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Development of design and construction of high-speed railway bridges in Germany

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ABSTRACT

Bridges are vital components of high-speed rail (HSR) lines for crossing obstacles such as valleys, rivers, and existing highways or railway lines. The main goal of this paper is to provide a review of the development of HSR bridges in Germany. A short summary of the history of high-speed rail lines is given first. Subsequently, the development of HSR bridges, along with emerging design issues and the two relevant German design guidelines, is reviewed. Further, bridge structure types on German HSR lines, such as simply supported bridges, continuous bridges, arch bridges, integral and semi-integral bridges, composite truss bridges and rigid-frame bridges are discussed. The article concludes with a short discussion about the current situation and future trend of HSR bridges.

1. Introduction

High-speed rails offer a safe, fast, and comfortable mode of travel that improves quality of life and supports economic growth. When the first segment of the Shinkansen (Japanese bullet) train line (Tokyo–Osaka) with an operating speed of 210 km/h was opened in 1964 in time for the Olympic Games, high-speed rail travel was born. In France, the first HSR line (also known as TGV), connecting Paris and Lyon, which had a maximum operating speed of 260 km/h, was opened in 1981. In contrast to the Shinkansen concept, the new European HSR was fully compatible with the existing railways, which facilitated further development of the system on the old Continent. After the success of the Shinkansen and the TGV, HSR construction fever spread across the world. Joining the group of countries offering HSR services were Italy in 1981, Germany in 1988 (ICE trains), Spain in 1992, Belgium in 1997, the United Kingdom and China in 2003, Switzerland and South Korea in 2004, the Netherlands and Turkey in 2009, Austria in 2012, and Poland in 2015. So far, sixteen countries have developed a HSR network (with minimum operating speeds V of 250 km/h). Detailed reviews of the HSR networks in these countries can be found in the literature [1–7]. As Fig. 1 shows, the length of HSR lines constructed worldwide has increased almost exponentially since the first HSR line was opened.

The number of countries boasting HSR networks will likely continue to increase. There are more than 1000 km of HSR lines under construction in Denmark, Iran, Saudi Arabia, and Morocco. Survey data collected by the International Union of Railways (UIC) shows that even more countries, such as the USA and Australia, are currently planning to develop HSR networks [4,5]. According to a UIC report issued in April 2017, there are currently 37,343 km of HSR lines in operation, 15,885 km under construction, and 35,909 km in development. HSR fever will likely continue in the foreseeable future.

Germany was one of the first countries that planned to build a HSR network. Construction on the first line connecting Hanover in Saxony and Würzburg in Bavaria started in August 1973, and the line was opened section by section between 1988 and 1991 [8]. Subsequently, the following segments were opened: Mannheim–Stuttgart in 1991, Hanover–Berlin in 1998, Cologne–Rhine/Main in 2002, Nuremberg–Ingolstadt in 2006, and Erfurt–Leipzig/Halle in 2015. As of 2017, 1475 km of HSR lines are in operation in Germany, a further 368 km are under construction, and 324 km are being designed. The German ICE HSR has been a great success since its inception and has set an example to be followed. Valuable experience has been gained from its operation that is being used in the design of HSR lines all over the world.

Bridges are essential parts of HSR infrastructures for crossing valleys, existing train lines, and other obstacles. In the initial years of German HSR line construction, a large number of simply supported bridges were built. Including the latest trend in bridge construction, integral bridges, more than ten different types of bridge structures can be found on German HSR lines. The history of German HSR bridge development is full of innovations. The objective of this paper is to

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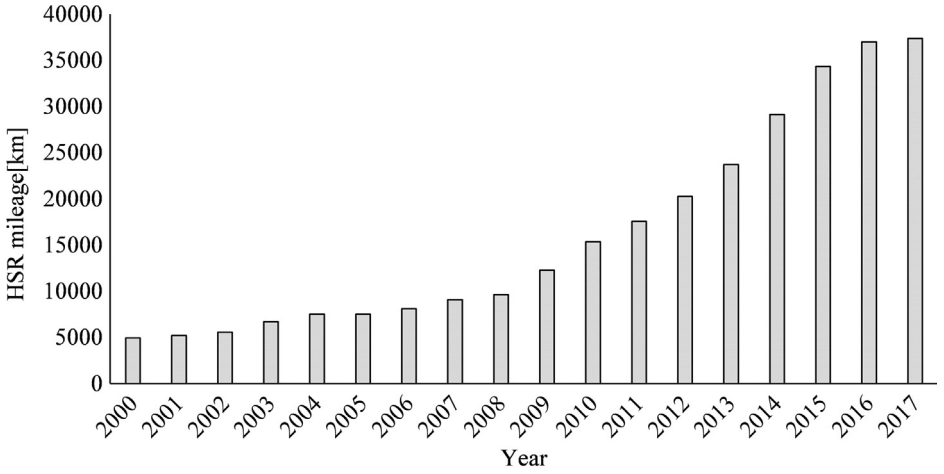

Fig. 1. Global HSR line development.

present an up-to-date review of the design and construction of HSR viaducts and valley bridges in Germany. This paper includes a brief history of HSR bridges, followed by an introduction of two important HSR bridge guidelines. Subsequently, the different types of bridges found in HSR networks are discussed. The discussion, however, only includes bridges with a main span of 20 m or longer.

2. HSR bridge development

The history of HSR bridge development since the opening of the first HSR line segment in Germany can be divided into two stages (1988–2006 and 2007–today), the beginning of each coinciding with the release of a new guideline.

2.1. 1988–2006: "Rahmenplanung Talbrücken" (bridge design framework)

In 1968, a wheel/rail research program was launched by the German Federal Ministry of Research and Technology. As part of this program, many experimental measurements, investigations, and calculations were carried out to evaluate the behavior of bridges under high-speed traffic loads. Based on the results of this program, the German Railway (DB) Council published the guideline "Rahmenplanung Talbrücken" [9] in the early 1980s. The guideline, which will henceforth be called "Bridge Design Framework," included basic rules for designing bridges on HSR lines. It also provided some standard examples of simply supported and continuous bridges, as shown in Table 1.

The standardized cross sections for a 44-m-span simply supported box girder bridge and a 44-m-span continuous box girder bridge are displayed in Fig. 2. The dimensions in the transverse direction are the same for both cross sections. The major difference between them is their cross-section height: 4.105 m for the simply supported structure, and 3.606 m for the continuous structure.

Rahmenplanung Talbrücken was used in the design and construction of HSR bridges built on the HSR network: from the first line opened in 1991, connecting Hanover and Würzburg, to the Nuremberg–Munich line opened in 2006.

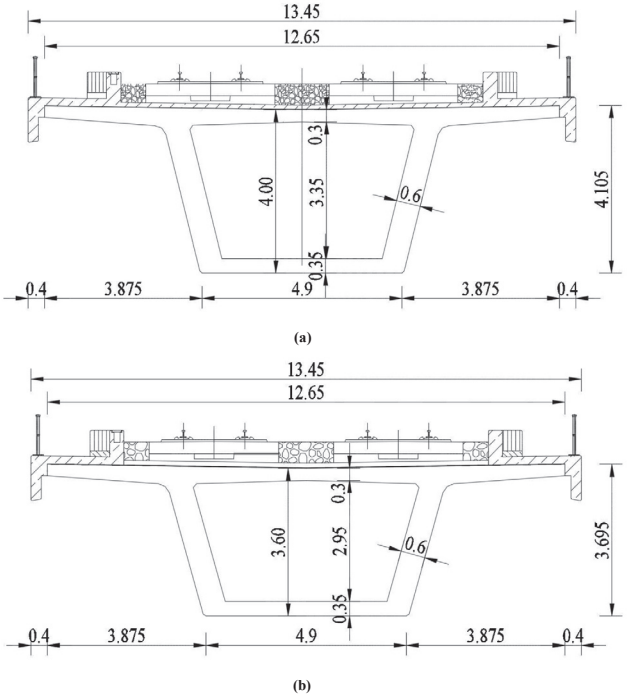

Fig. 2. Cross sections of two 44-m-span bridges [9] (a) Cross section of the 44-m-span simply supported bridge and (b) Cross section of the 44-m-span continuous bridge.

Table 2 shows the HSR lines that were opened from 1988 to 2006. The last segment of the Hanover–Würzburg high-speed railway line was opened on June 2nd, 1991. This line was the first high-speed railway line for InterCity Express (ICE) trains in Germany. There are more than 45 bridges along this line. At roughly the same time, in May 1991, the 98.8 km Mannheim–Stuttgart line was opened. In the following years, several more lines were constructed and opened. As the terrain from

Table 1
Bridge design information given in Rahmenplanung Talbrücken [9].

Bridge material	Concrete		Steel		Steel–concrete composite
Bridge type	Simply supported	Continuous	Simply supported	Continuous	Simply supported
Length of main span [m]	44/58	44	50	58	58
Cross section type	Box girder	Box girder	Steel truss	Steel truss	Steel truss with concrete deck
Number of tracks	2	2	2	2	2