



Transrapid Guideway Beams

**Modular construction method Beams,
pre-fabricated in pre-stressed spun concrete**

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Summary: This document describes a solution for guideways for magnetic levitation (maglev) railways such as the *Transrapid* as an alternative to the present elevated constructions in steel or steel-reinforced concrete at the test track in Emsland, Germany. The monolithic beams are replaced by guideway carrier beams and guideway sections of steel or concrete. This reduces costs for transport, manufacture and on-site erection. At the same time, it largely eliminates distortion caused by uneven temperature influences on the carrier beams. The beams, as well as the guideway support columns are manufactured as pre-fabricated sections in high-strength pre-stressed spun concrete.

The innovative Flessner/Pfleiderer guideway carrier system has already been patented in Germany, and registrations are in progress in Europe and overseas.

1. Introduction

The guideway supports for the *Transrapid* test-track in Emsland were built some 20 years ago, with support from the then Federal Minister for Research and Technology. It has been known for some time that constructing the guideway in the same fashion in a contract construction situation would be too expensive and that the supports as used at the test-track could not be used without substantial improvements. They are not optimized for the demands of long-term constant operation, and in many ways will hardly satisfy the high guarantee demands expected from the operator. Moreover the manufacture and erection of the supports used at the test-track, and originally planned for the Berlin-Hamburg line, is far too cumbersome and also very costly. The long-standing operations manager at the *Transrapid* test-track made the point with the following statement: "...the decisive cost savings potential is in the optimal manufacture and construction technology for the *guideway*, the longer the route the more significant the savings. On the other hand we could afford to equip the *vehicles* with every possible comfort, we could even plate them with gold".

The author is an Emeritus at the University of Hamburg, Germany. He has been working together with Pfeleiderer AG, a company in Neumarkt/Oberpfalz (Germany), for several years. This co-operation is based on a special calculation method he developed in 1965 and has constantly updated. The method was specially developed for use on digital computers for strength proofing in concrete construction, particularly for pre-stressed concrete technology. - Pfeleiderer AG, with its 10, 000 employees and annual revenues of 1.5 billion Euros, specializes in infra-structure technology, wood materials and finishing systems for building construction. Some 2000 employees at Pfeleiderer Infrastrukturtechnik GmbH & Co. KG in Neumarkt produce wind energy and mobile communications technology and, above all, Pfeleiderer is a supplier of rail track systems such as the *ballastless track* specially developed by them for high-speed rail traffic (Rheda 2000).

Since 1997, together with Pfeleiderer, the author has developed a guideway carrier system in the valid standard dimensions for the *Transrapid*, consisting of a modular system of individual structural elements. The actual supports (carrier beams) are of spun concrete pre-stressed in a pre-stressing bed. This support system has been registered for patents in Germany and abroad. The German patent has been granted. Spun concrete technology has existed for almost 100 years. Pfeleiderer took up the technology and developed it further, and is now able to manufacture support structures, such as for wind energy installations, in spun concrete, which can withstand very high dynamic loads. They have proven themselves perfectly in practice. In the meantime Pfeleiderer has become the world leader for transmitter masts in spun concrete. The special demand placed on this type of mast is very high (deflection) strength to minimize bending.

2. Optimising construction and transport costs to site

The guideway supports in Emsland still have the following problems for which no solution has been found:

- 1) Distortion of beams due to uneven temperature influences,
- 2) Effects of aerodynamic influences at high speeds,
- 3) Achievement of a minimum *erection weight* versus a maximum *standing strength* against critical deflections,
- 4) Quality control and reasonable maintenance costs for long guarantee periods.

One year ago, a dual-track hybrid concrete guideway support developed by the Max Bögl company, also from Neumarkt/Oberpfalz, in co-operation with the engineering company Büchting - Streit - Feix, was erected in Emsland. In contrast to all previously erected supports it represented, primarily, a quality improvement compared to the previous situation. Whether this improvement also applies to items 1) and 4) above is being tested. However, as far as items 2) and 3) are concerned, not much can have changed. In any event, the erection weight has remained at about the same level.

In the Flessner/Pfeleiderer system the actual carrier and guidance elements for the *Transrapid* vehicles also consist of guideway sections, either completely in steel or of pre-stressed concrete, depending on the specifications (however Pfeleiderer is presently not pursuing the concrete section). Both are planned in the present draft tenders as stand-alone elements, however not in the elevated sections but only at near ground level. They are specified with a standard length of 6.20 m, four fitting exactly on one carrier beam at the new standard length of 24.80 m, five on 31 m, three in the also planned length of 18.60 m and two on type II beams of 12.40 m length, see Fig. 1.

What are the advantages here? As opposed to the "one-piece" (monolithic) guideway support beam the advantage is first in the more cost-effective production of smaller, factory-produced, pre-fabricated sections. This naturally makes quality control, transport and erection of these sections simpler and cheaper. Finally the transport weight of the individual sections is substantially lower than the weight of a complete carrier beam. The present concrete beam at 24.80 m length in the Emsland test-track weighs some 114 tons; the heaviest version of the support beam produced in spun concrete at the same length weighs only 70 tons, thus yielding a weight saving of 39%.

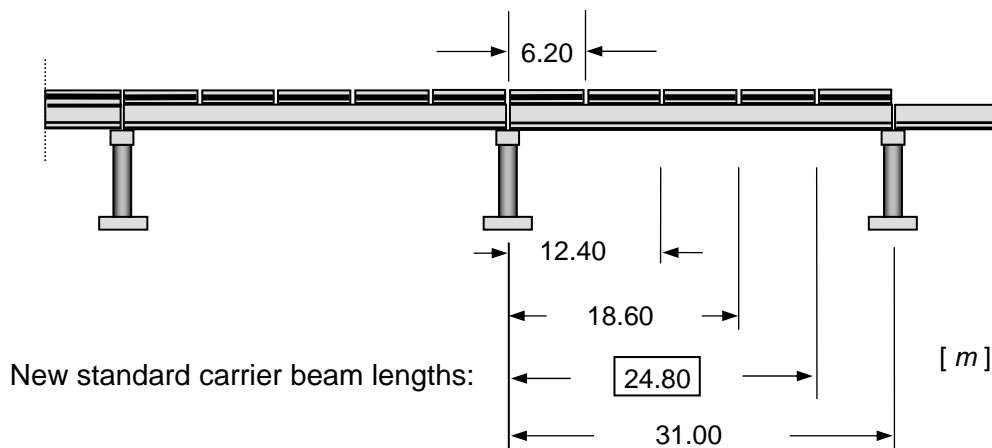


Fig. 1 Guideway section lengths and carrier beam spans

A guideway section in steel weighs 3 tons, in pre-stressed concrete some 12 tons, including the fittings to hold the stator packs and guidance systems. In total then, for one support beam and four guideway sections, a total weight of 82 tons is achieved with steel guideway sections. With pre-stressed concrete sections we would have a standing weight of $70 + 4 \times 12$ or 118 tons.

2.1 Beam distortion due to uneven temperature influences.

That all materials, including concrete and steel structural elements, expand with increasing ambient temperature, or shrink with lower temperatures is nothing new. However the question of *how much*, *how quickly* and *at what time* is more complex. When the average ambient temperature changes gradually and evenly, like in the summer as opposed to winter, the distortion of all components is practically identical. A beam, when warmed, will get longer and, when cooled, will become shorter. Everybody knows this from driving over a long bridge, especially if he has looked at the roadway construction. - Concrete and steel also have practically the same expansion quotients, otherwise there would be no usable steel-reinforced concrete, a whim of nature.

As far as the *Transrapid* guideway is concerned, one has this form of warming and cooling very much under control. However the situation is different in respect of the distortions caused by *unilateral* temperature influences on the guideway support beams. The Flessner/Pfleiderer modular system offers further advantages here. Imagine it's summer. After a cool, clear night comes a hot summer's day; the beams, which had cooled overnight, are now heated from above. At two in the afternoon the upper side of the beam, i.e. the guideway section is now substantially warmer than the lower area, which has not been heated to the same extent. Subject to an irrevocable law of nature the upper area will expand against the lower part. The beam develops an arched back, like a cat's, as shown in Fig. 2.

For a beam with 24 m span, a height $d = 2,00$ m and $\Delta t = 15^\circ$ C this amounts to $f_t = 5.4$ mm. In a cold winter's night the exact opposite occurs. On the top side the temperature radiates into the cold winter sky, in other words, the beam top side cools down. In this case the beam bows downward.

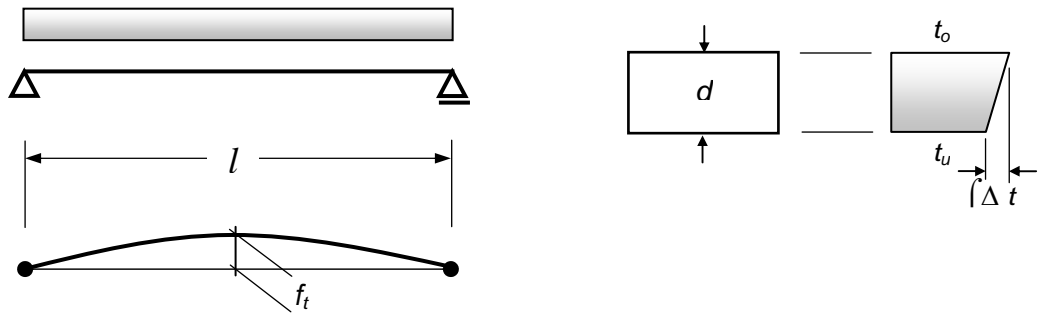


Fig. 2 Temperature differential loading upper vs. lower areas.

of a size defined by the formula:

$$f_t = \frac{l^2 \cdot \Delta t}{8 \cdot d} \cdot \alpha_T, \quad \text{with } \alpha_T = 1.2 \cdot 10^{-5} \text{ (per degree Celsius).}$$

For a highway bridge these effects are practically insignificant. With the strict precision requirements of the high-speed *Transrapid* system and the need to maintain an air gap of $10 \pm 2 \text{ mm}$ between stator and linear motors, the effect described above leads to a clearly perceivable wash-board effect, even at speeds between 250 and 300 km/h. Grounding can even occur at the joint between two beams, i.e. contact between stator and motor. Nobody can "calculate away" this temperature problem. It occurs with both steel and concrete. However with concrete, put simply, it occurs more slowly and is thus less pronounced, because heat conduction is lower, or slower, than in steel by a factor of 30. The time period for warming during the day or cooling during the night is usually too short. In the building regulations the normal expected temperature differential in German regions is laid down as *15 degrees Kelvin (Celsius)*. In Emsland, in one single extreme situation, a temperature difference Δt of *25 degrees Kelvin* was measured. For the monolithic beams described above this would result in bowing of $f_t = 9,0 \text{ mm}$, which could no longer be tolerated at high speeds.

One can only counter this phenomenon with clever structural or system changes. This was another reason for preferring modular construction. The mathematical rule is that the effect of the beam length on the change in shape with linear temperature differentials is multiplied by the power of two, that of the beam height however is inversely proportional (linear reciprocity). Put simply, this means that when comparing two beams, where the first has double the span of the second but with the same height, the first will deform by four times the amount of the second at the same temperature difference. At the same span where the first beam is double the height of the second then its temperature distortion is only half that of the second.

The short guideway sections ($l = 6.20 \text{ m}$) cover the sub-support beams (normally 24.80 m), thus shielding them from sun radiation or heat loss. The lower beam does not distort at all. Because the separate structural elements only distort due to the heat radiation or irradiation affecting them directly, these sections, because of their short span and low height, experience a distortion of only 2 mm maximum. This is opposed to 11 mm in a 2 m high monolithic beam of 31 m span, as measured at the test-track

in Emsland. Built in modular fashion the temperature effects would therefore be substantially lower. However this still needs to be tested and measured at the test-track.

2.2 Module erection

The Flessner/Pfleiderer system's modular construction requires special connection methods between the upper sections of the guideway and the carrier beams, which a monolithic beam, of course, does not need. Several different methods have been investigated or developed including some that the German railway has used for years in high-speed rail applications. They enable joints with millimeter precision and the necessary adjustments. It is important that the different inclinations of the beam in curves can be accounted for and do not require additional measures. With long continuous beams the required *lateral distortion* also has to be considered where the track inclination changes. The modular construction presented here also has apparent advantages simply because, here also, no special variants are needed. There are only the standard types *straight carrier beam* and *flat guideway sections*. Alignment of the edge beams is, as before, carried out in 6.20 meter sections. Fine adjustment is handled by means of the stator packs.

The erection of the guideway on-site should be by a cantilever construction process where possible. Our proposal is that the modules, including the pillars, should be transported by normal means of transport to points adjacent to the *Transrapid* route and from there be cantilevered into their final position. Logistics costs are reduced compared with other known plans, because only the components required for the advance work need to be specially developed. Otherwise, according to experts, transport can be performed with normal means, as even the heaviest version of the pre-fabricated carrier beam (70 tons at 24.8 meter length) can be transported on standard low-loaders by rail and road. For maintenance and possible later replacement of defective guideway components the existing transport infrastructure is sufficient, at least as far as Europe is concerned. This is an important cost argument. Our proposals are illustrated in Figs. 3 to 6.

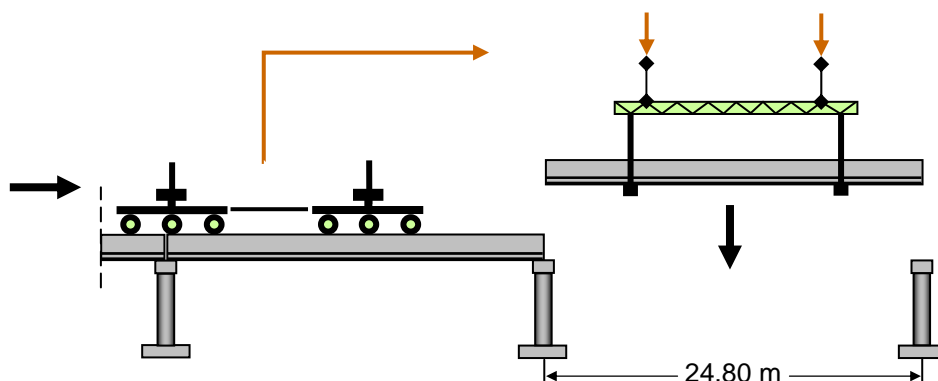


Fig. 3 Mounting the carrier beam

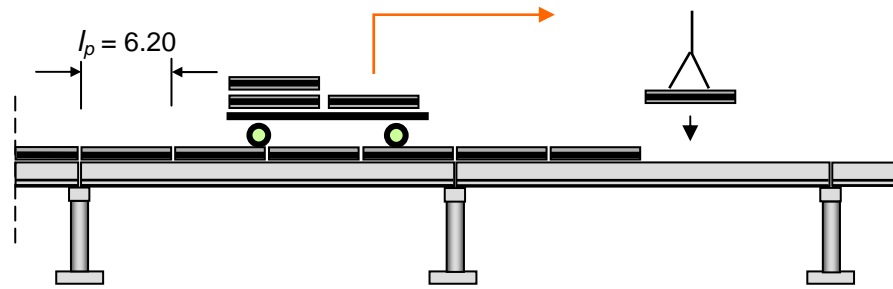


Fig. 4 Laying and installing the guideway sections.

The precise mounting of the guideway sections and alignment and adjustment of the stators is an elaborate process. The operators of the Emsland test-track have suggested that the carrier and guidance structures should be attached on both sides in multiple section lengths up to the total beam length ($l_p \times 1$, where $1 = 2, 3, 4$), to eliminate geometric errors as far as possible. There is also an idea to construct the guideway section in full beam length in steel and then simply hang it in (this proposal is illustrated in Fig. 5). If the guideway section were mounted after the carrier beams are in their final position some lateral adjustment would be possible. This is still to be investigated.

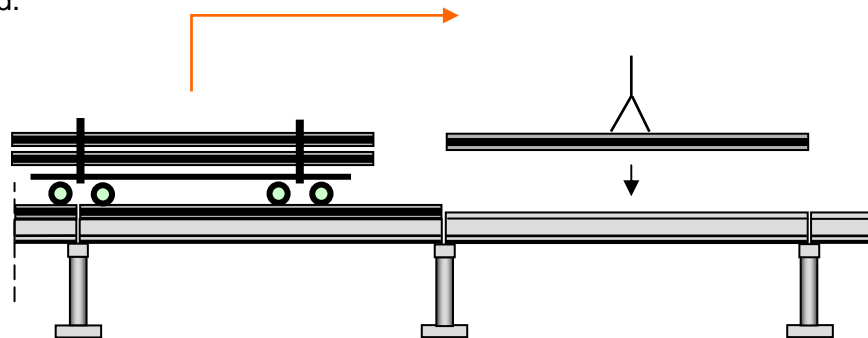


Fig. 5 Mounting guideway sections in full beam length.

Finally there is also a proposal to mount the guideway sections complete at the factory. This would have the advantage that all parts would be at the same ambient temperature when bolted together, and the erection effort on-site would be reduced. However the disadvantage would be that the transport weight would now be the total weight. Fig. 6 shows this procedure.

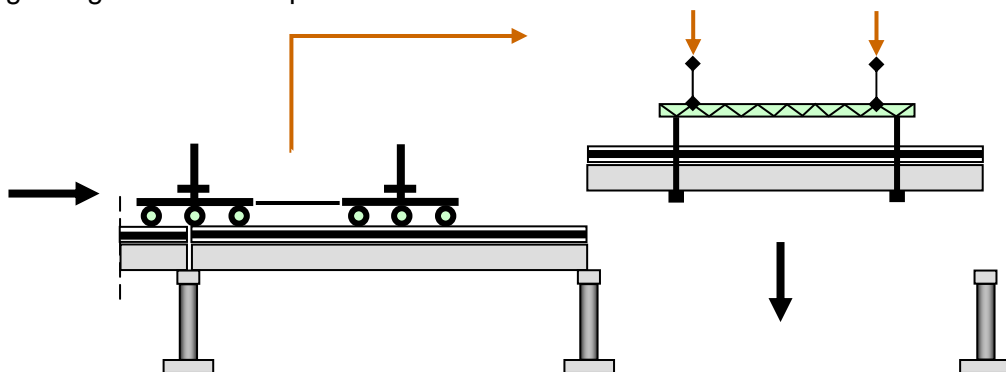


Fig. 6 Mounting a beam complete with guideway section(s)

2.3 Aerodynamic influences

What is obvious and already outlined in section 2.1, the guideway must satisfy the highest possible precision requirements during manufacture, erection and geodetic alignment. Any geometric "disorder" in the upper surface of the guideway sections or the side parts of the carrier beams, in the form of indentations (gaps) or buckling in the boundary layer area, would have a dynamic effect during high-speed running of a maglev train. This would be not only audible, but also perceivable as vibrations or swaying. A maglev train at high speed could be described as a maglev (air) craft surrounded by a boundary layer.

A number of things have been learned in this respect in Emsland over the past two years. For instance, it has become clear that the present form of *cross-beams* under the actual guideway beams have a negative aerodynamic effect on ride comfort at high speeds. The ends of the cross-beams which jut out on both sides transverse to the running direction disturb the boundary layer between the train cabins and the ambient air, both audibly and motional, at $v > 250 \text{ km/h}$. The effect is comparable to non-welded joints in railway tracks. In consultation with the experts at the Emsland test-track, Pfleiderer has countered this situation with special bearer design for the carrier beam on the shortened crossbeam.

3. Use of spun concrete technology

Masts in spun concrete have been the technological standard for decades. Pfleiderer has constantly worked on improving the stiffness and thus the load bearing capacity of its spun concrete products. The production of high-quality and highly durable structural elements such as masts and pillars is Pfleiderer's day-by-day business. Manufacturing takes place at 8 plants in Europe and in the USA. Figs. 7 to 9 below show some of the production phases.



Fig. 7 Mounting the upper half of the steel mould

(Photo: Pfleiderer)



Fig. 8 The centrifuge process for an antenna mast (Photo: Pfeleiderer)



Fig. 9 The completed mast (Photo: Pfeleiderer)

Fig. 10 below shows the lower section of a wind-energy tower with a diameter of approximately 2.0 m. This diameter corresponds to the sectional dimensions of the carrier beams for the planned guideway being discussed here.



Fig. 10 Lower section of a spun concrete wind-energy tower

The special characteristics of Pfeleiderer's pre-stressed spun concrete products are their extreme stiffness, their absolute precision and the immediately obvious very dense and pore-free surface, which is particularly important for protection against weathering. These are all benefits of special significance for the guideway beams and were the reason for development of the new Pfeleiderer product. The stress-strain curves in Fig. 11 display their stiffness characteristics (B 76 to B 115) compared to non-spun concrete (B 35 to B 55). These have been confirmed by the German Institute for Building Technology in Berlin and are used for measurement of masts.

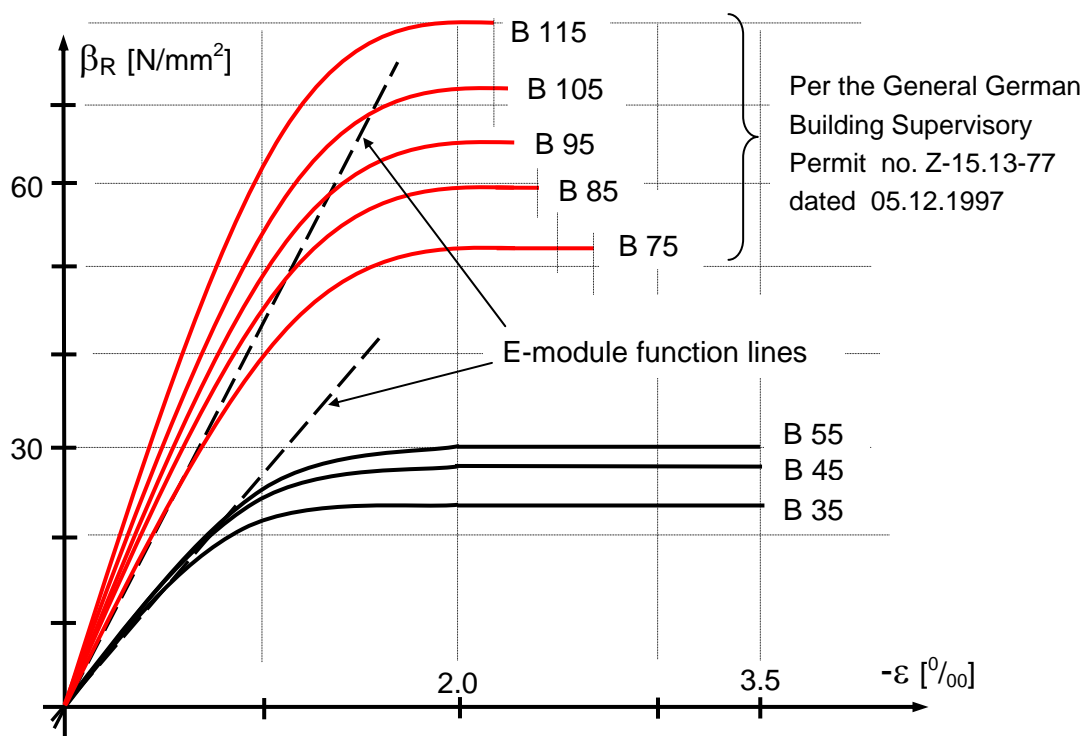


Fig. 11 Stress-strain graph for the concrete types examined

Before taking up his development work, the author undertook research and found some 300 relevant patents, most of which have expired. About half of these patents relate to problems occurring during de-moulding and the subsequent treatment of spun concrete pipes and masts. An American patent (expired in 1968) concerned a process for spinning masts with non-circular, oval or almost square, and even double-T formed cross-sections, as well as conical masts. However all are symmetrical, at least *in* one axis. And in all cases, during spinning the deviation moment of the cross-sections = 0, i.e. the axis through the center of gravity is equal to the main axes, which naturally made calculation of potential deviations and or variances (unbalances) much easier.

In the autumn of 1997, the author undertook experiments with which he could prove, if on a small scale, that armoured concrete structures, even with asymmetrical forms, could be spun, and this with precisely pre-calculated rotational axes and centrifugal forces, without producing unbalances. The cross-sections used could, in principle, be asymmetrical even in two axes. In other words a deviation moment could be permitted. After investigation by Pfeleiderer and the design of mould geometry the patent was registered jointly.

These calculations had to take into account not only the mass of the concrete and various steel inserts, but also the heavy and necessarily stable steel forms of the mould in rotation position with its complicated geometry and mass. The moulds weigh approximately the same as their contents. After all, centrifugal forces occur up to approximately 30 *g*. During spinning the moulds rotate on driven rollers without requiring further measures to prevent them lifting off. Naturally, the whole spinning process only functions with properly shaped centrifuge moulds, using an optimum filling process, which takes place at varying rotation speeds.

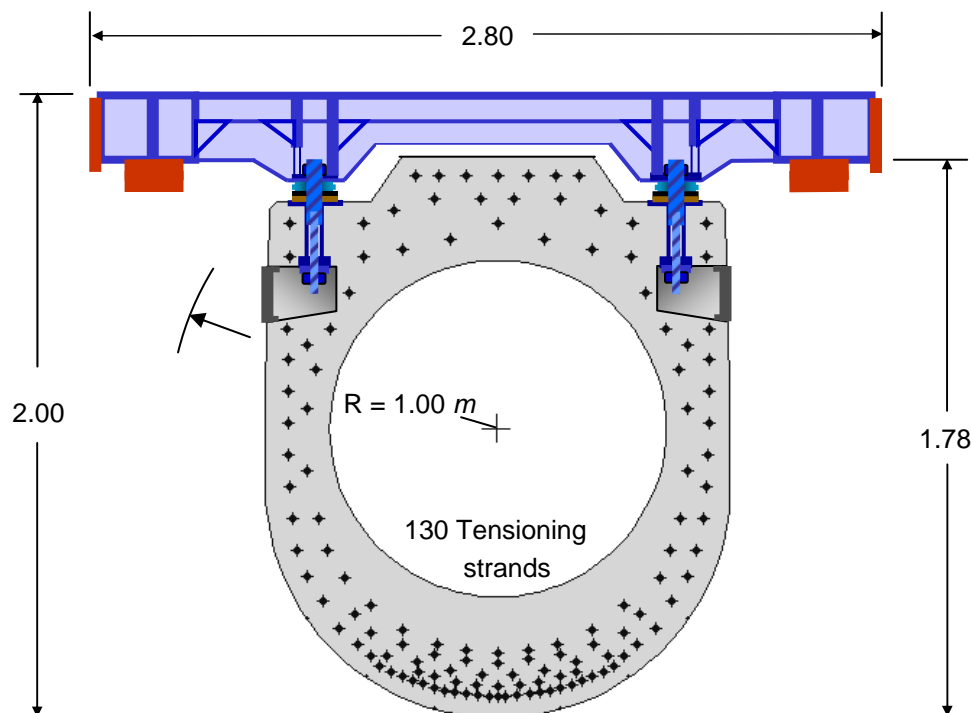


Fig. 12 Cross-section of carrier beam spun in a pre-stressing bed, $l = 24,80 \text{ m}$ with steel guideway section mounted.

The development of the carrier beam to be produced with centrifuge technology, as shown in Fig. 12, involved more than 20 cross-sections in more than 40 variants. Data input is millimeter-precise in interactive CAD, and for each newly entered cross-section takes approx. one hour. Changes can be made in a few minutes. The calculation program delivers the results in fractions of a second on a notebook.

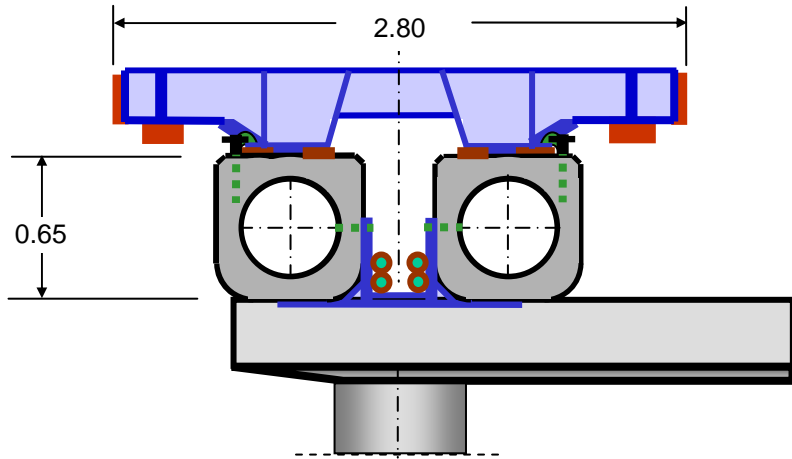


Fig. 13 Spun twin beam for beam spans up to $l = 18,60 \text{ m}$.

Looking at the mould illustrated in Fig. 7 for spinning antenna masts, you can easily relate to the schematic cross-section shown in Fig. 14 of the mould for the spinning of a carrier beam. The actual form is a thick steel plate, welded or bolted together with the lateral arming strands and the transverse stiffeners (the latter are not shown). The dimensions are pre-calculated based on its own weight and the centrifugal forces it will be subjected to. To counter unbalances these dimensions are increased in certain parts or counterweights are bolted on in addition (also not shown).

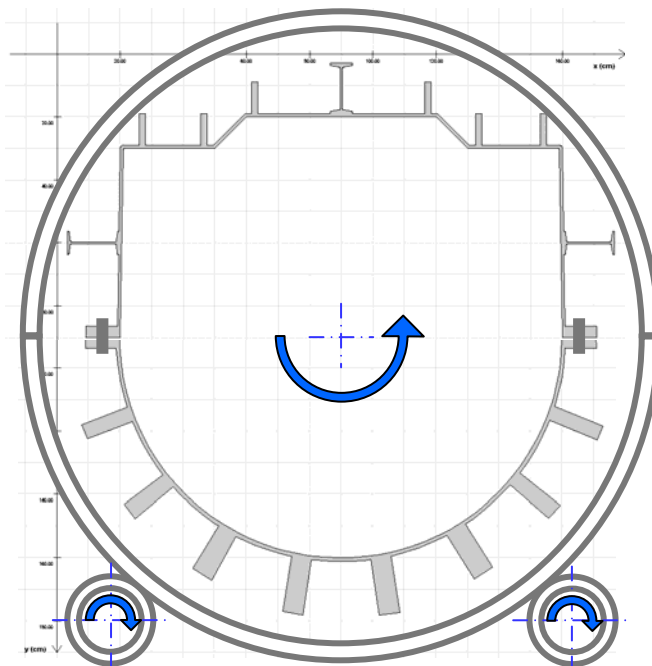


Fig. 14 Cross-section of a centrifuge form for a carrier beam, upper and lower forms bolted together at mid-height

Because the manufacture of a spinning mould is costly, the method is understandably only economic for large production series. But this is the case for the construction of a maglev track. Decisive is the constant cross section, whereby minor changes are relatively insignificant. Because the forms are normally bolted together in 2 m long sections, variations in beam length can easily be achieved. A maglev route of 30 km with two parallel guideways alone requires 2, 400 beams at 24.80 m length.

No inner form is required. This also enables substantial savings in comparison to the costs normally incurred in conventional concrete moulding.

Manufacturing a beam using the centrifuge method takes two days. The following is a rough list of the various steps: Preparing the form, preparing and installing the armouring baskets and tensioning strands including pre-tensioning in the pre-stressing bed and the automatic addition of the concrete. Then the spinning process follows. After the concrete has set, which takes approx. 1 day, the very high pre-stressing forces, up till now absorbed by the centrifuge forms, are transferred to the concrete cross-section. At this point the concrete has already reached 80% of its final stiffness.

The development work has been constantly discussed with the experts at the Emsland test facility, and we were grateful for many ideas and important advice. Since approximately six months ago, our investigations and calculations have matured so far, and have been played through in so many variations that, as soon as possible, trial beams can be spun and installed in the test-track in Emsland. Final information about improvements, which will certainly need to be made, will be gained there. We are convinced that the guideway system roughly described here will offer substantial potential for construction and cost optimization.

Finally, a virtual computer image shows one of the possible erection methods for support beams, guideway sections, transverse beams and columns by Pfleiderer in Fig. 15.

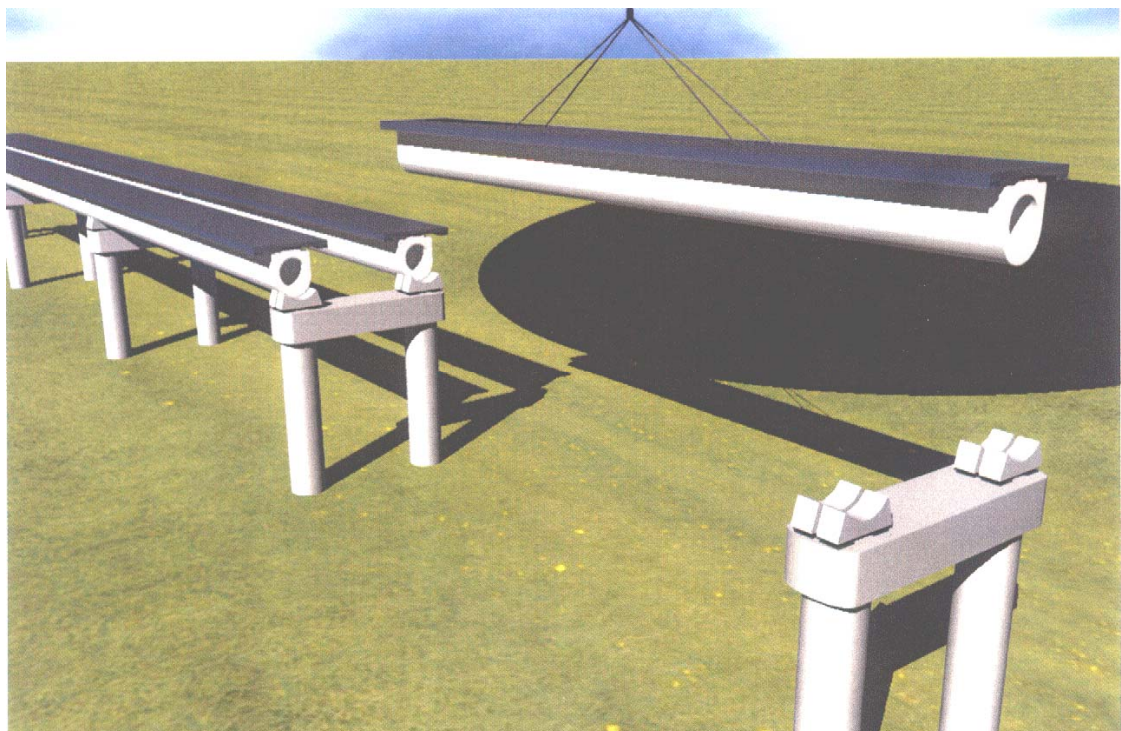


Fig. 15 Virtual Computer graphic of the Flessner/Pfleiderer maglev guideway system