The German Transrapid guideway – Conclusions on the guideway's first use in Shanghai

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Abstract

In the article, there will be taken a look at the different guideway types of the Transrapid from both a technical and an economic point of view. The different guideway concepts result from the projects Berlin-Hamburg and Shanghai, as well as from the present project in Munich, Germany.

The analysis of design and production of the first guideway in China has led to conclusions concerning the ultimate potential of these processes. The results will be applied to the future track in Munich, Germany.

1 Introduction

On December, 31st 2002, the maiden voyage of the Transrapid (TR 08) successfully took place in Shanghai. The regular operation of the first Transrapid world-wide started at the beginning of 2004. Looking at these milestones and considering the fact that, in the twenties and thirties of the last century, the engineer Hermann Kemper was the first to reflect upon an electromagnetic railway, and that the fundamental patent on the maglev railway was taken out as early as 1934, it is obvious that not only the vehicle but also the guideway of the maglev train show a long time and many stages of development.

Figure 1: Maiden voyage TR 08 on 31. December 2002 in Shanghai

In 1979, the first passenger traffic upon a licensed magnetic lane (TR 05) was made possible on the occasion of the International Traffic Exhibition in Hamburg.

In 1983, the Transrapid testing facility in the Emsland (TVE) was put into operation. Upon this test track the vehicle was developed until it was ready to go into production (TR 06 to TR 08).
To this day, all system components, for example the guideway girders, have been tested as well as licensed at the TVE so that these components can be used on commercial tracks.

In the following, the guideway concepts of the Transrapid will be looked at from both a technical and an economic point of view, starting with the track Berlin-Hamburg and the project in Shanghai. The analysis of design and production of the first guideway in China has led to conclusions concerning the ultimate potential of these processes. The results will be applied to the future track in Munich.

2 Guideway concepts

According to the significant system document Transrapid, the one lane track as well as the two lane track of the magnetic levitation transport system consist of guideway girders that have been specially manufactured, equipped and installed. The system document describes the two different types of guideways the Transrapid track consists of:

- **Elevated guideway**
  Elevated guideways come to use upon tracks that may not separate ecologically or agriculturally connected areas. In addition, elevated guideways do not interfere with existing infrastructures.

  There are two primary characteristics of this guideway type:

  - First, the elevated guideway can be easily adjusted to the topography given, i.e. hill, mountain or the crossing of traffic routes, due to variable pillar heights.

  - Second, this guideway can be used at gradient heights of 3, 5 m to 20 m.

- **At-grate guideway**
  In contrast to the elevated guideway, the at-grate guideway is used in flat and even areas, in cuts, through tunnels as well as upon primary structures, for example bridges and station buildings.

  According to the system document ´Transrapid´, the primary characteristic of the at-grate guideway is its gradient height of 1, 25 m to 3, 5 m.

2.1 Berlin - Hamburg

In July 1997, the Federal Government of Germany decided to include a magnetic levitation transport system, connecting the cities of Berlin and Hamburg, in the federal traffic route plan of 1992 (BVWP ´92). This decision was taken due to the results of an evaluation concerning national economy as well as business management.

From 1994 to 1996, additional laws and resolutions established a legal basis for the concrete process of planning, whereupon the definite stage of planning began. However, in February 2000, the Federal Government of Germany that had been newly elected in 1998, German Rail and the Transrapid consortium decided not to carry out the Transrapid track due to financial reasons.

Fig. 2 shows the standard configuration that has been specified for the guideway of the maglev system between Berlin and Hamburg at a length of 292 km.

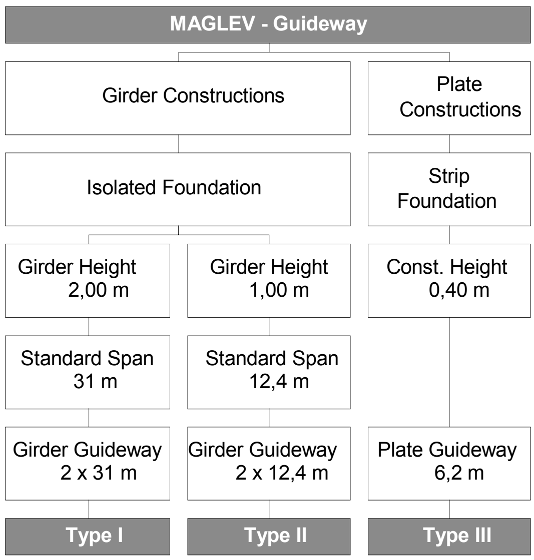

Figure 2: Guideway concept B - HH

The guideway was divided into the following components:

Superstructure: girders, respectively plate, including bearings
Substructure: pillars with bearing brackets and foundation

In this project, each lane was to be allocated its own guideway, called ´double-track guideway´.

2.1.1 Guideway consisting of girders

The system-technical demands of the guideway can be derived from the fact that the vehicle levitates in a designed distance of approximately10 mm to its guideway, even at speeds up to 500 km/ h.

For example, the guideway girders of the track Berlin-Hamburg had to be double-span systems (31 m span and a construction height of 2, 0 m (type I)), in order to meet the rigorous system-technical demands on deformation. As far as planning and construction were concerned, the tender documents demanded guideway girders with a steel construction as well as plate guideways consisting of either steel or concrete.

Since 1996, employees of the engineers´ office CBP, Munich, and the building company Max Bögl, Neumarkt / Oberpfalz, have been developing guideway systems for the Transrapid. These companies have had their hybrid guideway girder patented, which was presented on the occasion of the tender procedure for Berlin-Hamburg as the world-wide first model of a hybrid maglev guideway construction.

In the following, the most important types of guideway girders will be briefly introduced.

a) Steel guideway girder

The steel guideway girder type I was designed as a double span girder with a length of 2 x 31 m = 62 m. It was intended to be applied for a system length of approximately 31 m. The dimensions of the steel girder type I that are relevant to its alignment, are as follows:

- span length approx. 31 m
- girder length approx. 62 m
- minimum gradient height 2,20 m
- maximum gradient height 20,00 m
- construction height 2,00 m

This girder is a double span girder with short cantilevers at its ends. The ends rest upon the points of support of the substructures. There are two points of support for each bearing axis so that each guideway girder lies upon 6 points of support (bearings). The end supports of two neighbouring guideway girders rest upon common substructures. Within the support axes at the end of each girder there is one bearing that is generally mobile as well as one bearing that is lengthwise mobile but fixed in transverse direction. With a height of 1, 55 m between the space curve (gradient) and the lower edge of the supporting steel bracket, as well as with an overall construction height of 250 mm for the bearing construction, there will be a difference of 1, 8 m in height between the space curve and the upper edge of the substructure/ bearing bases.

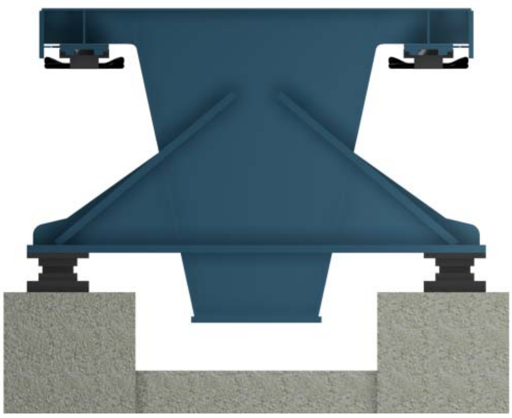

Figure 3: Steel guideway girder type I, B-HH

Additionally, as far as the track Berlin-Hamburg is concerned, there was intended additionally a steel guideway girder type II with a system length of 12, 40 m. This girder type was designed as a double-span girder with a length of 24, 80 m. The relevant dimensions of the steel girder type II are:

- span length approx. 12,40 m
- girder length approx. 24,80 m
- minimum gradient height 2,20 m
- maximum gradient height 10,00 m
- construction height 1,00 m

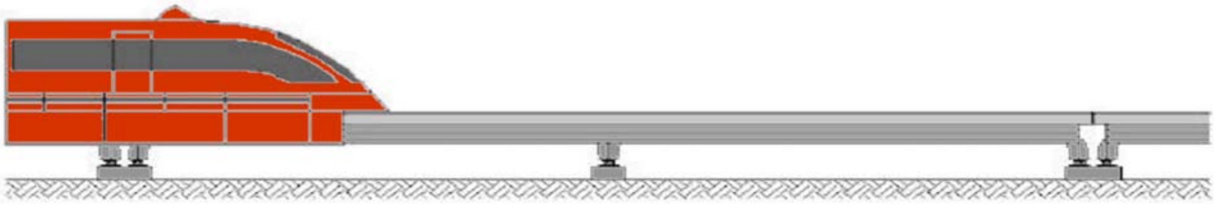

Figure 4: Steel guideway girders type II, B-HH

The steel guideway girder type II (construction height 1, 00 m) rests as a double-span girder with short cantilevers at its ends upon the substructures, too. For each support axis there exist two points of support so that each girder has got 6 points of support (bearings) altogether. The end supports of two neighbouring guideway girders rest upon common substructures. Within the support axes at the end of each girder, there exist both a bearing that is generally mobile as well as a bearing that is lengthwise mobile but fixed in transverse direction.

With a height of 1, 55 m between the space curve (gradient) and the lower edge of the supporting steel bracket, as well as with an overall construction height of 250 mm for the bearing construction, there will be a difference of 1, 8 m in height between the space curve and the upper edge of the substructure/ bearing basis.

Both of the steel girders show a trapezoid box section tapering downwards. Each section of the entire girder geometrically follows the space curve in an accurate way, a fact that leads to highly complex demands upon the manufacturing process. Therefore, the concept of the steel girder leads to comparatively high manufacturing costs. It shows the following specification:

- high sound emission, in comparison to concrete girders
- comparatively low stiffness in vertical direction
- high temperature gradient ($t_{top} - t_{bottom}$ and. $t_{left} - t_{right}$)

b) Hybrid guideway girder

Since 1996, the hybrid guideway girder has been developed on the basis of the advantages and disadvantages of the pure steel and the pure concrete guideway girders. When the hybrid girder was developed, the basic idea was to combine different building materials in order to profit from the advantages of the respective material. At the same time, specific disadvantages of each building material could thus be avoided. In contrast to the pre-stressed concrete girder that is apt to carry loads most effectively, the steel construction perfectly meets the system-specific demands on exactness, especially in the functional areas. Moreover, the newly developed

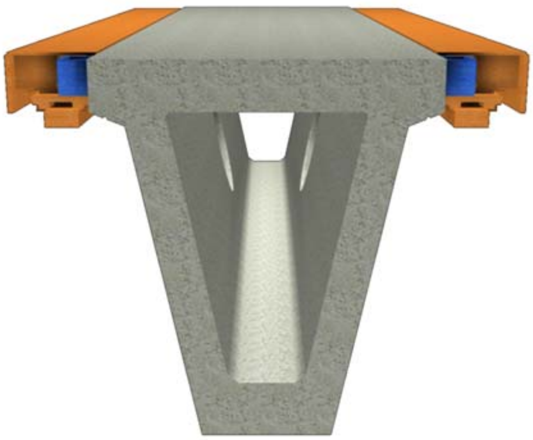

Figure 5: Hybrid guideway girder type I, B-HH

Hybrid Guideway Girder unites the three important elements of the Transrapid, sliding-rail, guidance-rail and stator-pack-fastening to a modular function unit. This concept of a guideway girder allows the accurate reproduction of the guideway´s space curve according to the system given.

Before assembly of the function-unit-girders only the bracket heads have to be machined, which must be seen a highly economical solution.

In accordance to the tender documents of the project Berlin-Hamburg, the hybrid guideway girders type I and II show cross-sections and dimensions relevant to alignment that are similar to those of the steel girders.

2.1.2 Guideway consisting of plates

The concept of the concrete plate guideway (type III) at ground level is based on the quasi-monolithic connection between the guideway plate and the substructure. This plate guideway is composed of plates with a length of approximately 6 m, consisting of reinforced concrete. Every 6 m along the guideway, the plates are clamped on the substructure by means of four attachment axes.

- plate length approx. 6,20 m
- minimum gradient height 1,45 m to 1,67 m
- minimum gradient height on special structures 1,35 m
- maximum gradient height 2,20 m

The design of the track Berlin-Hamburg offered a second variant on the at-grate plate guideway. The alternative concept of the plate guideway type III made of steel is based on the principle of the guideway plate made of concrete, i.e. plate segments with a length of 6 m that are monolithically connected with a continuous strip foundation.

In contrast to the guideway plate made of concrete, each segment of the steel guideway plate unites the superstructure and the substructure into one construction unit. The system ´Transrapid´ lays down a certain clearance that has to be kept, a fact that means a construction height of 1, 45 m minimum over ground, as far as the at-grate guideway is concerned.

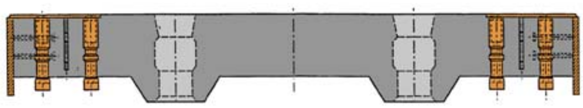

Figure 6: Concrete guideway plate type III, B-HH

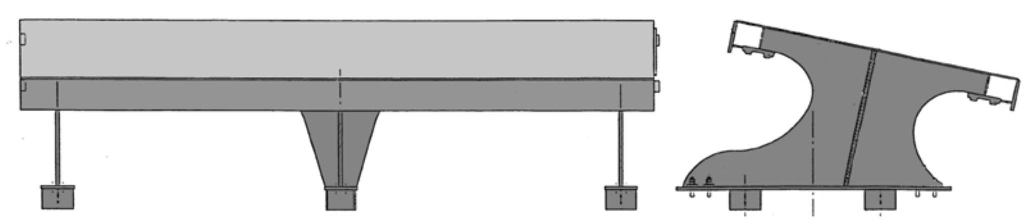

Figure 7: Steel guideway plate type III, B-HH

2.2 Shanghai International Airport – Long Yang Road Station

In November 1999, parallel to the design of the track Berlin – Hamburg, the Chinese ´Ministry of Science and Technology´ decided to choose a suitable Transrapid track in the Peoples´ Republic of China, as well as to examine the feasibility of the track under technical and economic criteria. As a consequence, the city of Shanghai decided to draw up a study concerning the feasibility of a link between the new International Pudong Airport and the center of Shanghai by means of a Transrapid track with a length of 30 km. Having examined the technical and economic aspects of the different guideway concepts, the Chinese decided to take the hybrid guideway into consideration. For this reason, CBP and two German building companies (Max Boegl and Gebr. v. d. W.) that are united in the so-called Transrapid Guideway Consulting Group (TGC) accomplished a feasibility study concerning the technical realization of the required guideway, in November and December of the year 2000.

Project data Transrapid Shanghai	
Distance	30 km double track
Maintenance connection	3 km single track
Stations	2 terminals
Quantity of vehicles 2003	3 vehicles to 5 sections
Maximum operation speed	430 km/h
Run time	8 minutes
Turnover	10 minutes
Operation period	18 hours / day

Figure 8: Project data Transrapid Shanghai

Besides the realization of the guideway concerning economic aspects as well as durability, these investigations focused primarily upon the keeping of a short production period of 2 years maximum. With regard to the various specific requirements of the project, the hybrid guideway girders, their components and their production processes were subject to an extensive development and optimization.

2.2.1 Elevated and at-grate guideway

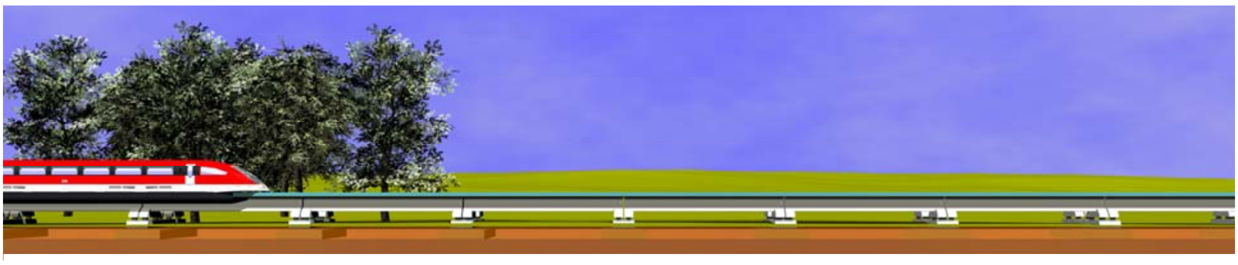

Figure 10: Discretely supported at-grate guideway type II

The City of Shanghai with its surrounding areas is characterized by the two rivers Yangtse and Huan, which cause a subsoil consisting of alluvial silt. Due to these subsoil conditions, long-term settlements of the buildings had to be drawn into consideration. There had to be chosen a guideway concept that was apt to provide an economic and efficient way of adjusting the guideway additionally at a later time. Due to these requirements, all the plate guideways had to be ruled out because of their quasi-monolithic connection between guideway girder and substructure. If plate guideways had been chosen, uneven settings of the subsoil could not have been adjusted but by methods that are both technically complex and extremely expensive. Therefore, a guideway concept with discreetly supported girders was proposed to the Chinese. Especially in case of uneven subsoil settlements, the hybrid guideway girders type I and II used in Shanghai make possible to readjust the bearings in an easy, reliable and economic way. The fact that the girder variants coming to use in Shanghai are reduced to the girder types I and II, presents an additional economic advantage. For it allows the construction of a specified production plant that is exclusively geared to produce hybrid guideway girders of type I and II.

2.2.2 Cross sections

Within the framework of new development and optimization mentioned before, the cross-sections of the hybrid guideway girders type I and II were revised in detail as well. The reorganization of the cross-sections was only made possible because the Chinese owner removed all restrictions other than system-specific or functional. This fact contrasted the project Berlin – Hamburg in an important way and made possible a profound and new development of the guideway girders. As mentioned above, the stiffness and the dynamic behaviour of the guideway girders are fundamentally important for the overall system ´Transrapid´. Due to extensive parameter studies concerning the optimization of the carrying behaviour as well as of economic aspects, the span length of the girder type I was reduced from 31 m to 25 m.

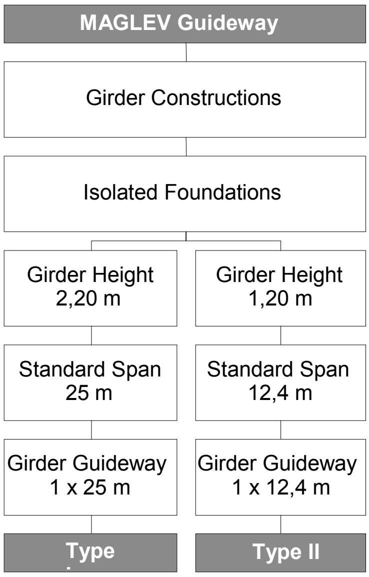

Figure 11: Guideway concept Shanghai

Based on the system-oriented clearance diagram of the vehicle, the cross section of the hybrid guideway girder type I was redesigned. The influence of temperature differences of the girder´s cross-section was considered in particular. The cross-section of the hybrid guideway girder type I (Fig. 12) now represents the optimal shape. It meets the static and dynamic demands on the guideway girder and, additionally, minimizes the costs of material.

In contrast to the girder type I, the cross-section of the girder type II is not designed in the shape of a hollow box, but of a solid concrete cross-section. In order to equip the entire guideway with a homogenous cross-section, the cross-section of the girder type II was developed on the basis of girder type I. The construction height of the girder type II was additionally limited to 1, 20 m in order to achieve a maximum of transparency for the silhouette of the at-grate guideway.

Figure 12: Hybrid guideway girder type I, Shanghai

2.2.3 Structural system of the girders

In comparison to the project Berlin – Hamburg, the newly developed cross-sections of the project Shanghai were additionally optimized in an essential way. The conversion of double span girders into single span girders in the course of the project Shanghai proved to be economically beneficient. This change of the structural concept led to the fact that forced strains upon the superstructure as well as upon the substructure could be avoided, especially in case of uneven subsoil settlements or temperature gradients. As a result, costs of design, production, transport and assembly on site were reduced at a considerable degree. In addition, this alteration guaranteed a maximum construction period of two years.

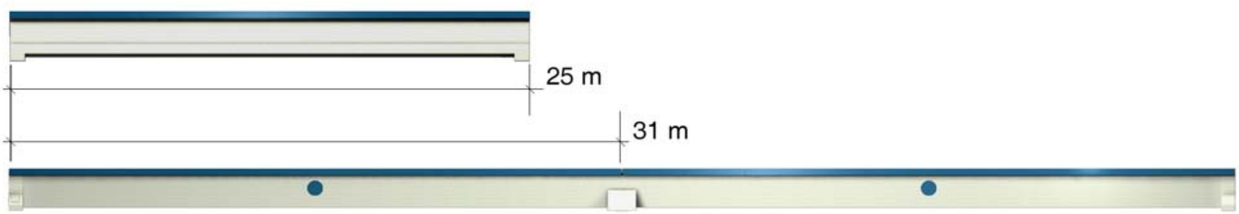

Figure 13: 1. Single span girder type I, 25 m standard span, Shanghai
2. Double span girder type I , 31 m standard span, Berlin - Hamburg

2.2.4 Detailed work preparation

Due to the technical and economic solutions described above, the Chinese owner was convinced of the efficiency of the redeveloped hybrid guideway. In January 2001, the contract between the two parties was signed. In order to attain the ambitious goal of the TR 08´s maiden trip in Shanghai as early as 31, December 2002, the transfer of technology was accomplished in two stages.

Stage 1: Consultation and training of Chinese engineers in Germany
Stage 2: Consultation and support of the Chinese on site in Shanghai

During the first stage of the project, the Chinese owner had to be introduced into the special demands of the guideway. Besides, a smooth start of the guideway´s design and production had to be ensured. For this reason, Chinese engineers were prepared for the project to come in a ten-week-training, shortly after the signing of the contract. The training focused on the following topics:

- system-specific requirements of the Transrapid concerning the guideway
- hybrid guideway girders and their components
- substructures
- subsoil and foundations

In the training, the main topics were looked at from the point of view of both design and manufacturing. In order to prepare the implementation planning, which was to be carried out by the Chinese engineers´ offices, the training included the following topics: specific technical principles of design, methods of static and dynamic calculation as well as the application of specific software, which had been developed for the design of hybrid guideway girders in particular. The Chinese side was extensively taught in 3-D implementation planning following the prototype girders I and II.

As far as the production of the hybrid girder is concerned, the topic of manufacturing can be divided into two relevant aspects:

- layout of a plant producing hybrid guideway girders
- work preparation: construction of prototypes

In coordination with the project Shanghai, a layout of a production plant was worked out in the course of the training. Besides, the start of a serial production was prepared. Thanks to the complete design of the prototype girders in 3 D, all conflicts and problems could be detected and resolved during the design period. On the basis of the feasilbility study that had been worked out during the training, a production plant of hybrid guideway girders was constructed in Shanghai from March to September 2001. The plant is approximately 1, 8 km long and 300 m wide. Due to the extremely short construction period of the Transrapid in Shanghai, the manufacturing capacity had to be guaranteed by the use of 32 formworks in the production plant.

Figure 14: Consulted layout of the production plant for Hybrid Girders in Shanghai

In order to support the Chinese owner, employees of the German companies were constantly positioned in Shanghai from February 2001 to December 2002. Apart from supporting the Chinese owner with regard to the implementation planning and construction of the guideway, the consultants focused upon the coordination of German and Chinese enterprises. According to plan, the TR 08 ran at a maximum operation speed of 430 km/ h and successfully completed its maiden voyage. At the beginning of 2004, the commercial enterprise was taken up successfully and according to plan as well.

Figure 15: Maiden voyage TR 08 in Shanghai

The guideway´s impressively short construction period of 18 months could only be realized by a permanently thriving cooperation between the Chinese and German project partners during the preparatory period. Besides, shift operation around the clock, seven days a week, led to a rapid construction of the guideway by the Chinese (Fig. 7 and 8).

2.3 Main station Munich – Munich Airport

The Transrapid track Berlin – Hamburg was cancelled in Februar 2000. As early as in October of the same year, the German States of Bavaria and Nordrhein-Westfalia decided to run feasibility studies of the airport link in Munich (length of approx. 37 km) and the so-called Metrorapid connection between Dortmund and Düsseldorf (approx. 80 km). At the beginning of 2002, the results of the two feasibility studies were presented. They showed that both tracks were perfectly apt to be operated, from an economic, technical and environmental point of view. In June 2003, Nordrhein-Westfalen stopped the design of the Metrorapid due to financial reasons. Bavaria, however, still advances the project of the Transrapid connection between Munich Airport and the central railway station in the city centre of Munich.

In October 2003, stage I of the project began, i.e. production of the documents for the official approval of the plan. In order to run the two feasibility studies mentioned above, the kinds of guideways were chosen in accordance to those of the project Berlin – Hamburg (see point 2.1.)

2.3.1 Classification of guideway types

After by the project Shanghai new ways of the Transrapid guideway were pointed out, the classification of the guideway types in the Bavarian project also show new starting points.
If for the project Berlin – Hamburg the guideway types were specified into elevated and at-grate guideway, now a distinction of the guideway takes place according to Shanghai to following criteria:

a) Construction type

The project in Bavaria presents a new standard guideway, following the solutions of the project Shanghai. The development is shown in Fig. 16.

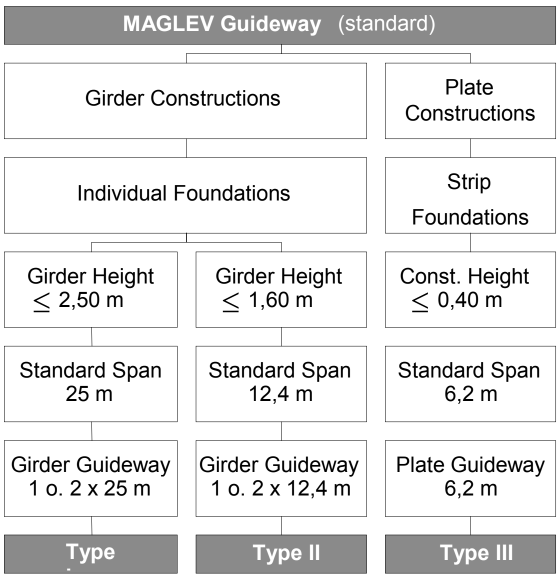

Figure 16: Guideway concept, Bavaria

In the following, the relevant changes are presented.

- trapezoid cross-sections tapering downwards are no longer used for the guideway girder type I and II
- the maximum construction height of the girder´s cross-section is increased
- the standard span of the girder type I is reduced from 31 m to 25 m.
- alternative use of single and double span solutions

b) Gradient height

Moreover, the guideway is classified with regard to different gradient situations. The assignment of the guideway girders to the route is, therefore, no more strictly gradient-bound.

- cut section: gradient ≤ + 1,45 m over TGS
- at-grate level: + 1,45 m ≤ gradient ≤ + 3,50 m over TGS
- elevated level: gradient > + 3,50 m TGS

This way of allocating the guideway girders to the guideway makes it possible for the project in Bavaria to construct the at-grate guideway by discretely supported girders as well, as already practiced in Shanghai.

c) Material

Different materials ensure a maximum variety of guideway girders. In order to clearly distinguish between the different guideway types, there has to be taken a look at the guideway´s material. In the following, the characteristic materials are described.

- steel guideway: guideway girders type I to III, as used for Berlin – Hamburg
- concrete guideway: plate guideway type III, as used for Berlin - Hamburg
- hybrid guideway: guideway girder type I and II, as used for Shanghai

3 Optimization potentials during design and realization

The design processes of the project Shanghai, and the preliminary work concerning the implementation planning and construction of the guideway, show that a smooth and economic course of the project can be ensured only by a competent and detailed project preparation, especially in the technically critical sections of the guideway. In the following, there will be described exemplarily, which technical and economic investigations are required in order to optimize the efficiency of both the technical concept and economic aspects.

3.1 Technical aspect

During the process of developing and optimizing the hybrid guideway it finally turned out that the guideway´s carrying and deformation behavior at that time when the vehicle is driving over, can be represented in a realistic way only by dynamic simulations at the overall system (super structure – substructure – foundation). The same applies to the verification of the factors concerning dynamic load capacity, which have to be explicitly proved in accordance with the system specification.

Simulations of a vehicle driving over the guideway work with the help of software applications that have been developed for this particular purpose.

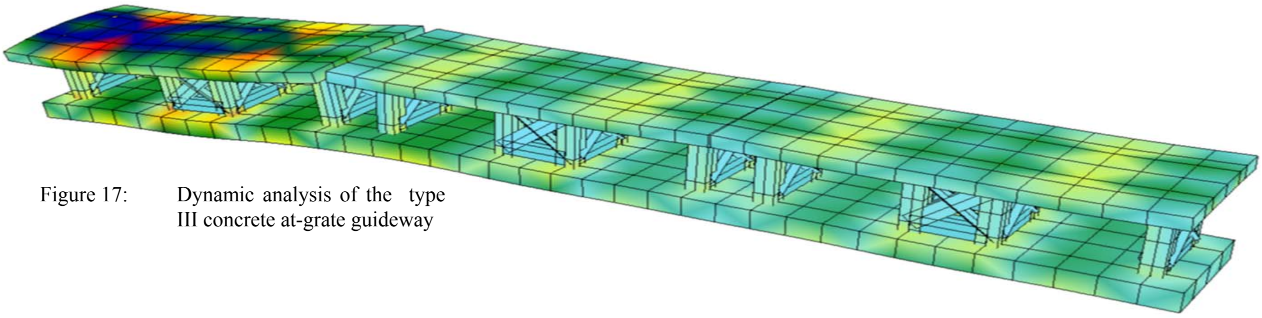

Figure 17: Dynamic analysis of the type III concrete at-grate guideway

3.2 Economical aspect

During the system development, the primary criteria are safety and durability of the guideway. However, economic aspects concerning design and construction of the commercial track of the Transrapid have to be taken into account as well.

For example, during the design period of the project Shanghai there was paid attention to develop a girder arrangement with a reduced number of girder types, in order to reduce the manufacturing costs. Further, an efficient and economical production of girders can be realized by standardizing the guideway concept (steel-, hybrid or plate guideway). The more one standardized type of a guideway girder is used on the track, the more the production plant and its machinery get profitable.

Depending on the project and thus depending on the respective construction period and length of track, investment costs can be reduced in a highly efficient way. To this aim, concepts of construction are developed with regard to either centralized or decentralized manufacturing processes. Profound analysis and the identification of the individual parameters of the investment costs make it possible to recognize beforehand potential risks and thus to minimize them by necessary adjustments in the stages of planning.

4 Conclusion

In an impressive way the project Shanghai proves that almost impossible tasks can be realized, if owner, operators, planners and building companies work towards the same objectives.

Apart from that, a comparison of the guidelines and conditions of the Transrapid track Berlin-Hamburg and of the guideway in Shanghai shows that one can obtain technically and economically optimized solutions only by reducing the fixed points and requirements as far as possible. The demands on the future Transrapid track in Bavaria have been adapted accordingly so that innovative guideway concepts can be made use of in Germany as well.

Experience in the development of new guideway concepts, in the engineering and support of the project Shanghai and in the analysis of future maglev projects has shown that costs can most effectively be reduced by a punctual, prudent and competent management and design of a project.

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