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Seminar III

Transit Guideway Structures

Structures des moyens de transport en site propre

Tragwerke für Verkehrsmittel auf Eigentrassee

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SUMMARY
Evolution of transit technology and effects on design of transit structures are reviewed. Development of divergent technologies is described, using existing transit systems to illustrate differences in structural support requirements. Cost, aesthetic, and social challenges to structural engineering profession are discussed.

RESUME
Le rapport passe en revue le développement des moyens de transport en site propre ainsi que ses conséquences sur le projet de l'infrastructure. L'évolution des nouvelles technologies est présentée à partir de systèmes de transport existants. Les exigences nouvelles posées aux structures porteuses sont ainsi mises en lumière. L'article traite aussi des nouveaux problèmes posés à l'ingénieur civil, tels que coûts, esthétique, problèmes sociaux.

ZUSAMMENFASSUNG
Die Entwicklung öffentlicher Verkehrsmittel auf Eigentrassee und deren Auswirkungen auf die Gestaltung der Bauwerke werden besprochen. Die Entwicklung neuerer Technologien wird aufgrund bestehender Transportsysteme beschrieben. Dabei werden neuere Anforderungen an Tragwerke erläutert. Fragen der Kosten, der Aesthetik und der sozialen Probleme werden dem Bauingenieur neu gestellt.

1. INTRODUCTION

Structures designed for transportation represent some of mankind's finest achievements. Centuries of refinement have brought us from the primitive footbridge to today's sophisticated highway and railway bridge. Transit structures are an offshoot of this evolutionary bridge development. Unique for their controlled access, the definition of loads they sustain, and the high degree of member repetition, transit structures offer the engineer an opportunity to optimize structural design and to introduce innovative concepts to the design and construction practice.

The paramount objective of the urban transit system is to move people efficiently. The system and its structures must be cost effective and must meet often-stringent community architectural standards. Since the transit structure is a continuous link which ties diverse portions of the community together, the successful designer must be familiar not only with current transit technology and physical site restraints but also with the fabric of the system's urban setting.

Until recently, the architectural profession has had little input to the aesthetic design of the transit structure. Thus, the responsibility for appearance and acceptance of the structure within the community falls to the engineer. Within the engineering profession, it is primarily the structural engineer who has influenced the growth and direction of new transit development.

The twentieth century has seen a marked change in the evolution of transit technology and a corresponding change in the development of the structural systems needed to support transit systems. The extremely high cost of tunnel construction has called for greater emphasis on elevated transit solutions. This paper will examine several of the unique structural solutions developed to meet transit needs.

2. HISTORICAL DEVELOPMENT

The first few decades of this century saw the adaptation of railroad technology to several transit systems. Early examples in the United States include the Chicago El and portions of elevated transit systems in New York and Philadelphia (Figure 1). In Europe, the Wuppertal monorail, spanning the Wupper River, represents an original solution to the needs of elevated transit in confined urban spaces.

All of these early structures are designed and fabricated from built-up steel members. The influence of low labor costs and high material costs is evident in these structures when the change in cross-section depth at each span is examined. Considered archaic by current architectural and urban integration standards, these structures were considered engineering advances in their day.

The evolutionary changes in the past two decades have had a pronounced effect on the design of transit structures. Developments which have most affected structural design considerations are

- Development of precast concrete structural systems
- Placement of continuously welded rails directly on elevated structures
- Development of rubber tire transit systems

Secondary features affecting the design of transit structures include

- Increase in operating velocity of interurban trains
- Automatic train control

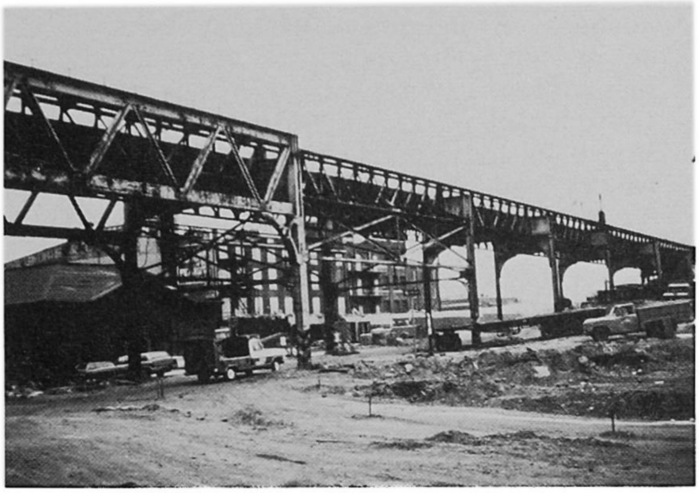


Figure 1 The built-up steel members of the Philadelphia transit system are indicative of early transit development. (Photo by author)

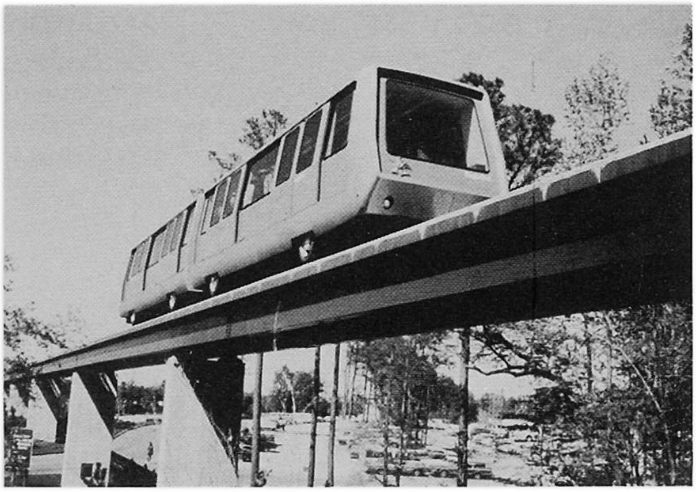


Figure 2 The Westinghouse Electric Corporation Skybus Guideway is a composite steel and concrete structure which uses a center steel rail for vehicle guidance and retention. This amusement park operation needs no walkways for emergency egress. (Photo by author)

Figure 3 The Dallas-Fort Worth Airport uses a precast concrete box girder with side walls to support the transit vehicle. The vehicle steers off the top of the concrete wall. (Photo by author)

Most recently, the emergence of exotic suspension and propulsion systems is influencing the direction of structural design. Linear induction motors (LIMs), magnetic levitation, and air-cushioned suspension systems offer unique opportunities for new structural concepts, introduction of new materials, and development of new construction techniques. In addition, the introduction of high-speed passenger trains in Japan, France, and Great Britain is extending the state of the art of bridge design. An examination of some specific installations illuminates these developments.

3. BART, A CASE STUDY

Prestressed concrete was introduced in the twenties but did not become widely used in bridge structures until the late forties and early fifties. The first large transit project to make extensive use of prestressed concrete was the Bay Area Rapid Transit (BART) system in the San Francisco Bay area of the United States. The BART project assembles many state-of-the-art transit technologies into a single project. Consequently, the lessons learned in its development are useful to modern transit systems.

3.1 Precast Concrete Structural Systems

The BART elevated guideway is a series of simple span beams with directly fixed continuously welded rails placed continuously along the structure and across the structural expansion joints. The project was of sufficient size that the designers concluded a new cost-effective precast concrete structural element could be designed and fabricated specifically for this project. The resulting beams are fully integrated structural elements that were delivered to the job site, ready for erection and installation of final trackwork.

3.2 Continuous Welded Rail Placement

Trackwork consists of continuously welded rails mounted on rail fasteners that are cast in a second pour into a groove on the beam deck. This procedure assures adequate bonding of the rail anchors with the parent beam. A second pour was determined essential on the BART project to assure that the electrical isolation between the rails and the structure is maintained. Running rails are used for the electrical ground return system.

Use of continuously welded rails on simple span beams creates thermal strain discontinuities at the beam expansion joints. The resulting forces must be accommodated into the structure. Accumulation of these forces in longer structures creates severe structural difficulties that will be discussed in the Vancouver Automated Light Rail Transit (ALRT) project.

3.3 Automatic Train Control

Totally automatic operation of transit systems has a number of subtle influences on the design of transit structures, most associated with safety issues such as vehicle restraint and passenger egress in the event of an accident. One early discovery in the BART project was that safe stopping distances must be programmed into the vehicle control system. This required that engineers be able to predict vehicle decelerations accurately enough to support control system assumptions. Using steel wheels with conventional braking systems, the coefficient of friction between the steel rails and the steel wheels under all environmental conditions had to be determined, a more difficult issue than originally anticipated. It is this uncertainty of traction that gave impetus to development of automated rubber tire transit systems.

Figure 4 The Metropolitan Toronto Zoo Guideway used precast concrete double tee beams to achieve a low-cost guideway system. A cast-in-place topping provides continuity and steering curb. (Photo by author)

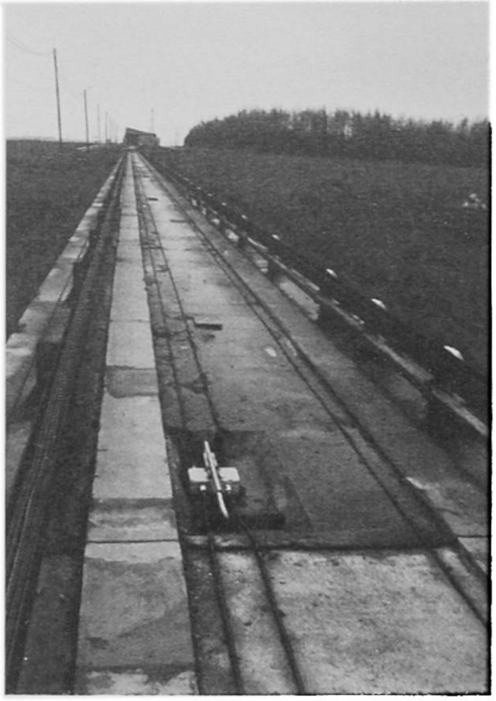


Figure 5 The Matra-Val Transit System in Lille, France, uses a precast concrete running pad for its at-grade and elevated guideway. The running pads can be equipped with heating cables for operation in ice and snow environments. Steel I-beams at the side of the guideway provide a steering surface and serve as power distribution rails. (Photo by author)

Figure 6 Busch Gardens in Tampa, Florida, uses an I-beam guideway to support a suspended vehicle. Low operating speeds allow use of a very small guideway section. (Photo by Dr. Robert Stevens, used with permission)

4.0 RUBBER TIRE TRANSIT

Rubber tire transit systems were proposed for slow-to intermediate-speed transit applications to take advantage of the increased coefficient of friction between the rubber tire and the support surface. Rubber tire systems use concrete as the traction surface. Several systems use steel superstructures with composite concrete top surfaces and, occasionally, steel beams are used with an abrasive material bonded to the steel for traction. For the sake of discussion, the rubber tire systems have been divided into two categories: Conventional support and monorails. Conventionally supported systems use structures similar to a bridge to carry the vehicle. Monorails refer to the type of system where the vehicle straddles a single beam.

Both conventional and monorail systems must address the issue of vehicle steering. It is this steering function and associated switching problems that differentiate the transit guideway from the conventional bridge. In addition to resolving the vehicle steering interaction with the guideway, the designer must also examine associated issues such as wayside power, control systems, switch hardware placement, emergency egress planning, and geometric control for rider comfort.

4.1 Conventional Systems

These systems are so named because the vehicles, except for unique features necessary for system operations, resemble small buses. They are supported from below. Figures 2 through 7 describe several different rubber tire transit systems and illustrate many of the systems' features. The photographs also depict the wide range of structural engineering solutions available for specialized transit systems.

4.2 Monorails

Monorails represent a special subset of rubber tire transit systems. Monorails have been in existence for over a century; however, the straddle-type monorail has been in commercial existence only since the early fifties. One of the earliest commercial applications was at Disneyland in Anaheim, California. Figures 6 and 7 show amusement park monorails that are designed for small vehicles and low-speed operation. The first public transit monorail was constructed in Seattle, Washington, for the 1962 World's Fair. Other mass transit monorails are in use in Japan. The Walt Disney World-EPCOT complex in Orlando, Florida, uses over 10 miles (16 kilometers) of monorail as a principal transportation link between major activity centers and is typical of the type of monorail in mass transit service (Figure 8).

A derivitive of the monorail developed in the late sixties and early seventies used air cushions as its principal means of suspension. The French Aerotrain and the British Hovercraft were the two most advanced prototypes of this type of monorail. Neither project was developed past the prototypical test phase.

The simplicity of a monorail structure differentiates it from other transit structures. The total structure is combined into a single load carrying member. Structurally, the interaction of shear, torsion, and flexural moment creates an exacting engineering condition. Thus, the engineer is obliged to perform a detailed design investigation of all the possible interacting loads which may occur. The lack of redundant load paths and the relatively small size of the structural members make the design one of true structural optimization.

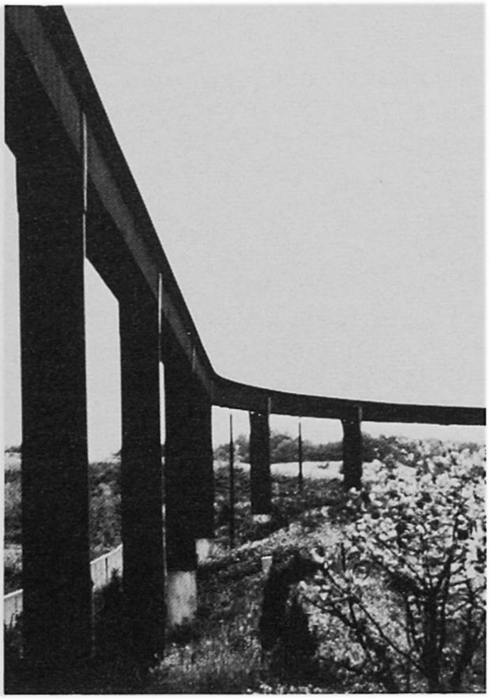


Figure 7 The Minneapolis Zoo uses a small steel box girder to support a lightweight low-velocity train. (Photo by M. LaNier, used with permission)

Figure 8 The Walt Disney World Monorail uses precast concrete beams and a flexible steel plate to connect the beams to the columns. The resulting structure is virtually maintenance free and close to an optimum structural design. (Photo c. Walt Disney Productions, used with permission)

5. EMERGING TECHNOLOGIES

New and exotic technologies are emerging for use in transit applications and are having a pronounced effect on the degree of sophistication of associated structural design. The majority of current development appears to be focused on linear motor technology and magnetic levitation systems.

5.1 Linear Induction Motor Systems

The Urban Transportation Development Corporation (UTDC) of Toronto, Canada, has developed a lightweight intermediate capacity transit vehicle which runs on continuously welded steel rails and is powered by a LIM. The structural development of two- and three-span structures was required to allow the transit system to operate in an urban setting with short radius turning requirements. In turn, these structures have required advancements in state-of-the-art rail structure interaction analysis. Secondary forces resulting from the relative motion between the continuous rails and the continuous structure during changes in ambient temperature become significant. Horizontal curve radii as small as 115 feet (35 meters) generate thermally induced rail forces on the structure which can become the dominant design condition.

The design rationale of the UTDC system includes extensive consideration of urban integration concerns such as noise and visual intrusion, and life-cycle operation costs of the transit system. To this extent, the high capital costs of direct fixation running rails and LIMs are traded off against lower projected operation and maintenance costs. This trade-off resulted in the use of continuously welded running rails and a steerable vehicle bogie. Since acceleration and deceleration are accomplished by the LIM, there is little running rail wear and no dependence upon mechanical friction. This combination produces a 25-year useful life for the running rails.

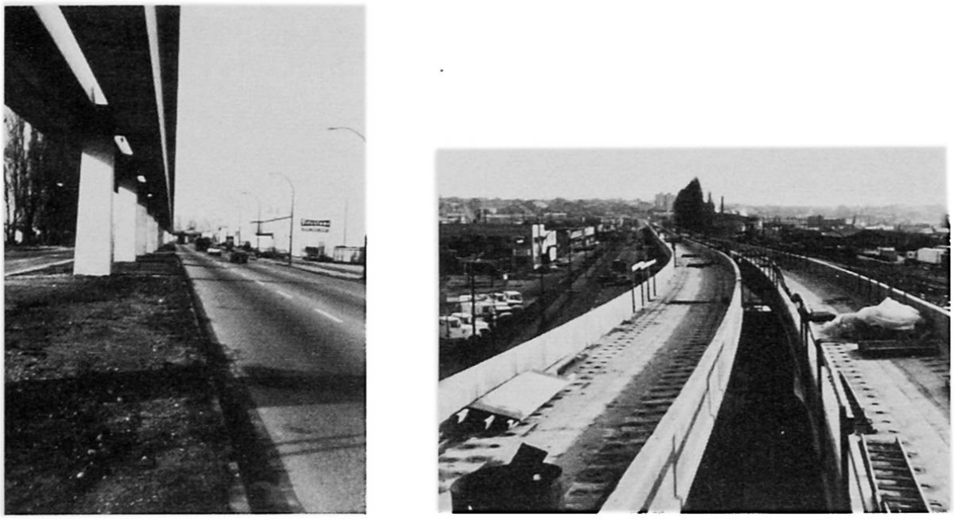
The first commercial installation of a UTDC system is the Vancouver, Canada, ALRT system. In addition to the LIM propulsion, a second feature of the transit structure is the fabrication of precast guideway beams to their final geometry, complete with inserts for installation of running rail fasteners. This process is projected to substantially reduce the site construction time and to result in superior trackwork dimensional stability.

The German Cabinentaxi is another application of LIM technology for transit application. The Cabinentaxi system uses small 3- to 20-passenger vehicles traveling in a closed loop. A unique feature of this system is the configuration of the vehicle such that half the fleet operates on top of the beam while the other half is suspended below. The resulting structure is extremely efficient and requires little more than 3 feet (1 meter) of width for a dual-lane transit system.

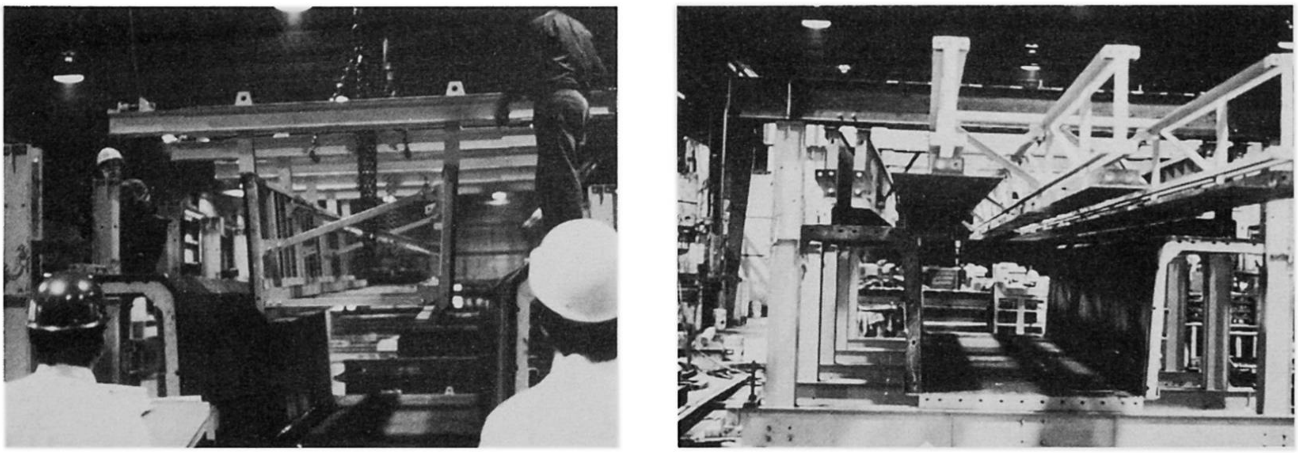
5.2 Magnetic Levitation Systems

The German and Japanese governments are sponsoring research and development of new transit technologies based on magnetic levitation suspension systems. Magnetic levitation (MagLev) technology uses magnetic attraction or repulsion to support, guide, and propel the transit vehicle. MagLev offers the potential for very high-speed operation at low energy consumption levels. Operational speeds of 155 miles per hour (250 kilometers per hour) would make MagLev competitive with air travel for short-haul operations.

To achieve projected energy use and speed potentials, the vehicle must operate with a very small separation between the vehicle and the guideway reaction rails. A paramount factor in the structure design is the installation and



<u>Figure 9</u> The Vancouver Advanced Light Rapid Transit System uses linear induction motors and continuously welded rails. Left is a photo of the completed structure from below, and right shows the beams during construction. (Photos by ABAM Engineers)



<u>Figure 10</u> Adjustable forms allow the Vancouver beams to be manufactured to final geometry and tolerance. Left is the form and inner liner, and right is the form and the insert jig mounting frame. (Photos by ABAM Engineers)

maintenance of very tight reaction rail tolerances on the guideway. On prototypical structures now under construction in Germany, beam formwork tolerances of ±0.039 inch in 82 feet (±1 millimeter in 25.6 meters) are being reported for the precast concrete beams.

6.0 CONCLUSIONS

A great need exists to develop new and innovative transit structures to complement existing and emerging transit technologies in order to meet the cost, constructability, and service requirements of transit systems in the world's cities. Transit structures present the structural designer and contractor with unprecedented opportunities for development of creative designs and construction techniques.

7.0 REFERENCES

An extensive bibliography of transit-related articles and data can be found in the following reports.

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2. Steel Structures for Mass Transit. American Iron and Steel Institute, New York, 1975.