Ingbert MANGERIG
Professor University of Federal Forces Munich, Germany

Cedrik ZAPFE
Doctor Civil Engineer Mangerig und Zapfe Munich, Germany

Ulf LICHTE
Civil Engineer University of Federal Forces Munich, Germany

Oliver ZAPFE
Civil Engineer University of Federal Forces Munich, Germany

Thermal effects on guideways for high speed magnetic levitation transportation systems

Summary

The high speed serviceability of modern magnetic levitation transportation systems requires very high accuracy of the guidance correspondence with the gradient. The acceptable deflection of a single-span guideway girder for the TRANSRAPID system is limited to a less than four thousandth part of its total length under gravity loads. More severe additional limitations are standardized for vertical upwards and downwards orientated thermal deflections as well as for lateral deflections caused by the surrounding climate. The aim of one research programme was to give recommendations for specific guideway design in order to avoid, that the amount of required construction material and total costs are primarily determined by thermal effects on the construction due to climatic influences.

Keywords: high speed magnetic levitation transportation system, guideway, climatic influences, long-term simulation, thermal deflection, temperature distributions, equivalent temperature differences, deflection criteria, end rotation restriction, parameter studies

1 Introduction

The testing of high speed magnetic levitation transportation system prototypes under conditions of semi-commercial operation, covering vehicles as well as guideway constructions, started 1984 on the testing facility TVE in Emsland, Germany. A speed of 450 km/h was attained in regular operation with Transrapid Type 07 in 1988 on the total 31.5 km long track. From the beginning on difficulties with high speed operation especially under extreme friendly weather conditions were reported. Further investigation on such effects lasted longer than one decade. Various measuring programmes were installed on selected guideway girders for continuous determination of temperature distributions over the cross-sections and for the assessment of corresponding deflections. Experiments with coatings and heat insulation systems on girder surfaces exposed some positive effects; however reliable calculation methods for design procedures could not be developed solely based on those measuring programmes.
With signing of letters of intent for building commercial high speed magnetic levitation lines as an airport link in Munich and as a high speed regional transportation system in the Rhein-Ruhr congested area a research programme concerning thermal effects on guideway structures was initiated. Further commercial lines are planned in several countries. An airport link in Shanghai will be completed this year. The use of magnetic levitation transportation systems for high speed traffic is considered as being highly energy efficient on low noise emission.

2 Requirements from standard documentation

Levitation of Transrapid system is provided by a permanent support magnet on the vehicle and an additional stator magnet under the upper plate of the guideway, what pulls the vehicle upwards. Between those magnets a gap of approximately 10 mm is required. Lateral guidance is provided by pairs of guidance magnets and guidance rails, as shown in fig. 1.

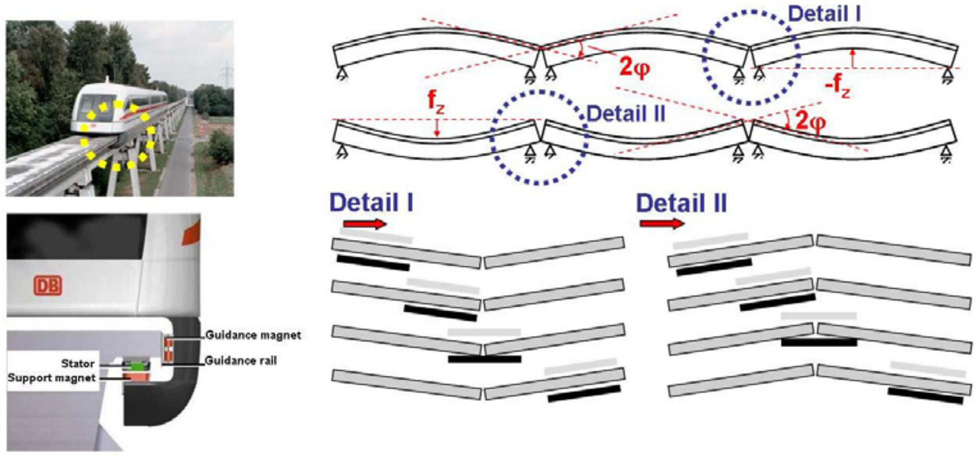

Fig. 1 Levitation system of Transrapid, Kinks caused by guideway deflections

For comfortable and safe service the guidance needs to follow approximately a straight line. Deflections cause kinks at the transitions from each girder to the next (see fig. 1). Those kinks reduce the gap between stator and bearing magnet and may affect contact between the vehicle and the guideway or may disturb the system control effecting maximum speed reducing. The aim of limitation to acceptable deflections is to limit the angle of rotation in the end of a guideway girder respectively the kink. This angle may not exceed $6.2 \cdot 10^{-4}$ for upward thermal deflection and $7.4 \cdot 10^{-4}$ for downward climate influenced deflection.

3 Method for assessment of thermal effects

As method for assessment of thermal effects on elevated high speed magnetic levitation transportation guideways simulations based on long time recordings of regional climate data received from meteorological organizations were chosen. A software tool was developed for this purpose considering all exterior influences as shown in fig. 2 and all internal material parameters for heat transmission and heat transfer.

By this way temperature distributions across the guideway cross-sections could be calculated. Equivalent vertical temperature differences ΔT between the lower and the upper edge of the girders or equivalent horizontal temperature differences between the side edges could be derived from each temperature distribution considering the shapes of specific cross-sections. As an example calculated temperature distributions for a double-span hybrid guideway girder, built in on the testing facility in Emsland/Germany in a north-south orientation, are shown in fig. 3. The comparison between results from a measuring programme dated from 2001 with the calculated equivalent temperature differences based on meteorological data for the period from 1997 to 2000 enables a verification of the accuracy of long term simulation results. The extreme values of measured and calculated temperature differences confirm a highly satisfying correspondence. Means of coefficients of thermal expansion for usual materials like concrete or steel deflections and rotations could be determined. Extreme deformations were calculated based on long time simulations.

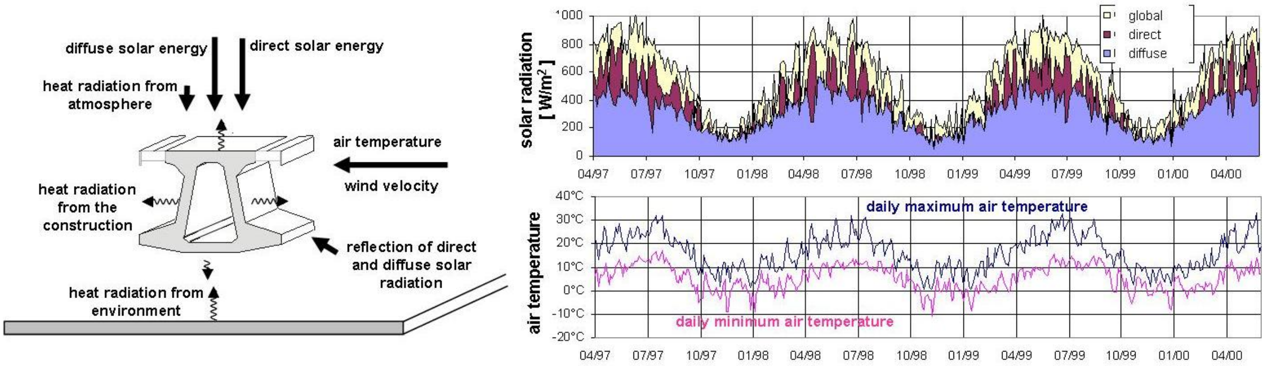

Fig. 2 Thermal environment of guideways on the testing facility in Emsland/Germany

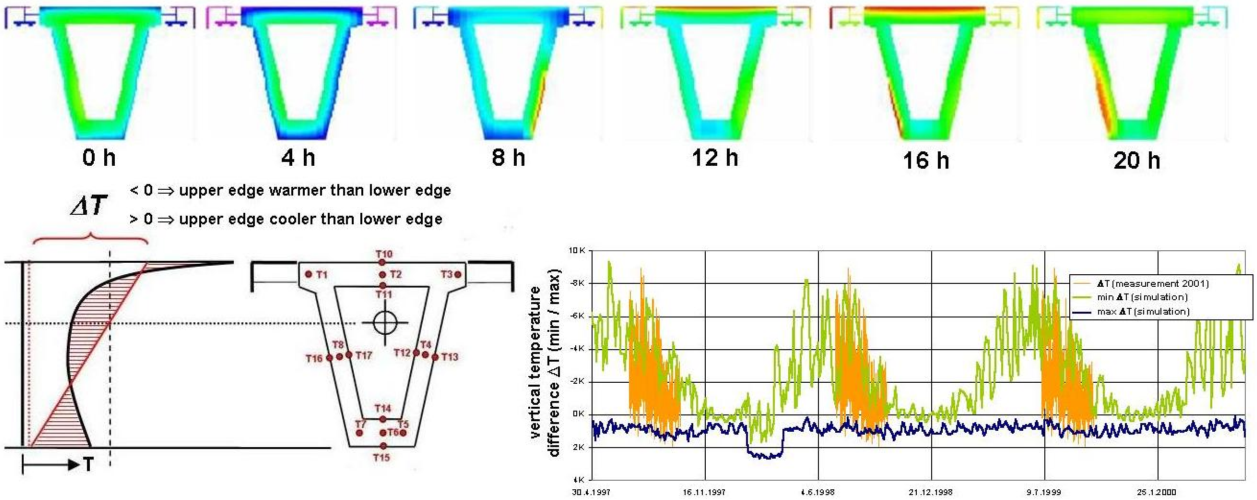

Fig. 3 Examples for calculated temperature distributions, comparison between simulation and measurement for a double-span hybrid girder on testing facility in Emsland/Germany

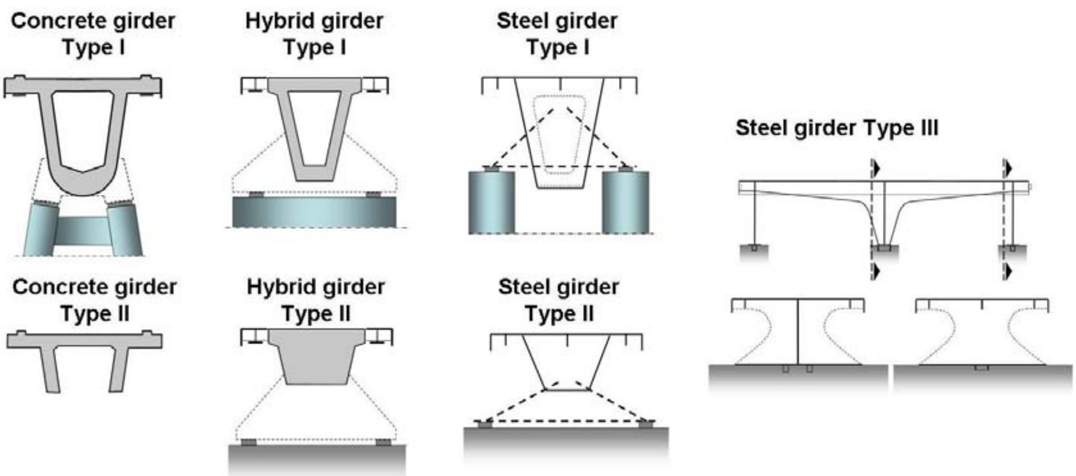

Fig. 4 Examples for analyzed existing or planned girders

An analysis of various existing or planned guideway constructions on the testing area TVE in the current state (e.g. fig. 4) resulted in the recognition, that all existing systems fulfilled the deformation criteria for permanent and temporary gravity loads, however all missed the requirements for climate induced deflections minimum for a couple of days per year. This fact previously was reported by the operators of the testing facility. Extreme deflections caused speed reductions and accordingly missing of desired quality of service due to schedule disturbances and a loss of reliability.

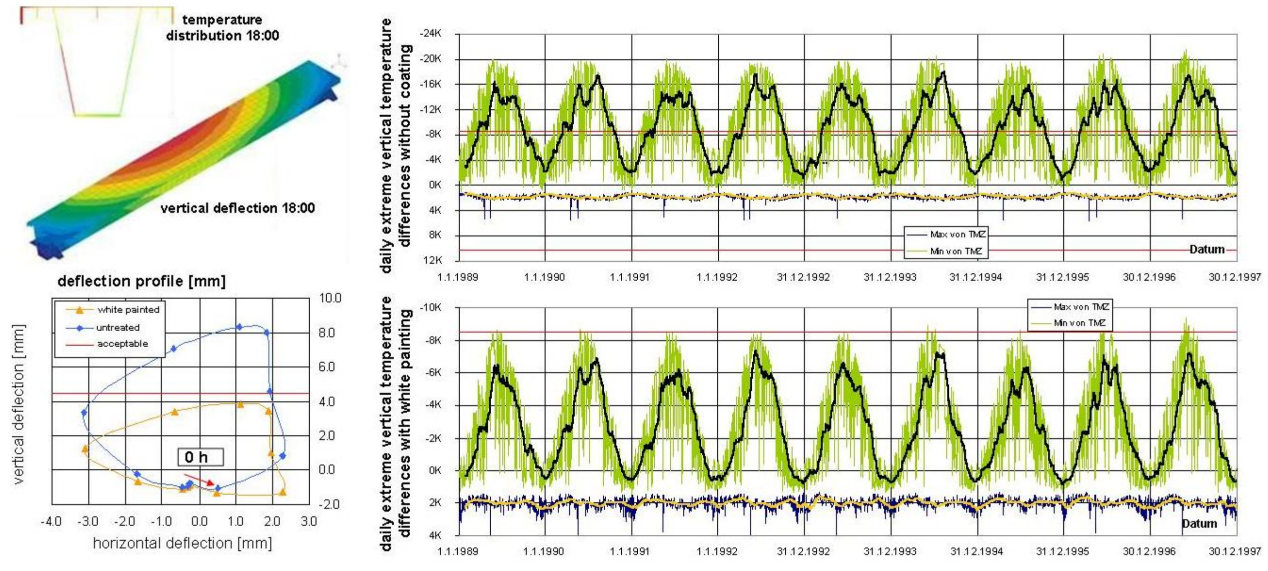

Fig. 5 Results of analysis for a single-span steel girder

As a further example the results of analysis for vertical deflections of a east-west oriented 25 m single-span steel girder are demonstrated in fig. 5 for untreated surfaces as well as for reflecting white painted surfaces. The acceptable vertical temperature difference corresponding with deflection limits is noted as a red line. The untreated guideway girder exceeds the limits most days of the year. Reflecting paintings represent a good improvement, however in this case on several days standards are violated even more.
One special case of a double-span steel girder with a lengthwise variable cross-section and additional the width bigger than the span, entitled as plate-solution, is shown in fig. 6. The deflection criteria are not suitable for this guideway structure. Finite-Element methods were applied for analysis, to determine the end tangent rotation under extreme climatic conditions separately for complete sunlight effect and for one span shadow coverage. The rotation restriction is missed for this guideway type.

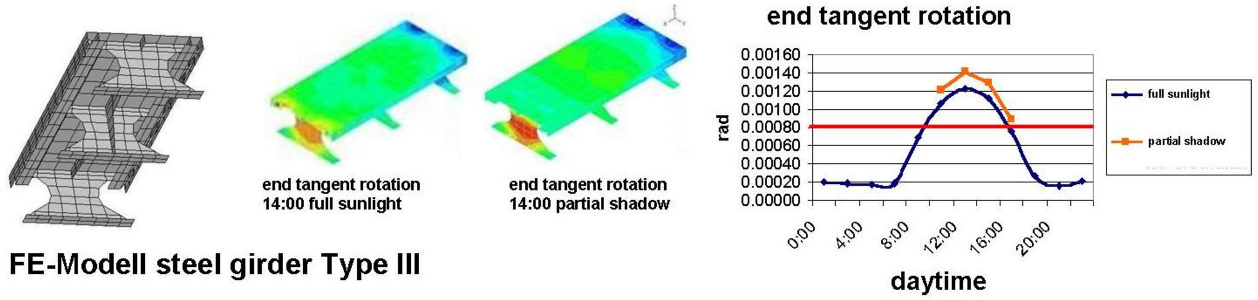

Fig. 6 Results of analysis for a double-span steel girder with variable cross section

A full scale analysis of guideway girder prototypes for new traffic lines requires more detailed parameter studies particular considering partial shadows (e.g. two parallel tracks), track direction (e.g. west-east) and seasonal influences (e.g. snow on the ground, vegetation) separately for horizontal and vertical deflections.

4 Proposals for improvements to guideway structures

Research on thermal effects on guideway structures comprised proposals for improvements to existing guideway girders and recommendations for new track favourable design. The most effective measure for existing guideways is light colour painting of the upper surface; however criteria are missed for some days per year in several cases. Occasionally horizontal deflection restrictions were exceeded, when constructions were amended on vertical deformation criteria. Cost estimations for paintings and coatings, considering cleaning and renewal at regular intervals enlightened that those methods need contemplation in design process for economical reasons particular for future projects. Furthermore disagreeable interruptions of service are anticipated due to maintenance reasons.

Various construction principles were analyzed for new tracks. Composite structures (e.g. fig. 7) were analyzed as well; however they did neither represent the optimum guideway girder system from thermal aspects nor from the economic point of view. An example for a combined system from a concrete beam bearing the support and guidance system consisting of steel plates similar to steel girders type III, designed by Pfleiderer Inc./GE, is shown in fig. 7.

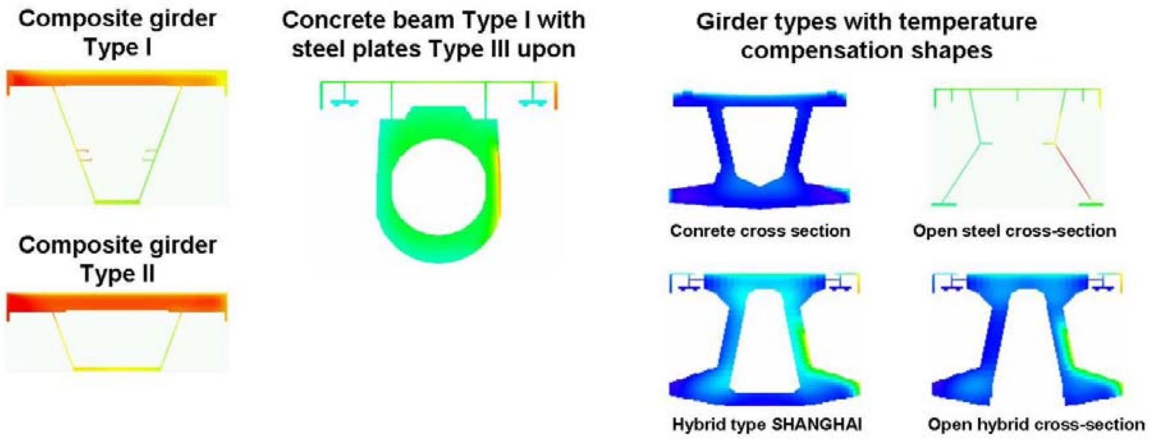

Fig. 7 Temperature distributions over alternative cross-sections

Approaches for thermal optimizing of guideway girders were identified in cross-section design and in structural system design. Thermal effects could be considered through increasing of cross-sections height, however from aesthetic aspects and concerning building material consumption this solution is not desirable. A suitable alternative is the arrangement of temperature compensation shapes to the bottom part of cross-sections, as shown in fig. 7 for concrete, steel and hybrid girder types. This principle aims at approximately equal warming respectively cooling properties of upper and lower portions of cross-sections under climate influences and at an increasing horizontal stiffness for the hybrid girder types and is highly effective. Side shadow coverage unfortunately can reduce those advantageous effects. One hybrid girder type with temperature compensation shapes, similar to the figured SHANGHAI type, was applied for the Shanghai Transrapid airport link.

Other options for thermal optimizing are modifications to the structural system as shown in fig. 8. One proposal is the partial column integrated guideway type, what effects a 50 % reduction of the summarized end rotation angles at the girder transition. If this effect is mentioned in the deflection criteria, almost all existing guideway girder types on the testing facility would fulfil the restrictions. On unchanged column distances increasing of total costs needs not to be expected. An alternative approach is a fine adjustment of the camber particularly regarding upward oriented thermal deflection as critical. Instead of full compensation of calculated gravity load induced vertical deflection portions of them could be tolerated up to the corresponding criteria for gravity load. A thorough calculation of long-term creeping and shrinking effects would be mandatory. The success of such a design process cannot be assured for all girder types. For composite guideway girder types e.g. the downward thermal deflection can get critical.

A guideway girder end connection with pre-stressed anchors and spring-elastic bearing elements could generate multiple-span girders from single span-systems with positive effects on thermal deflection. Partial shadow coverage must be taken into account. The stators could also be fixed to a continuous support rail without gap at the guideway girder transition. On this way the extension of the slope’s change could be enlarged to avoid kink effects. Thermal extension of the single members requires detailed analysis.

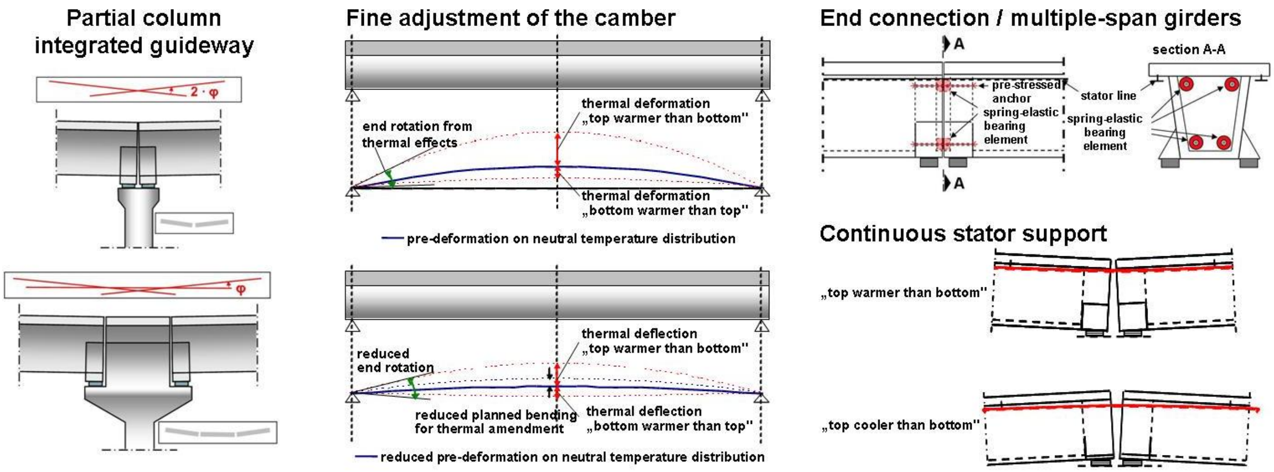

Fig. 8 Proposed modifications to the structural systems for temperature effect amendment

The durability of most amendments to the structural system except from partial column integrated guideway system needs further research. Therefore those systems are not advisable for an application within the closer future without previous long-term testing. A further aspect of guideway development is system integration. Main restriction is to keep the vehicle movement zone free from all constructive components. Limb structures as framework constructions, which could be highly effective for almost equal temperatures in upper and lower guideway structural members, are not acceptable due to high noise emission on high speed operation.
An assessment of economical issues was accomplished in the framework of the research project for various girder types based on rough cost estimations assuming material costs, working costs, transport costs for pre-fabricated single span-girders, costs of foundations, general extra charges and outstanding maintenance costs. The final economical optimizing is planned to be achieved through a competition under the guideway girder manufacturers. Concrete structures initially were identified as more economical than steel guideway constructions.

5 Conclusions

High speed magnetic levitation transportation systems are sensitive against discontinuous guidance. Severe guideway structure deflection restriction particularly requires a thorough consideration of climatic temperature loads within the design process as well as track orientation and partial shadow coverage effects. A reliable calculation method for climatic induced thermal effects was developed in order support rapid and economical design procedures replacing long-term testing of prototype guideway girders. Some general principles for structural guideway design are acknowledged as advantageous

6 References

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