

# MAGLEV GUIDEWAY DESIGN ISSUES

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(Reviewed by the Urban Transportation Division)

**ABSTRACT:** This paper reports results from guideway analyses conducted as part of the National Maglev Initiative (NMI), a government-industry effort from 1989 to 1994, formed to encourage the development of U.S. maglev technology and to assess its potential application within the U.S. transportation system. Covered here are some key guideway design issues that were common to the designs assessed for the NMI, and to maglev guideways in general. They represent aspects that will need additional attention in future efforts to produce structurally sound and economical maglev guideways. These recommendations come from the analyses conducted by a team from the U.S. Army Construction Engineering Research Laboratories, the Civil Engineering Department of the University of Illinois, and Alfred Benesch and Company. The recommendations focus on design philosophy and the development of general design criteria, guideway maintenance and the provision for future alignment adjustment in both the guideway and the magnets, foundation design, and the long-term performance of guideway materials and reinforcement. Generally, one of the main challenges to guideway designers is to produce a structure that will be easily maintainable to the narrow tolerances and precise alignment required for practical high-speed maglev operation.

## INTRODUCTION

In the fall of 1989 a government-industry effort known as the National Maglev Initiative (NMI) was formed to encourage the development of U.S. maglev technology and to assess its potential application within the U.S. transportation system. The NMI partnership, led by the Department of Transportation, Department of Energy, and the U.S. Army Corps of Engineers, solicited industry for ideas for complete maglev system designs and ultimately awarded four contracts to further develop these ideas.

After a work period of 12–18 months, the four industry partnerships submitted their designs, or System Concept Definition (SCD) reports as they were formally called, to the NMI for review. Within the NMI, the Corps of Engineers' Huntsville Division (HND) was made responsible for analyzing the guideway system for each of the four maglev concepts. HND, in turn, tasked the U.S. Army Construction Engineering Research Laboratories (USACERL), Champaign, Illinois, to perform major portions of the guideway system analysis. The material in this paper is derived from that effort.

Presented here are some key guideway design issues that are common to the SCDs and to maglev guideways in general. They represent aspects that will need additional attention in future efforts to produce structurally sound and economical maglev guideways.

## DESIGN CRITERIA

General design criteria, or design standards, need to be developed for maglev guideway systems. Establishing these criteria will make it easier to produce structurally adequate designs and allow more effective and consistent review of different designs.

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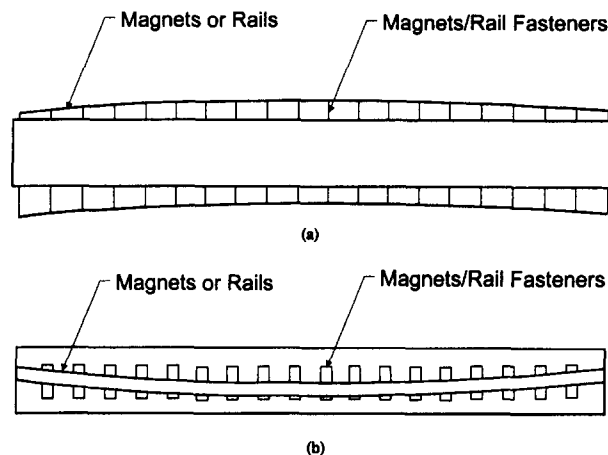
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Note. Discussion open until November 1, 1997. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on January 26, 1996. This paper is part of the *Journal of Transportation Engineering*, Vol. 123, No. 3, May/June, 1997. ©ASCE, ISSN 0733-947X/97/0003-0189-0191/\$4.00 + \$.50 per page. Paper No. 12527.

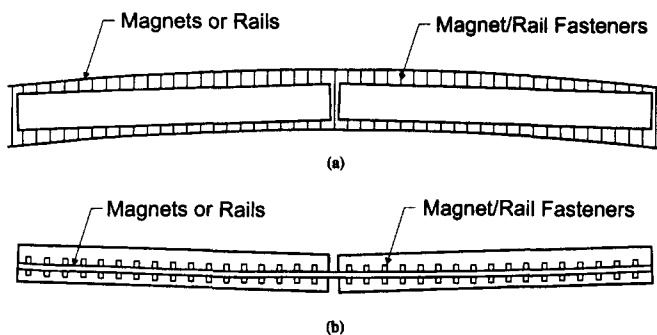
## HORIZONTAL AND VERTICAL CURVES

The provision for obtaining exact horizontal and vertical curvature in a guideway is an important design requirement. Using the example Baltimore-Newark route from the NMI study as a reference, about 25% of the guideway mileage on that route would be constructed on a (horizontally) curved alignment. In addition, for each of the 27 curves on that route, a spiral (transition curve) must be provided at each end to transition from straight to fully curved alignment—thus there must be 54 spirals. Within these spirals the guideway must also transition from a level to a fully superelevated (banked or tilted) position at the curves. Further, every change in gradient requires a vertical curve in the guideway to transition between the different gradients. Finally, gradient changes occurring on curved sections require both horizontal and vertical curvature in the guideway at the same location.

Generally, it is intended that guideway girders be fabricated straight, with the required curvature obtained by adjusting the position of the magnets or magnet rails, as shown in Fig. 1. Even for the sharper 4,600-m radius curves on the NMI example route, the maximum offset from tangent is only 1.5 mm in a 25-m length. Thus, this method seems feasible, and allows



**FIG. 1. Forming Curves on a Straight Guideway Girder: (a) Plan View, Showing How Horizontal Curves Are Formed by Adjusting Position of Magnets or Rails; (b) Side View, Showing How Vertical Curves Are Formed by Adjusting Position of Magnets or Rails**



**FIG. 2. Forming Curves across Straight Guideway Girders: (a) Plan View, Showing How Horizontal Curves Are Formed across Guideway Girders; (b) Side View, Showing How Vertical Curves Are Formed across Guideway Girders**

for more economical girder fabrication. The same method applied to vertical curves is also shown in Fig. 1.

Along the guideway, the approximate curvature is obtained by small angle changes between spans, as shown in Fig. 2. In spirals, spans must change superelevation as well. Thus, the girder spans would appear similar to a train, with the rigid cars changing angle and elevation at the couplers, while the rails (representing the magnets) maintain smooth curves below.

Setting and maintaining curvature is dependent on sufficient allowance for magnet adjustment and is complicated by the requirement for the magnet connections to support the full dynamic load of a traveling maglev. Thus, the magnet connections must be strong and rigid, while at the same time, they must be fully and easily adjustable in the vertical and horizontal planes. In addition, the magnets must provide proper alignment and support across the joints between spans. Additional design challenges relating to setting and maintaining magnet alignment are covered in the sections entitled "Construction and Fabrication Tolerances" and "Provisions for Alignment Adjustment."

### MAGNET OR RAIL SUPPORT ACROSS GUIDEWAY GIRDER JOINTS

Especially in vertical and horizontal curves, there will typically need to be some space and change in angle at girder joints to accommodate the curving alignment, to allow for girder expansion and contraction, and to allow for imperfections in girder fabrication and guideway construction. This requirement then calls for a design to hold the magnets (or keep rail alignment secure) across the girder joints. Fig. 2 illustrates this situation. Providing magnet support at girder joints will likely be a challenge in future guideway design efforts.

### FOUNDATIONS

For the most part, the SCDs assumed that spread footing foundations would suffice. However, to resist differential settlements and help maintain the strict alignment requirements for a high-speed maglev, piles or other deep foundations are likely to be needed in many cases.

The requirement for deep foundations is even more likely for curved sections. Unlike tangents, curves are subject to high lateral forces, and as guideway elevation increases, higher overturning moments must be resisted; these place great demands on the foundation. Deep foundations may also be needed to provide adequate resistance to wind and earthquake loads.

### CONSTRUCTION AND FABRICATION TOLERANCES

Generally, as tolerances are tightened, fabrication and construction costs go up, and the likelihood of producing a sub-

standard component increases. In addition, the production of unusual (by current standards) shapes generally increases the difficulties.

For more economical guideways, future designs would likely benefit from minimizing the need for special shapes and by not requiring tolerances stricter than the current industry standard, unless clearly necessary. With this philosophy, the larger imperfections would be handled with an ample allowance for girder and magnet adjustment in the field.

### PROVISIONS FOR ALIGNMENT ADJUSTMENT

Variation in vertical alignment of the supporting piers and in the dimensions of the girders, and some twist or shrinkage warping of girders must always be allowed for. Some imperfections in construction are also bound to occur. Some of these deviations are likely to be additive at certain locations as well. Ends of adjacent girders may not align well all the time, the walls of one may perhaps lean slightly compared to the other.

Even a small differential settlement in the foundation of a 10-m-high pier can cause significant misalignment, as can long-term material shrinkage or creep from the repeated passages of maglevs, repeated thermal stresses, or the long-term effect of prestress or posttensioning loading.

In addition, smooth horizontal and vertical curves will often be formed through the adjustment available in magnet or magnet rail fastenings. Thus, high-speed maglev guideways need ample allowances for the adjustment of girders and magnets. Designs must also allow convenient access to these adjustments.

### NONMETALLIC REINFORCING FOR CONCRETE

Electrodynamically suspended (EDS) maglevs, which use repelling magnetic forces for propulsion, levitation, and guidance create large magnetic fields around the guideway magnets when a maglev passes. If conventional steel reinforcing were used in the guideway near the magnets, large electric currents (eddy currents) would be generated in the reinforcement, resulting in large power losses, even to the point of preventing a maglev from operating at all.

Using one of the SCD designs as an example, the study results suggest that standard steel reinforcement is best kept away from areas that experience fields stronger than 0.001 T. Following this guideline, standard reinforcing steel would need to be about 1 m or more away from the center of the guideway magnets to prevent excessive power loss in this particular system.

To minimize eddy current power losses, the use of fiber reinforced plastic reinforcing has been proposed. This material is still under development, and its long-term behavior, particularly resistance to creep, has yet to be determined.

Thus, one challenge in designing a concrete EDS guideway is to find a means of providing reliable and economical reinforcement for areas near the magnets. Improved materials and/or shielding methods will be needed.

### THERMAL EFFECTS, CREEP, AND SHRINKAGE

Allowances for expansion and contraction of guideway material, caused by seasonal and daily temperature changes, must be added to the allowances for expected guideway fabrication and construction variations. Providing for these variations tends to make girder joint design even more critical, especially in sections of horizontal and vertical curvature.

Given the generally strict alignment requirements for a high-speed maglev, handling daily cycles may prove challenging. During different parts of the day, the sun may warm one side of the guideway while leaving the other side in shadow,

and thus cooler. This produces very uneven stresses in the guideway and uneven strains. The degree to which this may alter magnet alignment, and its corresponding effect on maglev operation, should be investigated further.

The character and magnitude of material creep and shrinkage must also be quantified, particularly where nonstandard shapes and new reinforcing materials are used.

### **CORROSION POTENTIAL**

Anchorage in posttensioned members is vulnerable to corrosion attack, and providing protective coatings and cathodic protection must be considered. The prestressing strand must also be protected during storage, transit, construction, and after installation.

Stray electric currents cause corrosion in embedded reinforcing steel, leading to deterioration of surrounding concrete. Maglev systems have the potential to generate these currents.

### **GUIDEWAY DYNAMIC RESPONSE**

Guideway designs will have to be analyzed for dynamic response from the passage of maglev trains, wind loads, and seismic loads. Unfavorable responses could result in excessive vibration, which could adversely affect ride quality and accelerate material fatigue.

### **MAINTENANCE**

As a high-speed maglev guideway will be subjected to many cycles of large load applications over time, the deterioration or failure of certain components should be anticipated, particularly the magnets (EDS) or rails (EMS) and their connections. Thus, it is recommended that designs incorporate provisions for the removal and replacement of components (or sections of them) that can be accomplished with minimal disruption to service.

### **COMPLEXITY OF GUIDEWAY DESIGNS**

The evaluations of the NMI designs generally found no special benefit in unusual, nonstandard girder shapes sometimes proposed for use in the guideway. More often, these special shapes were found to be detrimental by increasing fabrication costs, making construction more difficult, incurring high local stresses, and generally having unknown long-term structural performance.

Benefits of material efficiency and lighter weight were sometimes cited to justify unusual shapes. However, there is little indication that these objectives are particularly advantageous in a maglev guideway. More important are low initial and long-term maintenance costs, ease of construction, and structural reliability. These are perhaps best obtained by maximizing the use of common construction elements. The common designs are typically the most inexpensive to produce, the easiest to build with, and by experience, the most structurally reliable elements available for building a maglev guideway. Some alternative designs were produced for the NMI study to show that simple, standard construction can be effectively used in a maglev guideway.

### **SUMMARY AND RECOMMENDATIONS**

For future concept development or more in-depth design, engineers should pay close attention to the combined effects of all lateral loads, including wind and earthquake loads, and associated loads and overturning moments on the foundation. The moments may be especially severe on piers higher than 10 m.

Also, for EDS reinforced concrete guideways, consider the two-component (or two-level) girder concept, in which the lower element carries the major portion of the load while the upper element holds the magnets. This arrangement could have the advantages of reducing the amount of nonstandard reinforcement needed, allowing larger tolerances in guideway fabrication, providing additional adjustment capability for setting initial alignment, and perhaps even allowing for a significant change in maglev technology without the need to replace the whole guideway girder.

It is suggested that guideway designs maximize the use of standard, simple shapes that are simple to fabricate and erect. Whenever possible, designs should also permit standard fabrication and construction tolerances, with final guidance alignment obtainable through generous allowance for magnet or rail adjustment.

### **ACKNOWLEDGMENTS**

The following people were instrumental in producing the work summarized here: Harold Sandberg and Jack Williams of Alfred Benesch & Company; William Hall and James Lefter of the Department of Civil Engineering, University of Illinois; and Can Balkaya and David Beto of the U.S. Army Construction Engineering Research Laboratories. The writers appreciate the excellent work they did for this study.