MONORAIL SYSTEMS

FOR

MASS RAPID TRANSIT

APRIL 27, 1954

SPONSORED BY
THE TRANSPORTATION INSTITUTE
OF
THE UNIVERSITY OF MICHIGAN
AND
THE ENGINEERING SOCIETY OF DETROIT

GIBBS & HILL, Inc.
CONSULTING ENGINEERS
NEW YORK—LOS ANGELES

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PRESENTED IN

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FOR

MASS RAPID TRANSIT

Edward H. Anson

Senior Vice President - Gibbs & Hill, Inc.

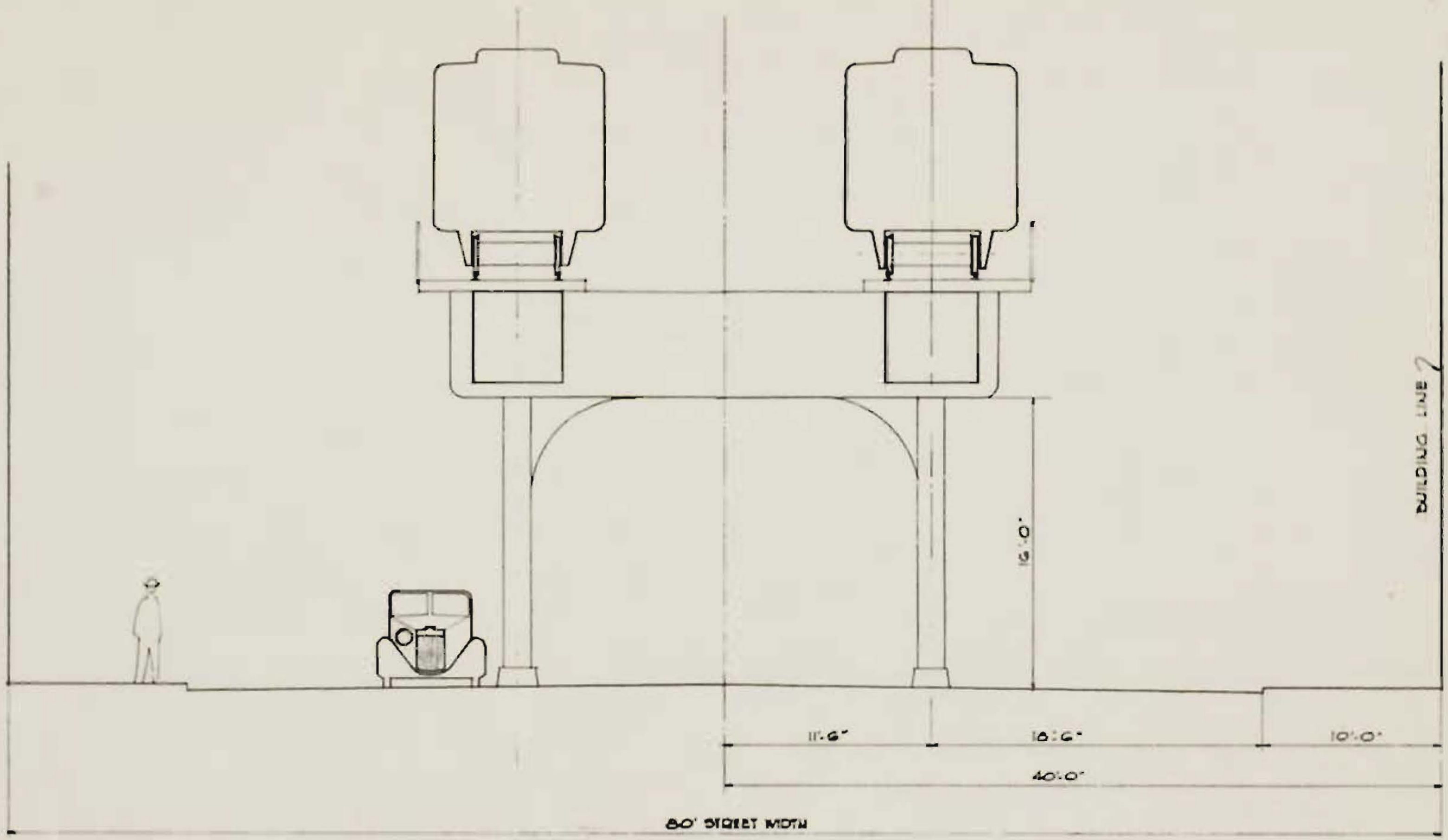
Development of Rapid Transit

In the early days of our cities all land transportation was on the surface of the ground. As mass transportation became a necessity it continued on the streets and on the roads first by the stage coach and horse car, and later by the trolley car and bus. When some of the larger and faster growing cities began to feel the pinch of traffic, elevated train operation was initiated to separate and speed the mass movement. This became the noisy elevated train running upon conventional tracks built close to the ground, shutting off light and air and with several lines of supporting columns in the street causing a depreciation in real estate values along its route, and with the advent of the automobile becoming a traffic aggravation. Because the surface was already congested and the elevated structure was causing concern, thoughts were forced to turn towards subways. Subways, as an operating device, were a good answer for the majority of the population for most of the time. Except when one had to ride in the subway, it was out of sight and almost out of mind. The great hitch is economics. Can the luxury of a subway be afforded today by any of our cities, though they are strangled by automotive traffic on their streets? If so, then there is the answer to the traffic problem. Unfortunately, it has been demonstrated that hardly any city in this country can afford the luxury of a subway sufficiently extensive to provide real traffic relief.

The elevated did provide the desired private right of way and as a form of transportation could be satisfactory. Its cost is, relative to the subway, a step in the right direction. Starting from the well known older form of elevated, the problem is to strip away its objectionable features and improve its better ones with the aid of modern technical progress.

In the most modern concept of an elevated railway the more or less conventional roadbed of the early elevated, its ties, and rails are replaced by concrete surfaces on which pneumatic rubber tired wheels ride. The car would be guided by a steering device of which several types are possible, one among them is now operating satisfactorily in the Paris underground. Both single and double-track arrangements require only a single row of columns presenting a limited surface obstruction. In fact, whatever obstruction is involved becomes almost negligible when columns are placed in the center division provided for traffic separation in most important new highways.

The following two illustrations show comparatively the



CONVENTIONAL
ELEVATED STRUCTURE

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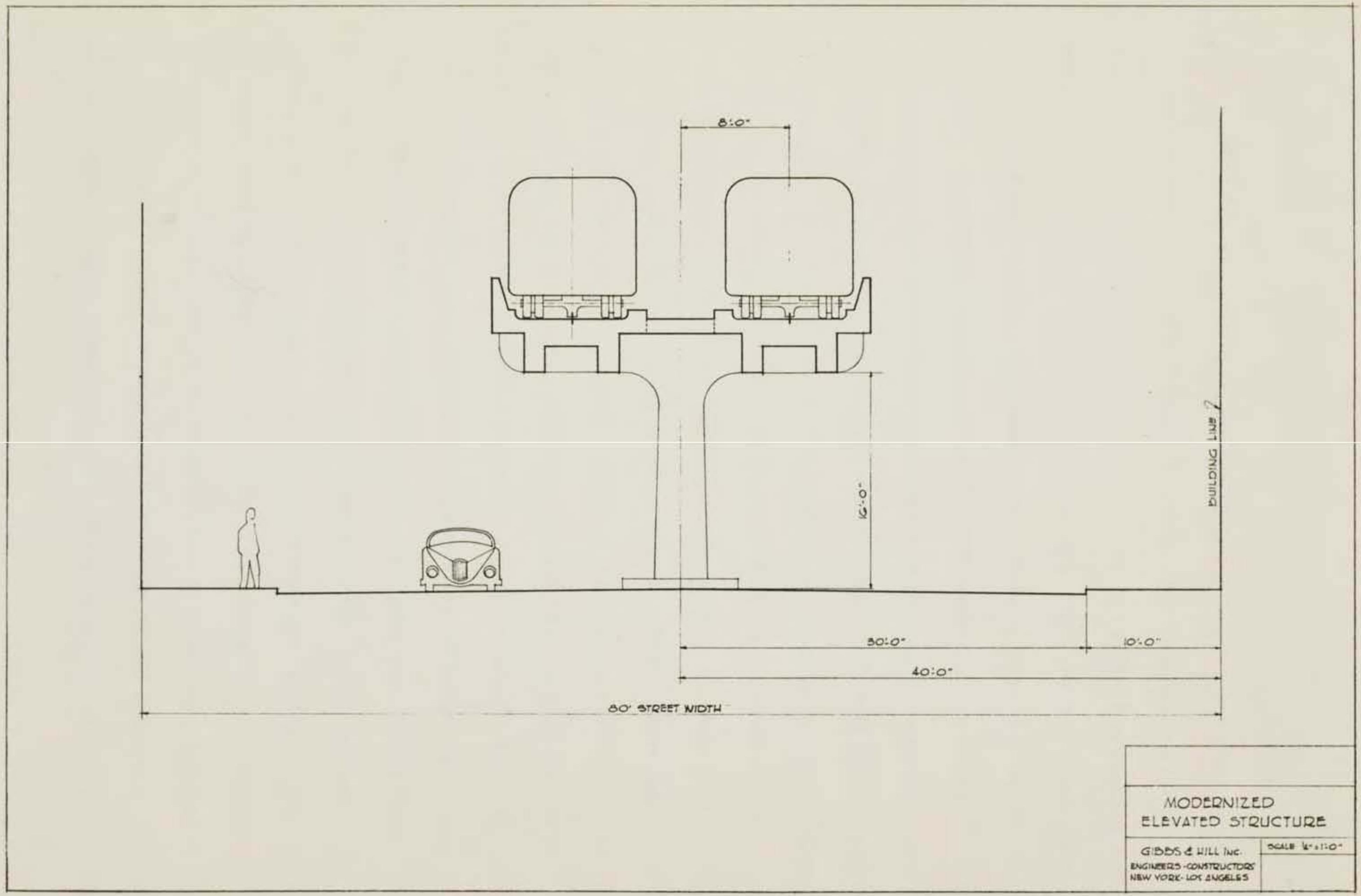
8'-0"
16'-0"
BUILDING LINE
30'-0"
10'-0"
40'-0"
80' STREET WIDTH
MODERNIZED
ELEVATED STRUCTURE
GIBBS & HILL INC.
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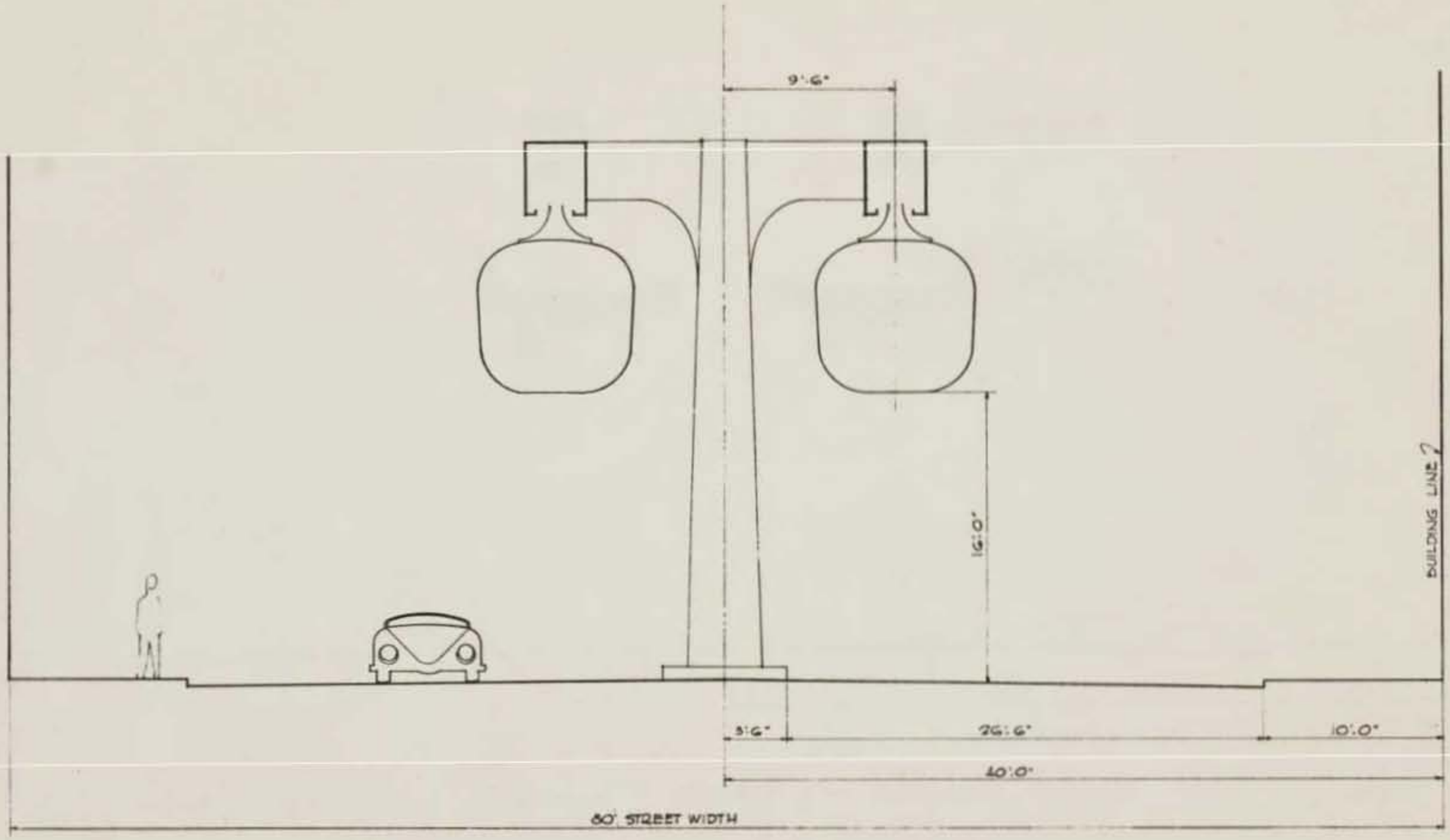
NEW YORK-LOS ANGELES
SCALE

structural forms of the present elevated railway and the proposed modern elevated. Many of the objectionable features of the present elevated systems have been removed. Certainly the noise has been reduced if not eliminated entirely by the pneumatic tires, the traffic hazard of multiple columns has been materially lessened and access to abutting property is no longer restricted. But there is one objectionable feature which has not been changed. The roadbeds or roadways still present a roof over the street with the resulting loss of light and airiness. You will note from the illustrations that little change in this physical obstruction has been accomplished by the modern concept of an elevated railway. Because of the compelling necessity for removing this characteristic which is particularly objectionable in community streets, the thought of suspending the car from the track was originated. Because the car does not depend on the track width for stability against overturning, the track gauge can be narrowed to the extent permitted by equipment dimensions. Also, because the car is suspended from the track the supporting structure assuming equal ground clearance is raised considerably higher above the street. The next illustration shows the advantages gained by these changes, resulting in a structure along the street that is smaller and higher and that no longer imposes a roof over the street. The comparison of the continuing longitudinal structure of the modern concept of elevated and that of the suspended railway (Monorail) is shown on the second following illustration. Note the small separated areas of the suspended structure.



SUSPENDED RAILWAY

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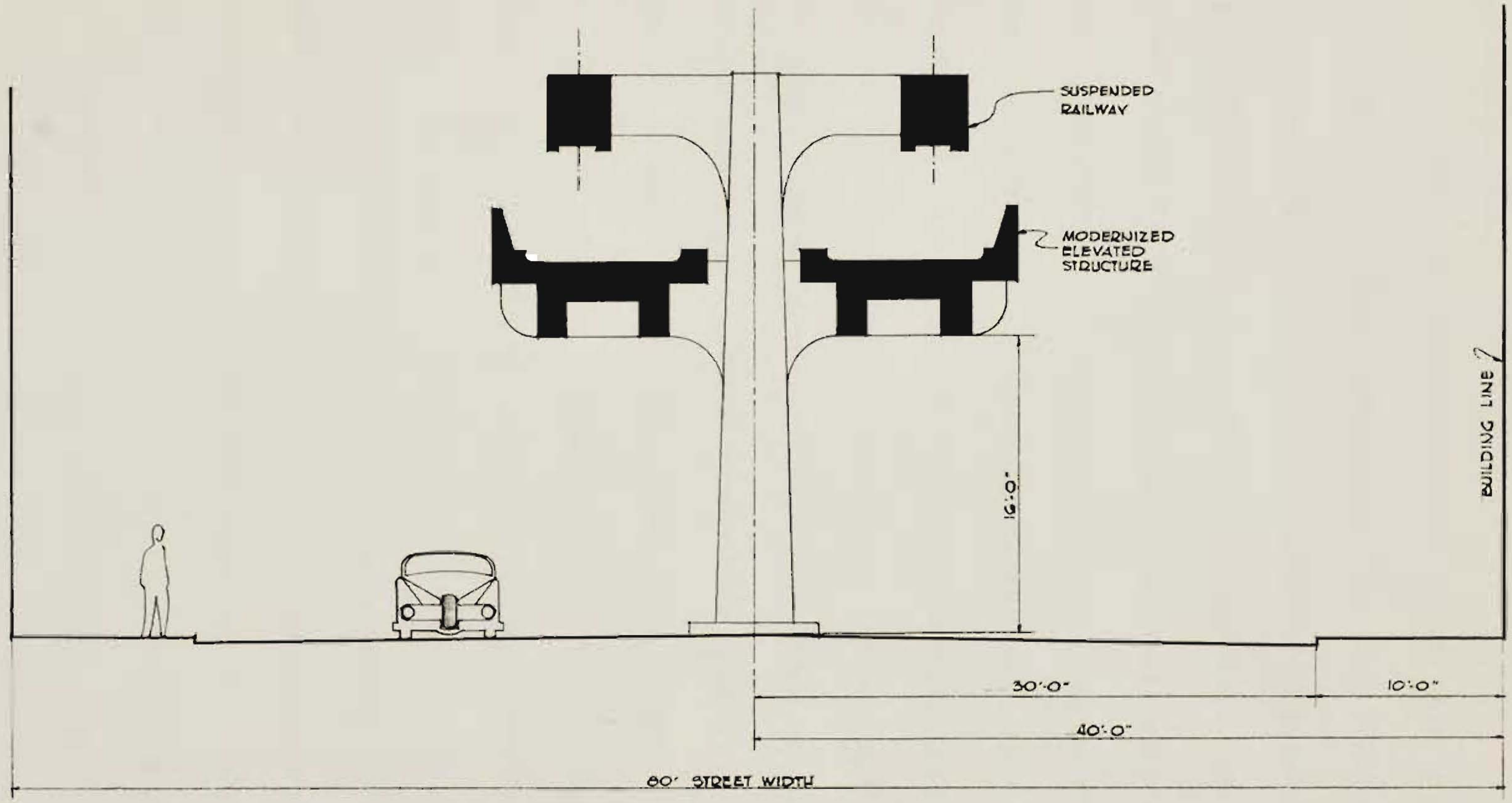
SCALE: 1/4"=1'-0"



COMPOSITE SECTION OF SUSPENDED RAILWAY & MODERNIZED ELEVATED STRUCTURES

SCALE 1/4" = 1'-0"

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Need for Rapid Transit

Because of the tremendous post war growth of population around large American cities, today more than ever before, our metropolitan areas are faced with the immediate necessity of expanding and providing adequate public services to their inhabitants. Every phase of economic and social life is involved. Schools, water supply, sewerage system, fire department, transportation and all other community facilities require assistance from public funds for expansion to meet the ever increasing demand. Among these, none is being discussed with more urgency than the possible solution of problems pertaining to mass rapid transit. The conclusion has been reached after many years of study that public transportation on the surface cannot keep pace with the changing requirements of mass rapid transit and that a new approach will have to be developed, departing from the idea of the use of surface for mass trans portation, impeded by the cross current of street traffic flow. The solution lies in the design of a transit system where the freedom of movement is not hampered by other traffic mediums, where speeds can be maintained in excess of those obtainable by existing systems, and for which the capital and operating costs would not exceed those of any other system attempting to provide comparable service. These are the reasons traffic and transit engineers have been looking longingly for some other means of mass rapid transit above the surface of the street.

From numerous studies, it has become increasingly clear that a modernized form of suspended railway is an available solution of today's problem of mass rapid transit. Several other solutions have been suggested, but today we are concerned with monorail systems as a most promising answer.

Although this discussion relates to mass rapid transit, I am never able to talk about transportation in general terms without considering, for at least a moment, the effect of the private automobile on our traffic problems.

Right here in your city, I have heard the questions --

Why mass transportation? Do we need a rapid transit system?

I do not propose to attempt to answer these questions offhand because they can be resolved only after serious technical examination of the problem and expert appraisal of the findings, but there are a few fundamentals which must be borne in mind. Especially in metropolitan areas the services performed by various forms of transportation are interrelated. The ultimate achievement must be the economical and expeditious movement of people -- not necessarily vehicles.

As a solution to the problem of moving large numbers of people into or through any central district, the private automobile is decidedly a poor answer. At the usual average loading the automobile is extremely prodigal of street space. In most cases, it must be stored somewhere until the return journey which storage requires still more space whether it be for curb parking, private off-street parking or public parking areas.

Therefore, it appears self-evident that every large community must look carefully at mass rapid transit.

This is logically followed in inquiring minds by the question "What is this monorail business all about?" I have already developed the desirability of adopting suspended railway, or monorail, for mass rapid transit in our communities and now I am going to describe the various systems available.

Classical Monorails

Mr. Webster, in his dictionary, doesn't leave much to the imagination in the description of Monorail. He says, and I quote from the New International version, "Monorail - a single rail serving as a track for a wheeled carriage, truck, etc. Specif. Railroads, a single rail mounted on trestles constituting the track for cars that usually sit straddle-wise over it or being suspended from it."

Under this definition there could be only three general types of monorail, only one of which appears to be practical.

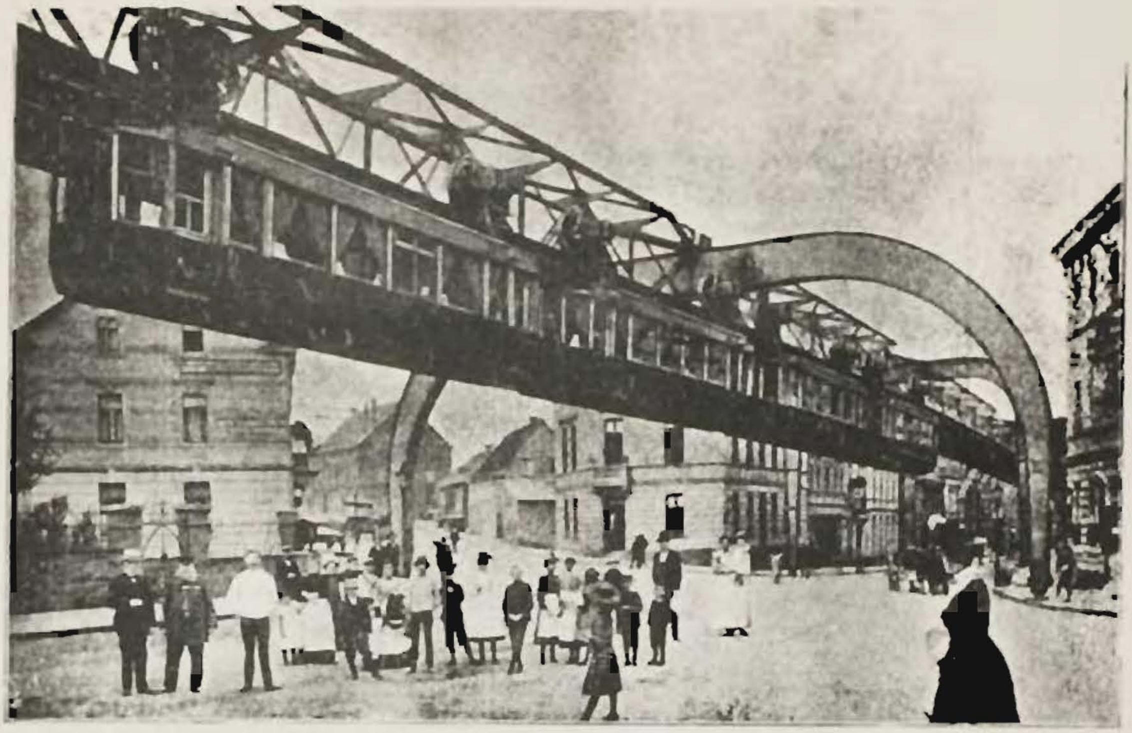
One type is the "saddle-bag monorail" with cars balanced on either side of the single rail. Any appreciable unbalance could overturn the whole works. In spite of this handicap a system of this type, called the Lartigue monorail, was operated for many years in a French post in eastern Africa.

The second, which I shall connotate as the "guided monorail", has the car running upon a single rail but held upright by a gyroscopic device. But what happens when the gyroscope stops? This system was proposed by no less an individual than Mr. Louis Brennan, who invented the Brennan torpedo used by the British. Others subsequently experimented with the idea but no one has ever answered that challenging question.

The third, and apparently the only practical form, has the cars hung below the rail and has naturally been called the "suspended monorail." This type is exemplified by the Barmen-Elberfeld-Vohwinkel line presently operating in Wuppertal, Germany. Much has been written about this prototype of the classical monorail, connotated "classical", solely because Mr. Webster says so. Photographs of parts of that electric railway are shown on the next page.

Modern Concept of Monorail

Because monorail construction is in no sense a new engineering idea, we should not be confined to the narrow wording of Webster's dictionary and the definition of classical monorail but we should examine the practical industrial monorails long used extensively in this country in large industrial plants, warehouses and other businesses for the handling of relatively heavy pieces of material or equipment moving generally along the same routing and often propelled by motors. These monorails are well developed and highly satisfactory. In some of the better designed industrial monorail systems there are two wheels opposite each other running on two bearing surfaces, one on each of the two sides of a flange



Barmen-Elberfeld-Vohwinkel Suspended Electric Railway.
Train going up the Main Street of Vohwinkel.

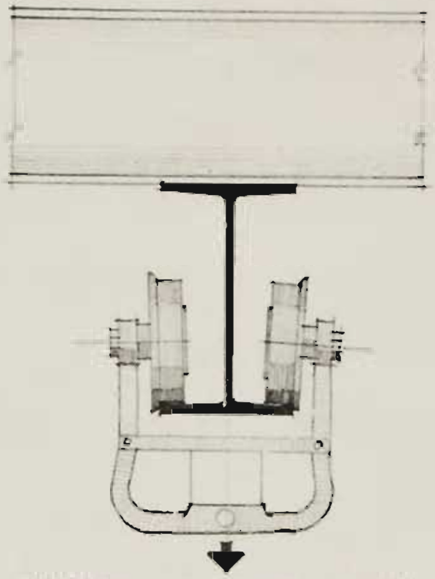
Barmen-Elberfeld-Vohwinkel Suspended Electric Railway.
Above the Wupper River in Barmen.

of a single structural member, like an I-beam. The load is suspended from a frame hung below the two wheels. This is shown pictorially on an adjacent sketch.

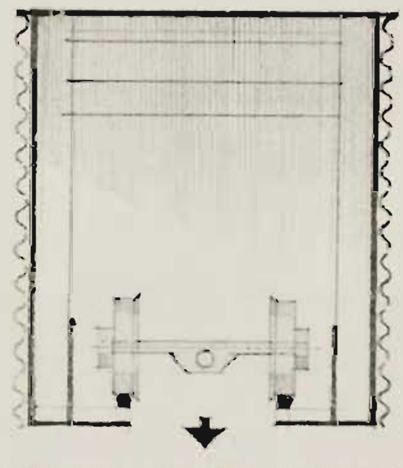
So, we also have a monorail with two bearing surfaces. Support of the bearing surfaces is a purely structural problem -- for example, two channels could replace the I-beam. In fact, this has been approached by some forms of barn door supports.

A look at our modern encyclopedic works such as Americana, Chambers and Standard, discloses that the "guided monorail" has taken many forms with any given number of rails. One type has a single bearing rail on the ground with a guiding rail vertically above to prevent the car from overturning. This is generally known as the Boynton system. Another has a single rail straddled by the car with a guide rail on the ground on either side. This is known as the Behr system. The latest development called Alweg, a running model of which was recently demonstrated near Cologne, Germany, has a bearing surface upon which the car runs and vertically-curved extensions below the frame of the car to which wheels, bearing on the sides of the structure supporting the running rail, are attached. This is an adaptation of a very early monorail described in the Encyclopedia Americana for 1951, about page 366, from which I quote in part.

"The downward vertical force consists of the weight of cars, trucks and loads. This weight is delivered to, and directly sustained by,



TYPICAL INDUSTRIAL
MONORAIL



SPLIT-RAIL MONORAIL ADAPTATION
OF INDUSTRIAL MONORAIL.

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two centrally disposed bearing rails laid with precision as to alignment and surface, and closely gauged to each other, so as to constitute practically a single support, while the vertical integrity or stability of the weight thus delivered to a central point is conserved when necessary by upward forces acting through the medium of dependent tension members, fitted with frictionless wheels bearing against inverted girders or rails; . . . . "

Now, we have a monorail with several bearing surfaces.

So, how do we define the modern monorail for mass rapid transit?

Again, I stress that the development of modern urban and suburban areas tends towards the elimination of all mass transportation devices from the surface of the streets. Certainly the lesson of the New York and Chicago elevated railroads indicates that the structure must have as few supports from the ground as possible, involve as small a blanketing of light and air as feasible and be located as high above the ground surface as is reasonable.

Certainly the "saddle-bag monorail" with all its cumbersome supporting structures would not be acceptable in or above city streets.

While some form of "guided monorail" might be applied to problems of transportation where a stable, continuous roadbed is not practical, it does not appear likely that the questionable advantages gained by guiding the car movement could overcome the objectionable added structure necessary to support the guiding rails.

The requirements can be met much better by any type of suspended railway design than by any other form of structure. Because support of the traveling cars is provided by a single integrated member we have the "mono" portion of its definition. The car wheels run on bearing surfaces analogous to rails providing conventional rail rapid transit, from which we have the remainder of the generic name "monorail".

But, if you do not like the terminology "Monorail" please remember that today it is fundamentally a suspended railway.

Brief Description of Suspended Monorail Systems

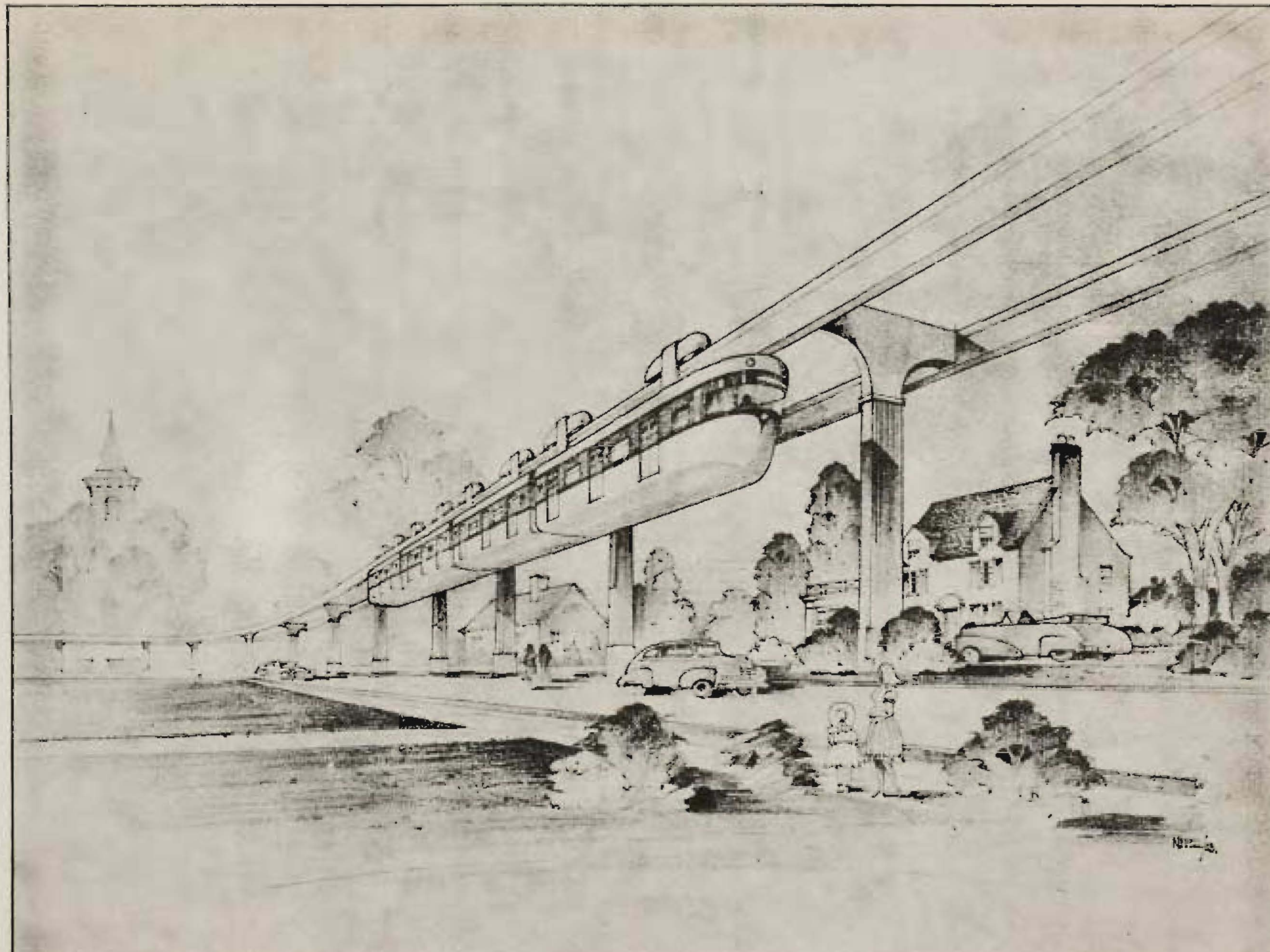
The modern concept of suspended monorail has progressed considerably beyond the original design now operating in Germany without the loss of any of the fundamental advantages. Many of the improvements have, naturally, been inspired by progress in structure and equipment designs of modern surface systems, for example by the PCC car.

The running surface is supported by a simple girder or member of sufficient strength to obviate the necessity of cross-bracing between the two rail supports of a double track line. Thus, the unsightly lattice-work effect of the Barmen-Elberfeld-Vohwinkel construction has been eliminated. The supporting structure may be an arch type bent as formerly, or where more suited to the conditions, a single column with suitable cantilever brackets. Thus, any semblance of a floor above the street has been entirely removed. If conditions dictate, such as a short section of subway in a rapid transit system, a simplified form of the girder could be easily supported from the roof of the subway construction permitting the operation of the suspended railway train through the subway.

The car body, truck and drive are logical adaptations of aircraft fuselage design practice. PCC car development and torque converter drive application to motor driven vehicles. Modern high strength, lightweight materials would be used to the fullest extent found to be economical.

All cars are equipped with modern high-speed motors and operated in multiple, including centralized door control from a single control point in each train. Motorizing all four axles per car not only permits the use of smaller, lighter motors, but, more important, permits outstanding schedule performance, by making the entire weight available for rapid acceleration and braking rates within permissible values of adhesion. This latter feature of design is of prime importance because rates of acceleration and deceleration, even more than maximum speed on level tangent track, determine the average or schedule speeds for runs up to one mile or even more in length. As top speed is increased, the consumption of power and cost of motor equipment increases even more rapidly, which indicates the selection of a top speed of sixty miles per hour. With the rates of acceleration and deceleration available, this top speed will usually result in an average speed of over forty miles per hour including time for station stops.

Because the center of gravity of the car is well below the point of support, any transverse oscillations tend to dampen out, although

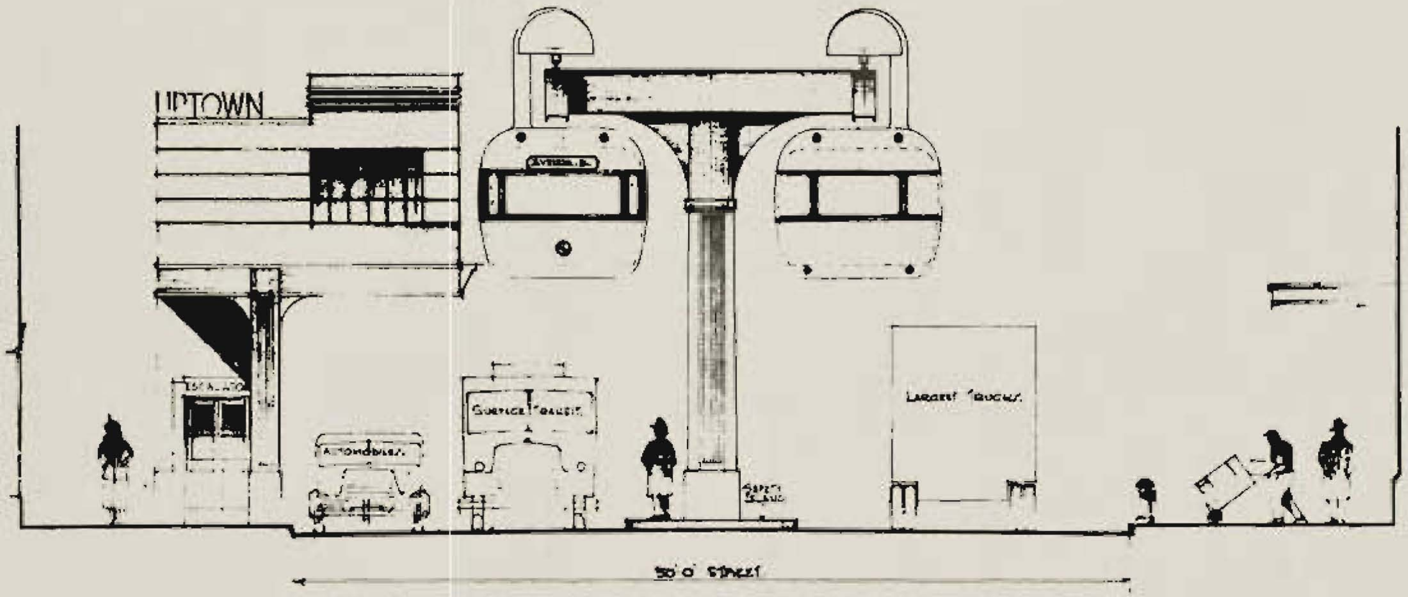


APPLICATION OF SUSPENDED MONORAIL SYSTEM. GIBBS & HILL INC - ENGINEERS - NEW YORK.

on curves outward swinging of the car as a unit is allowed nearly to a position of equilibrium between gravitational and centrifugal forces. This feature increases passenger comfort.

One typical system embodying much of the concept of the German prototype in Wuppertal was studied recently in an application of monorail to the rapid transit problems of a section of Los Angeles, Calif ornia.

It is interesting to note that the first costs developed in that study showed that a two direction rapid transit system approximately 45 miles long could be built for approximately $138,000,000 - including a section of subway construction about two miles in length - or at an average cost of a little over $3,000,000 per route mile including all appurtenances required for an operating system, plus 131 motored cars. Analyzing these figures, the two mile subway section would cost approximately $23,800,000, or an average of a little under $12,000,000 per route mile, not including electrical system or any rolling stock and the remainder of the classical monorail covering 43 miles would cost approximately $2,700,000 per route mile including all of the 131 cars and all appurtenances such as turn-arounds, yards, repair shops, signal and power supply facilities and everything else required to provide an operating system. It must be borne in mind, however, that the subway excavation required here is about 15% larger than the excavation required for the usual and well known subway. The complete aerial monorail system costs



SUSPENDED MONORAIL SYSTEM

DIAGRAM OF TYPICAL STREET

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NEW YORK

No Scale

701 X 4.

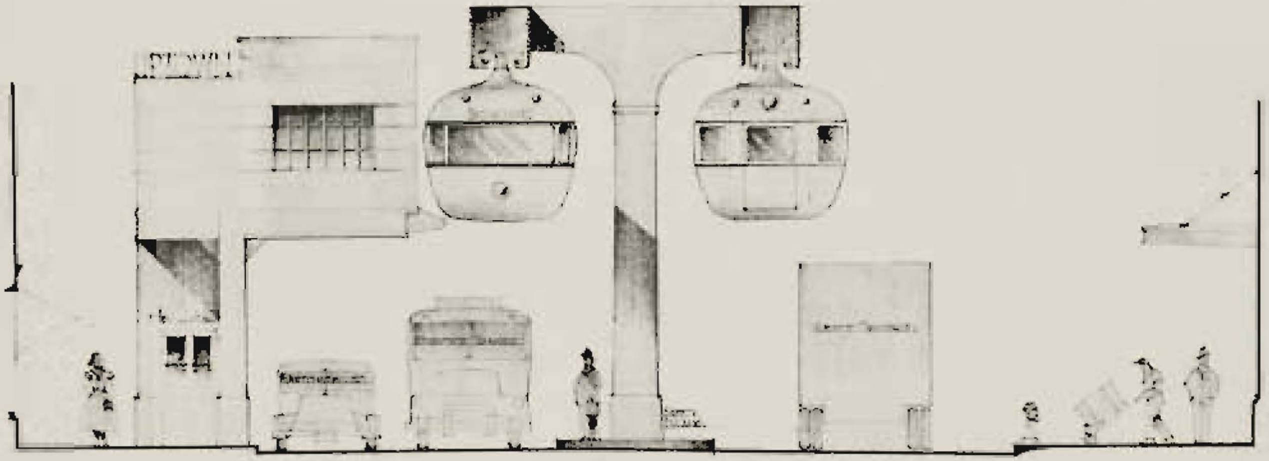
about 25 percent of that of the conventional subway.

The "classical" system of monorail was used in this particular report because the legislation providing for the study specifically required that a "monorail" be the subject of analysis and it was considered politically prudent in this case to comply with Mr. Webster's limited definition.

During all of this time, study of the use of various forms of monorail as one of the means of supplying mass rapid transit to traffic-strangled communities has continued. In some instances application of the single bearing surface, classical monorail system, has been found difficult due to local conditions and requirements, some of which are not generally encountered.

To meet these disadvantages of the single rail system, a leaf has been taken from the established practice of industrial monorail use in this country.

By merely splitting the two bearing surfaces on the bottom flange of the structural I-beam and supporting them by a revised but integrated structure and by suspending the load from a point between the wheels instead of from a frame around them, as shown on the sketch following page eight, the idea of another type of suspended railway is conceived. This type may be called, for lack of a better name, the split-rail type of suspended monorail, but better by its correct name, suspended railway. Adapting this arrangement to operation with loads and speeds of the magnitude required for mass rapid transit, results in a truck running



SUSPENDED MONORAIL SYSTEM
SPLIT-RAIL TYPE

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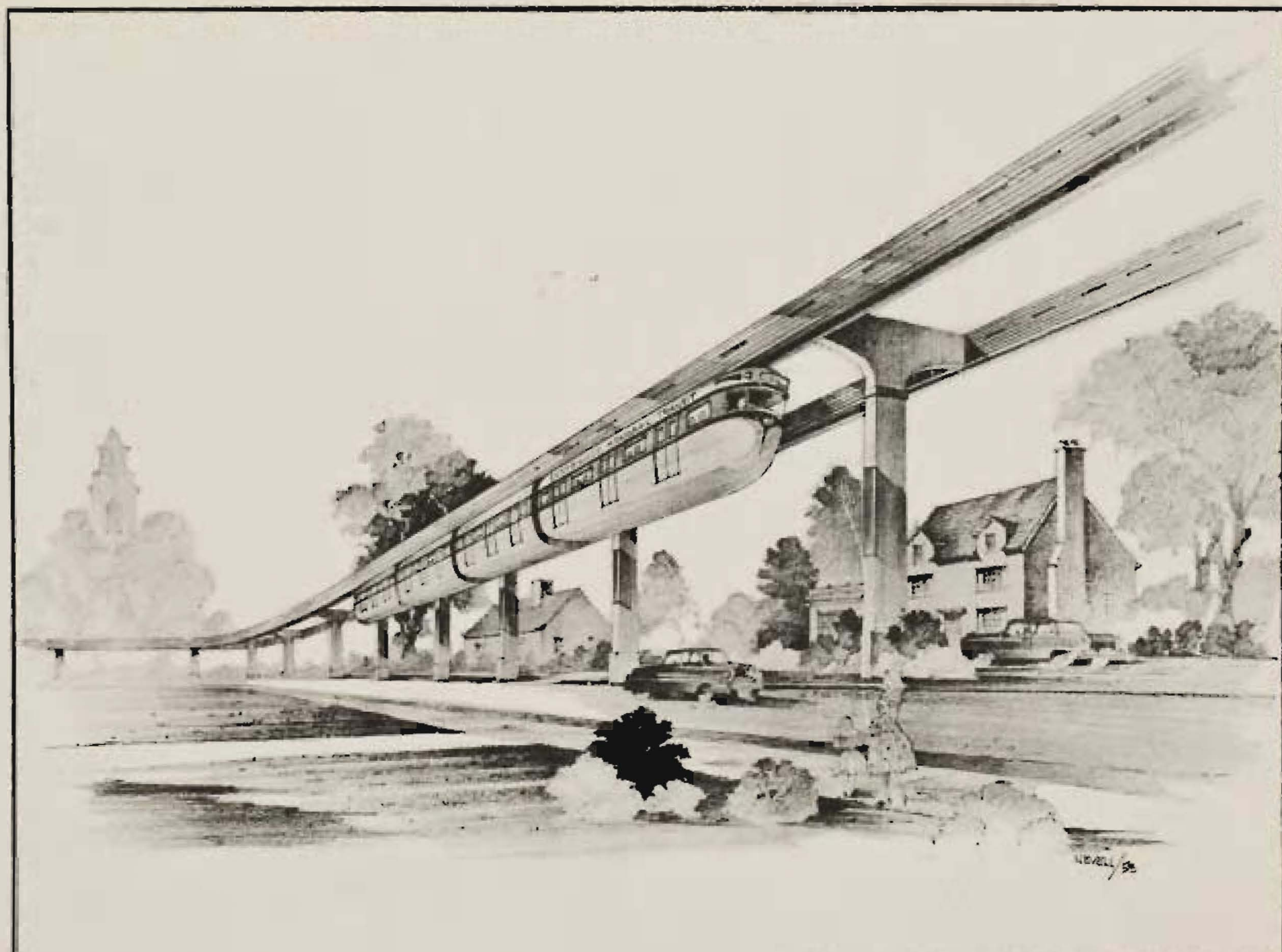
inside the integrated mono-structure on rails located with precision as to alignment and surface and closely gauged to each other so as to constitute practically a single support. It is necessary to suspend the car from the truck because the gauge of the rails becomes so narrow that a car running above the rails would be unstable, but by suspending the car from properly designed trucks a completely satisfactory railway results.

To accommodate the truck inside the split-rail girder of the suspended railway, that integrated structure becomes somewhat wider than the corresponding girder for the classical monorail. This added width is not considered significant because the girder is located about thirty feet above the street and the difference of thirty inches in width at that elevation could hardly result in any material increase in shadowing of the street. The split-rail girder would be almost wholly enclosed by a sound-deadening skin, with a streamlined effect, and with the top sections removable to facilitate emergency repair of the truck if such should become necessary along the route. Enclosing the girder will result in dry rail operation allowing higher rates of acceleration without the varying possibilities of wheel slippage.

One of the advantages of the split-rail system, having the two bearing surfaces, is the decreased possibility for derailment. On the classical monorail system a hook is provided to avoid serious damage in case of derailment, and, therefore, the classical monorail system is safe but the close clearances within the girder of the split-rail system make



APPLICATION OF SPLIT-RAIL SUSPENDED MONORAIL SYSTEM.

GIBBS & HILL INC - ENGINEERS - CONSTRUCTORS. NEW YORK. LOS ANGELES derailment practically impossible.

Because the split-rail system has the car suspended from the truck through a slot in the underside of the girder, there are no limitations to the means by which the integrated girder can be supported. This results in cleaner appearing structures where the requirements of application make it necessary to have supporting columns on different sides of the girder at various locations along the route.

In both systems the latest devices for providing safety by signaling and train control can be an integral part of the design.

The cars of both the classical monorail and the suspended railway are free to swing to compensate for centrifugal forces due to negotiating curves. However, in the case of the classical monorail there is no control on the amount of swing except the restraint afforded by adjoining cars. Because the truck in the split-rail suspended railway system always runs on an even keel and the car sway is centered about a point in the truck, it is possible to apply well-known methods of restraint to control the amount of swing of any individual car if that is found desirable.

Summary

There are at least two suspended transportation systems, properly called monorail, both of which meet the requirements of mass rapid transit in modern urban and suburban communities. There is little difference between the two in appearance of supporting structures, car design, electric drive, station arrangements and overall cost. The specific choice for any individual location will be indicated by a complete study of the problems of application in that particular case. The details of design of the system selected, based upon well-known underlying principles, must be developed in each instance.