

Long Carbon Europe
Sections and Merchant Bars

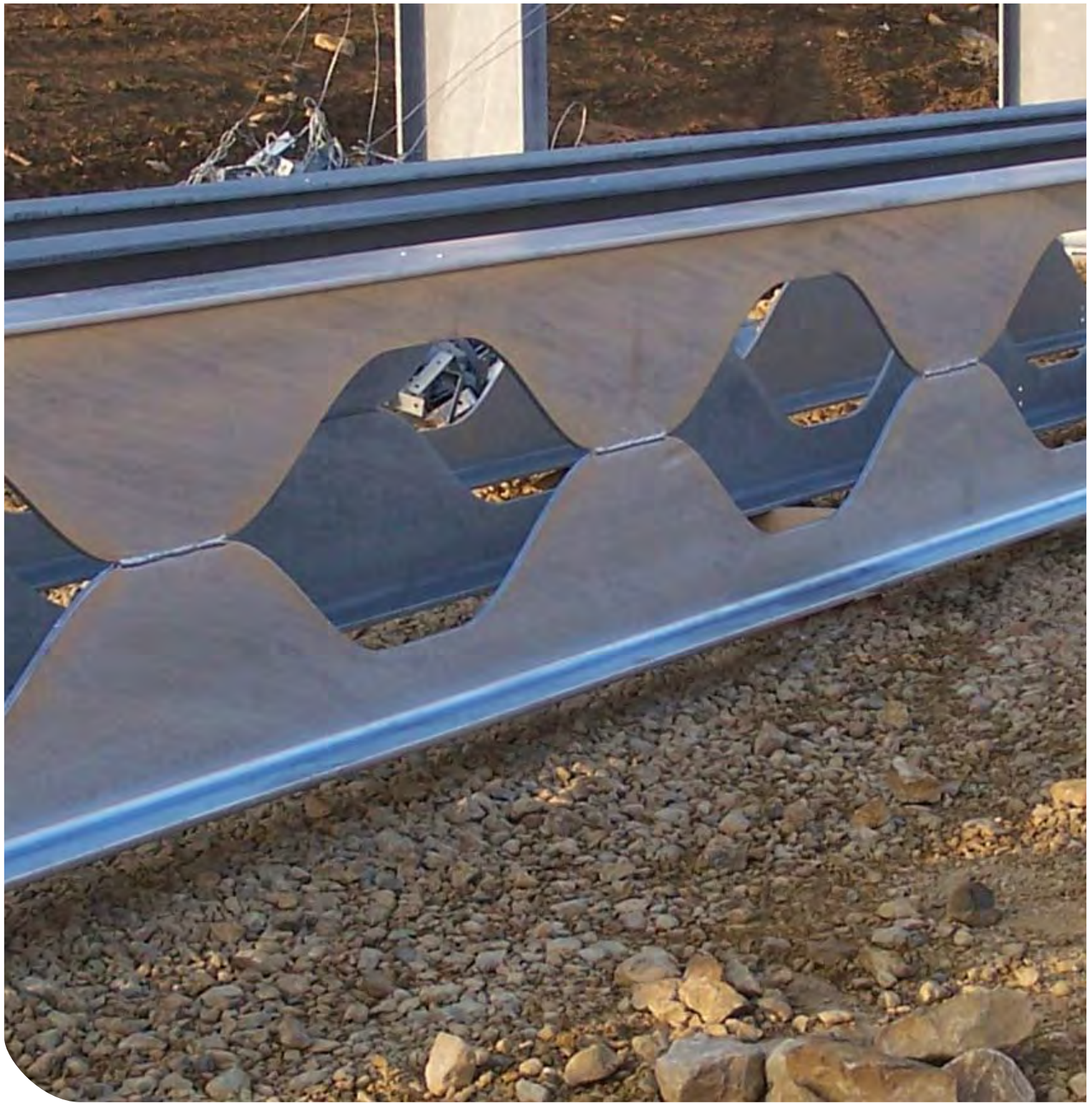


ArcelorMittal

Angelina™ beams

A new generation of castellated beams





The intelligent solution
for long spans

Contents

1. Introduction	3
2. Application fields	4
3. Concept – fabrication	6
4. Tolerances of Angelina™ beams	10
5. Angelina™ beams in roofing and metal decking applications	12
6. Angelina™ beams in composite floor application	17
7. Stability in fire and fire safety	21
8. Angelina™ Predesign charts	22
9. Predesign charts: design examples	30
10. Angelina™ beams: a solution for sustainable development	32
Technical Advisory & Finishing	35
Your partners	35



1. Introduction

The use of Angelina™ beams allows a new architectural expression. Structures are lightened and spans increased, thus open spaces by increased size of column-free floor areas.

This flexibility goes together with the functionality of allowing technical installations (pipes and ducts) to pass through the openings. The lightweight appearance of Angelina™ beams, combined with their high strength, stimulates the architects to new structural forms.

Progress has now been made on a number of factors that enable the use of Angelina™ beams to be extended:

• Manufacturing

The optimization of manufacturing methods (flame cutting, bending, etc.) now makes it possible to adapt to the requirements of project owners and guarantee rapid delivery of Angelina™ beams. Highly available hot-rolled beams in steel grades up to high strength steel S460 are used for a cost-effective fabrication.

• Standardization

The Eurocodes (Eurocode 3 for steel structures and Eurocode 4 for composite structures) provide answers to the calculation of strength in normal use, for fire accident situations and with regard to the use of S460 high strength steel.

• Composite construction

The consideration of the various aspects of composite steel and concrete construction – making the bond, use of linked trays, floating plates, fire resistance, user comfort and durability – has greatly contributed to the “Angelina™ beams” solution in floors.

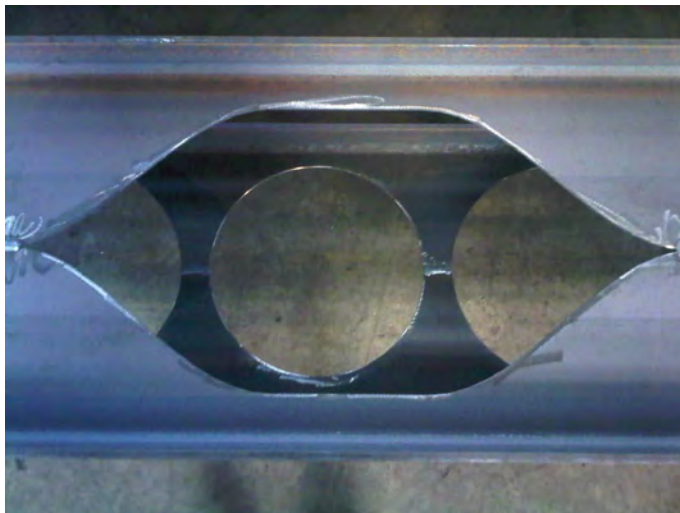
• Predesign tools

The development of a high-performance design and calculation tool (Angelina™ software), available to design offices and architects, favors the use of Angelina™ beams. The methods adopted in this software exploit the results of tests on full-size beams and of numerous numerical simulations. The implemented methods allow the optimization of weight (through section size, opening depth, width and distance) and steel grade adapted to the project's requirements. This optimization leads to the highest reduction of material consumption and cost.

• Intelligent use

The use of Angelina™ beams simplifies the construction process while keeping the structural elegance. No further time and effort is needed for the lay-out of building services during construction. The arrangement of pipes, ducts and electricity takes full advantage of the existing openings in the floor beam's web. Thereby the Angelina™ beams allow easily future modifications and retrofitting of building services without changes to the frame structure.

Size comparison of web opening between cellular and Angelina™ beams



2. Application fields

1. Roofing

The use of Angelina™ as roofing elements enables large spans, of about up to 40 meters, to be covered. The competitiveness of the Angelina™ solution is confirmed both by the retention of the functionalities of truss girders and by the reduction of on-site interventions for assembly.

Angelina™ beams offer architects attractive and practical solutions in terms of use of space without screening effect. The height of the openings can reach 80 % of the total height of the beam and it is possible to leave only a small distance – required for fabrication – between the openings.

This configuration of Angelina™ beams enables their transparency and blending into the space enclosed to be accentuated, which has great appeal for architects.

2. Decking

Modern constructions increasingly demand the accommodation of technical installations (heating, ventilation, air conditioning, etc.) within the available space enclosed.

The use of Angelina™ beams now provides effective solutions to the demands of project owners. This solution allows large column-free floor areas over a distance up to 18 meters and allows various pipes and ducts to be passed through the openings of the beams.

The total floor thickness is 25 to 40 cm less than that of conventional solutions. For current buildings, with an imposed height of the order of 35 to 40 meters, a gain of only 20 cm in floor thickness enables an additional floor to be installed. For buildings with a required number of floors (from two to six floor levels), the gain results from the economy in façades, columns, stabilizing structures, separating walls and vertical access walls.

Figure 1: Angelina™ roof beam



Figures 2 and 3: Angelina™ floor beams



3. Special applications

3.1. Renovation

In order to preserve the architectural heritage, light and flexible structures based on Angelina™ beams are used to strengthen, reuse and modernize old buildings.

3.2. Beams in car parks

There are four reasons for recommending the use of Angelina™ beams for building car parks even if special fire resistance is required:

- the traditional spans (15 to 16 m) are within the typical range,
- drainage is facilitated by slightly cambered beams,
- the openings improve the interior appearance of these structures allowing the natural light passing through the web,
- the openings facilitate smoke evacuation and permit better air circulation between sections.

3.3. Galvanization

Structural steels from ArcelorMittal are typically delivered with a Si content ranging between 0.14% and 0.25%, and are as such capable of forming a zinc layer during hot-dip galvanization. As the phosphorus content is usually lower than 0.035%, it does not have any influence on final thickness of the coating in the considered Si range. Additional tests have been performed to quantify the effect of the welding procedure between the two T-sections. No significant effect of the welding on the hot-dip galvanization process could be observed.

3. Concept – fabrication

Angelina™ beams are fabricated in modern installations on the site of ArcelorMittal's rolling mill for heavy sections at Differdange (Luxembourg). The proximity of these installations limits transport, maximizes responsiveness and contributes to the competitiveness of the manufacturing costs.

The patented method used for the fabrication of Angelina™ beams is based on the exclusive use of hot rolled sections.

A single cut following a specific sinusoidal line is made in the web by flame cutting. The two obtained T-sections are shifted and rewelded, leading to an increase in height (fig 4).

The structural product thereby obtained has an increased ratio of moment of inertia to weight.

The cutting process is digitally controlled in order to obtain perfect matching of the openings (fig 5).

It can be seen clearly from the diagrams that the weld line is limited. The weld seams are inspected visually or, on request, according to the project owner's or customer's own specifications.

Figure 4: Diagram of the fabrication of an Angelina™ beam

Stage 1:
flame cutting



Stage 2:
separation of T-sections



Stage 3:
re-assembly & welding



Figure 5: Flame cutting table for hot rolled sections



Fabrication of Angelina™ beams

1. Choice of size and spacing of openings

For a given starting section, there are endless possible combinations of opening sizes and spacings (fig 6). The choice is subject to the following principle.

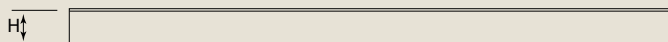
A final adjustment of the openings geometry allows an even more economical fabrication if it enables welding of the first and the last web post without fillings.

Figure 6: Definition of an Angelina™ beam

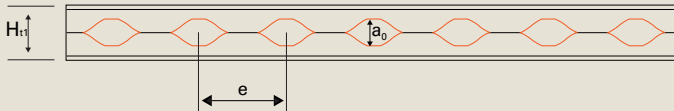
Objective 1:

Optimization of the load/weight ratio

Starting section (height h)



Design type 1



$$\begin{aligned} a_0 &= 1,0 \text{ to } 1,3 \, h \\ e &= 1,1 \text{ to } 1,3 \, a_0 \\ H_{t1} &= 1,4 \text{ to } 1,6 \, h \end{aligned}$$

Applications:

Floors
Car parks
Offshore structures

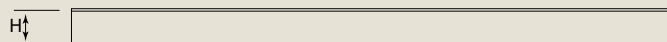
Common steel grades:

S355, S460, H12AR460

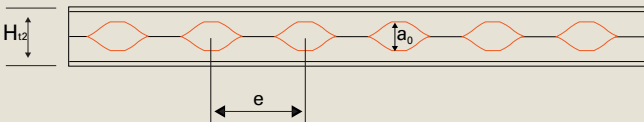
Objective 2:

Optimization of the height/weight ratio

Starting section (height h)



Design type 2



$$\begin{aligned} a_0 &= 0,8 \text{ to } 1,1 \, h \\ e &= 1,2 \text{ to } 1,7 \, a_0 \\ H_{t2} &= 1,3 \text{ to } 1,4 \, h \end{aligned}$$

Applications:

Roofing
Gangways/footbridges
Wide-span purlins

Common steel grades:

S235, S275, S355

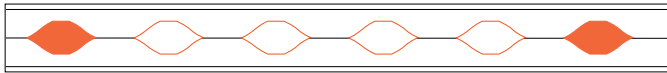


2. Reinforcement of openings

2.1 Filling of openings

In order to support high shear forces close to the supports or for reasons of fire safety, sometimes it becomes necessary to fill certain openings (fig 7). This is done by inserting discs made of steel plates and welding from both sides. The thickness of the plate and the weld seam are optimized according to the local stresses.

Figure 7: Example of Angelina™ beam with filled openings



2.2 Stiffeners

If, for aesthetic reasons, the opening must be maintained, a stiffener welded around the opening can be used to increase the rigidity (fig 8).

Figure 8: Example of Angelina™ beam with stiffened opening



2.3 Reinforcement

The criterion of satisfactory performance at the service limit state requires adequate flexural rigidity to reduce deformations and vibrations. Structural frames with Angelina™ beams can be optimized by increased inertia combined with a reduced web thickness favoring the use of IPE and IPE A sections. Four classical solutions can be considered:

- filling the openings, which can present a problem in the loss of free passage,
- stiffened openings to maintain free passage,
- choose a stronger section,
- choose a higher steel grade to increase the load bearing capacity.

2.4 Supporting concentrated loads

Local plastic deformation on the transverse diameter of an opening (usually isolated openings close to concentrated loads or at points of maximum stress) can be avoided by stiffeners as described in 2.2 (fig 8).

3. Welding work

Welding work is carried out by welders qualified in accordance with the European standard EN 287-1 for the MAG 135 and MAG 136 processes. Butt welding is used for standard Angelina™ beams. The weld thickness generally does not require full penetration welding.

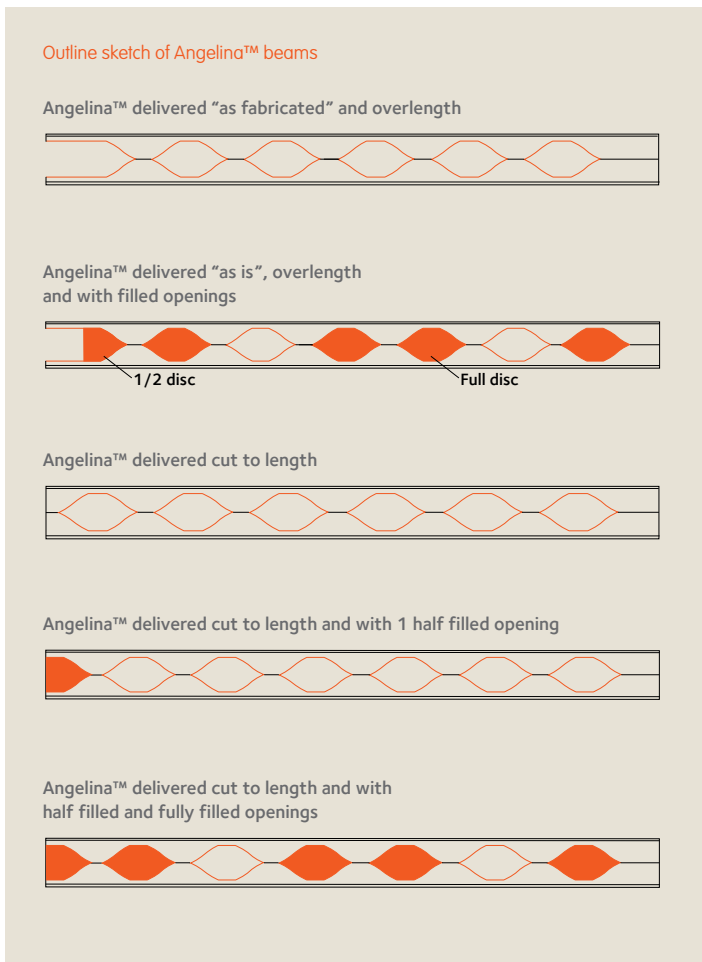
A series of tests has been carried out to validate the model used in the Angelina software. This model can be used to calculate the required weld thickness to resist the defined stresses.



4. Types of fabrication

Examples of Angelina™ beams that can be ordered are shown in figure 9.

Figure 9: Possibilities for the supply of Angelina™ beams

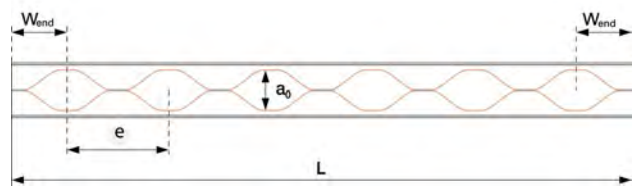


5. Connecting of Angelina™ beams

When designing the framework, special care should be given to the positions of the openings in order to avoid unnecessary filling (fig 10).

- The first step is to optimize the beam from a structural point of view.
- The second step is to adjust the spacing between openings so as to have a complete web at the ends of the beam.

Figure 10: Optimisation of positions of openings



6. Making assembly joints

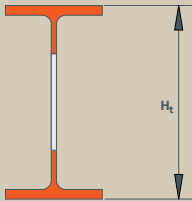
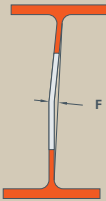
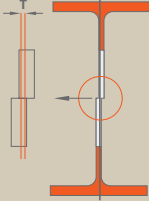
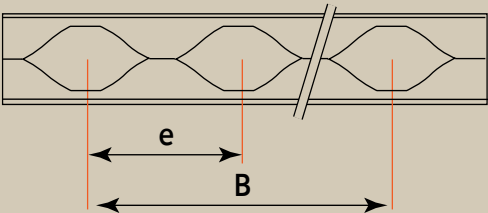
During design, the spacing of the openings and the abutments must take into account the presence of assembly joints and their correct execution. For those cases where it is required to fill or partially fill one or two openings, partial filling is easy and economical (fig 11).

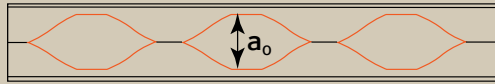
Figure 11: Examples of partially filled openings to allow for assembly joints



4. Tolerances of Angelina™ beams

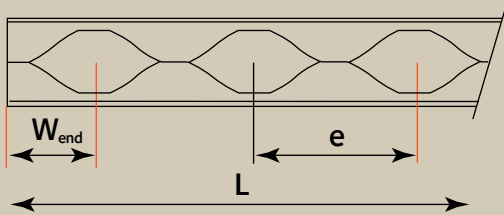
Angelina™ tolerances

	<p>Final Angelina™ height: H_t</p>	$H_t < 600$ $600 \leq H_t < 800$ $H_t \geq 800$	$+ 3 / - 5 \text{ mm}$ $+ 4 / - 6 \text{ mm}$ $+ 5 / - 7 \text{ mm}$
	<p>Bending of web: F</p>	$H_t \leq 600$ $H_t > 600$	$F \leq 4 \text{ mm}$ $F \leq 0,01 H_t$
	<p>Misalignment of T-sections: T (between axis of upper section and axis of lower section)</p>		$T \leq 2 \text{ mm}$
	<p>Spacing: e Distance from first to last opening: B</p>		$+ / - 0,01 e$ $+ / - 0,02 e$



Opening: a_o

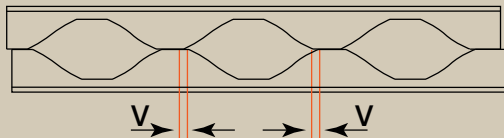
+ 5 / - 2 mm



Length: L
Distance of 1st
opening from end: W_{end}

+ / - 2 mm

+ / - 0,02 e



Offset of risers: V

$V \leq 0.03 \% L$
Example :
If $L = 10000 \text{ mm}$ $V \leq 3 \text{ mm}$

5. Angelina™ beams in roofing and metal decking applications

The Angelina™ beams used in metal roofs and decks are double symmetrical sections; the upper member and lower member are from the same parent section (fig 12).

Architects and engineers have a large choice of possible opening height and spacings. From these two values, the starting section can be determined and the final height of the Angelina™ beam can be deduced.

The process can also be reversed: from a required final height and opening dimensions, the designer can easily determine the starting section required to satisfy this configuration.

1. Design help

As for the rolled sections, it is essential to base the design of a project in Angelina™ beams on criteria and limits that make the best use of the performance offered by this type of element.

1.1. Choice of the height of the Angelina™ beam

The height, H_t , of the Angelina™ beam is determined as a function of (fig 13):

- the span (L) and the beam spacing (B),
- the load density (use for roofing or steel decking),
- the use of the Angelina™ beams as main beams (situation A) or secondary beams (situation B),
- the deformation criteria (limit of deformation for standard situations or for a particular project).

Figure 12: Make-up of a symmetrical Angelina™ beam

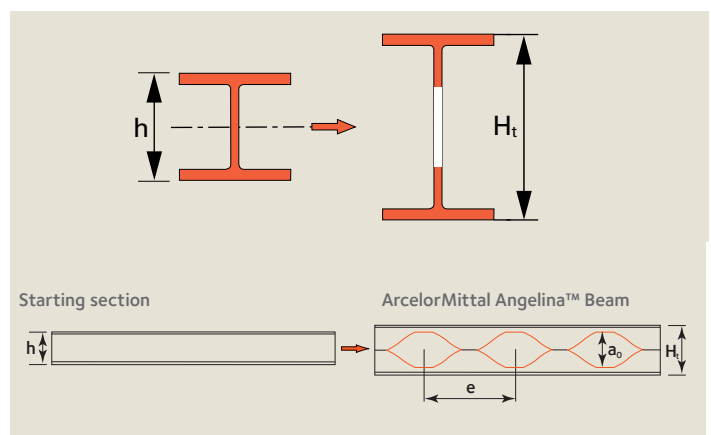
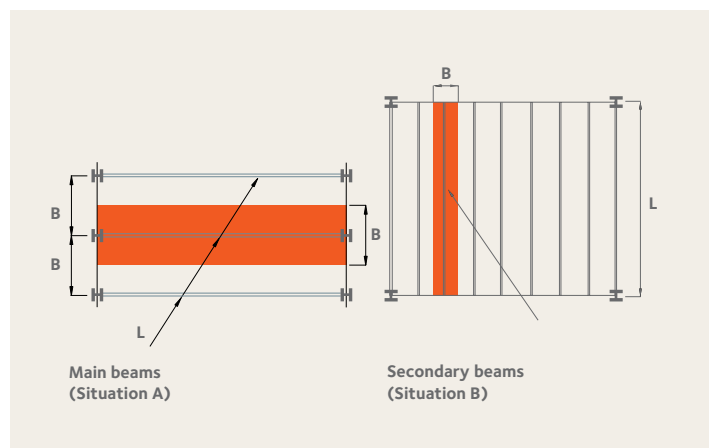


Figure 13: Use of Angelina™ beams in decks

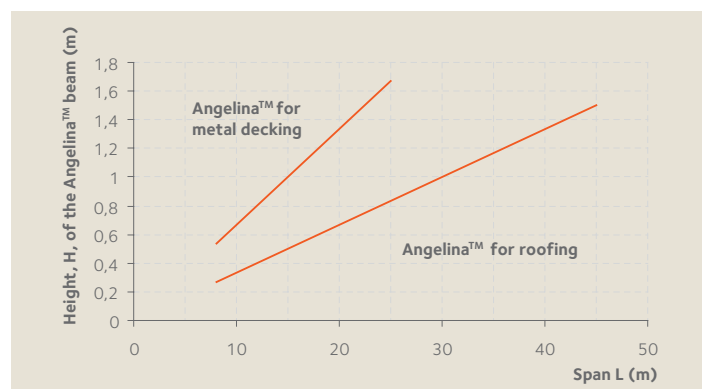




For standard roof projects, the beams can have a slenderness (span/height ration of the beam) from 20 to 40 depending on the support conditions.

An intermediate value of 30 can be used as a starting point for secondary beams and for the fixed beams of frames (fig 14).

Figure 14: Height of the Angelina™ beam as a function of the span



For floor beams of buildings, the slenderness varies between 10 and 20.

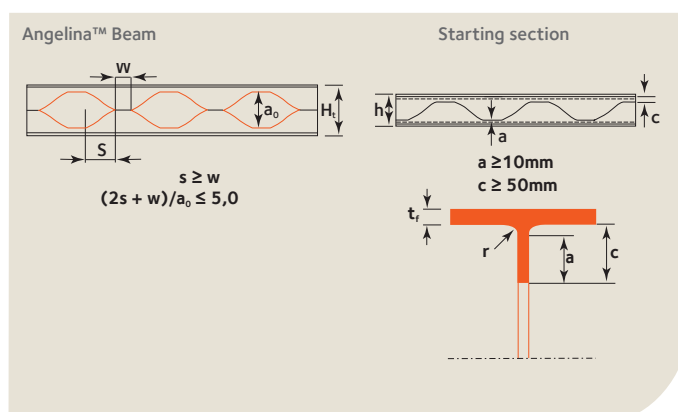
For normal working loads, an intermediate value of 15 can be used as a starting point for design.

1.2. Choice of height and spacing of openings

The choice of the height and the spacing of the openings is normally guided by architectural requirements (transparency and light effect) and functional requirements (passage of services through the openings).

However, there are geometric limits to be respected for good mechanical behaviour of the Angelina™ beam. These limits apply to:

Figure 15: Geometric limits on the openings in Angelina™ beams

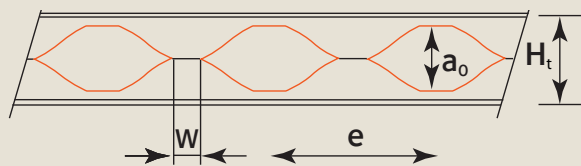




Spacing of the opening (fig 16):

Certain rules must be respected when choosing the spacing of the openings.

Figure 16: Geometric limits for the spacing between the openings in Angelina™ beams



All section ranges $w \geq 150\text{mm}$

Number of openings $n \geq 4$

Height of the opening (fig 15):

- Relative to the finished Angelina™ beam
- Relative to the starting beam

The minimum spacing is defined in order to guarantee satisfactory joining of the two parts of the Angelina™ beam and to avoid the presence of a weak point in the local behavior of the beam.

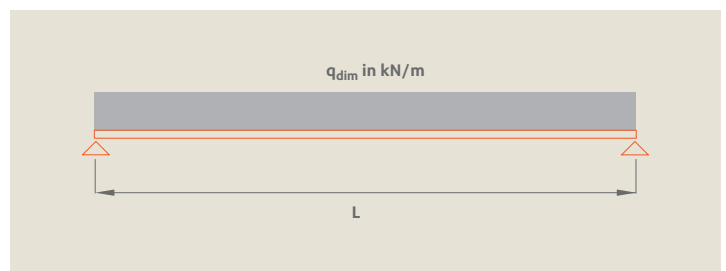
The maximum spacing results from considerations of both economic aspects in the fabrication of the Angelina™ beams and the mechanical behavior of the beam, which approaches with growing opening distance and decreasing opening height that of a beam with single openings.

2. Initial design and performance tables

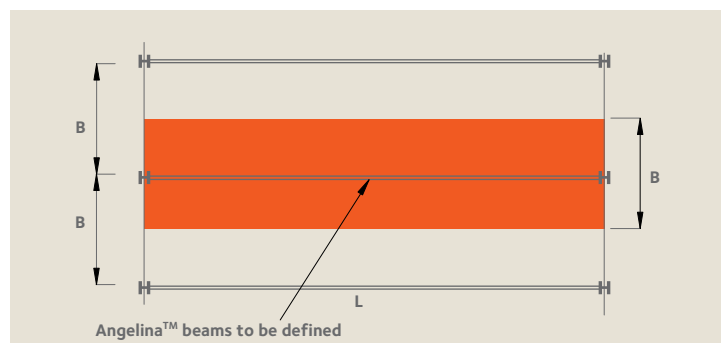
According to the geometric definition, the Angelina™ section to be considered in the project can be determined from the performance curves (see pages 27 to 32 for roofing and metal decking applications), using the following assumptions:

Loading:

Figure 17: Variables to be determined for the use of the tables



The design load, $q_{dim'}$ is to be compared with the ultimate load q_u . The load, $q_{dim'}$ is easily calculated from the weighting formula:
 $q_{dim} = (1.35G + 1.5Q)B$



where:

B = beam spacing,

G = permanent load per square metre,

Q = variable load per square metre.

Methods:

The designer has three procedures available for approaching his project.

1) Identification of the section from the load, $q_{dim} \leq q_u$, and the span, L , for steel grades S355 or S460 and for usual values of a_o and e (height and spacing of openings).
From the curves, the appropriate section can be read off from the intersection of the two lines for q_{dim} and L .

The value of H is the final height of the Angelina™ section.

2) Identification of q_u for a given Angelina™ section as a function of L .
From the (q_u, L) curve of the Angelina™ section in question, the ultimate load, q_u , can be found. It is then sufficient to verify that $q_{dim} \leq q_u$.

3) Identification of the maximum span, L , as a function of $q_{dim} \leq q_u$ for a given Angelina™ section.

The usefulness of this method lies in the quick identification of the maximum span between supports.

Admissible deflection

Deflection limit of $L/250$ applied only on the variable loads.

It is assumed that the deflection due to dead load can be compensated by precambering.

For the calculation of the overall deflection of a Angelina™ beam the beam is divided in elementary panels of two types: "Plain" and "Opening" panels, for which calculation method differs.

The contribution of the "Plain" panels to the deflection of the beam is derived from classical calculation under bending moment.

The calculation method for the deflection of the "Opening" panel is a sum of values of elementary effects due to axial, shear and bending deflection.

The deflection of the beam is obtained as the sum of the contributions of each elementary panel.



6. Angelina™ beams in composite floor application

The use of Angelina™ beams in composite floors (fig. 18) maximizes both the free height above the floor and the free spans without intermediate columns. The spans achievable with this solution can reach 30 meters. For the floors of office buildings, the usual spans are about 18 meters. These beams offer mechanical performances that make it possible to optimize the steel consumption while meeting the requirements for comfort and sustainability.

The beams are spaced by 2.5 to 3 meters in the case of slabs with steel decking and by 3 to 6 meters in the case of pre-slabs, depending on propping device. The openings are spaced by around 1.25 to 1.5 times their diameter, which reaches 300 mm in normal cases.

1. Design help

1.1. Choice of the height of the composite Angelina™ beam

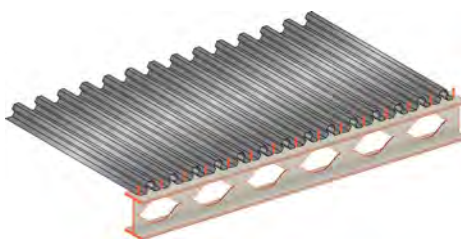
Apart from the criteria defined above for roofbeams, it is important to take account of the composite effect between steel and concrete in order to limit given phenomena that may affect the concrete at the time of pouring and during the use of the structure, especially in the event of shrinkage or creep.

The height H_t of the Angelina™ beam is defined as a function of:

The span, L

The span, L, can vary between 8 and 30 meters depending on the use. Assuming single spans, the concrete slab is in compression throughout the span, unlike situations of continuity, where the concrete is cracked over the intermediate supports.

Figure 18: Angelina™ beams in the deck application



The spacing, B

The spacing of the beams depends on three parameters:

- using steel decking
B = 2.5 to 3 meters without props
B = 3 to 5 meters with props

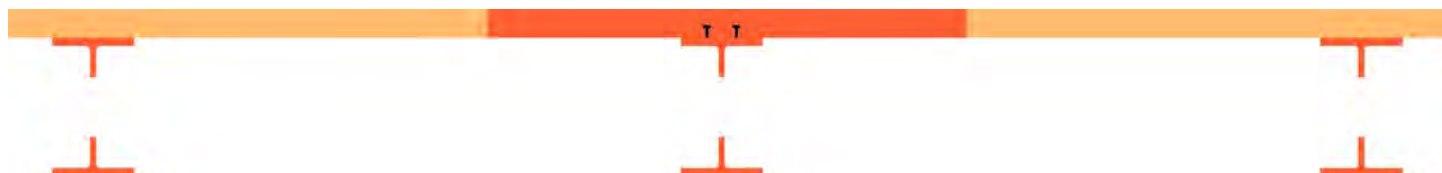
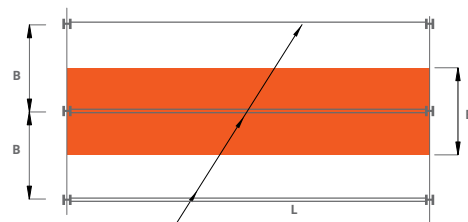
For spans of 5 to 7 meters without props, the use of ArcelorMittal Construction COFRADAL 200 or Cofraplus 220 is the optimal solution.

- Possibility of using prefabricated concrete slabs for short spans
B = 2.7 to 7 meters with props as required, however, for spans of 5 to 7 meters, the use of COFRADAL 200 or Cofraplus 220 is the optimal solution
- allowed structural thickness of floor, H_t
 H_t corresponding to the height of the composite section (height H_t of the Angelina™ beam plus the slab thickness)

The Angelina™ beams should be spaced according to the following ratios:

- $L/H_t > 20$: B = 2.5 to 3 meters
- $L/H_t < 15$: B = 3 to 5 meters

Figure 19: Composite steel-concrete application of Angelina™ beams for floors

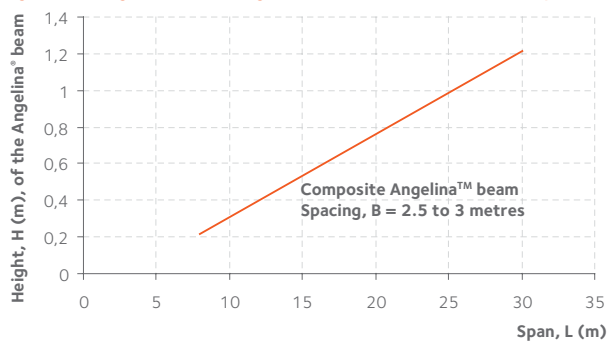




Users comfort

For slender floor structures, often serviceability criteria govern the design. Tolerable vibration may be specified by the introduction of acceptance classes and prediction of floor response due to human induced vibration with respect to the intended use of the building. An overview of this design procedure and guidance on the application is given in "Design Guide for Floor Vibrations" of ArcelorMittal.

Figure 20: Height, H, of the Angelina™ beam as a function of the span

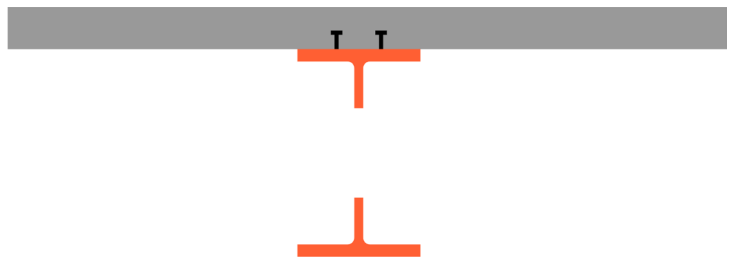


1.2. Choice of height and spacing of openings

The choice of the height and the spacing of the openings is normally guided by requirements for pipes and ducts. In office floors, a height between 250 and 350 mm is adequate in most cases.

Regarding the minimum and maximum values of height and spacing as a function of the parent section, the rules given above for steel Angelina™ beams apply equally to composite Angelina™ beams.

Figure 21: Composite Angelina™



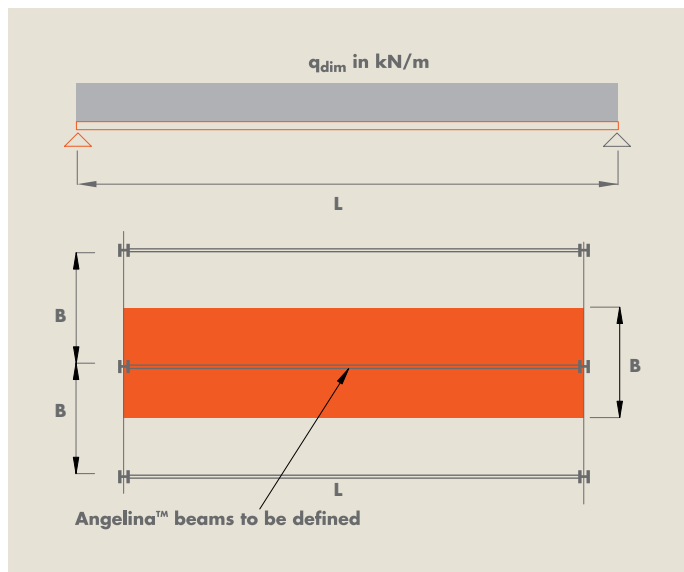
2. Initial design and predesign tables

For proper use of these curves (see pages 30-32 for the composite floor applications), the following rules must be respected:

Loading

The design load, q_{dim} , is to be compared with the ultimate load q_u .
 $q_{dim} = (1.35G + 1.5Q)B$

Figure 22: Variables to be determined for the use of the tables



where:

B = beam spacing,

G = permanent load per square metre,

Q = variable load per square metre.

Materials

The curves cover the use of S355 and HISTAR 460 steel grades and the normal concrete class C25/30.

Slab and connection

A composite slab with steel deck was taken into account for establishing these tables. 12 cm thickness is considered for the slab (this is the total thickness considering a rib height of 60 mm). A total connection between slab and Angelina™ section was assumed for elaboration of the performance tables. The type of connection is to be defined by the user.

Height and spacing

The curves cover the usual values of height and spacing of the openings.

Methods

The same methods as explained above can be applied. It should be noted that: The ultimate load, q_u , was established for:

B = 3 or 6 meters

$$G = g_{\text{Angelina}} + g_{\text{slab}}$$

G representing the weight of the Angelina™ beam itself and the weight of the normal concrete slab with a thickness of 12 cm ($g_{\text{slab}} = 2 \text{ kN/m}^2$) (steel deck with 6 cm high ribs).

The design load, $q_{dim} = (1.35G + 1.5Q) B$, is to be compared with the ultimate load, q_u .

It is then sufficient to verify that $q_{dim} \leq q_u$

Concrete pouring phase

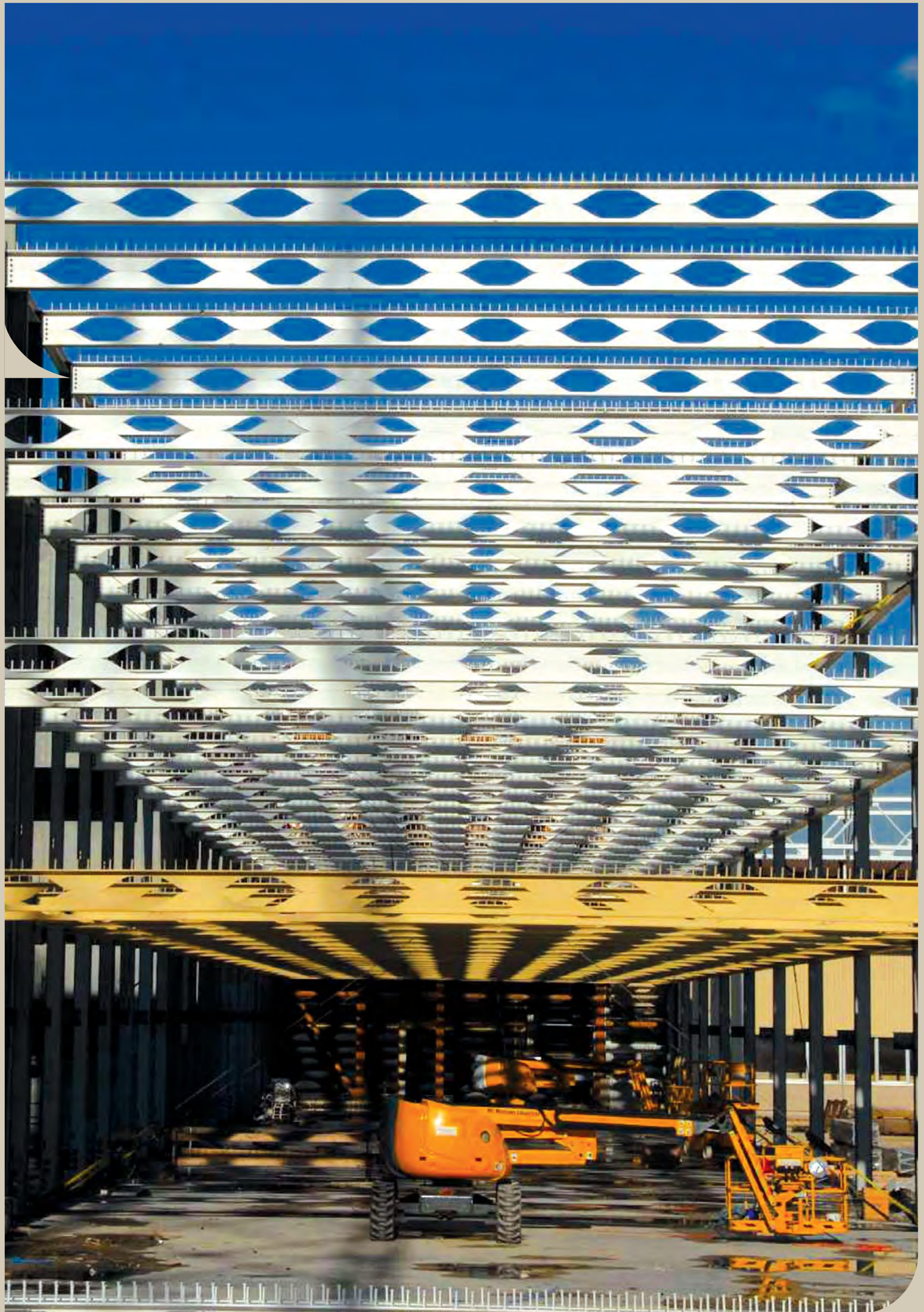
The initial design tables assume that the beam is propped and braced.

Admissible deflection

Deflection limit of $L/350$ applied only on the variable loads.

The deflection of the composite beam is derived from the method of non-composite beam by adding slab elementary contributions.

The deflection of the beam due to the shrinkage of concrete is calculated by applying the method for composite beams under an equivalent bending moment.



7. Stability in fire and fire safety

The required stability in fire for Angelina™ sections can be achieved with a sprayed coating, intumescent paint or by local reinforcement. In office buildings, where regulations usually require a fire resistance of one hour, the most suitable fire safety solution is spraying if the beams are not visible.

A difference between opening shape and duct size of 3 to 5 cm is recommended in order to prevent partial damage of the protection around the openings during installation of the services.

Particular care should also be taken when installing ducts, pipes and false ceilings.

In some cases, no additional anti-corrosion treatment is necessary if the product is sprayed onto the raw steel surface.

The surface area to be protected against fire is almost the same as the starting section.

Sometimes it becomes necessary to increase the thickness of the coating by 2 to 3 cm around the opening to ensure sound protection of the sharp contour.

In the case of visible Angelina™ floor or roof beams an application of intumescent paint provides fire resistance without influencing the architectural aesthetics of the structure.

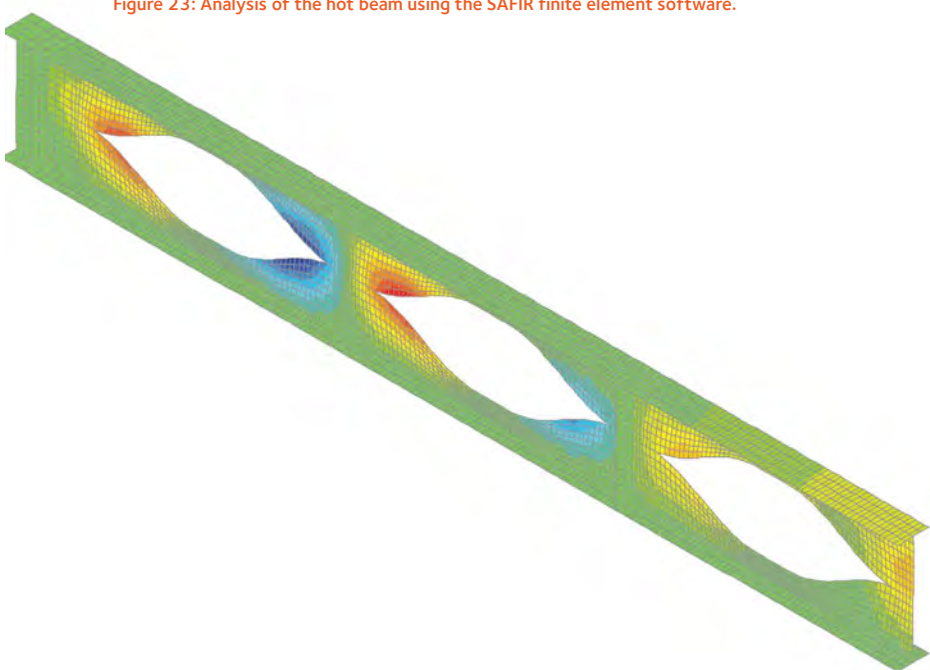
Insulation can be applied to cellular beams using exactly the same techniques as for standard beam sections. The thickness to be applied is generally determined by means of protecting manufacturers' design methods as a function of the appropriate section factor depending on the mode of failure. This thickness can also be determined by numerical simulation.

ArcelorMittal's Technical Advisory Department uses the SAFIR software, with a modal especially developed for the design of Angelina™ beams.

Using this model, it is also possible to reinforce locally the beam in order to reduce or even avoid passive fire protection.

Passive protection (sprayed coating or intumescent paint) can be reduced or even avoided in some cases if an analysis based on the natural fire safety concept in accordance with EN1991-1-2 is performed.

Figure 23: Analysis of the hot beam using the SAFIR finite element software.



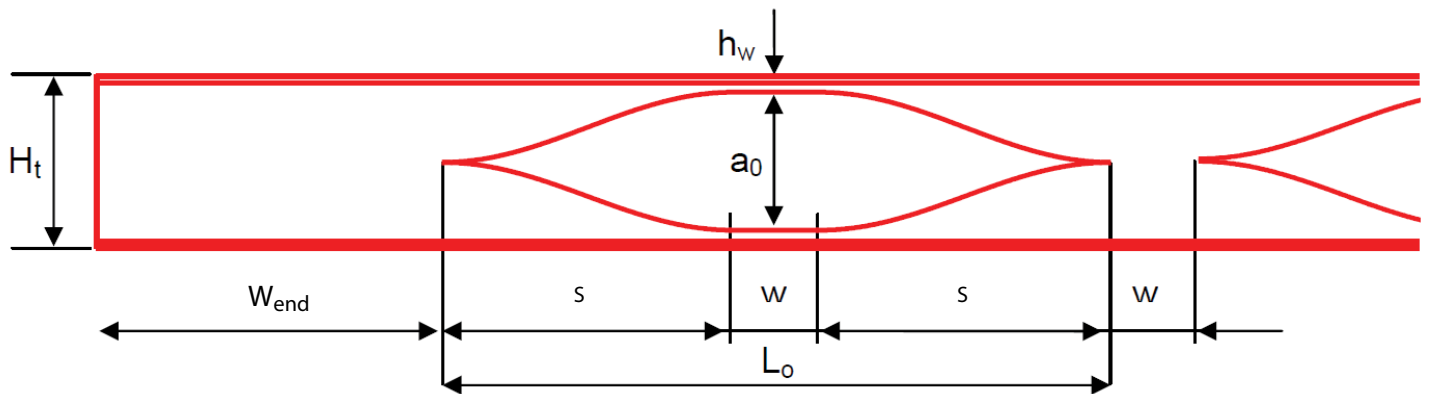
8. Angelina™ Predesign charts

The predesign charts allow the designer to get a quick and easy answer concerning the most suitable section to use in his project. A minimum of 5 openings is defined for all shown geometries. The charts show possible geometries but in order to suit project requirements unlimited geometrical configurations can be designed by Angelina™ software. Number and size of openings in combination with span may result in intersecting load capacity curves. This is explained by different number of openings and possible limit states. Partial closing or web stiffeners may be advisable to optimize load capacities.

The charts are made for non-composite and composite beams in steel grades S355 and HISTAR 460.

Further explanations for the different assumptions for the calculation are given in the corresponding paragraphs.

The Angelina™ section is obtained from a common hot-rolled profile. The length of the beam (L_t) is usually set by the overall layout of the project from the architect, whereas the parameters a_o , s , and w , which actually define only the shape of the opening, are governed by functional requirements and verified by the designer.



Where

- a_o height of the opening
- s length of the sinusoid
- L_o total length of the opening
- w length of the intermediate web post
- w_{end} length of the end web post
- h_w remaining web height
- H_t total beam height
- L_t total beam length
- e spacing between opening centers

Design load:

The design load, q_{dim} , required in the project has to be compared with the ultimate load q_u given in the charts. This ultimate load takes into account all criterias required for Ultimate Limit States (ULS) and deflection at Serviceability Limit States (SLS). As a consequence, the design load could be directly compared to the ultimate load.

The design load, q_{dim} , expressed in kN/m in the charts, should be calculated using following ULS load combination:

$$q_{dim} = (1,35G + 1,5Q) B$$

where:

B = beam spacing [m],

G = permanent load per square meter [kN/m²],

Q = variable load per square meter [kN/m²].

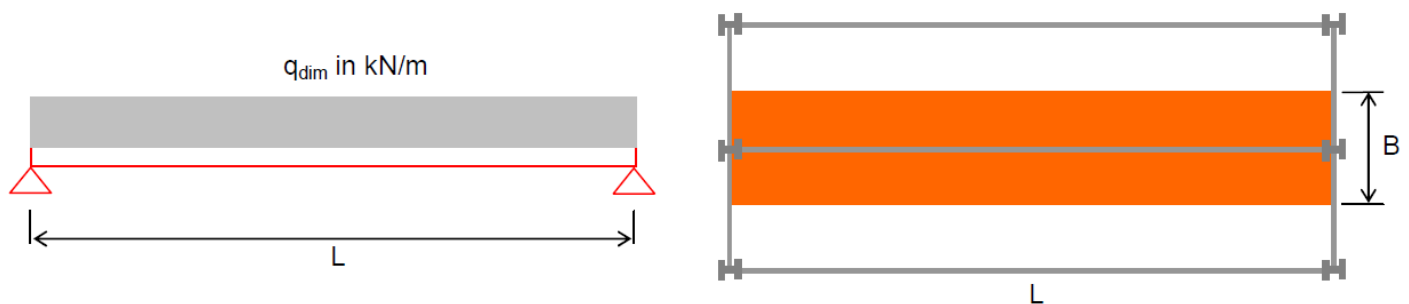


Figure 1 Design load

Correct use of the charts:

There are three possible procedures:

1) The section should be identified if the design load, q_{dim} and the span L are known. The first step is to determine the point of intersection of the two lines for q_{dim} and L. The required section is always situated vertically above this point when crossing the curves. Once the section is identified, the size of the opening should be checked against the functional requirements (if any).

2) The design load q_{dim} should be identified if the Angelina™ section and the span L are known. From the (q_u, L) curve of the chosen Angelina™ section, the ultimate load, q_u , can be found. It has to be verified that $q_{dim} \leq q_u$.

3) Identification of the maximum span, L, as a function of $q_{dim} = q_u$ for a given Angelina™ section.

Predesign charts for non-composite Angelina™ beams

The calculation of non-composite beams has been made with the following assumptions:

- Deflection limit of $L/250$ applied only on the variable loads (the deflection due to dead load can be fully or partially compensated by a pre-cambering of less or equal $3L/1400$).
- The openings proportions are fixed in such a way that $a_0 = s$
- The web post length w is set to 200 mm or 250 mm.

Chart 1: Angelina™ based on IPE sections, S355

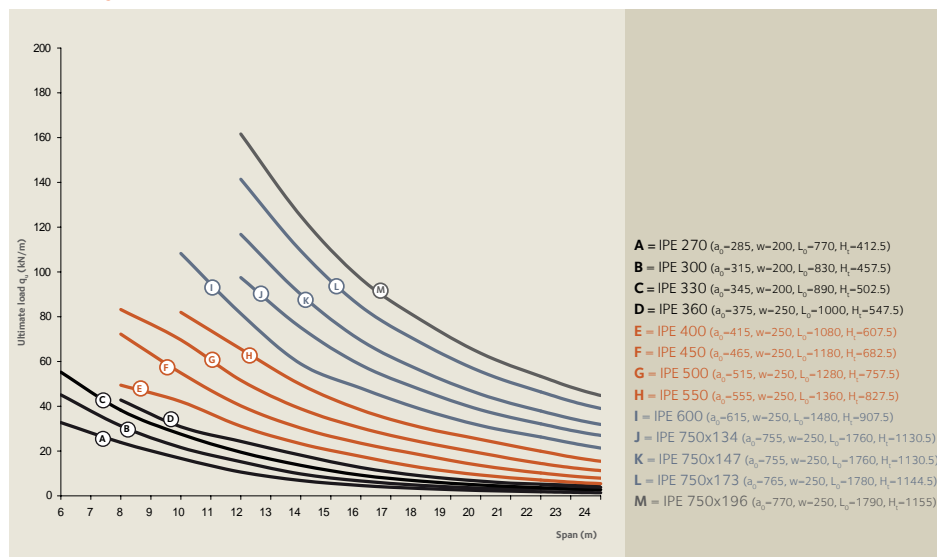


Chart 2: Angelina™ based on HE A sections, S355

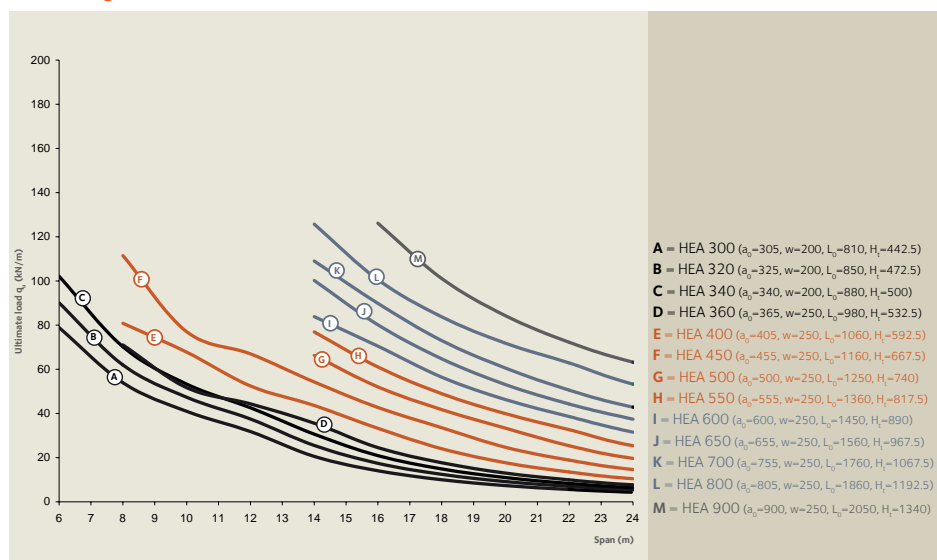
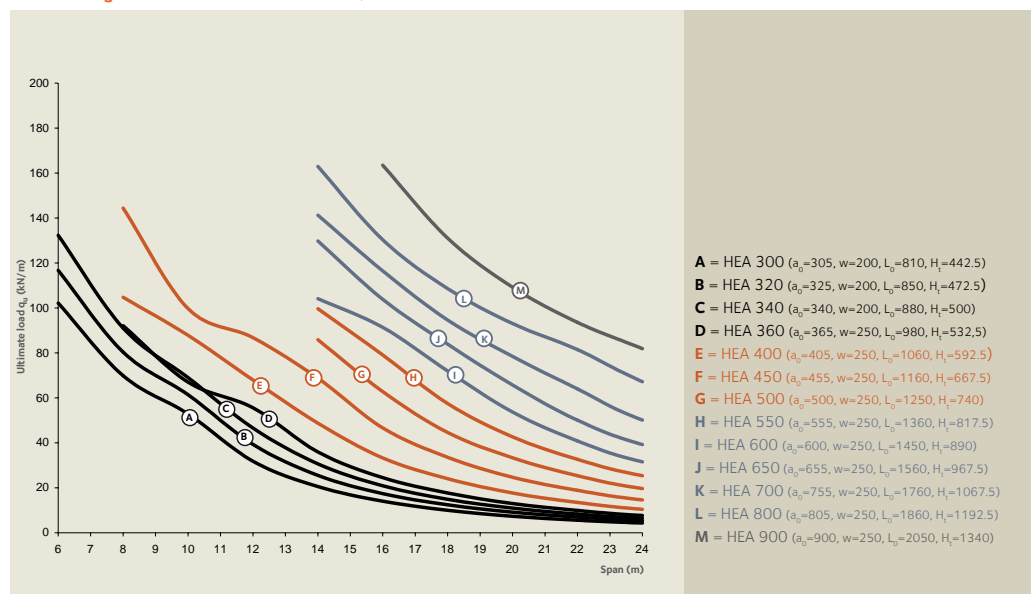


Chart 3: Angelina™ based on HE A sections, HISTAR 460



Predesign charts for composite Angelina™ beams

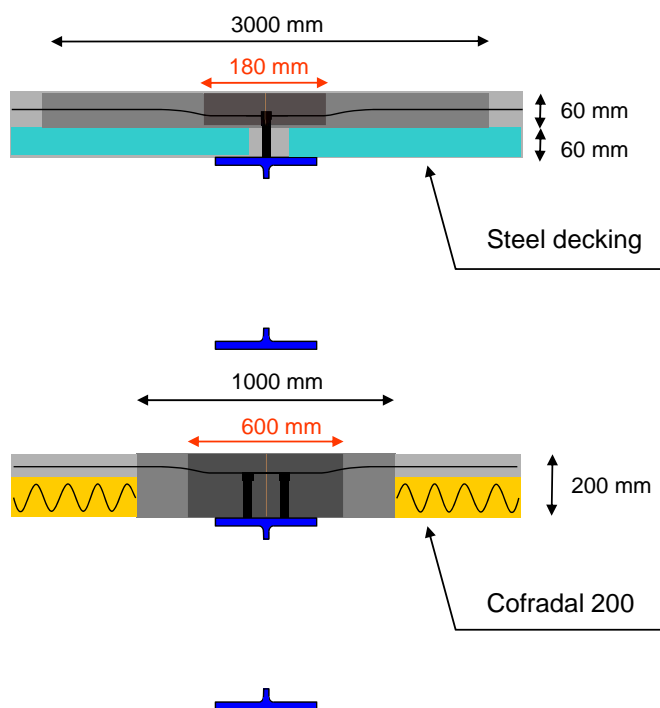
The calculation of composite beams has been made with the following assumptions:

Materials

The Charts cover the use of S355 and HISTAR 460 steel grades and the normal concrete class C25/30.

Slab and connection

A composite slab with trapezoidal steel deck was taken into account for establishing these tables. The span of the slab is set to 3 m perpendicular to the beam. The total thickness of the slab is 120 mm and the rib height is 60 mm. A full shear connection between the slab and the Angelina™ section is assumed for calculation of the charts.



Alternatively, the composite slab has been replaced by prefabricated slab element Cofradal 200 with a self weight of 2,00 kN/m₂. Thanks to this type of element, the beam distance has been set to 6 meters. The effective width is assumed to be 1 m and the available height for shear resistance is 20 cm.

Ultimate load

The ultimate load, q_u , was established for:
 $B = 3$ or 6 meters

G represents the weight of the Angelina™ beam itself and the weight of the slab ($g_{slab} = 2,0 \text{ kN/m}_2$)

Construction phase

The calculations assume that the beam is propped and braced during the construction phase.

Openings

The openings proportions are fixed in such a way that $a_0 = s$.

The web post length w , is set to 200 mm for small profiles and more than 200 mm for larger sections (see legend of predesign charts).

Admissible deflection

The curves consider a deflection limit of $L/350$ under variable load Q . (the deflection due to dead load can be fully or partially compensated by a pre-cambering of less or equal $3L/1400$).

Chart 4: Composite Angelina™ based on IPE sections, S355 with COFRAPLUS 60

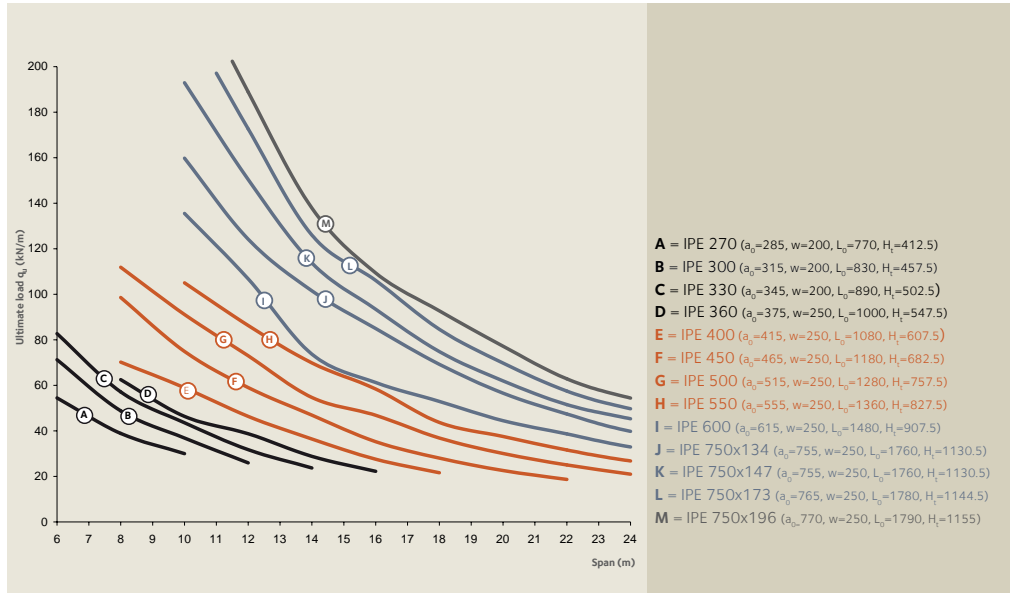


Chart 5: Composite Angelina™ based on HEA sections, S355 with COFRAPLUS 60

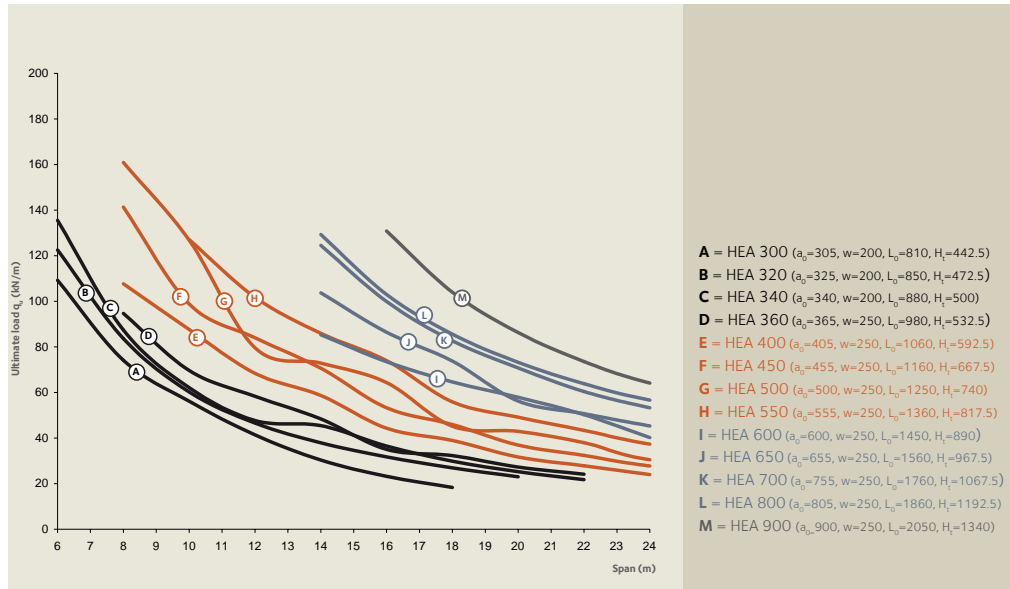


Chart 6: Composite Angelina™ based on HEB sections, S355 with COFRAPLUS 60

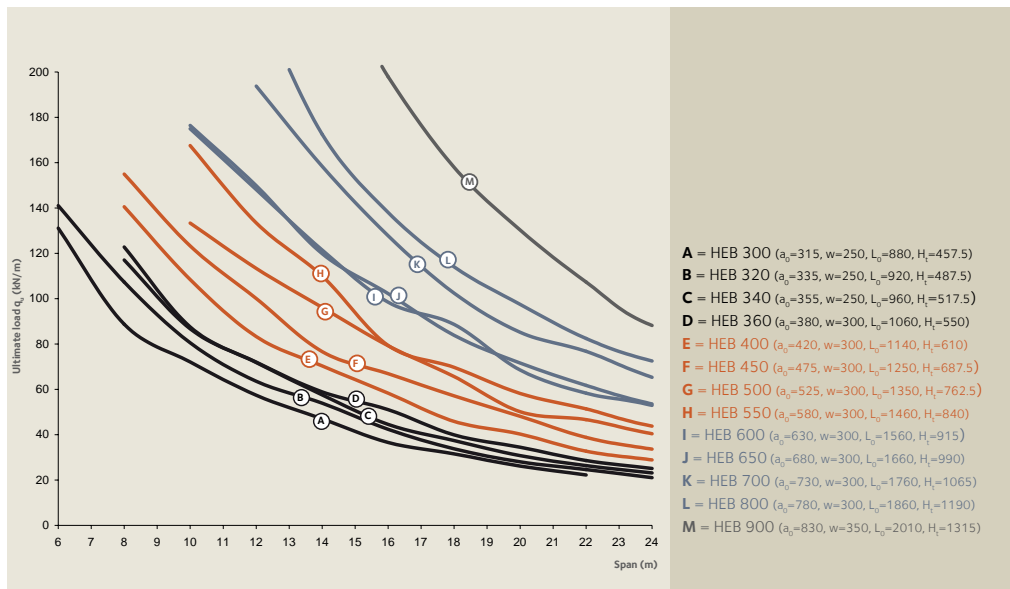


Chart 7: Composite Angelina™ based on HD sections, S355 with COFRAPLUS 60

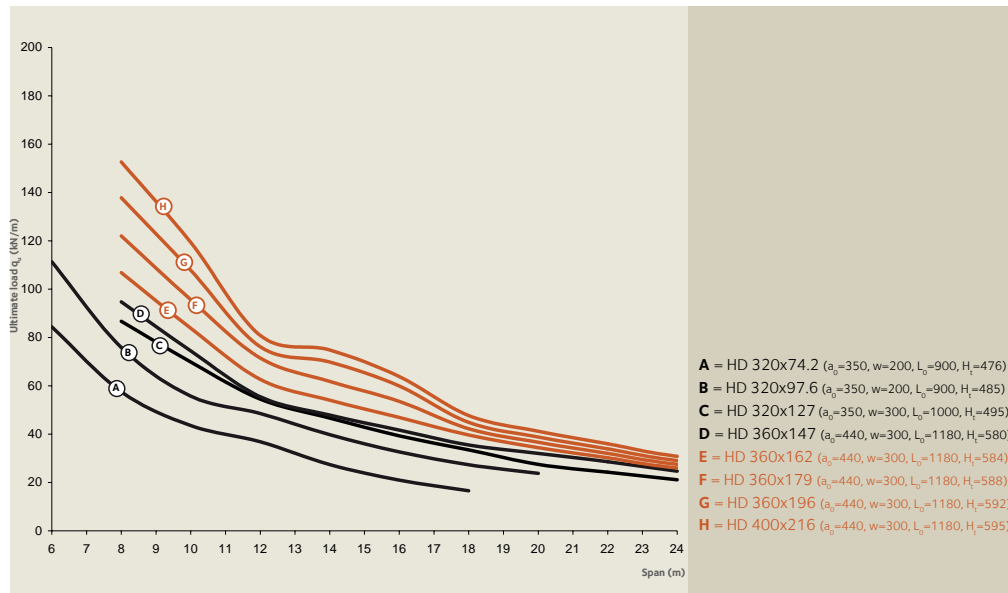


Chart 8: Composite Angelina™ based on HEA sections, HISTAR 460 with COFRAPLUS 60

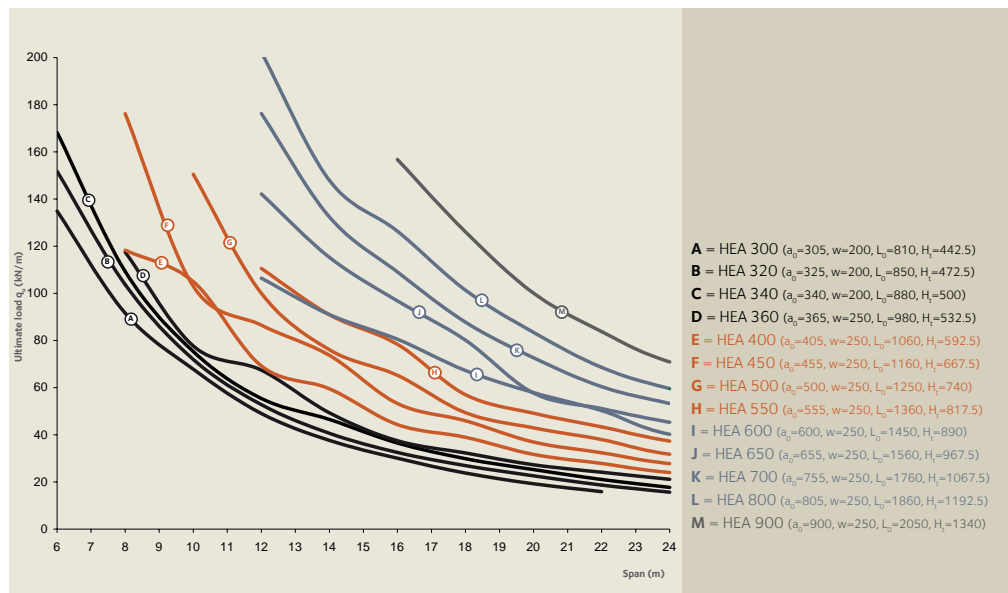


Chart 9: Composite Angelina™ based on HEB sections, HISTAR 460 with COFRAPLUS 60

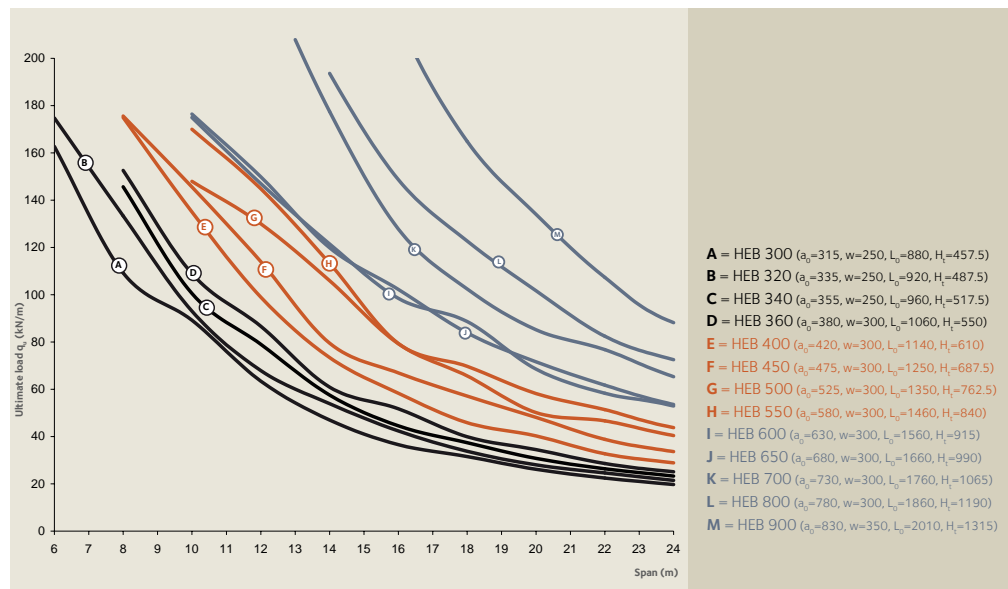


Chart 10: Composite Angelina™ based on HD sections, HISTAR 460 with COFRAPLUS 60

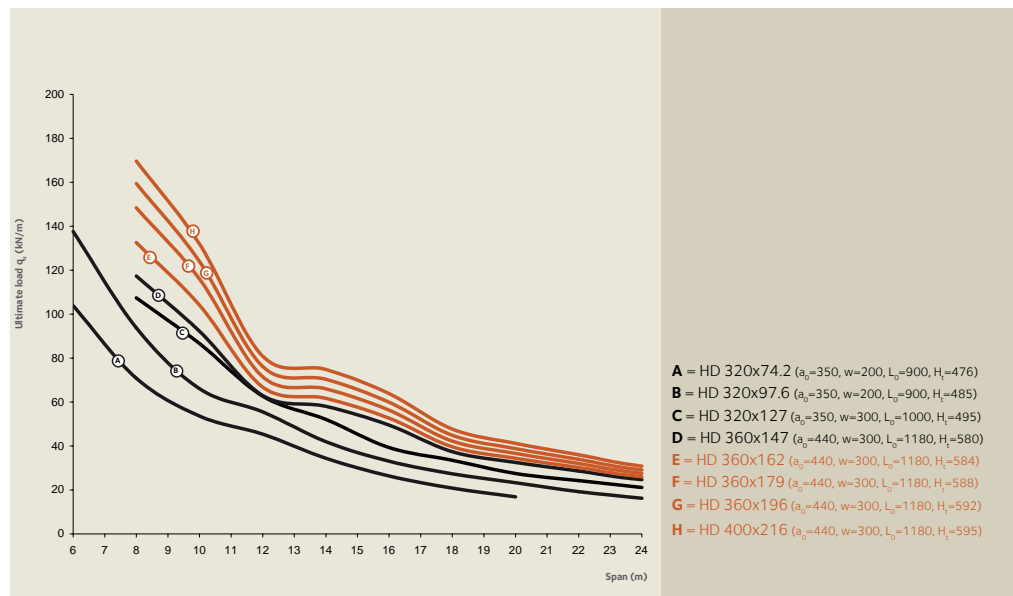


Chart 11: Composite Angelina™ based on HD sections, S355 with Cofradal 200

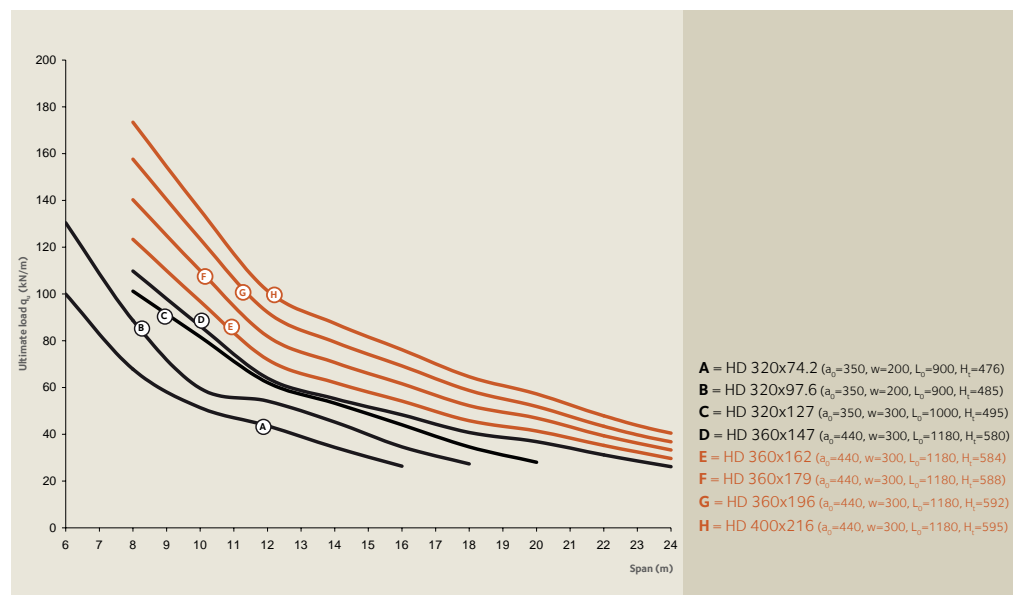
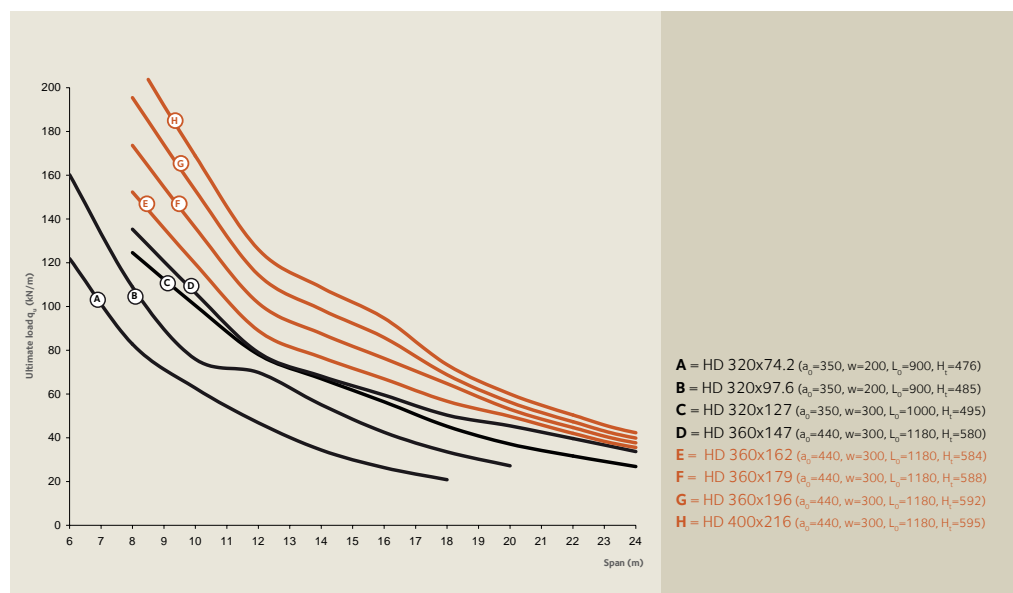


Chart 12: Composite Angelina™ based on HD sections, HISTAR 460 with Cofradal 200



9. Predesign charts: design examples

Secondary beams made of Angelina™ beams are to be sized for a composite floor with a span of $L = 16$ m and a spacing of $B = 3$ m. For architectural reasons, the final height of the floor is limited to $H = 700$ mm. This allows a maximum height of the Angelina™ section of $H_t = 580$ mm with a 120 mm slab.

Parameters to be taken into account:

$L = 16$ m

$B = 3$ m

Slab thickness = 12 cm

Concrete grade, C25/30

Steel deck by default with 60 mm rib height.

Loads to be taken into account:

$q_{dim} = (1.35G + 1.5Q)B$ with

$G = G_{Angelina} + G_{slab}$

G = weight of the slab itself and weight of the Angelina™ beam itself.

For a 12 cm thick slab on steel decking, the weight

$g_{slab} \approx 2$ kN/m²

The weight of the Angelina™ beam is initially assumed to be 1 kN/m,

equivalent to: $g_{Angelina} = 0.33$ kN/m²

G_2 = additional permanent load = 0.75 kN/m²

Q = variable load, value chosen for this example: 6 kN/m²

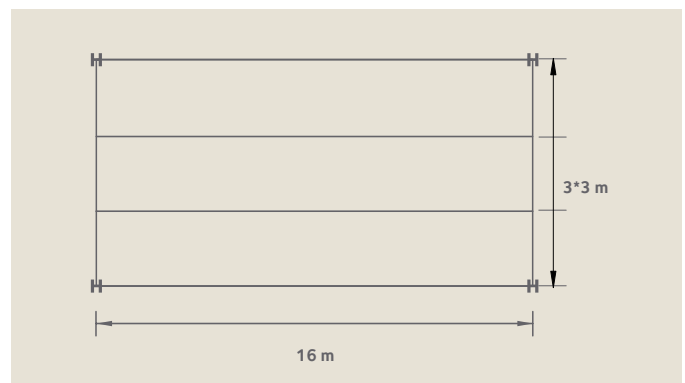
$G = g_{slab} + g_{Angelina} = 2.33$ kN/m²

$G = 0.75$ kN/m²

$Q = 6$ kN/m²

$q_{dim} = 39.5$ kN/m

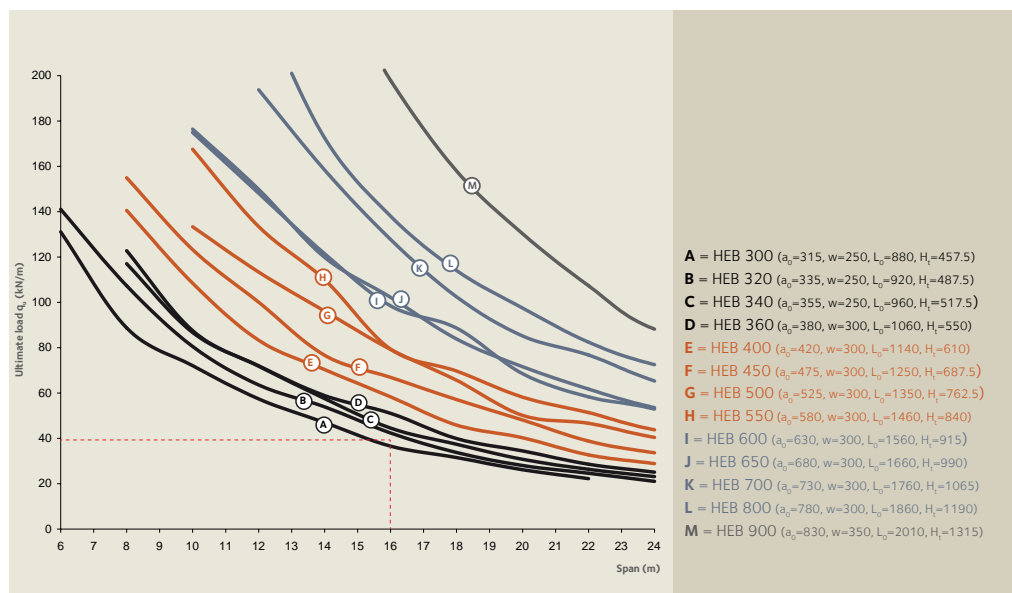
Using the predesign charts for sizing as a function of load and span, the required section can be determined. Given that a maximum final height is imposed, the choice of chart falls on the HEB range with the two steel grades, S355 and HISTAR460.



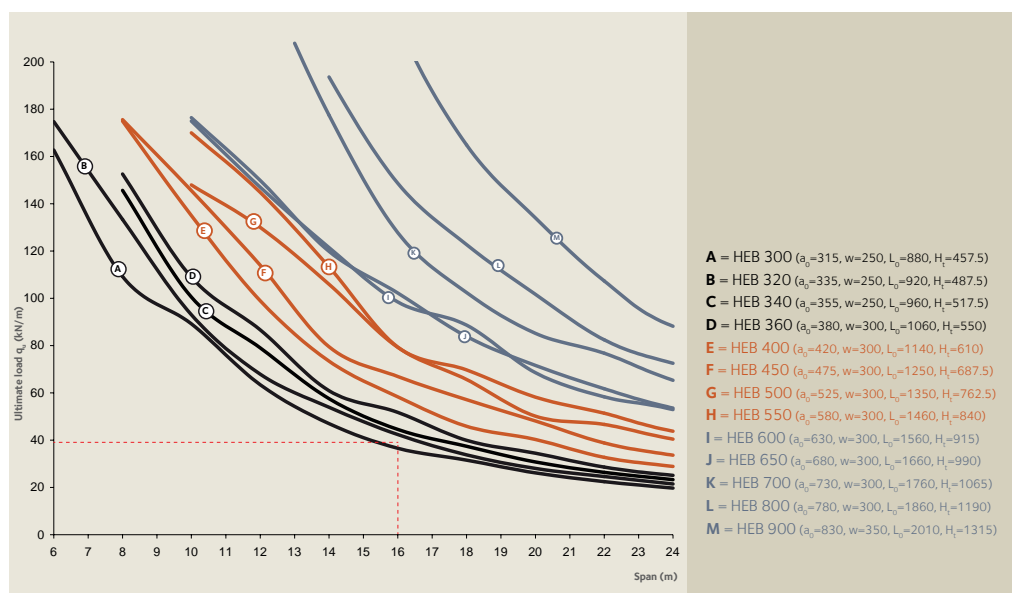
See following page: example 1.

The choice falls on curve G, based on HEB320 with $a_o = 335$ mm and $H_t = 487.5$ mm in grade S355. On performing the same operation on the table with steel grade HISTAR460, it turns out that the section required remains the same. This is due to the fact that one design criteria for this configuration is the deflection and the moment of inertia does not change with a higher steel grade. If the limitation on the final height is not truly strict, the use of the predesign chart with the configuration IPE or HEA can be considered which allow the reduction of the weight of the Angelina™ beam. Once the section is known, it is recommended to insert the values in the Angelina™ predesign software in order to refine the results and carry out the various checks in SLS and in ULS.

Example 1. Angelina™ HEB S355



Example 2. Angelina™ HEB HISTAR 460



10. Angelina™ beams: a solution for sustainable development

• Sustainable structures with the use of Angelina™ beams

The preservation of natural resources in our industrialized societies has become priority in the creation of the built environment. As a result, construction concepts have to comply with changing economical parameters like the incorporation of life cycle analyses in the design of structures as well as with technological changes in considering sustainability goals in respect to the environment and society.

These sustainability goals are in nature:

- ecological,
- economical,
- socio-cultural,
- technical oriented,
- process oriented.

They are interdependent as well as ambivalent, providing a coherent response to complex questions and ensuring future generations a pleasant environment.

Sustainable construction using Angelina™ beams is fully consistent with the various aspects of the sustainability goals.

• Ecological aspects of sustainability

The main ecological goals aim at using building materials that are safe from health and environmental points of view, at reducing building waste when dismantling buildings at the end of their service life, and at preserving as best possible the energy content in the construction materials, thus maintaining their ideal efficiency. Here, structural steels offer high material efficiency and rolled sections constitute the most recycled building material in the world. In the modern electric arc furnace (EAF) route, steel is produced using 100% scrap as a raw material (upcycling). Also, used steel elements can be deployed for further use in renovation and refurbishment of existing buildings. In addition, the EAF

technology allows for significant reductions of noise, particle- and CO₂-emissions as well as water and primary energy consumption in the production mills.

Angelina™ beams produced by ArcelorMittal allow to integrate all the services within the height of the beam in multi storey buildings and to optimize the cross section by reducing the steel material from the webs. These beams are really environmental friendly, they use a minimum of steel material being slender and lighter. For the straight Cellular Beams, the CO₂ saving can be estimated at 25% compared to the equivalent solution in plain steel profile.

• Economical aspects of sustainability

Besides being interested in the reduction of investment costs, investors are also concerned about the optimization of operational costs and the achievement of the

longest possible service life in combination with high flexibility in use of the structure.

Angelina™ beams in structures allow architects and designers to easily fulfill the requirements of investors by combining high quality, functionality, aesthetics, low weight and short construction times.

Slender superstructures can be designed which decrease construction height and earthworks leading to a further decrease of material, fabrication, transport and construction costs.

Angelina™ optimize the height of the construction or at equivalent height; they allow to add on storey each eight storey's (15% more usable surface for the same volume to heat) (Figure 24). They allow also reducing the number of columns and the size of the foundations.

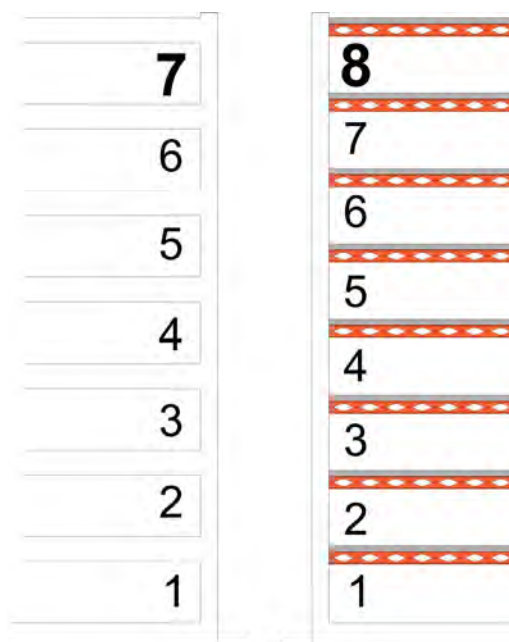


Figure 24. Additional level through Angelina™ beams

Recovered steel can be recycled indefinitely. Assuming an appropriate design, whole structures or their individual steel elements can be re-used after dismantling of the original building and offer so significant economical life-cycle potential.

- **Socio-cultural aspects of sustainability**

This aspect allows the architect to reconcile his own aesthetic demands for a building with the social expectations of its surrounding environment. Again, thanks to the prefabrication construction system, Angelina™ beams provide the user with transparent and lean structures combined with robustness and safety. Local inhabitants and their social environment remain clean in uncontaminated surroundings as steel in structures does not release any harmful substances into the environment.

- **Technical aspects of sustainability**

Structures made of Angelina™ beams have the advantage of being able to resist high level utilization and are adaptable to changes in use. These robust construction solutions are capable of coping well with variations in use during service life without damage or loss of functionality.

- **Process aspects of sustainability**

Steel constructions offer many advantages through its flexibility, lightness and cost effectiveness. Angelina™ beams are used as primary bearing elements. They are industrially produced to a high quality, offer good availability in a full range of sizes and steel grades, including ArcelorMittal's HSTAR high strength steels. Fabricated in specialized workshops the end product is delivered to site ready for erection. Quality control has already been carried out at the production. Smaller

construction sites and plant equipment are therefore needed whilst minimal noise and dust disturbance on site are characteristics for steel construction.

Structures using Angelina™ sections reduce erection times. Hence, transportation cost as well as accident potential is reduced.

To document in a standardized way the environmentally relevant information, an EPD (Environmental Product Declaration) is available for structural steel upon request on our website. (www.arcelormittal.com/sections >> download center)

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