

STRUCTURAL EVALUATION OF MAGLEV GUIDEWAY CONCEPTS

By Harold R. Sandberg¹ and Jack R. Williams,² Fellows, ASCE

(Reviewed by the Urban Transportation Division)

ABSTRACT: The National Maglev Initiative (NMI) resulted in four distinctly different concepts. The structural systems of the concepts varied greatly, but in general were very complex. This paper evaluates the concepts as to their performance of selected criteria: constructability, reliability, maintainability, adaptability, and durability. Three of the systems used precast, prestressed concrete for the main load-carrying element. One system used aluminum. Only one system, system concept design (SCD-1) could be readily produced in existing precasting plants. None of the systems provided for easy adjustment of operating elements after construction. These systems require construction tolerances that are much more restrictive than conventional practice. Among the stated goals of the NMI concepts were: (1) it should anticipate upgrade; (2) it should be economically and financially attractive; and (3) it should be robust in terms of its susceptibility to adverse weather and its requirement for maintenance. This paper concludes that none of the four concepts adequately met these goals. However, some concepts could achieve the desired goals by relatively modest redesign.

INTRODUCTION

The request for proposals for system concept designs (SCD) of the National Maglev Initiative (NMI) listed the following mission. "In soliciting the system concepts, the National Maglev Initiative view Maglev as an intercity transportation system which will supplement and interconnect with existing modes . . . Maglev systems should be safe and reliable. In the 160 km - 1Mm (100-600 mile) trip range, Maglev should be competitive in terms of travel times, cost, reliability and comfort" (Government Maglev System Assessment Team, unpublished report, 1993). The following further describes the mission:

"It should be clean and energy efficient. It should provide good connections with airports and major centers. Insofar as possible, it should utilize existing highway, railroad, and utility rights-of-way. Its design should anticipate upgrade. It should be economically and financially attractive. It should be robust in terms of its susceptibility to adverse weather and its requirements for maintenance. It should efficiently handle passengers and consideration should be given to its mail and freight handling capability" (Government Maglev System Assessment Team, unpublished report, 1993).

Total construction cost estimates for the SCDs ranged from \$14,000,000-\$30,000,000 per kilometer (Plotkin and Kim, unpublished report, 1994). Of these totals the cost of the guideway structure ranged from \$8,000,000-\$20,000,000 per kilometer. In percentage the guideway structure represented 46-67% of the total cost. In the present paper no attempt is made to quantify possible reductions in cost.

Each of the SCDs are evaluated against the criteria set forth in Sandberg and Williams (1996). The concepts are rated not only on how well they performed the criteria, but on the amount of modification needed to ensure that they would meet the criteria.

¹Chair. of the Board, Alfred Benesch & Co., 205 N. Michigan Ave., Chicago, IL 60601.

²Vice Pres., Alfred Benesch & Co., 205 N. Michigan Ave., Chicago, IL.

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System Concept Design-1

The proposed guideway shown in Fig. 1 is a precast, prestressed concrete box girder to which the levitation, propelling, and guidance systems are attached. It functions basically as a monorail. The typical span is 25 m (82 ft). The substructure is reinforced concrete supported on spread footings.

The apparent design philosophy is to incorporate the direct load-carrying element into the main structural element. This produces a compact section for typical spans, but does not address the need for longer spans over major streams. Use of standard bridge elements was not considered. Need for adjustment in the field was not sufficiently addressed. Details of the structural element of the guideway are shown in Fig. 2. Details of the magnet attachment are shown in Fig. 3.

For constructability this concept has merit. The guideway of prestressed concrete could be produced by existing precasting plants. The substructure is a common type. However, there are serious concerns about the use of concrete end lugs cast integral with the guideway and the use of end blocks. These items greatly complicate the fabrication. If these deficiencies are corrected and if the length of the element is limited to the typical span (25 m), then the concept meets the criteria.

For reliability this concept appears to meet the criteria. However, the relatively long span, 25 m (82 ft), of the basic guideway raises questions about the amount of differential deflections due to creep of the prestressed concrete. Also, the

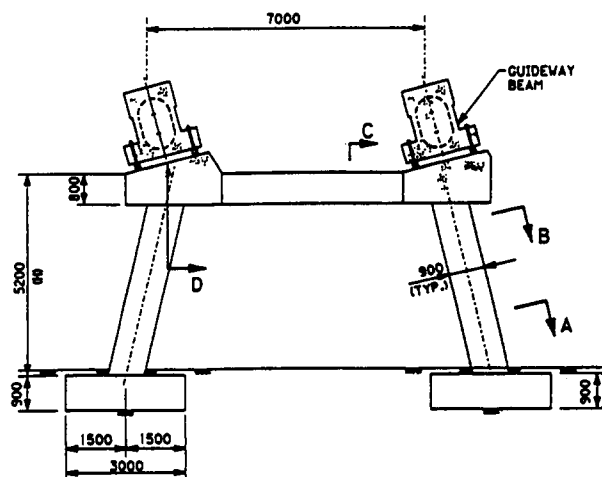


FIG. 1. Concept SCD-1—Typical Cross Section

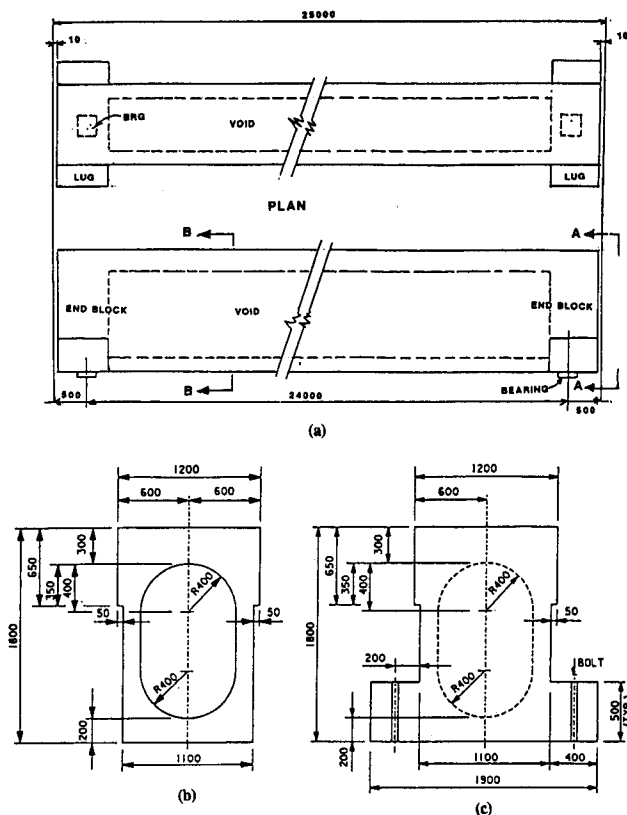


FIG. 2. Concept SCD-1, Detail of Structural Element: (a) Elevation; (b) Section B-B; (c) Section A-A

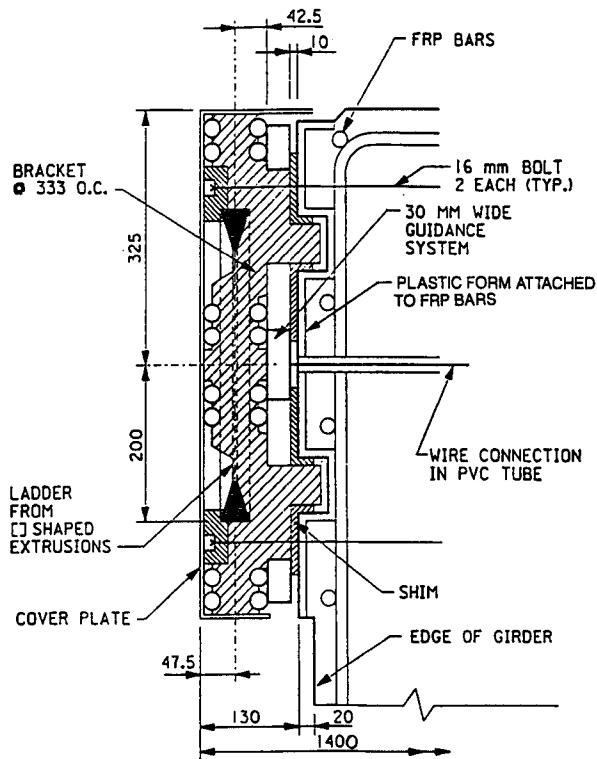


FIG. 3. Concept SCD-1—Attachment Detail, Driving Element

long time performance of the fiber reinforced plastic (FRP) rebars is unknown. This is particularly true of the anchorages of posttensioned FRP tendons (Government Maglev Assessment Team, unpublished report, 1993). Unless founded on rock, spread footings will result in unpredictable differential

settlement at some locations. This is undesirable; therefore, piles or drilled shafts should be used.

For maintainability this concept needs significant modifications. The attachment of the driving and guidance elements to a plastic form (Fig. 3) cast in the guideway allows very little adjustment. In addition, this adjustment is inaccessible and would require unmounting of the elements. The long length of the straight guideway, 25 m (82 ft), requires a horizontal offset of 13 mm (0.5 in.) on a 3,200 m (2 mi) radius curve. This is additive to the other construction tolerances that require adjustment.

For adaptability this concept needs modification. The 25 m (82 ft) long standard guideway weighs over 100,000 kg (112 t). This would require special equipment to handle or transport any replacement section. The method of attachment of the driving and guidance elements precludes their replacement with improvements that are sure to be developed. The optimum method of changing elements would be to replace each 25-m section together with the modified elements.

For durability this concept has significant weaknesses. The use of FRP reinforcement raises questions about the long time performance. An in-depth study of the performance of FRP reinforcement must be done. Details such as the end lugs are areas of weakness. If the guideway does not have the proper superelevation, then horizontal loads can produce unacceptable stresses.

Overall, with inclusion of some alternative details to correct the weaknesses noted previously, this concept is a viable one.

System Concept Design-2

The proposed guideway shown in Fig. 4 consists of two rails that are suspended from brackets attached to a reinforced concrete track slab. The slab is in turn supported by posts spaced at 4.5 m (14.8 ft). The posts are an integral part of a precast outrigger that extends on each side of a segmental concrete box girder. The basic girder span is 27 m (88.5 ft). The girders rest on cast-in-place concrete piers, which are supported by piles.

The basic guidelines used are the American Association of State Highway and Transportation Officials Design Specifications for Highway Bridges, modified for live loadings, load factors, and load combinations. Aesthetics is given high priority as is the provision for a continuous walkway for emergency services. The use of segmental construction is mandated by the geometry of the structure (width and outriggers).

For constructability this concept has many points of difficulty. The design of the guideway requires segmental construction of an unusual shape. The basic concrete box girder segment has an interior diaphragm and exterior cantilevers. The length of each segment is 4.5 m; the overall width is 4 m; and the height is 1.8 m. The main reinforcement of the cantilevers is a draped posttensioning strand. These segments would be

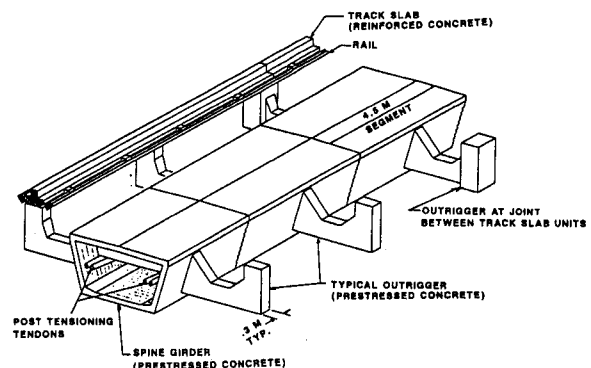


FIG. 4. Concept SCD-2—Typical Detail of Structural Element

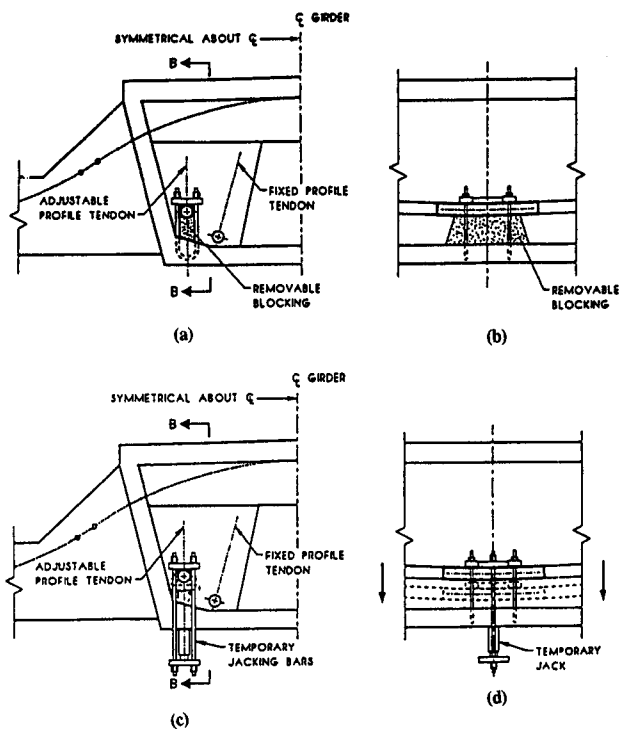


FIG. 5. Concept SCD-2, Post-Tensioning Details: (a) Section A during Initial Installation; (b) Section B during Initial Installation; (c) Section A during Tendon Restressing; (d) Section B during Tendon Restressing

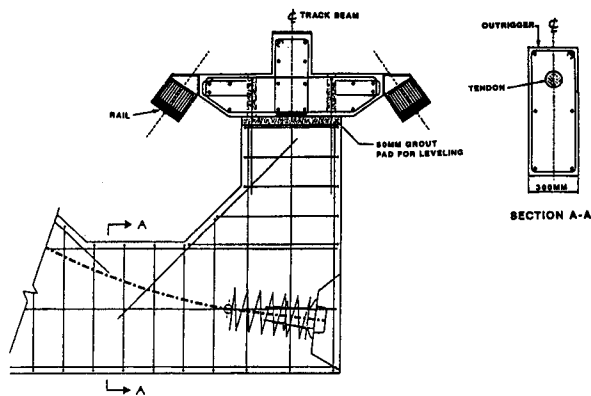


FIG. 6. Concept SCD-2—Track Slab Details

difficult to fabricate and to transport. The posttensioning elements of the box girder are external strands located inside the box girder. A special device shown in Fig. 5 is provided to permit restressing of the tendons. This increases the field labor. In summary, this concept uses minimum material, but is very labor intensive both shop and field.

For reliability this concept has many weaknesses. The cantilevers produce a torsional load on the box girder. Deflections due to this torsion are additive to the deflections due to the gravity load of the vehicle. Deflections due to temperature differentials in the box girder must also be considered.

Depending on the operational tolerances of the vehicle suspension system, these deflections could produce a less than desirable ride. A detail of the track slab that is supported on the cantilevers is shown in Fig. 6. The entire load of the vehicle is transferred to the track slab by steel brackets spaced 2.25 m apart. Details of these brackets were not clearly shown, but they represent critical connections. They function in shear and tension and must be attached to the edge of the track slab, which is only 120 mm deep.

For maintainability this concept needs significant modifi-

cations. The only adjustment, other than that provided by restressing the main posttensioning strands, is a 50-mm grout pad provided on the top of the cantilever post shown in Fig. 6. Once the track beam has been adjusted to the right position, this grout is placed and set. After that adjustments would require demolition. Provisions for adjustment of individual track beams were not shown.

For adaptability this concept also needs significant modifications. As cited in maintainability, once the guideway is completed there is no opportunity to change or replace any individual track beam without demolition.

For durability this concept needs an in-depth study. Weak points in this concept may develop flaws under operating conditions. This is particularly true of the rail-to-track beam connection. Correction of such flaws would be very difficult.

Overall this concept, at the present stage of development, needs significant modifications. However, if the track slab were supported on an independent structure, built of commonly used elements, it could be workable.

System Design Concept-3

The proposed guideway shown in Fig. 7 consists of two aluminum structures, forming a trough, curved to fit the shape of the vehicle. These structures typically span 9.14 m (30 ft), but could span 13.72 m (45 ft) or 18.29 m (60 ft). Where longer spans are needed, an aluminum structure spanning 4.57 m (15 ft) would be supported on a steel or concrete framework. The substructure is reinforced concrete supported on spread footings or piles.

The stated design philosophy is that the guideway should be adjustable and upgradable. Guideway troughs should be modular construction with an independent support structure. The elevated guideway has an aluminum trough supported ei-

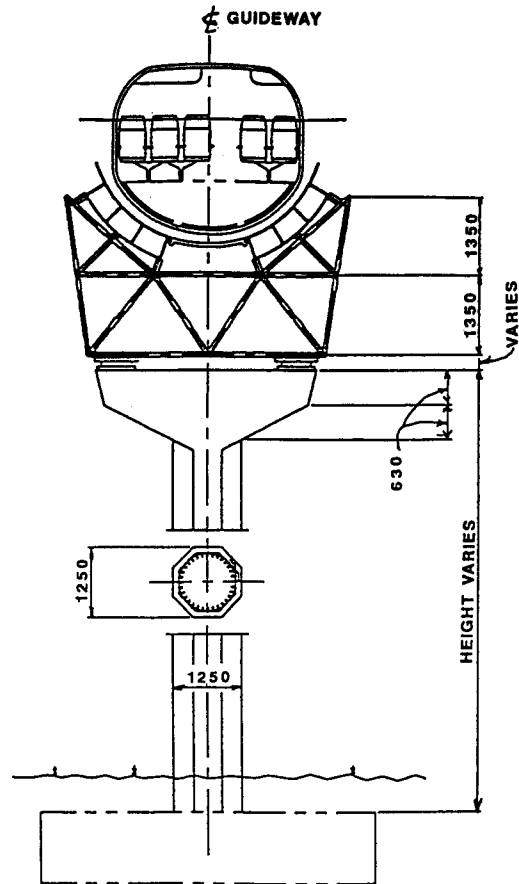


FIG. 7. Concept SCD-3—Typical Cross Section

ther by steel trusses or by concrete box beams that span between piers.

Standard construction elements for highway and railroad bridges were not selected to support the troughs. Instead, unusual trusses and box girders are indicated.

For constructability this concept needs an in-depth study. Welded aluminum sections require highly specialized fabrication techniques. Fabrication of curved box beams from thin plates is very difficult. Providing adequate support for the box beams is field labor intensive. Tolerances would be difficult to meet.

For reliability this concept also needs further study. During operation, the levitation plate could experience a 180°C (325° F) rise in temperature due to the frequent passage of vehicles. Since the levitation plate is an integral part of the curved box beam, there will be serious temperature strains that could cause deformations and large stresses in the guideway. The proposed expansion joint shown in Fig. 8 relies on the bearing of the levitation plate on a backing plate. This detail has no provision for these deformations.

For maintainability this concept would be difficult. The interior of the box beam is inaccessible for inspection and maintenance. Also as shown in Fig. 8 there will be uneven and highly concentrated wear on the levitation plates due to temperature movement, and hence more maintenance. On the plus side, the large gap between the vehicle and the surface of the

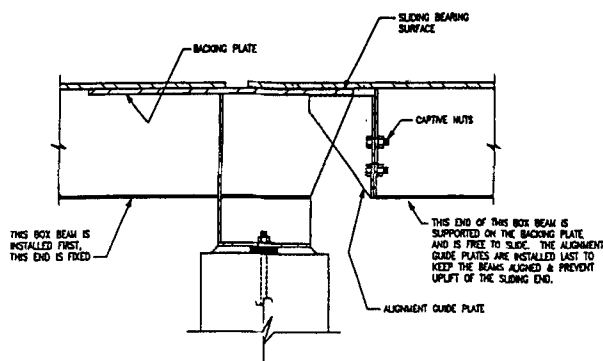


FIG. 8. Concept SCD-3—Expansion Joint Detail

levitation plates (150 mm) permits normal construction tolerances and normal changes in dimension after construction.

For adaptability this concept is limited. Any future improvements that would require dimensional changes in the vehicle or guideway could be extremely difficult to install. The ability to replace a faulty guideway element with another element is restricted. This is particularly true at the proposed expansion joint.

For durability this concept is uncertain. The extensive use of aluminum, particularly in curved thin plates, has a potential of becoming deformed due to high temperatures and secondary stresses. The wear at the expansion joint could severely limit the life of an element. Aluminum has a low fatigue threshold and therefore must be designed for a very low service load stress to achieve a reasonable service life.

Overall this concept, as the present state of development, needs extensive research and modifications to overcome the questions raised.

System Concept Design-4

The proposed guideway shown in Fig. 9 consists of a pair of double voided precast, prestressed concrete box girders. These are connected with precast, trussed diaphragms spaced 6 m (19.7 ft) apart. The girders and diaphragms are posttensioned together. The stated philosophy is that, in large measure, economy will be achieved by a selection that minimizes the quantities of structural materials used. This is contrary to the writers' experience that minimizing field labor, simplifying details, and eliminating as many operations as possible are the best way to address economy. The typical span is 27 m (88.6 ft). The substructure is a single leg hammerhead pier on spread footings.

For constructability this concept needs significant modifications. The unusual, nonsymmetrical shape of the guideway elements is very difficult to form and cast. The odd shaped diaphragms spaced 6 m apart makes erection very difficult. The guideway elements cannot be placed in position before installing the diaphragms. There are 432 transverse and vertical glass fiber, reinforced plastic posttensioned (GFRP) bars for every 27-m span. This is very field labor intensive.

For reliability this concept also needs significant modifica-

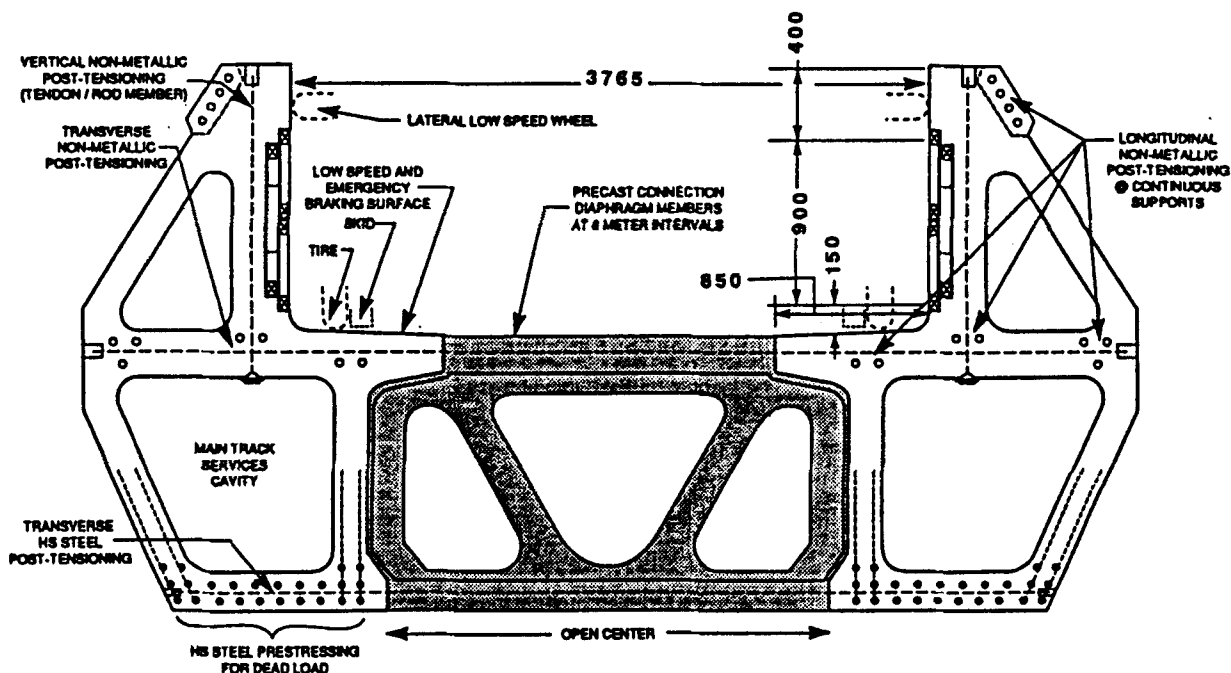


FIG. 9. Concept SCD-4—Typical Cross Section

tions. There are many weak points in this very complex structure that could develop flaws. This is particularly true of the many GFRP strands. Repair of this weak point is very difficult.

For maintainability this concept needs further study and development. There are no provisions for adjustment of the elements of the guideway. Details of end diaphragms for bearings were not shown. However, access to the voids for inspection would be very difficult. There is a need to periodically check the GFRP posttensioned strands to ensure adequacy of stress.

For adaptability this concept also needs further study and development. Because all elements are cast integrally, there is no provision for changing or replacing an element. The entire guideway would have to be changed.

For durability this concept needs an in-depth study. The extensive use of GFRP is a concern. Its long time performance is not proven. The complex shapes are certain to induce secondary stresses, which may be detrimental.

Overall this concept, at the present state of development, raises many questions. However, if the structural elements to which the levitation, propulsion, and guidance systems are attached were separated from the main carrying member the concept could be a workable one.

SUMMARY AND CONCLUSIONS

The main shortcoming of all the concepts lies in the philosophy that all functions, driving, guiding, and supporting

should be combined into one integral element. This reduces the ability to make adjustments after the guideway is complete. It very seriously affects the ability to remove and replace flawed elements.

A good analogy of an almost perfect concept of separation of functions is a railroad. The driving and guiding forces are primarily provided by the steel rail. The supporting forces are provided by the ties that spread the load transversely and by the structural system. The ballast transmits the load from the ties to the structure. This system permits ready adjustment in all three directions and easy replacement of any individual element. The maglev concepts should be redetailed to follow as closely as possible methods of construction and maintenance that have been developed in the railroad industry.

The mission of SCD is to produce a safe, reliable, economical, and financially attractive maglev. It should anticipate upgrade and be robust in resisting adverse weather and readily maintainable. No mention was made of aesthetics. Yet two of the concepts put great emphasis on it. The in-depth review of the four SCDs is reported in "Evaluation of Guideways for Structural Stability, Construction and Maintenance" (Alfred Benesch & Company, unpublished report, 1994). In this evaluation specific recommendations are made to improve the performance of each SCD.

APPENDIX. REFERENCE

Sandberg, H. R., and Williams, J. R. (1996). "Design criteria for maglev structure." *J Transp. Engrg.*, ASCE.