkeitsuntersuchung gekrümmter Trapezprofile; Technische Universität Graz 16.2.1987

[21] o.Prof.Tekn. dr R. Baehre: Untersuchung des Tragverhaltens von gekrümmten Trapezprofilblechen; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 15.1.87

[22] o.Univ.Prof.DI.Dr.techn. R. Greiner: Versuche zur Bestimmung der Tragschubkraft und Nachgiebigkeit der Hutprofile in zweischaligen Bogendachkonstruktionen; Technische Universität Graz 12.6.91

[23] Univ.Prof.Dr.-Ing. H. Saal: Experimentelle Untersuchung zur Ermittlung der Tragfähigkeit und Verformbarkeit von Hutprofilen in zweischaligen Bogendachkonstruktionen; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1995

[24] Univ.Prof.Dr.-Ing. H. Saal: Ermittlung der Schubtragfähigkeits- und Schubsteifigkeitswerte von zweischaligen Bogendachkonstruktionen; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1995

[25] o.Univ.Prof.DI.Dr.techn. R Greiner: Versuche zur Bestimmung der Tragfähigkeit der Auflagerelemente des Bogendaches mit Ergänzungsbericht; Technische Universität Graz 1992 und 1993

[26] DI. W. Radhuber: Versuchsbericht über Traglastversuche für ein Widerlager; Wernberg 2.12.85

[27] Univ.Prof.Dr.-Ing. H.Saal: Untersuchung des Tragverhaltens von gekrümmten Stahltrapezprofilen TRE 106; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1994

[28] Univ.Prof.Dr.-Ing. H.Saal: Untersuchung des Tragverhaltens von gekrümmten Stahltrapezprofilen TRE 40; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1994

[29] DI. E. Gartner: Schubeinleitung in Trapezbleche unter besonderer Berücksichtigung der Klemmplatten; Wien 2001

Material:

[30] DIN EN 10 147: Kontinuierlich feuerverzinktes Blech und Band aus Baustählen, Technische Lieferbedingungen

C. Production and Assembly

13. Allowable variations:

Curved trapezoidal sections are subject to the same allowable variations as straight sheets. Those for the individual sheets can be found in DIN 18 807 Part 1 and „Bauelemente aus Stahlblech, Gütesicherung, RAL-GZ 617“ (Prefabricated units of steel sheet, quality control RAL-GZ 617)

These documents determine ultimate values as regards ultimate dimensions of profile geometry such as

-) depth of section
-) structural width
-) width of top- and bottom flange
-) internal radii
-) flange beads in relation to height and position
-) web beads in relation to length and stemming
-) constriction and bulging
-) cross warping.

ÖNORM DIN 18 202 and ENV 1090 determine the allowable variations for the entire construction element.

14. Quality control

Self- and external monitoring is carried out in accordance with RAL-GZ 617.

Within the scope of self-monitoring the manufacturer examines compliance with section properties as regards construction material, zinc coating, sheet thickness and dimensional stability.

External monitoring has to be carried out by an acknowledged testing institute (LMPA Sachsen-Anhalt).

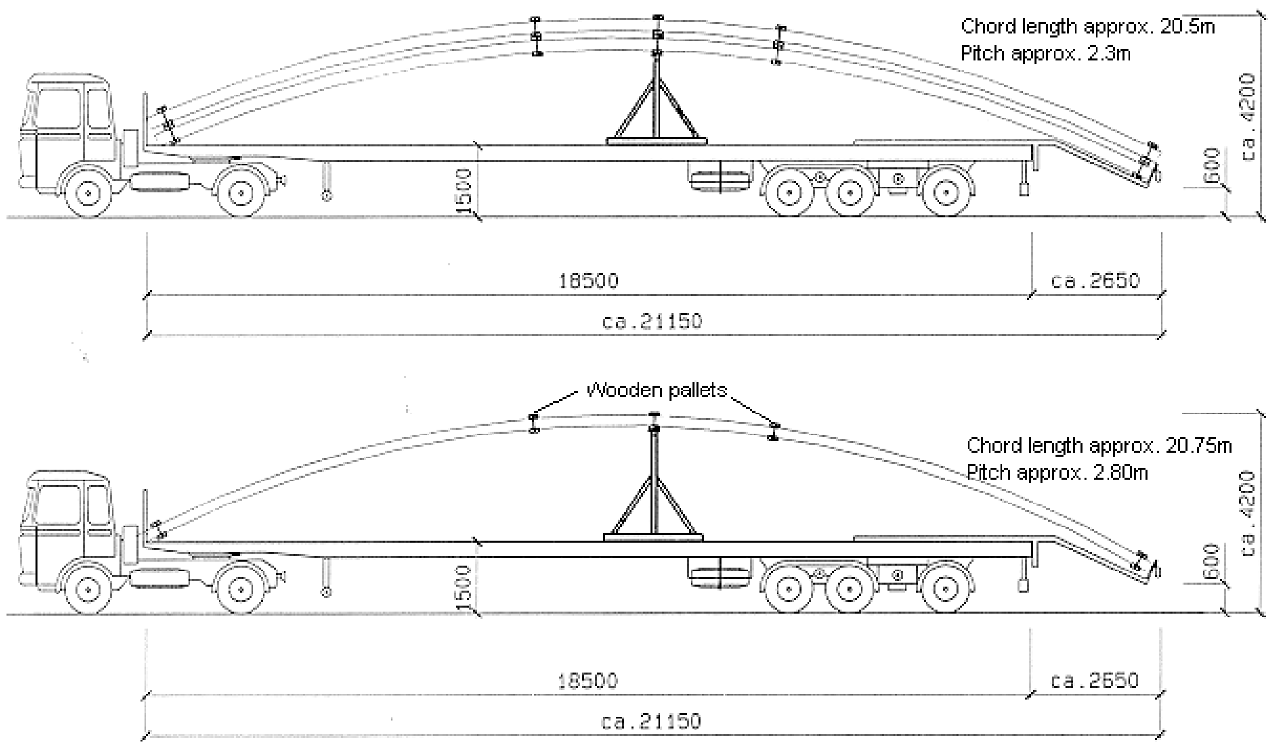
15. Guidelines for Assembly

At the assembly of the Legato arched roof some conditions and guidelines must be complied with to be able to guarantee perfect reliability of the arch system.

15.1. Transportation:

IFBS guidelines and below mentioned marginal conditions have to be followed at the transportation of System Legato:

-) The highway code imposes restrictions of height and length of the loaded vehicle.

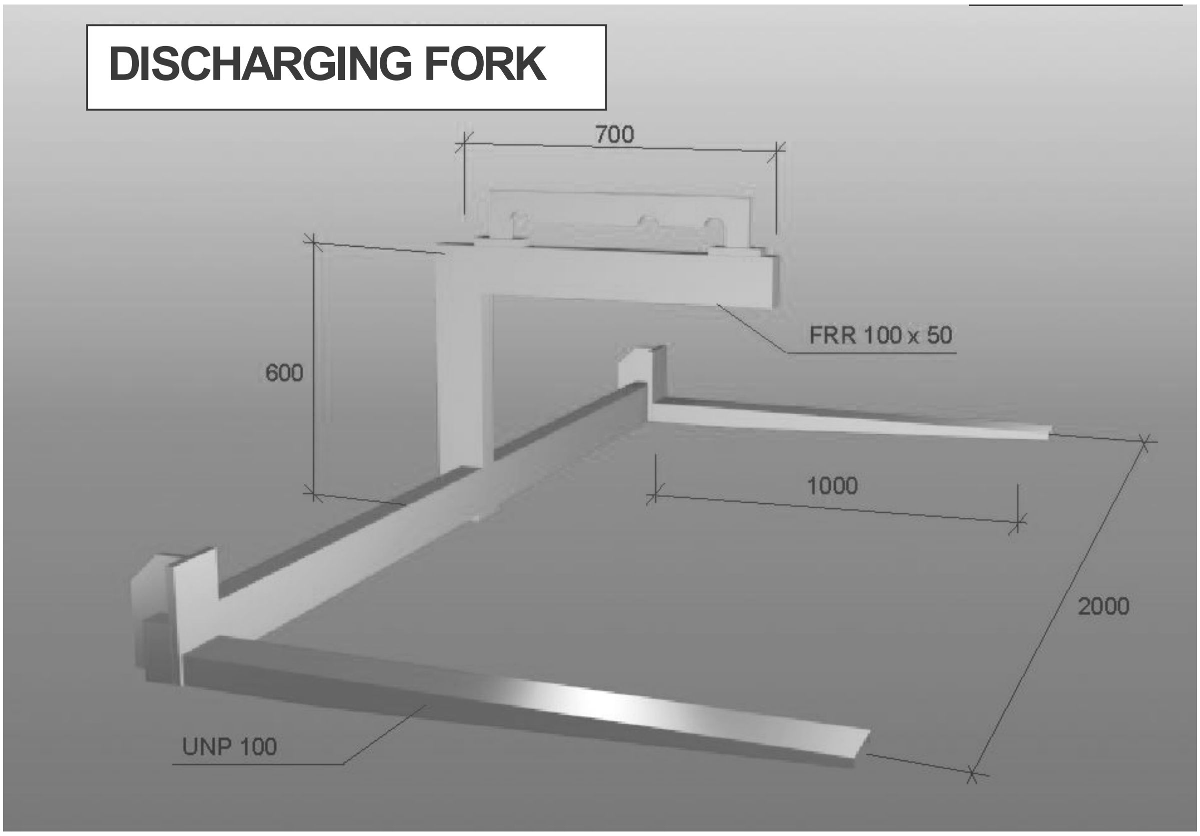


Sheet pack LT 41:	height 20-25cm
Sheet pack LT 107:	height 30cm
Pallets:	75mm thick each

-) Due to the risk of damage to the lower sheet plates an arch-element pack should not exceed 3000 kg.

-) To ensure stability it is recommended to load a maximum of three packs on top of each other.

At discharging high-strength belts have to be used that are led through underneath the two middle pallets. The belts should encompass an acute angle in order to keep the forces acting on the pallets in inward direction to a minimum.
In case shorter and lighter (up to 2000 kg) arch pallets are discharged, they may also be unloaded by means of a loading resp. discharging fork.

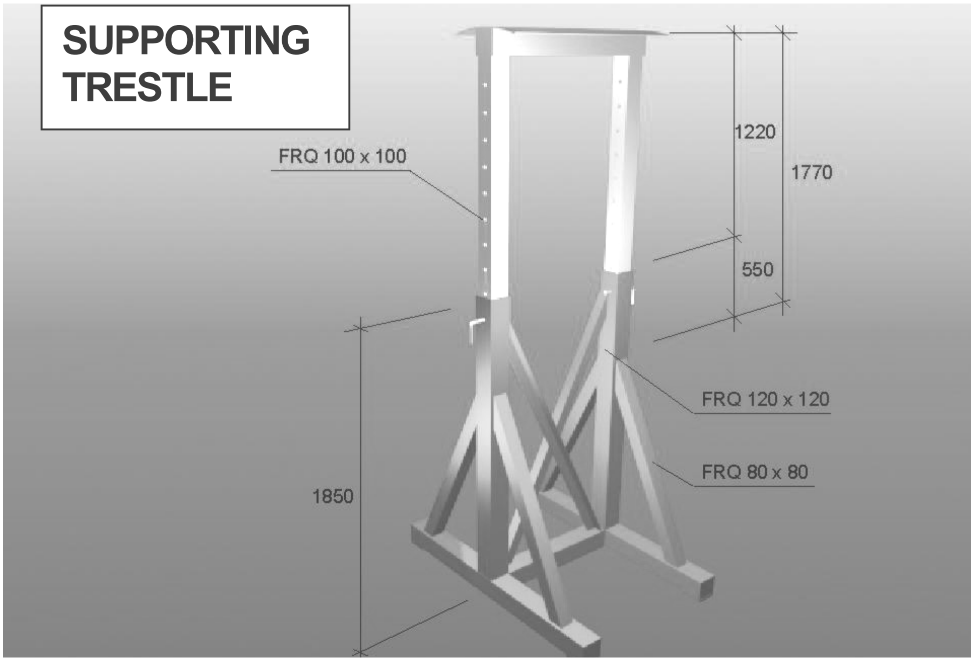


15.2. Storage:

Besides the IFBS guidelines that have to be observed obligatorily, below conditions should be considered. Furthermore the number of manipulations should be kept to a minimum due to risk of damage to the sheets.

The pallets that usually weigh between 2000 and 3500 kg, are most practicably stored as near as possible to the place of assembly. The defined areas have to be leveled and the ends of the elements are rested on horizontally fitted timber planks. The arch pallets must be centrically supported by means of vertically adjustable support trestles.

If the elements are stored for more than a few days, they must be covered by a wind- and weather resisting foil layer. Elements whose original packaging has already been opened must be secured against wind action.



15.3. Assembly:

A team familiar with laying trapezoidal sections could most certainly be entrusted with assembling the arch system. If possible one of the erectors should be a skilled sheet metal worker to carry out work involving buckled sheets.

The team required for the assembly of the Legato arch system consists of at least four erectors. Three are to be assigned for work on the roof, one is needed on ground- resp. storage level.

For a proper assembling process clear laying plans and parts list are essential. These must also indicate the laying direction (preferably against weather-side). Furthermore all details must be represented unmistakably and clearly; fixing regulations on the building site must exist.

-) Assembly of the single-skin system:

Before the arch elements are assembled the abutments and gutter parts have to be placed and mounted, respectively prepared for simultaneous placing. The erector has to check and certify the load-bearing capacity and tight fastening of these construction elements.

For speedy execution of assembly a mobile crane with a minimum bearing capacity of 500 kg at jib end is required.

Furthermore safety barriers have to be provided at the free roof edges. Before start of work the site manager in charge has to make sure that suitable safety barriers are available.

Once all these conditions have been fulfilled, laying the roof system can be started:

The first arch element is clamped to the discharging fork, secured against wind effects and slewed to the respective location. There has to be an erector at each abutment in order to temporarily secure the element in its position after placing. The specified fasteners (clamping plates) are not yet finally tightened. At this stage the arch element still has to remain secured by the discharging fork. After exact adjustment of the arch element by means of a crane, a mounting aid (e.g. rope ladder) is placed on the arch. The third erector can now climb up to the crown an loosen the clamps of the discharging fork. As soon as the erector has climbed down the element again, the crane can freely slew the discharging fork and take up the next element. Now the bolts of the clamping plates can finally be tightened.

The next step after securing the second element to the fork is tuning it in to the mounting location. It is fixed to the abutments, the third worker climbs to the crown of the first element and, beginning at the center, he puts bolts into the overlapping trough and loosens the erection fork again. By tightening the bolts the second element can now be secured in its final position. Subsequently the mounting aid may be put onto the newly mounted second element.

The above stated assembly procedure is repeated with the following elements, whereby the exact adjustment of the arch skin should be checked at every third to fifth element.

This is continued up to the end of the hangar, respectively to possible strip-line lights. The width of strip-line lights generally corresponds to that of an arch element. If one element is left out for the subsequent insertion of a strip-line light, assembly has to be continued as described with the first element.

Sometimes static reasons may require placing half an arch element each along the edges of the strip-line lights for edge strengthening.

In between the roof skins that are separated by the strip-line light connecting sections spaced at approx. 2m are mounted at right angles to the strip-line lights. These prevent lateral deformation of the edges, which are strained by the loads on the strip-line light. Only then can the strip-line lights be placed (usually polycarbonate-double-web plates).

At single-skin roof systems the individual elements are connected by self-drilling sealing bolts at a recommended spacing of 3 pcs. per running meter (max. 500 mm) along their overlapping. The spacing of the connecting elements at the abutment has to be determined by means of a static calculation.

Once the roof system has been laid, all remaining finishing work, as for example mounting drains and sheet covers, can be carried out.

-) Assembly of the double-skin system:

Basically the future internal skin is placed as described above. Differences merely exist as regards:

-) Fixing devices: the individual elements are connected with sealing rivets instead of self-drilling sealing bolts.
-) Strip-line lights: the connecting sections at right angles to the strip-line light may be omitted, as their function is taken over by the spacer structure. Moreover, it might be necessary to place half an element each along the edges.

After mounting the internal skin the continuous use of a crane is not necessary any more. It is merely required for lifting the elements up to the roof level, but does not serve as safety device.

In order to guarantee a diffusion-tight internal skin the overlapping clearances of the internal skin have to be closed with diffusion-tight, aluminum steamed adhesive tapes after final riveting. Thereby also the rivet heads have to be covered by the sealing strap.

After mounting the internal skin, the spacer structures can be erected. As described in part A, these may either be executed as continuous buckled elements or as isolated stirrups with a longitudinal profile placed on top.

Starting from the abutment the hat profiles are mounted towards the crown spaced at 1.25-1.5 m.

If possible the clear spacing between the spacer structures should always correspond to the standard width of the insulating mats; thus insulating material need not be cut to size.

-) continuous spacer structure: it is recommended to cut insulating material to size on the ground before putting it into the hat profiles, to secure it properly with adhesive tapes and arrange transportation to the mounting location afterwards. The spacer structure is fastened to the internal skin by means of sealing rivets that connect the bottom flange to the top waves of the trapezoidal section

-) Isolated stirrups: attaching an isolated stirrup to every second top wave is sufficient when using Legato 40. Profile types Legato 70 and 107, however, require attached stirrups at every top wave.

After mounting the stirrups the longitudinal sections can be attached by means of self-drilling sunken head screws.

The next step is filling the stirrups resp. the space under the longitudinal profiles with prefabricated insulating material.

After mounting the hat profiles the trapezoidal sheet elements of the external skin and the insulating material may be lifted onto the roof. It is practical to lift up 5-10 trapezoidal sheet elements at once and to store them at a distance corresponding to the overall width of the elements. This is usually the last time a crane is required.

Immediately after laying the insulating material sealing bolts are used to attach the trapezoidal sheets to the spacers in the respective areas. Simultaneously drain eaves flashings and buckled elements have to be fitted in along the eaves.

The strip-line lights may be mounted at a later time.

The external skin of Legato 40 is bolted to the spacers at every second bottom wave. Exceptions are the profile along the crown and the spacer structures closest to the eaves. In this case each bottom wave has to be connected to the spacer structure.

The external skins of profiles 70 and 107 must be attached at every bottom wave.

Detailed fastening guidelines of System Legato can be found in chapter 16.

16. Fastening guidelines

16.1. Single-skin system

Fastening to abutment:

Clamping plates with sealing layer (weather resisting and heat-proof), bolts M12 resp. M16; bolt grade 8.8

Profile type	Every resp. every 2nd bottom wave	Distance	Diameter
LT 40	Acc. To statics	160 resp. 320mm	M12
LT 70	Every	187.5 mm	M12
LT 107	every	250 mm	M16

The hole pattern of the substructure must correspond to that of the trapezoidal sheet.

Connection of individual elements (longitudinal joints):

Special sealing bolts of A2 steel inclusive washer with vulcanized Neoprene layer; shaft with sheet cutting thread; minimum length 25 mm, diameter 6.5 mm

Spacing: 3 pcs/running meter recommended; max. 500 mm for all profile types

16.2. Double-skin system

Fastening of internal skin:

Fastening to abutment:

Clamping plates with or without sealing layer (weather resisting and heat-proof), bolts M12 resp. M16; bolt grade 8.8

Profile type	every resp. every 2^{nd} bottom wave	Distance	Diameter
LT 40	Acc. to statistics	160 resp. 320mm	M12
LT 70	every	187.5 mm	M12
LT 107	every	250 mm	M16

The hole pattern of the substructure must correspond to that of the trapezoidal sheet.

Connection of individual elements (longitudinal joints):

Sealing rivet min. 4.8/10 mm; aluminum.

Spacing: max. 500 mm for all profile types

The longitudinal joints must have joint- and rivet hole covering form and be diffusion-tight through aluminum steamed adhesive tapes (min. width 50 mm).

Fastening of the spacer structure to the internal skin:

Sealing rivet min. 4.8/10 mm; aluminum.

LT 70 and 107: on every top wave
LT 40: on every 2^{nd} top wave

Thermal separation on the spacer structures:

Spacer stirrups: Recycling plastic slat (Weight 900-950 kg/m^3) bolted 1x to every stirrup (SFS Stadler, type SC5/46-DS 12-5.5x60, self-drilling)

Fastening of the external skin to the spacer structures:

Sealing bolts of A2 steel inclusive of plain washer with vulcanized Neoprene layer; shaft with sheet cutting thread; minimum length 25 mm, diameter 6.5 mm
(On the spacer stirrups the minimum bolt length must be 35 mm.)

LT 70 and 107: on every top wave

LT 40: on the hat profile closest to the eaves and running alongside the crown on every, or otherwise every 2nd top wave

Connection of individual elements (longitudinal joints):

Special sealing bolts of A2 steel inclusive washer with vulcanized Neoprene layer; shaft with sheet cutting thread; minimum length 25 mm, diameter 6.5 mm

Spacing: 3 pcs/running meter recommended; max. 500 mm for all profile types

16.3.) Double-skin system for structural stability of up to 90 min resp. F30 fire resistance grading:

Fastening of the internal skin:

Fastening to abutment:

For erecting state fastening to the abutment sheet is carried out by means of sheet cutting bolts resp. mounting bolts (spacing according to static calculation).

The external skin acts as bearing skin. Thus the internal skin only needs to resist loads during erection and in case of fire it should prevent the thermal insulation from falling down.

Connection of individual elements (longitudinal joints):

Sealing bolts of 4.8/10 mm min., steel (aluminum resp. alloys with lower melting point than steel must not be used!).

Spacing: max. 500 mm for all profile types

The longitudinal joints must have joint- and rivet hole covering form and be diffusion-tight through aluminum steamed adhesive tapes (min. width 50 mm).

Fastening the spacer structure to the internal skin:

Sealing bolts 4.8/10 mm; steel.
LT 70 and 107: on every top wave
LT 40: on every 2nd top wave

Thermal separation on the spacer structures:

Spacer stirrups: Recycling plastic slat (Weight 900-950 kg/m^3) bolted 1x to every stirrup (SFS Stadler, type SC5/46-DS 12-5.5x60, self-drilling)

Zeman

Fastening of the external skin to the spacer structures:

Special sealing bolts of A2 steel inclusive of plain washer with vulcanized Neoprene layer; shaft with sheet cutting thread; minimum length 25 mm, diameter 6.5 mm

(On the spacer stirrups the minimum bolt length must be 35 mm.)

LT 70 and 107: on every top wave
LT 40: on the hat profile closest to the eaves and running alongside the crown of every, or otherwise every 2nd top wave

Connection of individual elements (longitudinal joints):

Special sealing bolts of A2 steel inclusive washer with vulcanized Neoprene layer; shaft with sheet cutting thread; minimum length 25 mm, diameter 6.5 mm

Spacing: 3 pcs/running meter recommended; max. 500 mm for all profile types.

17. Expert reports and lists of standards

Allowable variations:

[40] DIN 18 807 Teil 1: Stahltrapezprofile; Allgemeine Anforderungen, Ermittlung der Tragfähigkeitswerte durch Berechnung

[41] Bauelemente aus Stahlblech; Gütesicherung; RAL-GZ 617

[42] ÖNORM DIN 18 202; Toleranzen im Hochbau, Bauwerke

[43] ENV 1090; Ausführung von Tragwerken aus Stahl

Quality control:

[44] Bauelemente aus Stahlblech; Gütesicherung; RAL-GZ 617

Guidelines for assembly:

[45] IFBS Richtlinie 8.01: Richtlinie für die Montage von Stahlprofiltafeln für Dach-, Wand-, und Deckenkonstruktionen

D. Appendix

18. Tables

18.1. Legato 40

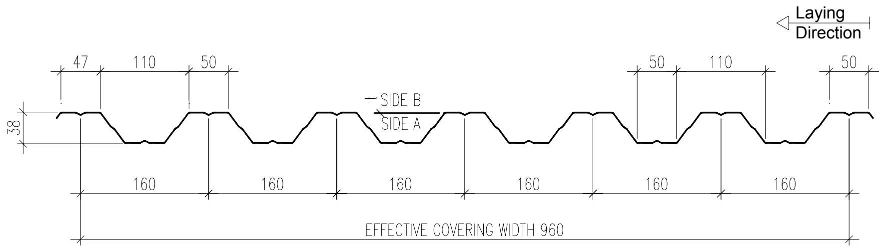


Table 18.1.1: Minimum radii

Profile type	Steel grade	Material thickness [mm]	Minimum radius [m]
Legato 40	Fe E 280 G	0.75	8.00
		0.88	6.00
		1.00	4.50
		1.25	4.00
		1.50	4.00
	(Fe E 250 G) not included in standard delivery program	0.75	(5.00)
		0.88	(3.00)
		1.00	(2.50)

Additional the radius should not be smaller than 75% of the span

Table 18.1.2: Section properties (all Fe E 280 G)

Sheet thickness	Rigidity and tension					Pressure and bending				
mm	A_g cm^2/m	I_g cm^4/m	i_g cm	e_o cm	e_u cm	A_{ef} cm^2/m	i_{ef} cm	I_{ef} cm^4/m	$W_{o,ef}$ cm^3/m	$W_{u,ef}$ cm^3/m
0.75	8.87	20.49	1.52	1.88	1.88	7.78	1.53	20.36	10.83	10.83
0.88	10.49	24.24	1.52	1.88	1.88	9.55	1.53	24.09	12.81	12.81
1.00	11.99	27.70	1.52	1.88	1.88	11.20	1.52	27.53	14.64	14.64
1.25	15.11	34.91	1.52	1.88	1.88	14.69	1.52	34.69	18.45	18.45
1.50	18.23	42.12	1.52	1.88	1.88	18.23	1.52	41.89	22.26	22.26

Table 18.1.3: Characteristic resistance forces

Steel grade	Sheet thickness t[mm]	Resistance for axial force [kN/m]		Resistance for bending moment $M_{R,k}$ [kNm/m]
		$N_{R,k\ tension}$	$N_{R,k\ pressure}$	
Fe E 280 G $f_{y,k}$ = 280 N/mm²	0.75	248.36	217.84	2.94
	0.88	293.72	267.40	3.54
	1.00	335.72	313.60	4.10
	1.25	423.08	411.32	5.16
	1.50	510.44	510.44	6.23

18.2. Legato 70

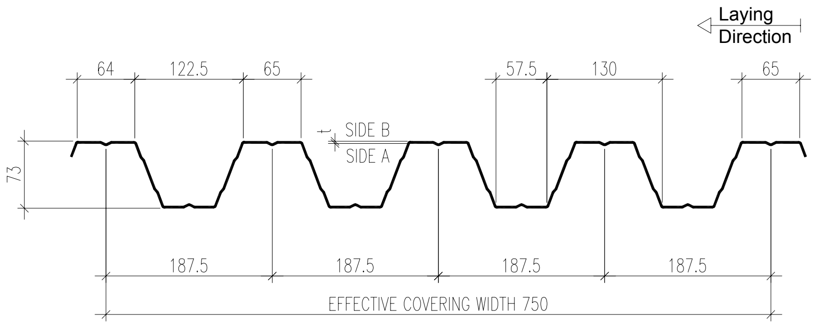


Table 18.2.1: Minimum radii

Profile type	Steel grade	Material thickness [mm]	Minimum radius [m]
Legato 70	**Fe E 320 G**	0.75	12.0
		0.88	10.0
		1.00	8.0
		1.25	8.0
		1.50	8.0

Additional the radius should not be smaller than 75% of the span

Table 18.2.2: Section properties (all Fe E 320 G)

Sheet thickness mm	Rigidity and tension					Pressure and bending				
	A_g cm²/m	I_g cm⁴/m	i_g cm	e_o cm	e_u cm	A_{ef} cm²/m	i_{ef} cm	I_{ef} cm⁴/m	$W_{o,ef}$ cm³/m	$W_{u,ef}$ cm³/m
0.75	10.98	86.08	2.80	3.65	3.65	6.95	2.97	85.97	23.44	23.23
0.88	12.99	101.84	2.80	3.65	3.65	8.96	2.92	101.72	28.19	27.48
1.00	14.84	116.35	2.80	3.65	3.65	10.89	2.89	116.25	32.63	31.41
1.25	18.71	146.69	2.80	3.65	3.65	14.99	2.86	146.52	41.80	39.58
1.50	22.57	176.95	2.80	3.65	3.65	19.20	2.84	176.79	50.63	47.76

Table 18.2.3: Characteristic resistance forces

Steel grade	Sheet thickness t[mm]	Resistance for axial force [kN/m]		Resistance for bending moment $M_{R,k}$ [kNm/m]
		$N_{R,k\ tension}$	$N_{R,k\ pressure}$	
Fe E 320 G $f_{y,k}$ = 320 N/mm²	0.75	309.40	219.80	6.57
	0.88	365.96	279.72	7.78
	1.00	418.04	336.00	8.89
	1.25	526.96	455.00	11.20
	1.50	635.88	576.52	13.52

18.3. Legato 107

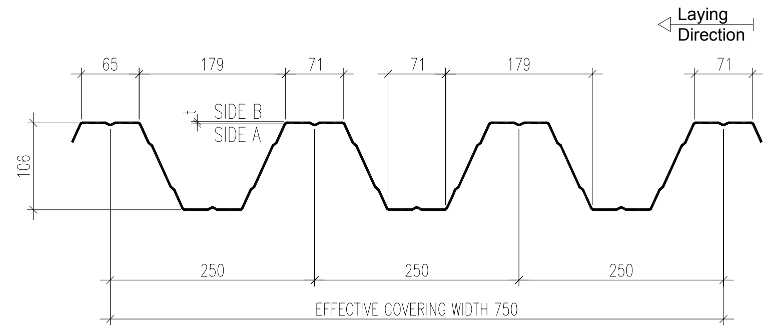


Table 18.3.1: Minimum radii

Profile type	Steel grade	Material thickness [mm]	Minimum radius [m]
Legato 107	Fe E 280 G	0.75	50.0
		0.88	28.0
		1.00	15.0
		1.25	11.0
		1.50	10.0
	Fe E 250 G	0.75	20.0
		0.88	13.0
		1.00	12.0

Additional the radius should not be smaller than 75% of the span

Table 18.3.2: Section properties (0.75 and 0.88 mm Fe E 250 G, all others Fe E 280 G)

Sheet thickness	Rigidity and tension					Pressure and bending				
mm	A_g cm^2/m	I_g cm^4/m	i_g cm	e_o cm	e_u cm	A_{ef} cm^2/m	i_{ef} cm	I_{ef} cm^4/m	$W_{o,ef}$ cm^3/m	$W_{u,ef}$ cm^3/m
0.75	11.81	182.7	4.00	5.30	5.30	9.01	4.20	182.4	34.43	34.43
0.88	13.12	209.9	4.00	5.30	5.30	9.35	4.31	209.6	39.55	39.55
1.00	14.99	239.8	4.00	5.30	5.30	10.83	4.28	239.5	45.19	45.19
1.25	18.90	302.4	4.00	5.30	5.30	15.01	4.18	301.9	56.96	56.96
1.50	22.80	364.8	4.00	5.30	5.30	19.47	4.10	364.3	68.74	67.74

Table 18.3.3: Characteristic resistance forces

Steel grade	Sheet thickness t[mm]	Resistance for axial force [kN/m]		Resistance for bending moment
		$N_{R,k\ tension}$	$N_{R,k\ pressure}$	$M_{R,k}$ [kNm/m]
Fe E 250 G $f_{y,k}$ = 250 N/mm^2	0.75	212.62	162.21	6.17
	0.88	328.00	233.75	9.55
Fe E 280 G $f_{y,k}$ = 280 N/mm^2	1.00	419.72	303.24	12.23
	1.25	529.20	420.28	15.87
	1.50	638.40	545.16	19.25

18.4. Ultimate spans of arched profiles (informative only, does not replace static calculation)

Values stated below were determined under the following conditions:

- -) closed building
- -) span/radius ratio = 1/1
- -) eaves height of building: 6.0 m above ground
- -) snow load 0.75 kN/m^2 resp. 1.00 kN/m^2
- -) wind forces: v_{10}=125 km/h; Terrain category II => q=0.57 kN/m^2
- -) load assumptions according to Austrian Standards
- -) determination of internal forces and moments according to DIN 18 800
- -) design according to DIN 18 807 and “Anpassungsrichtlinie Stahlbau” May 1996

Single-skin arch

Table 18.4.1: Ultimate spans - single-skin arch

Profile type	Sheet thickness [mm]	s_o=0,75 kN/m^2 Ultimate span [m]	s_o=1,00 kN/m^2 Ultimate span [m]
Legato 40	0.75	8.75	7.75
	1.00	9.75	8.50
	1.25	10.50	9.50
Legato 70	0.75	13.50	12.25
	1.00	15.00	13.50
	1.25	16.50	15.00
Legato 107	0.75	15.50 *)	14.00 *)
	1.00	18.50	16.50
	1.25	20.00	18.75

*) In this case the radius is 20.0 m (minimum radius), the Span/Radius ratio is not 1/1.

Double-skin arch

In addition to the above stated load applications the loads at assembly (only the lower bearing skin can be used for load transfer) have to be considered.

Loads at assembly can be compensated by means of the dead load of the arch and a imposed load of 1.5kN at four-point (most unfavorable position of load on the arch).

The skins are spaced at 130 mm (hat profile height). Different profile types are not practicable for bearing resp. covering skin. (different laying width; not useful from static point of view)

Table 18.4.2: Ultimate spans double-skin arch

Profile type	Sheet thickness [mm]	s_o=0.75 kN/m^2 Ultimate span [m]	s_o=1.00 kN/m^2 Ultimate span [m]
Legato 40+40	0.88+0.75	13.00 **) (16.00)	13.00 **) (15.00)
	1.25+0.88	14.25 **) (17.50)	14.25 **) (15.75)
Legato 70+70	0.88+0.75	20.00	20.00
Legato 107+107	0.88+0.75	20.00	20.00

**) In these cases the load at assembly is relevant. The values in parenthesis might be achieved by the finished double-skin system.

18.5. Hat profiles

Table 18.5.1: Moments of inertia and characteristic ultimate shear forces of the continuous hat profile determined by tests; fastening in every wave

Arch profiles		Calculated height[cm]	Per hat profile	
Bearing skin	Covering skin		I_{Hk} [cm^4/m]	T_{Hk} [kN/m]
LT 40/0.88	LT 40/0.75	17.12	0.9	12.5
LT 40/1.25	LT 40/1.00	17.12	1.0	
LT 70/0.88	*LT 70/0.75*	*20.02*	*1.2*	7.0
LT 70/1.50	*LT 70/1.25*	*20.02*	*1.5*	
LT 107/0.88	LT 107/0.75	23.49	1.5	
LT 107/1.50	LT 107/1.25	23.49	2.0	

Table 18.5.2: Moments of inertia and characteristic ultimate shear forces of the isolated stirrups with plastic slat determined by tests; fastening in every wave

Arch profiles		Calculated height[cm]	Per hat profile	
Bearing skin	Covering skin		I_{Hk} [cm^4/m]	T_{Hk} [kN/m]
LT 40/0.88	LT 40/0.75	18.10	1.17	11.2
LT 40/1.00	LT 40/0.75	18.10	1.17	14.5
LT 70/0.88	*LT 70/0.75*	*21.02*	*1.9*	*11.0*
LT 70/1.00	*LT 70/0.75*	*21.02*	*1.9*	*13.0*
LT 107/0.88	LT 107/0.75	24.70	2.6	10.9
LT 107/1.00	LT 107/0.75	24.70	2.6	12.1

For profile types in *italics* no tests were carried out. Above stated values are average values of the types LT 40 and LT 107.

Calculated height: fictitious bar length (spacing of centroids of skins)
I_{Hk}: imaginary moments of inertia (determined in tests)
T_{Hk}: ultimate shear force (determined in tests)

At bearing capacity tests the hat profiles resp. stirrups were fastened to every wave by means of sealing rivets.

18.6. Clamping plates

Clamping plates with sealing layer (weather resisting and heat proof) bolts M12 resp. M16; bolt grade 8.8

Table 18.6.1 Clamping plates

Profile type	Every resp. every 2nd bottom wave	Distance	Diameter
LT 40	Acc. to statics	160 resp. 320mm	M12
LT 70	every	187.5 mm	M12
LT 107	every	250 mm	M16

Table 18.6.2 Carrying capacity of clamping plates

Profile type	Every resp. every 2nd bottom wave	Carrying capacity min. T_{Rd} [kN/m]
LT 40	every	40,6
	every 2nd	20,3
LT 70	every	34,2
LT 107	every	40,3

The carrying capacity is depending on the thickness of the trapezoidal sheet, the prestress of the screws, the sealing layer and the kind of clamping plate (steel or cast iron). The above mentioned values are minimal values and it is possible to increase the carrying capacity by means of appropriate measures.

18.7. Bearing shoes

Table 18.7.1: Bearing capacity of supporting structure (bearing shoes)

Substructure	Design value T_{Rd} of resistance in [kN] (per bearing shoe)
Steel	86 kN
concrete B300 without load-spreading plates Jordahl anchor channel K 40/22/2.5	18 kN
Beton B300 with load-spreading plates Jordahl anchor channel K 40/22/2.5	23 kN

19. List of expert reports and standards

<u>Expert reports and standards for Part A (general part):</u>

Expert reports on construction physics:

[1] Physikalisch-Technische Versuchsanstalt am TGM Wien : Gutachten 6881/WS; Wärmeschutz einer zweischaligen Konstruktion aus Trapezprofilen; TGM ZL.: 1384/1/87; 23.10.1987

[2] Physikalisch-Technische Versuchsanstalt am TGM Wien : Gutachten 9260/WS; Wärmeschutz einer zweischaligen Konstruktion aus Trapezprofil Stahlblech; TGM ZL.: 1301/95; 22.1.1996

[3] Physikalisch-Technische Versuchsanstalt am TGM Wien : Gutachten 9880/WS; Luftschallschutz einer Dachkonstruktion aus Trapezblechen; TGM ZL.: 1348/87; 6.10.1987

Expert reports and standards on fire resistance:

[4] Institut für Brandschutztechnik und Sicherheitsvorschung: BV-Zahl 3612/96; Untersuchung des zweischaligen Bogendaches mit Einzelbügel und darüberliegender Kunsstoffleiste; 8.7.96

[5] Institut für Brandschutztechnik und Sicherheitsvorschung: BV-Zahl 2749/87; Untersuchung des zweischaligen Bogendaches mit durchlaufenden Hutprofilen; 10.7.87

[6] ÖNORM B3800 Teil 2:Brandverhalten von Baustoffen und Bauteilen

Corrosion protection:

[7] DIN EN 10 147; Kontinuierlich feuerverzinktes Blech und Band aus Baustählen

[8] DIN 18 807, Teil 1; Stahltrapezprofile, Allgemeine Anforderungen, Ermittlung der Tragfähigkeitswerte durch Berechnung

[9] DIN 55928-8; Korrosionsschutz von tragenden dünnwandigen Bauteilen

<u>Expert reports and standards of part B (static part):</u>

Loading and structural analysis:

[10] ENV 1991: Grundlagen der Tragwerksplanung und Einwirkungen auf Tragwerke

[11] ÖNORM B 4012: Belastungsannahmen im Bauwesen, Veränderliche Einwirkungen, Nutzlasten

[12] ÖNORM B 4013: Belastungsannahmen im Bauwesen, Schnee- und Eislasten

[13] ÖNORM B 4014-1: Belastungsannahmen im Bauwesen, Statische Windwirkungen (nicht schwingungsanfällige Bauwerke)

[14] Bundesversuchs- und Forschungsanstalt Arsenal: Bericht über Windkanalversuche an Modellen von Flugdächern; 1987

[15] Österreichisches Normungsinstitut, FNA 176 (Belastungsannahmen im Bauwesen): Interpretation der Lastnorm B 4012; 1996

[16] DIN 18 800 Teil 2 (11.90): Stabilitätsfälle, Knicken von Stäben und Stabwerken

Design:

[17] DIN 18 807 Teil 1-3: Stahltrapezprofile

[18] Mitteilungen des Deutschen Instituts für Bautechnik; Anpassungsrichtlinie Stahlbau; Mai 1996

[19] ENV 1993-1-3: Bemessung und Konstruktion von Stahlbauten, Allgemeine Bemessungsregeln- Ergänzende Regeln für kaltgeformte dünnwandige Bauteile und Bleche

[20] o.Univ.Prof.DI.Dr.techn. F. Resinger, ao.Univ.Prof.DI.Dr.techn. R. Greiner: Bericht über die Tragfähigkeitsuntersuchung gekrümmter Trapezprofile; Technische Universität Graz 16.2.1987

[21] o.Prof.Tekn. dr R. Baehre: Untersuchung des Tragverhaltens von gekrümmten Trapezprofilblechen; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 15.1.87

[22] o.Univ.Prof.DI.Dr.techn. R. Greiner: Versuche zur Bestimmung der Tragschubkraft und Nachgiebigkeit der Hutprofile in zweischaligen Bogendachkonstruktionen; Technische Universität Graz 12.6.91

[23] Univ.Prof.Dr.-Ing. H. Saal: Experimentelle Untersuchung zur Ermittlung der Tragfähigkeit und Verformbarkeit von Hutprofilen in zweischaligen Bogendachkonstruktionen; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1995

[24] Univ.Prof.Dr.-Ing. H. Saal: Ermittlung der Schubtragfähigkeits- und Schubsteifigkeitswerte von zweischaligen Bogendachkonstruktionen; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1995

[25] o.Univ.Prof.DI.Dr.techn. R Greiner: Versuche zur Bestimmung der Tragfähigkeit der Auflagerelemente des Bogendaches mit Ergänzungsbericht; Technische Universität Graz 1992 und 1993

[26] DI. W. Radhuber: Versuchsbericht über Traglastversuche für ein Widerlager; Wernberg 2.12.85

[27] Univ.Prof.Dr.-Ing. H.Saal: Untersuchung des Tragverhaltens von gekrümmten Stahltrapezprofilen TRE 106; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1994

[28] Univ.Prof.Dr.-Ing. H.Saal: Untersuchung des Tragverhaltens von gekrümmten Stahltrapezprofilen TRE 40; Versuchsanstalt für Stahl Holz und Steine der Universität Karlsruhe 1994

[29] DI. E. Gartner: Schubeinleitung in Trapezbleche unter besonderer Berücksichtigung der Klemmplatten; Wien 2001

Material:

[30] DIN EN 10 147: Kontinuierlich feuerverzinktes Blech und Band aus Baustählen, Technische Lieferbedingungen

<u>Standards of part C (production and assembly):</u>

Allowable variations:

[40] DIN 18 807 Teil 1: Stahltrapezprofile; Allgemeine Anforderungen, Ermittlung der Tragfähigkeitswerte durch Berechnung

[41] Bauelemente aus Stahlblech; Gütesicherung; RAL-GZ 617

[42] ÖNORM DIN 18 202; Toleranzen im Hochbau, Bauwerke

[43] ENV 1090; Ausführung von Tragwerken aus Stahl

Quality control:

[44] Bauelemente aus Stahlblech; Gütesicherung; RAL-GZ 617

Guidelines for assembly:

[45] IFBS Richtlinie 8.01: Richtlinie für die Montage von Stahlprofiltafeln für Dach-, Wand-, und Deckenkonstruktionen