The Influence of the German Railways on the Birth of Modern Timber Engineering

Mathias Seraphin

INTRODUCTION

In the early years of the railways, most of the buildings and bridges were built of wood for economic reasons. Before reaching the break-even-point the new transportation system had to construct its facilities at low cost and in the shortest time possible. Later, more representative stations were built of stone with halls of steel and glass. A majority of wooden bridges were replaced due to fire prevention in North America and Europe before the end of the 19th century.

On the other hand, the lack of corrosion resistance against engine fumes and the high costs of maintenance soon became obvious. A milestone was the ‘Reichseisenbahnhalle’ for the 1910 World Exhibition at Brussels built by Hetzer which had laminated frame girders of 43m span. In 1911 the Swiss Railroad Company ordered a central engine shed at Bern and advised all subdivisions of the company to use timber instead of steel for halls and sheds. In 1913, Copenhagen Central Station was built with wooden halls by Philipp Stephan. These halls still exist like those at Malmö from 1922 and Stockholm from 1925 built by Hetzer.

During World War I the construction of Stuttgart Central Station had been stopped. After the war, work on the halls was continued, however, not in steel, as planned, but in timber construction: for economic reasons.

At that time the newly founded “Deutsche Holzbau-Verein” brought in the concerns of modern timber engineering at the ‘Board of Normalisation of German Industry’ (Normenausschuss der deutschen Industrie – NDI). Due to a series of spectacular collapses, the panel was paralysed in the struggle between old-fashioned traditionalists and euphoric new timber protagonists: security and feasibility seemed incompatible.

Karl Schaechterle, responsible for the construction department of the Deutsche Reichsbahn, initiated scientific studies on timber construction linking the practical knowledge of Karl Kübler AG from Göppingen with the theoretical and experimental possibilities of the Materialprüfanstalt, associated with the Stuttgart Technical University nearby. The studies proceeded under the leadership of Otto Graf who followed the heritage of August Lang, from Hanover who was the first to do scientific experiments on wood as a construction material.

The 1926 ‘Preliminary Specifications on Timber Constructions’ developed by the Reichsbahn for the Stuttgart Central Station project finally brought the break-through. Once a guideline given, DIN 1074 ‘Bridges in Wood’ followed in 1930. In 1933, DIN 1052 ‘Construction in Wood’ set a general standard in timber construction based on engineering principles.

Up to the 1950s most of the railway facilities in Germany, Switzerland and Scandinavia were built in timber construction for their advantageous resistance against corrosion caused by locomotives’ smoke gas. Even though being a preferable targets for air strikes at the end of World War II an astonishing number of wooden railway sheds still exist, showing the high quality and functionality of these 80 year old halls now being menaced by their owners: as German Railways try to develop their real estate in prime locations while closing more and more railway workshops.

EARLY RAILWAY BRIDGES

In the beginnings of railway construction, most of the bridges and buildings were performed in timber construction for economic reasons. The early railway lines had to be built in a very short time and with rather small budgets as the profitability of the new transportation system wasn’t yet proven at that time (Marrey 1994, p 90).

So the bridges of the first European and North American railway lines were normally built, until approximately 1860, in timber construction, for instance, Paris-Versailles, the Bavarian North-South-Railway and in the United Kingdom: the Great Western, the South Devon, West Cornwall and Cornwall Lines projected by Brunel (Brockstedt 1994, p 100; Brown 1994; Marrey 1994, p 90; NN 1850). The earliest wooden railway bridges were often based on different types of composite arch structures: in the UK, Brunel created a variety of different structures e. g. a truss-stiffened polygone arch at Landore viaduct; in France the system of Armand Rose Emy, with piled thin laminates, jointed by clamps and bolts were used; in Germany we find tied arches developed by Pechmann.

In North America, trestle bridges were widespread, overcoming the obstacle by multiple storeys of short spanning repeated pilings. Whereas this type of construction was used in Europe as an interim construction buried in the embankment in completing the track, in America it was widely used up to the 20th century (Sembach 1990, p 95). In 1925 the Salt Lake Bridge in Utah was reported to be ‘the longest wooden bridge of the world’ with a length of 35 km (NN 1925, p 23; NN 1927, p 508).

Besides these rather simple, additive trestle bridges, innovative wide spanning bridges were also developed in North America, e. g. the systems by Town, Long and Howe, showing the way to the calculable framework systems. In Foersters Allgemeine Bauzeitung, Stevens reports in 1839 for the first time in German on American bridges. The consecutive famous reports of Ghega (1845) and Culmann (1851) make these bridges well-known in Europe, where lots of Howe's bridges were accomplished thereafter. We find Howe's system used on the bridges on the Moscow-Zarskoje-St. Petersburg line, enhanced by Yourawski who calculated and erected a continuous beam of 600 m based on a 60 m span for Msta bridge in 1848 that stayed in service for some 40 years (Timoshenko 1953, Yourawski 1850, Barz 1943, p 108). In Germany, part of the Iller Bridge near Kempten built on the Howe system still exists, now used as a footbridge.

By the end of the 19th century wooden bridges in Europe and North America were generally replaced by iron constructions. High maintenance costs of the uncovered bridges and several fires due to embers falling or flying sparks from the engine banned wood as a construction material for bridges in the guidelines of several railway companies, restricting it to branch lines only. As early as 1850 German railway engineers object to wooden bridges; from 1865 onwards, the Technical Regulations of the Association of German Railway Companies prohibit timber bridges for main lines (Brockstedt 1994, p 101). At the beginning of the 20th century, and in the UK in 1937, the last wooden railway bridges in Europe are set to be taken out of regular operation (Dietrich 1998, p 106).

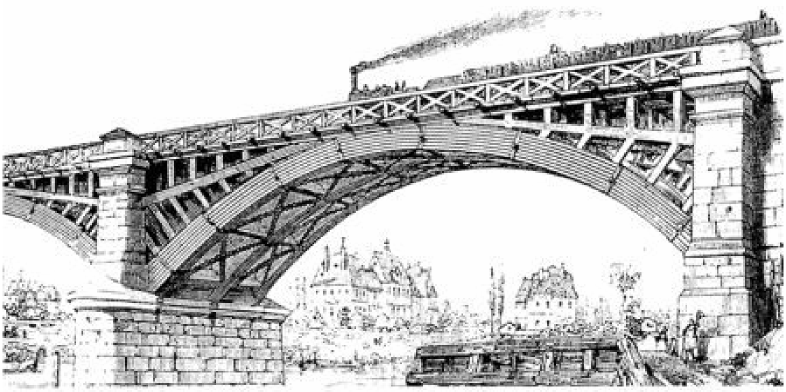

Figure 1. Railway Bridge, Emy system, near Maisons Lafitte ca. 1840 (Marrey 1994, p 90)

Figure 2. Railway Bridge, Pechmann system, near Augsburg ca. 1839 (Sembach 1990, p 67)

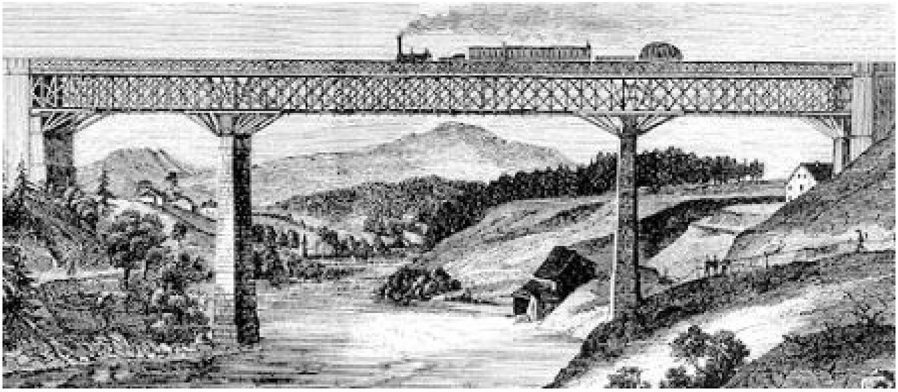

Figure 3. Auxiliary Trestle Bridge between near Plattling ca. 1875 (Sembach 1990, p 96)

Figure 4. Iller Bridge Howe system near Kempten (Dietrich 1998, p 101)

MILITARY AUXILIARY BRIDGES

Some special qualities predestine timber for auxiliary constructions in cases of damage or where time is very short: wood is less heavy then most other building materials, timber is available next to almost any railway track in Europe, it can be cut, transported and shaped by simple and mobile tools, the erection of a building can be done by semi and even unskilled workers under the guidance of a few specialists. Last but not not least: the adaptation of a construction principle to the particular issue is much easier than with other materials like stone or steel for it needs no prefabrication.

The German-French War of 1870/71 is the first war in Europe where troops and armaments were mainly moved by train. Therefore it became extremely important to keep supplies coming by maintaining the railway lines against the enemy's attacks. Sapper units were implemented to repair railway tracks, especially bridges that were the most exposed and vulnerable targets (Stoy 1942, pp 129ff).

Obviously for reasons of secrecy, there were no publications on sapper auxiliary bridges in imperial Germany until the end of World War I. Even in the following years, there was no reporting on bridges for military purposes. This might have been taboo in the first years after the defeat and the temporary demilitarisation in Germany. Later on, during World War II, we find some reporting on actual timber auxiliary bridges, referring as well to those of the wars of 1870/71 and 1914/18 that evidence the importance of sapper constructions for the development of timber engineering. Worth a foot note is the Hindenburg Bridge crossing the Dubissa in Eastern Prussia in 1915. It was once more a trestle bridge 670 m in length and 42 m in height. Stoy classified the bridge: "not ingenious, not economic, but useful". So he ‘follows’ Ludendorff who called it ‘a work of art’. We feel that the publication of the former secret war bridges that Stoy escorted by lectures and public talks, was obviously part of the publicity campaign at war time (Stoy 1942, pp 129ff; Fiedler 1939, pp 28ff, 63ff, Barz 1943, pp 105ff).

> [For the sapper] there is only one rule that reads as follows: The bridge has to be built or to be restored in shortest time, in a load-carrying capacity sufficient for the purpose. That means that the rapidity of the set-up of operability of the blocked railways and roads depends essentially on the rapidity of the reconstruction of the destroyed bridges. On the same account, there is no building material to be handled with little preparation at wartime as easily and therewith as fast as wood.
>
> (Stoy 1942, p 129)

In the armament of the German Empire, structural solutions could be developed in a niche free from civil building regulation, just based on structural analysis. The army was very interested in new technologies for building in big dimensions, fast, at low costs and with local material and simple means. Auxiliary bridges to replace destroyed railway and other bridges as well as wide-spanning halls for storage, aircrafts and airships were supposed to get along without the otherwise disposed steel. As a matter of fact, we realise a great leap ahead in timber construction: just after the war, hundreds of applications for patents were filed in the years 1919 to 1922, whereas there were only very few on timber construction in the decade before the war (Seraphin 2005).

There was also a strong impulse towards standardisation concerning the entire war economy, including the construction sector. It was due to Heinrich Schaechterle (1887-1917), chief engineer of the Royal construction agency that was installed in Spandau in 1916, that right in the middle of the war, determined, result orientated and widespread standardisation projects were launched. At that time he was assigned by the chief of the war department, General Groener, in line with the Hindenburg plan to increase the mass production of weapons, ammunition and material by standardisation. (Schaechterle 1943, p 36) When Karl Schaechterle formulated this notion in World

War II and in the ambiance of the Organisation Todt, the logistic institution of the 3rd Reich, warfare again pushed the development of timber construction for auxiliary bridges:

After a prototype with nailed truss girders in Adorf, erected and published by Stoy in 1928, Gaber and the Material Testing Institute at the Technical University Karlsruhe were commissioned by the army's department of weaponry (Heereswaffenamt) in 1935 to execute trials on auxiliary bridges with nailed girders. The technique seemed to be unbeatably fast and simple i.e. ideal for the military purpose. However the testing showed that the alternating loads of the trains tended to cause nail fractures and diminish seriously the load-bearing capacity of nailed timber constructions. Therefore nailed trusses were furthermore only used for auxiliary bridges where fatigue-strength was secondary. The longest span executed in this manner (admittedly a road bridge) was the war bridge on the river Rhine built in 1940 between Kehl and Strasbourg spanning some 50 m in width, identified in 1951 by Borchard. Stoy, in 1942; obviously referring to the same bridge, described it as "a bridge over a large German river" for secrecy reasons (Borchard 1951; Gaber 1935; Schaechterle 1943: Stoy 1928, 1942).

In World War II road bridges became more important, because mobility of the troops had become more individual (tanks, lorries) compared to World War I. At that time railways got medium term logistic tasks, where durability weighted more than just set-up time (Barz 1943, pp 105-110). Thus, the auxiliary bridges systematically developed by Siemens Bau Union with Schaechterle and Riedl in 1942/43 were aimed primarily at road bridges, using claw-plate-dowels. Klingbeil reported that in the Russia campaign in 1942, 3267 auxiliary bridges with an accumulated length of 168 km had been built, most of them mounted of prefabricated unified trusses of 5m in length to be added to free spans of 5m, 10m or 15m, to be set side by side according to the load specification up to bridge class 60 (tank). (Klingbeil 1943, pp 241-244) In 1945/46 a timber bridge of this type replaced the destroyed bridge over the river Elbe near Wittenberg. Some other bridges were rebuilt as nailed truss constructions e. g. a bridge over the river Main near Lohr in 1946 and another one near Karlsruhe (Gattnar 1950).

Maintaining the operability of railways in times of war was a strong motive for the development of wooden bridge construction in Germany from 1870 to 1945. Although there was no renaissance of regular railway bridges made of timber, the German engineers' experience in World War I, who normally had not dealt with timber construction before, was the precondition for the fulminant rise of modern timber engineering after 1918. Standardisation in general construction as well as in timber construction was initialised at that time. In the years before and during World War II all the activities of research and development in timber engineering were embedded in the logistic Organsitation Todt, after the founders death, led by Albert Speer (Fritz Todt 1891-1942).

Worth closer examination are, beyond doubt, the numerous scaffolds and centrings for bridge construction that have to be omitted in this article, however worth mentioning are the dissertation of

Erich Gaber (1914) and the famous scaffolding of Richard Coray (1869-1946), a Swiss Carpenter who worked between 1897 and 1940 on Bridges like the Gmündertobel Bridge (1905), the Langwiesviadukt (1913), the Bagdad Railway (1916) and later on Maillard’s famous Salginatobel Bridge. For Coray refer to Jürg Konzett’s Research (e.g. Konzett 1999)

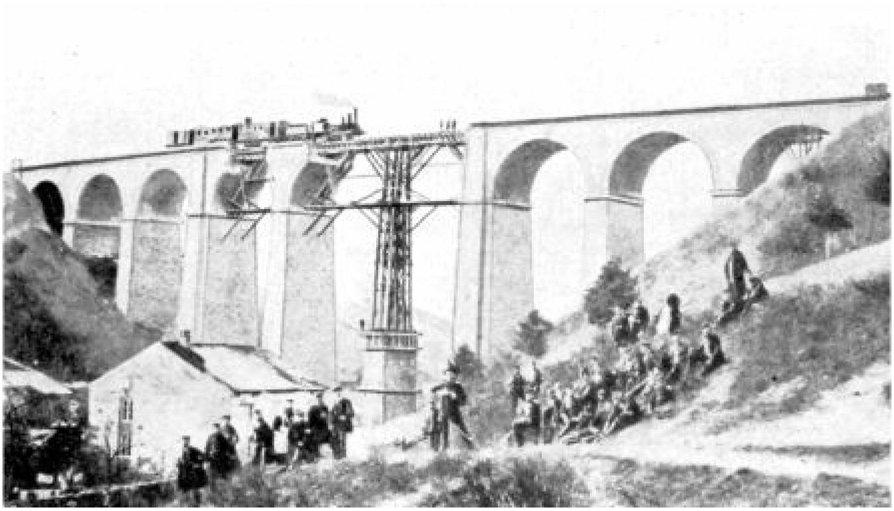

Figure 5. Auxiliary bridge near Xertigny in northern France 1870 (Stoy 1942, p 134)

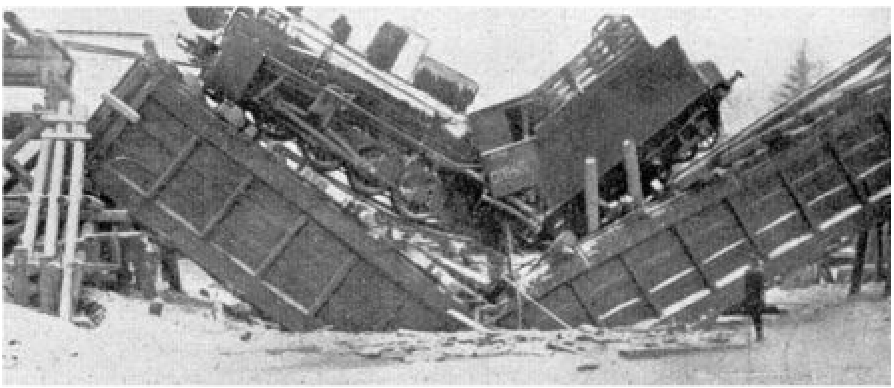

Figure 6. Fatal test loading of a reused plain beam 1919(Barz 1943, p 108)

STATIONS, SHEDS AND WORKSHOPS

Timber had never really stopped being used in the construction of railway facilities. In analogy to bridges, early station buildings had been built in timber construction e. g. Munich Central Station by Bürklein in 1847 and Lewis Cubitt's Kings Cross Station, 1851/52, both using a sort of laminated arch, Bürklein's glued and nailed similar to Emy’s or Wiegmann’s systems, Cubitt's similar to Paxton's as used in the transepts at the Chrystal Palace a year earlier.

In the second half of the 19th century cast iron and steel construction displaced wooden construction as to the representative halls of the grand stations. Wood seemed to gain an old-fashioned appearance. The second generation of central stations were built in steel like Berlin Anhalter Station in 1880, Frankfurt in 1888, Cologne in 1894, Hamburg in 1906 and Leipzig 1915 (Gerkan 1996). On the other hand, the lack of corrosion resistance due to engine fumes and the high costs of maintenance soon became obvious. Soot-blackened timber is preserved and of low flammability.

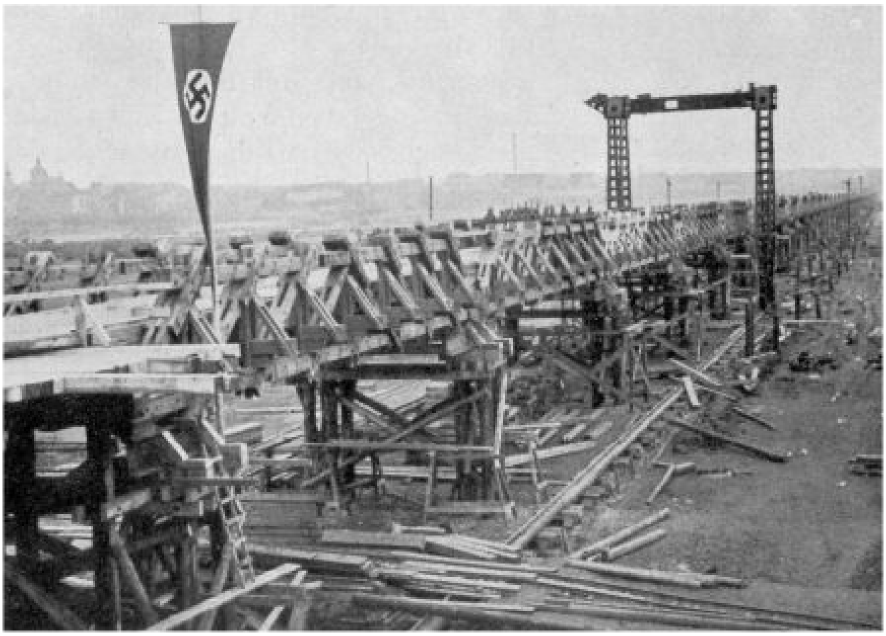

Figure 7. Auxiliary war bridge in Russia 1941 (Stoy 1942, p 135)

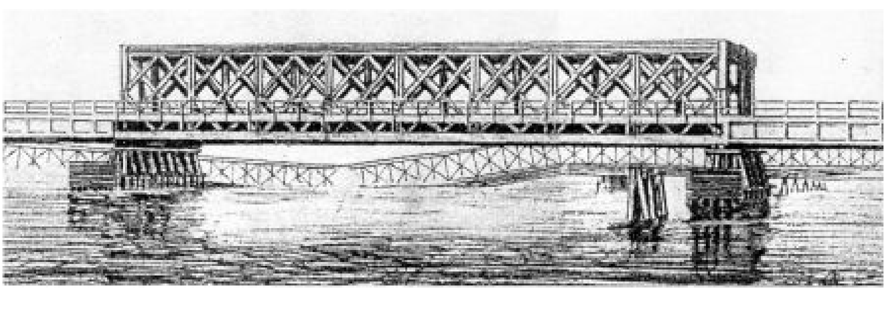

Figure 8. Auxiliary Bridge near Strasbourg with nailed trusses (Borchard 1951, p 145)

At the 1910 World Exhibition in Brussels, Germany presented an electric railway system in a special “Reichseisenbahnhalle”, built by Otto Hetzer (1846-1911) which had glued laminated frame girders of 43m span. The hall itself, designed by Peter Behrens and Hermann Kügler, caused a sensation showing the competitiveness of timber construction by slender frame girders with varying profiles and a very flat vault rise of 15m, reducing thus the volume of the hall, that was no longer required to dissipate engine fumes.

> The Hall was meant to be a shelter for the locomotives and the wagons, but one that expresses the power of these iron organisms. This is achieved by the form of the girder itself. Everything is breathing tenseness.
>
> (Mannheimer 1910, p 206)

All of a sudden wood construction was en vogue.

The next milestone was reached, when in 1911 the Swiss Railroad Company ordered a central engine shed at Bern that was erected by Terner & Chopard, the Swiss franchising partner of Otto Hetzer AG, using pin-jointed frames of 20-24 m in span. The site now in service for 95 years! One year later, all subdivisions of the company were advised to use timber instead of steel for halls and sheds (NN 1913, pp 289ff; Urban 1913, p 22).

The process in Switzerland was watched very closely by the above mentioned Dr. Ing. Karl Schaechterle (1879-1971) who was responsible for the construction department of the Württembergische Staatsbahnen, at that time (after 1918 he assumed the same office for the united Deutsche Reichsbahn, and later on was responsible for the Bridges of the Reichsautobahnen). In 1914 a similar shed was erected in Stuttgart by Karl Kübler AG, another franchising partner of Otto Hetzer AG in Weimar (Jackson 1921, p 113). Schaechterle remarks that the wooden construction tender was 45% lower than the concrete construction tender submitted by Wayss & Freytag (Schaechterle 1924, p 543).

In 1913, Copenhagen Central Station was built with wooden halls by Philipp Stephan AG. From the beginning of the century Stephan developed filigree lattice vaults with varying dowel joints, normally with a tensile bar. The halls of Copenhagen still exist like those at Malmö from 1922 and Stockholm from 1925 built by Hetzer (De Bruyn 1913, 377). A station in Warsaw similar to the one in Malmö was demolished by German troops after the insurrection in 1944 (Kersten 1926, p 221; Bracht e. a. 2005).

Other timber construction companies like Christph & Unmack in Niesky, Tuchscherer in Breslau, Ambi and Sommerfeld in Berlin and Meltzer in Darmstadt were also developing light wide span structures that were executed more and more for railway facilities, sheds, workshops and platform roofing at that time (Gesteschi 1928, p VII).

The innovative approach lay in the use of engineering methods: simplifying the structures to make them calculable, using trials on mock-ups and prototypes and the implementation of mechanical fasteners made of steel to reduce the traditionally tall joint slip in wooden construction (Lewe 1922). Special glue is used to build more or less homogeneous profiles of a bigger size than given by natural sources. Both means allow building of composite profiles that can compete against steel trusses in terms of span and loads.

Working for the railways meant working for an authority that issued construction licences for its own purposes. Thus, like working for the army, under certain conditions the design process could be more creative, because obsolete regulations could be quite easily suspended by the administration as the example of Stuttgart Central station shows: During World War I the work on the halls of the Station had been stopped. After the war, the halls were completed, for economic reasons however, not in steel, as planned, but in timber construction. It was Karl Schaechterle who initiated scientific studies on timber construction linking the practical knowledge of Karl Kübler AG from Göppingen with the theoretical and experimental possibilities of the Material Testing Institute (Materialprüfanstalt) associated with the Stuttgart Technical University nearby. The studies proceeded under the leadership of Otto Graf who followed the heritage of August Lang, from Hanover, who was the first to do scientific experiments on wood as a construction material. As a result, not only Stuttgart Central Station was built using continuous frame trusses on the Kübler system with conical metal dowels, but also the 'Preliminary Specifications on Timber Constructions' of the Reichsbahn were issued in 1926 (Graf 1922; Schaechterle 1921, p 33). These can be looked upon as the first instance of evidence based regulation in timber construction in Germany, considering the research by Winkler, Bauschinger, Tetmajer, Lang, Bach, Baumann, Graf, Rudeloff, Schoenhoefer, Jackson, Seitz and the material testing institute Zurich (Schaechterle, 1927, 84).

It was a disembarrassment for civil engineering because in the early 1920s, upon resumption of business the timber construction panel at the German board of normalisation (Normenausschuss der deutschen Industrie – NDI) was paralysed in the struggle between 'old-fashioned traditionalists' and 'euphoric new timber protagonists' security and economic feasibility seemed incompatible.

Stuttgart Central Station was the last grand station to be built in Germany for a long time. It's the first one that leaves the roof of the hall open above the track to let the fumes out. That way the volume of the hall can be efficiently reduced. This principle led directly to platform oriented roofs that were performed in the reconstruction of many central stations in Germany after World War II. It wasn't before the new ICE-stations at the end of the 20th century (e. g. Frankfurt Airport, Berlin Main Station) that grand station halls had been erected.

Up to the 1950s most of the railway facilities in Germany, Switzerland and Scandinavia were built in timber construction for their advantageous resistance against corrosion caused by locomotives' smoke and fumes.

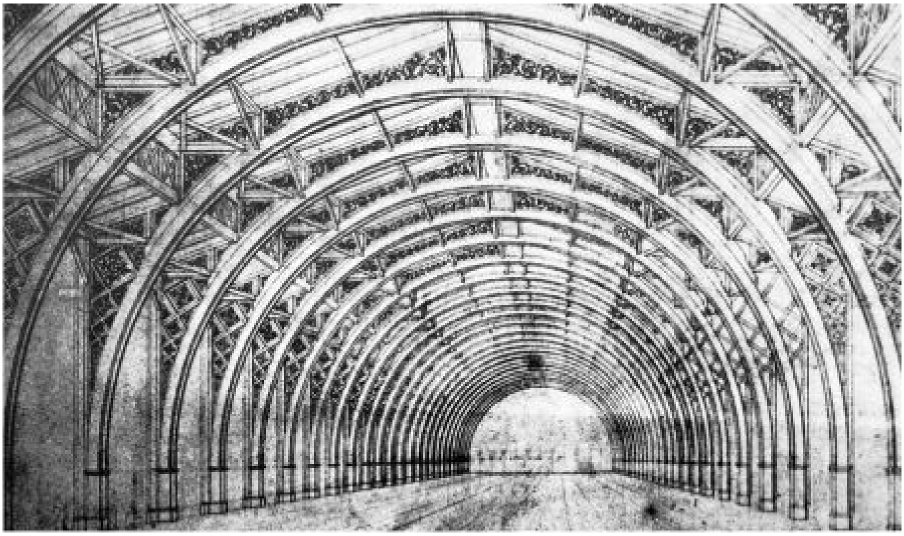

Figure 9. Centralbahnhof München by Bürklein 1847 (Krings 1985))

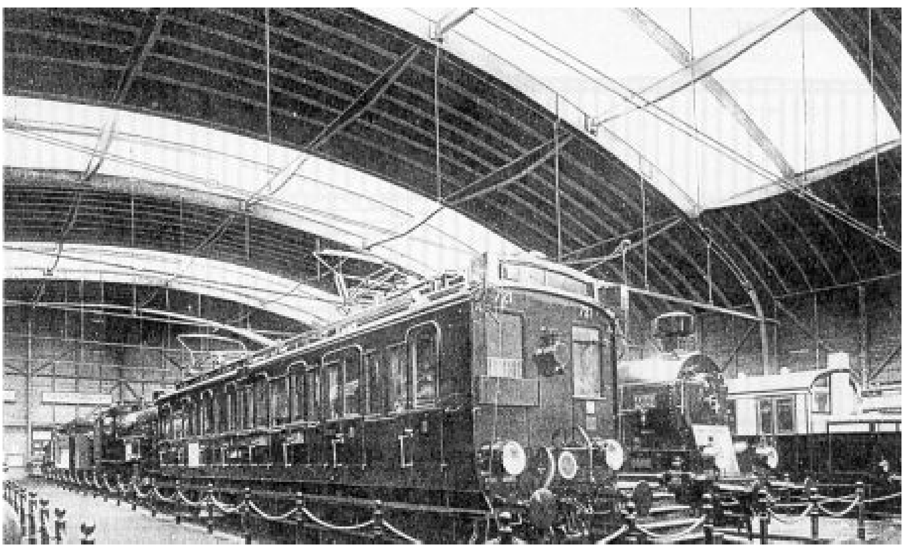

Figure 10. Reichseisenbahnhalle Interior, Brussels 1910 (Mannheimer 1910, p 207)

Figure 11. Railway Engine Shed in Bern 1911, photograph recent (Müller 2000,p 72)

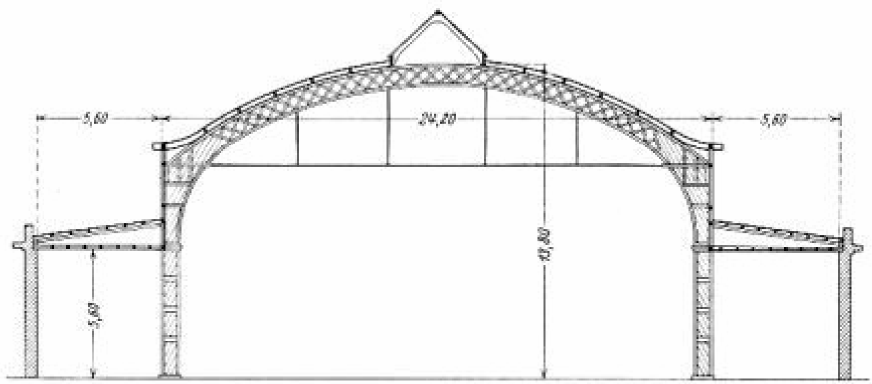

Figure 12. Warsaw Central Station Annex (Kersten 1926, p 221)

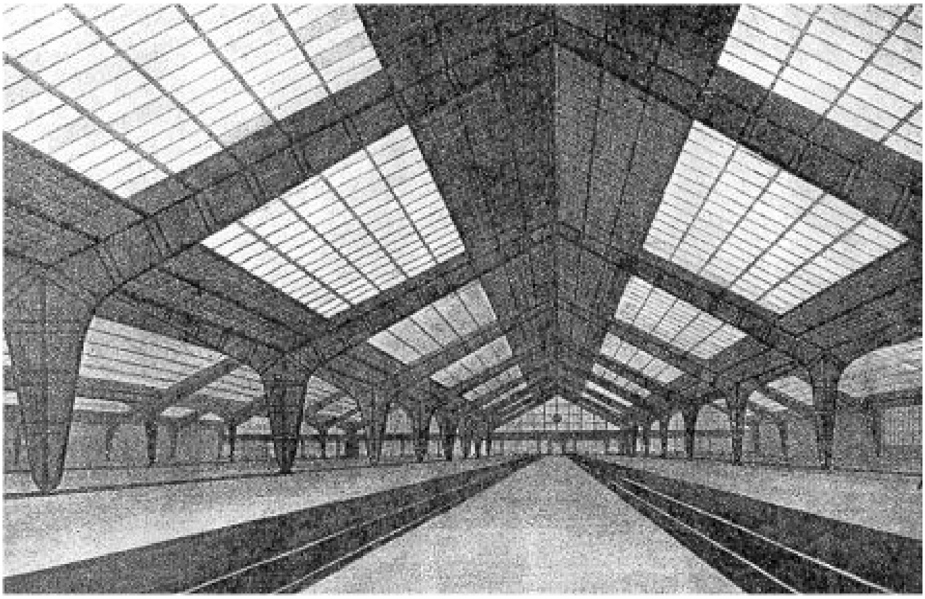

Figure 13. Stuttgart Central Station Original Project in Steel Construction (Schaechterle 1921, p 33)

Figure 14. Stuttgart Central Station Executed Project in Timber Construction (Schaechterle 1921, p 39)

EXCURSE: FROM INNOVATION TO STANDARDISATION

The “Deutsche Holzbau-Verein”, founded in 1920, brought in severe objections to modern timber engineering against the 'Regulations on Loads to be assumed with Building Structures and on the Permissible Stresses of Building Materials ' ('Bestimmungen über die bei Hochbauten anzunehmenden Belastungen und über die zulässigen Beanspruchungen der Baustoffe') of 24th of December 1919 (Deutscher Holzbau Verein 1920; Ellerbeck 1920):

> The decree caused lively unrest in the circles of the German timber construction industry. In addition, it met heavy doubts from the economical point of view. It cannot be unimportant for the economic life, if, in a time of largest housing shortage due to the lack of the high prices of all building materials, restrictions are put on the one building material, which is still available on the market at the moment, (restrictions), which it had not to carry in economically favourable times. Nevertheless the new decree means nothing more and nothing less than raising the price of all buildings made of timber for the consumer, i. e. the German people, by 25%.
>
> (Mylius, 1920, p 9)

Alfred Jackson, summarises his criticism on the aforementioned decree in one sentence:

> ... in my judgement the permissible values stated for wood only apply to carpenters' constructions; for modern cantilever constructions, where only selected wood comes to the use, special regulations are to be set up.
>
> (Jackson, 1920, p 9)

On the other hand there had been a couple of spectacular collapses causing reservations against the new technique that tried to spare so much of the building material. At that time the companies even published the facts of the defeat in analysing the reasons for the disaster to reach a better understanding of the structural conditions (Maier-Leibniz, 1928, Marx, 1926). In 1921, Alfred Jackson resumed his lectures on timber construction held at the conference of timber construction engineers in April 1920 adding technical basics and a general review of the current building methods in the volume “Ingenieur-Holzbau” (Jackson 1921). “The practice of modern timber construction” was published by Kersten (editor) in the same year in the VDI lectures of November 1919 (Kersten 1921). Hugo Seitz contributes a comprehensive article "Grundlagen des Ingenieurholzbaus", answering in 1924 to demands of the German board of Standardisation and the German Reichsbahn administration “in collecting and arranging the rich material for evaluation, to help to master the difficulties arising in the projected reorganisation" (Seitz 1925, preface).

It was the concerted effort of Karl Schaechterle, officer of the Reichsbahn administration, Otto Graf of the Material Testing Institute, Stuttgart and Alfred Jackson, chief engineer of the executing company (Karl Kübler AG) to create a persuasive precedent in the design of the halls of Stuttgart Central Station. The referring testing was the foundation of the 'Preliminary Specifications on Timber Constructions (BH)' of the Reichsbahn of 1926.

The 1926 'Preliminary Specifications on Timber Constructions' issued by the Reichsbahn finally brought the break-through and were widely used outside the railway industry as well. Once a guideline given, DIN 1074 'Bridges in Wood' followed in 1930. In 1933, DIN 1052 'Construction in Wood' set a general standard for timber construction based on engineering principles. The following decade was dedicated to engross the knowledge and to elaborate the code of standardisation. Due to on-going trials (Gaber 1935; Graf 1935; Fonrobert 1941; Stoy 1942) DIN 1052 was revised in the issues of 1938, 1940 and 1943 (idem the dependant DIN 1074 and DIN 4074). The 1940 release of DIN 1052 with the appendix of 1943 was affirmed without corrections in 1947 in post war Germany. The German 1943 standard in timber engineering kept valid for more than 25 years until the revision of DIN 1052 in 1969.

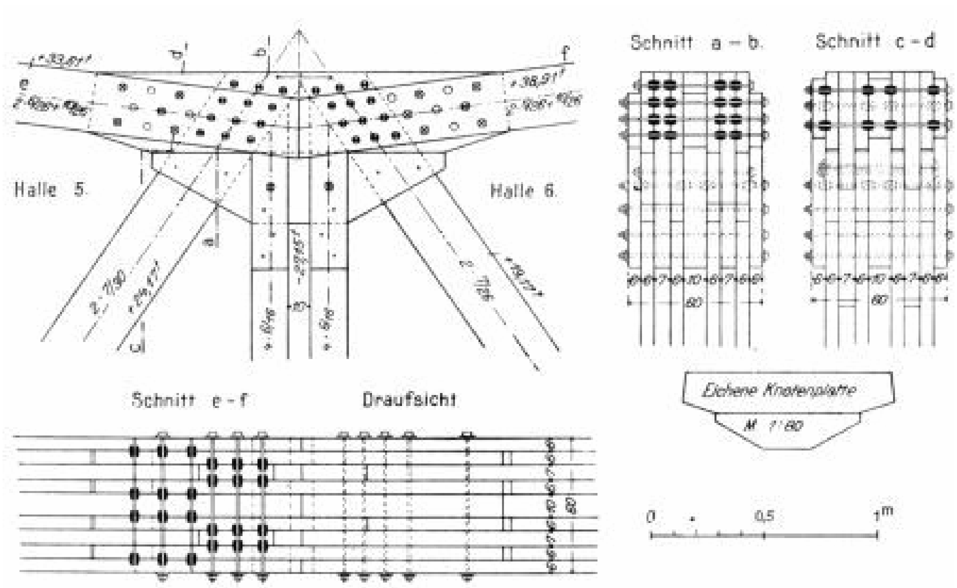

Figure 15. Stuttgart Central Station Joint Plate (Kersten 1921, p 154)

CONCLUSION

The names of the protagonists of standardisation in timber construction correspond to those mentioned above in the development of auxiliary bridges for military purposes: Schaechterle, Graf, Stoy, Gaber. In Nazi-Germany wood research was pushed forcefully to reach autarchy. The system of standardisation in industries (DIN) initiated in World War I was resumed and forcefully completed by the Nazi organisation as an instrument to armament, obviously in the trials on nailing constructions for wooden railway bridges. The Organisation Todt bundles the activities that incorporate enterprises, universities and last but not least the railways to prepare for the war. Evidence the brochure for the Centenary of Christoph & Unmack in 1935 showing the employees being mustered under the nazi symbols (Christoph & Unmack 1935). Another *festschrift* (150 years Kübler AG), issued in 1960 (!), gives a shadow of an idea of what was the subject matter of the enterprise engaged in concrete and timber construction and in mobile huts:

> In World War II the enterprise undertakes completely new tasks in fulfilling a patriotic duty. They have to be taken and to be solved far from home. Almost all the staff members, that aren't in the army, are involved and gain experience that they benefit from in times of peace.
>
> (Kübler AG 1960, p 6)

The histories of timber construction and of railways are interwoven in many ways:

- Wood was the material to implement the innovative transportation system up to 1860.
- From 1910 to the end of the steam age, wood was the preferred material for railway halls and shelters because of its advantageous resistance against fumes.
- Timber was the preferred material to rebuild bridges, especially railway bridges in World War I.
- Railways, being a key industry that was one of the biggest contracting entities in construction stood right at the centre of the standardisation process in the decade between 1933 and 1943, where inter alia the guidelines for timber construction were fixed.

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