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Hybrid or composite constructions: A way to economic and sustainable structures

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ABSTRACT: Hybrid or composite constructions with a reasonable arrangement of different building materials within one cross-section or one member by using the advantages and avoiding the disadvantages of each material will lead to optimized structures in comparison to structures built completely with one material [1]. Some record breaking structures could be realized by using that principle [2].

Nevertheless real hybrid constructions are not very common till today. This paper describes two examples which demonstrate the capabilities of composite and hybrid structures. One example is the development of a completely prefabricated timber-concrete – composite slab. Research results on this topic will be shown.

The other example is the prototype of the hybrid guideway for the maglev track in Shanghai.

1 INTRODUCTION

The physical and mechanical capabilities of building materials differ quite a lot. This is the reason why for every building material there exists a maximum possible span width of a structure depending on the statical system like for example an arch or a beam. The limit span is directly proportional to the ratio of permissible stresses σ or τ to specific weight [1]. For conventional concrete this ratio is 600 m, for structural steel it is five times as high. Especially when additionally cost considerations are taken into account it is quite obvious that it would be a very efficient concept to use different materials for different parts of a structure or cross-section depending on the stressing of the different parts. The basic idea of composite or generally speaking hybrid structures is to combine different building materials in order to take profit from the advantages of the respective material. At the same time specific disadvantages of each building material can be avoided.

But due to traditional thinking and specialized education at the universities till today many engineers tend to think in only one material – concrete or steel or wood – when designing new structures.

Nevertheless built structures like for example the cable stayed Normandy bridge but also theoretical and experimental research clearly show that the use of different materials in one construction may lead to more economic, more sustainable and technically advanced structures [2].

The two following examples of composite and hybrid structures will substantiate that statement.

2 PREFABRICATED TIMBER-CONCRETE COMPOSITE FLOORS

2.1 *History and basic idea*

During the last decades, timber-concrete composite (TCC) slabs have gained their popularity, particularly in the field of rehabilitation and strengthening of existing timber floors [6], [11]. And also recently in central Europe completely new timber-concrete composite floors have been implemented during the timber-based construction of schools, offices and administration buildings.

Timber-concrete composite elements are constructed from a concrete layer which absorbs mainly compressive stresses and a timber profile which absorbs mainly tensile loads. The complete load-bearing system is activated by implementing connective elements, so called shear connectors, which give the complete system lateral rigidity. In contrast to rigidly-connected structural members small amounts of structural movement are noticeable and acceptable. Within this statically indeterminate system structural and connective elements can only be calculated using values for the shear stiffness gained from experience. Methods to establish short-term and long-term models of timber-concrete composite beams are introduced in references [3], [4], [5] and in references [6], [7] and [8]. The design of the different parts of the cross section in the ultimate and serviceability limit states is ruled by the international and national codes [3], [4], [9].

Despite the many advantages resulting from the use of the two building materials, the timber-concrete composite system has been unable to make an impact within the standard construction sector and is only used in a limited number of structural applications. This is probably due to the popular use of insitu-concrete with all of its inherent disadvantages for the concrete parts of timber-concrete composite members. The use of insitu-concrete (wet system) brings moisture into the building and needs a certain period of time to gain the necessary strength by hardening of the concrete. Thus the extremely short time of completion of pure timber constructions is not reached.

In view of the moisture effects of the aforementioned in situ concrete it is suggested that the two systems are prefabricated independently of each other and connected to a structurally-sound element on the building site.

This new construction system with its inherent low moisture level brings together the advantages of the two independent materials, particularly when prefabricated to a high quality and very tight tolerances. The complete elimination of wet concrete work on the building site means that the construction is not adversely affected by low temperatures. The relatively late stressing of the members and the elimation of a big part of the concrete shrinkage can be regarded as a long-term advantage.

2.2 *System specifications*

The TCCs were developed by the Department for concrete structures and Bridge Design at the University of Innsbruck. The glulam timber profile with a width of approx. 60 cm is prepared in a timber engineering company. Depending on the structural requirements the beams have a depth of between 12 and 18 cm (Fig. 1). The concrete layer has a depth according to structural requirements of between 8 and 12 cm. The width of the elements is limited to effectively 250 cm for easy of transport. This results in the use of 4 × 60 cm glulam elements together with one prefabricated concrete slab element. Minimum reinforcement is introduced into the concrete to eliminate damages during transport and to reduce long-term shrinkage to a minimum.

Finally, both elements are brought to site, positioned and supported temporary where required. The two elements are then connected together using structural fasteners or so called shear connectors.

2.3 *Tests*

The main criteria for using the two advantages of the materials the tensile strength of timber and the compressive strength of concrete are the shear stiffness and the bearing capacity of the shear connectors. As there are no adequate shear connectors yet available in order to most of the technological research at present to connect the two parts in a efficient and effective way serves to develop practical connection systems.

Sixteen experiments with three composites have been carried out to establish absolute tensile/loading characteristics.

A cam (notch) construction with cast in situ mortar has proven to be the most efficient structural method of connecting the two components.

The connecting geometry shown in Fig. 2 gives a medial maximum load bearing capacity for two cams

Figure 2. Specimen of shear tests with cams during casting in the grout.

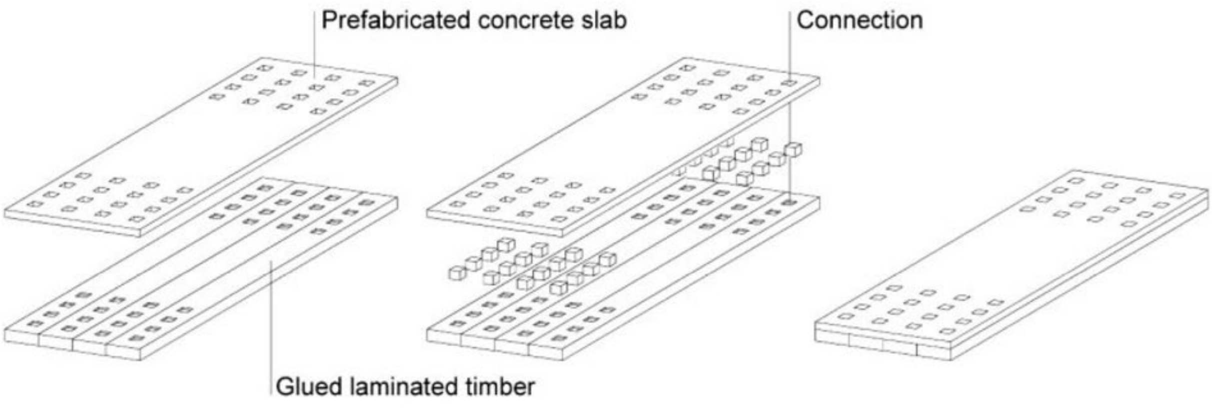


Figure 1. Schematic drawing of the assambling of the prefabricated timber-concrete composite slab.

Figure 3. Bending test with cams as shear connectors.

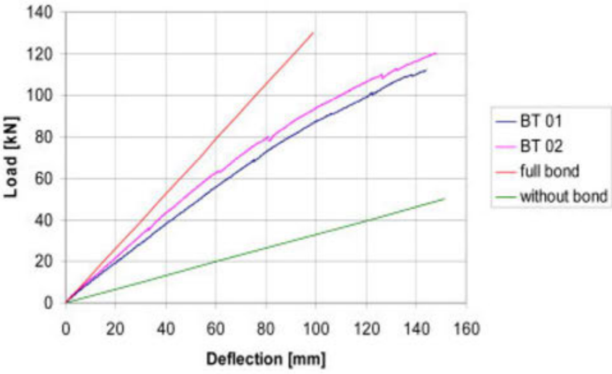


Figure 4. Load deflection curves for the bending tests.

of 200 kN. The initial shear capacity was determined at about 140 kN/mm. A ductile failure of the shear connectors was reached with cams which had a depth of 20 mm in the timber section. Thus a local compression failure in the timber with huge lateral deformations under constantly high loads could be reached.

The practical structural advantages of using cams (notches) are that the openings can be filled effectively and any cavities or openings resulting from defective pouring of the concrete can be eliminated completely. Due the rectangular cam openings a faulty formwork can be eliminated completely.

Initial large scale tests of composite members involving cams a shear connectors have been carried out. Slab elements with a span of 7.3 m, an element width of 56 cm, a timber profile thickness of 14 cm and a concrete thickness of between 8 and 10 cm achieved a maximum load-bearing capacity of between 110 and 125 kN. The elements failed due to a tensile break in the timber element and a maximum deflection of 160 mm.

With a load of 40 kN the value of deflection was between 37 and 43 mm Fig. 3. A later calculation of the elements was able to prove that the initial values for the shear stiffness were reached.

2.4 *Further research*

In order to implement the new timber concrete composite system effectively, an innovative method of connecting the two separately prefabricated materials on the building site, has been developed. Up until now, the main methodology for connecting the two components has concentrated on cams within the timber and concrete which are filled by mortar pours. Positive shear experiments have proven that the system is structurally viable and usable.

Further short-term and long-term shear and bending experiments should prove that the cam methodology is structurally viable. The shear stiffness and the bearing capacity obtained from the shear experiments should be proven and optimized by means of further large-scale testing.

On the basis of the figures obtained by the experiments, a structural-design procedure has to be established.

3 HYBRID GUIDEWAY GIRDERS FOR MAGLEV TRAINS

3.1 *History and basic idea*

In the about 30 year old history of guideways for Transrapid tracks for a very long time guideway concepts were dominated by one material, either steel or concrete [13], [14].

The system-technical demands for the guideway con be derived from the fact that the vehicle levitates in a design distance of approximately 10 mm to its guideway, even at speeds up to 500 km/h:

- least permissible tolerance in the area of the functional elements
- least permissible deflections
- precise geometrical demands caused by the guideway covering vehicle

These serviceability demands are harder to meet than those arising from the ultimate limit state. They are a challenge to every engineer.

For example in vertical direction, the permissible deflections under live load amount to only $1_{sys}/4800$ and by the maximum vertical temperature gradient to $1_{sys}/8000$. The specification prescribes that a temperature gradient of 22 K ($t_{top} - t_{bottom}$) has to be applied for the calculation. This figure exceeds the requirements for usual bridge constructions by far.

Furthermore, the first natural mode of the girder represents an essential parameter for the design. If the frequency criteria are kept, resonance of the superstructure can be avoided while the train crosses the girder.

Demands concerning the grider stiffness can be derived from the proportional cohesion between the natural frequency, stiffness and masses of the girder.

The steel guideway girder (Fig. 5) has a trapezoidal, downward tapering, box section. For design reasons, the whole girder geometrically follows the space curve, which sets very complex requirements for production. This leads to comparatively high construction

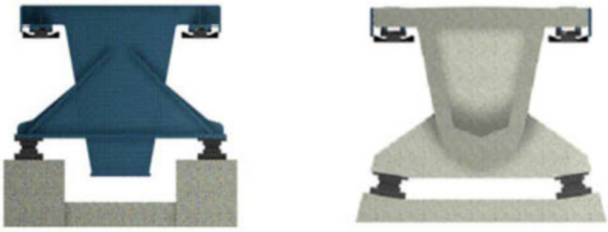


Figure 5. Former steel and concrete girders.

Figure 6. Principle of the Hybrid Guideway Girder: concrete/bracket/function unit girder.

costs for this type of girder. In addition, the steel girder has the following characteristics:

– high noise emissions compared to concrete girders
– double-span systems for compliance with the deformation criteria

The prestressed concrete guideway girder (Fig. 5) shows a box-shaped cross-section with a construction height of 2.0 m. The lower flange is roughly shaped semi-circular. The construction with pre-stressed concrete proved advantageous in regard to resistance to guideway vibrations. The high dead load and the good damping properties also prevent a build up of harmful guideway vibrations especially in the vibration-critical case of levitation at rest.

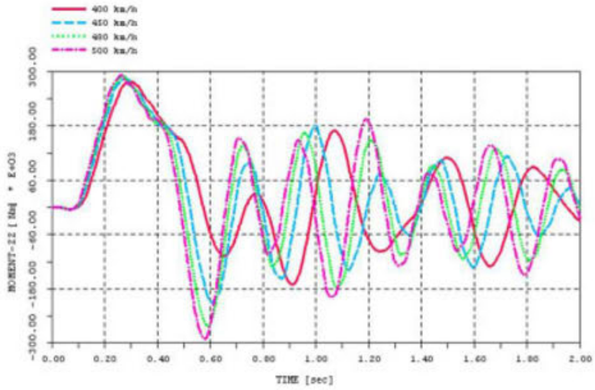
On the other hand, grouting the functional components i.e. the stator pack, slide rail and lateral guidance rail proved to be an unsuccessful means of fixing. This grout was inadequately durable and resulted in holes and flaking, which requiredexpensive and time-consuming rework.

The disadvantages of the two girder types described above led to the development of a new girder type. This new girder was to unite the advantages of the existing constructions. The new patent was called the Hybrid Guideway Girder.

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 disadvantage of each building material could be avoided.

While a pre-stressed concrete girder 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 Hybrid Guideway Girder unites the three important elements of the Transrapid, sliding-rail, guidance-rail and stator-pack-fastening to a modular function unit (Fig. 6), [15], [16].

The function unit girder is produced with a module length o approximately 3.10 m corresponding to the



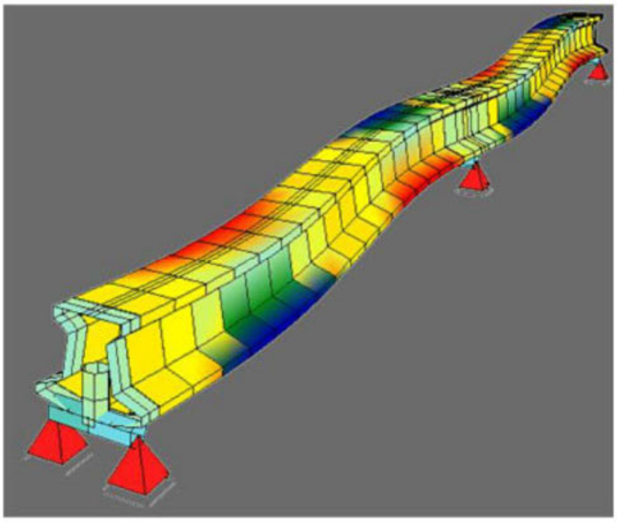


Figure 7. Dynamic calculation of the hybrid girder.

triple system length of the stator packs. Except for a few special models, the modular function unit girders are all identical (Fig. 6). This system makes possible a serial production as well as precision work to the finest tolerances ever reached in the building industry.

Being the connecting element between the main structure (precast pre-stressed concrete girders) and the function unit girders (welded steel structure), the brackets had to be newly designed and checked with regard to their usability. The brackets lead the loads of the function unit girders into the pre-stressed cross section of the main girder. A redundant system of fit bolts and pre-stressed screws is used here.

The prestressed concrete girders are produced in precasting works. The girders are prestressed by centric or balanced pretensioning. In addition, tendons with post-tensioning in the form of parabolas help to shape the concrete girder. After production and storage, the girder is finished by using computerized methods of comparing the design and actual geometry and corresponding machining of the connecting plane of the brackets. This is the way to ensure the required precision in the mounted function unit girders over the whole length of the guideway girder.

3.2 *Development steps of the hybrid girder*

The whole hybrid girder as well as its single components were subjects of statical calculations and

Figure 8. Hybrid guideway under use in Shanghai.

dynamical analyses. All modern techniques, i.e. the Finite Element Method, were used in order to calculate the bearing behaviour of the girder.

It has to be mentioned that not only the bearing capacity (ultimate limit state) of the girder had to be checked. As comfort is of great importance to the Transrapid, the girder's behaviour (e.g. deformation) under live load had to be verified and proved too (serviceability limit state). Of course the fine tolerances given by the Transrapid design code had to be respected.

Furthermore in oder to generally use this new girder type for the Transrapid Guideway, it is and was necessary to go through a detailed testing procedure. The series of tests can be roughly divides into three steps:

- during the development: lab tests of construction components
- during the testing phase: prototype girders
- during the commercial use: selective long term measurements

3.3 *First application*

The worldwide first commercial track for maglev trains was built in Shanghai and opened in 2003 ([15], [16]). This 30 km long double track connects the city of Shanghai with Pudong Airport.

The Cinese client decided to use the hybrid girder after a long evaluation of all existing girder types. Within a record breaking time a complete girder production was set up in China and within two years the complete guideway with an overall length of more 60 km was built thus confirming not only the technical but also the economical advantages of this hybrid construction in comparison with traditional girders made of one material.

4 CONCLUSION

The two examples of composite or hybrid structures described in this paper clearly demonstrate technical, economical and environmental advantages in comparison to traditional construction consisting only of one certain material.

Especially in times with economic restrictions and under the influence of sustainability aspects this king of constructions will gain more and more importance.

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