Editorial

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Isn't it everyone's dream to drive without having to comply with a speed limit on a German motorway?

The network of federal motorways, totalling almost 13 000 km, represents only 6% of the entire German road network, yet approximately 32% of all vehicles travel on them. The federal motorways call every kilometre of a bridge their own; their areas cover approximately 20 km². Smaller bridges are generally made from reinforced concrete whereas prestressed concrete dominates in the larger and very large bridges. Steel and steel composites are niche products (Figure 1). The construction boom of federal motorways took place between 1960 and 1980 (Figure 2). Therefore, the bridges in West Germany are getting old, as shown in the statistics on the condition of the bridges by the Bundesministerium für Verkehr und Digitale Infrastruktur (Federal Ministry of Transport and Digital Infrastructure – BMVI) (Figure 3). Coupled with the unforeseeable success of private transport and the explosion in traffic quantities on the federal motorways, German engineers in the western, 'old' federal states are now faced with the challenge of completely renovating and expanding motorway sections and bridges by 2030. Not included here are the 'new' federal motorways in the eastern part of Germany, which were newly built after the reunification of Germany from around the year 1995.

But how did it all begin? The success of private transport and the 'roads purely for cars', as motorways were originally named, was not initially foreseeable. Too powerful was the *Deutsche Reichsbahn* (German National Railway), as was the official machinery linking it with politicians and the military. Therefore, not having a speed limit was in fact one of the starting points for constructing roads purely for cars.

According to Gabriel (2005), the request for a car racing track was made around 1902, and around 1925, the first requests were voiced for a road network suitable for cars. Originally, enthusiastic building contractors wanted to build an approximately 5 km-long car racing track without crossings shortly after the turn of the century in West Berlin. But instead of this, wealthy car drivers began to conduct daredevil races on narrow country roads in the Taunus area. Felice Nazzaro, a famous racing driver in his day, won the first *Kaiserrennen* (Emperor's Race) in 1907 in a Fiat. The people of Hesse, led by the City of Frankfurt, were more determined and succeeded in persuading the German Emperor Wilhelm II to issue approval for an *Automobil-Verkehrs- und Übungsstraße* (Automobile, Transport and Practice Road) in the Taunus area near Frankfurt. The City of Frankfurt envisaged less of a round race track than a road for cars as a permanent connection between two main traffic centres. And so the motorway would have been born, except that, oh dear! The banking and financial City of Frankfurt set the stakes too high

regarding the cost-sharing of the industry and the German Reich. The Hessian concept of a combined racing and crossing-free road purely for cars, which separated traffic moving in different directions, was commenced in 1913 in Berlin and, due to the advent of the First World War, was handed over for transport purposes in 1921.

After the First World War, the Italian *Autostrade* – put into operation from 1924 between Milan and the northern Italian lakes – reanimated the wish for 'roads purely for cars', and in 1924 the Studiengesellschaft für den Automobilstraßenbau (Research Association for Automobile Road Construction – STUFA) was founded in Berlin, headed by Josef Brix (1859–1943), Professor of Urban Construction at the Technical University of Charlottenburg, Berlin. One of the main initiators was the Hanoverian Professor of Bridge Construction, Robert Otzen (1872–1934).

If we ignore the big cities for the moment, Germany was not a car traffic country. In 1926, the vehicle concentration (vehicles per inhabitant) in the USA totalled 1:6; in England it was 1:49, but in Germany it was only 1:211. Hikers, bicyclists, horse carts and cars shared the constricted transportation space on frequently unpaved roads full of potholes belonging to the financially hard-up road construction administrations of the states and Prussian provinces. In these conditions, it was simply not possible to achieve competitive travel times. The car was no sparring partner for the *Deutsche Reichsbahn*, which was why the foundation of the STUFA, which found its counterpart at the road construction administration in the Deutschen Straßenbauverband (German Road Construction Association – DStrBV) was urgently necessary in order to develop road constructions that made the German road network efficient for cars (Ruppmann, 2007). Yet STUFA and DStrBV, which were obligated to conduct the conversion and expansion of the existing roads, jointly opposed the construction of 'roads purely for cars'. "These are only expedient," said STUFA and DStrBV, "for the transportation of goods between neighbouring cities, which however is already optimally served through the *Deutsche Reichsbahn*."

At that time, Germany was not yet ready for a futureproof infrastructure policy. Private commitments assisted the dream of the 'road purely for cars' on its way. Willy Hof (1880–1956), a pioneering entrepreneur from Frankfurt, who made his money through the invention of special fuses for low-voltage current (Ruppmann, 2007), enthused the Economic Council of the City of Frankfurt and its Lord Mayor Ludwig Landmann enough for them to call into being the Association for the preparation of the Hamburg–Frankfurt–Basel roadway (HaFraBa) in 1926. The Chair of this association was Professor Otzen, but the soul of HaFraBa was Willy Hof, who, after Otzen stepped down in 1931, remained as the driving force. His

Figure 1. Bridges on federal motorways – materials used in bridge construction by percentage of bridge area, as at 1 September 2016 (Source: BMVI)

objective was the evaluation of the execution and preparation of the Hamburg–Frankfurt–Basel road in terms of financial and technical aspects. The route proposed by HaFraBa accords with today's federal motorways A7 (Hamburg to Hattenbacher junction/Hesse) and A5 (Hattenbacher junction/Hesse to Basel).

STUFA and HaFraBa laid the foundations for the federal motorways. They created the network that exists today; they developed the route and drafted regulations regarding height and position and determined the main construction designs in guidelines.

HaFraBa was not pursuing a public solution, but rather wanted to create an independent, privately-financed traffic system – what we would call a public–private partnership today (Ruppmann, 2007), and yet this attempt finally failed completely in 1932. However, the German motorway network was basically conceived on this basis in 1932.

After 1933, the National Socialists adopted HaFraBa's plans and founded their own private association for the construction of *Reichsautobahn* (Reich motorways), which they assigned to the *Deutsche Reichsbahn*. The fate of the *Reichsautobahn* was from now on steered by the construction engineer, full colonel and General Inspector for the German Road Sector, Fritz Todt (1891–1942), who Adolf Hitler acclaimed without scruples as the inventor of such motorways. In order to draw a veil over its achievements, the National Socialists renamed the HaFraBa as Gezuvo. In 1937, the Gezuvo was moved – or submerged – into the Reichsplanungsamt (Reich Planning Office) as the Reichsstelle für Raumordnung (Reich Office for Regional Planning). Willy Hof, who actively contested the authorship for the HaFraBa in public, was shut down. In 1936, Hof resigned himself to his fate and withdrew from office completely (Ruppmann, 2007).

In 1938, the construction industry was finally synchronised and militarised. The Gesellschaft Reichsautobahnen merged into the paramilitary 'Organisation Todt', called into being by Hitler to build the Siegfried Line (Seidler, 1987).

Approximately 3900 km of *Reichsautobahn* were completed under the National Socialist regime. They were neither a military nor a civilian success, but rather pursued fascist propaganda objectives, like the first

Figure 2. Bridges on federal motorways – age of structures by percentage of bridge area, as at 1 September 2016 (Source: BMVI)

Figure 3. Condition grades by percentage of bridge area, as at 1 September 2016 (Source: BMVI)

Autostrade. The vehicle concentration remained at approximately 1:47 (England: 1:21; USA, 1:4.5). The *Deutsche Reichsbahn* remained the transport monopolist. During the Second World War, the *Reichsautobahn* were also approved for bicyclists and horse carts.

To create the routes, initially track construction elements were adopted in terms of height and position. The inspections by the HaFraBa for economic goods traffic on ‘roads purely for cars’ resulted in a maximum regulation longitudinal gradient from 4% to 8% (for the temporary overcoming of gradients in mountain regions) (Speck, 1926). This was the trigger for a multitude of bridges.

Bridge constructions were originally modern with characteristic steel constructions. Yet even before the announcement of the ‘Four Year Plan’ on 18th October 1936 through the National Socialists, the deviation of steel masses into the armaments industry began in preparation for war. As a result, arched bridges coloured by ideology were constructed, and the search for steel-saving construction methods began (Pelke, 2011a, 2011b) but were never developed beyond pilot constructions due to the industrial self-reliance ambitions of the Third Reich.

Whereas lightweight steel and steel composite constructions were heavily promoted through the responsible road administrations, the construction of prestressed concrete bridges was a company development, closely linked with the companies Dyckerhoff & Widmann A.G. and Neue Baugesellschaft (NBG) Wayss & Freytag A.G. This is astonishing in light of the fact that the construction of prestressed concrete bridges lies closest to the ideological specifications of steel mass-savings.

Owing to the mediation of a member of their Board and Jewish fellow citizen Professor Karl W. Mautner (1881–1949), NBG Wayss & Freytag A.G. procured in 1935 the patent from the French engineering genius Eugène Marie Leon Freysinnets (1879–1962). The backbone of the motorways of post-war Germany was built upon the expertise and the negotiating skills of Professor Mautner. The thanks given to him for his work by Germany was shameful. Professor Mautner was successively relieved of all his offices and

taken to the concentration camp in Buchenwald in 1938, from where his release was most likely paid for by the British Secret Service. Mautner never got over the humiliation imposed upon him by his country, and died in 1949 in London (Grote and Marrey, 2000).

On 9th May 1945, the Allied Forces ended the National Socialist terror regime – ‘Zero Hour’ for Germany. Millions of uprooted people wandered through the country without destinations and homes. They found only the remainder of an infrastructure, without construction administrations or construction industries available to build or repair it. In the last weeks of the war, many bridges were still being blown up, at will and without any military expediency.

Not until military governments took over, followed by the deployed state governments in 1947 and finally in 1949 the first elected federal government, was the task of reanimating transport infrastructures within Germany as quickly as possible addressed. The military government and the local city administrations initially concentrated on bridges and river crossings within settlements. These were reinstated with easily manageable construction methods, construction materials found on-site and reusable components, frequently steel bridges. Permanent solutions were not attempted in this first phase, but rather in a second phase. Once again, the railway, not the motor vehicle, guaranteed mobility.

From 1947 onwards, the state governments began to represent the interests of the supra-regional road network with regional connections, but it wasn’t until 1949, by being anchored in the constitution (section 90) for the new Federal Republic, that the planning, construction and operation of the highway network for West Germany was regulated. Another seven years went by before the German Bundestag (National Parliament of the Federal Republic of Germany) passed the first financing plan for the expansion of the motorway network, on the basis of which the first specific plans for the expansion of the motorways were actually issued. Whereas the railway, owing to the construction of its network in the 19th century, still has the competitive disadvantage of its west–east orientation to this day, the post-war-defined north–south orientation of the federal motorways after the ‘economic boom’ of the new, democratic Federal Republic was an important component for the success of road traffic. Today, with a market proportion of almost 80% for goods and up to 90% for passenger traffic, the road has sent the railway packing, to become a mere niche provider.

This has been possible due to the rapid implementation of the pilots of prestressed concrete (Pelke, 2011a, 2011b) and steel composites (Pelke and Kurrer, 2015) in regulated construction methods as well as the new developments in cable-stayed bridges (Pelke and Kurrer, 2012) and the orthotropic plate (Pelikan, 1958; Pelikan and Eßlinger, 1957) used in the construction of large steel bridges.

But why are so many of these motorway landmarks now being replaced? Focusing on prestressed concrete, three main reasons have been identified.

1. Traffic development (the aspects of effects on structures)

- *Increase in traffic:* The federal motorways, and therefore also the bridges, were dimensioned for an average daily traffic (DTV) of approximately 22 000 vehicles per day; of these 5–6% are trucks. In fact, the DTV is on average almost 70 000 vehicles per day, with high-concentration routes seeing up to 20 000 trucks per day.
- *Increase in axle load:* The legislators have successively increased the permitted total weight from 22.5 t to 44 t (Figure 4).
- *Overloading:* The average overload rate for trucks totals 15%. In this way, the average, real total weight of the trucks lies between 46 t and 50 t.
- *Increase in heavy load transportation:* The increase in transportation with weights of more than 44 t up to approximately 350 t has been exorbitant. Whereas their quantity was negligible at the beginning of the 1990s, they now have to be taken into account during fatigue calculations.

The bridges have not been dimensioned to cope with all the effects acting on them today. In accordance with a basic principle expert report commissioned in 2007 by the BMVI (Geißler, 2009), the bridges experience levels of traffic in accordance with the national application document of BS EN 1991-2 (BSI, 2003), the DIN Report 101 (DIN, 2003), but certainly only cater for traffic of the national bridge class 60, which was valid for dimensioning during the phase of main building activities (Figure 4).

2. Development of the construction technology for the main construction method using prestressed concrete (the aspect of component resistances)

- The ingeniousness of Freyssinet in creating a new rheological, crack-free material through complete overpressure was gradually halted in the national regulations for Germany in favour of an exclusively longitudinal prestressing, which today is almost partial, with a high proportion of steel-reinforced concrete. This change in policy philosophy led to significant

safety deficits, in particular regarding the shear capacity of prestressed concrete bridges during the construction period up until 1977.

- The temperature difference, ΔT , via the component height was neglected up until 1979.
- For section-wise construction, the prestressing tendons were initially fully abutted. In particular the coupling elements of the prestressing tendons in the working joints are subject to fatigue, which led in 1974 to a case of damage in Düsseldorf. Due to this, the authorisations were changed, and building owners instructed their contractors that two thirds of the prestressing tendons must penetrate the coupling joints without abutments. As of 1977, the coupling joints were of a fatigue-resistant design.
- In early prestressed concrete bridges, particularly high-quality, ‘hardened’ prestressing steels were installed, which over the years turned out to be sensitive to hydrogen-induced stress corrosion. In 1978, further installation of such materials was prohibited. Constructions featuring these prestressing steels tend to sudden failure.
- An overview of the deficits of early prestressed concrete bridges provides the assessment of the post-test calculations by Hessen Mobil (Schölch, 2015) (Figure 5).

3. Environmental influences

- *Chloride pollution:* After spiked tyres were prohibited in the middle of the 1970s, the widespread distribution of de-icing salts suddenly became popular. The chloride in de-icing salt penetrates gradually down into the concrete, which then loses its protective effect. Concrete, steel and prestressing steel reinforcements were installed too close to the surface, and the concrete tends to spall away due to the increase in volume of the reinforcement rods as they corrode.
- *Carbonation:* Due to the environmental pollution in the air (CO_2), the concrete loses its protective effect, and the reinforcements begin to corrode.

Figure 4. Permitted total weights and rated loads

Figure 5. Post-test calculation results from prestressed concrete bridges in Hesse (Schölch, 2015)

So what can prestressed concrete bridges actually cope with? Up until now, we can only estimate their real load capacity. It will be the future challenge for engineering sciences to leave the field of reconstruction and the development of safety factors, and to develop methods for the reliable estimation of the actual load capacity of existing load-bearing structures. The orientation on real load capacity is no sanctimonious wish by someone interested in the history of construction technology, but rather an elemental requirement for the careful handling of the infrastructure assets of a nation. The articles by Kolodzieczyk and Maurer (2017) and Gleich and Maurer (2017) in this issue of *Engineering History and Heritage* therefore concern themselves with the attempt to better gauge the shear stability of older prestressed concrete bridges.

The estimation of the load capacity of existing bridges is currently conducted within Germany on the basis of the *Post-Test Calculations Directive* by the BMVI (Marzahn, 2011). This is a directive that has proven its worth in practice and permits engineers to cautiously approach the load capacity of bridges over four stages.

- *Stage 1:* The verification management to the target load level LM 1 in the DIN Report 101 (DIN, 2003).
- *Stage 2:* The verification management to the target load level LM 1 in the DIN Report 101 (DIN, 2003) or a reduced target load level depending on the real truck traffic with limitation of the verification management in service load condition and the possibility of compensating the target load level via traffic restriction measures or temporary limitations in the duration of use.
- *Stage 3:* Measurement value-supported calculation.
- *Stage 4:* Application of scientific methods.

The essay by Krill (2017) provides an insight into the procedural method of the *Post-Test Calculation Directive* based on two significant motorway bridges, also in terms of construction technology history.

Initiated through the Swiss SIA Standard 269, the object-related determination of the effects and the realistic recording of the load characteristics through experimental load capacity determinations are now receiving an increased amount of attention in Germany too, in order to calculate the load capacity even more accurately.

Boros *et al.* (2017) provide insights into the lifting of reserve load capacities through experimental load capacity determinations for a bridge construction method, the load capacity of which is still underestimated today.

In constant competition with prestressed concrete, steel composite and, in particular, purely steel bridges can only exist through the use of exact building statics methods and filigree and material-optimised construction methods. Today, this leads to low reserve load capacities and the superordinate deficit of material fatigue even if measurement value-supported calculations are conducted. For the development of steel and steel composites and the resulting repair requirements, readers are referred, for the sake of brevity, to the more in-depth study of the paper by Hanswille and Neumann (2012).

Steiner *et al.* (2017) concern themselves with the fatigue of the component of a steel bridge that is directly driven on, the orthotropic roadway and its reinforcement.

Finally, Goj and Hennecke (2017) provide an insight into the complex realisation of the Echelsbacher Bridge in the field of tension between building technology history, environmental protection and traffic requirements.

Most motorway bridges will not be able to fulfil the requirements defined by BMVI. Due to the replacement of constructions in all main routes and the route optimisations of the three-lane and multi-lane expansions, which is taking place in parallel, the federal motorways will lose much of their original appearance and our driving experience

will change a second time. Renewing itself like a living organism, the construction technology historical triad of the routing, earthworks and covering structure, as well as bridge constructions, will become abstract, remaining only apparent in the network system. This is also the case because there is a lack of scientific knowledge of the real load capacity of prestressed concrete bridges in particular.

Oh, but perhaps you would rather hear from a German colleague where the ‘no speed limit’ still applies on motorways? Well, my home state of Hesse may be ‘Vettel’ country, but the traffic concentration is usually too high. Try the BAB A4 between Dresden and Eisenach. Have a nice trip and a good flight!

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