THE TECHNICAL FEASIBILITY OF HIGH-SPEED RAIL LINES ALONG INTERSTATE HIGHWAYS IN VIRGINIA

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

To show the trend toward modern high-speed rail systems, an overview of recent developments in the subject is presented. Countries as Japan, France, Germany, England, and Canada, as well as the United States, are actively involved, with Japan and France having proven success records on their operating rail systems. Magnetic levitation guideway systems, being tested by Germany and Japan, promise speeds in excess of 250 miles per hour to compete with air transport for intercity travel.

Numerous states in America have ongoing studies on how to finance and build high-speed rail or guideway lines between their major cities. Many such proposals involve the construction of rail systems in conjunction with existing interstate highways. In anticipation of proposals to use the interstate highways of Virginia in that way, this study outlines the technical problems involved and suggests several possible solutions.

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INTRODUCTION

As pressures on existing transportation systems occur due to population increases, energy concerns, and a deteriorating infrastructure, alternate transportation systems are being explored. For intercity passenger travel, one system receiving extensive attention is that of high-speed rail. The Japanese "Shinkansen", or Bullet Train, operating successfully since 1964, is often cited as an example of what can be done. Even newer high-speed guideway designs as magnetic levitation are being developed by both the Japanese and Germans for the near future.

In the United States, at least ten states have study commissions investigating the possible construction of some sort of high-speed rail or guideway system for passenger travel. California, in fact, has well-advanced plans for the construction of a new high-speed rail line between Los Angeles and San Diego along the right-of-way of Interstate Highway I-5.

The first purpose of this report, then, is to summarize the latest developments of high-speed rail not only in this country, but also in Japan, Germany, France, England, and Canada. Because many of the proposed rail or guideway systems are envisioned along existing highway interstate corridors, this report also briefly explores the technical feasibility, problems and possible solutions of constructing new rail or guideway systems along already built interstate highways.

Anticipatory research into the possible joint use of existing highways and high-speed rail should provide direction for long-range planners in this regard. The general conditions prevailing in Virginia are used for case studies.

TRENDS

Japan

The Shinkansen, or Bullet Train,of Japan, with a top speed of 200 mph and successfully operating since 1964, first brought high-speed rail to the attention of the world. Their first line went from Tokyo south to Fuknoka via Osaka, a distance of about 663 miles. The most traveled run from Tokyo to Osaka, a distance of about 250 miles, operates at an average speed of 130 miles per hour over a computerized rail system, 60% of which is on bridges or elevated structures. The system has carried 2 billion passengers safely since its inception.

Currently under construction are two northerly extensions of the system. One is from Tokyo to Morioka, a distance of about 288 miles, and the other is from Tokyo to Niigata, a distance of about 168 miles. The Tokyo station at present is a few miles north at the city of Omiya, but eventually the line is to link directly into Tokyo. The running time to Morioka is expected to be three and one-quarter hours, and to Niigata an hour and three-quarters. The northern lines were particularly difficult and expensive to build because of mountainous sections requiring numerous tunnels. The projected cost of these two lines is $18 billion. Still another problem in the connection between Omiya on the outskirts of Tokyo and the central terminal in Tokyo is that it passes through dense urban areas where construction and noise problems are acute.

It may also be noted that to maintain high speeds with safety on these electric powered trains, constant maintenance on the trains and rail system is required. The Shinkansen trains are relatively light, having an axle load of only 38 kips in comparison with U. S. copper E-80 loads of 80 kips per axle. Japanese requirements for vertical deflection on structures, however, are more stringent in that they set a maximum of 1/1,800 of the span's length in contrast to that of 1/640 for structures in the United States. Their horizontal deflection of structures is limited to 1/3,600 of the span length. Generally speaking, the higher the vehicle speeds, the straighter the alignment.

Under experimentation by the Japanese National Railways since 1977 is a new concept in high-speed public transport called "maglev", standing for magnetic levitation. In this system, the passenger coach rides several inches above a guideway, levitated by super cooled magnets, rather than by wheels. Propulsion on this frictionless plane also is by magnetic induction. On their test track of 4.3 miles in length, a top speed of 320 mph has been reached, although operating speeds would be of the order of 186 mph.

France

The French National Railways also have in operation a high-speed, lightweight, wheeled train called the TGV, or Train de Grande Vitesse. Powered by electric motors, it has a running speed of 167 mph, although a top speed of 236 mph has been reached. Service between Paris and Lyon, a distance of 266 miles, was initiated in 1981 and has proved so successful that several additional lines are planned. The proposed new routes go from Paris to Chartres (a distance of 25 miles) then divide into two lines; one going to Tours (a distance of 124 miles) and the other going to Le Mans (a distance of 131 miles). The cost of construction of the proposed 280 miles is estimated at $1.1 billion. Continuous welded steel rails on concrete ties are to be used. After completion of the system in 1989, a ridership of 6 million passengers annually is expected.

England

In England, British Rail has recently initiated service with their Advanced Passenger Tain, or APT, that is designed to operate on existing rail lines. In order to increase running speeds, particularly on curves, the new coach bodies are constructed to automatically tilt or bank as much as 9 degrees when negotiating curves. With this innovative concept, a speed of 162 mph has been reached on the same rails that conventional trains must travel at considerably lower speeds.

Canada

VIA Rail of Canada, as of 1982, is also using tilt body trains on existing rail lines. Called LRC (Light, Rapid, Comfortable) trains, they run between Toronto, Ottawa and Montreal, a total distance of 350 miles, at an average speed of 95 mph. By 1990, after upgrading of some tracks, speeds are expected to increase to 125 mph. Under study is a new network of high-speed rail lines for passenger trains only in the Toronto-Ottawa-Montreal corridor. Three options are being considered. One is an all new dedicated line for HSR (High-Speed Rail) electric trains to operate at an average speed of 156 mph; the second is a new guideway system for the operation of maglev trains at a speed of 270 mph; and the third is an ISR (Intermediate Speed Rail) system partly operating on new tracks and partly on existing tracks. These diesel-electric trains would run at 120 mph. The estimated costs of construction of the three systems are $1.5 billion, $3 billion, and $1 billion, respectively.

Germany

As early as 1936, Germany was experimenting with magnetic levitation as a means of increasing the speed and improving the efficiency of passenger trains. Work on the system was halted by World War II and was not resumed until about 1970. At that time, an updated experimental train, the "Transrapid", was built using a long stator, linear motor which used less energy than the Japanese maglev design. It may also be mentioned that in the 1970's experiments on maglev propulsion were also carried out in the United States at the Massachusetts Institute of Technology under a federal grant. Although small-scale tests proved satisfactory, no funding for prototype development was provided; so further work at MIT was discontinued. The current state of development of maglev in Germany now involves the Transrapid 06 (TR06) that has reached a speed of 250 mph at the 19.5 mile long test track in Emsland, West Germany. Other data on the TR06 include the weight of the vehicle (102,400 pounds, empty), seating (100 passengers), length of each unit (89 feet), minimum guideway curve radius (1,640 feet) and maximum guideway grade (10 percent). However, on steep grades or sharp curves, speeds are reduced. For example, on an uphill grade of 10 percent, the speed reduces to 125 mph, and on a radius of curvature of 5,400 feet with a bank of 12 degrees, the maximum speed is 175 mph.

United States

Currently in the United States, although no work is being done on equipment development, numerous studies have been or are being undertaken on possible locations of inter-city, high-speed rail lines. Several decades ago it was decided that the existing rail lines between Washington, D.C. and New York City be upgraded and that new high-speed rolling stock be used on them. To some degree, the rail lines were improved, but they were still inadequate for operation much above 110 mph. The new trains, built by the Budd Company (a U.S. firm), however were tested to run as high as 152 mph. At present, due to gradually deteriorating track conditions, the average speed between Washington and New York is only 70 mph on the fastest regularly scheduled passenger train, the Amtrak Metroliner.

American interest in high-speed rail service is now focused on using either the Japanese Shinkansen or the German Transrapid trains. (The Budd Company, the last U. S. firm making passenger coaches for the railroads, ceased that branch of their operations in 1982.) To date, the following corridors recently have been or are being considered for high-speed rail.

Los Angeles to San Diego
Los Angeles to Las Vegas
Los Angeles to San Francisco and Sacramento

Miami to Orlando and Tampa
Tampa to Jacksonville
Dallas to Houston
Dallas to San Antonio
Chicago to Milwaukee
Chicago to Minneapolis/St. Paul
Chicago to Detroit
Chicago to St. Louis
Chicago to Dayton
Cincinnati to Columbus and Cleveland
Cincinnati to Louisville
Toledo to Columbus
Toledo to Detroit
Dayton to Indianapolis
Cleveland to Pittsburgh
Philadelphia to Pittsburgh and Youngstown
Portland to Seattle
New York City to Buffalo
Washington, D.C. to New York and Boston
Washington, D.C. to Dulles International Airport

Major organizations particularly active in such studies in the United States include the American High-Speed Rail Corporation (AHSRC, an affiliate of Amtrak), the Ohio Rail Transportation Authority (ORTA), the Budd Company (headquarters in Troy, Michigan), and the Japan Railway Technical Services (JARTS) and the Japanese Railway Technology Corporation (JRTC) (both arms of the Japan National Railways). Several of the studies that are most advanced are summarized below.

The Los Angeles to San Diego route study is being directed by the AHSRC with assistance from the JARTS and the Fluor Corporation of Irvine, California. Current plans are to use the Japanese Shinkansen train on new tracks that start at the Los Angeles airport along the existing Santa Fe Railroad right-of-way, then along Interstate Highway I-5 and Santa Fe rights-of-way to the railroad depot in San Diego. Fifty percent of the 127 miles is to be on grade or embankment, 38% on elevated viaducts and 12% in tunnels. The project is estimated to cost $2 billion, one-quarter of which is to come from Japan and the remainder from U. S. sources. In 1982 the California legislature passed a bill authorizing $1.125 billion in tax-exempt state revenue bonds to help finance the project. The bill also exempts the project from all requirements of the California Environmental Quality Act in order to speed up the project, which is estimated to take 5 years of construction time. However, soundproofing along the urban sectors is being planned. Once completed, the trip time is estimated at 59 minutes, with speeds up to 160 mph. Twelve million passengers per year are expected to use the facility.

The Japanese National Railways, through its New York City subsidiary, Japan Railway Technology Corporation, has also been conducting a feasibility study on the use of the Shinkansen in Florida between Miami, Orlando, and Tampa. This route is to use the rights-of-way of the existing Florida Turnpike and I-4 highway system. One million dollars have been allocated for this study. Although generally supported by Florida, it is currently opposed by the Federal Highway Administration on the grounds that the highway curves are too sharp for high-speed rail, the clearances are too low at highway overpasses, and the modifications needed to existing highway interchanges would be too costly. Current estimates of construction costs range from $4 to $5 billion for the 301 miles.

A new Bullet Train line between Dallas and Houston is currently under study by the Texas Railroad Transportation Company. The 240 miles of track are expected to cost $1.2 billion, with construction to start in 1985. In 1988, when the system is operational, the travel time between the two cities will be less than 2 hours.

The Budd Company, recently associated with the developers of the Transrapid trains (Thyssen Henschel of Kassel, West Germany) has conducted feasibility studies of several other routes using maglev trains, which they call the "Skytrain" in that they would operate on elevated guideways. Supported by a Department of Transportation grant, the city of Las Vegas commissioned the Budd Company to study possible routes for high-speed trains from Las Vegas to Los Angeles. All routes proposed use the median of highway I-15 for part of the run. With maglev trains, this 230-mile route could be travelled in approximately 70 minutes at a top speed of 250 mph. The cost of construction is estimated at $1.9 billion over a 5-year construction period. The projected patronage is 3.7 million passengers per year.

The Budd Company also conducted a feasibility study of using maglev trains in the corridor between Chicago and Milwaukee. This 79-mile route could be made in 32 minutes with 250 mph maglevs. The estimated cost of construction is $1.2 billion.

The connection between Washington, D. C. and Dulles International Airport, a distance of about 30 miles, by maglev trains was also investigated by Budd. Joint use of the existing Dulles International Airport Road was envisioned.

A setback for high-speed rail was recently incurred by the ORTA. After an extensive study of various networks of new rail systems for Ohio, ORTA's proposals were rejected by the voters of Ohio. Planned were 545 miles of new tracks for 150 mph passenger trains (either Japanese or French), along with a 20 mile experimental test track near Warren, Ohio. The $8 billion cost apparently proved its undoing.

Although not a true inter-city high-speed rail system, the rapid rail Metro line currently being built in the median of I-66 between Rosslyn and Vienna, Virginia, should be mentioned as an example of the joint right-of-way use of highway vehicles and rail vehicles. The rail line, after emerging from the tunnel under the Potomac River, is essentially on grade (although depressed in places) the entire distance to Vienna. Since its construction was an integral part of I-66 and not an added feature as described for the proposed rail systems along I-4, I-5, and I-15, it is a useful but not perfect model for integrating new rail lines with existing interstate highways.

TECHNICAL FEASIBILITY

If there is an interstate route in Virginia that would be a candidate for the incorporation of a high-speed rail system in the future it is I-95 between Richmond and Washington. Even now, the traffic volume is extremely large on this route. Furthermore, this corridor is a direct extension of the existing Metroliner rail line between New York and Washington. High-speed rail service in this location could reduce the growing vehicular pressure on this heavily travelled highway. For these reasons, I-95 between Richmond and Washington will be examined as an example of how a new rapid rail line might be incorporated within the existing system.

Along this route there are a number of basic physical encumbrances that must be considered. In brief, they include uneven terrain (in the median or off-shoulders) water crossings of various lengths, space limitations along the rights-of-way for new piers, stations, terminals, etc., and existing overpasses, ramps, and interchange structures. Other, nonphysical aspects as noise, safety, esthetics and, of course, cost (both construction and operating) must also be considered, along with ridership demand.

It is not the intention of this initial study to actually develop a specific plan, mile by mile, for a rail system along I-95. Rather the various choices appropriate for the different conditions will be presented and discussed. It is fortuitous that the AASHTO geometric and alignment requirements regarding grades and curves on interstate highways generally are compatible with those for rail at operating speeds of about 125 mph. Speeds on long, straight sections can be appreciably higher, possibly reaching the design limit of the train itself of up to 250 mph for maglevs. Thus, it is reasonable to assume that, except for station stops and terminals, the horizontal alignment of high-speed rail lines could be contained within the existing rights-of-way of interstate highways, and in particular I-95. The technical problems arise primarily in connection with where the rail lines fall with respect to the existing pavements and the accommodation of grade limitations at overpasses, interchanges, off-pavement terrain irregularities, and the like.

Many types of rail and guideway systems are being used or experimented with. These include double track steel or rubber tired vehicles riding on guideways, single track vehicles riding on or suspended from guideways (monorails), and side track vehicles riding alongside guideways. For this study, only the two types of systems described previously will be assumed; these being the double steel rail track for trains as the Shinkansen and the single track magnetic guideway as for the Transrapid.

As for the position of the rail or guideway system within the existing right-of-way, there are five basic alternatives:

a. In the median between roadway pavements.

b. In the shoulder strips immediately adjacent to the pavement.

c. In the off-shoulder sectors, but within the right-of-way.

d. Over the roadway.

e. Under the roadway.

A mix of these locations should also be considered over any long length of highway. For example, in one stretch the new system could be in the median, then go over or under the roadway to run in the off-shoulder sector.

In conjunction with the horizontal alignment, grade also must be considered. In that connection, eight basic alternatives exist for supporting the rail or guideway. These are listed below in order of approximate construction cost for a two track guideway. These costs include grading, structure, track, electrical work, and stations, but not land acquisition.

A. By the existing grade of land ($10 million/mile).

B. On a low constructed embankment or fill ($17 million/mile).

C. In a shallow trench or cut ($18 million/mile).

D. On a low elevated structure with short spans ($20 million/mile).

E. On a high elevated structure with medium spans ($35 million/mile).

F. In a cut-and-cover tunnel($45 million/mile).

G. On a high elevated structure with long spans ($50 million/mile).

H. In a dug tunnel ($55 million/mile).

A mix of these conditions along any given stretch of line should, of course, be considered.

Thus a matrix of the 5 position alternatives and the 8 types of support alternatives can be developed, as shown below, to give 40 theoretically possible combinations for each location along the highway.

SUPPORT TYPE	POSITION: a	b	c	d	e
A	O	O	O	X	X
B	O	O	O	X	X
C	O	O	O	X	X
D	O	O	O	X	X
E	O	O	O	O	X
F	O	O	O	O	O
G	O	O	O	O	X
H	O	O	O	O	O

For reasons of inconsistency (such as having an embankment cross a highway), some of these theoretical combinations fall out and are marked by an X in the matrix. The viable ones, totalling 30, are marked by an O.

Specific site conditions could conceivably rule out other combinations. For example, a rail line in a median that had to pass under an overpass bridge would probably eliminate B and D (an embankment and low elevated structure).

Also an essential factor to consider is the continuity and compatibility of one system with another along the route. Whereas changing from an embankment to an elevated structure over a distance of several hundred feet is reasonable, changing every few feet is not.

Safety, too, is a big concern. A depressed rail line immediately adjacent to a roadway is not desirable, even with a parapet barrier. Similarly, pillars for the support of an elevated structure should not be too close to the roadway.

At a massive interchange, as on I-95 near the Pentagon in Arlington County, options are limited to either a dug tunnel or a high elevated structure with long spans, both of which are expensive.

From a standpoint of noise, tunnels are best, with a depressed rail line being second best. Third best would be a high elevated line. Otherwise, acoustic baffles along the line may be required for those segments that pass close to developed areas.

Station stop facilities could be built either as overhead or underground structures. However, additional land outside the existing right-of-way would probably have to be acquired for automobiles and bus parking. An exception might be at stations located near interchanges where considerable unused land exists between ramps and roads. A terminal for servicing of the trains, at least at one point in the line, would also require additional land.

Good engineering practice would require the careful evaluation of all possible alternatives, including that of not building along the interstate highway at all. However, as an example of an "ideal" solution involving anticipatory design, one such solution will be sketched out. Envisioned is a rail or guideway system elevated high above the right-of-way, conceptually soaring freely over all land based obstacles. Realistically, a high, elevated, continuous bridge structure with long spans and minimal size piers is a reasonable approximation to this ideal. Two types of structures are pictured: one for spans of about 500 feet and another for spans of about 1,000 feet. These spans greatly exceed currently used spans (of the order of 100 feet) for high-speed trains. A major concern in high-speed travel is that of good alignment, both vertically and horizontally. Structures designed for very low deflections, particularly at long spans, can be both massive and expensive. A new way of designing structural systems that use active control concepts could prove to be the answer to this problem. (Refer to the report "Kinetic Bridges", VHTRC 81-R6, by W. Zuk, July 1980.)

In an actively controlled bridge, sensors such as accelerometers are positioned at various locations on the bridge. These sensors feed their information to a small computer that sends appropriate signals to a system of quick responding jacks acting on the structure. The jacks act in such a way that deflections of the structure are limited to some predetermined amount. In this way, a bridge need be built primarily for strength, with deflection and vibration control being maintained by the active control system. The end product should be a long-span structure capable of doing its job but at much less cost.

An alternate solution, using active controls in a different way, is to design the long spans for strength only and to allow the structure to be flexible. The active control system, rather than being incorporated into the bridge, would be built into the train bodies. Just as the British APT train bodies automatically tilt when rounding a curve, so too could trains of the future have automatic levelers and bankers in their suspension mechanisms. A smooth ride could thus be experienced by the passengers regardless of the deflections of the rails or guideways. Lightweight structures of considerable span could thus be built, possibly making them cost effective for construction in difficult site conditions as in the median of I-95.

With either type active control system (whether incorporated in the bridge or in the train body), a technically appropriate bridge design for the span lengths under consideration is the cable-stayed structural configuration. A version of this design suitable for a double track or a double guideway system spanning 500 feet is shown in Figure 1. In this design, there is a single pier of either steel or prestressed concrete approximately every 500 feet. By varying the height of the towers, the roadbed can be built level, regardless of the shape of the terrain below. Although this same structure can be constructed without any form of active control system, it is believed that significant economies can result if some sort of active control is used. A logical way to incorporate active control in the bridge is to have an automatic jacking system working within the diagonal cable system, such that when a section of the horizontal girder deflects under the weight of the train, the jacks would pull up on the cables to keep the girder at its undeflected position. To minimize weight, girders fabricated of high strength steel would be appropriate. The illustration shown in Figure 1 is conceptual in nature only, and considerable additional detail designing has to be carried out, which may result in some changes (such as requiring additional cables or modifying the size of the members).

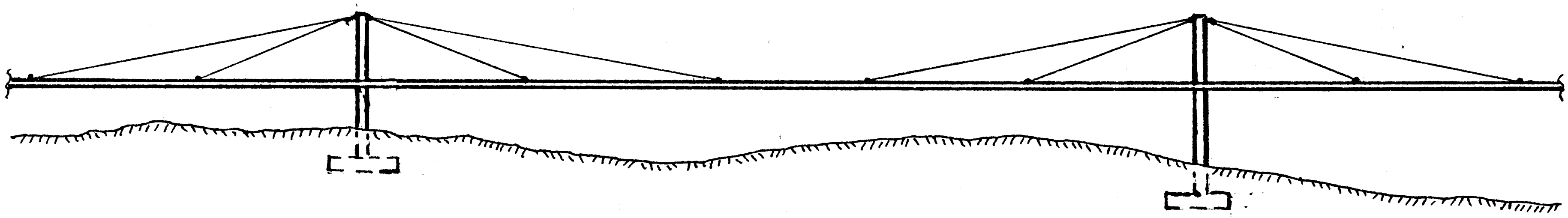
Figure 2 illustrates a cable-stayed, elevated bridge structure intended to span 1,000 feet. Note that in addition to the normal cable stays from above, there are others from below as well. These lower ones, called counter cables, serve to reduce vibrations, which are particularly significant on long spans. Again, as with the previously described structure, the bridge could be built without active controls, but would require much less material with active controls in either the bridge itself or the train bodies. The drawing shows a ground clearance of about 20 feet to the lowest cable; however, in some lower locations (as in the median) no clearance is required and the height of the towers could be reduced accordingly.

The designs depicted can be easily modified to accommodate station stops as drawn in Figure 3. Assuming the structure to be located in the median of an interstate highway, access to the stations could be either via a tunnel under the highway or a covered walkway over the highway. The bridge piers at these stations would assist in supporting the vertical transportation systems as escalators and elevators for the handicapped. The roof and walls for weather protection at the stations could be supported by the cables already there. Horizontal curves, using the cable-stayed design, can also be made in one of two ways. The first and easiest way is to use a straight span between piers, but to widen the riding platform to accommodate the curvature of the rails or guideway. The second way is to use a curved platform following the curvature of the rails or guideway. In the latter system, the cables would radiate at different angles and cause a more complex condition of stresses. However, present-day computerized analysis can handle such conditions.

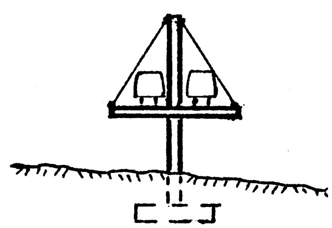
Other special situations as at terminals, tunnels, or transition to another kind of support system could also be accommodated by appropriate modifications, depending on the specific conditions. All concepts proposed, of course, need further detailed study before implementation.

Figure 1

500 FOOT SPAN STRUCTURE
Scale: 1" = 100'



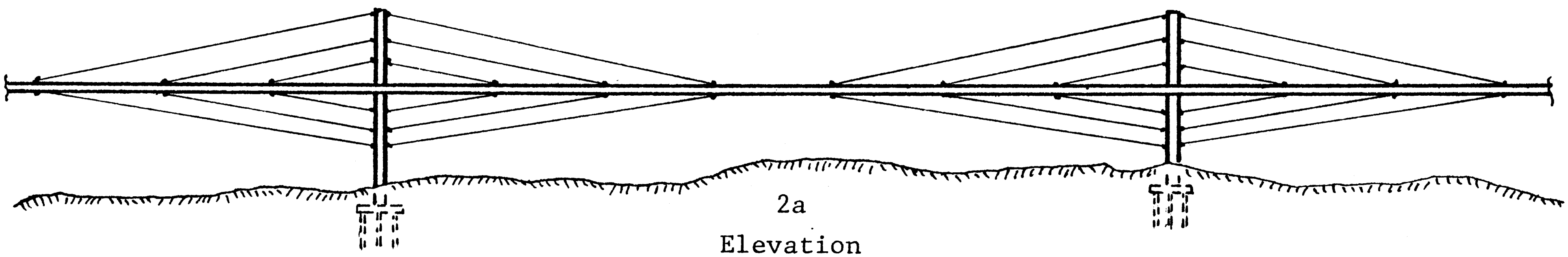
1a
Elevation



1b
Section

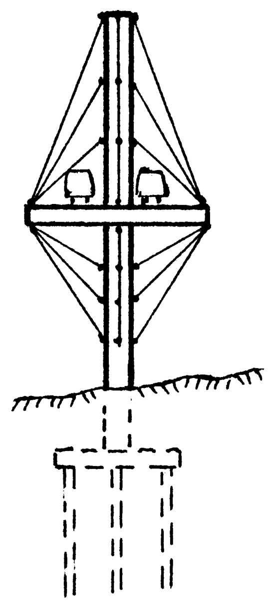
Figure 2

1000 FOOT SPAN STRUCTURE



2a

Elevation
Scale: 1" = 200'

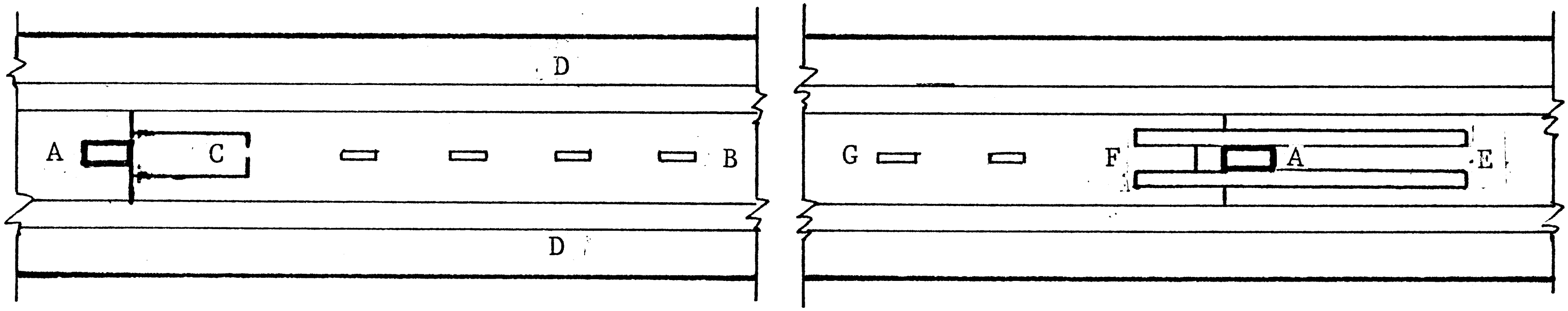


2b

Section
Scale: 1" = 100'

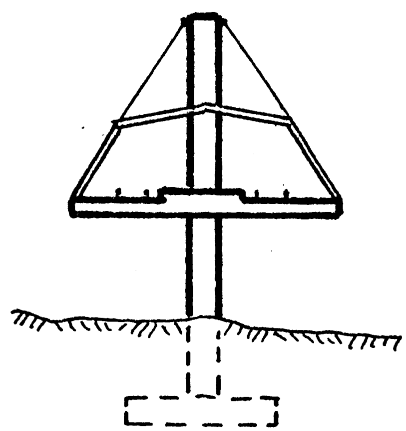
Figure 3

STATION DESIGN
Scale: 1" = 50'



3a

Plan



3b

Enclosed section
over platform

A — Pier
B — Waiting platform
C — Ticket Office
D — Track
E — Escalators
F — Elevator
G — Benches

CONCLUSIONS

The construction of a new high-speed rail system is technically possible but is very expensive, whether it be in conjunction with an interstate highway or not. If it is assumed that construction is within the rights-of-way of existing highways, then land acquisition costs are minimal. However, extra costs are likely to be incurred by virtue of more expensive structural and support systems designed around existing highway obstacles.

Given that construction costs are high, the economics of user demand and payment must be carefully studied for any given route. In that connection, account should be taken that new rail and guideway systems offer speed and service not available by any other mode of transportation. In the future, with highway and air transport likely to be increasingly congested, an alternate service could prove profitable, as it has in Japan and France.

It is believed that conditions along I-95 between Richmond and Washington, D. C. have not yet reached a stage where rapid rail would prove profitable, but could well do so in another 10 years. Anticipation of such a possibility warrants consideration, particularly if the proposed rapid rail lines in California, Nevada, Texas and Florida are successful.

A wide variety of different ways of constructing high-speed lines are possible with present-day technology. However, since most of the systems will be built in the future, as needs require, new forms of vehicles and structures should be anticipated. The use of active control systems as described could significantly reduce costs of such construction.

This study is but a preliminary one. Nonetheless, based on recent trends in high-speed rail in this country as well as abroad, there is evidence that such transportation systems are viable.

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