MAGLEV GUIDEWAY COST AND CONSTRUCTION SCHEDULE ASSESSMENT

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(Reviewed by the Urban Transportation Division)

ABSTRACT: A summary of construction cost and scheduling information is presented for four maglev guideway designs on an example route from Baltimore, MD to Newark, N.J. This work results from the National Maglev Initiative (NMI), a government-industry effort from 1989 to 1994. The system design concepts used as a basis for developing cost and construction scheduling information, were submitted by four industry consortia solely for this analysis, and represent their own unpublished designs. The detailed cost and construction schedule analyses cover the main guideway only. A summary estimate was made for stations, power distribution systems, maintenance facilities, and other types of infrastructure. The results of the analyses indicate a number of design aspects which must receive further consideration by future designers. These aspects will affect the practical and economic construction and long-term maintenance of a high-speed maglev guideway.

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designs, or system concept definition (SCD) reports, to the NMI for review (Bechtel Corporation, San Francisco, Calif., unpublished report, 1992; Foster-Miller, Inc., Waltham, Mass., unpublished report, 1992; Grumman Aerospace Corporation, Bethpage, N.Y., unpublished report 1992; Magneplane International, Inc., Bedford, Mass., unpublished report, 1992). Within the NMI, the Corps of Engineers' Huntsville Division (HND) was given the responsibility 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, Ill., to perform major portions of the guideway system analysis. The material in this paper is derived from that effort.

SYSTEM CONCEPT DESIGN SUBMISSIONS

In developing the SCDs, design options were left open to the creativity and imagination of the four industry partnerships, subject to the performance criteria supplied by the NMI. Generally, the performance criteria required the capability for maximum speeds of at least 500 km/h, a reasonable ride comfort level, and safety in all operations. The basic vehicle and guideway configurations for the four SCDs are illustrated in Fig. 1.

SCD 1

The main guideway elements are a simple span, precast and prestressed concrete girder (one for each direction of travel). Piers are spaced 25 m on center with battered (angled) columns. The electrodynamically suspended (EDS) maglev (employing repelling magnetic forces) wraps around the top and sides of the girder. The levitation, guidance, and propulsion magnets are mounted on the upper sides of the girder by nonmagnetic fasteners. The girder prestressing is obtained by conventional high-strength steel strands that are located away from the magnets. End block and shear reinforcement near the

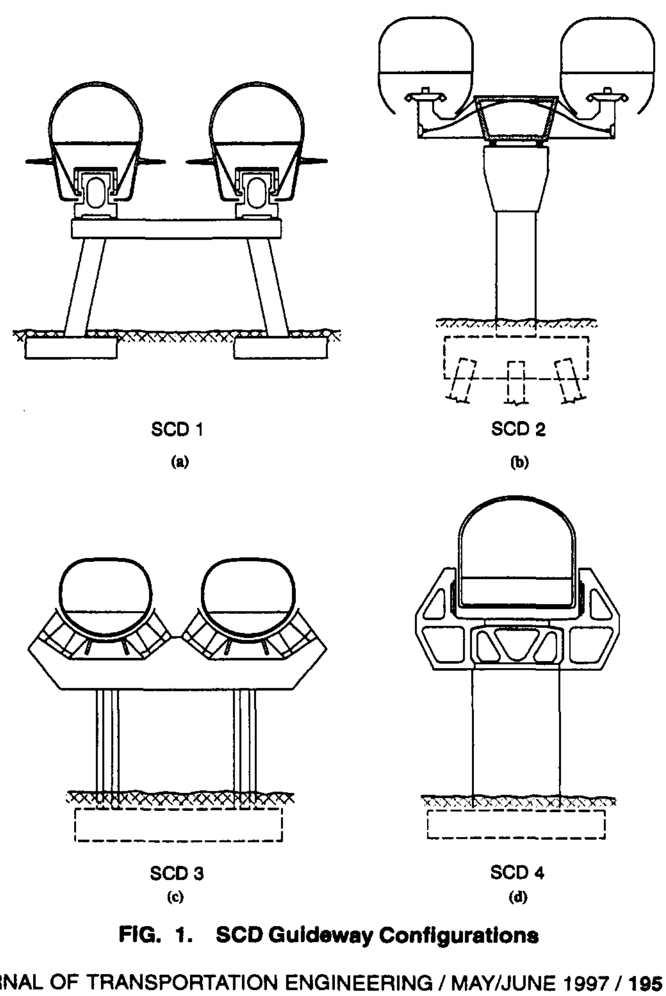

FIG. 1. SCD Guideway Configurations

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magnets consists of fiber reinforced plastic (FRP) reinforcing bars.

SCD 2

The guideway girder is made from six segments that are posttensioned together in the field, creating a simple span nearly 30 m long. Each segment consists of a precast concrete trapezoidal center section with a reinforced concrete outrigger extending out from each side. The outriggers support a track beam (of inverted T-shape), which has rails attached to each side. An electromagnetically suspended (EMS) maglev (employing attracting magnetic forces) operates over each track beam, thus the girder assembly forms a dual guideway.

The six spine girder elements are individually transported to the field, aligned, posttensioned, and set in place. The spine girders are supported on single round columns. All concrete reinforcement is either conventional steel reinforcing or high-strength steel prestressing strand.

SCD 3

This guideway consists of a two-span continuous curved trough for each direction of travel. The trough consists of the upper flange of two structural orthotropic plate aluminum sections spanning about 10 m between piers. The curved aluminum sheets also form part of the levitation and guidance system. Propulsion magnets are mounted in a ladder-like arrangement running along the center of the trough. The guideway is supported by conventionally reinforced piers consisting of a single footing, two octagonal columns, and a single pier cap.

SCD 4

This guideway consists of twin box girders held together by spacers placed at 6-m intervals. Each guideway segment is nearly 30 m long. The EDS maglev operates in the channel formed by the girders, with magnets attached to the inside wall of each girder. Each guideway supporting pier consists of a single pier cap, two rectangular columns, and one footing, all made of conventional reinforced concrete.

Longitudinal reinforcement and ties in the girders are a mix of steel and FRP. The FRP prestressing and posttensioning tendons are in the upper girder area near the magnets. The girders are made continuous over alternate spans by posttensioning with FRP during construction.

COST AND SCHEDULE ANALYSIS ON EXAMPLE ROUTE

Cost estimates and construction schedules were prepared for a route from Baltimore, MD to Newark, N.J., a distance of approximately 264 km. This route was investigated to establish realistic construction requirements and cost estimates. The costs and schedules for each SCD are for a dual guideway.

The evaluation began by investigating the example route through site visits and map studies, and documenting characteristics that could affect construction. Available literature was consulted to establish basic labor and material costs. Then, regional suppliers and fabricators were contacted for verification or adjustments. Other relevant organizations and documents were also consulted until sufficient information was obtained for producing the detailed cost estimates and construction schedules.

Tables 1–3 present general route characteristics. The main construction challenges along this route involve a large number of road, railroad, power line, and drainage (small stream) crossings, plus the crossing of three major rivers. The number of road and railroad crossings (almost one every 1.5 km) made elevating the route a necessity; only 2% of the route is suitable for at-grade construction. Crossing the Susquehanna, Delaware, and Raritan rivers requires about 13 total route km of guideway with maximum elevations of 225–315 m above the water level.

TABLE 1. Route Characteristics: Baltimore to Newark

Characteristic (1)	Length (km) (2)	Percent of route (3)
(*a*) Natural terrain		
Flat: 0–3% slope	197.1	75
Undulating: 3–8% slope	51.2	19
Rugged: 8–15% slope	15.7	6
(*b*) Population density		
Urban (United States Geological Survey map definition)	22.5	9
Nonurban	241.5	91
(*c*) Vegetation		
Heavy (requires clearing/grubbing)	80.0	30
Light	184.0	70
(*d*) Soil conditions		
Good (spread footings used)	216.0	82
Poor (piling required)	37.5	14
Wetland	10.5	4
(*e*) Alignment		
Tangent	197.8	75
Curves: 25 of 7,300-m radius 2 of 4,600-m radius	66.2	25
(*f*) Guideway heights		
At-grade	4.5	2
5 m	68.9	26
7.5 m	43.3	16
9 m	104.7	40
14 m	25.9	10
23 m	4.0	1
Over 30 m	12.7	5

TABLE 2. Crossings along Example Route

Feature crossed (1)	Number (2)
Railroads	21
Roads	126
Power lines	15
Cross drainage	131

TABLE 3. Crossings along Example Route: Major Spans

Feature crossed (1)	Length (m) (2)	Height above water (m) (3)
Susquehanna River	2,750	53
Delaware River	4,600	60
Raritan River	5,500	43

DIVIDING CONSTRUCTION INTO WORK PACKAGES

After studying route characteristics and construction requirements, it was decided that the construction should be divided into work packages, each representing a manageable amount of effort—not too large for medium-sized contractors. This division resulted in 23 work packages. Nineteen of the packages represent construction of an average of 13 km of dual guideway, with one package each for the Susquehanna River, Delaware River, Raritan River, and Rancocas Creek crossings. [Passenger stations, maintenance facilities, power distribution, and command, control, and communication (CCC) are not included in the work packages.]

In addition to route characteristics, work package division also accounted for governmental jurisdiction and work classification. Package boundaries were selected with consideration for natural boundaries such as rivers, political boundaries, and the location of roadways for access to the construction site and for material delivery.

BASIS FOR COST ESTIMATES: APPROACH AND ASSUMPTIONS

Costs were determined by using the resource approach of estimating. Construction procedures were selected, then productivities were estimated to determine the amount of each resource required (labor, equipment, and materials), and finally, the resources were priced. All costs are in July 1993 dollars.

Cost estimates are based on constructing the guideways as they were documented in the SCDs. Figures for pier heights, depths of cut, foundation pile lengths, and percentage of column reinforcing steel are average requirements for each 300-m section along the example route. Cost estimates do not include an allowance for crossovers between the dual guideways.

The estimates are intended to reflect only the cost of constructing the guideway structure, rather than total ownership costs. Thus, the estimates assume that the right-of-way is already available, so no provision for purchasing land or air rights is included. Also excluded are costs for environmental impact assessments and permits.

Information on productivities and costs was obtained from construction contractors, material suppliers, concrete precasting companies, metal fabricators, published estimating manuals and state departments of transportation. This information, combined with knowledge of the route and the guideway designs, and with professional judgment, produced the cost figures used for this study.

Wage rates and fringe benefits used in the estimates are based on the June 1993 prevailing wages and fringe benefits in the counties through which the route passes. Work in the state of New Jersey was priced at the higher of the wages required by Davis-Bacon and the Department of Labor for a given craft. Sales tax applicable in each state is added to material prices. Estimates also include the following costs:

1. Field office and staff—\$29,600/month/package
2. Mobilization—8% of project cost
3. Traffic control—nonurban: 2% of project cost; urban: 4% of project cost
4. Engineering—2% of project cost
5. Insurance—1% of project cost
6. Bond—1% of project cost
7. Home office expenses—5% of project cost
8. Scheduling—0.1% of project cost
9. Mark up—10% of project cost

COST ESTIMATES

Table 4 summarizes the estimated total cost of constructing each of the SCD guideways on the Baltimore-Newark route and average cost per km. Examples of elements contributing to cost differences among the four SCDs can be seen by examining Table 5.

TABLE 4. Guideway Construction Cost

Cost (1)	SCD 1 (\$ million) (2)	SCD 2 (\$ million) (3)	SCD 3 (\$ million) (4)	SCD 4 (\$ million) (5)
Total cost on route	2,018	2,169	5,578	2,820
Cost per km	7.6	8.2	21.1	10.7

TABLE 5. SCD Substructure Data

Design characteristics (1)	SCD 1 (2)	SCD 2 (3)	SCD 3 (4)	SCD 4 (5)
(*a*) For each pier				
Spacings (m)	25	27	19	27
Footings	2	1	1	1
Columns	2	1	2	2
Cap length (m)	19	3	11	12
(*b*) In each km				
Piers	12	11	34	11
Footings	24	11	68	22
Columns	24	11	68	22
Cap length (m)	180	50	608	222

TABLE 6. SCD Guideway Construction Schedule Summary

Time (1)	SCD 1 (2)	SCD 2 (3)	SCD 3 (4)	SCD 4 (5)
Construction time (years)	2.6	3.6	4.9	4.0
Field worker years required	2,857	2,442	6,460	2,773

CONSTRUCTION SCHEDULING

Construction schedules were produced to show the sequence of construction activities, the labor resources, and the required time frames for the 19 nonbridge work packages for each of the four SCD guideways. (The four bridge packages cover the major spans over the Susquehanna, Delaware, and Raritan rivers and Rancocas Creek). The same construction methods, construction crews, crew productivity, number of crews, and activity durations were used as a basis for both the cost analysis and construction scheduling.

The schedules assume average productivities, with 260 work days per calendar year, and a standard work day of 8 hours. On the optimistic side, no requirement for overtime was provided, nor were delays due to bad weather, equipment breakdowns, or other unforeseen events factored into the schedules. On the other hand, each work package was treated as if constructed by a different contractor. This meant that when the shorter duration work packages were done, these workers were not available to speed progress on the longer packages. Thus, overall, the schedules provide a reasonable view of the projects.

The major delays for current construction are the development of environmental impact reports and obtaining the required permits. It was assumed for this study that these activities were previously completed.

While the procurement of materials, the fabrication of reinforcing and formwork, and the precasting of the girders could also impact the schedule, the lead times built in should be sufficient to allow for these activities. The numerous tests and inspections associated with a project of this type could also delay the project. These delays were not considered in this study.

A summary schedule for the four SCD guideways is shown in Table 6.

SUMMARY AND CONCLUSIONS

As presented in the SCDs, the average cost for constructing 1 km of dual guideway structure along the example Baltimore-Newark route varied from \$7,600,000 to \$21,100,000. These average costs do not include propulsion and guidance equipment, turnouts and crossovers, land purchases, environmental studies, or stations and other fixed facilities. Guideway analyses conducted as part of the study indicated that guideway costs could be reduced through design modifications.

The guideway designs and alternatives presented in the SCDs show a wide range of ideas on how a maglev guideway could be built and supported. Two major structural issues not yet resolved are provisions for long spans, which will be required to cross any large waterway or certain built-up areas, and the extent to which deep pile foundations will be required under guideway piers, rather than the shallow foundation spread footings often assumed in the SCDs. In the analyses, estimates were based on modified long-span bridge construction.

For EDS maglev systems, where large magnetic fields would adversely interact with conventional steel reinforcing in concrete, fiber reinforced plastic (FRP) material was proposed as the alternative reinforcing in the SCDs. This material is still under development, is very expensive, and has yet to be proven in actual long-term service.

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