# The Crucial Impact of Improvements in Both Steelmaking and Rolling on 19th and Early 20th-Century Building Construction

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## DEVELOPMENT OF STANDARD 'I' AND 'H' BEAMS SINCE THE LATE 1840S

It is generally supposed that it was in the 1845-strike of the Paris carpenters that Ferdinand Zorès first got the idea of substituting wrought iron I-beams for timber for ceiling joists (Belhoste 1996). Thus the first beams of this shape in 1849 were fitted to a new residential building there on the Boulevard des filles du Calvaire. With a web of 140 millimetres they could span up to 5.4 metres (Mehrtens 1887). However it is possible that Zorès did not only start thinking about the I-beam during the carpenters' 1845-strike. It is possible that he might have begun at least his preparation work on the design somewhat earlier. Indeed when we lok closer it seems clear that he was not the only one who had taken part in the design of that standard member which would later become so crucial for iron and steel construction.

Zorès was considering the design at the same time as Mr Chibon, a Paris building contractor with whom he might have been consulted in 1845. Chibon's previous idea was just to take a pair of T-beams already available as standard components, and to add a sheet iron strip for combining them together at their respective webs by riveting it all into a double T-beam forming a standard unit of I-shape. The flange of the upper T-beam then would be used as the compression-resisting top boom and the flange of the lower one as tension-resisting bottom boom. Obviously both men were not really convinced of the practical advantages of this design as they decided instead on a solid one-piece wrought iron member which would have to be rolled and at the same time would make the riveting superfluous. The development of the appropriate rolling technique, however, would take several years to become workable. Thus it was only by 1849 that the rolling mills at Montataire on the river Oise and Fourchambault near Nevers could supply I-beams without any deficiencies. Those soon became quite successful and at least in Paris therefore rather an ubiquitous feature in construction practice. For the time being they mainly were used as ceiling joists in residential buildings, but already in the following year they had also been used by Eugène Flachat for the rafters of the platform shelter at Saint Lazare terminus (Belhoste 1996).

By 1860 the Paris rolling mill of Pétin, Gaudet & Cie. had for the first time managed to get into use an universal mill by which a pair of active horizontal rollers would shape the web and a pair of passive vertical rolls without any drive of their own would shape the flanges, like rails every standard beam was produced by means of grooved rollers. A patent for such rollers already had been applied for in 1723 by John Payne in Britain and in 1749 in France. Three years later the

Swedish engineer Christopher Polhem also made use of them, and by 1766 John Purnell would use grooved rollers for the manufacture of iron rods, bolts, and extraordinarily long shipbuilding nails, an improvement well adapted to both the puddling process Henry Cort had developed in 1748 and the prefabrication of a great many of wrought iron fittings urgently demanded in large numbers by the British navy for their men-of-war (Bosak 1970, Mende 2001). Already by the end of the 18th-century in this regard for example the rolling mills of Cyfarthfa established in 1786 by Richard Crawshay, or at Bradley established in 1784 by John Wilkinson and soon a prominent destination for travellers like the Swedish Eric Svedenstjerna who visited it by 1802, both could make 200 tons of sheet iron, bar, nail, and band iron within *a few weeks* (Davies 1933, Svedenstjerna 1804/1973).

Though by the occasion of the 1867 Paris Universal Exhibition the company of Pétin, Gaudet & Cie. proudly presented a rather giant I-beam of 2.5 tons, with a 1 metre web, a length of 10 metres, and another I-beam with a web of just 280 millimetres but a total length of 32 metres (Mehrtens 1887), the capacities of the French rolling mills still remained under some constraints. Standard I-beams of such a big size not only would remain an exception, but due to the peculiarities of the puddling process it generally would also remain rather hard to gain any satisfying result which in its flawless shape and structure as well as production might actually meet the demand. Whereas constraints on the capacities on one hand could be overcome by the changeover from puddled wrought iron or steel either to ingot iron or ingot steel as well as by more powerful rolling mills able to turn the increasing amount of ingots also growing in size into standard beams, on the other hand it would take rather longer to get not only flawless H-beams particularly with parallel flanges.

Though H-beams of 15 metres length and a web of up to one metre in height could already be rolled by French mills they still had to tackle with rolling fins on the median line of the flange surfaces. To avoid these fins during the rolling process the beam frequently had to be turned around. That factor of course made rolling quite a troublesome procedure and only by 1902 would the rolling mill at Differdingen in Luxemburg succeed in avoiding this imperfection for the first time. These Grey, or Differdingen H-beams as they were called in Germany, however, still featured on both insides gradients of about nine degrees going from the flange edges to the web. It would take a dozen years more, before the efforts to roll standard H-beams featuring really parallel flanges would eventually produce a fairly reasonable result (Cords 1952). The outbreak of World War I would soon put a check upon this development so that in the end at least in Germany standard H-beams featuring parallel flanges only became available in the mid-1920s. Only then was the introduction of the new ways of steel-frame construction really possible and therefore comparatively light but towering multi-storey structures of quite a wide span.

## ROLLING WROUGHT-IRON BEAMS

Albeit Ferdinand Zorès's invention of an one-piece wrought-iron I-floor beam quite obviously would have made a crucial impact and in this regard has to be recognized as a kind of turning point even if it actually had several pioneering predecessors. By 1786 Victor Louis had already used forged iron rods for the first time as basic construction material in his design of the principle couples for the Théâtre Français. For that purpose he combined bars of both flat and quadratic shape into a kind of a double strut frame with straining pieces. The upended flat bars were inserted as rafters while the thinner rods either were used as hanger bars or purlins (Mehrtens 1887). For the suspension of the auditorium ceiling he had proposed a wrought iron tied arch with spreaders both also composed of forged bars each of an appropriate shape. By 1823 Eloi Labarre basically would have adopted this design for the Paris stock exchange (Lemoine 1986) and in the end it would become something like the ancestor of the French truss developed in the mid-1830s by Camille Polonceau for rectangular engine sheds.

Just as Polonceau had at first proposed cast iron or timber for the rafters, only later wrought iron I-beams would be taken instead, elsewhere the use of upended flat bars was continued. Sometimes, as for example in the case of a hippodrome in 1849 erected by Andrea Busiri Vico in Rome, they might have been bent in order to increase their flexural strength (Jodice 1985). Even when by the early 1880s the Thomas-Gilchrist, or basic Bessemer process was going to dominate steelmaking in Germany pushing it to an unprecedented scale, "very often every part of a truss frame and particularly beams, suspenders, and rafters, still will be made from wrought iron rods, at least if no flooring would be wanted" (Mothes 1883).

While at that time this material was mostly rolled, for the roof framework of his Théâtre Français Labarre in 1823 still used hammered bars. He got them from the forges of the Berry south of the river Loire in central France at that time consistently the main supplier for Paris and its environs. In the long run, however, their utilization as components of *Paris flooring grids* would become much more widespread and therefore of quite a lasting influence even beyond the French border (Mehrtens 1887). It was to those flooring designs which Ferdinand Zorès eventually would add his I-beam, and it was this feature that made the *Paris flooring grid* up to the eve of Word War I an internationally influential model (Mothes 1882d). Implementing his I-beams Zorès in fact merely (but considerably) improved a previous design.

Initially the *Paris flooring grid* was consisting of a grid or framework of commercial wrought iron bars instead of wooden flooring beams. Primarily it was used for larger ceilings like those of halls suspending on wrought iron rods from the roof structure above. But as early as 1785 a certain Ango, probably an architect or building contractor, had fitted a house in Boulogne with "floorings of an iron grid consisting of some trussed flat-iron beams connected by a number of crossbracings", shortly afterwards it was considered by the Royal Academy a model to be copied (Mehrtens 1887). Thus Zorès I-beams would improve that structure by making it useful for floors of both a wider span and a heavier load.

Since his innovation, the *Paris flooring grid* mostly was executed in two ways. Either thin iron rods of usually a square shape would be put between a pair of I-beams, frequently at a distance of about one metre, clutching the upper flanges and themselves bearing a tier of flat iron bars upon which then the proper flooring of hollow bricks could be laid. Alternatively the iron rods traversing the gap between a pair of I-beams on both sides could each be fitted by plugging in a cast iron ring previously pushed over each beam. These iron rods would support a tier of thinner ones merely measuring one centimetre in square cross section. The maximum span it was possible to bridge by such a structure was about eight metres. In this case the web would have to measure by 225 millimetres in height and it never should be calculated upon less than the 36th part of the beam's full length (Mothes 1882d).

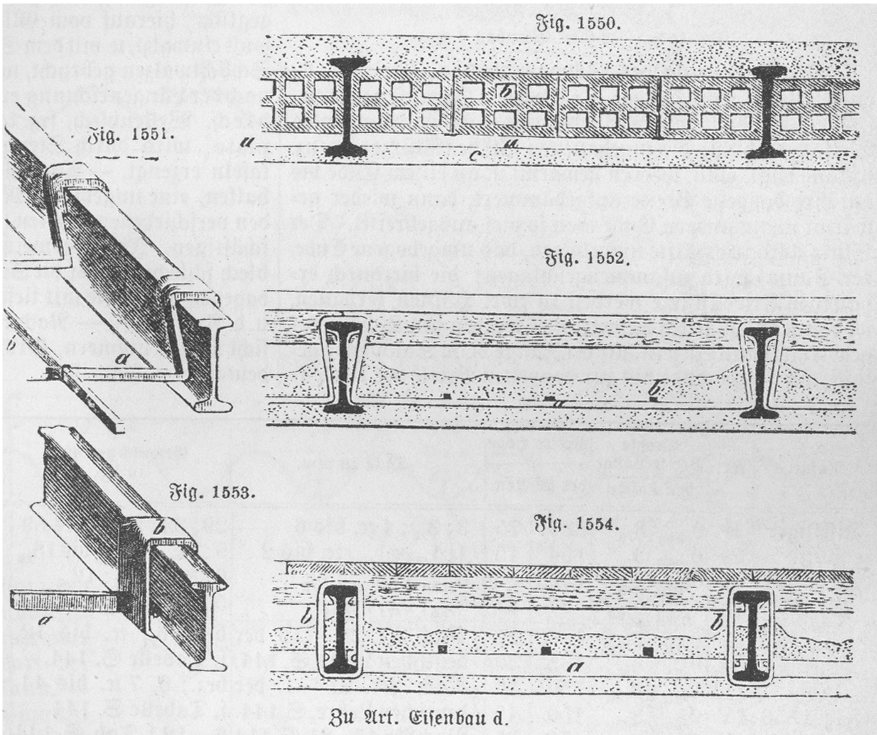


Figure 1. Paris flooring grids comprising I-beams and iron rods of squared shape (Mothes 1882)

Initially bar irons everywhere solely were forged in waterpowered tilt mills. In France, however, by the mid-17th century at the latest waterpowered slitting mills were going to replace the tilt hammer in bar-iron making, at least for the final operations. Comprising a pair of grooved cylinders through which rather thick iron bars, preforged under a tilt hammer into squared shape, could be rolled into those of rather flat shape and besides that another pair of cylinders with sharp-edged gearing grooves by which the flat iron in the end continuously could be cut into thin iron rods of squared shape again, the slitting mill would speed up the production and would make its results more homogeneous at the same time.

This device had initially been developed by the 16th century in the area of Liège to improve the prefabrication of iron bars for the subsequent manufacture of nails demanded in particular by Dutch shipyards. Though for the first time in Germany a certain Johann Friederich Muller had proposed the installation of slitting mills to the dukes of Brunswick as early as 1683, as Emanuel Swedenborg would do again a couple of decades later, and by 1698 the first one was installed in Brandenburgian Neustadt-Eberswalde not least for the prefabrication of gun barrel flat bars, by 1800 there were still only a dozen of them were operating in the whole country (Bosak 1970). As regards sheet iron manufacture the situation here was quite comparable. It was only 1769 when Heinrich Wilhem Remy at his Rasselstein ironworks near Neuwied on the Rhine for the first time in Germany had taken the smoothed cast iron cylinders of a rolling mill for final sleeking the rough sheets under a tilt hammer instead.

Though the Rasselstein ironworks were in fact pioneers in various fields it would take several decades more before they eventually could pass over to puddling with coal in reverberatory furnaces instead of continuing the traditional charcoal hearth process. The puddling process following Henry Cort's pattern was introduced by 1824, just a year after angle iron had been rolled for the first time in an English mill. The Rasselstein works only followed in 1831, after they had previously started to roll flat iron bars in 1825, whereas the first German T-bar was rolled by 1835 in a mill at Warstein on the river Diemel in southeastern Westphalia and not very far away from Cassel.

Both puddling and rolling were progressed the use of shaped iron, first of all in boiler construction but very soon also in building construction. There remained, however, some constraints to overcome. They concerned specific conditions and capacities of manufacture as well as rolling techniques and the properties of wrought iron and its suitability as construction material. To quite a large extent puddling was dependent on the availability of coal both for the process itself and in the form of coke for gaining pig iron in an amount sufficient enough really to profit by the advantages of this refining method, namely the reduction of expenditure and time involved as well as a clear increase in the wrought iron output. As it was assumed that each ton of wrought iron blooms would need at least 1.25 tons of pig iron or iron scrap and on an average 1.8 tons of coal, eventually about seven tons of raw material in all for its production, an appropriate location with favourable transport facilities soon would become a crucial factor deciding whether puddling in the end might be a success or failure. Thus it was not very surprising that from the late 1840s puddling works and rolling mills alike were beginning to concentrate in expanding industrial districts like the Rhine-Ruhr area.

For gaining rolled wrought iron sheet or rails and beams of various shapes the bloom first of all had to be forged so that remaining slags could be squeezed out and the bloom compressed into a form ready for a first quick roughing-down, a procedure to be repeated twice and involving one turn of 90 degrees. For gaining the final shape, however, several steps of a *sealing assembly rolling process* were necessary. Before rolling the profile into its final shape, mill bars, old rails, or scrap had to be bundled and then pack-rolled into a billet of normally about half a ton in weight. By proceeding from blooming to roughing, then cogging, and finally several times finishing the shape wanted would be yielded. During the whole process the material was stretched to the fivefold of its prior length and doubled in its width. This result meant that the tensile strength of the beam in cross direction would fall below that in the longitudinal or rolling direction. Because of the fibrous structure of wrought iron in general, the cross tensile strength across the lamination on the average amounted to only 80% of that in the other direction (Foerster 1902). After all the beam itself would have been only about ninety percent of its original mass.

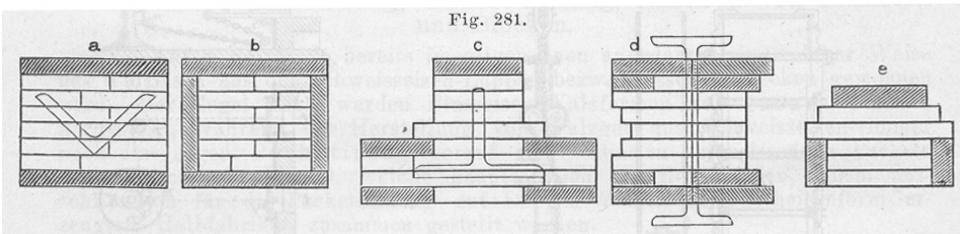


Figure 2. Bundling flat bars for rolling into beams of various shapes (Mehrtens 1887)

The first rolling passes had to be made with greatest compression. During the whole process, however, special attention would always have to be paid because otherwise considerable faults could be the inevitable result. In particular the rather deep grooves of the rolls necessary to get the right shape of the flanges could by their rather different peripheral velocities make an irregular stretching would cause irregular crowding in the material and therefore in the end would induce stresses diminishing considerably the strength of the beam. That way they would cause deformations and even cracks, particularly between the web and the flanges. One possible way to escape these unpleasant results was on one hand to try a compensation in the compression within the roll nip between the grooves, and on the other hand to roll the L-beam with its angle legs symmetrically either falling or rising, whereas an I-beam always must be rolled horizontally to its final shape. By using this rolling position the differences between the peripheral speed of the groove surfaces could be minimized. T-beams which in this regard generally had even more problems, were therefore at least in France usually cogged with Y-grooves and only then finished to their T-shape. In fact, it would only be the universal mill with its pairs of both active horizontal and passive vertical rolls which would help solve that problem. It was the French company of Pétin, Gaudet & Cie., meanwhile at Rive de Gier, starting by the 1860s with an universal mill by which the horizontal rolls would shape the web while the vertical rolls by the same time would shape the flanges of the I-beam (Mehrtens 1887).

## THE RISE OF INGOT STEEL TECHNIQUES

The first I-beams in Germany were rolled only in 1857 on the Ruhr by the *Phoenix* mill. Those beams, however, would almost solely be used for bridge construction, in shipbuilding, or for the chassis of railway wagons. It seems rather significant that at the same time even roof structures of an advanced iron design would still have either had cast iron rafters and wrought iron rods for the purlins, sometimes with wrought iron flat bars or T-beams for the rafters, and round rods for suspenders (Mothes1882c). Wherever wrought iron girders had to serve as members of flooring structures subject to increased safe loads, however, with almost without exception plate girders or lattice beams, were used instead of solid I-beams. As composite structures of various panels, L- and sometimes alsoT-bars, however, both would always need rather time-consuming riveting before use. Almost the same was the case with wrought supports where a pair of [-bars or more slender I-beams by riveting clasps on their flanges had to be assembled into an unit before they could be used.

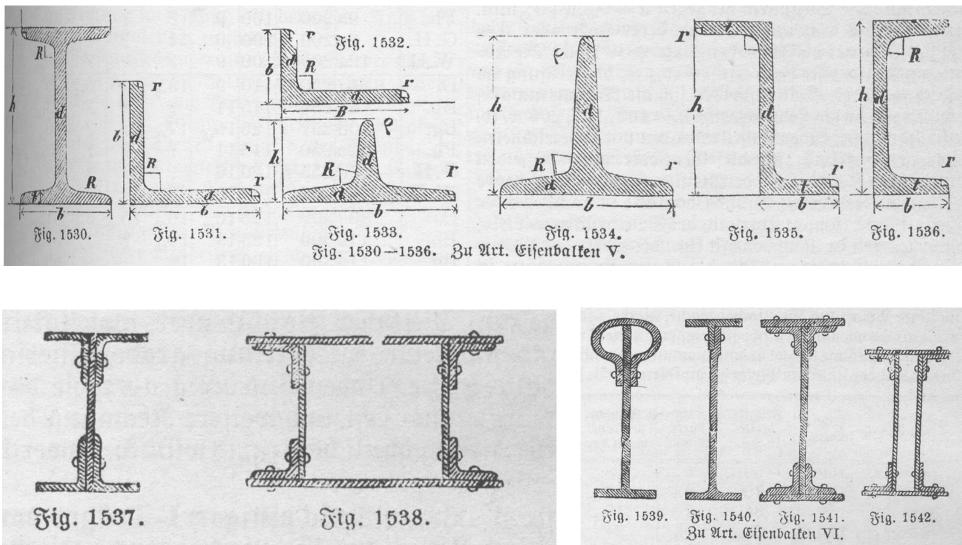


Figure 3. Solid beams rolled and plate beams fitted by riveting (Mothes 1882)

By the 1880s iron (and even now steel) had become one of the main construction materials, particularly because the scarcity (and the therefore rising prices) of timber, but also because of their advantages in durability and strength which, even compared to the much more expensive oak wood, both would allow to take less material for the same expected load(Mothes 1882b). Meanwhile, too, the leading mills and associations of engineers in Germany had agreed to a catalogue of standard beams which then soon would become declared obligatory standards by the authorities (Mehrtens 1887).

By 1862 *Krupp* in Essen started rolling rails of Bessemer ingot steel. Though compared to puddling the Bessemer process enabled a gain of about a fiftyfold of material within the same time, even if the time demanded for melting down the pig iron in the cupola furnace prior to charging the

Bessemer converter was taken into account, however, initially the Bessemer process was not as efficient as expected. With Krupp the Bessemer ingot steel sometimes still seemed to be too solid for the rolls so that they would have fractured (Bosak 1970).

The leading German joist rolling mills therefore either would start by the mid-1870s with open hearth furnaces or at least very soon after their late 1860s' experiments in the Bessemer acid process switched over to them. Leaders like the *Burbach* works in the Saar basin or the *Gutehoffnungshütte* at Oberhausen in the west of the Ruhr district by the early 1880s both added a Bessemer basic plant as the basic process was more appropriate to the rather rich deposits of phosphorous ores, mainly to be found in the north of Lorraine by 1871 ceded to Germany.

The Gutehoffnungshütte, or the GHH by abbreviation, had tried the Bessemer acid process for both her rolling mills as early as 1876. But as late as 1868 this firm also had put a second steel mill into operation based on the basic open hearth process. The smaller mill was rolling about 1 500 tons of light beams each month whereas the bigger mill was able to roll about 5 000 tons of heavy beams within the same time (Woltmann and Frölich 1910). By 1885 a new beam mill was installed where small I- and [-beams could be rolled which since 1877 were already being supplied by the *Dortmunder Union*. In both cases, on the other hand, these beams had been almost solely used either in the companies' own bridge construction shops or sent to the shipyards on the coast where they replaced British imports (Johannsen 1929). In 1888 *Dorman Longs' Britannia mill* was opened. From 1896 solely open hearth steel ingots were used for beam rolling in Britain while in the opposite direction wrought iron joists were sometimes still imported from Germany or Belgium when they were occasionally needed (Hurst 1990).

Although both the open hearth and the Bessemer acid process provided increasing amounts of steel to roll, the ability to meet the demands of the construction firms as consumers of I-beams still depended on the availability of an universal mill. The GHH for example by 1893 would have disposed of its universal mill. Without such a mill rolling I-beams, or later on even rolling H-beams with both broader and parallel flanges and without any flaws, in constant dependability was almost impossible. As their shape made splicing much easier, those beams, however, were an inevitable prerequisite for any considerable improvement to steel framed construction.

## ROLLING TECHNIQUES FOR PARALLEL FLANGE H-BEAMS

The first key improvements in rolling H-beams, the flanges of which no longer had the inward inclination anymore which prevented quick and easy splicing of joists and supports alike, had of which been made by the mid-1880s in the United States. Nevertheless avoiding the burrs on the axis of the flange surfaces remained quite difficult if between each finishing pass the beams were turned frequently through 180 degrees. In this regard in 1897 Henry Grey gained a first success but only with the unpleasant side effect that the beams would leave the rolling mill at the *Ironton*

*Structural Steel Co.* in Duluth on the Lake Superior, where he was working at that time, considerably bent. It was Max Meyer of the Differdange ironworks in southern Luxemburg, who had previously visited the Duluth mill, who would succeed in 1902 in sustainable defeat of such flaws, American mills like by 1906 that of *Bethlehem Steel* would try rolling Grey or *Differdingen H-beams* anew (Cords 1952).

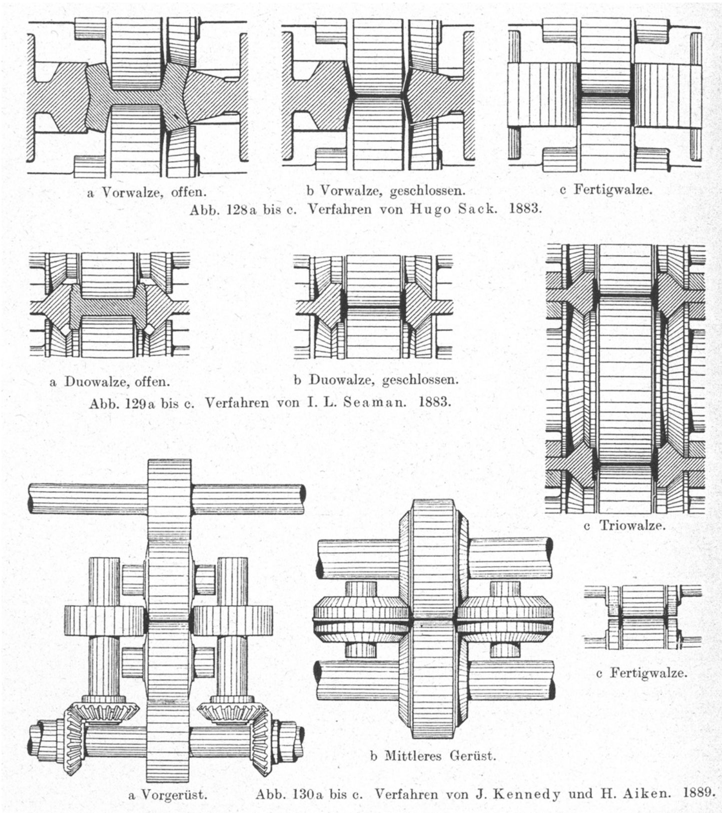


Figure 4. Types of universal mills for rolling I-beams, 1883-89 (Johannsen 1929)

Although the great rolling mill at Bethlehem Steel could make 1 000 tons of standard H-beams a day, for the time being it did not overcome the inclination of the flange facing above nine percent. That was still a considerable disadvantage in steel construction. It would take eight years more until July 1914 when the Peine mill, about half way between Hanover and Brunswick on the railway line running from Cologne and the Ruhr to Berlin, managed to avoid that imperfection for the first time. "Though the web still was somewhat undulated it could be clearly recognized, however, that the new rolling technique would have been right. …By using the new H-beam rolling mill of the firm Klein Bros from Dahlbruch in Westphalia H-beams with parallel flanges and no inward inclination of their facings could be made in a sufficient way whereas prior experiments made by Hugo Sack form Rombach in Lorraine would have remained imperfect and that technique therefore became abandoned" (Treue 1960). The main feature of the *Peine H-beams* of course was in fact that their shape would display only a very small quadrant in the right angle between the web and the flanges.

Due to the imminent outbreak of World War I only 1.5000 tons of H-beams monthly could be rolled and in 1918 production would be interrupted for two years. It was only in 1920 that their production could be started again. But the capacities at Peine were too small for a long time to make a considerable impact on German steel construction. On the other hand, however, the capacities of the bigger joist rolling mills could not be fully exploited before 1924 with the Dawes' loans from the United States which would stimulate anew steel construction projects not at least for department stores, large cinemas, office towers, and even residential buildings (Hawranek 1931, Neumann 1995).

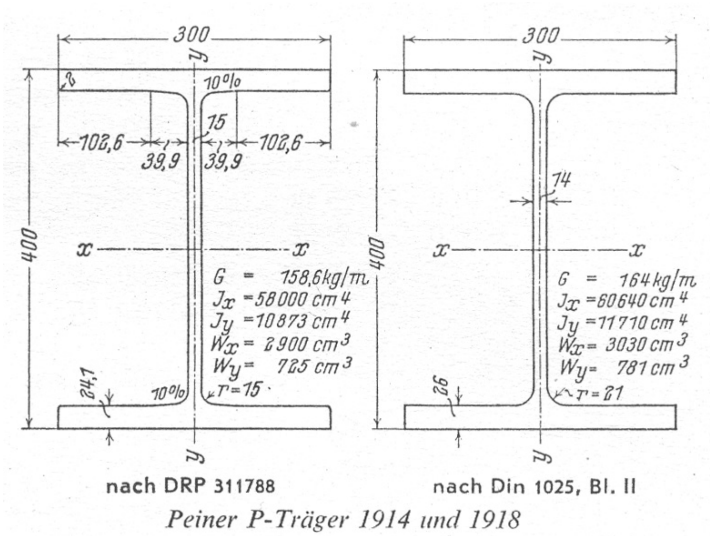


Figure 5. Peine H-beams, 1914 and 1918 (Cords 1952)

In all these cases standard H-beams and in particular those of the Peine shape made sure that joists and supports could be fitted to a common frame structure. Such a design would promote multi-storey self-supporting steel skeleton sructures without needing rather thick walls as a kind of supporting cladding but instead allowing for the light and transparent curtain-wall. It also permitted bridging of spacious floors in a free span which was often requested for department stores as well as for cinemas, and exhibition halls, which from the mid-1920s were being erected in the commercial centres of expanding cities. All these building types eventually required joists which were different to plate girders being both advantageous in displaying a lower web for an improve incidence of day-light, or even a less shady lighting in general, and by less time-consumption in their fitting while promising a considerable reduction in construction costs.

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