DILLINGER HÜTTE GTS

Heavy plates for economical constructional steelwork and offshore structures

R.Hubo, F.Martin, F. Schröter*

Abstract

There are traditionally three important fields of application for heavy plates in civil engineering: heavy steel buildings made of welded constructions (for example multistory buildings, shipbuilding halls or power plant buildings), bridges with spans between 4 and 1000 m as well as offshore platforms for the oil and gas production and processing at sea. Nowadays, a wide range of heavy plates is available for these fields of application. Heavy plates offer to technical designers a nearly unlimited range of dimensions, strength and toughness levels. Due to optimised properties heavy plates enable very economical and durable constructions.

User-oriented development of heavy plates

At present heavy plates are widely used in constructional steelwork. Among these in particular the steel grades between S235 and S355 are very popular. The development of heavy plates for steel structures during the past decades firstly aimed at increasing the strength level with at the same time keeping an acceptable weldability. Thus, the volume of steel used in the construction could be reduced. At the beginning of the 70th, the development reached the high-strength steel levels S460 and S690 which, however, require a relatively difficult welding procedure coming along with higher fabrication costs and, therefore, limiting the wider use of these steel grades.

The demand to reduce weight, i.e. the reduction of the dead weight of the structure and the reduction of the total volume of steel required, was the starting point for the development of the longitudinally profiled plates (LP-plates) /1,2/. By a special control of the roll gaps during the rolling process a longitudinal profile with a continuously varying thickness along the length of the plate can be given to a heavy plate. Thus, various types of LP-plates with different geometries can be produced (Figure 1). Such plates allow an optimised

* Dr.-Ing. Ralf Hubo, General Marketing Manager; Dipl.-Phys. Francis Martin, Marketing Constructional Pipes and Offshore; Dr.-Ing. F. Schröter, Marketing Constructional Steelwork, Dillinger Hütte GTS, P.O. Box 1580, D-66748 Dillingen, Germany

adaption of the plate thickness to the actual stress in the structure. Examples for the application of these plates are presented in the Figures 2-6. Today, LP-plates are applied in bridgebuilding all over Europe (Figure 7). Besides reducing the weight, the application of LP-plates saves also fabrication costs and time due to the possibility of avoiding complicated weldings.

Aspects of fabrication and manufacturing costs savings gained more and more importance during the 80th and led to the development of the modern generation of thermomecanically (TM or TMCP) rolled heavy plates /3,4,5/. TM-rolled heavy plates in steel grades S355, S420 and S460, which can be delivered since the end of the 80s, offer not only a high strength but also an excellent weldability. Thus, the possibility of designing even more economical steel constructions is established.

The recent heavy plates for offshore applications were derived from fine-grained structural steels and standard grades as the normalised S355 steels. They are designed to give a reasonable thoughness in the heat affected zone after welding. Since the end of the 80s TMCP-heavy plates of the yield levels 355, 420, 450 and 500 were developed for this field of application too. These grades are characterised by excellent thoughness levels after welding even with these high strength properties.

Building construction

As far as building construction is concerned, two different fields of application may be distinguished; on the one hand the simple and standardised multi-story and hall buildings and on the other hand the heavy welded constructions for industrial halls, power plants and special tall multi-story buildings. Regarding the standardised constructions, which hold the biggest share of the total steel consumption in the construction market, heavy plates are only used for head plates or stiffeners for framework constructions predominantly composed of rolled beams. Mostly the steel grades S235 and S275 are applied here /6/.

In cases in which high loads or large spans have to be designed, columns, piles and girders are normally welded and made from heavy plates. This design and construction method shows an economical advantage up from a girder height of about 600 mm because the cross sections of the supporting structure can be adapted individually to the constructional task by only using a minimum of steel. The steel grade S355 is predominantly applied for these applications, but sometimes even heavy plates of the higher steel grade S460 are used. Common dimensions for heavy plates in the heavy building construction area are:

thicknesses from 8 to 100 mm,
widths up to 1.5 m and
lengths up to 18 m.

The following examples give an impression of the typical application range of heavy plates:

- Power plant buildings, e.g. the thermal power station Schwarze Pumpe, Germany, (Figures 8 and 9) with an overall height of 161 m. The columns and beams were mainly fabricated with TM-rolled heavy plates S355M/ML and the standard structural steel S255J2G3 mod. in plate thicknesses up to 65 mm. Additionally, S690QL grade in some high tension loaded areas was used.

- Commerzbank Tower, Frankfurt, Germany (Figures 10-12)
  Due to the very high requirements of architects on the asthetics of multi-story buildings, heavy steel skeleton constructions have been more and more used during the past 10 years. A typical example for this is the Commerzbank Tower in Frankfurt with a height of more than 298 m /7/. Its steel framed

structure contains about 18000 t of heavy plates. Thereby, the S355M steel was used for plate thicknesses exceeding 30 mm, whereas in highly loaded girders and columns S460M has been applied. Thus, fabrication costs could be reduced by this optimal selection of heavy plates.

- Sony Center Berlin, Building F, Germany (Figure 13)
  Also in this example the architectural requirements were decisive for the application of high-strength heavy plates. The supporting structure consists of 3 heavy columns on which 2 welded truss girders made of heavy plates form the load bearing structure. On the latter the individual stories are hung up. The truss girders were made of plates with thicknesses up to 100 mm of the grades S460M/ML and S690QL1 /8/.

- High-speed train (ICE) station Frankfurt-Airport, Germany
  The 700 m-long and 50 m-broad reception hall of the high ICE-station near the Frankfurt airport rests on heavy welded columns. More than 18000 t of the steel grades S355M/ML and nearly 2000 t of S355K2G3 were totally used for this building. Each upper supporting framework has a weight of about 320 t and is leant on the columns with an individual carrying force of 7500 t.

Bridges

In bridge construction during the last years more and more heavy plates have been applied in particular due to the progress in the construction of composite bridges (steel supporting structure with a concrete deck) /9/. In regard of the size bridges with a medium span between 30 and 150 m are in particular concerned. Typical examples for cross sections of these composite bridges are presented in the Figures 3,4 and 16. These constructions can exploit the whole range of feasibility in regard of both dimensions and steel grades. Very thick plates (girder with a thickness of up to 150 mm) are as well used as very wide plates (width up to 4300 mm, in special cases also more than 5000 mm), long plates for segment lengths between 18 and 36 m or steel grades up to S690QL1 /11/. These dimensions enable very cost-saving bridge constructions.

Bridges with very small spans between 3 and 6 m can be built by a single heavy plate /11/. Plate thicknesses up to 250 mm may be reached depending to the loading and the deflexion criteria used. Typical plate bridges are shown in the Figures 17 and 18 (La Moyaz and Creux de Mas in Switzerland). These plate bridges consist of heavy plates of the steel grade S275NL lying side by side. The dimensions used in these plate bridges are: thicknesses between 160 mm and 220 mm, widths of about 2300 mm and a length of about 4400 mm. The main advantage of this bridge type is the small traffic interruption period during erecting the bridge. So, the whole process of erecting the bridge from pulling down the old bridge structure up to the passage of the first train does not take more than 8 hours.

Due to construction technique, bridges with big spans (more than 150 m) belong to the field of pure steel structures. Constructions made of welded heavy plates are almost generally applied for such types of bridges.

Mainly heavy plates of the steel grade S355 are used in the European bridgebuilding. However, high strength plates of S420 and S460 are more and more employed for big-span bridges. Sometimes even the higher-strength steel grade S690, e.g. in the water-quenched and tempered condition, is used. Normally the plate thicknesses are less than 50 mm, but exceptionally even plates of thicknesses up to 150 mm can be found in the load bearing sections.

Typical examples for modern bridgebuilding are given by the following figures:

- Railroad bridge Nantenbachtal, Germany
  The double-track composite bridge /12,13/ has an overall length of 695 m and a maximum overall height (at the posts) of 15.5 m (Figure 19). The main span is 208 m. This three-span, concrete-haunched composite building consists of an upper concrete deck plate and a concrete compression plate in the region of negative bending moments above the posts (double composite). The steel grade S355J2G3 mod. is used in plate thicknesses up to 65 mm.

- TGV-Méditerranée, France
  Among the 23 bridge constructions 15 were established as composite bridges with twin girders. The most important composite bridges are the bridge of Cavaillon (5200 t), the bridge of Orgon (3600 t) and the bridge Cheval blanc (3500 t). In addition, 5 smaller bridges and three big truss arched bridges were built in steel: Viaduc de Donzère, Viaducs de Mondragon and Mornas (Figures 20 and 21). Besides the classical steel grade S355K2G3 (plate thickness up to 30 mm) also heavy plates of the steel grades S355N and S355NL (plate thicknesses more than 80 mm) were applied, even partly in form of LP-plates.

- Erasmus-bridge Rotterdam, The Netherlands
  The Erasmus-bridge /14/ connects the inner city of Rotterdam with the North bank of the Nieuwe Maas, Kop Van Zuid, where a new quarter will be established on a former harbour area (Figure 22). The steel bridge has an overall length of 499 m with a 410 m-long cable-stayed bridge composed of a 139 m-tall pylon and a 89 m-long flap bridge. Totally, 6000 t heavy plates of the steel grades S355M (thickness less than 100 mm, 4200 t), S460L (thickness less than 80 mm, 2000t) and S460QL (thickness less than 125) were used for this bridge.

- Øresund-bridge, Danmark-Sweden
  The Øresund fixed link (Figure 23) consists of a 7500 m-long framework composite bridge, a 4000 m-long artificial island and a 3500 m-long tunnel. The approach bridges and the cable-stayed main bridge were built as a truss bridge with a upper concrete deck and a lower steel deck (railroad deck). Heavy plates of the steel grades S460M/ML in thicknesses up to 80 mm (60000 t) were used for the shore spans, whereas the main bridge was constructed of S420M/ML in thicknesses up to 50 mm (16000 t).

- Normandy-bridge, France
  In 1995 the Normandy-bridge /15/ was opened to traffic. At that time it was the biggest cable-stayed bridge of the world (Figure 24). 624 m of the total length of the main opening (856 m) were constructed by heavy plates for weight reasons. The aerodynamically optimised cross section has been designed and built using plates in steel grades S355K2G3, S355N and S420M in thicknesses up to 30 mm (single pieces up to 125 mm).

Offshore construction

In the 60s and 70s the construction of offshore platforms for the oil and gas production in the North Sea required heavy plate properties significantly exceeding the requirements of conventional constructional steels. Due to high requirements on the safety and reliability of the platforms under even very extreme external conditions (low temperature, severe storms, high waves of the sea, corrosion by sea water) as well as the necessity of a partial assembling on site at sea, heavy plates with especially high ductility, high resistance against crack growth and good fabrication properties had to be developed. These steels are substantial developments form fine-grained steels to special offshore grades.

The supporting framework of platforms standing on the ocean floor usually consists of a framework made of relatively thick-walled constructional pipes. In order to produce these pipes in an economical way, the heavy plates have to be as wide as possible. That way, the number of pipe segments necessary for the welded framework structure can be reduced strongly. Typical plate widths for such structures are between 3500 and 4500 mm with thicknesses between 20 and 90 mm. Today, heavy plates of the steel grade S355-Offshore are applied as a standard. These plates can be delivered in either a normalised or a TM/TMCP-rolled condition with a thickness up to 250 mm and 120 mm respectively. In particular the TM-rolled heavy plates show very good thoughness properties after welding and can be processed in a very cost-saving manner.

Recent platform constructions are characterised by the necessity of a higher overall height due to deeper sea levels or the development of swimming platforms. When applying the classical S355-Offshore steel grade in these constructions, the necessity of big carrying cross sections considerably increases the total weight of the structure. Therefore, higher-strength heavy plates of the steel grade S420-Offshore have won recognition in the North Sea platform applications. These plates are delivered in thicknesses up to 120 mm in a TM/TMCP-rolled condition. Plates with greater thicknesses are normally used in the quenched and tempered condition.

The following figures show typical examples of modern offshore platforms:

- Ekofisk IIa (Figure 25)
  The Ekofisk-field, a very old oil and gas field near the Norwegian coast, had to be reconceived because of the lowering of the central storage tank. Therefore, two new platforms were built. About 45.000 t of plates predominately of the steel grade S420M-Offshore were used for these two platforms. The six-legged platform 2/4X weighs 7900 t , the jacket alone already 5800 t (not including the ram piles for the foundation into the sea bottom). The new central platform 2/4J consists of a 11400 t jacket tied to sea bottom by 16 ram piles of a total weight of 5500 t and carries the deck with a weight of 23000 t. The two platforms are standing about 90 m over sea bottom and are connected to each other and the total complex by several bridges.

- Petronius Tower (Figure 26)
  Today, the Petronius Tower with is overall height of 564 m is the highest (or better: deepest) offshore platform all over the world. It is situated in the Gulf of Mexico, around 200 km from New Orleans. This big project was only possible to succeed because of the application of high-strength steels of the grade S460M-Offshore (about 2200 t used) in the area of especially constructed elastic flexible joints. These flexible joints permit the tower to adapt to the movement of fluxes and waves. The plate thickness used for this construction was 90 mm.

- Siri (Figure 27)
  Siri is situated in the north-western part of the Danish sector of the North Sea, around 220 km from the coast. The 104 m-long legs have an outer diameter of 3.5 m and a single weight of 800 t. The jacking system is characterised by a special locking mechanism, which enables the platform to be temporarily a fixed structure. The steel grade S690Q-Offshore, for which improved fracture thoughness properties had to be approved, was for the first time used for this kind of construction.

At present the offshore grade S500TMCP, for which the same thoughness properties as for lower-strength steels are required, is being prepared for application (e.g. the Grane-project in Norway). In addition, the yield strength grade S690Q-Offshore is more and more used. However, many open questions concerning crack resistance and corrosion fatigue have to be clarified prior to a wide spreading of this very high-strength steels.

Perspectives

Today, the designers of constructional steelwork and offshore structures can choose from a nearly unlimited program of heavy plates with regard to dimensions and steel grades.

Dimensions:

- thickness between 8 mm and 250 mm
- width between 300 mm and 5200 mm
- length between 6000 mm and 36000 mm
- weight of single piece up to 60 t

Steel grades:

- General structural steels S235N - S355N incl. offshore-grades and LP-plates
- Fine-grained steels N S275N - S460N incl. offshore-grades and LP-plates
- Structural steels with improved atmospheric corrosion resistance S235W - S355W incl. LP-plates
- Fine-grained steels TM/TMCP S355M - S460M incl. offshore-grades
- Water quenched and tempered structural steels S460Q - S690Q incl. offshore-grades

By this program nearly unlimited opportunities are offered to designers in order to combine optimal dimensioning and design of the building as well as efficient fabrication properties with regard to an economical and competitive construction. The current delivery programs of the plate products accomplish the demands and the desires for the next coming decades.

The future developments of heavy plate technology for steelwork and offshore constructions are characterised by the user's desire of facilitating further reductions of fabrication costs using further improved heavy plates. Additional higher requirements on the homogeneity of the mechanical and chemical characteristics and on the dimensional tolerances and flatness signify a great challenge for the processing and rolling technologies of the heavy plates.

References

/1/ Richter, K. and H. Schmackenpfeffer, Fabrication of long-profile-plates and their application in bridge construction, Stahlbau 57 (1998), No. 2, p. 33-38.

/2/ Borovikov, A. et al., Possibilities of the application of thickness variable plates at the production from steel structures and cranes, Stahlbau 63 (1994), No. 4, p. 101-104.

/3/ Streißelberger, A. et al., Thermomechanical rolling with accelerated cooling for the production of structural plates, Stahl und Eisen 111 (1991), No. 5, p. 65-73.

/4/ Streißelberger, A. et al., Erweiterte Nutzungsmöglichkeiten der thermomechanischen Behandlung von Grobblechen, Stahl und Eisen 117 (1997), No. 4, p. 49-57.
/5/ Hubo, R. and F.E. Hanus, Thermomecanically rolled heavy plates for constructional steelwork, Stahlbau (1994), No. 3, p. 84-89.
/6/ Hubo, R., Stähle für den Stahlbau, DASt, Berichte aus Forschung, Entwicklung und Normung, Vorträge der Fachsitzung 1, Deutscher Stahlbautag Bremen 1996, p. 35 - 40.
/7/ Ladberg, W., Commerzbank Hochhaus Frankfurt am Main, Bauingeniuer 72 (1997), No. 5, p. 241-252.
/8/ Sischka, J., Sony Center Berlin, Stahlbau Gebäude F, Tagungsunterlagen Österreichischer Stahlbautag, Insbruck 1999.
/9/ Kuhlmann, U., Developments in composite bridge construction, Stahlbau 65 (1996), No. 10, p. 331-337.
/10/ Bornscheuer, B.-F. and S. Eisele, The Nesebachtal-bridge, Stahlbau 67 (1998), No. 11, p. 827-830.
/11/ Reber J.J., Heavy-plate bridges, Stahlbau 67 (1998), No.8, p. 677-681.
/12/ Schwarz, O. and R. Saul, Mainbrücke Nantenbach, Entwurf, Ausschreibung und Vergabe, Bauingenieur (1994), No. 7/8, p. 301-309.
/13/ Schwarz, O. and H. Jungbeck, Mainbrücke Nantenbach, Bau der Vorlandbrücke und der Stromunterbauten, Bauingenieur (1995), No. 2, p. 85-90.
/14/ den Adel, W.A. et al., Erasmusbrug Rotterdam, Bouwen met Staal, Nov./Dec. 1995, p. 26-49.
/15/ Voucriat, J.-C., Pont de Normandie, Bulletin Ponts Metalliques No. 17, OTUA, Paris, p. 185-217.

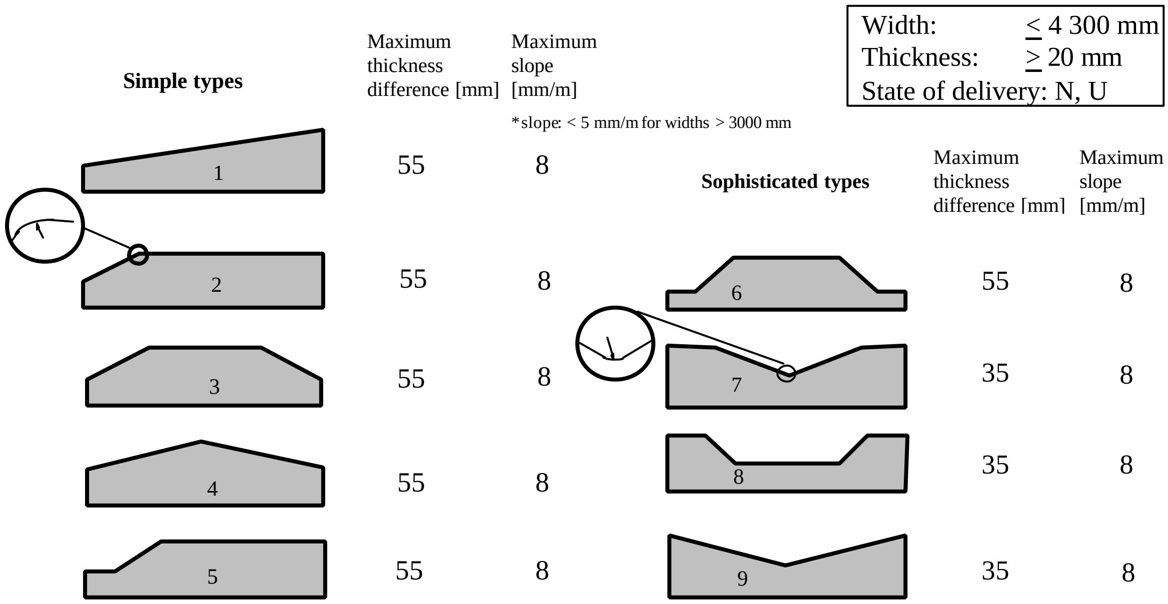


Figure 1: Types of LP-plates

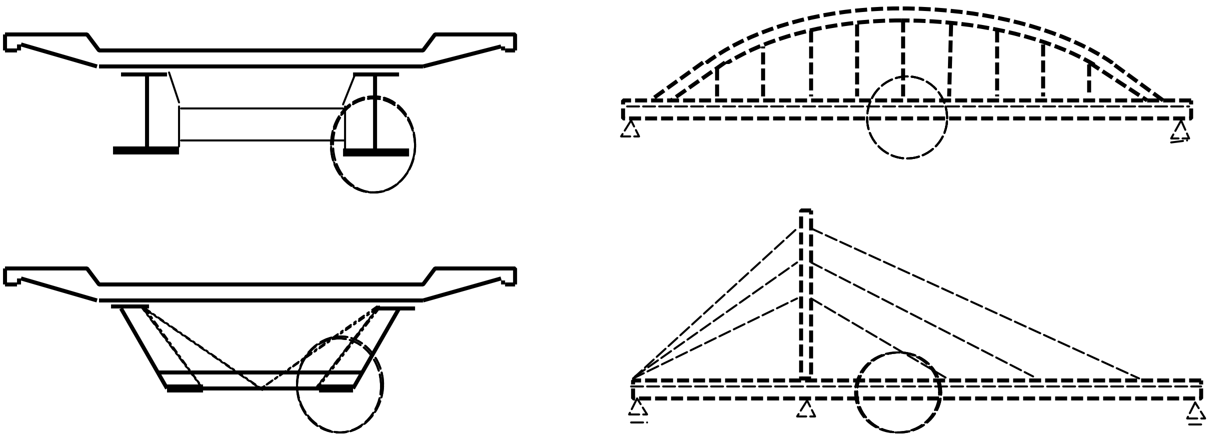


Figure 2: Common applications of LP-plates

Figure 3: Highway bridge Wellingen (A8), D

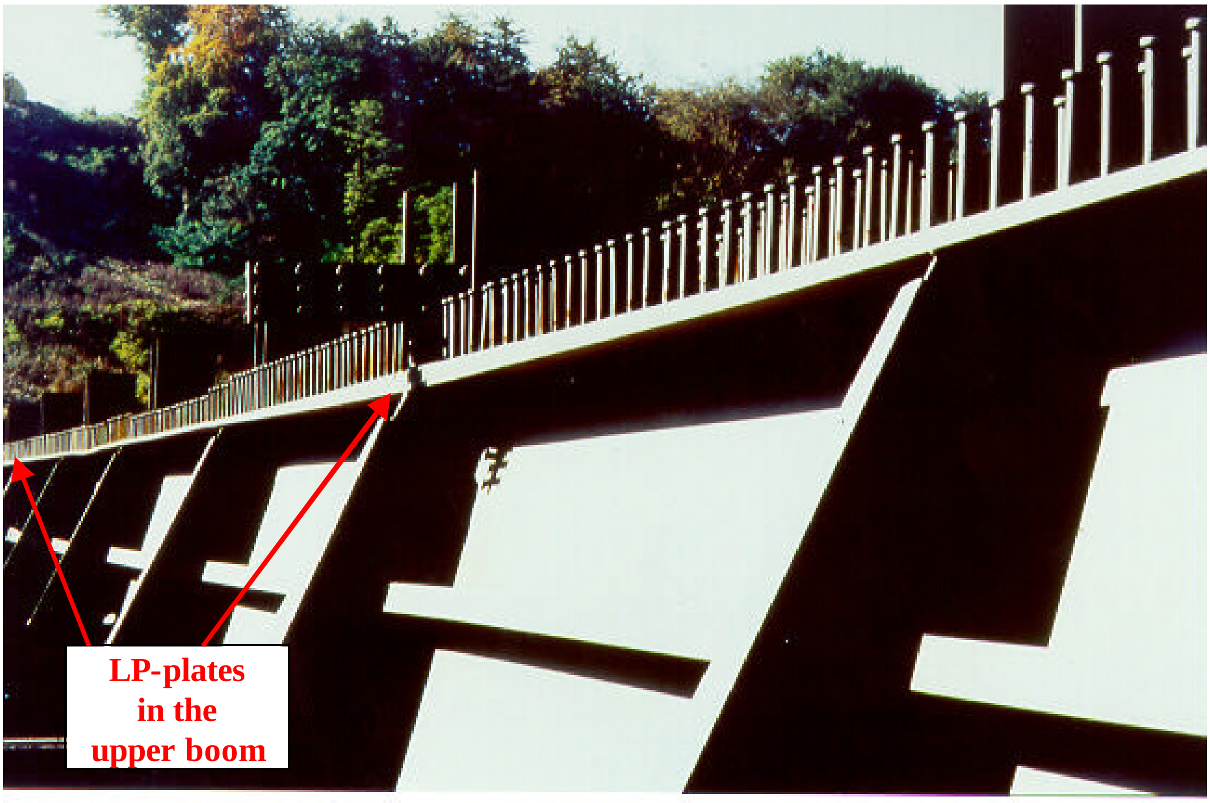


Figure 4: Highway bridge Wellingen (A8), D

Figure 5: Highway bridge Sauertal (A48), D-L

Figure 6: Highway bridge Beekerwerth (A42), D

Projekt	Country	Year	Amount (total/LP)	Steel grade
Maasbridge	F	1983	350/90	S355J2G3
Sauertalbridge	D	1987	11600/400	S355J2G3 mod.
Highway A42(Beek)	D	1988	8500/600	355J2G3 mod.
Viad. De la Somme	F	1990	2600/1047	S355K2G2
Viad. Haute Colme	F	1991	5200/1270	S355K2G2
Highway A2 (Porta)	D	1993	2085/880	S355J2G1W
Wellingen Bridge	D	1995	800/290	S355J2G3 mod.
Viad. de l´Arve	F	1996	3400/1400	S355N/NL
Viad. De Orgon	F	1996	3600/583	S355N/NL
Highway A9(Vockerr.)	D	1997	7000/2400	S355J2G3 mod.
Dintelhaven Spoor.	NL	1997	3000/985	S355J2G3
Riv. Clyst Bridge	UK	1997	100/75	S355J2G1W
Viad. Altwis	L	1998	995/667	S355J2G3
Chanalbridge Magde.	D	1999/2001	23000/4500	S355J2G3 mod.

Figure 7: Reference projects for LP-plates in Europe

Figure 8: Building construction with heavy plates, power station Schwarze Pumpe

<u>Figure 9:</u> Building construction with heavy plates, power station Schwarze Pumpe

<u>Figure 10:</u> Building construction with heavy plates, Commerzbank-Tower (total view)

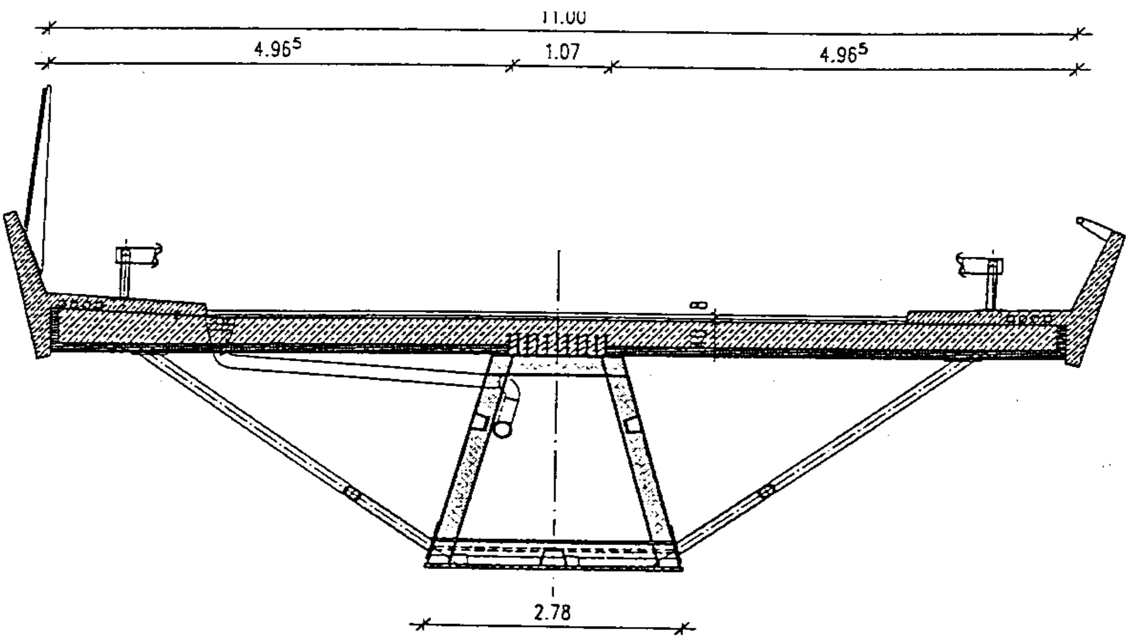
Figure 11: Building construction with heavy plates, Commerzbank-Tower (structure of piles)

Figure 12: Building construction with heavy plates, Commerzbank-Tower (floor construction)

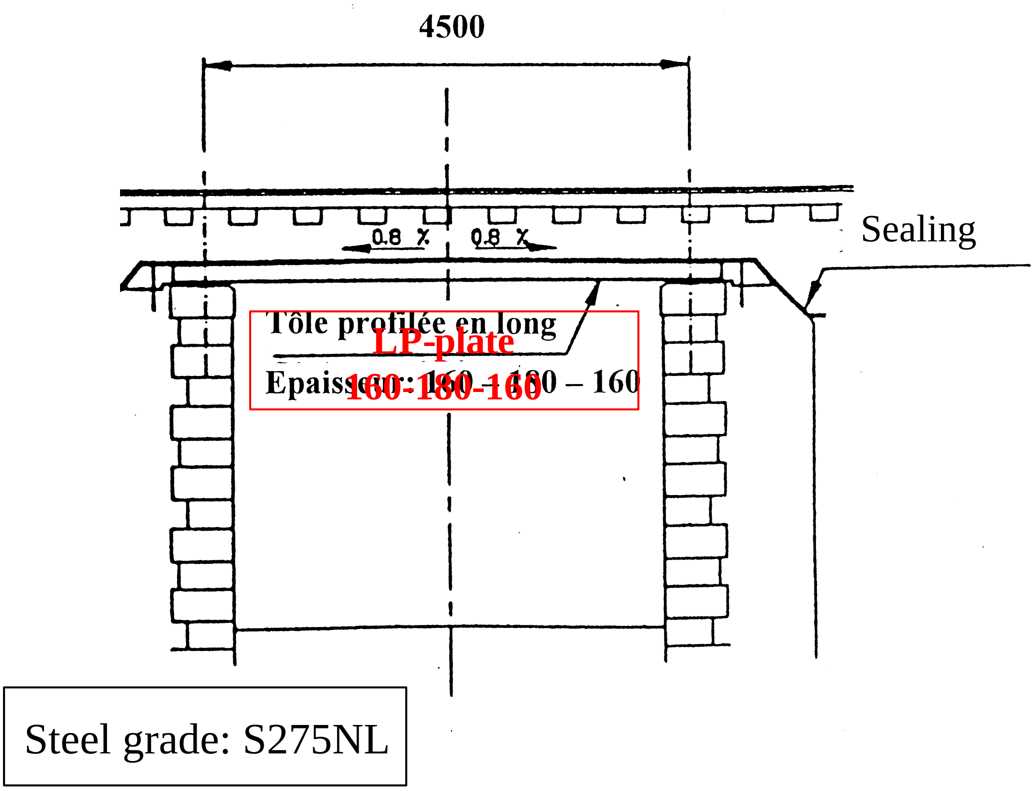
Figure 13: *Building construction with heavy plates, Sony Center Berlin, Building F*

Figure 14: *Building construction with heavy plates, High-speed railway station Frankfurt-Airport*

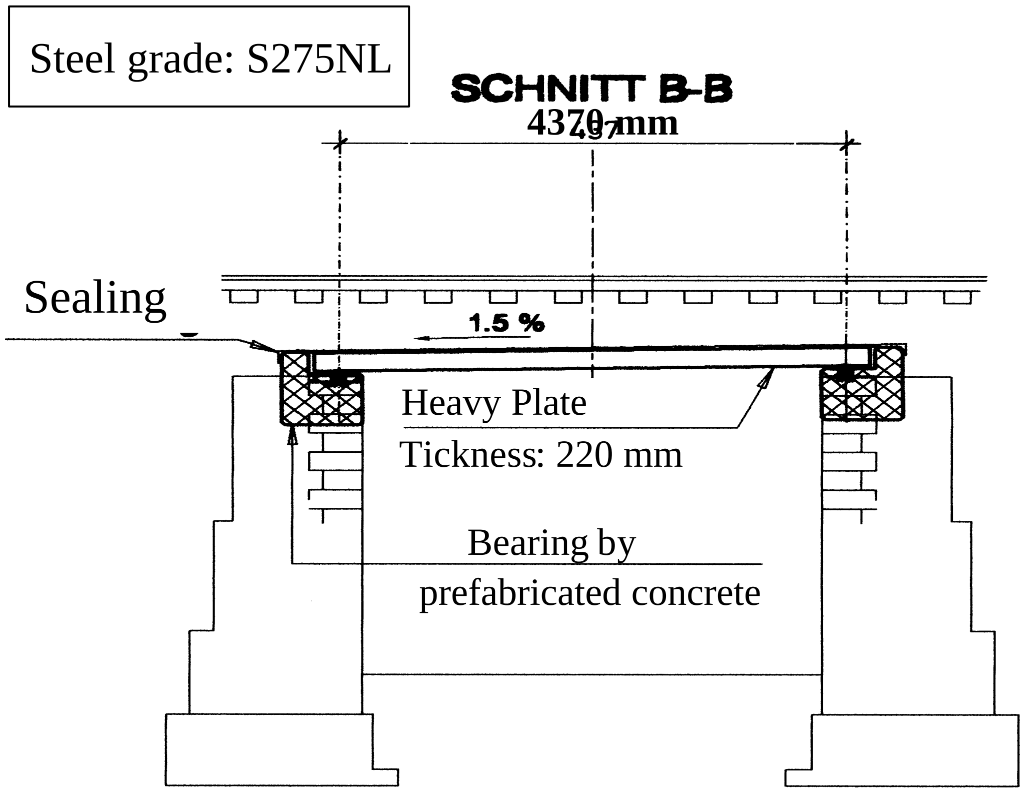
<u>Figure 15:</u> Building construction with heavy plates, High-speed railway station Frankfurt-Airport



<u>Figure 16:</u> Bridgebuilding with heavy plates, box beam section of Nesebachtal-bridge, D



<u>Figure 17:</u> Bridgebuilding with heavy plates, Pont de Moyaz, CH



<u>Figure 18:</u> Bridgebuilding with heavy plates, Creux du Maz, CH

Figure 19: *Bridgebuilding with heavy plates, Nantenbachtal-bridge, D*

Figure 20: *Bridgebuilding with heavy plates, Bridge of Mornas, F (TGV Méditerranée)*

<u>Figure 21:</u> Bridgebuilding with heavy plates, Bridge of Mondragon, F (TGV Méditerranée)

<u>Figure 22:</u> Bridgebuilding with heavy plates, Erasmus-bridge, NL

Figure 23: *Bridgebuilding with heavy plates, Øresund-bridge, DK-S*

Figure 24: *Bridgebuilding with heavy plates, Normandy-bridge, F*

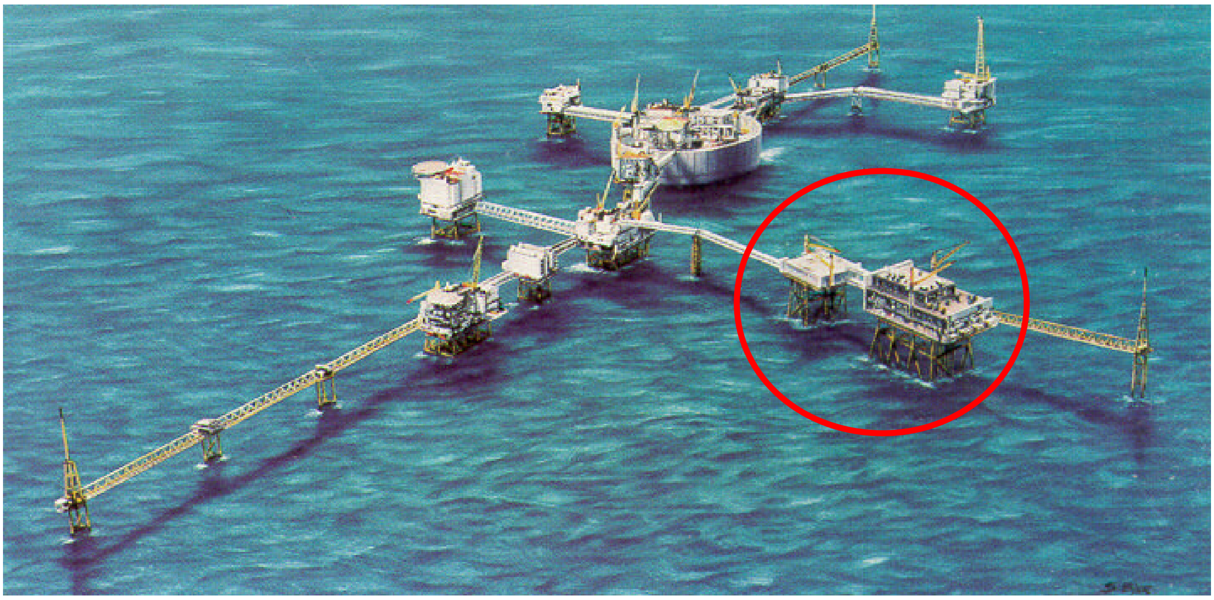


Figure 25: *Heavy plates for offshore platforms, Ekofisk II*

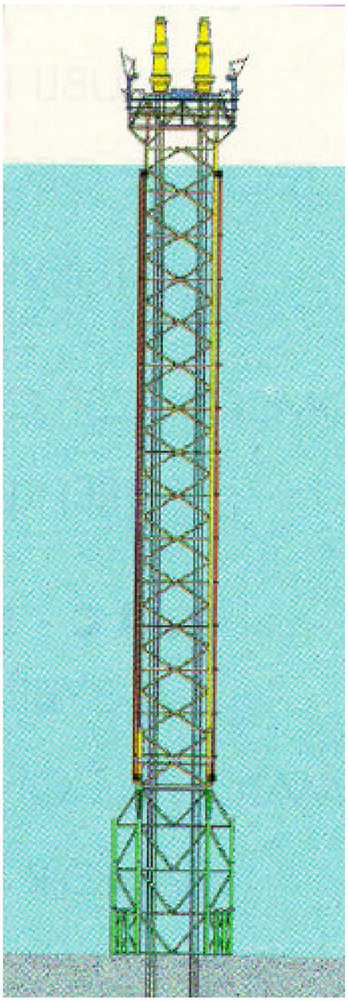


Figure 26: *Heavy plates for offshore platforms, Petronius Tower*

Figure 27: *Heavy plates for offshore platforms, Siri*