TESTING OF THE SUSPENDED VEHICLE SYSTEM
SCALE MODEL

by

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INTRODUCTION

The Suspended Vehicle System is a relatively new concept in the field of high-speed mass transportation. This system can be readily adapted to large train type vehicles or small personal type vehicles or combinations of the two types. The concept has been proposed as a low cost alternative to high speed rail trains, tracked air cushion vehicles, and conventional monorail systems. The SVS[1] makes very efficient use of land and material in its construction and operation. Previous studies have indicated that the SVS deserves further consideration as a candidate for future intercity transportation systems [1][2].

The guideway structure for the SVS is a multi-plane cable stayed structure using steel cables to support a truss arrangement consisting of the two guideway rails and connecting struts. Stay cables are used both above and below the guideway truss and connect to slim towers at the top and near ground level. Because of the complexity of the structure, analytical analysis is both difficult and time consuming. In order to determine

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[1] SVS will be used instead of Suspended Vehicle System.

[2] Numbers in brackets designate References at the end of this paper.

the behavior of this structure, it was decided that a representative scale model of the SVS guideway should be built and tested. The main concerns in the testing of the scale model were: (1) that structural resonance does not occur and produce destructive deflections and fatigue and (2) that the frequencies and amplitudes of normal structural vibrations should be compatable with safety considerations and ride quality.

The SVS project in the Mechanical Engineering Department for the academic year 1972-73 was involved with the design, construction, instrumentation, and testing of the SVS scale model. The SVS research was sponsored by the Department of Transportation with the TRW Systems Group being the main contractor and with VPI&SU doing the guideway research under subcontract to TRW.

Two professors and three graduate students from the Mechanical Engineering Department were engaged in the SVS research. Professor Robert Whitelaw was the project director and Associate Professor Adorjan Szeless was involved in the model scaling, construction, and testing. Barry Stanley was a graduate research assistant working with the design, instrumentation, and testing of the SVS model and using this project as material for his Master of Science thesis. Graduate teaching assistants Donald

T. Vaughn and James T. Stettner worked part-time on the project as they were needed.

The SVS research at VPI&SU was multi-departmental and included members from the Engineering Science and Mechanics and the Civil Engineering departments. These participants developed theoretical models which were used to predict the behavior of the scale model. It was planned that the scale model would be used to validate the theoretical models and then the theoretical models would be scaled up to predict the behavior of a full size prototype.

The model produced was based on an overall geometric scale factor of 1:24. This scale factor gave a model that was large enough to be easily constructed and tested but small enough to be built along the south wall of the Turbomachinery Laboratory in the basement of Randolph Hall. It was desirable to have the model inside so that work could continue in any weather and to provide a protected and uniform environment for the instrumentation and model.

Five 250 ft spans of SVS guideway were simulated and this gave a model length of 52 ft, 1 in. with 125 in. between towers. The model was constructed on a 60 ft steel base that was rigidly attached to the floor of the laboratory. The propulsion device was placed at the west end of the room and brackets for the drive cables were attached to the walls at each end.

Scaled vehicles of ranging sizes and weights were used to test the response of the guideway to static and moving loads. The vehicles were moved along the guideway by a falling weight propulsion system that moved a cable loop to which the vehicles were attached. The system was designed to accelerate the model vehicles in the first two spans of the guideway mode., give a constant velocity across the middle or test span, and then brake the vehicles to a stop in the last two spans. No attempt was made to simulate the dynamic suspension system proposed by TRW for the prototype vehicle.

The test plan for the model was divided into three parts or "phases": Phase I--static testing, Phase II--free vibration or "plucking" tests, and Phase III--moving load tests with one or more model vehicles. The static tests were used to determine the behavior of the model under static loadings in the vertical and horizontal planes and to give a base for comparison of the dynamic test data. The free vibration tests indicated some of the natural frequencies of the structure and gave some indication of the degree of damping in the system. The moving load tests simulated the response of the prototype to actual load conditions and were considered the most important of the tests.

REVIEW OF THE LITERATURE

The idea of supporting a roadway by employing inclined stays is not new. Stayed bridge structures date back to 1784 when the German carpenter Löscher used timber stays to support a bridge deck from timber towers. Several stayed bridges were built in the early nineteenth century and many of them failed soon after construction. The failures can be attributed to the unsuitable materials used for stays (e.g., timber, chain, and iron bars), and to the difficulties engineers of the period had in understanding this type of structure and in designing effective stay attachments. The famous French engineer Navier investigated some of these failures and his comments condemned the stayed bridge concept. This led to concentration on the development of suspension type bridges for long spans and the almost total abandonment of the cable stayed bridge idea until recent times.[2]

In 1905, however, Arnodin engineered a cable stayed transportation device--the Pont Transbordeur, an aerial ferry across the harbor at Marseilles, France.[3] Although this appears to be one of the earlier uses of modern cable stayed techniques, little information was found concerning this device or its designer. The Pont Transbordeur (shown in Figure 1) bears more resemblance to the SVS concept than the later cable stayed bridges. The beam or rail was supported by cable stays from two towers on opposite sides of the harbor. The actual ferry was suspended a few yards above the harbor waters by cables attached to a dolly moving on the beam. The ends of the beam were stayed vertically to the ground at both ends.

The cable stayed bridge concept was rediscovered in 1938 by the German engineer Dischinger, and later put to wide scale use in the reconstruction of German bridges destroyed in World War II. Cable stayed bridges are gaining world wide acceptance but over a third of the existing bridges of this type are in Germany [2].

Although analysis techniques for cable stayed structures do exist, they are usually based on simplifying assumptions that allow standard computer analysis programs to be used [4]. The use of scale models is a standard method of supplementing and validating the theoretical analysis. Seim, Larsen, and Dang describe the testing of a scale model in their analysis of a cable stayed bridge crossing the lower arm of the San Francisco Bay [5].

The development of the SVS concept and the design recommendations for the prototype are contained in the

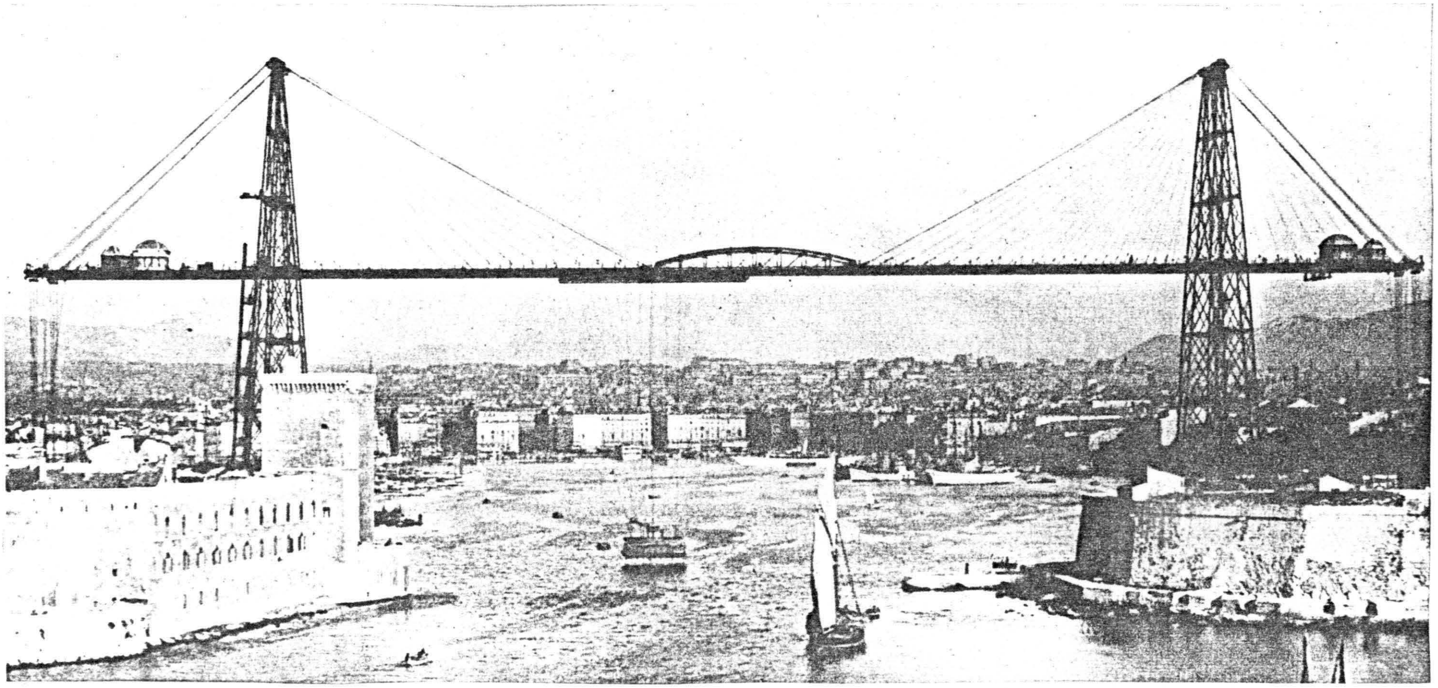


Figure 1 Pont Transbordeur, Marseilles, France

In 1905 Arnodin, a French engineer, used this cable stayed structure with a 787 ft span to support an aerial ferry that traveled across the city harbor. From Architecture of Bridges[3], by Elizabeth B. Kassler, page 82.

final report of the 1971-72 SVS-II project.[1] With regard to the guideway, this report details the optimization of the cable stayed concept and relates some preliminary observations regarding the dynamic behavior of the structure.

Both suspension and cable stayed guideway configurations were evaluated in a parametric analysis. These studies indicated that the cable stayed guideway was the minimum cost configuration and that its cost curve was essentially flat for span lengths between 150 ft and 350 ft. Various tower types were also studied and a single tapered column with cables fanning out from the top and from near the bottom was selected as being the most economical and esthetic choice.

The preliminary dynamic analysis predicted a fundamental resonant frequency of approximately three cycles per second for a cable stayed guideway with a span length of 250 ft and capable of carrying 300 ft, 90,000 lb trains. The analysis also predicted that the guideway would be stable under all design conditions and would have a dynamic amplification factor of about 1.9 at the design speed of 200 mph.

MODEL SCALING

The objective in the design of the SVS scale model was to create a structure that would behave in a manner similar to that of the proposed prototype. The ideal situation would be a model that would behave exactly the same as the prototype. This would require a full scale model with every parameter exactly the same as that of the prototype; in effect, the model would be the prototype.

The alternative was to build a scale model of the prototype and relate the various parameters by the use of scaling factors. The scaling factors for the SVS model were developed in the early stages of the project and are documented in Reference 6. Six "selected" scale factors were determined by material selection and by the prototype design constraints. These selected scale factors are given in Table 1.

Other scale factors were derived by combining groups of the selected scale factors. Table 2 gives a list of the important derived scale factors. Design parameters based on these scale factors are given in Table 3.

There was some difficulty in matching the horizontal and vertical scaling factors for deflection and natural frequency. Normal scaling methods resulted in

TABLE 1 Selected Scale Factors

$$\lambda_i = \frac{\text{Value of i for prototype}}{\text{Value of i for model}}$$

Linear scale (gross geometry)	λ_L	=	24
Modulus of elasticity, trackway (steel/brass)	λ_E	=	2.0
Modulus of elasticity, cables (bridge strand/music wire)	λ_{Ec}	=	0.8
Material density, trackway (steel/brass)	λ_ρ	=	0.92
Trackway cross sectional area	λ_A	=	102.4
Moments of inertia	λ_{Ix} & λ_{Iy}	=	617,300

TABLE 2 Derived Scale Factors

$$\lambda_i = \frac{\text{Value of i for prototype}}{\text{Value of i for model}}$$

Mass distribution of trackway	$\lambda_m = \lambda_A \lambda_\rho =$	94.2
Applied forces and weights	$\lambda_F = \lambda_m \lambda_L =$	2261
Moments of inertia (See Appendix A, Ref. 11) trackway truss, lateral	$_{IL} =$	617,300
Deflections: (desired value = 24)		
Of trackway between cables	$\lambda_\delta = \dfrac{\lambda_m \lambda_L^4}{\lambda_E \lambda_{Ix}} =$	25.3
Of a cable	$\lambda_\epsilon = \lambda_\delta =$	25.3
Of trackway truss, lateral	(See Appendix A, Reference 11) $\lambda_\beta =$	25.3
Gradients (desired = 1.0)	$\lambda_\varepsilon = \lambda_\delta / \lambda_L =$	1.05
Cable stress	$\lambda_\sigma = \dfrac{\lambda_{Ec} \lambda_\varepsilon}{\lambda_L} =$	0.843
Cable area	$_{Ac} = \lambda_F / \lambda_\sigma =$	2680
Natural frequencies:		
Of trackway	$\lambda_{\omega b} = \sqrt{\dfrac{\lambda_E \lambda_{Ix}}{\lambda_m \lambda_L^4}} = \lambda_\delta^{-\frac{1}{2}} =$	0.20
Of cables and truss	$\lambda_{\omega c} = \sqrt{\dfrac{\lambda_{Ac} \lambda_{Ec}}{\lambda_m \lambda_L^4}} =$	0.20
Of trackway truss, lateral (See Appendix A, Ref. 11)	$\lambda_{\omega L} =$	0.20
Vehicle velocity at $\lambda_{enc} = 1.0$	$\lambda_v = \lambda_L \lambda_{\omega c} =$	4.80

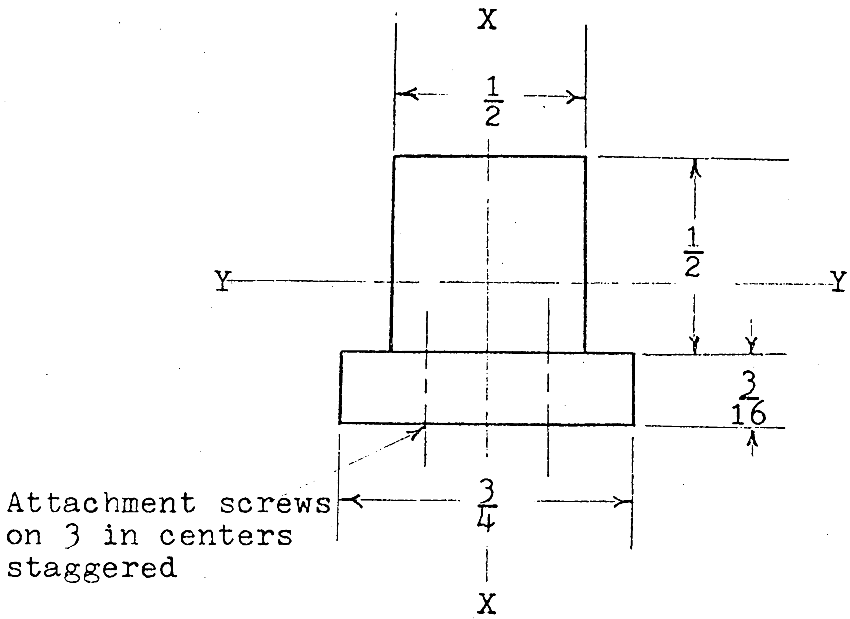
TABLE 3 Design Parameters Based on Scale Factors

Parameter	Prototype	Model
Car length	60 ft	30 in
Car weight	40,000 lb	17.7 lb
Typical midspan deflection	4.0 in	0.16 in
Cable stress	90,000 psi	107,000 psi
Cable sizes		
Upper #1		
area	0.846 in^2	0.000316 in^2
diameter		0.020 in
Upper #2		
area	1.24 in^2	0.000463 in^2
diameter		0.0242 in
Upper #3		
area	2.11 in^2	0.000787 in^2
diameter		0.031 in
Lower #1		
area	0.459 in^2	0.000171 in^2
diameter		0.014 in
Lower #2		
area	0.677 in^2	0.000253 in^2
diameter		0.018 in
Lower #3		
area	0.938 in^2	0.000350 in^2
diameter		0.020 in
Span length	250 ft	125 in
Tower height	70 ft	35 in
Velocity needed for $\lambda_{enc} = 1.0$	292 ft/sec	61.4 ft/sec

the scale factor for lateral deflections being over ten times that for vertical deflections. However, it was found that these factors could be closely matched by the use of properly selected diagonal brace wires. The considerations for the selection of these bracing wires are given in Appendix A of Reference 11.

Figure 2 shows the cross section selected for the "trackway" (or individual guideway rail). Although this cross section was not geometrically similar to the prototype cross section, it fit the scaling factors and provided an external flange for support of the model vehicles. Brass was selected as the most desirable material for this trackway section.

The SVS guideway model and model vehicles were fabricated in the VPI&SU Research Support Shop. The propulsion device was constructed in the Mechanical Engineering Shop. The shop drawings used in the fabrication and assembly of the SVS model are presented in Appendix A. Nomenclature used in this report relating to the SVS model is presented in Figures 3 and 4.



Material: Drawn brass rod, ASTM B-16 SAE-72

Properties of Selected Trackway Section

Section data		Model	Prototype	Scale factor
Area	in^2	0.3906	40.0	102.4
I_x	in^4	0.0162	10,000	617,300
I_y	in^4	0.0118	7450	617,300
Density	lb/ft^3	530	487	0.92
Weight distribution	lb/ft	1.40	135	92.2
Modulus of elasticity	lb/in^2	15×10^6	30×10^6	2.0

Figure 2

Model Trackway Cross Section

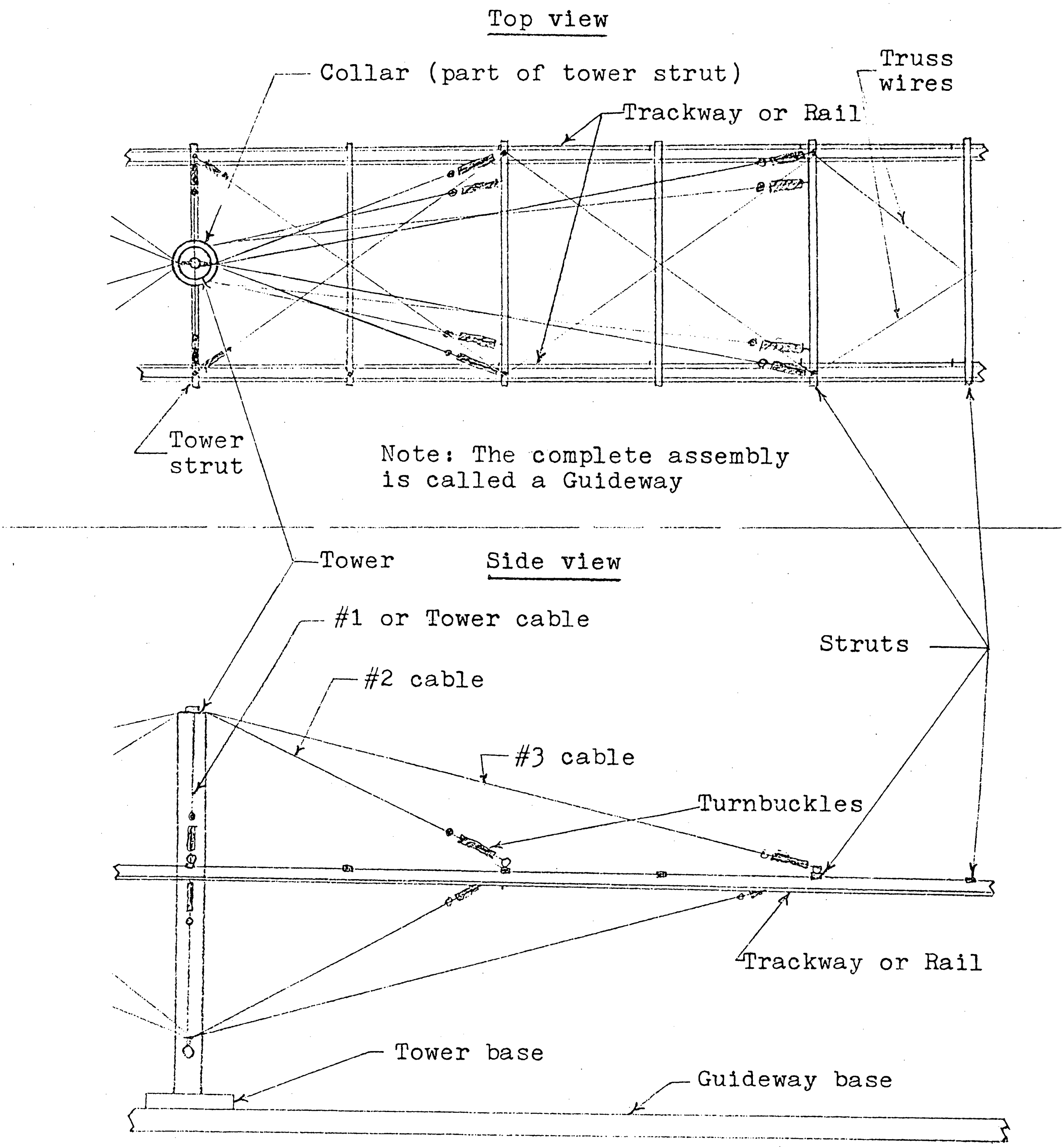
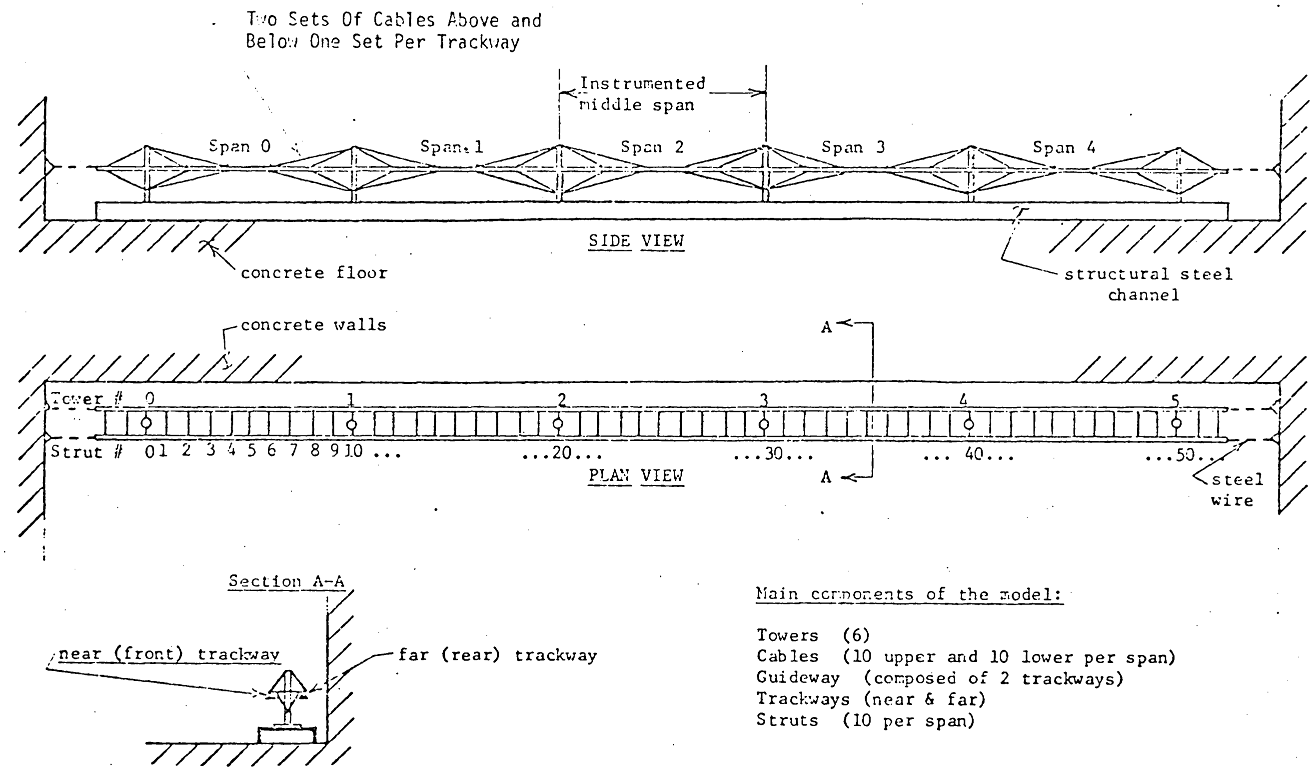


Figure 3 Nomenclature Relating to the SVS Model



Main components of the model:

Towers (6)
Cables (10 upper and 10 lower per span)
Guideway (composed of 2 trackways)
Trackways (near & far)
Struts (10 per span)

Figure 4 Additional Nomenclature Relating to the SVS Model

MODEL DESIGN

The "trackway" or rail was constructed from two extruded brass rods held together with #6 brass screws on 3 in. centers. The rods were obtained in 12 ft lengths and had to be joined by lap joints and brazing. The joints were staggered so that upper and lower joints did not fall at the same place. These joints were arranged so that none fell in the instrumented middle span. The details for this assembly are given in Figures A-1[3], A-2, and A-3.

Two-inch-diameter aluminum rods were used to simulate the towers for the guideway model. Threads were cut on one end of the rods and this end was screwed into a six inch diameter aluminum base plate. The base plate was held in place by four $\frac{1}{2}$ inch diameter bolts that threaded into tapped holes in the guideway base. The six towers were placed 125 in. apart on the 3 x 12 in. structural steel channel used as the guideway base. The steel channel was bolted to the floor using expansion bolts in the concrete floor. This part of the design is detailed in Figures A-4, A-5, and Figure 5 shows the base and towers during construction.

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[3]Figure numbers with the prefix "A" refer to figures in Appendix A. Shop Drawings Used During Construction of the SVS Model.

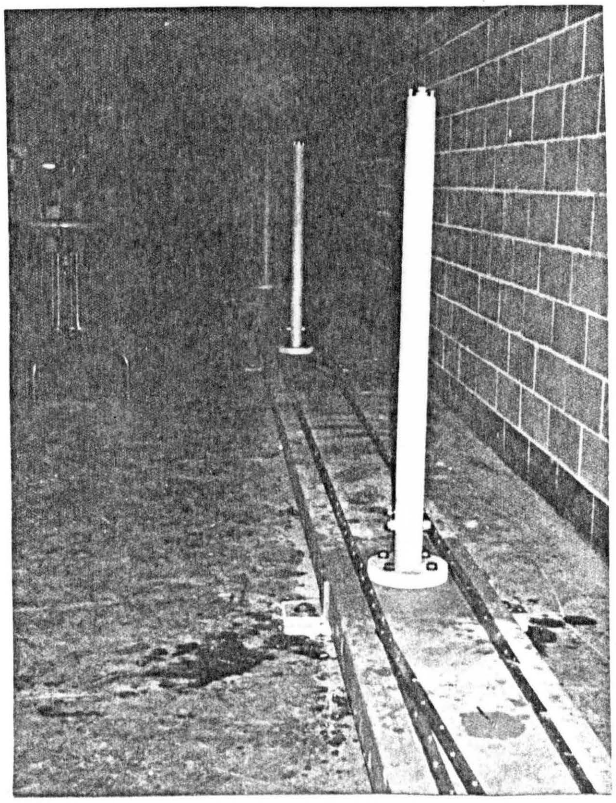


Figure 5

Tower and Base During Construction

The two trackways were held apart by $\frac{1}{2}$ x $\frac{1}{4}$ inch aluminum struts placed every $12\frac{1}{2}$ inches. The struts had 00.50 in slots which fitted the top of the trackway and locked the assembly into a fairly rigid truss. Special struts with an aluminum collar were used at tower locations. The collars encircled the towers and allowed the strut to move vertically but restrained motion in the horizontal plane. Steel music wire of 0.010 in diameter was used for diagonal bracing of the trackway-strut assembly. Figures A-7 and A-8 give the design details and Figure 6 shows the actual trackway-strut assembly before the bracing wires were applied.

The cables were simulated by steel music wire ranging from 0.012 to 0.031" inches in diameter. Stack washer arrangements were used to secure the wires at the tower top (Figure A-9) and tower bottom (Figure A-10). Turnbuckles were attached to the ends of the wires (Figure A-11) and provided a method of easy attaching and adjusting the simulated cables. Figure 7 shows the cable attachments at the towers and at the trackway.

The simulated vehicles were constructed from steel and aluminum plates selected to give the desired vehicle weight. Two vehicle sizes with three weight combinations were used in the test program. The weight of the

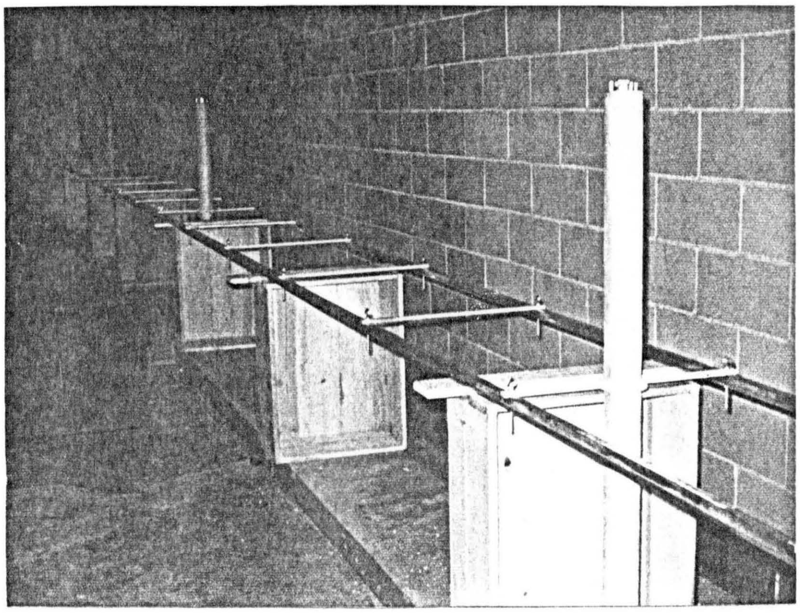


Figure 6

Trackway-Strut Assembly

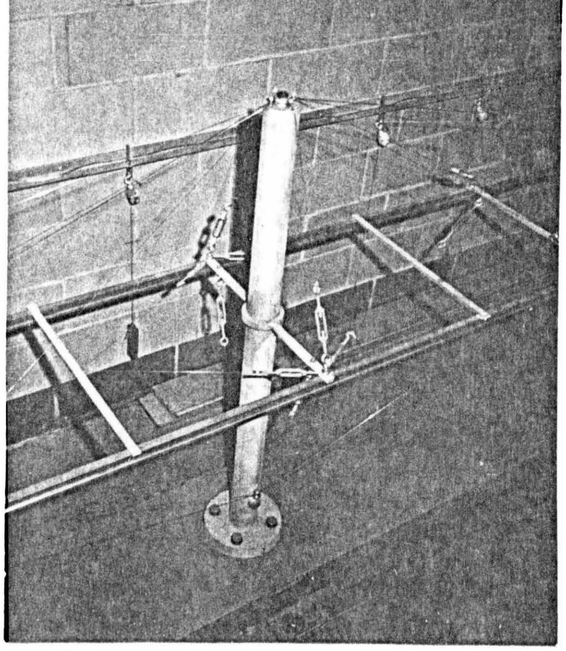


Figure 7
Cable Attachments at Tower
and Trackway

smaller vehicle was changed by substituting aluminum center plates for the original steel plates.

Steel axles (Figure A-12) were machined from bar stock and small flanged instrument bearings (SKF type SC16242Z) were used as wheels. Eight bearings were used for each car. The four upper bearings were used for support wheels and the four lower bearings were guides to prevent the vehicle from jumping up and hitting the struts. Figure A-13 shows the axle-wheel assembly as it rides on the trackway. Due to difficulties in obtaining a sufficient quantity of the flanged bearings, unflanged bearings of a similar type (SKF SB16242Z) were used for the lower guide wheels. The small bearings were subject to frequent failure because of the relatively high loading and the high rotational speed. (Assuming no slipage the bearings were turning over 27,000 RPM at a vehicle speed of 45 ft/sec.) The supply of spare bearings was adequate and replacement was rather easy, so these failures did not affect the test program significantly.

The lightest of the three vehicle types, called a "single bogey," weighed 9.1 lb and corresponded to an actual vehicle weight of 20,577 lb. It was 6 in. long and 5 in. high and its wheelbase of 4 in. corresponded to a full scale value of 8 ft. Two model vehicles of this type were constructed and used in the moving load tests as moving concentrated loads.

The aluminum center plates of the single bogey were replaced with steel plates to form the "heavy bogey" used in some of the tests. The heavy bogey weighed 13.25 lb and represented a full scale load of 29,958 lb. This vehicle had the same overall dimensions as the single bogey.

Two longer vehicles, called single cars, were constructed with a weight of 17.9 lb, an overall length of 30 in, and a wheelbase of 29 in. Originally this vehicle was to use eight wheels in a rigid two bogey arrangement. During the preliminary testing, however, it was found that the deflection of the trackway caused the bearings to bind and break. The solution to this problem was to remove the inner four support bearings and let the car ride on only four bearings. The alternative was to redesign the vehicle so that the two bogeys were individually movable. This alternative was rejected as requiring too much time at a critical period in the test program.

This vehicle simulated an actual car of the size proposed for a prototype and corresponded to a full scale weight of 44,672 lb. The single cars were used to simulate moving vehicle load conditions on either one or both trackways. Table 4 summarizes the design parameters for the three vehicle types, Figure 8 shows the three vehicles, and Figures A-14 and A-15 give assembly details.

The propulsion system for the vehicles consisted of a cable loop driven by falling weights through a chain and sprocket. Acceleration of the vehicle occurred in the first two spans of the model, constant speed was maintained across the middle span, and the braking occurred between the end of the test span and the end of the guideway.

The vehicles were connected to the drive cable with turnbuckles and this allowed the tensioning of the cable loop as necessary. The loop arrangement made it possible to propel either one vehicle in one direction or two vehicles in opposite directions without major changes. Steel spacer bars (Figure A-16) were used to replace the missing vehicle in the single vehicle tests and to compensate for the differences in vehicle length.

At each end of the guideway model four idler pulleys were used to return the cable and at the west end of the model the cable also traveled over the 12 in diameter drive pulley. A one inch diameter shaft connected the drive pulley to the drive sprocket. The pulley-sprocket combination gave a ratio of vehicle travel to falling

TABLE 4 Design Parameters for Model Vehicles

Vehicle	Overall length	Wheelbase	Weight	Weight with 1/16 in cable	Weight with 1/8 in cable	Weight with 1/8 in cable & spacer bar
	in	in	lb	lb	lb	lb
Single bogey	6	4	9.10	9.33	10.02	11.7
Heavy bogey	6	4	13.25	***	***	15.85
Single car	30	29	17.90	18.13	18.85	***

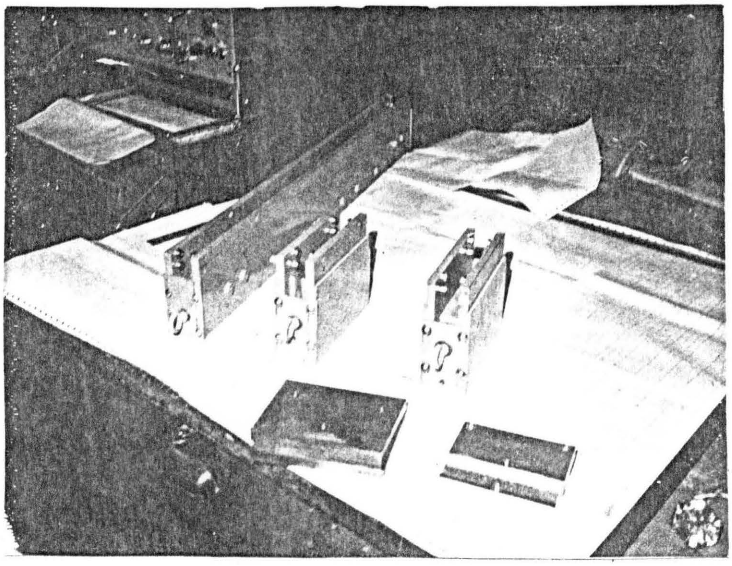


Figure 8

Model Vehicles Used in SVS Testing

On the left is the 17.9 lb single car, in the center is the 13.25 lb heavy bogie, and on the right is the 9.1 lb single bogie. Also shown in the foreground are the center plates for the two bogie configurations.

weight travel of 4.36:1. A roller chain ran around a set of idler sprockets, and vertically down to the weights. Figure 9 shows a schematic diagram of the propulsion system and Figure 10 presents a photograph of the drive pulley and sprocket, idler pulleys, and mounting framework. It was determined that an acceleration of 3.238 g was needed to bring the vehicle up to the design speed of 61.6 ft/sec, and that a deceleration of the same value was needed to stop the vehicle in the required distance. Considering the drive ratio of 4.36:1 and the weight of two of the single cars, it was calculated that an accelerating weight of 500 lb was needed. Figures 11 and 12 give details of these calculations.

A steel basket was fabricated to hold the acceleration weights and was attached to the end of the roller chain. A smaller container was used to hold the "constant speed" weights and was attached farther up the roller chain at a distance corresponding to the travel across the test span (155 x 1/4.36 in.). The other end of the roller chain was also connected to the basket. The two containers are shown in Figure 13. In this photograph one end of the roller chain has been replaced with a section of cable--after the chain kinked and broke near the basket attachment point.

In operation, the constant speed weight was raised

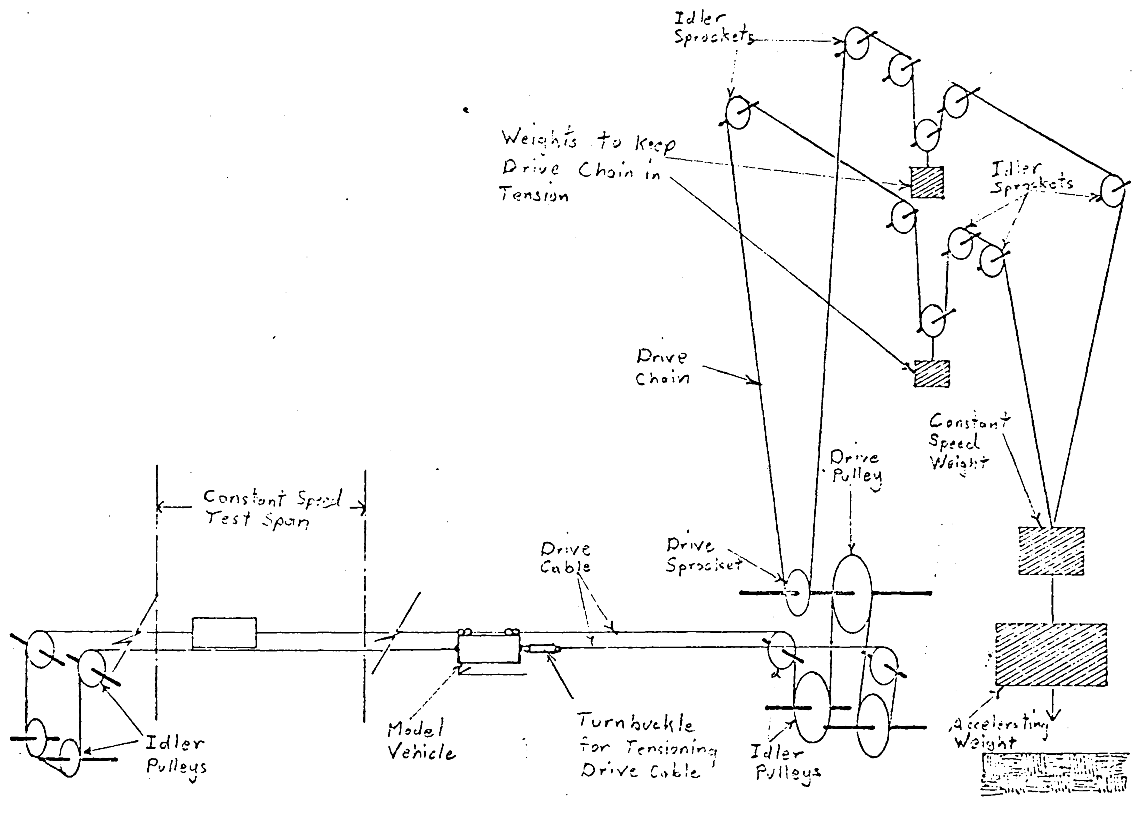


Figure 9 Diagram of Propulsion System for SVS Model

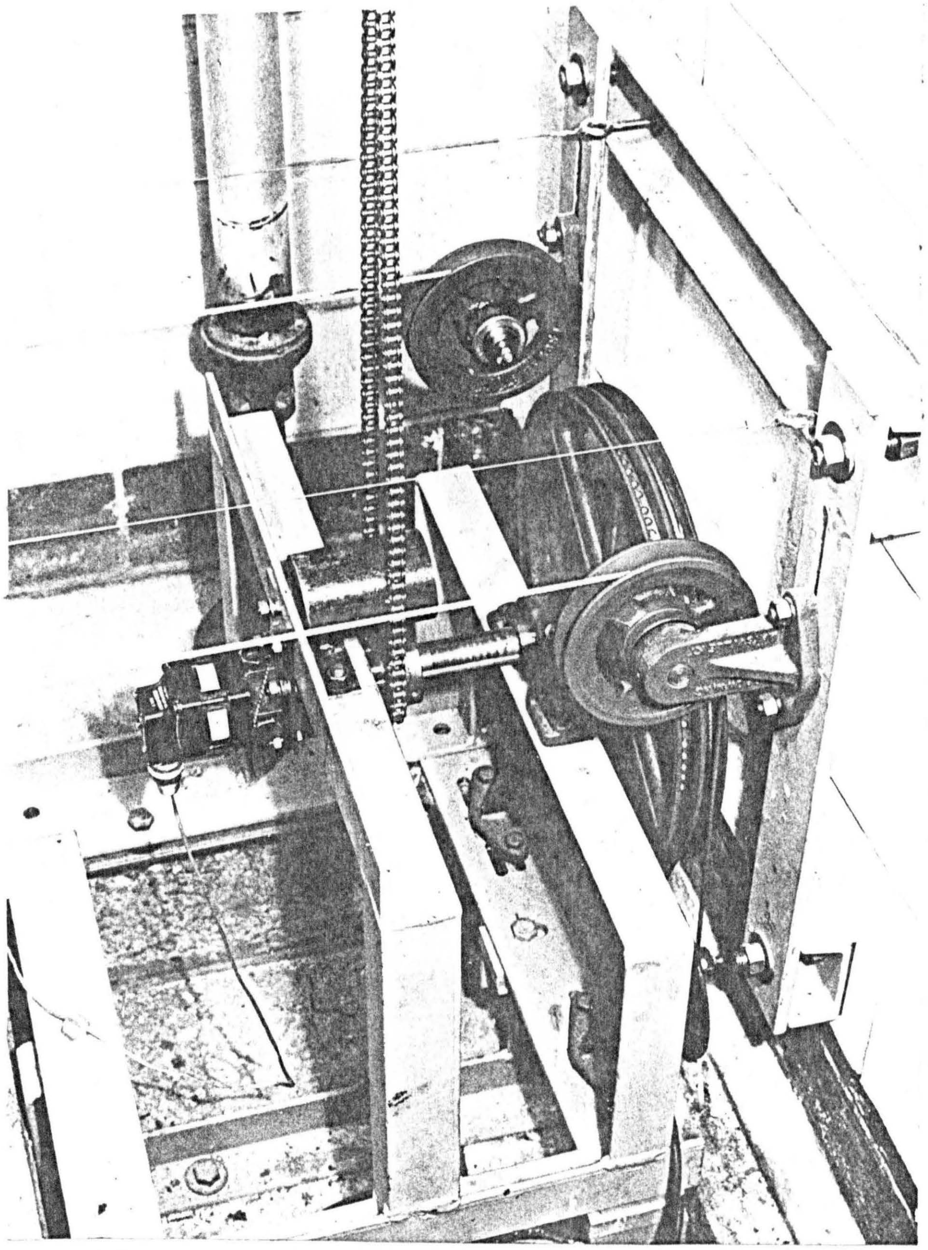
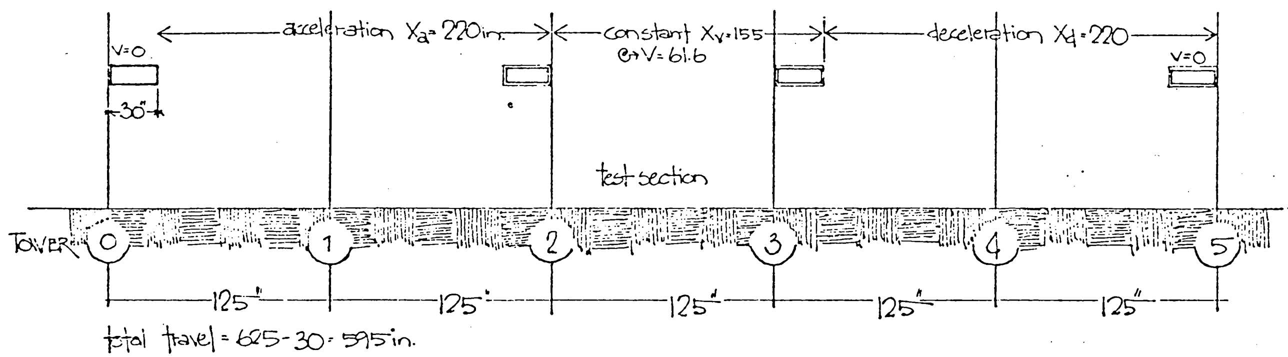


Figure 10

Drive Pulley and Sprocket Arrangement



$$\text{Acceleration and deceleration} = \frac{V^2}{2X_a} = 104 \text{ ft/sec}^2 = \underline{3.238}$$

$$\text{Ratio of car travel/weight travel: } \frac{\text{Pullev dia}}{\text{Sprocket dia}} = \frac{12.0}{2.75} = 4.36$$

Displacement of falling weights:

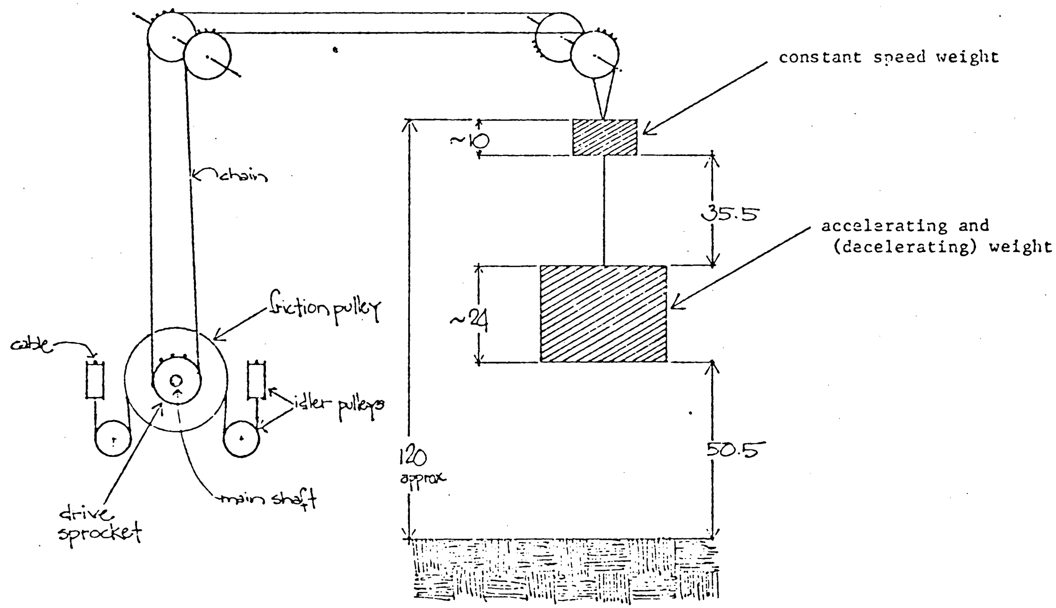
$$\text{Y acceleration} = \frac{220}{4.36} = 50.5 \text{ in}$$

$$= 86 \text{ in down}$$

$$\text{Y constant speed} = \frac{155}{4.36} = 35.5 \text{ in}$$

$$\text{Y deceleration} = 50.5 \text{ in} = 50.5 \text{ in up}$$

Figure 11 Design Considerations for SVS Model Propulsion System



2 cars of 17.7 lbs each = 35.4 lbs

force needed to accelerate at 3.23g = (35.4)(3.23) = 114.5 lbs
weight needed at 4.36 drive ratio = (114.5)(4.36) = 500 lbs

Figure 12 Design Considerations for SVS Model Propulsion System

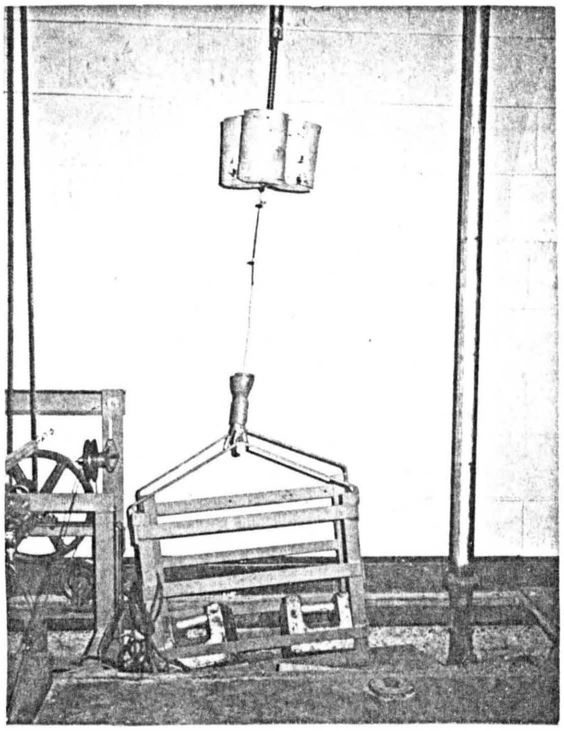


Figure 13

Weight Basket and Container

At the top of the photograph is the container for the constant speed weights and at the bottom is the basket for the accelerating weights.

until all slack was removed between the two weights as the vehicle being tested was positioned at the start of the test span. An electric hoist was then used to raise the weighted basket as the vehicle was pulled to the starting position at the end of the guideway. A hook held the vehicle and weights in place while the hoist was released. When the hook was released, the large weighted basket fell and accelerated the vehicle until the basket hit the floor. The smaller weight continued to fall until it rested on the basket and maintained constant speed across the test span as it fell. At this point the other end of the roller chain became taut and began to exert a braking force on the cable loop. The design called for the two weights to be lifted as the vehicles slowed, but in practice the weights were lifted very little by the decelerating vehicle.

The maximum velocity obtained with this arrangement was 46 ft/sec using 652 lb in the basket, 63 lb in the constant speed container, and propelling only one of the 9.1 lb single bogeys. It was felt that this velocity was approaching the practical limit for this propulsion method and that larger weights would produce more cable slippage on the drive pulley rather than higher velocities.

Figures A-17 through A-30 give additional design details of the SVS guideway model.

INSTRUMENTATION

The third or middle span of the SVS model was instrumented to measure and record deflections and frequencies of vibration. The middle span was selected because it more closely simulated a section of guideway in a semi-infinite system. In the dynamic (moving load) tests the first two spans were needed to accelerate the model vehicle up to the test speed and the last two spans were needed to brake the model to a stop.

Linear variable differential transformers (LVDTs) were selected for the measurement of displacement. LVDTs were found to be the most desirable transducers because they were relatively inexpensive, provided good sensitivity and linearity, and were easily compatible with the available recorders. Two Schavitz model E300 and ten model E200 LVDTs were purchased for the project and eventually all were installed and used.

Other alternatives considered for displacement measurement included a laser-photodiode arrangement and a photoresistive device. The photodiode array consisted of 64 photodiodes on 0.002 in. centers. This array was to be attached to the trackway and illuminated by a fixed laser beam. As the trackway deflected under load, the position of the laser beam on the array would change and different photodiodes would be activated. This signal could be detected and interpreted as trackway deflection. This alternative required a separate laser and photodiode array for each test point and, therefore, was rejected as being too expensive.

The second alternative was a semiconductor photoresistive device that gave a change in output as the location of an incident light beam changed. Although this device was much cheaper than the photodiode array and used an ordinary light source instead of a laser, it was also rejected as being more complicated and costly than the LVDT system.

The LVDTs were supported in wooden split blocks and attached to a steel cantilever bolted to the wall behind the model. This method of mounting the transducers prevented guideway vibrations from being transmitted to the LVDT body. The LVDT cores were attached to the guideway by means of light weight aluminum push rods approximately 12 inches long. This arrangement did not add appreciably to the mass of the guideway and allowed movement normal to the transducer axis without creating a noticeable error. If the transducers had been mounted closer to the trackway rails, the vertical transducers would have had to be horizontally movable and the horizontal transducers would have had to be vertically movable to allow free motion of the guideway.

The cantilever mounting beams were easily movable and transducer locations could be changed quickly. A symmetrical arrangement of LVDTs was used in the earlier static tests of Phase I. Symmetric behavior of the structure was noted and the instrumentation was changed to monitor a larger number of points in one-half of the test span. Figure 14 shows a photograph of the earlier symmetric arrangement and Figure 15 shows the unsymmetric grouping used in the later testing. Tables 5 and 6 give details of transducer locations and types.

The LVDTs were calibrated by applying a static load to the guideway, measuring the deflections, and adjusting the recorder sensitivity to a convenient value. A dial indicator was attached to the cantilever mounting beam and measured the displacement of the LVDT cores. Weights were placed on the guideway to give a convenient deflection, e.g. 0.080 in., and the recorder sensitivity was adjusted to give a convenient scale deflection, e.g. 1 cm. In this example the calibration of the LVDT would be 1cm = 0.080 in. This procedure was repeated for each LVDT used and the calibration was rechecked before each major test.

Strain gages were purchased, installed, and used in some of the earlier testing and checkout. Later, however, it was decided that the LVDT outputs were more

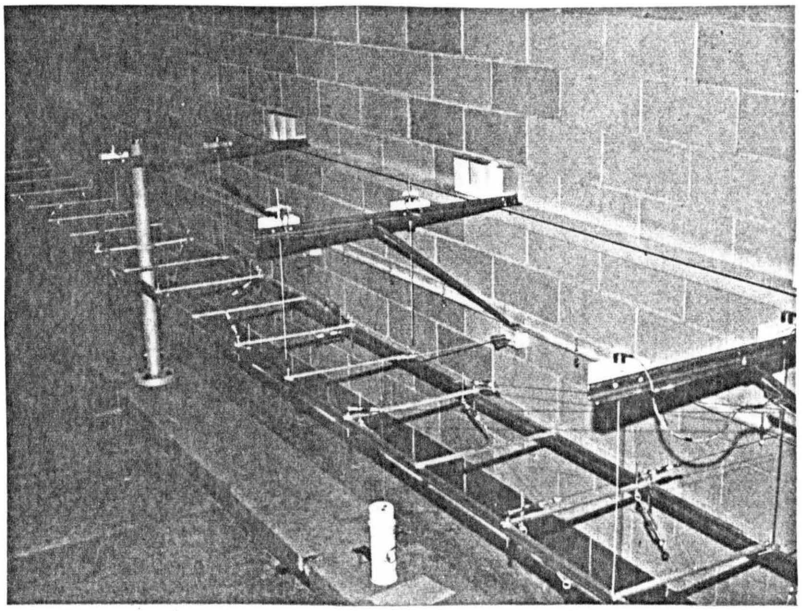


Figure 14 Symmetrical Instrumentation Grouping Used in Earlier Testing

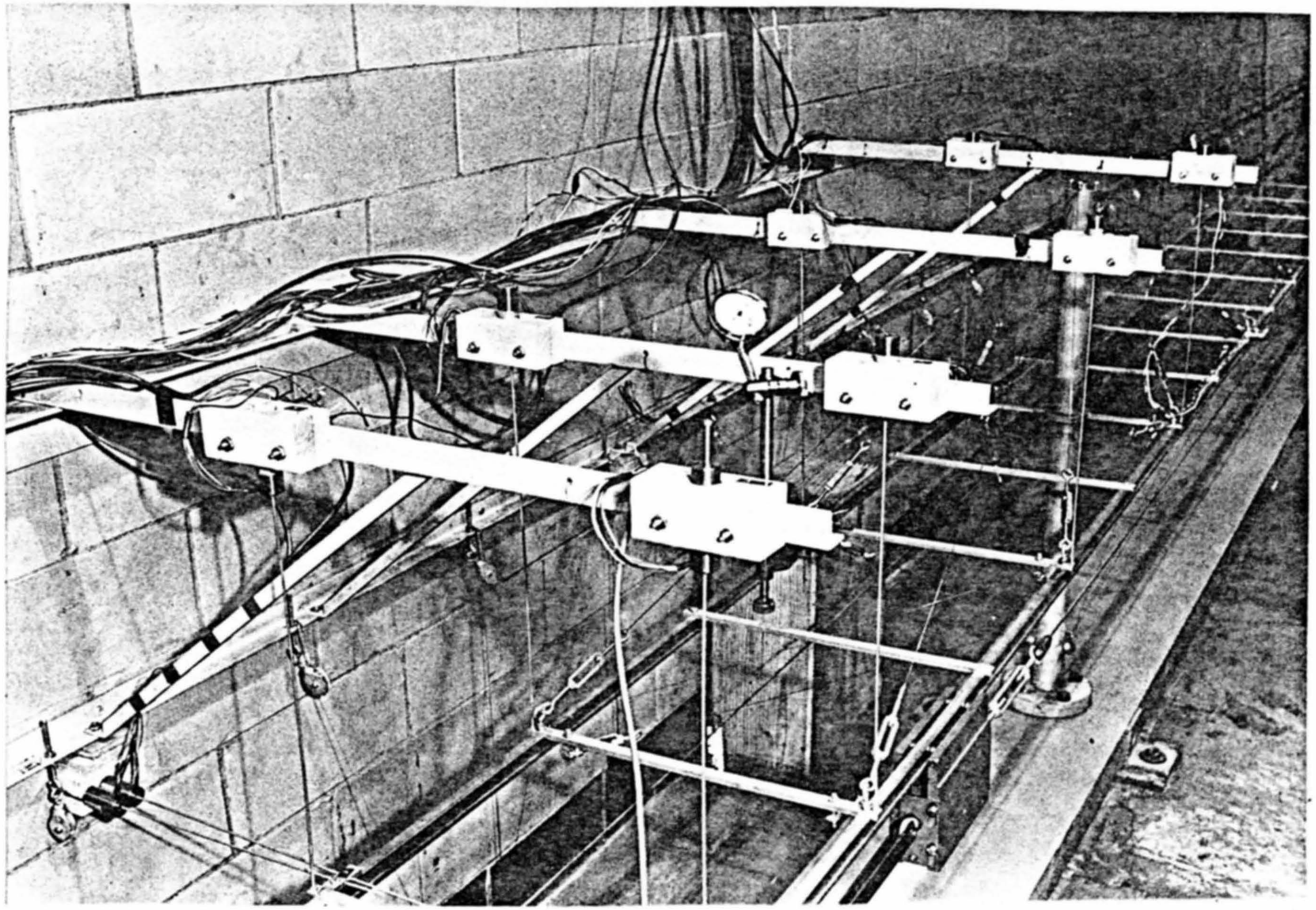


Figure 15 Unsymmetrical Instrumentation Grouping Used in Later Testing

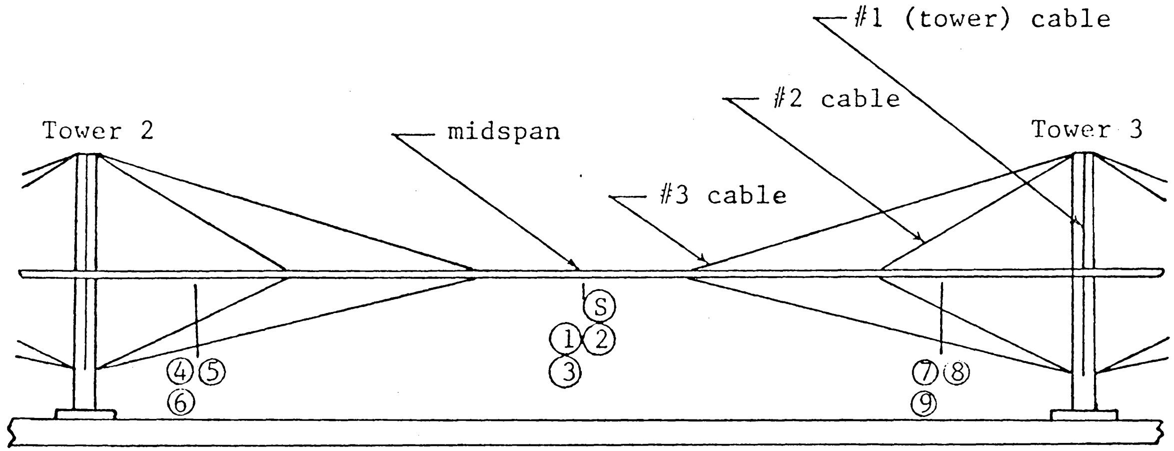


TABLE 5 Transducer Locations Used in Phase I, Tests I* and V

Transducer Number	Type	Transducer Location	Orientation
1	LVDT	Midspan, Near Trackway	Vertical
2	LVDT	Midspan, Far Trackway	Vertical
3	LVDT	Midspan, Far Trackway	Horizontal
4	LVDT	Strut 21, Near Trackway	Vertical
5	LVDT	Strut 21, Far Trackway	Vertical
6	LVDT	Strut 21, Far Trackway	Horizontal
7	LVDT	Strut 29, Near Trackway	Vertical
8	LVDT	Strut 29, Far Trackway	Vertical
9	LVDT	Strut 29, Far Trackway	Horizontal
S	Strain Gage	Midspan, Near Trackway	Vertical

*Runs 1 and 2

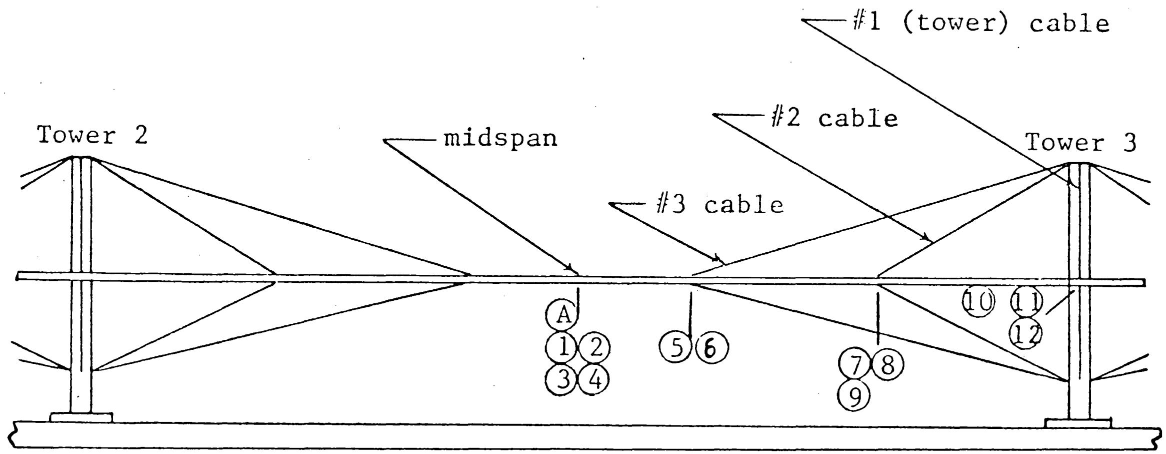


TABLE 6 Transducer Locations for All Tests Not Mentioned in Table 5

Transducer Number	Type	Transducer Location	Orientation
1	LVDT	Midspan, Near Trackway	Vertical
2	LVDT	Midspan, Far Trackway	Vertical
3	LVDT	Midspan, Far Trackway	Horizontal
4	LVDT	Midspan, Near Trackway	Horizontal
5	LVDT	#3 Cable, Near Trackway	Vertical
6	LVDT	#3 Cable, Far Trackway	Vertical
7	LVDT	#2 Cable, Near Trackway	Vertical
8	LVDT	#2 Cable, Far Trackway	Vertical

Continued on next page

TABLE 6 (continued)

Transducer Locations for All Tests Not Mentioned in Table 5

Transducer Number	Type	Transducer Location	Orientation
9	LVDT	#2 Cable, Far Trackway	Horizontal
10	LVDT	Tower, Near Trackway	Vertical
11	LVDT	Tower, Far Trackway	Vertical
12	LVDT	Tower, Far Trackway	Horizontal
A	Accelerometer	Midspan, Near Trackway	Vertical or Horizontal

important and the channels used for strain gages were switched to LVDTs. The interest in the testing of the SVS model was in deflections and frequencies rather than stresses and strains, therefore, the LVDT outputs were more suited to the test objectives.

Ten recorder channels were available in the form of two Sanborn 154-100-B four-channel recorders and one Sanborn 152-100-B two-channel recorder. These recorders used a heated pen and heat-sensitive paper to record data vs time up to a linear chart speed of 100 mm/sec. Also available for use with these recorders were ten Sanborn carrier preamplifiers and one Sanborn AC-DC preamplifier. More recorders were available but it was felt that additional channels would create additional instrumentation problems and paperwork without adding significantly to the usefulness of actual data.

The LVDTs (and strain gages when used) were wired directly to the carrier preamplifiers according to the manufacturer's instructions.[7] The carrier preamplifiers provided an excitation of approximately 4.5 volts at 2400 Hz to the LVDTs and conditioned the returning signal for the recorder. The excitation frequency of 2400 Hz gave a transducer frequency response of approximately 240 Hz which was satisfactory for this application.[8]

Four conductor electrical cable with shielded pairs was used for the connections between the LVDTs and the carrier preamplifiers. The shielded pairs were needed to reduce background noise and inductive coupling between the signal and the excitation leads.

Initally, the LVDT-carrier preamplifier combination caused erratic readings. Circuit checks indicated that the large deflections in the model were overloading the carrier preamplifiers. The signal from the LVDT was about one volt, whereas, the carrier preamplifier was designed for strain gage operation with signals of the order of millivolts. After the problem had been diagnosed as "sensitivity too great", a voltage divider consisting of two resistors was added to the signal circuit and the signal level was reduced to a value the carrier preamplifiers could tolerate. Figure 16 shows the circuit diagram for the LVDT hookups. The voltage divider is shown as resistors R1 and R2 in this diagram.

The limiting factor in the frequency response of the instrumentation system appeared to be the response of the Sanborn recorders. Figure 17 gives the manufacturer's data for frequency response.[9] The instrumentation system used was assumed to have less than critical

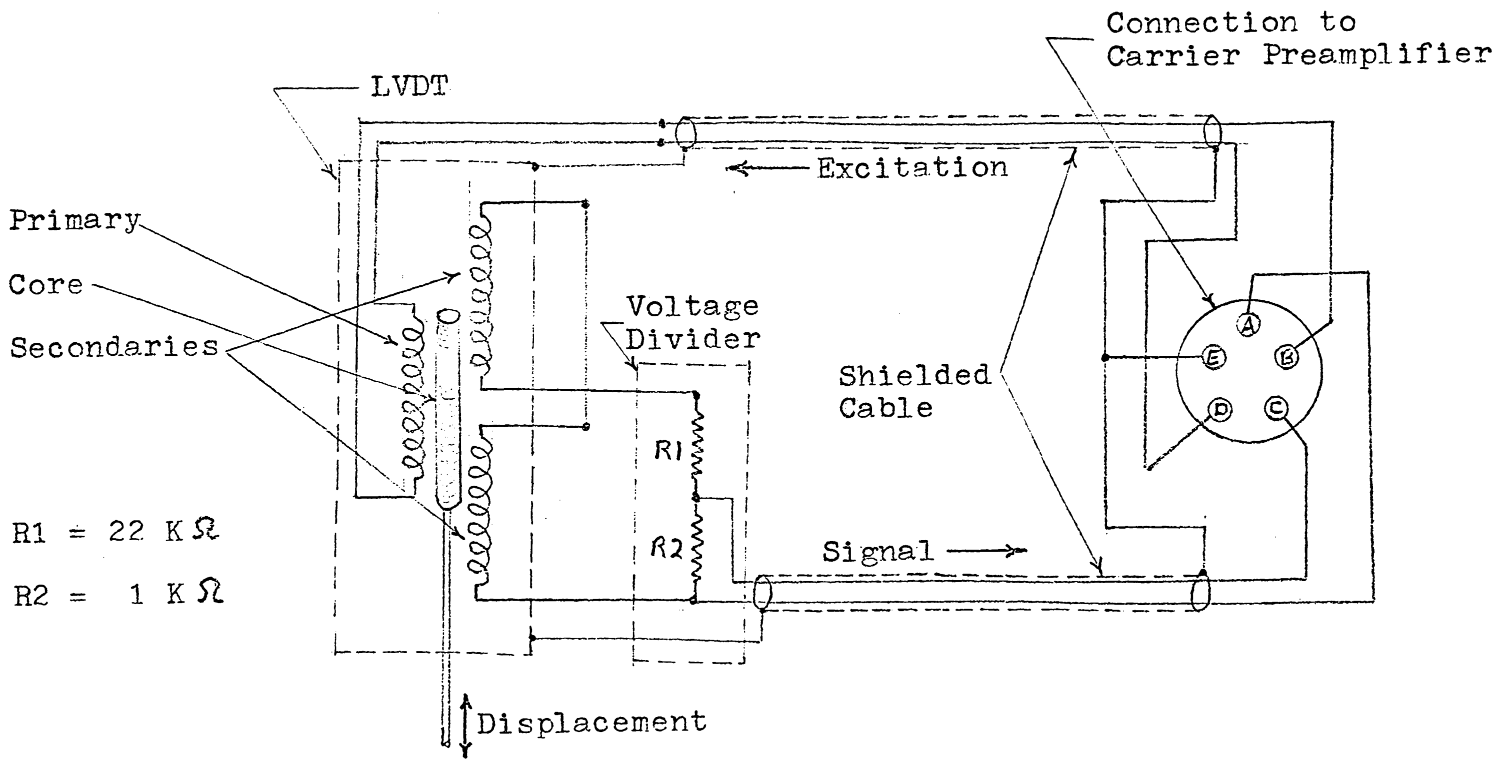
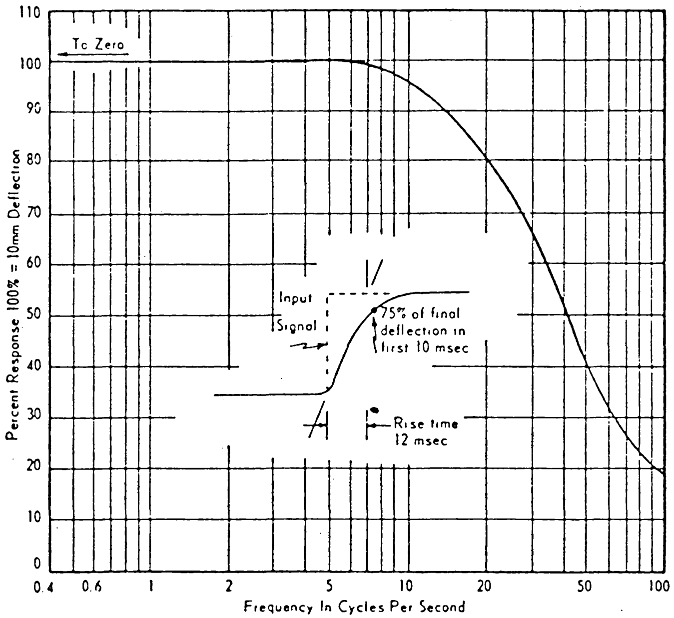
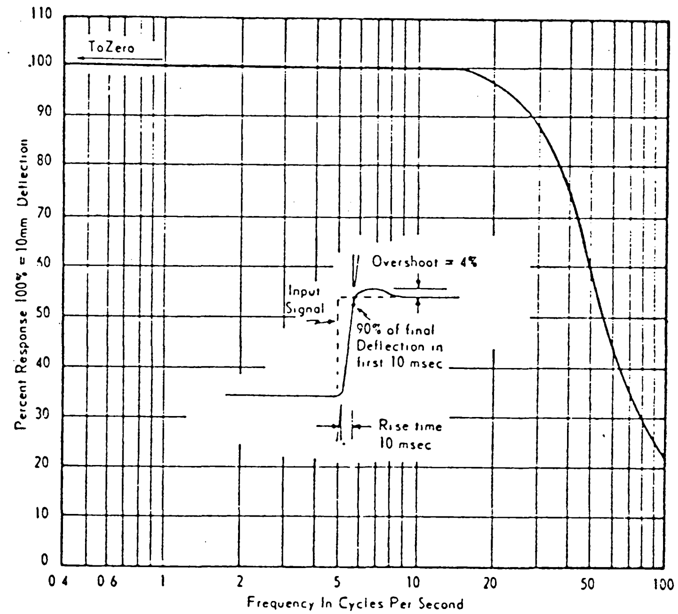


Figure 16 Circuit Diagram for LVDT Hookups



Sanborn 150 Series Recorder Galvanometer Characteristics at Critical Damping.



Sanborn 150 Series Recorder Galvanometer Characteristics at 71% of Critical Damping.

Figure 17 Manufacturer's Data For Frequency Response damping so that the plot for 71% of critical damping would be more applicable to this system. The response was flat up to approximately 15 Hz, but at 50 Hz it was reduced to 60% of input and at 100 Hz it was down to 23% of input. In all cases the fundamental frequencies appeared to be in the region of flat response. For the higher frequencies, however, it should be noted that the recorder output was attenuated.

The Sanborn recorders had a provision for a marker signal on a fifth trace (third on the two channel recorder) on the output paper. This marker signal was activated by the closing of a panel switch or a remote switch that could be attached to a panel mounted receptacle. For the moving load tests it was desirable to have this marker signal operational when the vehicle was in the test span. To accomplish this the three recorders were connected in parallel at the panel receptacle. The parallel leads were then connected in series with two switches mounted on the trackway and activated by the moving vehicle. The first switch, initially open, was closed as the vehicle passed and completed the marker circuit. The second switch was initially closed and was opened as the vehicle passed, thus breaking the marker circuit. Figure 16 gives a diagram of the marker signal circuit. Adequate switches could not be found in the

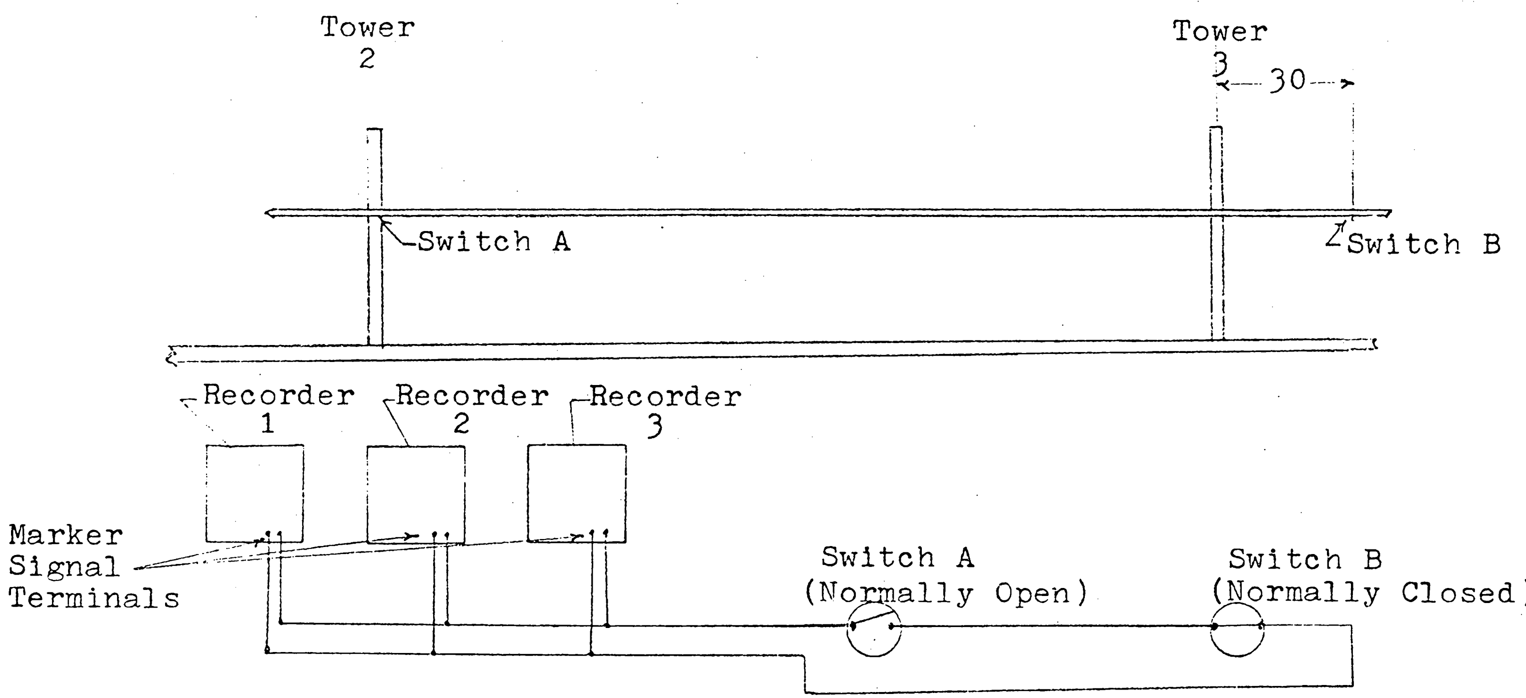


Figure 18 Diagram of Marker Signal Circuit

Electrical Shop, so the switches used were handmade in the laboratory. The switches were inexpensive and effective, but they had to be reset after each run.

A tachometer generator was attached to the main cable drive pulley shaft as a speed measuring device. The tachometer generator was a small AC generator for which both the frequency and magnitude of the signal varied with rotational speed. Its output was amplified by the Sanborn AC-DC preamplifier and recorded on the output paper of the Sanborn recorder. In practice the magnitude of the signal was used to indicate constant velocity across the test section and the frequency was used to determine the value of the velocity.

For some of the free vibration and traveling load testing an accelerometer was used for frequency analysis. A mounting hole was drilled and threaded into the top of the trackway so that the accelerometer could be mounted either vertically or horizontally. The accelerometer was a piezoelectric type (B & K Model 4315) and was used with a Kistler Charge Amplifier. In the free vibration tests the accelerometer signal was analyzed by a real time frequency analyzer (Spectral Dynamics Model 330 Spectroscope) in the ranges 0-25 Hz, 0-100 Hz, and 0-500 Hz. The memory output of the real time analyzer was connected to an oscilloscope that had a Polaroid camera attachment. The oscilloscope camera was used to obtain a record of the signal being analyzed (amplitude vs. time). The frequency analysis (amplitude vs. frequency) was recorded with a X-Y recorder. The mass of the accelerometer was 30 grams and was judged to be negligible in comparison to the mass of the trackway. The accelerometer response was within 2% for the frequency range 2-5000 Hz and all recorded frequencies were within this range [10]. Figure 19 gives a block diagram of the instrumentation used for frequency analysis and Figure 20 is a photograph of the real-time frequency analyzer and the X-Y plotter used to reproduce its output.

In the later part of the testing program a 14-channel tape recorder (Consolidated Electrodynamics Model VR-3300) was made available for use in the testing of the SVS model. The tape recorder belonged to the Federal Highway Administration and had been used for the recording of strain gage data from bridge tests. The tape recorder was used in the model tests to record the output of four LVDTs, and accelerometer, and the marker signal.

It was desired to record simultaneously on both the Sanborn recorders and the tape recorder. However, there was no output connection either to the carrier preampli-

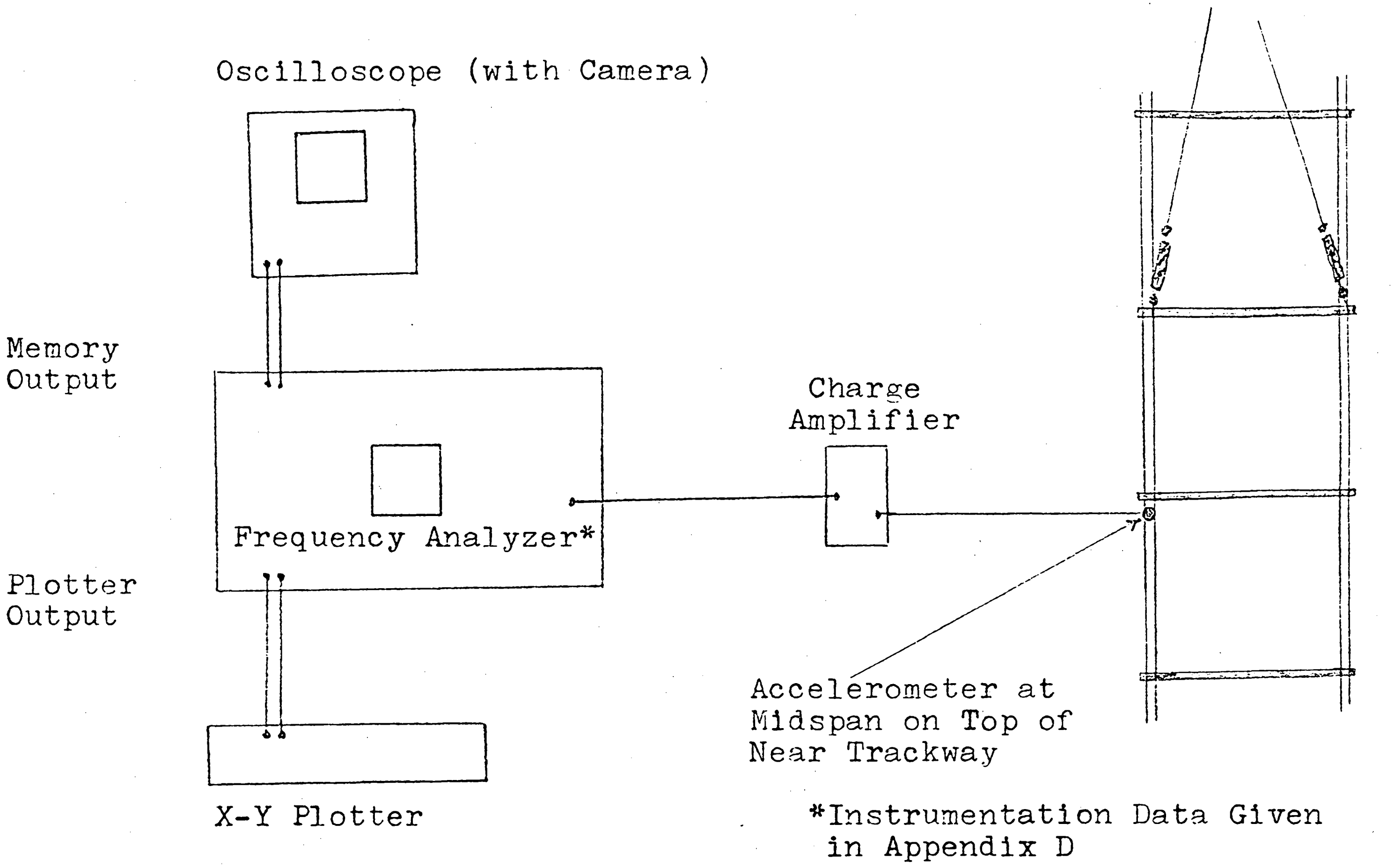


Figure 19 Block Diagram of Instrumentation Used for Frequency Analysis in Phase II Free Vibration Tests

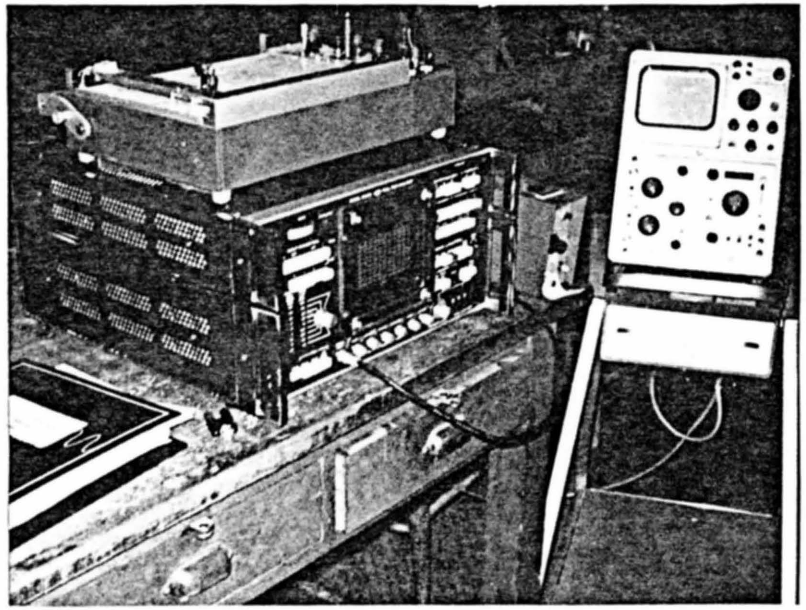


Figure 20 Real Time Frequency Analyzer and X-Y Plotter Used In Phase II Tests

fier or the driver amplifier of the Sanborn recorder. Attempts were made to obtain a demodulated output from internal connections to the carrier preamplifier, but a satisfactory signal could not be obtained.

Because of these difficulties, an entirely new LVDT circuit was developed for use with the tape recorder. This made it impossible to record an LVDT channel simultaneously on the Sanborn recorder and the tape recorder. The new LVDT circuit used a Sanborn Transducer Converter which excited the LVDT, demodulated the LVDT output, and gave a DC output that could be used with the tape recorder. The use of the transducer converter required two major changes in the LVDT wiring; first, an additional connection to the transducer center tap was necessary and, second, the voltage divider used with carrier preamplifiers had to be bypassed for the transducer converter. Four transducer converters were available and four LVDT channels were switched from the Sanborn recorder to the tape recorder.

The accelerometer circuit did not require any modifications for use with the tape recorder. A DC power supply was used with the marker switch circuit to give a square wave as the car traveled over the test section. Figure 19 gives a diagram of the circuitry used with the tape recorder. All channels not put on tape were re-

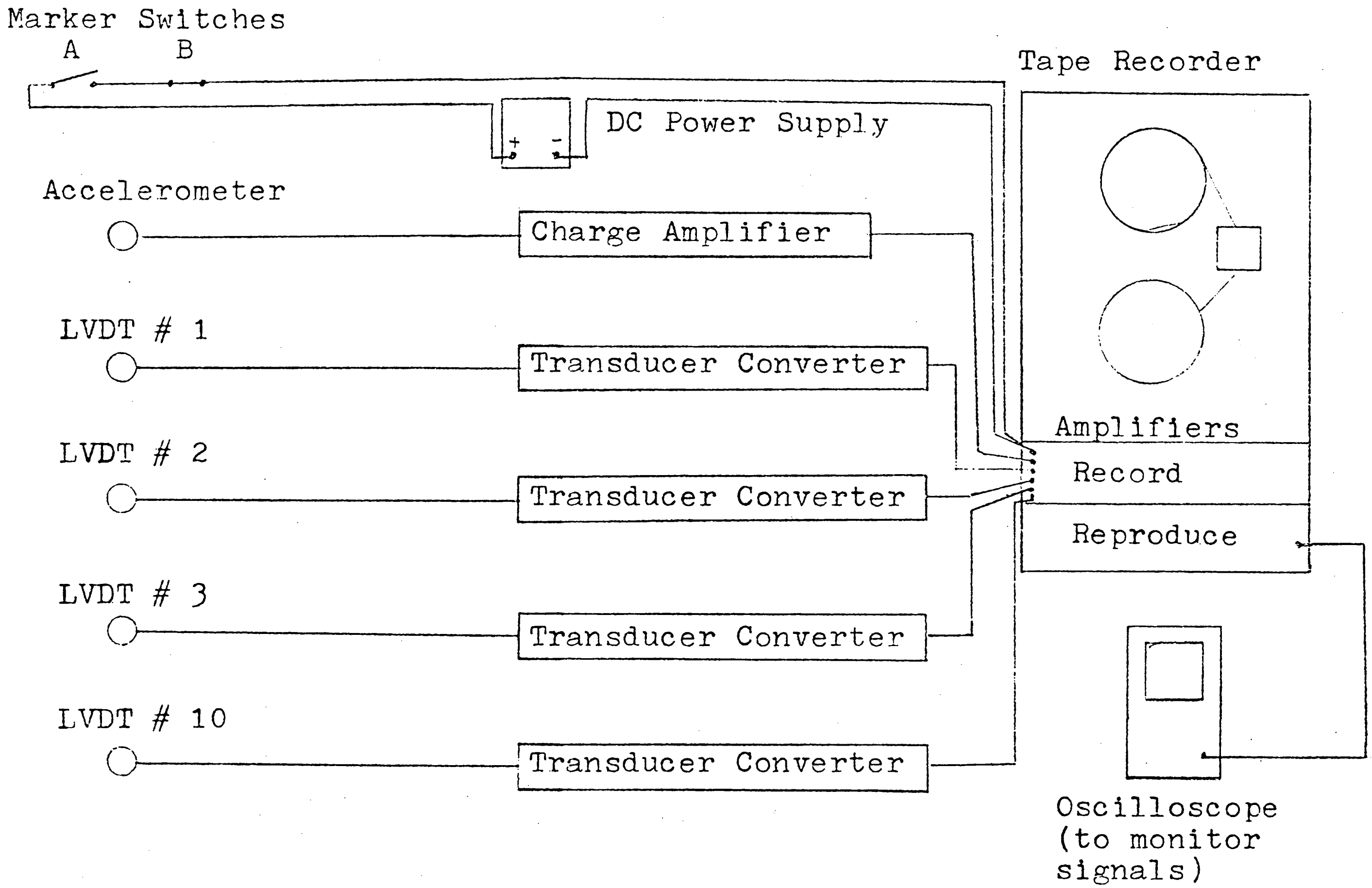


Figure 21 Block Diagram of Instrumentation Used With Tape Recorder

corded by the Sanborn recorders in the usual manner.

The data recorded on tape was sent to the Federal Highway Administration's Fairbanks Laboratory to be converted to digital form in an analog to digital converter. This data is to be computer analyzed at a later date with regard to frequency content and dynamic amplification.

TESTING OF THE SVS MODEL

The testing program for the SVS model consisted of three parts or "phases." Phase I consisted of static tests to determine the response of the structure to the application of static vehicle and wind loads. The tests of Phase II were free vibration or "plucking" test which were used to determine natural frequencies. Phase III tests simulated the motion of one or more vehicles on the guideway and indicated the response of the system to actual moving load conditions.

In Phase I the deflection of the guideway in response to three types of vehicle and wind load was measured and recorded. In the first test a 13.25 lb "heavy bogey" was advanced along the guideway stopping at each strut location and the deflections were recorded on the Sanborn recorder. The next test simulated the maximum design steady wind load, a 150 mph wind normal to the guideway axis with no vehicles on either trackway. Starting with no load on the guideway, the 150 mph wind load weights were applied one strut at a time until all weights were connected. They were then removed one span at a time, first the end spans, then the second and fourth spans, and finally the middle span. The recorders were running during this process and recorded the response of the guideway to wind loads on specific spans as well as a continuous wind load. The third test in this phase was a combination of two 17.9 lb "cars" advancing in opposite directions with a simulated 60 mph wind load normal to the guideway axis. In the test the 60 mph wind load weights were all attached to the guideway. Starting with a 17.9 lb car at either end on opposite trackways, the cars were advanced, one at a time, until they reached the other end of the trackway.

The Phase I tests were very useful in "checking out" the instrumentation for later tests. The data from this phase was also used as a base for comparison of the other deflection data taken in Phase III.

The Phase II free vibration tests were used to determine the natural frequency of the guideway structure and give some indication of the degree of damping present in the guideway. The test consisted of displacing the guideway by applying a known force at midspan, suddenly releasing the force, and recording and analyzing the resultant vibrations. This was done in both the vertical and the horizontal planes with the 13.25 lb "heavy bogey" used to displace the guideway. In the vertical tests the bogey was attached to the center of the midspan strut by a length of nylon cord. The weight of the bogey displaced the guideway and when the cord was cut the guideway vibrated freely. For horizontal tests the same weight was used with a pulley attached to the wall to displace the guideway horizontally.

In all tests the Sanborn recorders were used to record the vertical and horizontal vibrations of the structure. The output of an accelerometer mounted on the near trackway at midspan provided the signal for the real time frequency analyzer. In the "A" tests of this phase the frequency analysis is in the range 0--25 Hz. For the "B" tests the range is 0--100 Hz and for the "C" tests it is 0--500 Hz.

The Phase III tests consisted of 37 runs of various vehicle weights and combinations at various speeds. A 9.1 lb "single bogey" traveling on the near trackway was first tested with few weights in the propelling device. As more weight was added the larger 17.9 lb car and 13.25 lb "heavy bogey" were tested. A spacing bar was used to compensate for the difference between the lengths of the "bogeys" and the cars. Two 9.1 lb bogeys traveling on opposite trackway in opposite directions were tested and, finally, the maximum load of two 17.9 lb cars were propelled along the guideway. The testing then returned to the smaller bogeys, and with heavier weights higher speeds were obtained. A maximum velocity of 46.2 ft/sec was reached with a 9.1 lb car and 652 lb in the propulsion device.

During the moving load tests there were many minor failures involving both the model vehicles and the propulsion device. The most common failure involved breakage of the small instrument ball bearings used for wheels on the vehicles. Fortunately, the supply of spares was adequate to complete this series of tests. There was also a problem with the drive chain jumping off the sprocket as the propulsion device went from acceleration to deceleration. A set of idlers and a chain guard were added to the system and solved this problem.

DISCUSSION OF RESULTS

The results of the Phase I Static Tests are presented in Appendix C. During the testing program several model vehicles of differing weights were statically tested on the guideway model. The results of these tests are compared in Figure 22. The model vehicle weights tested were as follows: 9.1 lb for the single bogey alone, 11.7 lb for the single bogey with the cable and spacer bar,[4] 13.25 lb for the heavy bogey, and 18.8 lb for the single car with the cable. The deflection appears to be linear with loading for the three bogey configurations with approximately 0.009 in. deflection for each pound of bogey weight.

The data for the single car did not seem to fit the linear curve and the first thought was to attribute this to non-linear behavior of the guideway. However, this is better explained by the differences in load distribution. The weight of the bogeys is distributed over a 4 in. section of the guideway and this is much less than the 29 in. over which the single car weight is distributed. This results in two distinctly different loading conditions and this explained the deviation of

[4] 0.9 lb was added to the weight of the bogey and the single car as the weight of the cable carries by the vehicle. 1.7 lb was added to the bogey by the use of the spacer bars.

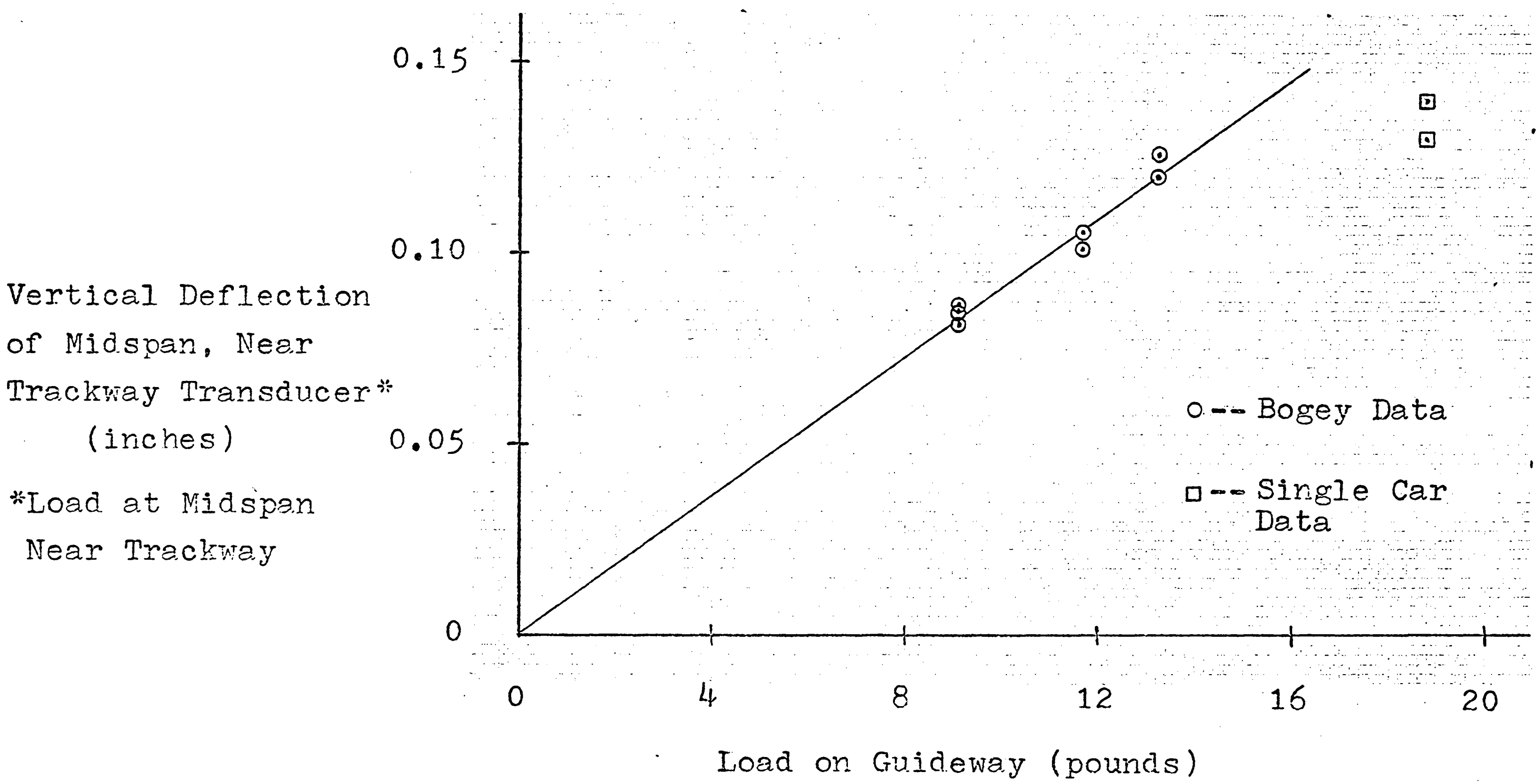


Figure 22 Comparison of Phase I (Static Test) Data

the single car data from the linear curve of bogey data in Figure 22.

Tables 7 and 8 give a comparison of some of the measured data with theoretical data predicted by the computer model described in Reference 11. The data compared best at the midspan transducer locations and these were considered the most important test points. In all cases the model data indicated a more flexible guideway than the theoretical data. It was suggested that this effect could be caused by either too little pretension in the stay cables or by the effect of the trackway rail being built up from two rods, rather than being a solid rod.

The results of the Phase II Free Vibration Tests compared very favorably with the predicted results obtained from a computer model of the dynamic system (Reference 11). Deflection data from the static tests was used to determine the spring constants for this model so that the guideway stiffness was not a factor in this comparison.

The complete data sets from the Phase II testing may be found in Appendix C. The frequency analysis in the vertical plane gave fundamental structural frequencies of 11.5, 13, and 15 Hz and the theoretical model predicted frequencies of approximately 11 and 15 hz. In the hori-

TABLE 7 Comparison of Phase I, Test I Vertical Deflection Data with Theoretical Data

Strut Number	Load at Midspan		Deflection Under Load	
	(Deflection at Strut) (inches)			
	Measured	Computed	Measured	Computed
20		0.000665	0.0163	0.0090
22	0.039*	0.0123	0.0465*	0.0390
24	0.098*	0.080	0.099*	0.0908
25	0.128	0.107		

*Linearly interpolated test data between measured deflections at struts 21 and 25.

Note: Theoretical data taken from analysis found in Reference 11, SVS Guideway Studies, Volume III.

TABLE 8 Comparison of Test Data with Theoretical Data for Phase I, Test VII (Wind Load and Cars on Both Trackways)

Vehicle Location (Strut Number)	Vertical Deflection of Trackway at Load		Vertical Deflection of Trackway at Midspan	
	Measured	Calculated	Measured	Calculated
20	0.018	0.007	0.0064	0.0013
22	0.068	0.0344	0.10	0.033
24	0.153	0.01036	0.151	0.1147
25	0.151	0.1256	0.151	0.1256
	Horizontal Deflection of Trackway at Load		Horizontal Deflection of Trackway at Midspan	
	Measured	Calculated	Measured	Calculated
20	0.028	0.0	0.026	0.0124
22	0.038	0.0156	0.035	0.0236
24		0.0356	0.053	0.0399
25	0.053	0.043	0.053	0.043

Note: Theoretical data taken from analysis found in Reference 11, SVS Guideway Studies, Volume III.

zontal tests the frequency analysis indicated a natural frequency of 10 Hz and the theoretical model predicted the same value.

The frequency analysis was made in higher frequency ranges also but the 0-25 Hz range gave the fundamental natural frequencies with which the test was more concerned. It is in this range that structural resonance may occur as the result of the vehicle traveling on the guideway.

Figures 23 and 24 show the results for midspan vertical deflection as measured on the actual model and as predicted by the theoretical model. Figures 25 and 26 give the same information for the horizontal free vibration tests. The data compares closely with the major differences being the absence of damping in the theoretical model.

The data set for the Phase III Moving Load Tests consisted of approximately 180 pages and was not included here to reduce the bulk of this report. The complete data set may be found in Appendix C of Reference 11, the final report for the SVS-III project. Five channels of data from Runs 10 through 27 of the Phase III testing were put on magnetic tape and this information is not available in graphical format. Once converted into digital form, this data will be suitable for computer plotting and analysis.

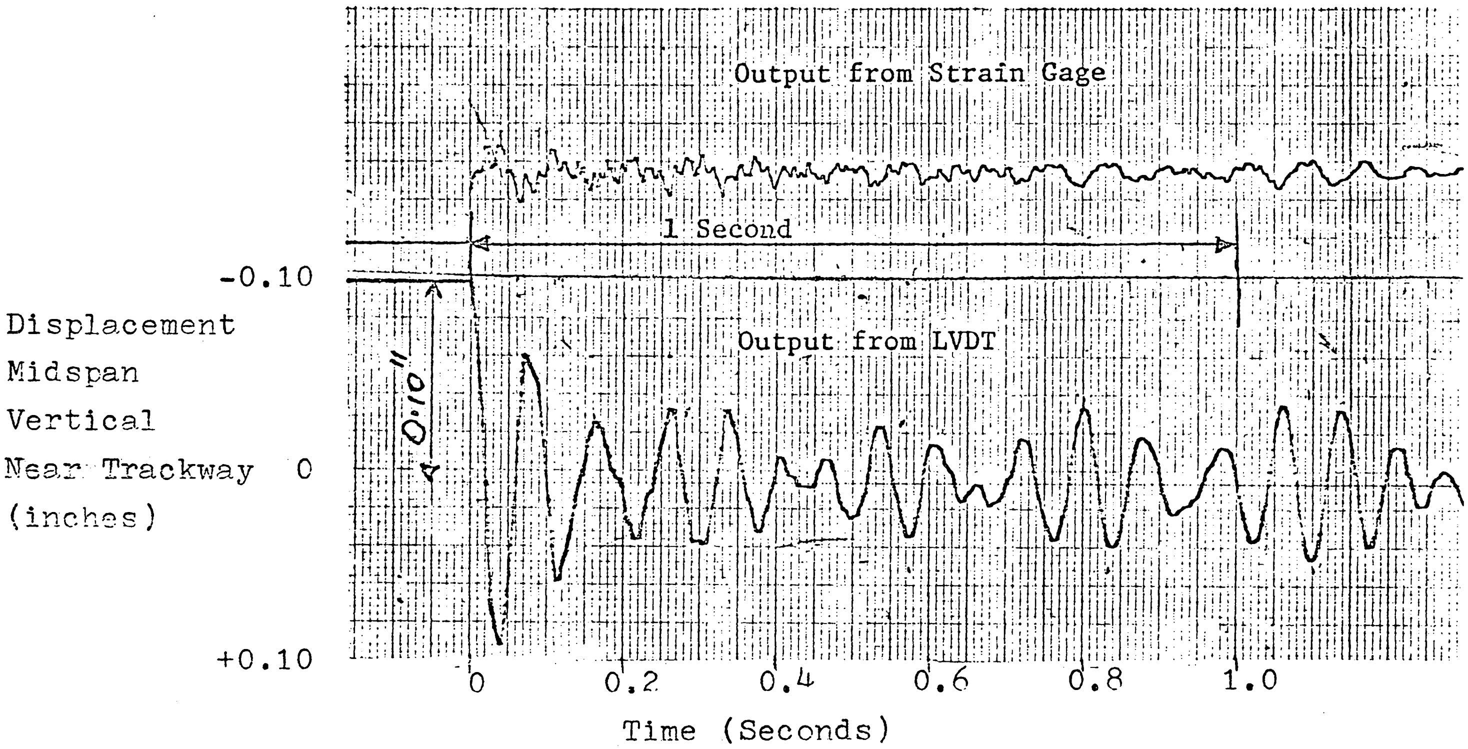


Figure 23 Measured Data for Phase II, Test I
(Vertical Free Vibration Test)

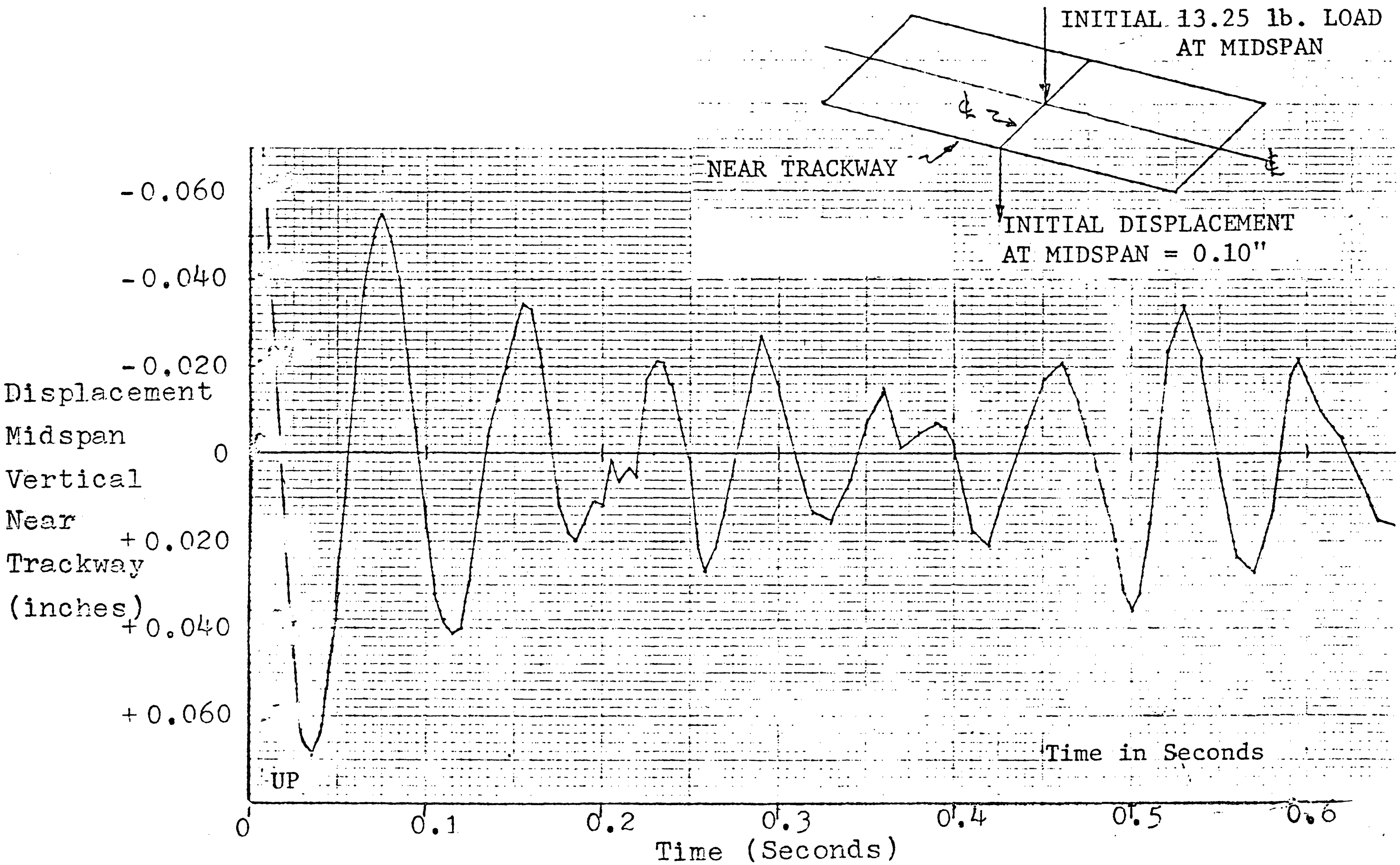


Figure 24 Predicted Results for Phase II, Test I (Vertical Free Vibration Test). Taken from Reference 11, SVS Guideway Studies, VPI&SU, August 1973.

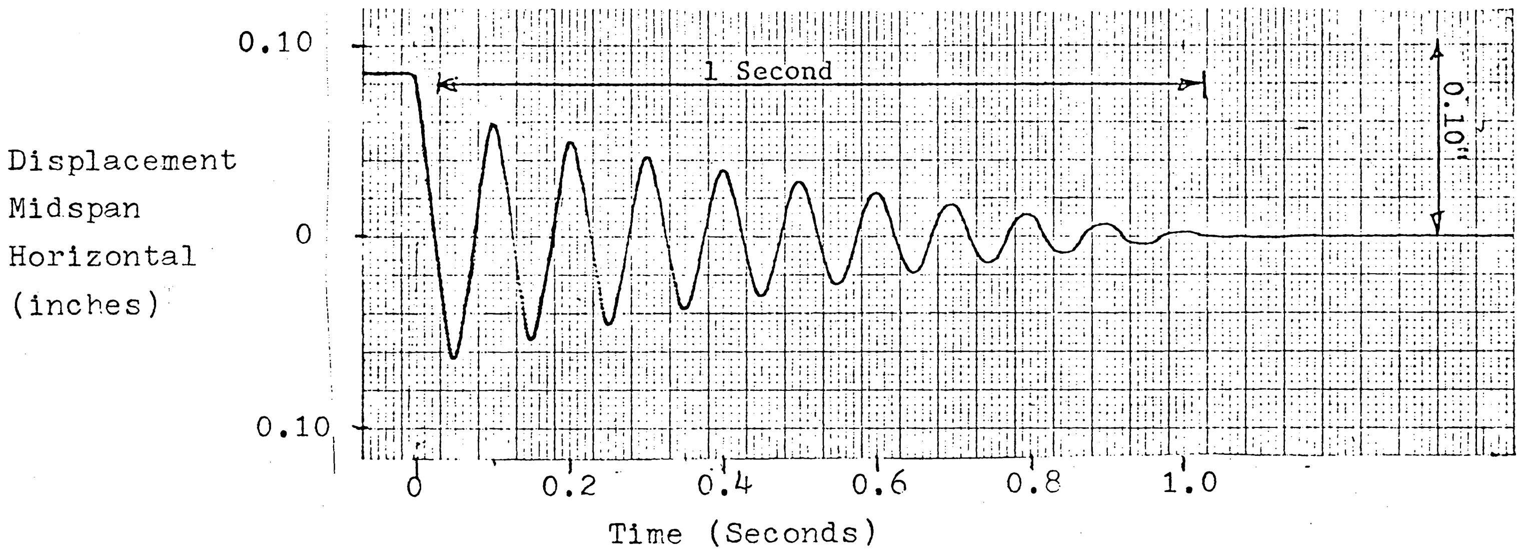


Figure 25 Measured Data for Phase II, Test V (Horizontal Free Vibration Test)

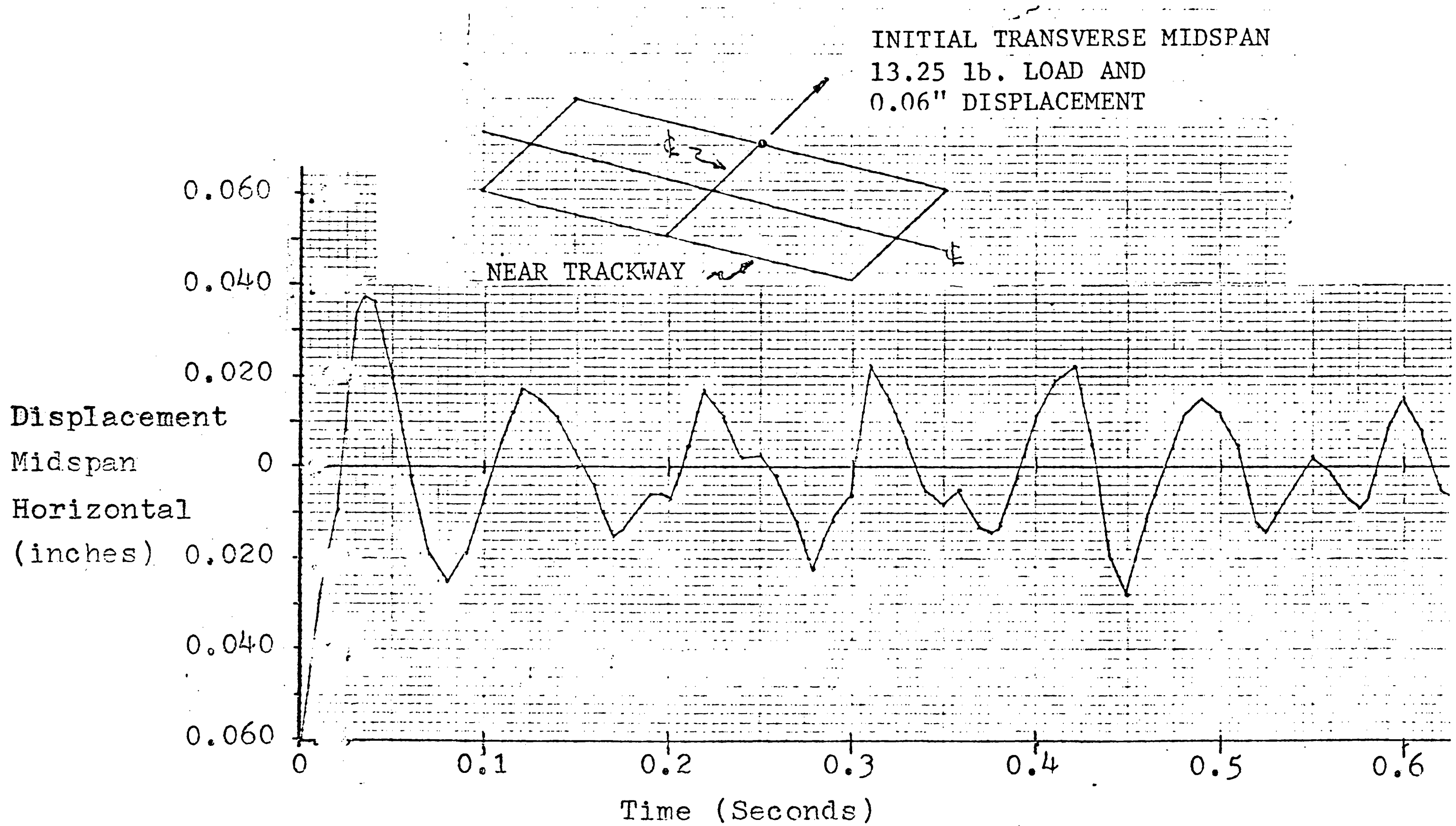


Figure 26 Predicted Results for Phase II, Test V (Horizontal Free Vibration Test), Taken from Reference 11, SVS Guideway Studies, Volume III.

Preliminary analysis of the data recorded on paper during the moving load tests has been completed. Figure 27 shows the maximum vertical deflection of the midspan LVDT as a function of load for various speeds. As with the static tests, the data from the single car tests cannot be compared directly with that of the bogey tests. The theoretical and actual amplification factors for midspan deflection and a single bogey on the near trackway are plotted in Figure 28. The actual amplification factors are greater than the theoretical in all cases. Although there is not enough information to accurately determine the magnitude of the difference, it appears that the actual factors are at least 100% higher than the theoretical values.

The moving load tests were made at velocities up to 46.2 ft/sec and this corresponds to a prototype speed of approximately 150 mph. At these velocities the dynamic amplification factor was higher than the predicted value for the bogey vehicle configurations. The guideway, however, did not experience destructive resonance conditions for any of the vehicle combinations or speeds tested.

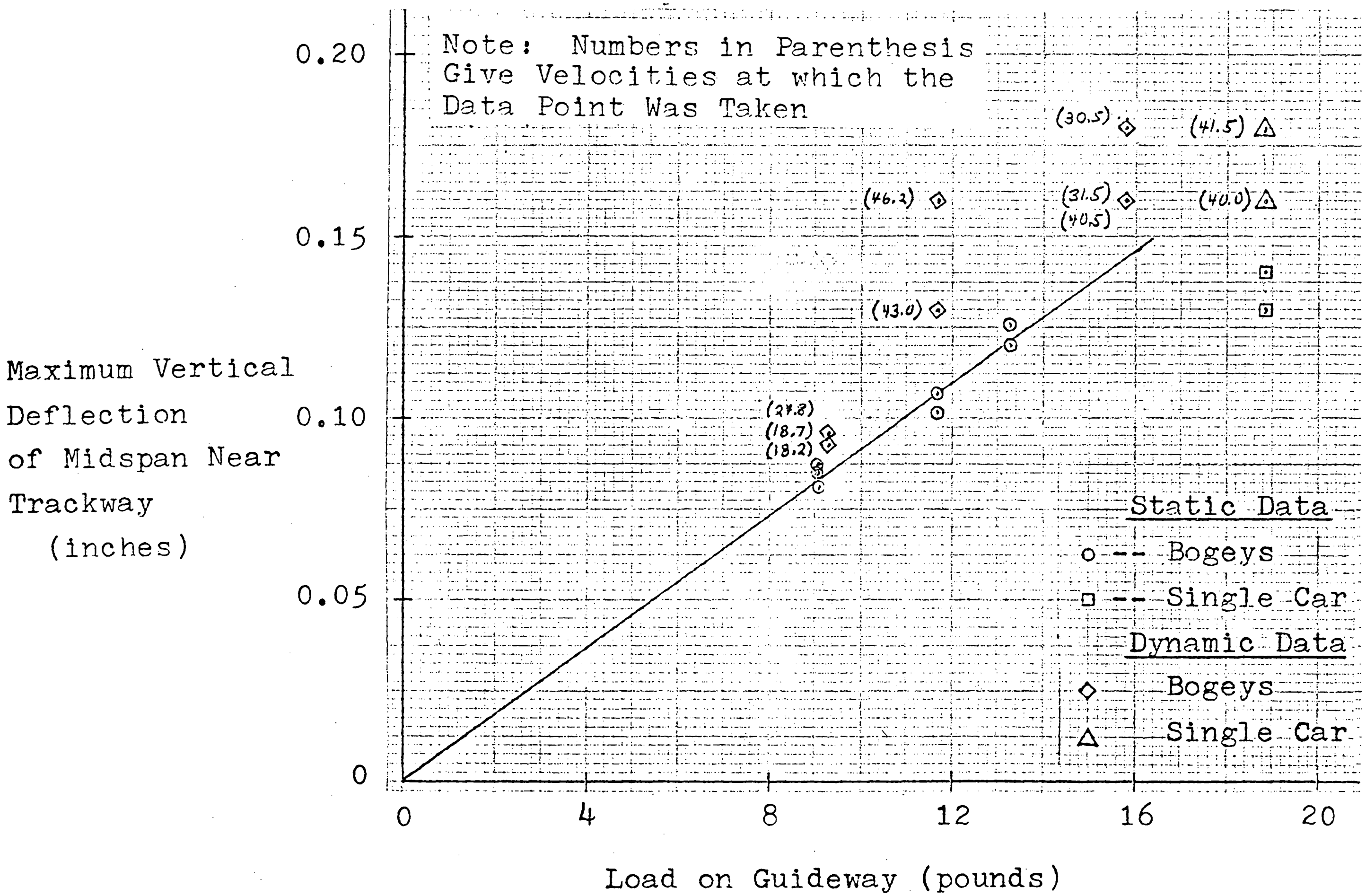


Figure 27 Data from Phase III, Test I (Moving Load Tests)

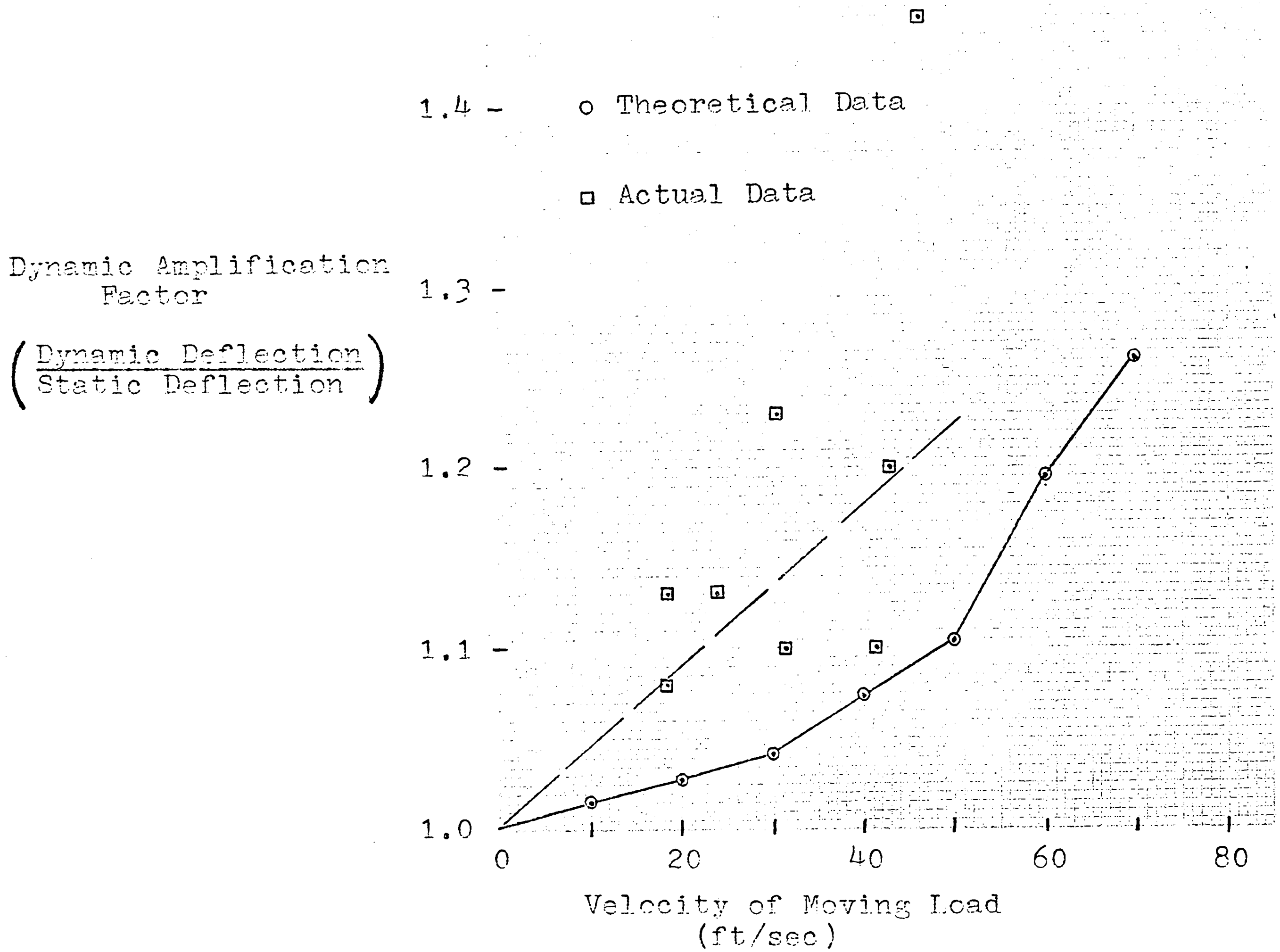


Figure 28 Amplification Factor at Midspan When Using Bogey Type Vehicles, Theoretical Data Taken from Reference 11, SVS Guideway Studies, Volume III.

SUMMARY

A scale model of the Suspended Vehicle System guideway was constructed and tested. By the use of scaling factors, it may be possible to predict the behavior of a full scale prototype from the data of this testing. The center span of a five span model was tested, and it was assumed that the behavior of this span approached that of a span in a semi-infinite continuous system. Model vehicles representing an independent bogey and a single full-sized car were constructed and a propulsion device capable of propelling the vehicles at velocities up to 45 ft/sec was fabricated. Provisions were made for testing one vehicle traveling in one direction or two vehicles traveling in opposite directions.

An instrumentation system consisting of transducers and recorders was used to measure and record deflections and vibrational frequencies. Linear Variable Differential Transformers (LVDTs) were used to measure displacements and an accelerometer was used as a frequency transducer. Three Sanborn 150 recorders were available to record up to ten channels of data on paper and a tape recorder was used to put some of the data on magnetic tape. A real time frequency analyzer was used to analyze some of the frequency data. The transducers were easily movable

and both symmetrical and asymmetrical transducer arrangements were used during the testing program.

The testing program consisted of three phases that evaluated the response of the system to static and dynamic loading conditions. Phase I was a series of static tests in which deflections due to vehicular loading, wind loading, or combinations of the two were measured and recorded. This phase included tests of the maximum design wind load of 150 mph with no vehicles on the guideway and tests of the operational condition of a 60 mph wind load with vehicular loading on both trackways. The data from this phase indicated that the deflection of the guideway was fairly linear as bogey weight increased. Theoretical data from a computer analysis of the structure was comparable but generally gave lower deflections than those measured for the guideway model.

The Phase II free vibration tests consisted of displacing the guideway with a known force, suddenly releasing it, and recording and analyzing the resultant vibrations. A real time frequency analyzer was used to determine the frequency content of the vibrations and the actual displacements were recorded by the Sanborn recorders. The results were compared to the predictions of a theoretical model and the measured data closely matched the theoretical data. Fundamental frequencies were found at 11.5, 13, and 15 Hz in the vertical tests and at 10 Hz in the horizontal tests.

The tests of Phase III simulated actual guideway operations with various vehicular loads. Tests were made with one vehicle on the near trackway traveling from left to right and with two vehicles traveling in opposite directions on the two trackways. A maximum velocity of 46 ft/sec corresponding to a prototype speed of 150 mph was attained during these tests and this was approximately 75% of the desired velocity.

The results of the moving load tests indicated that the guideway behavior was stable for the loadings and velocities tested. Some dynamic amplification at the higher speeds was detected but the excessive displacements of structural resonance were not found.

Although no theoretical analysis is presented in the present report, an analysis was carried out independently [11], and was used as a basis of comparison for the experimental results.

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6 Szeless, A. G., and Whitelaw, R. L., "Design Basis and Test Plan for the 1/24th Scale Guideway Model," Special Report to TRW/DOT, VPI&SU, Blacksburg, Va., December 19, 1972.

7 The Sanborn Company, Sanborn Carrier Preamplifier, Model 150-1100, Instruction Manual, The Sanborn Company, Waltham, Massachusetts.

8 Holman, J. P., Experimental Methods for Engineers, McGraw-Hill Book Company, New York, 1966.

9 The Sanborn Company, Sanborn Recorder, Models 152-100B and 154-100B, Instruction Manual, The Sanborn Company, Waltham, Massachusetts.

10 Bruel & Kjaer, Instructions and Applications, Accelerometer, Model 4312-4315, Bruel & Kjaer, Copenhagen, 1962.

11 Whitelaw, R. L., Szeless, A. G., Counts, J., and Garst, D., "SVS Guideway Studies, Volume III, Dynamic Model Tests of a Cable Stayed Guideway," VPI&SU, Blacksburg, Va., August 1973.

APPENDIX A

SHOP DRAWINGS USED IN THE CONSTRUCTION OF THE SVS MODEL

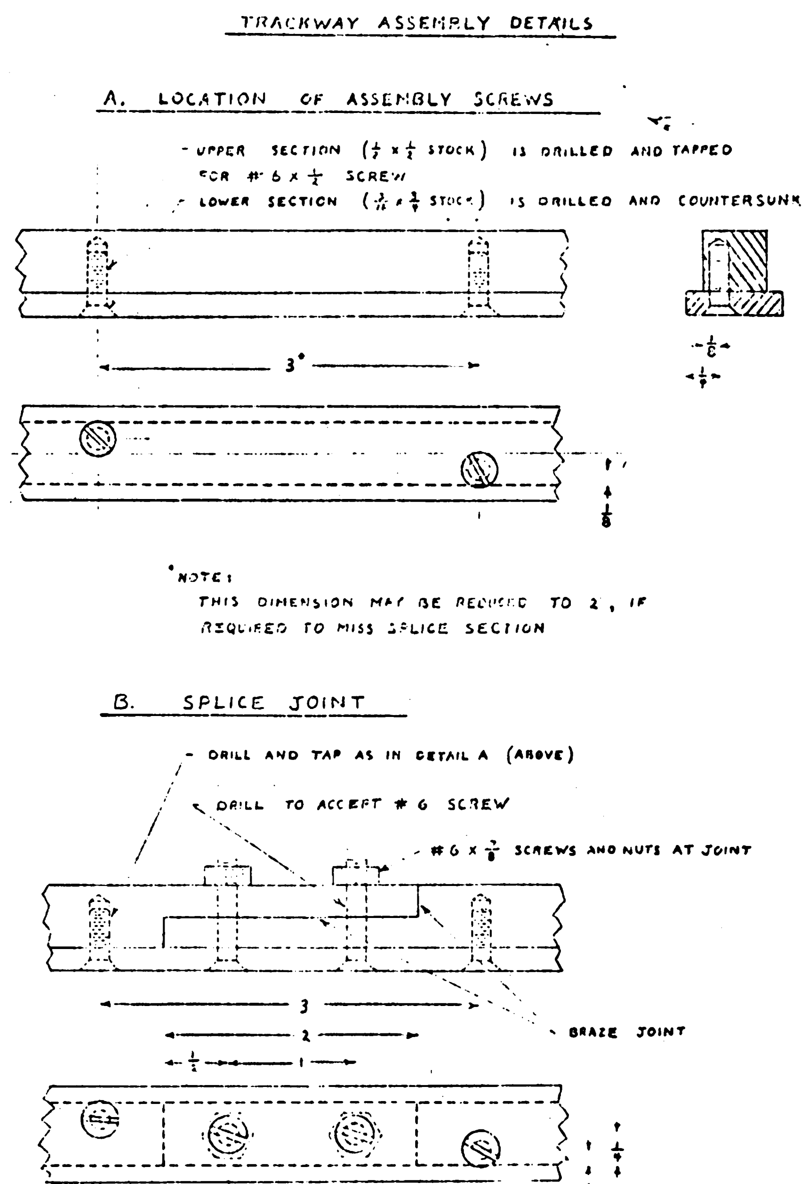


Figure A-1

Trackway Assembly Details

TRACKWAY ASSEMBLY DETAILS

C. BUTT JOINT OF TRACKWAY FLANGE

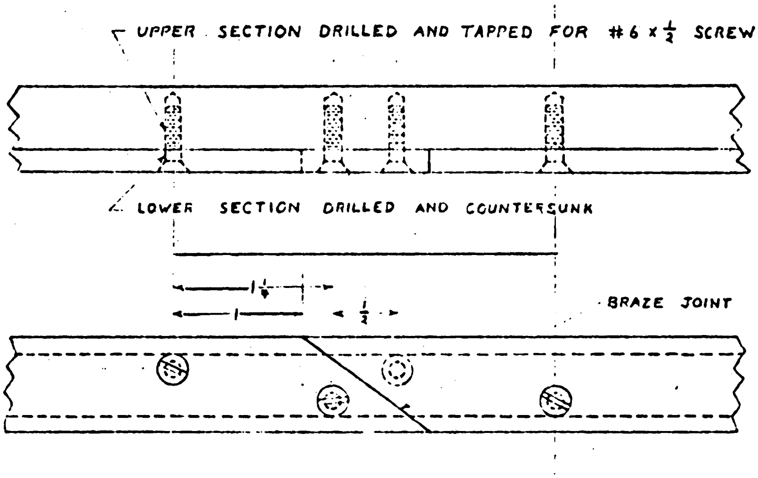


Figure A-2

Trackway Assembly Details

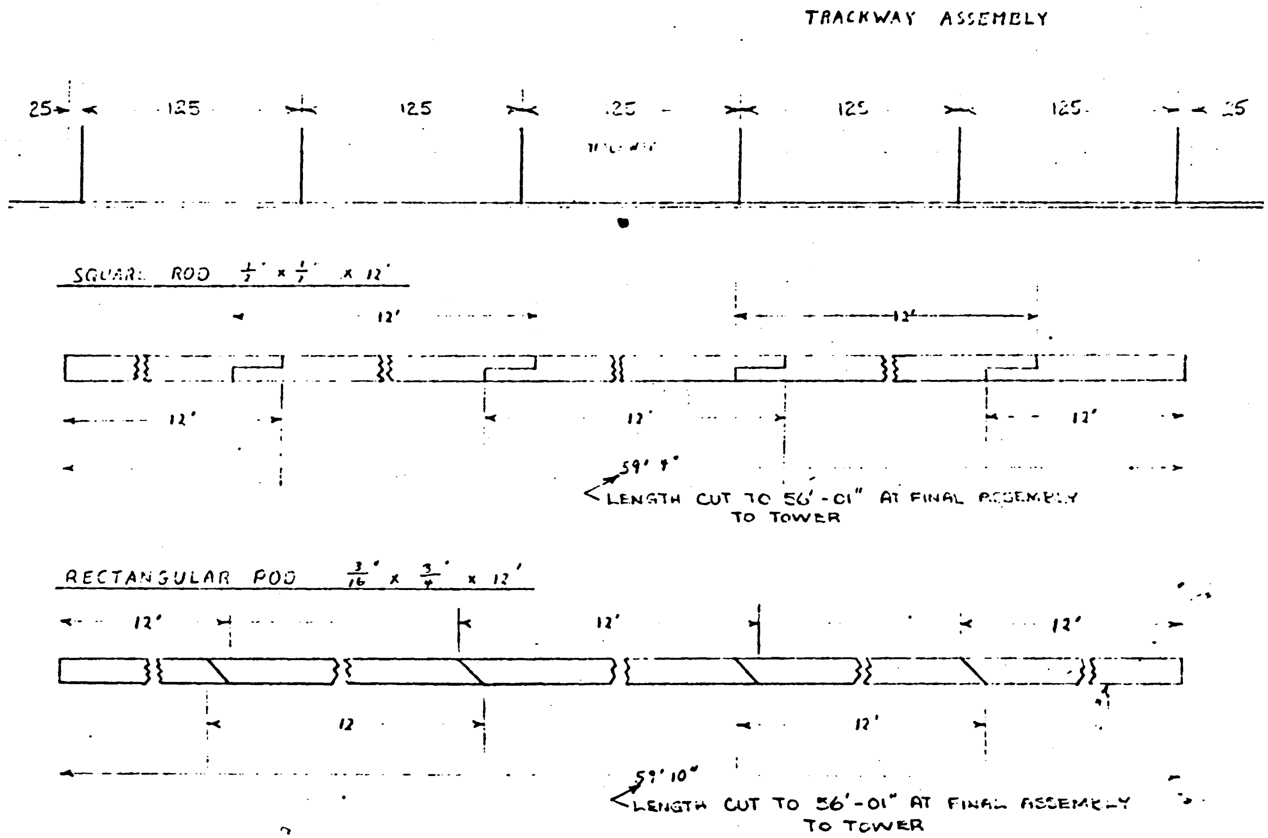


Figure A-3 Trackway Assembly Details

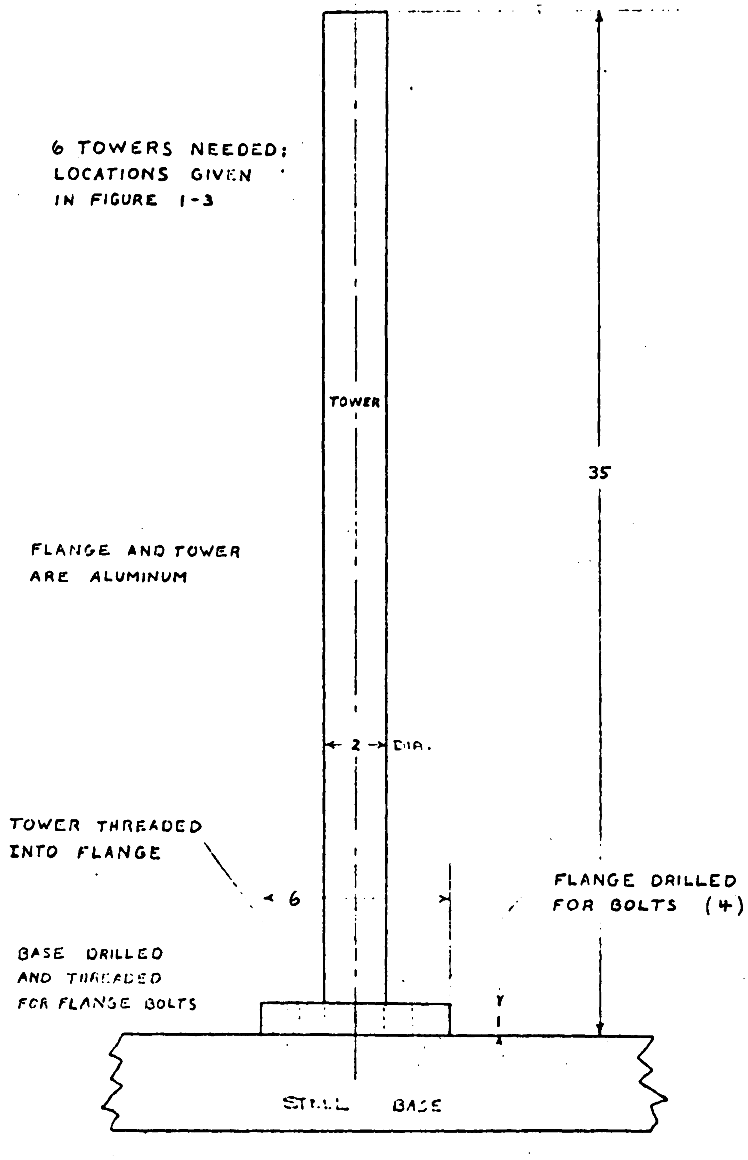


Figure A-4 Model SVS Towers

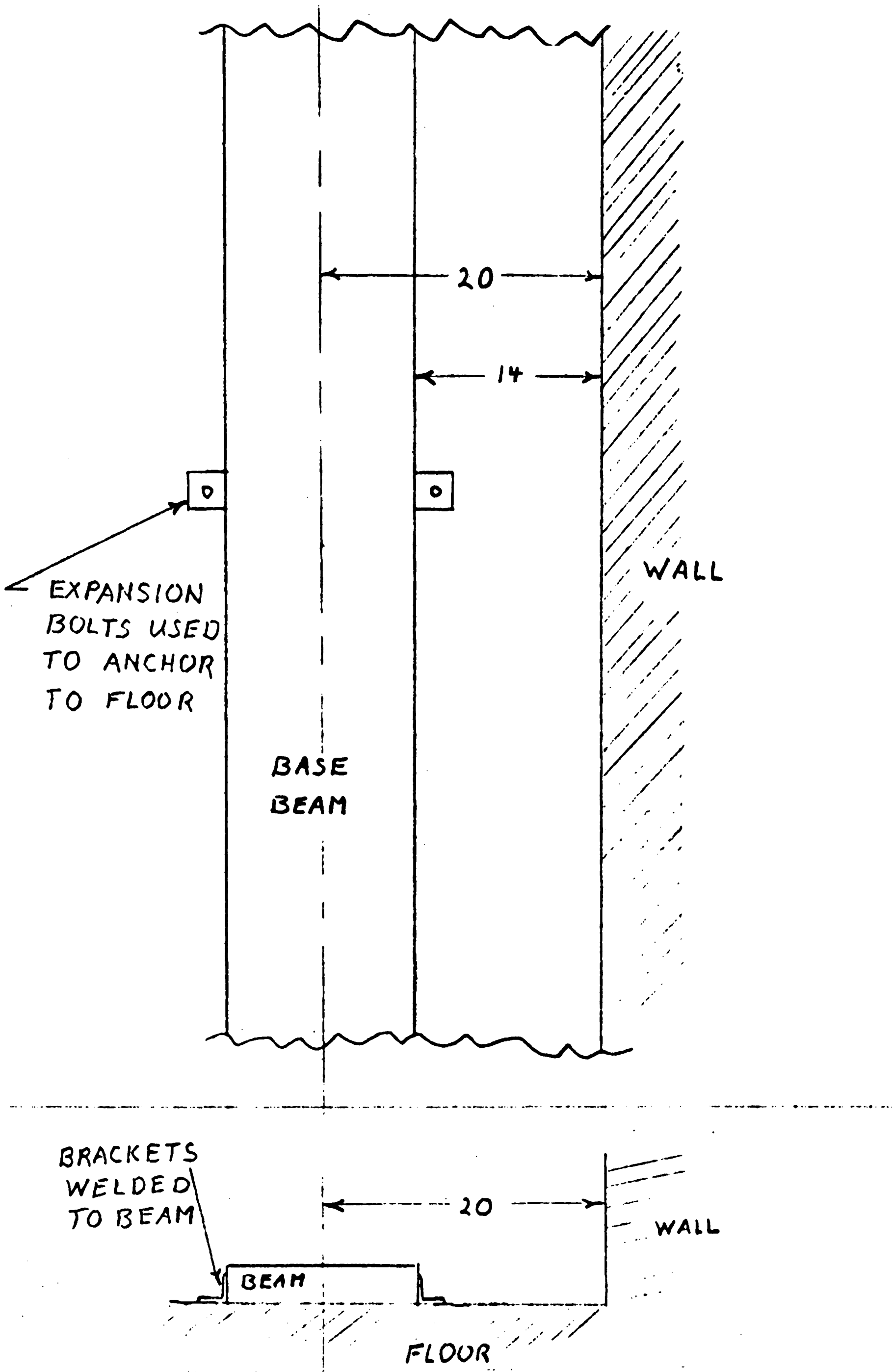


Figure A-5 Guideway Base Details

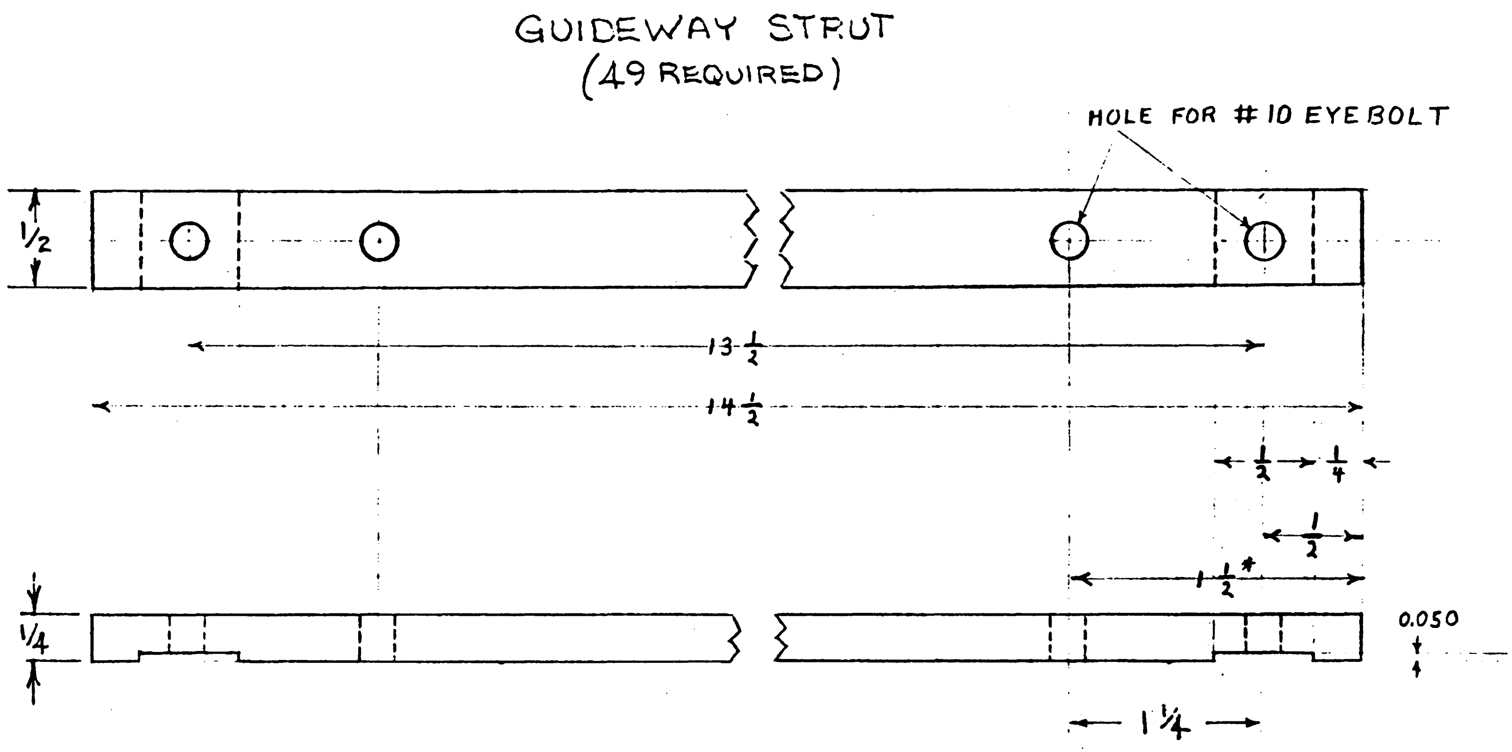


Figure A-7 Guideway Strut Details

Tower Struts

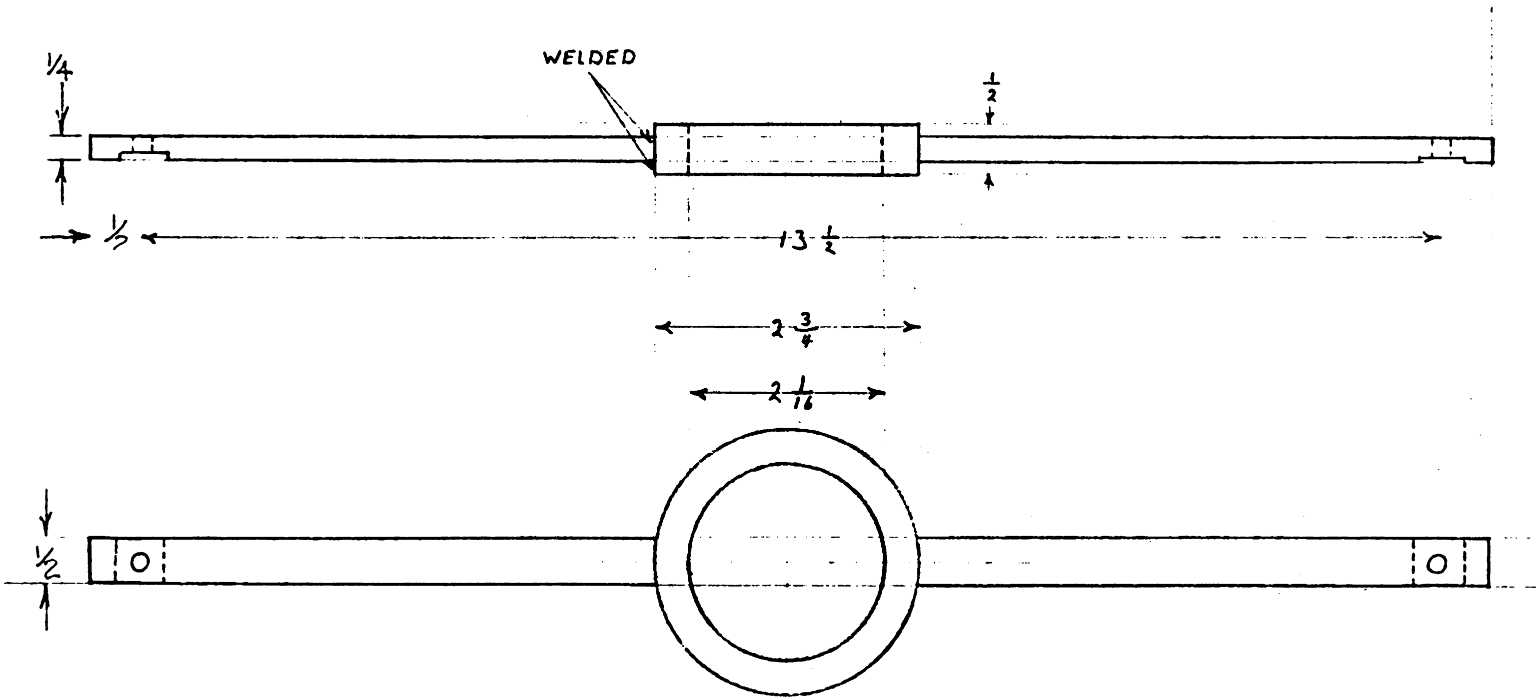
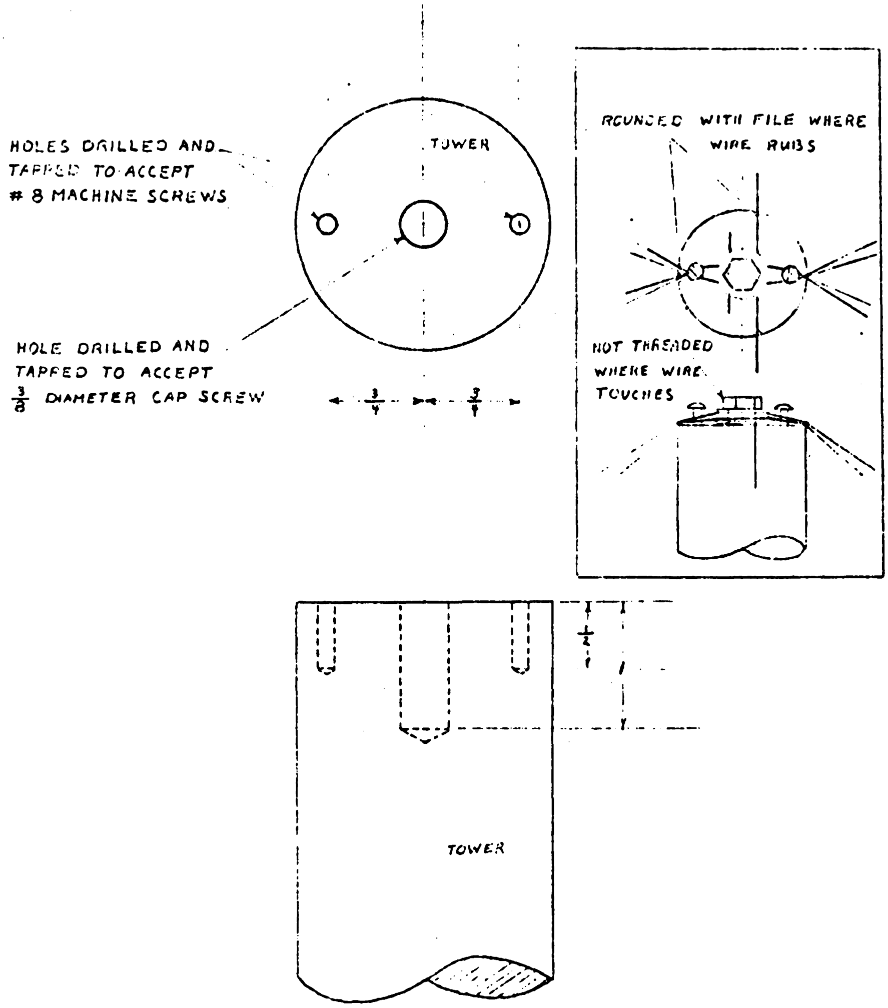


Figure A-8 Tower Strut Details



<u>Figure A-9</u>

<u>Details of Cable Attachment at Tower Top</u>

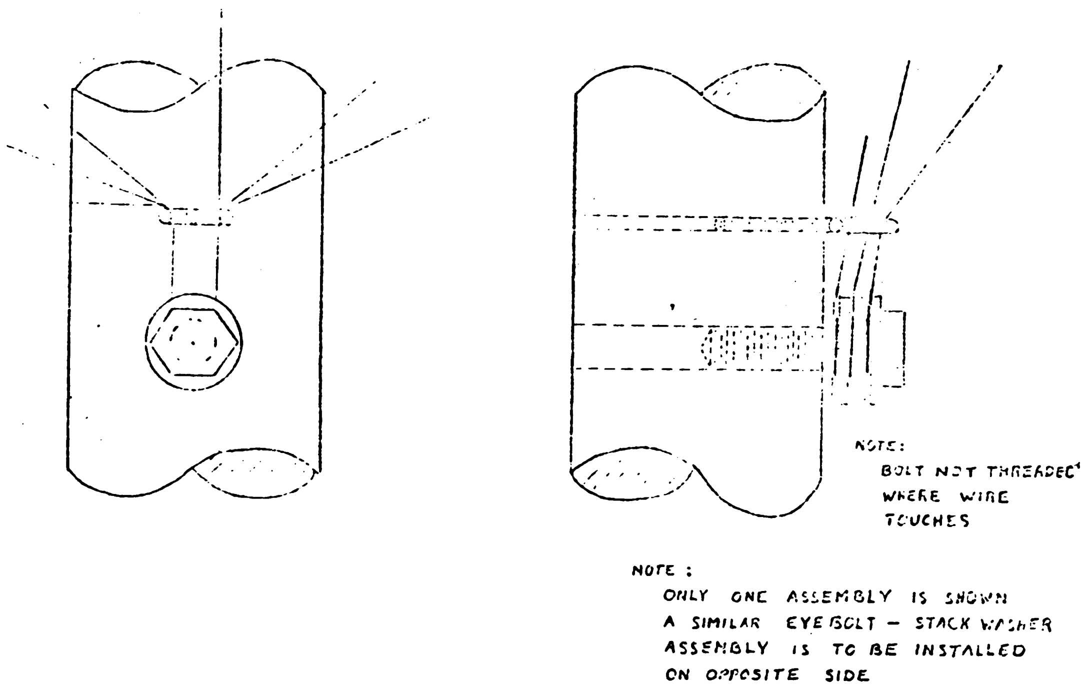
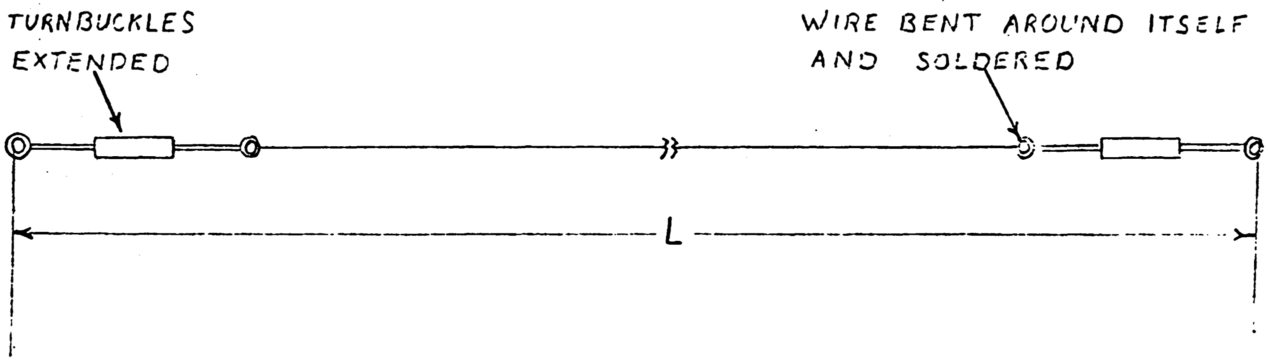


Figure A-10 Cable Attachment at Lower Part of Tower

TURNBUCKLE - WIRE ASSEMBLY



	CABLE	WIRE SIZE (in.)	L (in.)	NUMBER NEEDED
UPPER	No. 1	0.020	32	5
	No. 2	0.024	59	10
	No. 3	0.031	105	8
LOWER	No. 1	0.014	36.5	6
	No. 2	0.018	61	12
	No. 3	0.020	107	8

<u>Figure A-11</u> <u>Turnbuckle-Wire Assembly and Table of Cable Data</u>

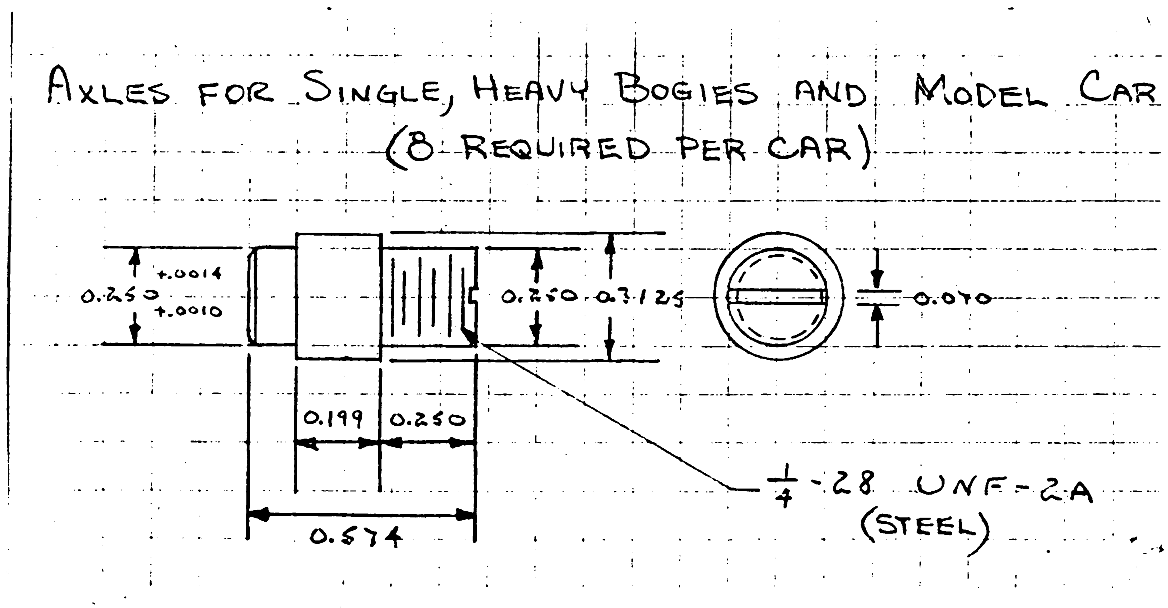


Figure A-12 Axles Used For All Vehicle Types

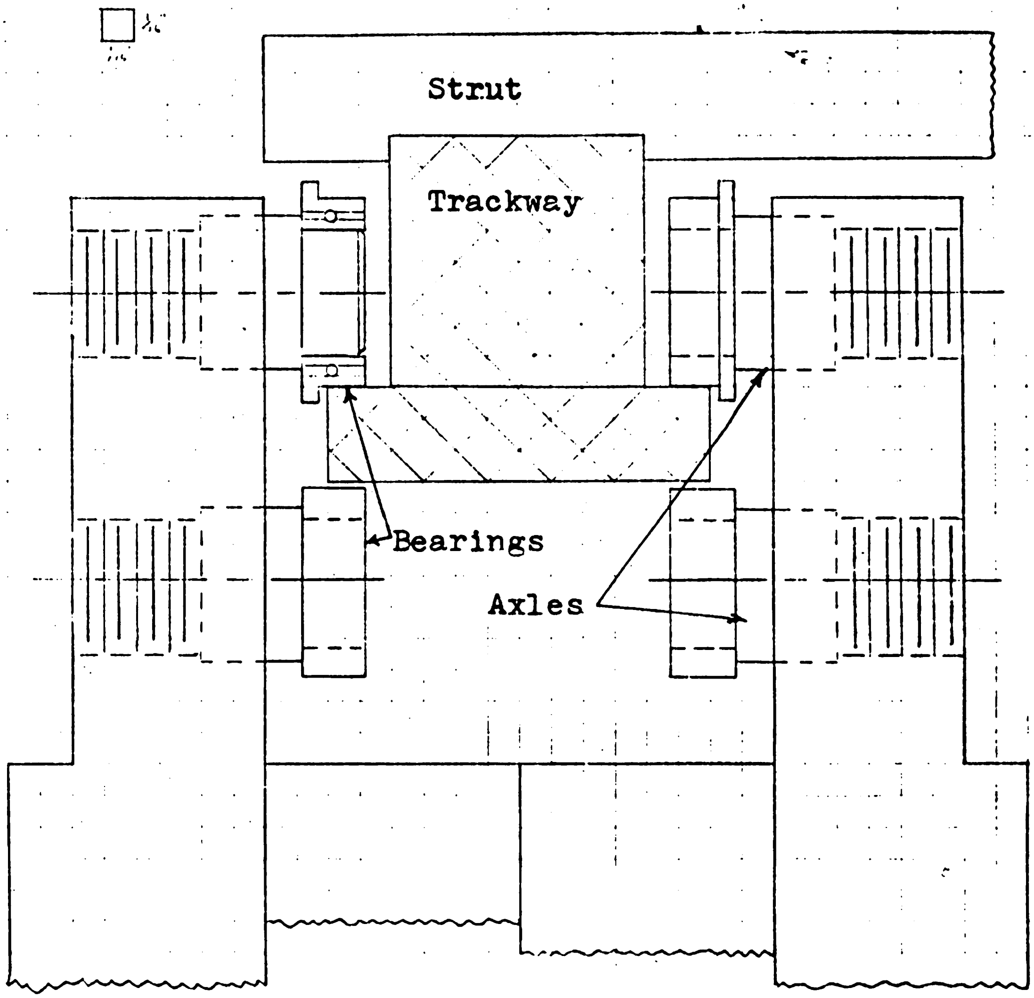


Figure A-13

Diagram of Bearing-Axle Assembly on Trackway

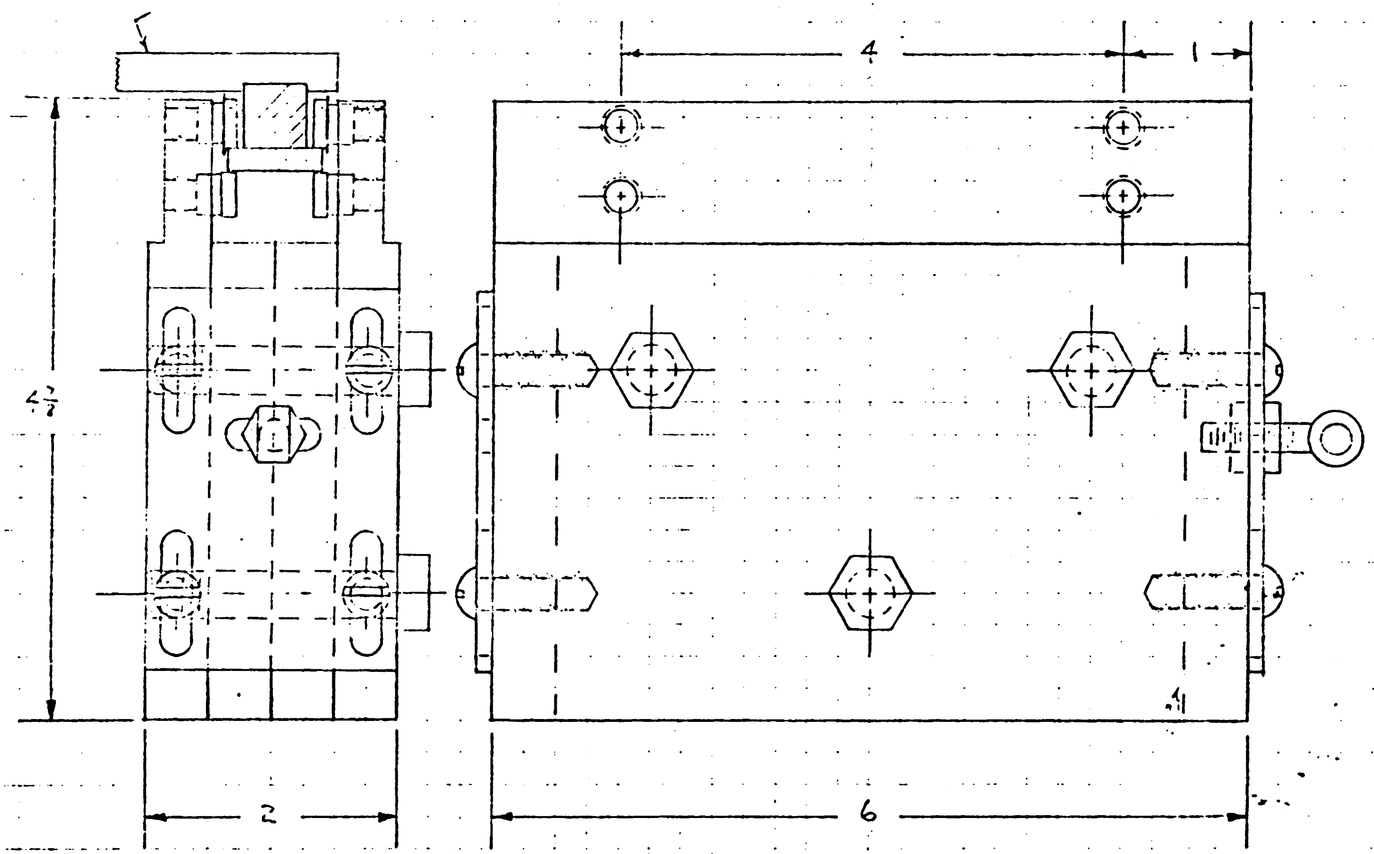


Figure A-14 Assembly Details for the Single Bogey and Heavy Bogey

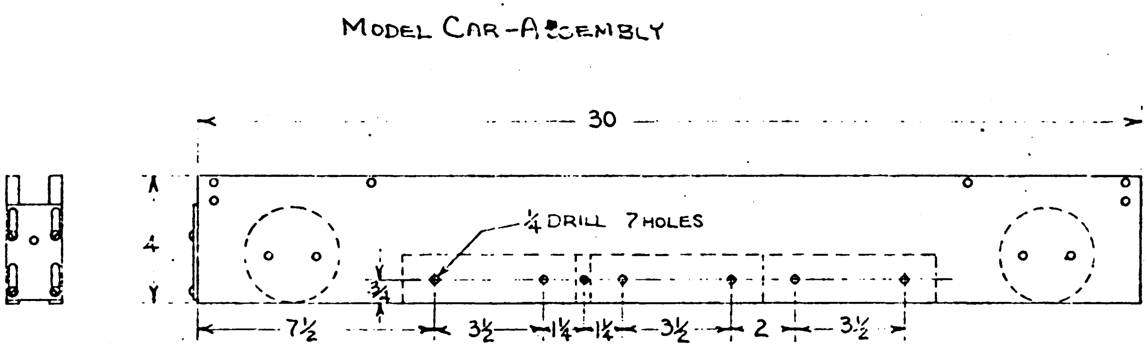
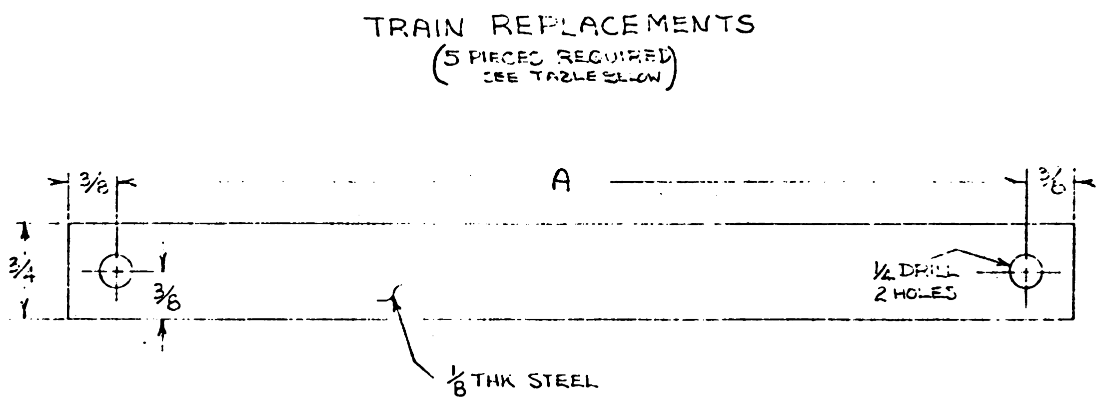


Figure A-15 **Assembly Details for the Single Car**



TYPE No.	DIMENSION "A"	No. REQUIRED
1	31 1/4	1
2	24	4

Figure A-16 Steel Spacer Bars Used to Replace Bogeys or Single Cars when Testing on One Trackway

SVS GUIDEWAY FOUNDATION

BRACKETS FOR SECURING
BEAM TO FLOOR

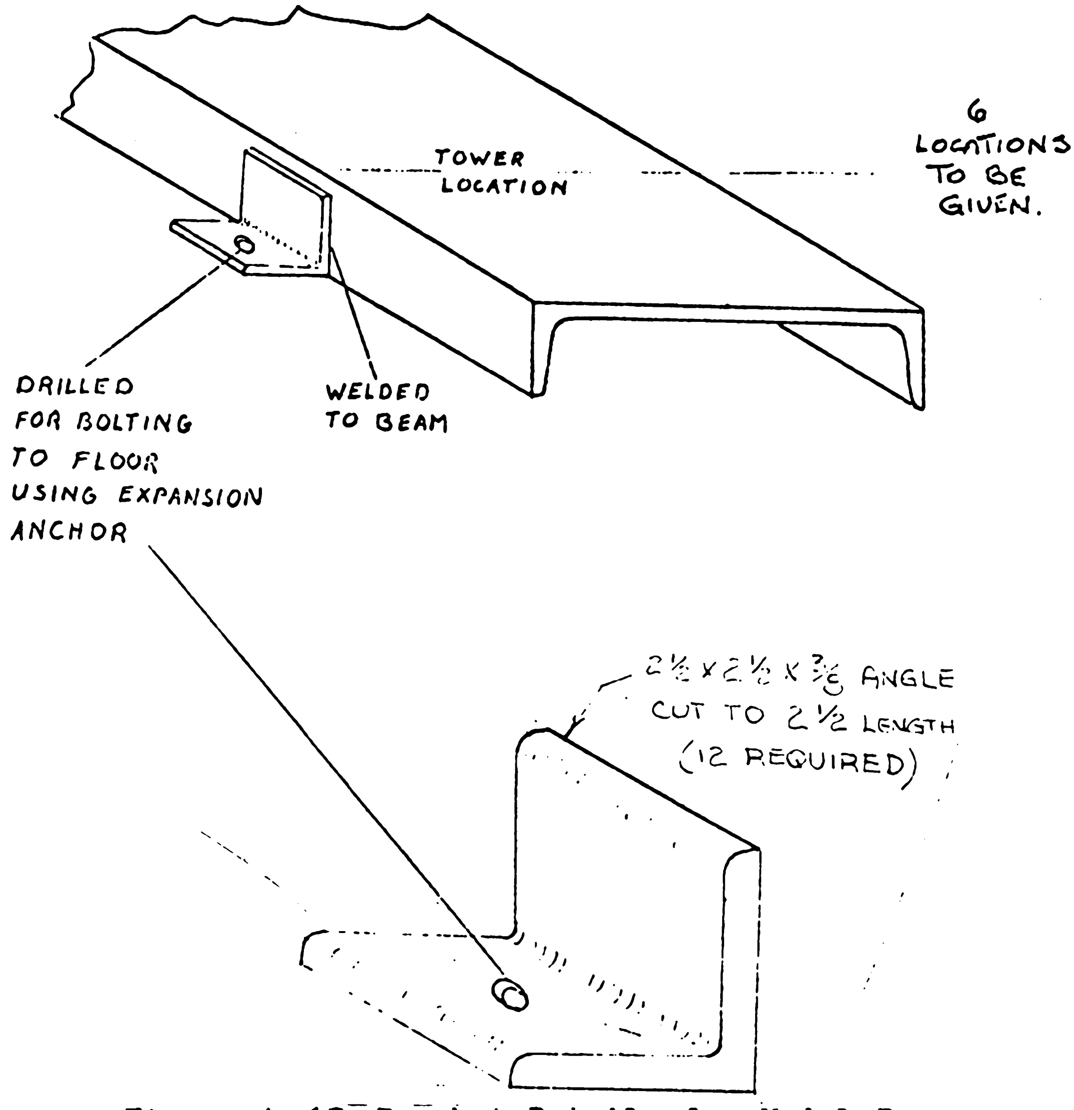


Figure A—17 Bracket Details for Model Base

LOCATION OF BRACKETS FOR SECURING BEAM (TRACKWAY BASE)

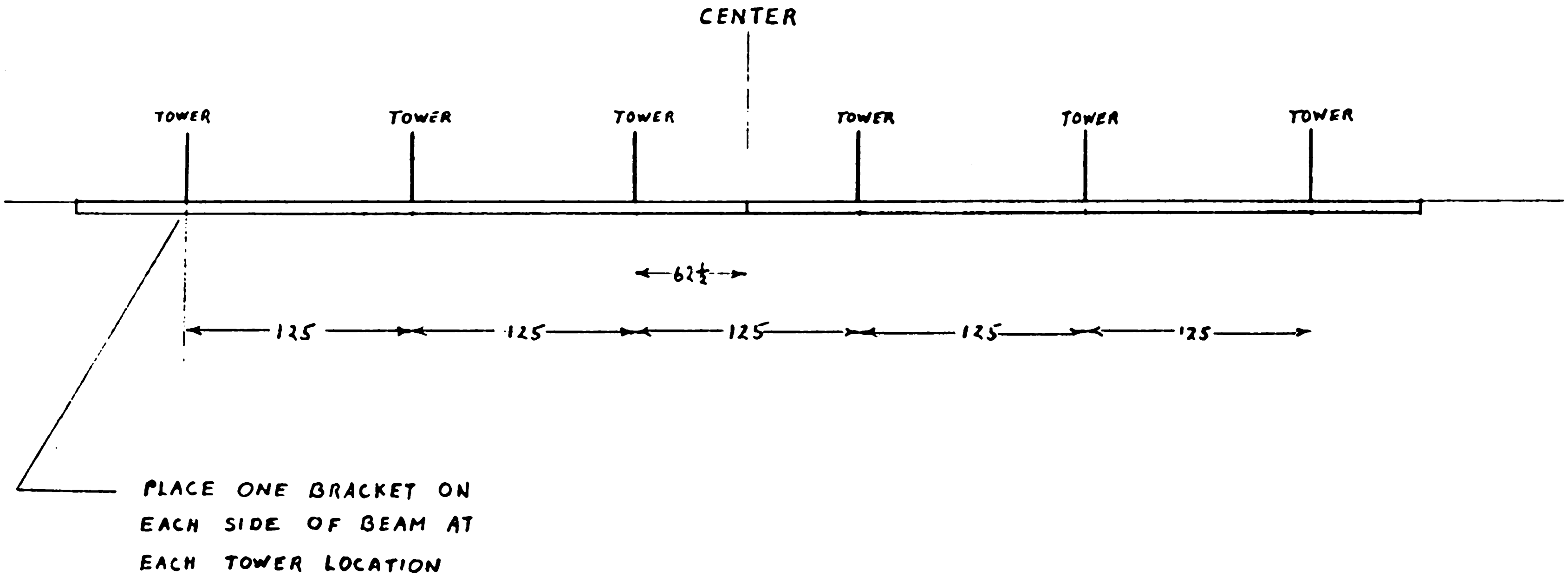


Figure A-18 Bracket Details for Model Base

LOWER CABLE ATTACHMENT

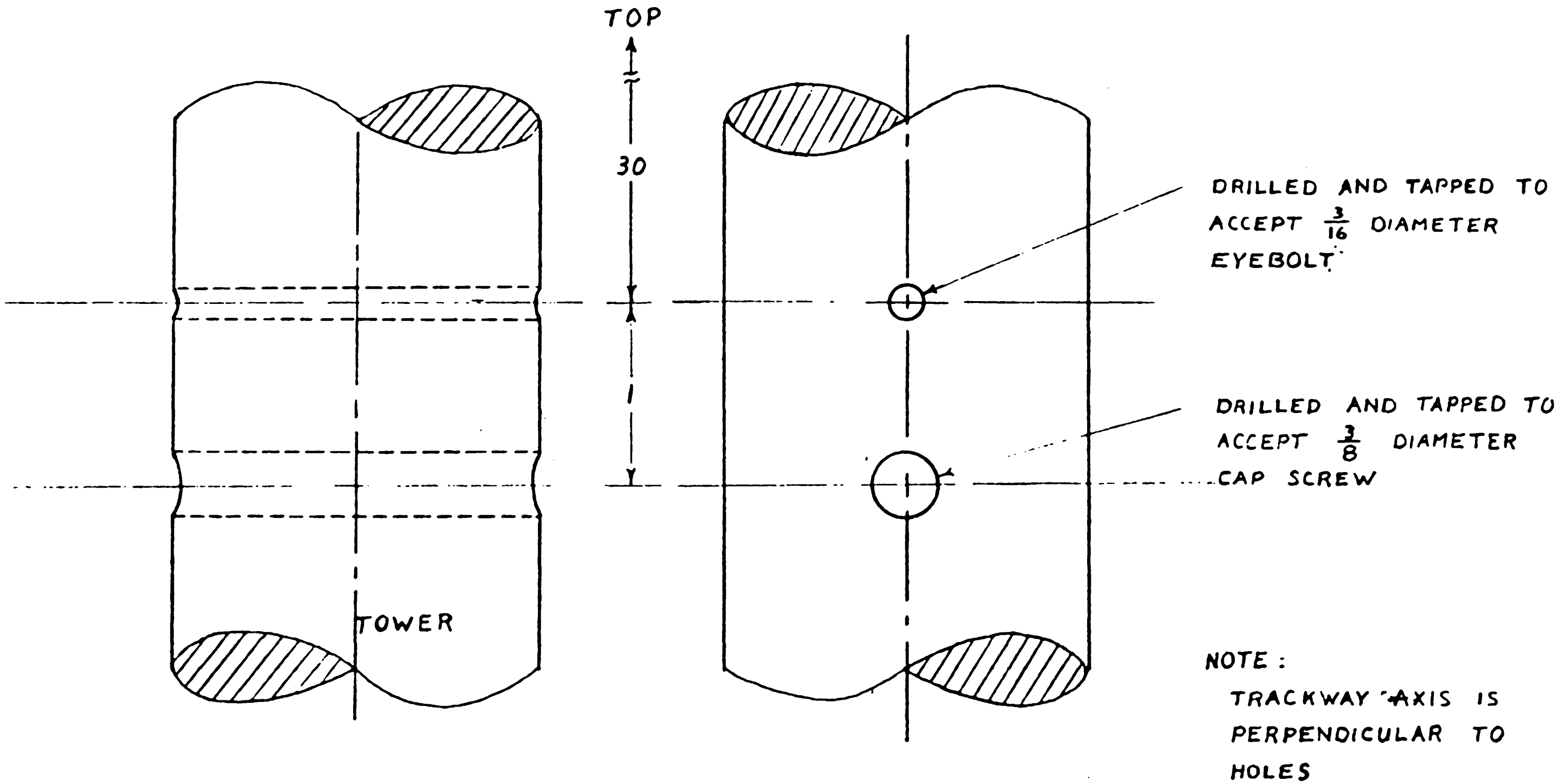


Figure A-19 Hole Locations for Lower Cable Attachments

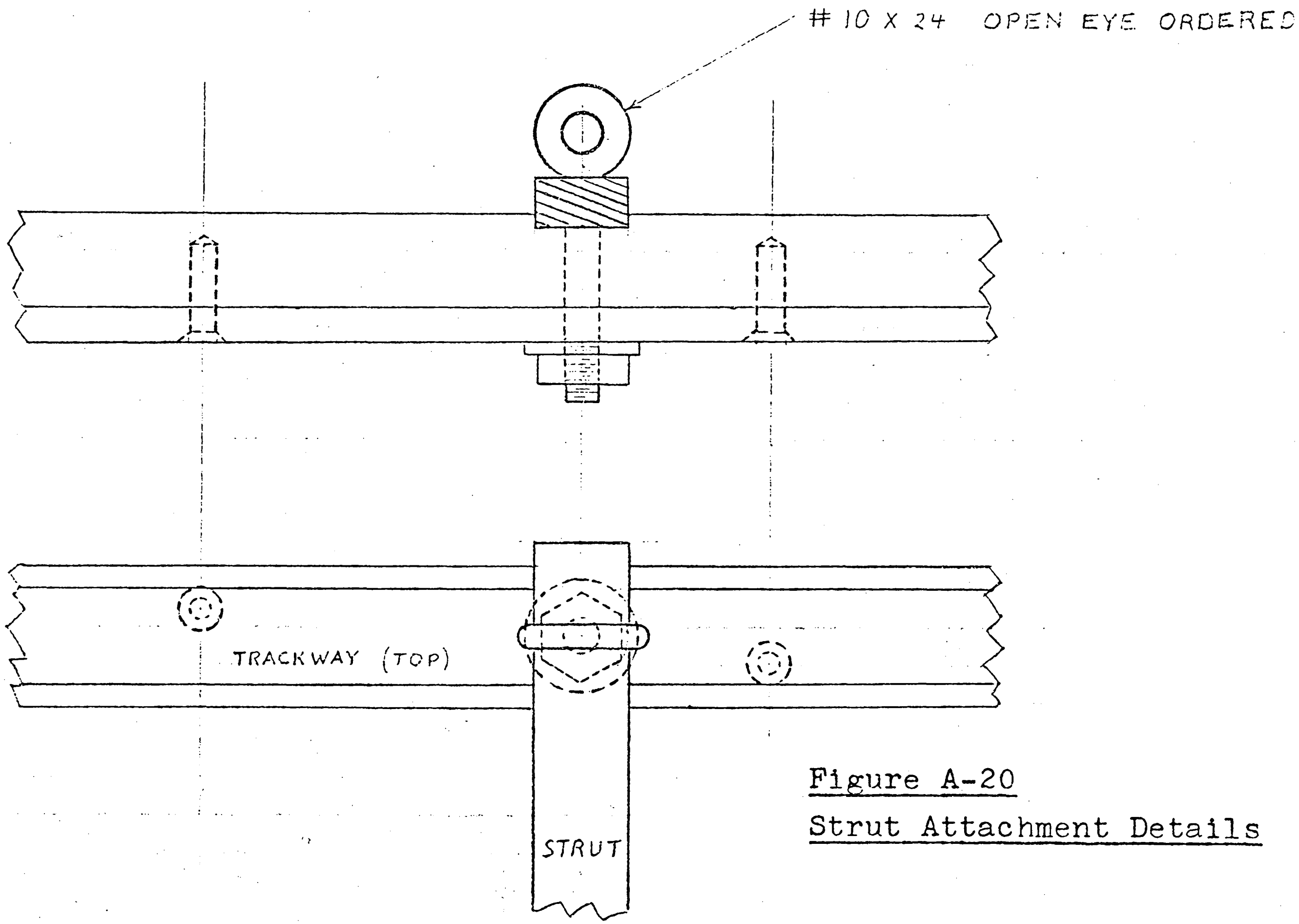


Figure A-20

Strut Attachment Details

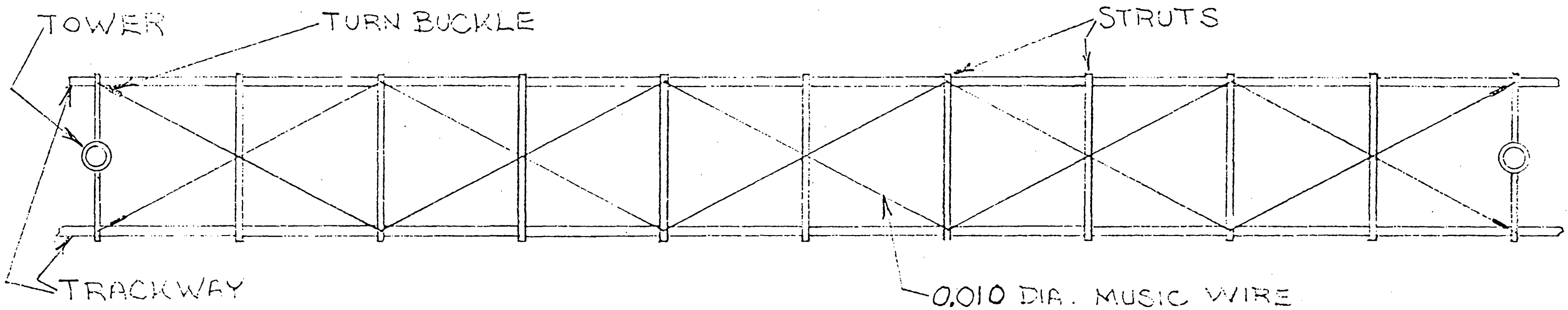


Figure A-21 Trackway Truss Assembly

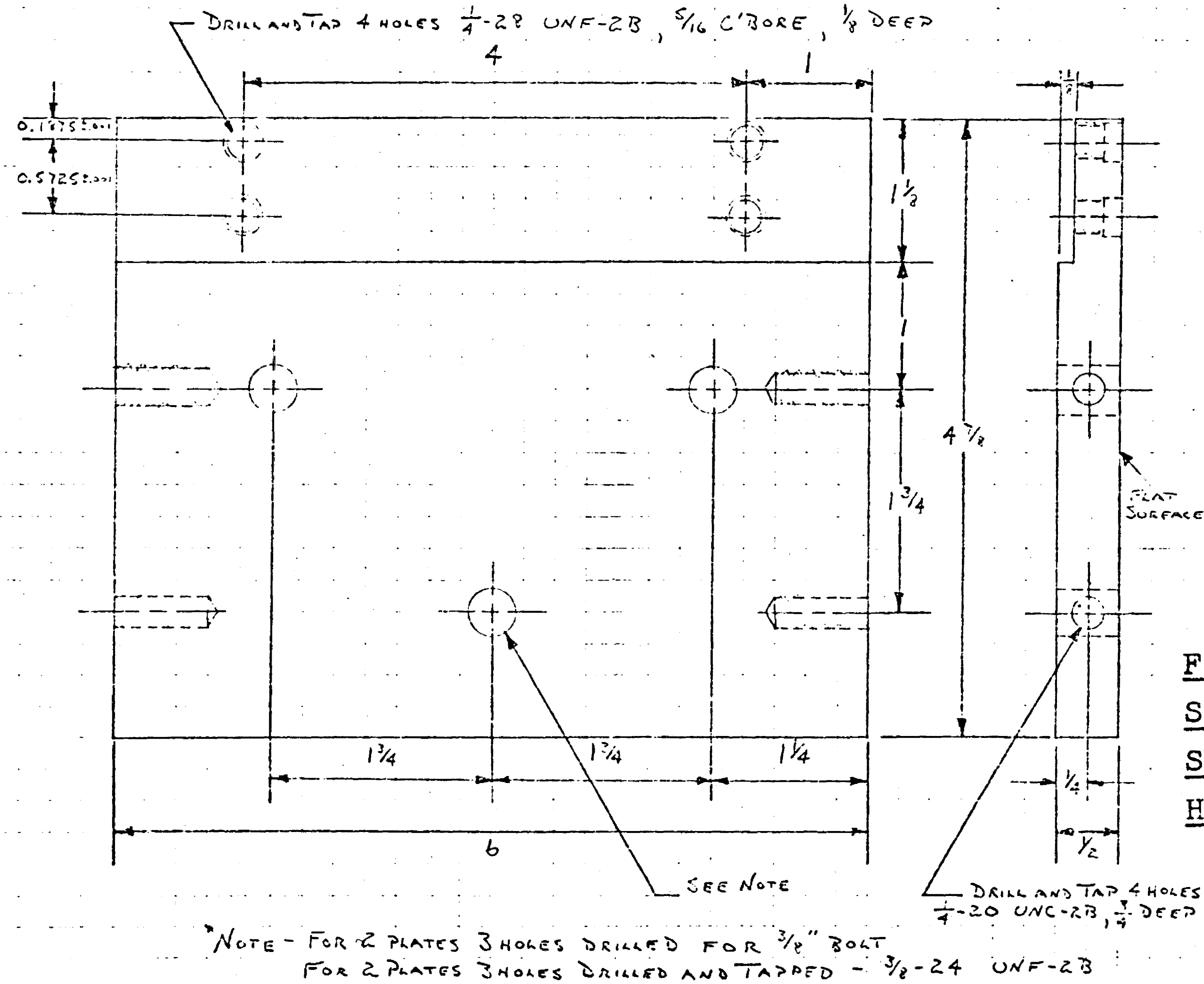


Figure A-22

Side Plates for

Single Bogey and

Heavy Bogey

MODEL CAR
SIDE PLATE - DETAIL (TYP.)
(ALUMINUM - 4 REQUIRED)

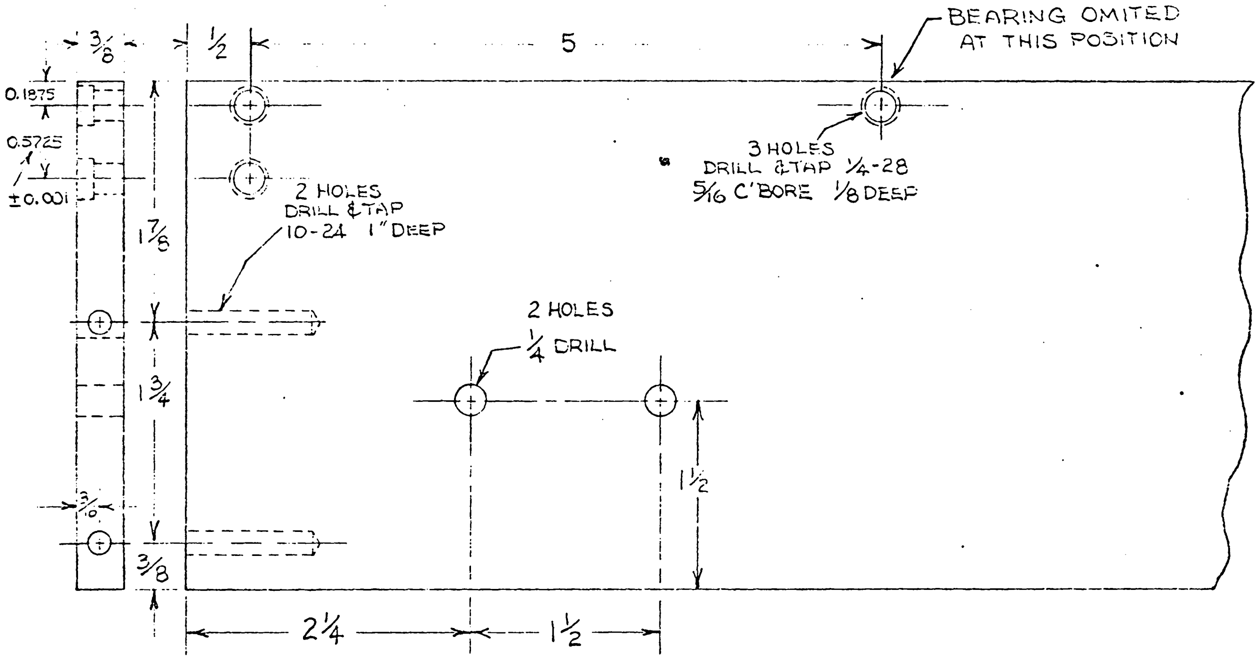
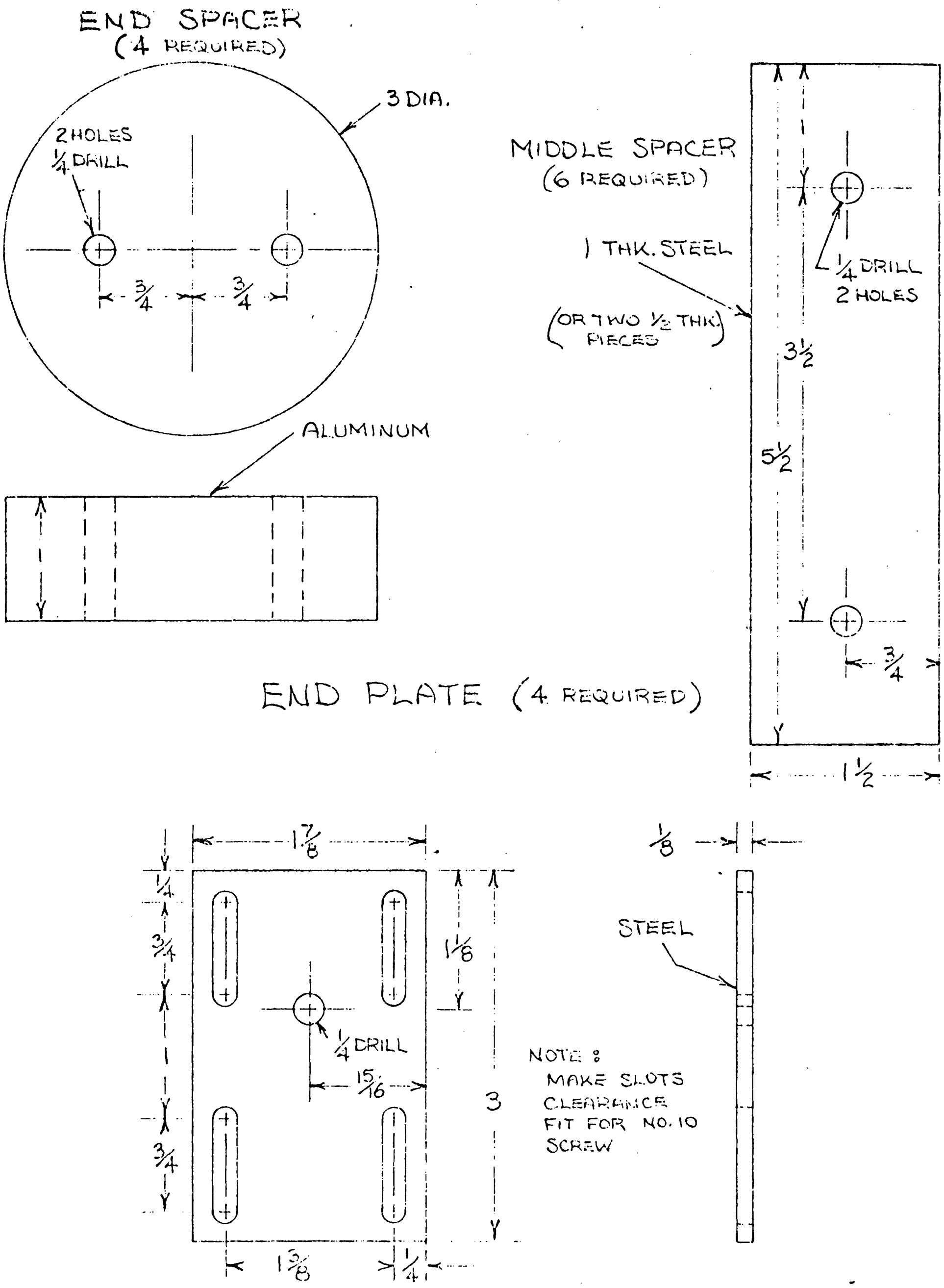


Figure A-23 Side Plate for Single Car

FULL SIZE
DRAWN: JTS 4-21-73



FULL SIZE
DRAWN: JTS 4-21-[illegible]

Figure A-24

Center Spacers and End Plates for Single Car

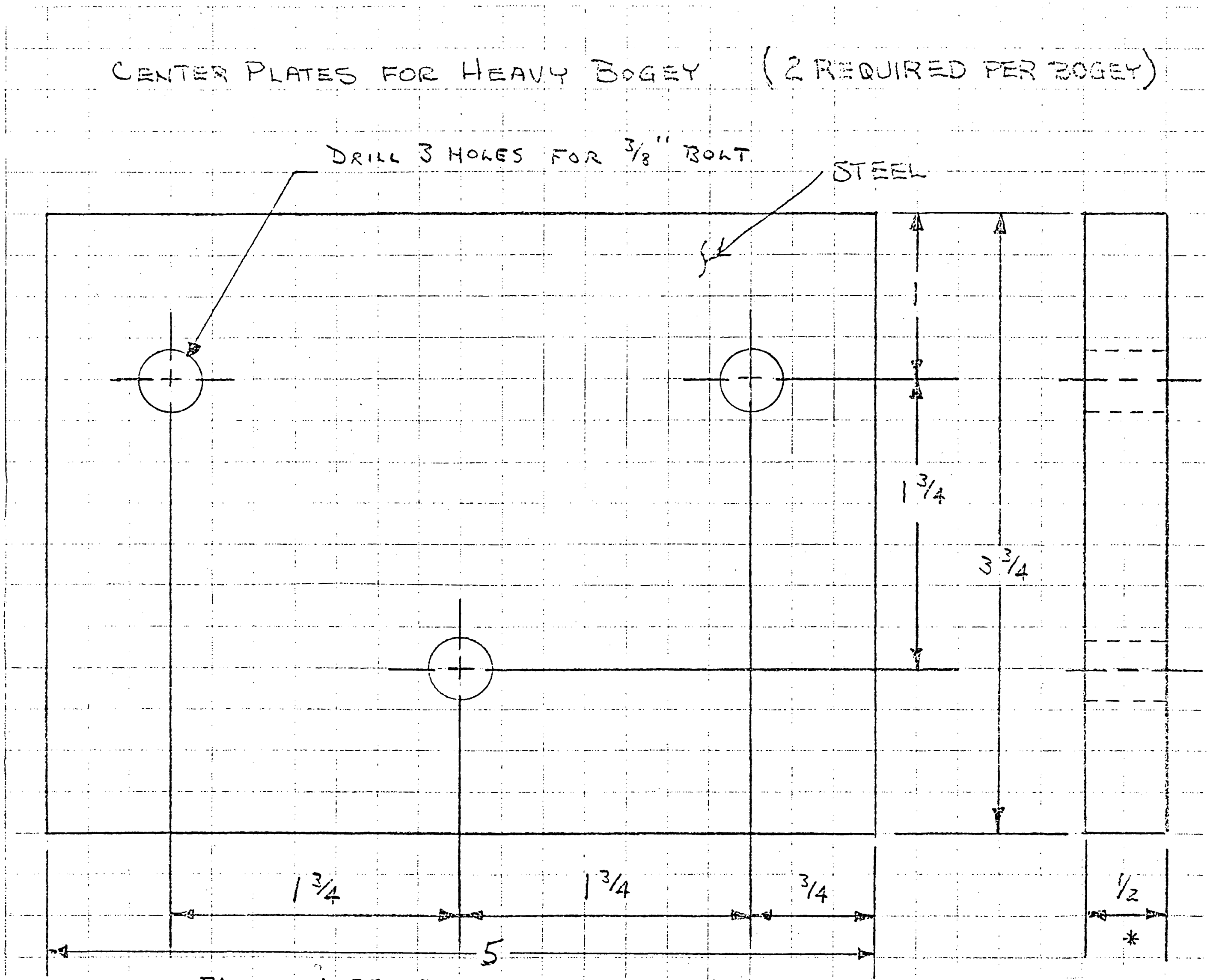


Figure A-25 Center Plates for Heavy Bogey

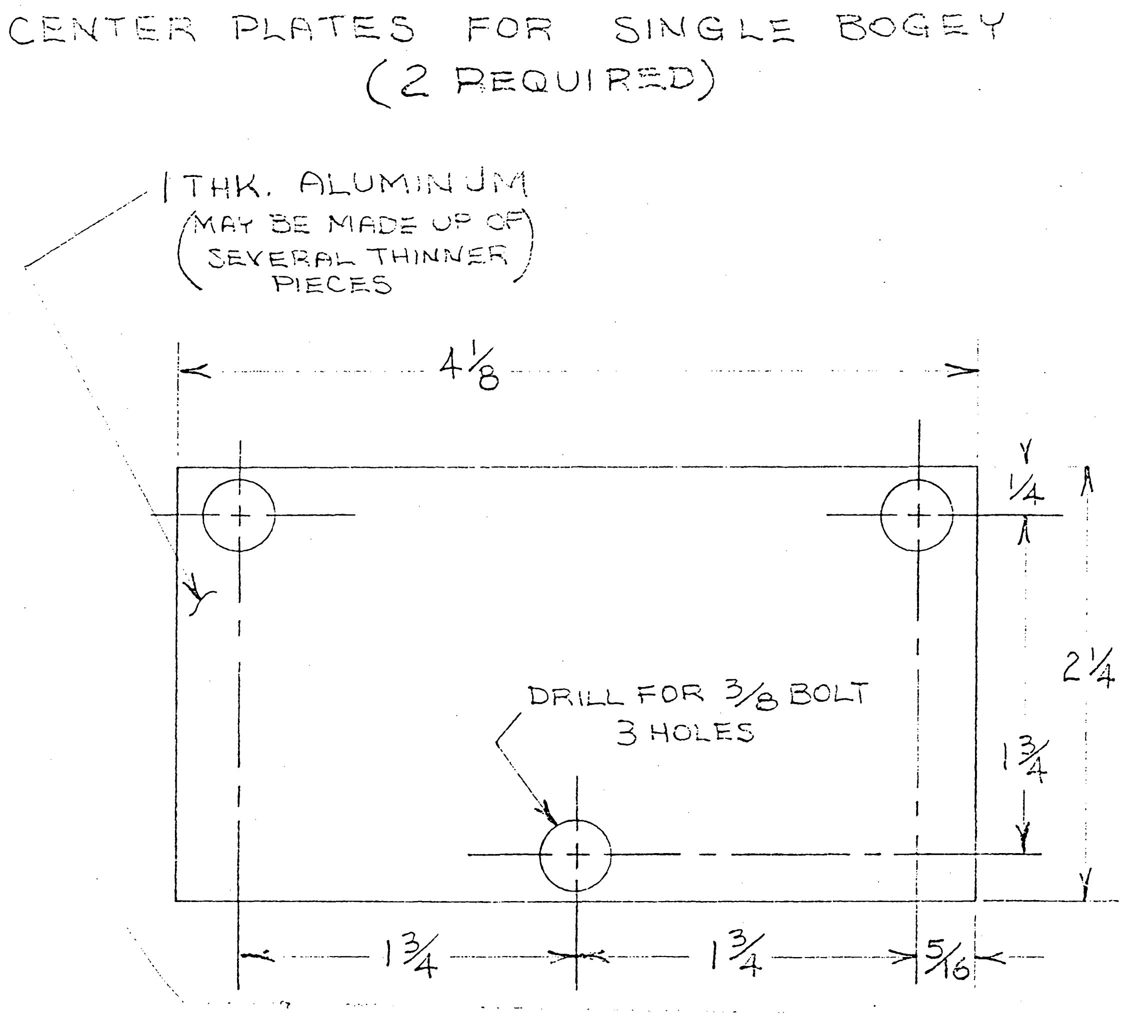


Figure A-25 Center Plates for Single Bogey

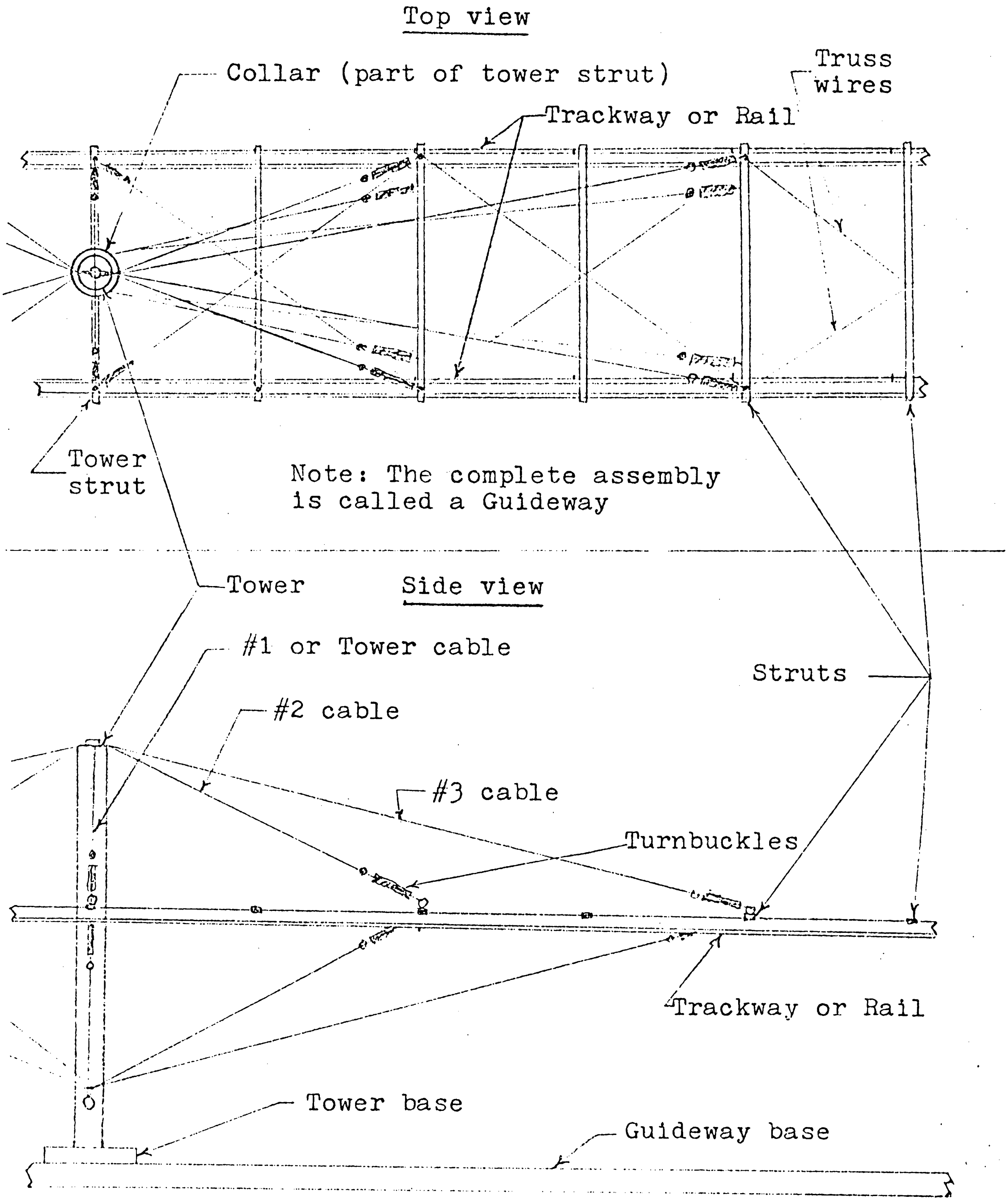


Figure A-26 Nomenclature Relating to the SVS Model

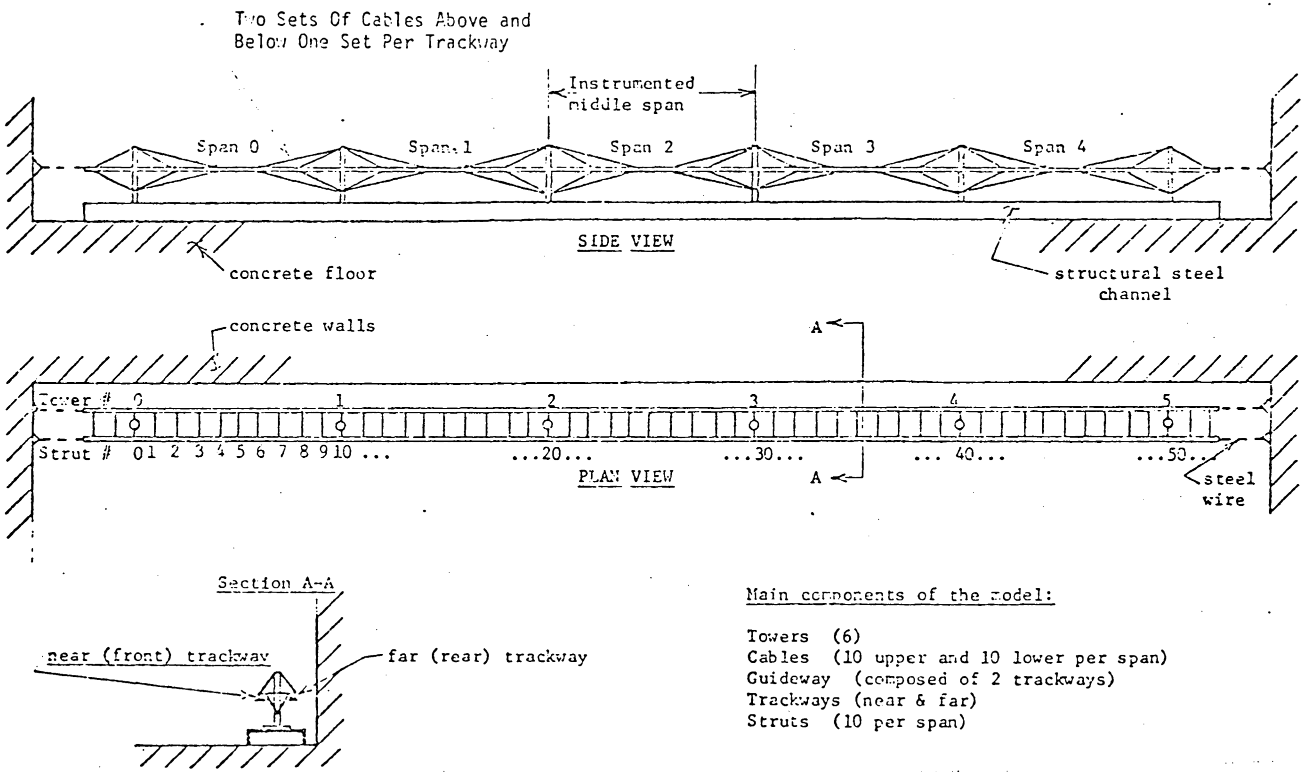
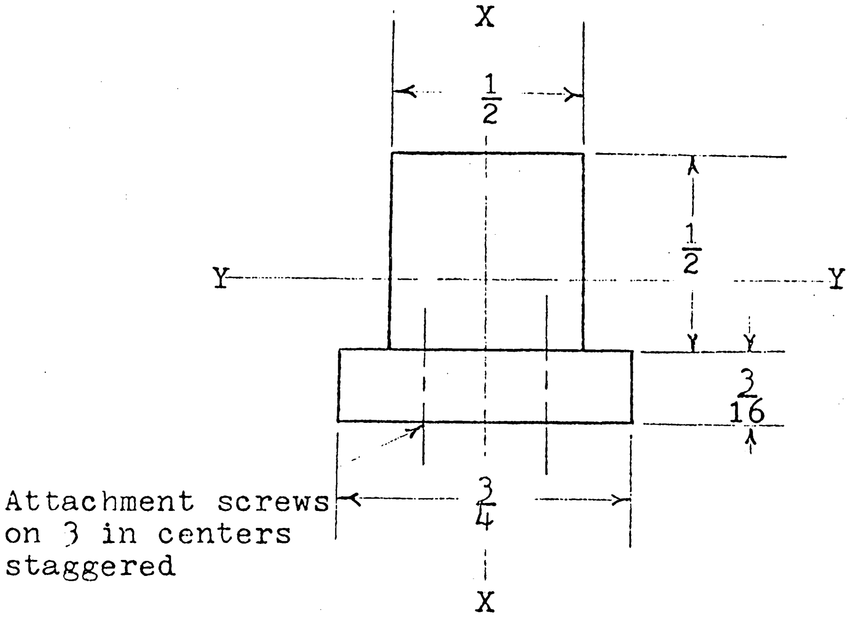


Figure A-27 Additional Nomenclature Relating to the SVS Model



Material: Drawn brass rod, ASTM B-16 SAE-72

Properties of Selected Trackway Section

Section data		Model	Prototype	Scale factor
Area	in^2	0.3906	40.0	102.4
I_x	in^4	0.0162	10,000	617,300
I_y	in^4	0.0118	7450	617,300
Density	lb/ft^3	530	487	0.92
Weight distribution	lb/ft	1.40	135	92.2
Modulus of elasticity	lb/in^2	15×10^6	30×10^6	2.0

Figure A-28

Model Trackway Cross Section

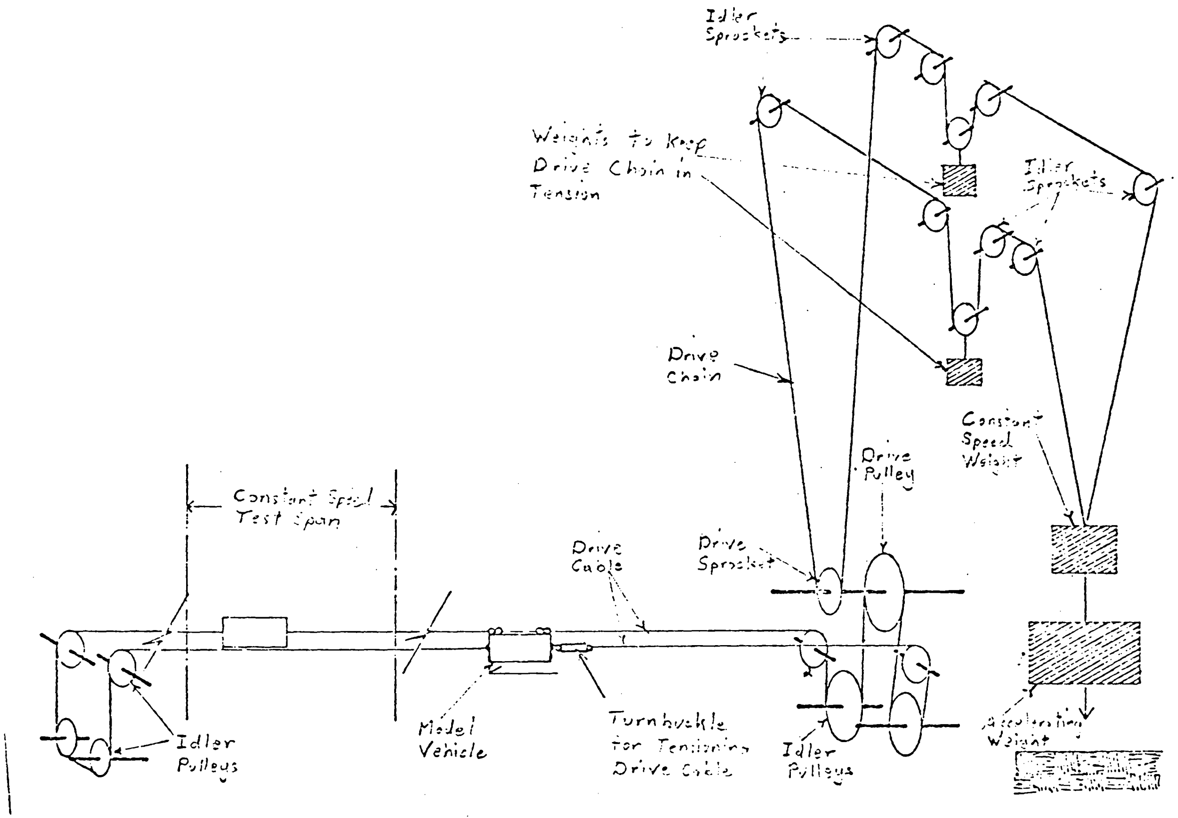
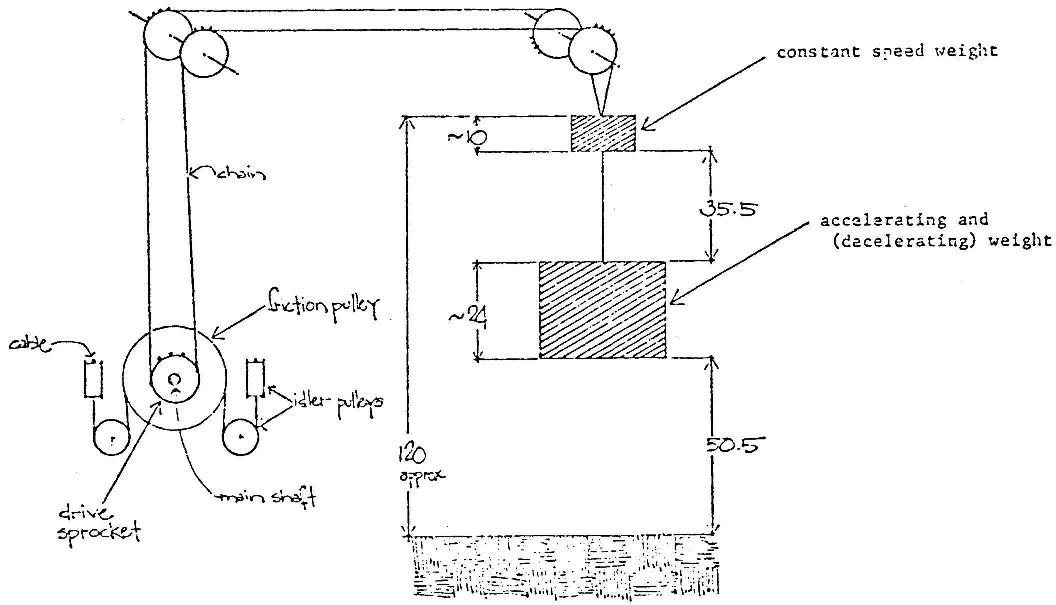


Figure A-29 Diagram of Propulsion System for SVS Model



2 cars of 17.7 lbs each = 35.4 lbs

force needed to accelerate at 3.23g = (35.4)(3.23) = 114.5 lbs
weight needed at 4.36 drive ratio = (114.5)(4.36) = 500 lbs

Figure A-30 Design Considerations for SVS Model Propulsion System

APPENDIX B

LIST OF INSTRUMENTS USED IN THE SVS TEST PROGRAM

APPENDIX B

Recorders:

Sanborn 150
Model 152-10013
Serial number 366

Sanborn 150
Model 154-100B
Serial number 2063

Sanborn 150
Model 154-100B
Serial number 2034

Tape Recorder (Data Tape VR 3300)
Consolidated Electrodynamics
Type 12-305A
Serial number 14065

Accelerometer
Bruel & Kjaer Type 4314
Serial number 117921

Charge Amplifier
Kistler Model 566
Serial number 1364

Transducer Converter
Sanborn 592-300
Serial number 294-351

LVDTs

Schavitz	E200	E300
Serial numbers	5318	4422
	5320	4423
	5321	
	5322	
	5323	
	5325	
	5326	
	5327	
	5328	
	5334	

Frequency Analyzer
Spectral Dynamics
Model 330 Spectroscope

APPENDIX C

RESULTS FROM THE TESTING OF THE SVS MODEL

TEST LOG Phase I Static Tests

Test I	
Run 1	March 31, 1973 One 13.25 lb heavy bogey on near trackway. One vertical LVDT used.
Run 2	April 14, 1973 One 13.25 lb heavy bogey on near trackway. Six LVDTs and one strain gage used.
Run 3	May 27,1973 One 9.1 lb single bogey on near trackway. Ten LVDTs used.
Run 4	May 27, 1973 Same as Run 3.
Run 5	May 28, 1973 Same as Run 3.
Run 6	May 28, 1973 Same as Run 3.
Test V	
Run 1	April 19, 1973 Horizontal wind load test simulating 150 mph wind load with no vehicles on guideway.
Test VII	
Run 1	June 8, 1973 Wind load test with 60 mph wind load and one 17.9 lb single car on each trackway.

TEST LOG Phase I Static Tests

Test I-A Static Tests With Cables	
Run 1	June 14, 1973 Static test with one 9.1 lb single bogie with 1/8 in cable on near trackway.
Run 2	June 14, 1973 Same as Run 1.
Run 3	June 14, 1973 Static test with one 17.9 lb single car with 1/8 in cable on near trackway.
Run 4	June 14, 1973 Same as Run 3.

SUSPENDED VEHICLE SYSTEM

Phase I, Test I
Run 1

Displacement of Transducer Number 1			
Vehicle Location (Strut Number)	Displacement (inches x 10^3)	Vehicle Location (Strut Number)	Displacement (inches x 10^3)
10	0.0	27	-60
11	+0.25	28	-26
12	+1.0	29	-8.5
13	+2.5	30	-1.0
14	+5.0	31	+3.75
15	+8.0	32	+6.75
16	+10.25	33	+9.0
17	+9.75	34	+10.0
18	+7.5	35	+8.0
19	+5.0	36	+5.25
20	0.0	37	+3.0
21	-7.5	38	+1.5
22	-25	39	+0.25
23	-59.5	40	0.0
24	-96.5		
25	-120		
26	-97		

SUSPENDED VEHICLE SYSTEM

Phase I, Test I
Run 2

Transducer Number	1	2	3	4	5	6	7	8	9	S
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									Strain μin/in
00	0	0		0	0		0	0		0
01	0	0		0	0		0	0		0
02	0	0		0	0		0	0		0
03	-1.2	-1.2		0	0		0	0		0
04	-1.8	-1.8		0	0		0	0		0
05	-1.8	-1.8		0	0		0	0		0
06	-1.8	-1.8		0	0		0	0		0
07	-1.2	-1.2		0	0		0	-0.25		0
08	-0.6	-0.6		0	0		0	-0.25		0
09	0	0		0	0		0	-0.25		0
10	0	0		0	0		0	0		0
11	+1.2	0		0	0		0	0		0
12	+6.0	+1.2		+1.5	+0.75		0	0		0
13	+10.8	+6.0		+2.5	+2.5		0	0		0
14	+16.8	+11.4		+4.0	+4.75		0	0		2
15	+21.0	+13.2		+5.5	+6.25		0	0		30
16	+20.2	+12.0		+7.0	+6.25		0	-0.5		20

SUSPENDED VEHICLE SYSTEM

Phase I, Test I
Run 2

Transducer Number	1	2	3	4	5	6	7	8	9	S
Vehicle location (Strut Number)	Displacement (inches x 10^3)									Strain in/in
17	+15.0	+10.8		+7.5	+5.75		-0.5	-0.5		0
18	+7.8	+6.0		+7.0	+5.0		-0.5	-0.5		0
19	-1.2	0		-12.5	+0.75		-0.5	-0.5		0
20	-1.8	-1.8		-47.5	-2.5		-0.5	0		70
21	-66	-7.2		-40	-3.75		-1.25	0		100
22	-120	-15		-25.0	-3.7		-2.5	0		0
23	-127	-22.8		-16.3	-3.0		-2.5	-0.5		-420
24	-128	-25.2		-9.5	-2.0		-9.5	-2.25		-920
25	-126	-21		-5.0	-0.5		-17.0	-3.5		-420
26	-120	-15		-2.25	0		-26.3	-4.75		0
27	-66	-6.6		-1.25	0		-40.5	-4.75		90
28	-24	-1.8		-0.5	-0.5		-48.8	-2.5		60
29	-6.0	0		-0.5	-0.5		-11.3	-1.75		0
30	+6.0	+4.8		0	-0.75		+2.5	+5.0		0
31	+12	+9		0	-0.75		+3.75	+7.0		0
32	+18	+12		0	-0.5		+3.25	+7.5		20
33	+19.8	+13.8		0	0		+2.5	+7.0		20

SUSPENDED VEHICLE SYSTEM

Phase I, Test I

Transducer Number	1	2	3	4	5	6	7	8	9	S
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									Strain in/in
34	+15	+12		0	0		+2.0	+5.0		0
35	+9.0	+6.0		0	0		0	+2.5		0
36	+4.8	+3.0		0	0		0	0		0
37		0		0	0		0	0		0
38		0		0	0		0	0		0
39		0		0	0		0	0		0
40		0		0	0		0	0		0
41		0		-0.25	0		0	0		0
42		0		-0.25	0		0	0		0
43		0		0	0		0	-0.25		0
44		0		0	0		0	-0.25		0
45		0		0	0		0	-0.20		0
46		0		0	0		0	-0.20		0
47		0		0	0		0	-0.20		0
48		0		0	0		0	0		0
49		0		0	0		0	0		0
50		0		0	0		0	0		0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I
Run 3

Transducer Number	1	2	3	4	5	7	8	9	10	11
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-82	-16	-10	-10	-64	-18	-3	-6	-1	-1
26	-66	-14	-10	-10	-76	-27	-5	-7	-2	-1.5
27	-40	-8	-8	-8	-55	-37	-5	-7	-2.8	-1.5
28	-16	-3	-5	-4	-25	-35	-3	-6	-4	-1.5
29	-3	+2	-3	-2	-6	-23	0	-4	-7	-1.5
30	+2	+4	-1	0	+3	-2	+2.5	-1	-9	-1.5
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I

Run 4

Transducer Number	1	2	3	4	5	7	8	9	10	11
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-84	-16	-10	-10	-64	-17	-3	-9	-1.2	-1.2
26	-66	-14	-10	-9	-76	-28	-5	-9	-2	-1.5
27	-40	-8	-8	-8	-56	-35	-5	-9	-2.5	-1.5
28	-16	-3	-6	-5	-27	-35	-3	-8	-4	-1.5
29	-4	+1	-3	-2	-8	-23	0	-5	-7	-1.5
30	+2	+4	-2	0	+1	-2	+3	-2	-9	-1.5
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I
Run 5

Transducer Location	1	2	3	4	5	7	8	9	10	11
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-85	-16	-10	-10	-68	-20	-2	-8	-1	-1
26	-68	-14	-9	-9	-80	-36	-4	-8	-1	-1
27	-42	-10	-8	-8	-60	-40	-4	-7	-2	-1
28	-16	-4	-4	-4	-28	-39	-2	-5	-3	-1
29	-3	0	0	-1	-8	-24	0	-3	-5.5	-0.8
30	+1	+2	0	0	0	-3	+4	-1	-7.5	-0.8
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I
Run 6

Transducer Number	1	2	3	4	5	7	8	9	10	11
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-87	-16	-10	-10	-70	-16	-4	-8	-1	-1
26	-68	-13	-9	-9	-75	-33	-6	-8	-1	-1
27	-41	-8	-7	-8	-56	-38	-6	-8	-2	-1
28	-16	-3	-3	-4	-24	-37	-4	-5	-3	-1
29	-3	0	0	-1	-6	-22	-1	-2	-5	-1
30	+1	+2	0	-1	+2	-1	+2	0	-7	-1
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test V

Transducer Number	1	2	3	4	5	6	7	8	9	S
Wind Load Applied at Strut Number	Displacement (inches x 10^3)									
00			0			0			0	
01			0			0			0	
02			0			0			0	
03			0			0			0	
04			0			0			0	
05			0			0			0.1	
06			0			0			0.2	
07			0			0			0.2	
08			0			0			0.2	
09			0			0			0.2	
10										
11			0			0.1			0.3	
12			0			0.1			0.3	
13			0			0.2			0.3	
14			0			0.2			0.3	
15			0			0.2			0.7	
16			0			0.2			0.8	

SUSPENDED VEHICLE SYSTEM

Phase I, Test V

Transducer Number	1	2	3	4	5	6	7	8	9	S
Wind Load Applied at Strut Number	Displacement (inches x 10^3)									
17			0			0.2			0.8	
18			0			0.2			0.8	
19			0			0.2			1.2	
20										
21			2.8			0			7.5	
22			8.8			1.2			12.5	
23			20.4			3.2			18.5	
24			32			5.0			21	
25			50			9.0			23.5	
26			60.8			14			25.3	
27			68.4			18.5			26	
28			75.2			25.5			26.6	
29			76			28.8			26.8	
30										
31			76			28			26.7	
32			75.2			27.2			26.7	
33			74.8			27			26.7	

SUSPENDED VEHICLE SYSTEM

Phase I, Test V

Transducer Number	1	2	3	4	5	6	7	8	9	S
Wind Load Applied at Strut Number	Displacement (inches x 10^3)									
34			74.4			26.9			26.7	
35			74.0			26.8			26.7	
36			74.0			26.8			26.5	
37			74.0			26.8			26.5	
38			74.0			26.6			26.5	
39			72.4			26.2			26.2	
40										
41			72			26			26	
42			72			26			26	
43			72			26			26	
44			72			26			26	
45			72			26			26	
46			72			26			26	
47			72			26			26	
48			72			26			26	
49			72			26			26	
50										

SUSPENDED VEHICLE SYSTEM

Phase I, Test V

Transducer Number	1	2	3	4	5	6	7	8	9	S
	Displacement (inches x 10^3)									
Wind Load Removed from Span 4			70.8			26			27	
Wind Load Removed from Span 0			71.6			26			27	
Wind Load Removed from Span 3			72			28			27	
Wind Load Removed from Span 1			70			28			25	
Wind Load Removed from Span 2			2			0			0	

SUSPENDED VEHICLE SYSTEM

Phase I, Test VII

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
01	-4.8	+8	-19.2	-20	-8	-6	+2.8	-14.4	-3	-12
02	-4.8	+8	-19.2	-20	-8	-6	+2.8	-14.4	-3	-12
03	-5.8	+8	-19.2	-20	-8	-6	+2.8	-14.6	-2.6	-12
04	-6.4	+6.4	-19.2	-20	-8	-6	+1.2	-14.4	-2.6	-12
05	-8	+6.4	-19.2	-20	-8	-6	+0.8	-14.6	-2	-12
06	-8	+6.4	-19.2	-20	-8	-6	+0.8	-14.6	-2	-12
07	-8	+6.4	-19.2	-20	-8	-6	0	-14.6	-2	-12
08	-8	+6.4	-19.2	-20	-8	-4.8	0	-14.6	-2	-12
09	-8	+6.4	-19.2	-20	-6.4	-4	0	-15	-2	-12.6
10	-5.6	+8	-19.2	-20	-6.4	-4	0	-15	-2	-13.6
11	-3.2	+8	-19.2	-20	-6.4	-4	+0.8	-16	-2.4	-14
12	0	+12	-20	-20	-2.4	-4	+3.2	-16	-2.6	-15.4
13	+8	+16	-20	-20	0	-2	+6.0	-17	-3.4	-17
14	+20	+24	-20	-20	+8	+1.2	+9.8	-18	-4	-18
15	+32	+32	-22	-23	+16	+5.2	+10	-19	-4.4	-20
16	+38	+36	-22	-23	+18	+6.8	+32	-20	-6	-22

SUSPENDED VEHICLE SYSTEM

Phase I, Test VII

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
17	+38	+36	-23	-24	+17.7	+7.2	+17.2	-21	-9.6	-24
18	+32	+32	-24	-25	+16	+8	+16	-22	-14	-28
19	+16	+22.4	-23	-24	+8	-4	+12	-24	-17.6	-28
20	-6.4	+8	-26	-27	-9.6	-32	+4.8	-30	-18	-28
21	-50	-18	-29	-30	-48	-53	-2	-35	-13.6	-27
22	-100	-52	-35	-36	-84	-68	-8	-38	-8	-24
23	-150	-96	-40	-42	-128	-80	-16.8	-38	-4	-22
24	-151	-136	-48	-48	-153	-70	-29	-36	-1	-20
25	-151	-146	-53	-53	-153	-58	-44	-32	-0.4	-19.4
26	-151	-144	-54	-54	-136	-44	-58	-30	0	-18
27	-149	-104	-48	-48	-91	-58	-64	-27	0	-18
28	-104	-60	-36	-36	-56	-22	-56	-23	-0.4	-17
29	-42	-24	-28	-29	-26	-12	-46	-20	-0.4	-16.6
30	-8	0	-26	-27	-8	-5.2	-23	-19	0	-16
31	+16	+14	-22	-23	+3.2	+2	-1.2	-17	0	-15
32	+28	+24	-23	-24	+14	+8	+12	-18	-0.4	-14.6
33	+40	+31	-23	-24	+18	+11.2	+15	-18	0	-14

SUSPENDED VEHICLE SYSTEM

Phase I, Test VII

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
34	+40	+31	-23	-24	+18.4	+12	+14	-18	0	-13.6
35	+38	+28	-23	-24	+18.4	+12	+12	-18	0	-12.6
36	+24	+20	-22	-23	+10.4	+5.2	+8	-18	-0.6	-13.6
37	+16	+14	-22	-23	+8	+4	+5.2	-17	-1.4	-13.6
38	+8	+8	-22	-23	+8	+0.8	+3.2	-17	-2	-13
39	+1.6	+6.4	-22	-23	0	0	+0.8	-17	-2	-13
40	0	+4	-22	-23	-2.4	-1.2	0	-17	-2	-13.6
50	+4	+4	-22	-24	-6.4	-4	0	-17	-2	-14
Wind load only	+4	+4	-22	-24	-6.4	-4	0	-17	-2	-14
No load	0	0	-1.2	-2.5	-1.6	-2	-2	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I-A
Run 1

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-102	-24	-12	-12	-88	-20	-4	-9	-1.8	-1.5
26	-82	-20	-11	-10	-99	-34	-8	-10	-2.2	-1.5
27	-50	-16	-8	-8	-72	-44	-7	-9	-3.5	-1.5
28	-22	-6	-4	-4	-36	-48	-5	-7	-6	-1.5
29	-6	0	-2	-2	-14	-30	-2	-6	-10	-1.5
30	0	+1	0	0	-2	-2	+3	0	-13	-1.5
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I-A
Run 2

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-106	-24	-12	-11	-85	-22	-5	-8	-9	-2
26	-86	-22	-10	-9	-96	-34	-8	-7	-8	-2
27	-52	-16	-8	-8	-70	-44	-8	-9	-7	-1.5
28	-24	-8	-4	-5	-34	-43	-5	-7	-5	-1.5
29	-1	-6	-2	-2	-14	-30	-2	-4	-1	-2
30	0	-2	0	0	-2	-4	+2	0	+2	-2
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I-A
Run 3

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-130	-32	-18	-17	-122	-36	-8	-13	-2	-2
26	-124	-30	-16	-16	-120	-52	-10	-14	-3	-2
27	-90	-22	-14	-14	-104	-63	-10	-14	-6	-3
28	-52	-14	-9	-8	-71	-56	-8	-12	-11	-4
29	-24	-5	-6	-5	-37	-42	-3	-9	-15	-4
30	-7	+3	-2	-2	-10	-24	+4	-5	-15	-4
50	0	0	0	0	0	0	0	0	0	0

SUSPENDED VEHICLE SYSTEM

Phase I, Test I-A
Run 4

Transducer Number	1	2	3	4	5	7	8	9	10	12
Vehicle Location (Strut Number)	Displacement (inches x 10^3)									
00	0	0	0	0	0	0	0	0	0	0
25	-140	-32	-18	-18	-120	-36	-3	-14	-2	-2
26	-130	-28	-16	-16	-120	-52	-10	-14	-3	-2
27	-92	-21	-13	-12	-102	-63	-10	-14	-6	-3
28	-54	-14	-9	-9	-68	-56	-8	-12	-11	-4
29	-24	-3	-5	-5	-30	-38	-2	-8	-15	-4
30	-4	+4	-1	-1	-6	-20	+4	-4	-15	-4
50	0	0	0	0	0	0	0	0	0	0

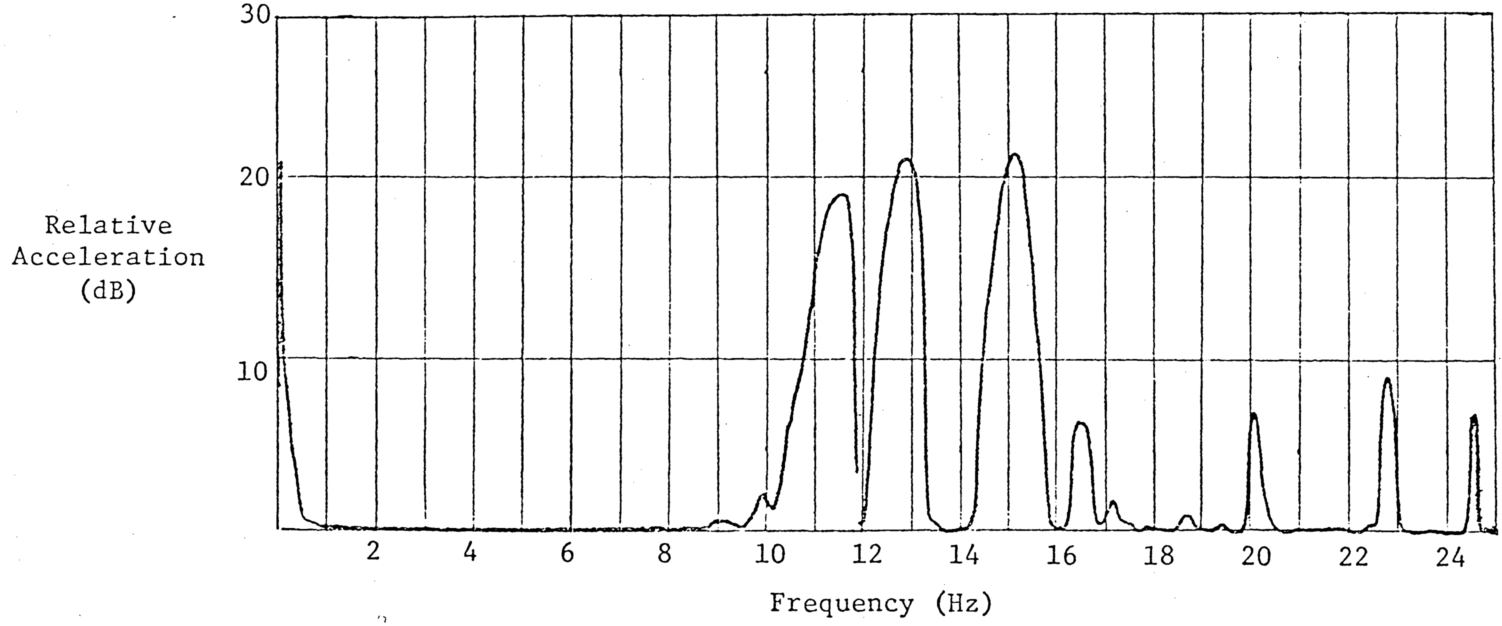
TEST LOG Phase II Free Vibration Tests

Test I	
Run A	May 23, 1973 13.25 lb force applied vertically to the center of the midspan strut, suddenly released, and the resulting vibrations recorded and analyzed* in the range 0-25 Hz.
Run B	May 23, 1973 Same as Run A except that the frequency analysis was in the range 0-100 Hz.
Run C	May 23, 1973 Same as Run A except that the frequency analysis was in the range 0-500 Hz.
Test V	
Run A	May 23, 1973 13.25 lb force applied horizontally to the midspan strut, suddenly released, and the resulting vibrations recorded and analyzed in the range 0-25 Hz.
Run B	May 23, 1973 Same as Run A except that the frequency analysis was in the range 0-100 Hz.
Run C	May 23, 1973 Same as Run A except that the frequency analysis was in the range 0-500 Hz.

*Spectral Dynamics Model 330 Spectroscope used for frequency analysis.

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

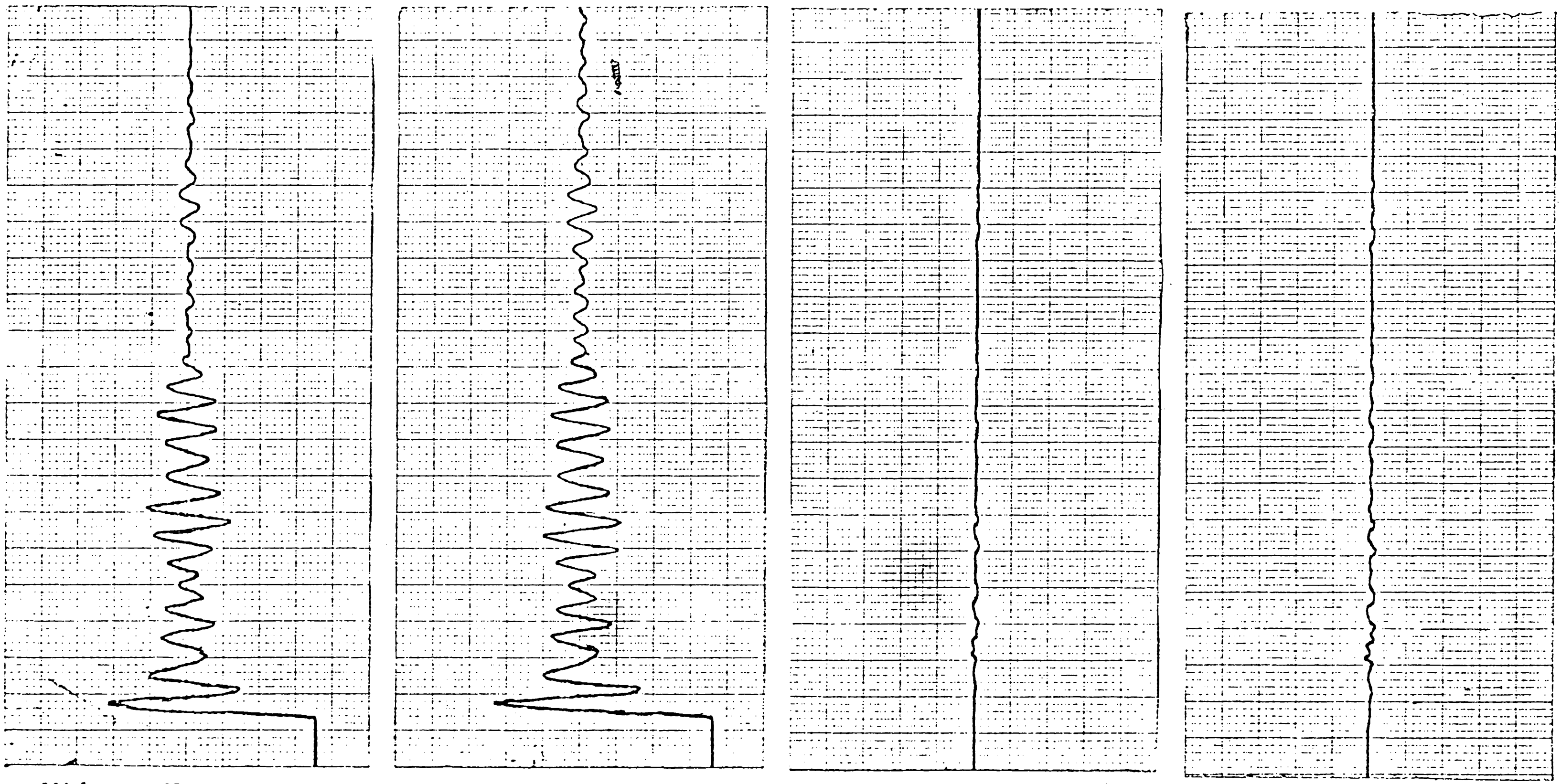
Phase II, Test I-A, Vertical Plucking Output of Real Time Frequency Analyzer *
[13.25 lb force applied vertically at midspan, strut center, suddenly released, and resulting vibrations and displacements recorded. Accelerometer used for Analyzer input.]



*Spectral Dynamics Model 330 Spectroscope

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test I-A



Midspan Near Trackway Vertical LVDT

Midspan Far Trackway Vertical LVDT

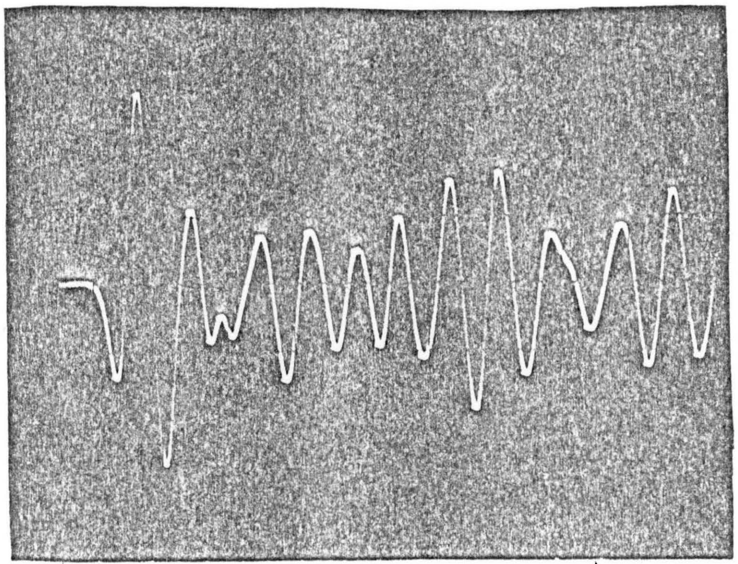
Midspan Far Trackway Horizontal LVDT

Midspan Near Trackway Horizontal LVDT

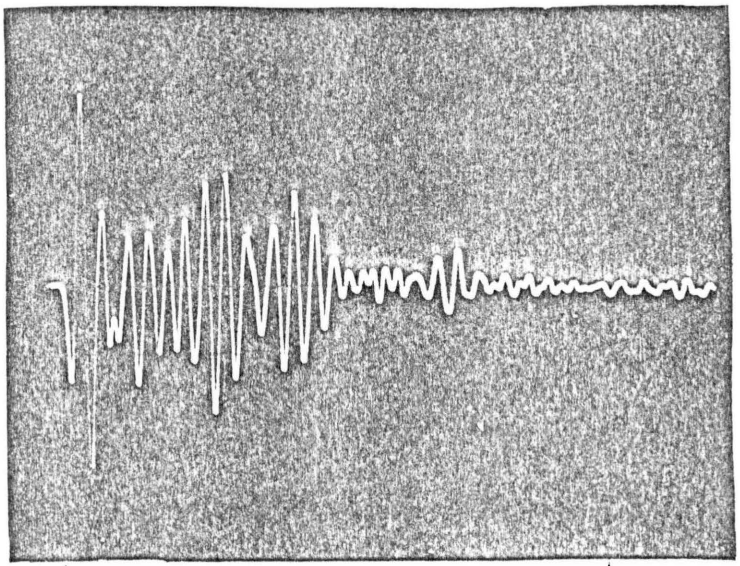
In all cases 1cm = 0.040 in and chart speed = 50 mm/sec

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test I-A, Output from Real Time Frequency Analyzer Memory. This is the signal analyzed in this test.



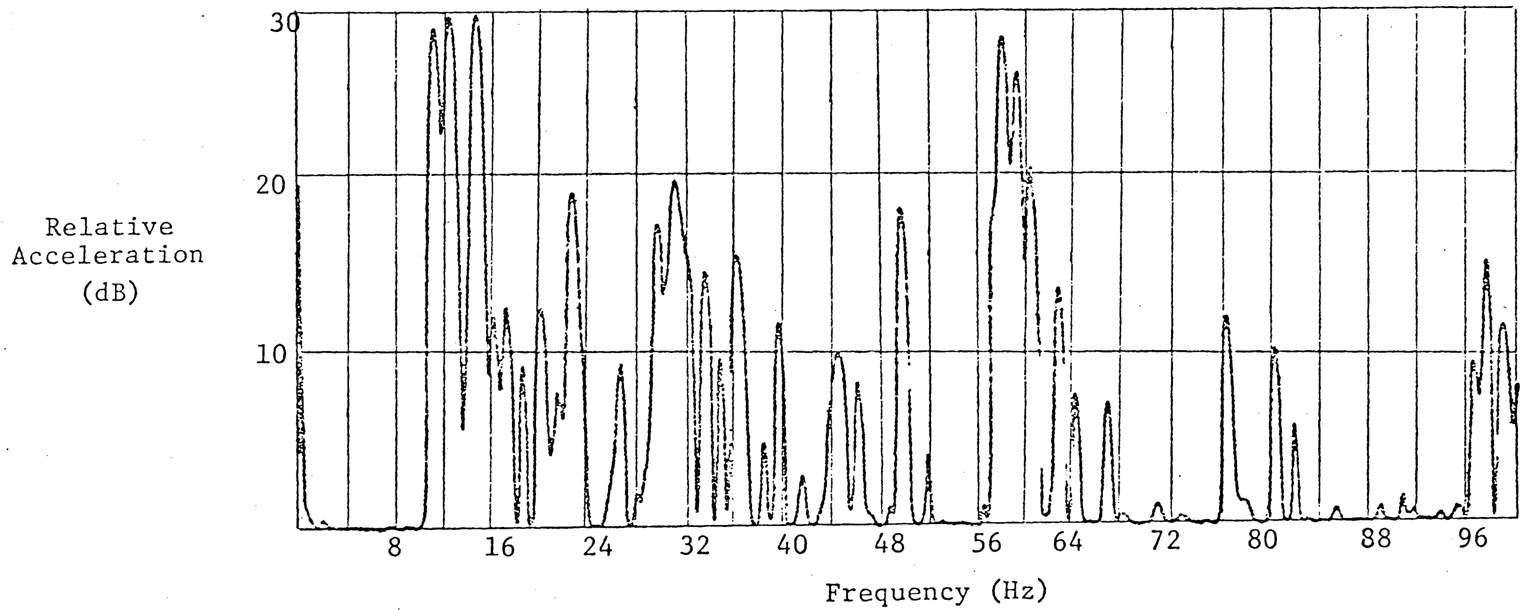
← Approximately one second →



← Approximately two seconds →

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

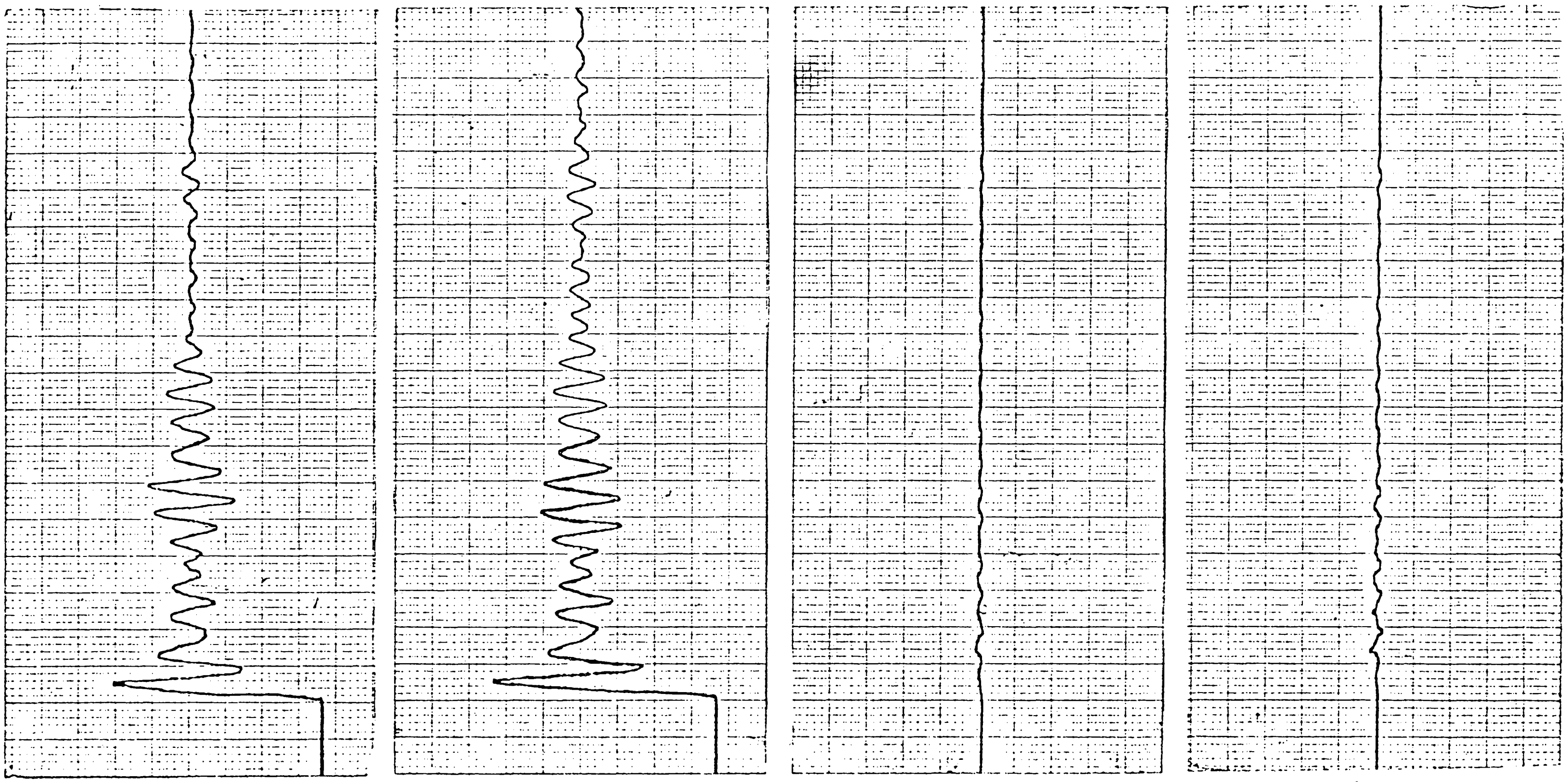
Phase II, Test I-B, Vertical Plucking Output of Real Time Frequency Analyzer*
[13.25 lb force applied vertically at midspan strut center, suddenly released, and resulting vibrations and displacements recorded. Accelerometer used for Analyzer input.]



*Spectral Dynamics Model 330 Spectroscope

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test I-B



Midspan Near Trackway Vertical LVDT

Midspan Far Trackway Vertical LVDT

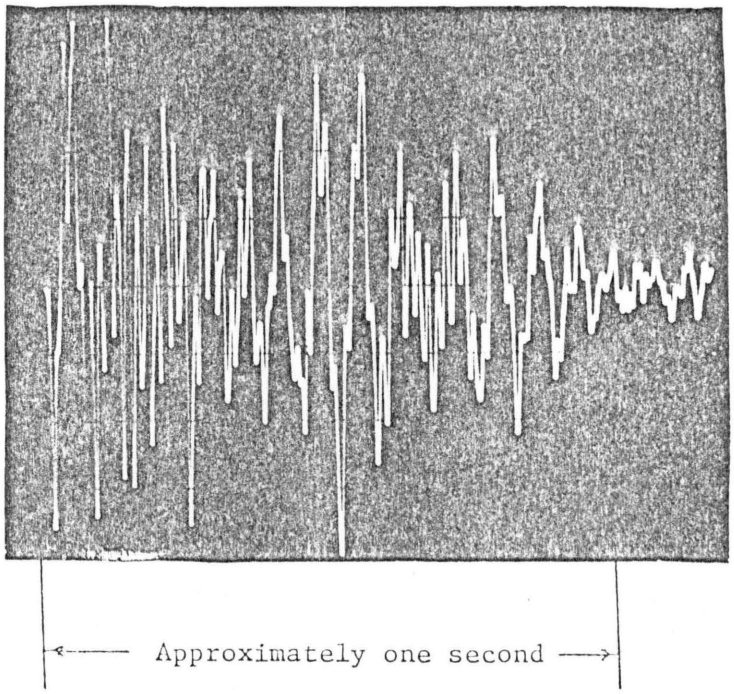
Midspan Far Trackway Horizontal LVDT

Midspan Near Trackway Horizontal LVDT

In all cases 1cm = 0.040 in and chart speed = 50 mm/sec

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

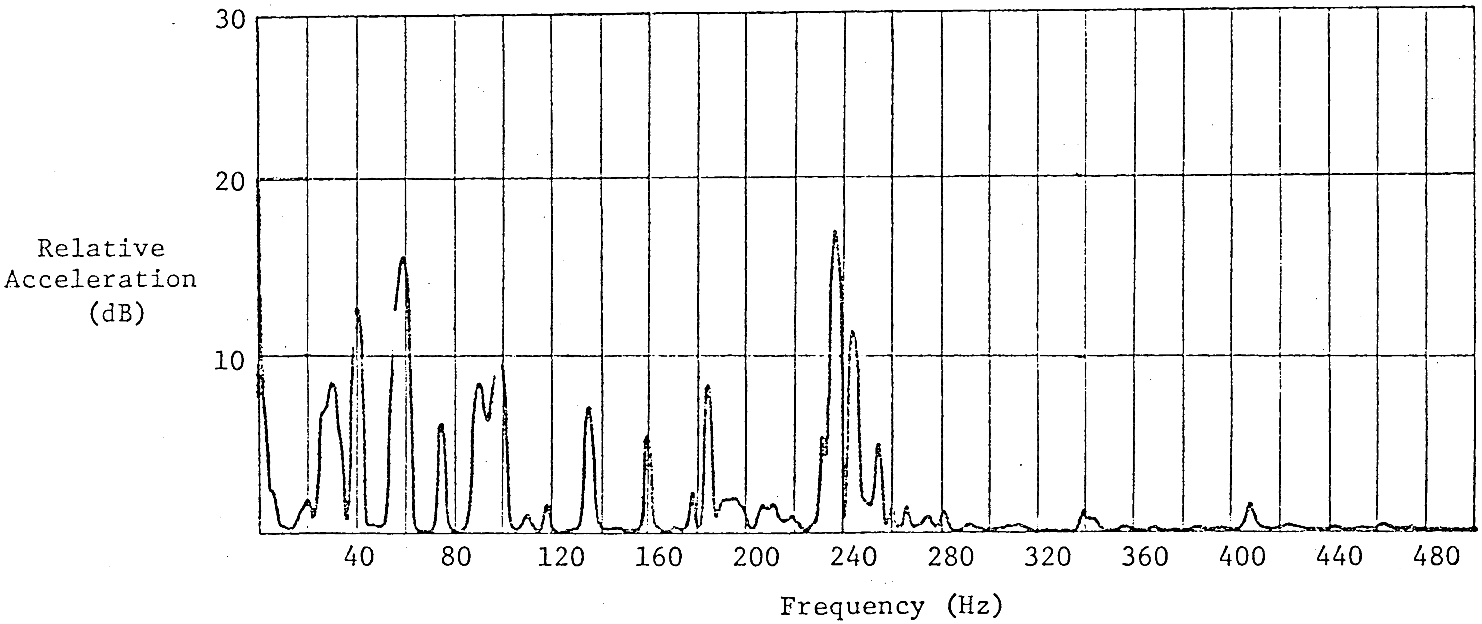
Phase II, Test I-B, Output from Real Time Frequency Analyzer Memory. This is the signal analyzed in this test.



←—— Approximately one second ——→

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

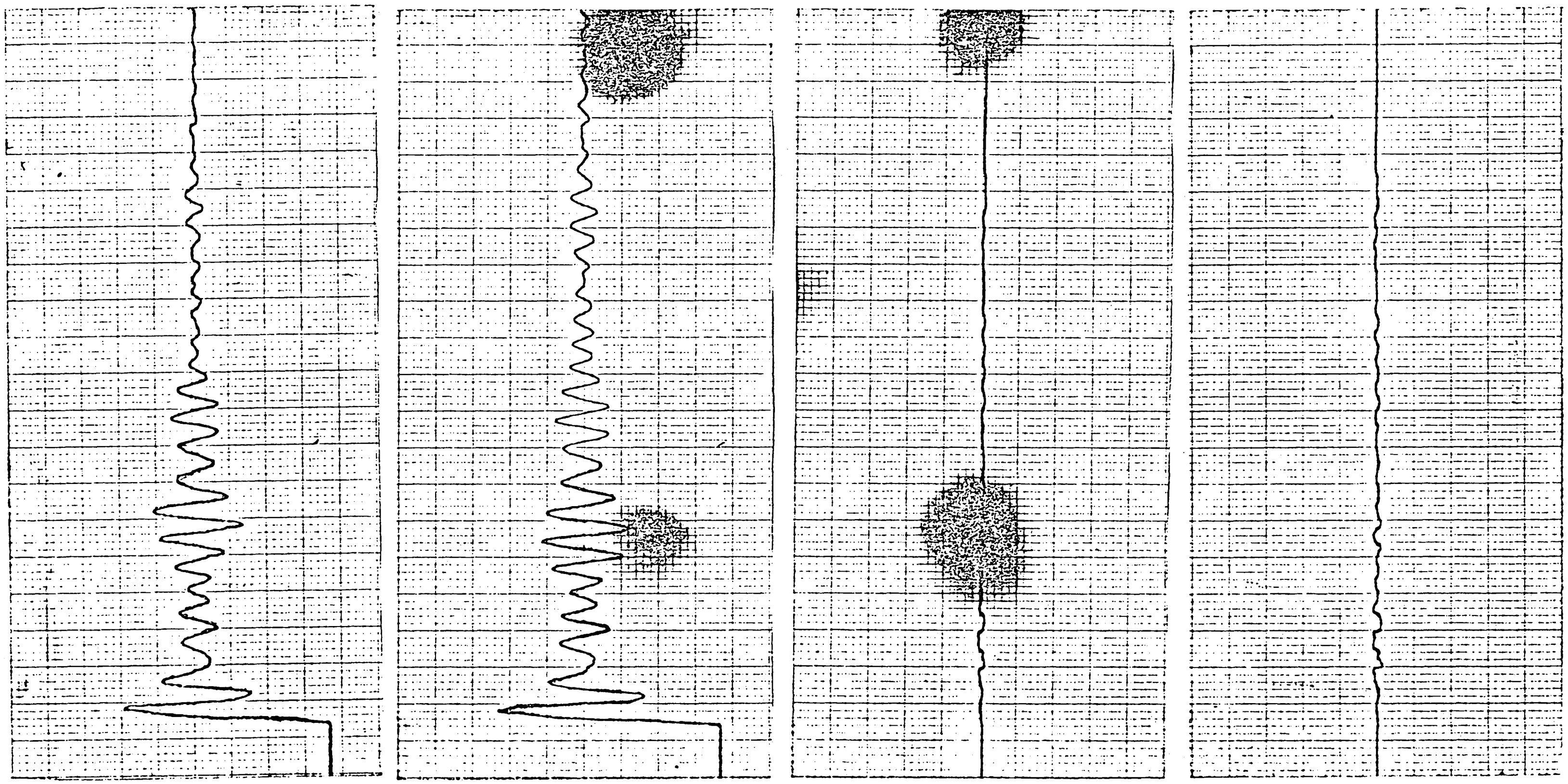
Phase II, Test I-C, Vertical Plucking Output of Real Time Frequency Analyzer*
[13.25 lb force applied vertically at midspan strut center, suddenly released, and resulting vibrations and displacements recorded. Accelerometer used for Analyzer input.]



*Spectral Dynamics Model 330 Spectroscope

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test I-C



Midspan Near Trackway Vertical LVDT

Midspan Far Trackway Vertical LVDT

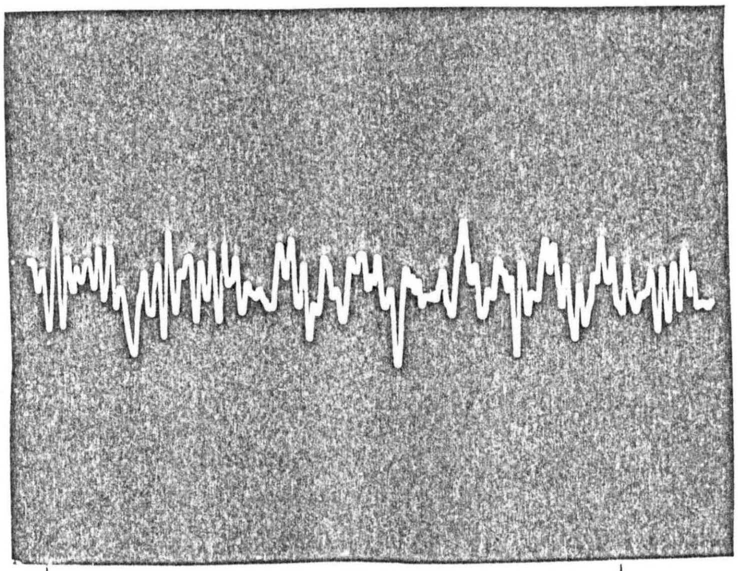
Midspan Far Trackway Horizontal LVDT

Midspan Near Trackway Horizontal LVDT

In all cases 1cm = 0.040 in and chart speed = 50 mm/sec

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

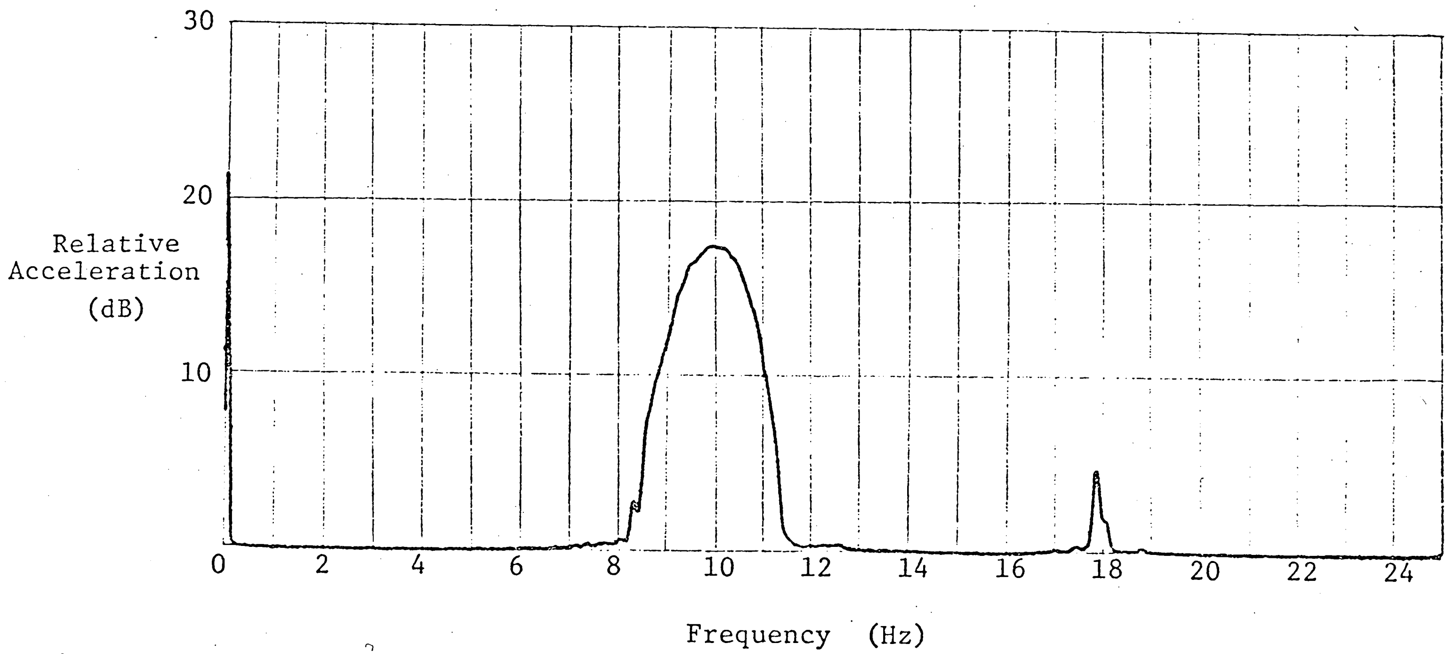
Phase II, Test I-C, Output from Real Time Frequency Analyzer Memory. This is the signal analyzed in the test.



Approximately one second

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

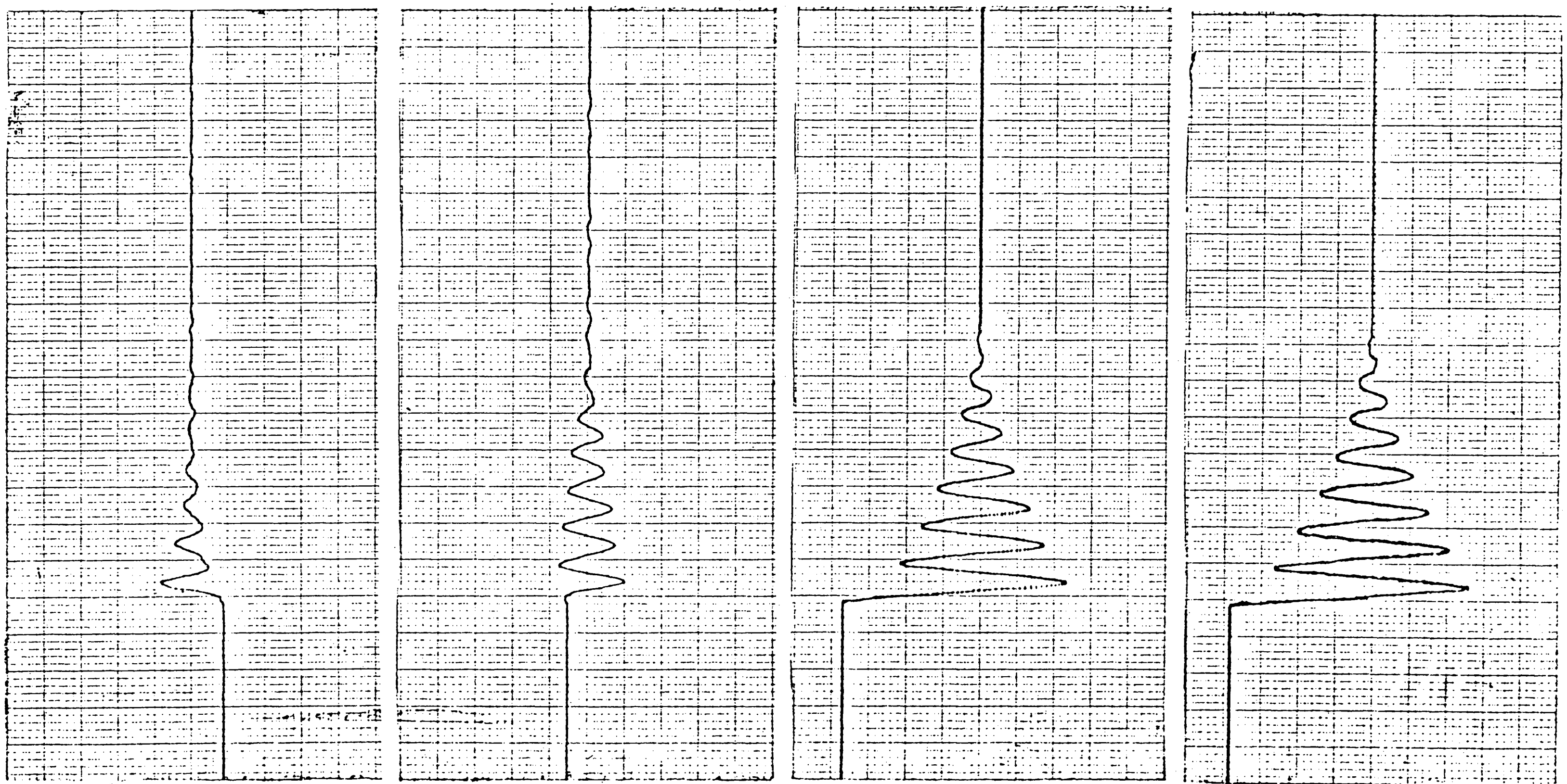
Phase II, Test V-A, Horizontal Plucking Output of Real Time Frequency Analyzer *
[13.25 lb force applied horizontally to midspan of far trackway, suddenly released, and resultant vibrations and displacements recorded. Accelerometer used for Analyzer input.]



*Spectral Dynamics Model 330 Spectroscope

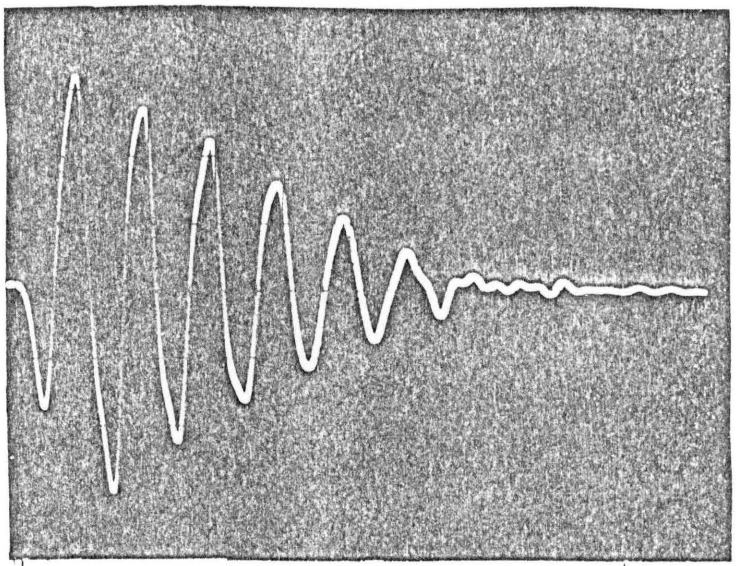
SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Deflections During Phase II, Test V-A

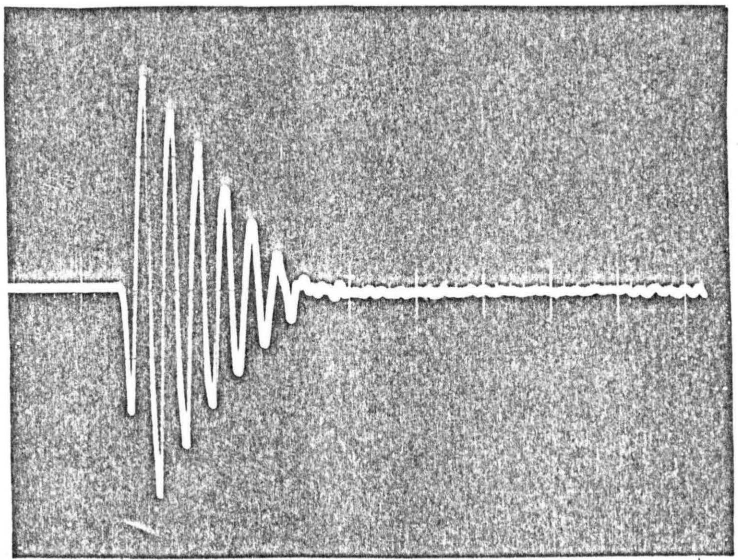


In all cases 1cm = 0.040 in and chart speed = 50 mm/sec

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL
Phase II, Test V-A, Output from Real Time Frequency Analyzer Memory. This is the signal analyzed during the test.



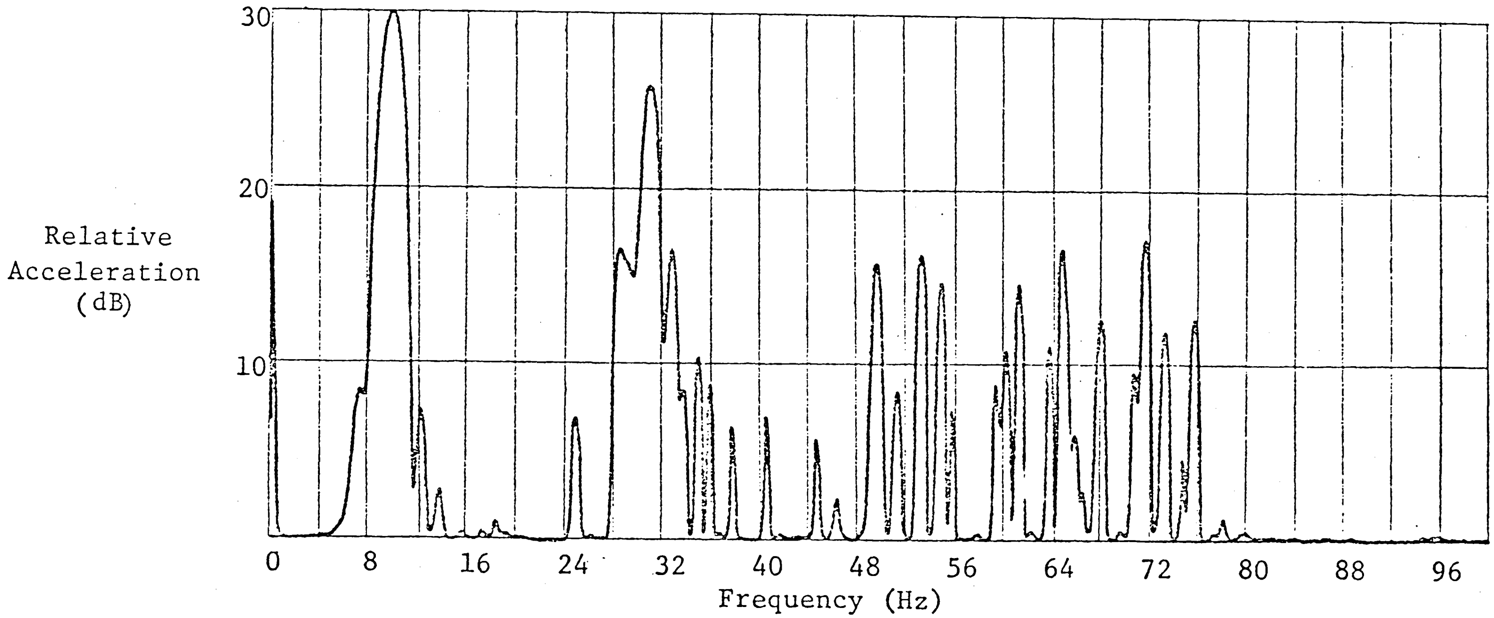
Approximately One Second



Approximately Two Seconds

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

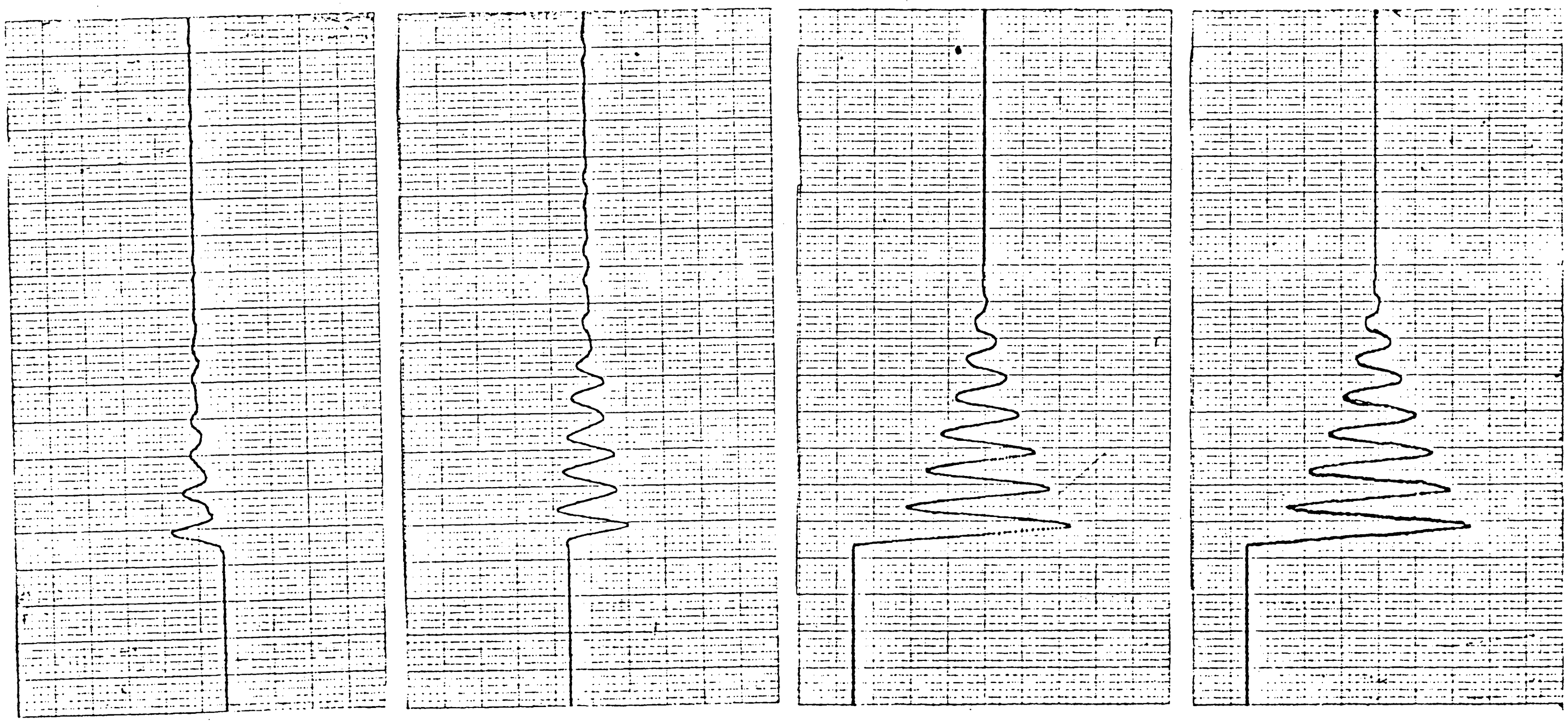
Phase II, Test V-B, Horizontal Plucking Output of Real Time Frequency Analyzer *
[13.25 lb force applied horizontally to midspan of far trackway, suddenly released, and resultant vibrations and displacements recorded. Accelerometer used for Analyzer input.]



*Spectral Dynamics Model 330 Spectroscope

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test V-B



Midspan Near Trackway Vertical LVDT

Midspan Far Trackway Vertical LVDT

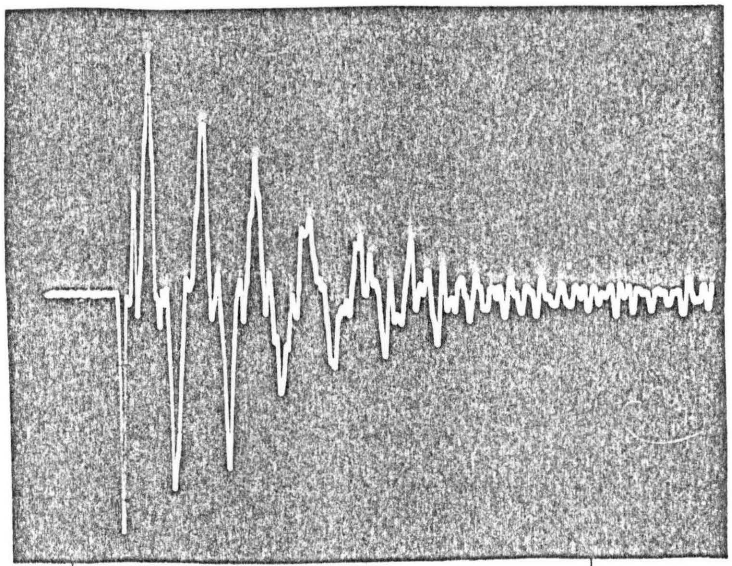
Midspan Far Trackway Horizontal LVDT

Midspan Near Trackway Horizontal LVDT

In all cases 1cm = 0.040 in and chart speed = 50 mm/sec

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

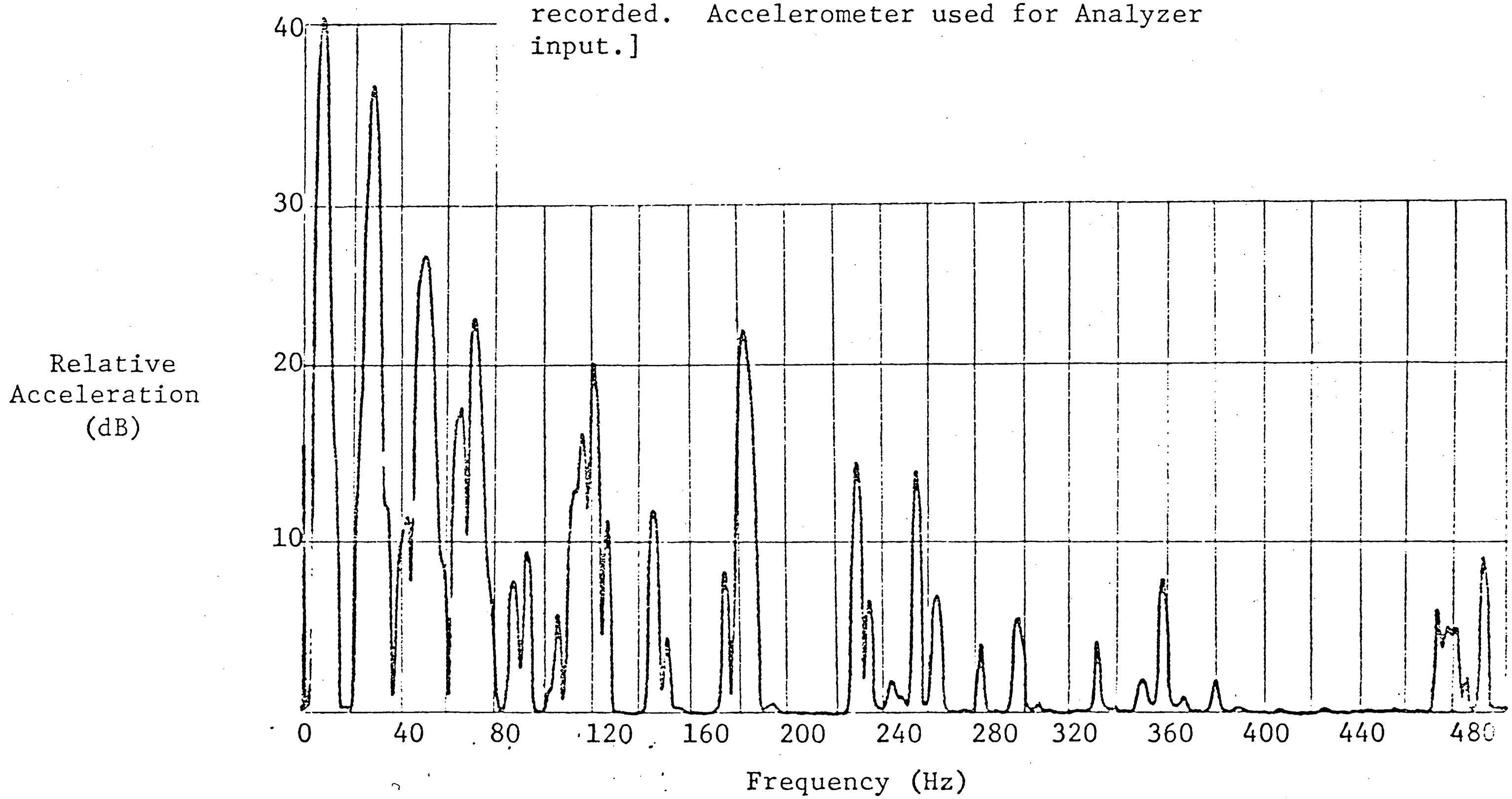
Phase II, Test V-B, Output from Real Time Frequency Analyzer Memory. This is the signal analyzed during the test.



Approximately one second

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

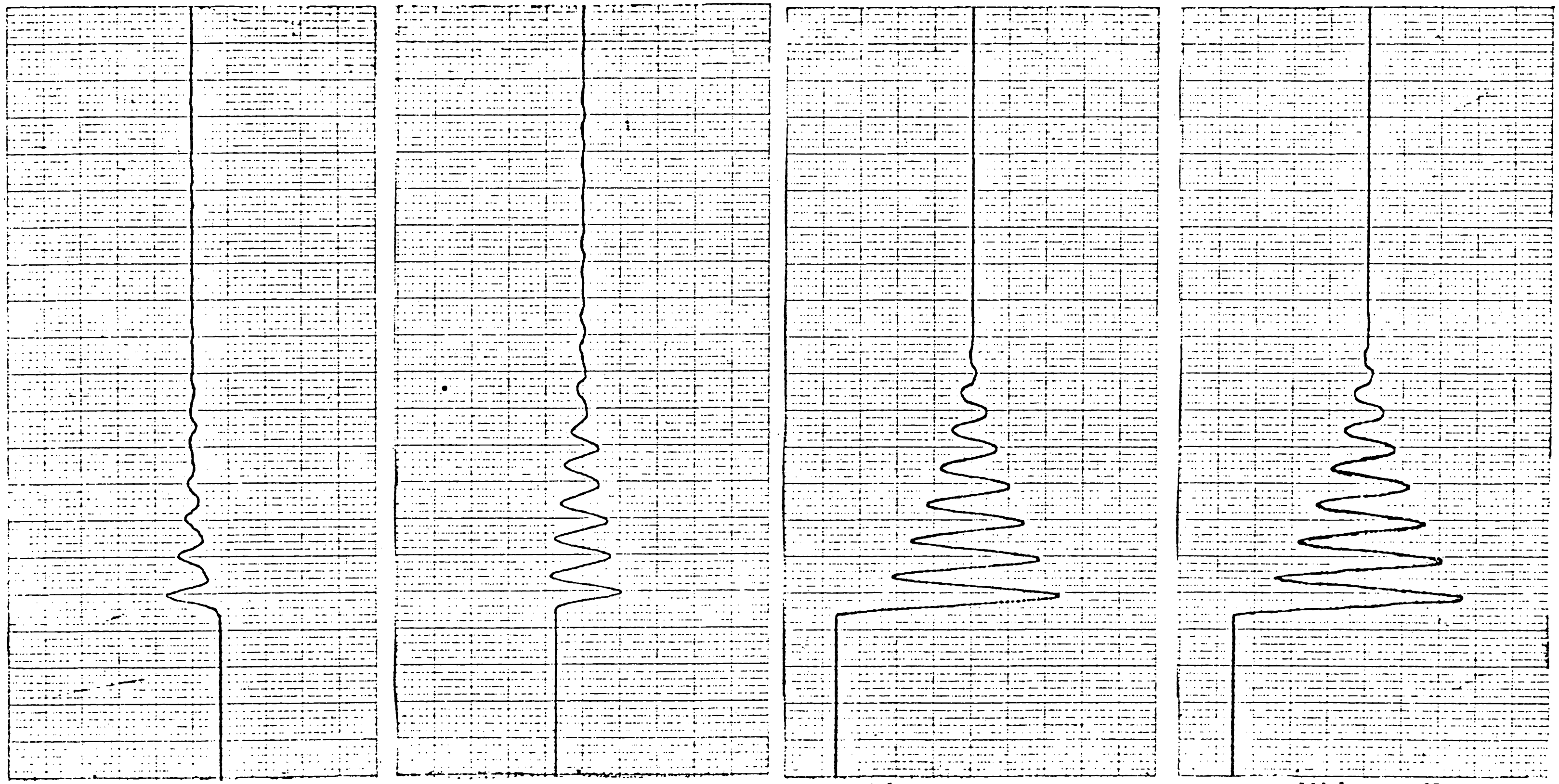
Phase II, Test V-C, Horizontal Plucking
Output of Real Time Analyzer *
[13.25 lb force applied horizontally to midspan of far trackway, suddenly released, and resultant vibrations and displacements recorded. Accelerometer used for Analyzer input.]



*Spectral Dynamics Model 330 Spectroscope

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test V-C



Midspan Near Trackway Vertical LVDT

Midspan Far Trackway Vertical LVDT

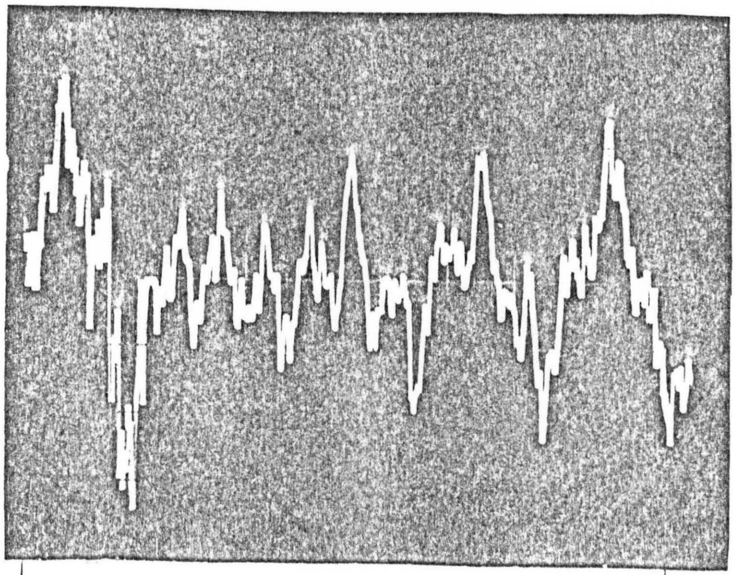
Midspan Far Trackway Horizontal LVDT

Midspan Near Trackway Horizontal LVDT

In all cases 1cm = 0.040 in and chart speed = 50 mm/sec

SUSPENDED VEHICLE SYSTEM, 1/24 - SCALE MODEL

Phase II, Test V-C, Output from Real Time Frequency Analyzer Memory. This is the signal analyzed during the test.



Approximately one-half second

TABLE C-4 TEST LOG FOR MOVING LOAD TESTS

Test Run #1 1/8" cable	June 19, 1973 1 - 9.1 lb car on near trackway 46 lb constant speed weight 50 lb accelerating weight Velocity not determined
Test Run #2 1/8" cable	June 19, 1973 1 - 9.1 lb car on near trackway 46 lb constant speed weight 100 lb accelerating weight Velocity not determined
Test Run #3 1/16" cable	June 20, 1973 1 - 9.1 lb car on near trackway 46 lb constant speed weight 50 lb accelerating weight V = 18.15 ft/sec
Test Run #4 1/16" cable	June 20, 1973 1 - 9.1 lb car on near trackway 46 lb constant speed weight 50 lb accelerating weight V = 18.7 ft/sec
Test Run #5 1/16" cable	June 20, 1973 1 - 9.1 lb car on near trackway 31 lb constant speed weight 50 lb accelerating weight V = 18.2 ft/sec
Test Run #6 1/16" cable car hit stop at end of trackway	June 20, 1973 1 - 9.1 lb car on near trackway 31 lb constant speed weight 100 lb accelerating weight V = 24.8 ft/sec
Test Run #7 1/16" cable	June 21, 1973 2 - 9.1 lb cars 46 lb constant speed weight 100 lb accelerating weight V = 23 ft/sec
Test Run #8 1/16" cable	June 21, 1973 2 - 9.1 lb cars 56 lb constant speed weight 100 lb accelerating weight V = 20.1 ft/sec

TABLE C-4 (continued)

Test Run #9 1/16" cable bad run - not constant speed	June 21, 1973 2 - 9.1 lb cars 56 lb constant speed weight 100 lb accelerating weight
Test Run #10 1/16" cable Data Not complete, balance on tape	June 26, 1973 2 - 9.1 lb cars 50 lb accelerating weight V 15 ft/sec
Test Run #11 1/16" cable Data not complete, balance on tape	June 26, 1973 2-9.1 lb cars 100 lb accelerating weight V 19 ft/sec
Test Run #12 1/16" cable Data not complete, balance on tape	June 26, 1973 2 - 9.1 lb cars 150 lb accelerating weight V 24 ft/sec
Test Run #13 1/16" cable Data not complete, balance on tape	June 26, 1973 2 - 9.1 lb cars 200 lb accelerating weight V 28 ft/sec
Test Run #14 1/16" cable Data not complete, balance on tape	June 26, 1973 2 - 9.1 cars 250 lb accelerating weight V 32 ft/sec
Test #15 1/16" cable Data not complete balance on tape	June 26, 1973 2 - 9.1 lb cars 300 lb accelerating weight V 32 ft/sec
Test Run 16 1/16" cable Data not complete, balance on tape	June 26, 1973 2 - 9.1 lb cars 300 lb accelerating weight V 32 ft/sec
Test Run 17 1/16" cable Data not complete, balance on tape	June 26, 1973 1 - 9.1 lb car on near trackway 200 lb accelerating weight V 23 ft/sec Set screw on tachometer generator loose

TABLE C-4 (continued)

Test Run 18 1/16" cable Data not complete, balance on tape	June 26, 1973 1 - 9.1 lb car on near trackway 200 lb accelerating weight V 23 ft/sec set screw on tachometer generator loose
Test Run 19 1/8" cable Data not complete, balance on tape	June 27, 1973 1 - 9.1 lb car on near trackway 200 lb accelerating weight V 28.5 ft/sec
Test Run 20 1/7" cable Data not complete, balance on tape	June 27, 1973 1 - 9.1 lb car on near trackway 200 lb accelerating weight V 28 ft/sec
Test Run 21 1/8" cable Data not complete, balance on tape	June 27, 1973 1 - 9.1 lb car on near trackway 300 lb accelerating weight V 30 ft/sec
Test Run 22 1/8" cable Data not complete balance on tape	June 27, 1973 1 - 9.1 lb car on near trackway 400 lb accelerating weight V 34 ft/sec
Test Run 23 1/8" cable Data not complete, balance on tape	June 27, 1973 1 - 13.25 lb car or near trackway 400 lb accelerating weight V 32 ft/sec
Test Run 24 1/8" cable Data not complete, balance on tape	June 27, 1973 1 - 13.25 lb car on near trackway 400 lb accelerating weight V 32 ft/sec
Test Run 25 1/8" cable Data not complete, balance on tape	June 27, 1973 1 - 17.9 lb car on near trackway 400 lb accelerating weight V 30 ft/sec
Test Run 26 1/8" cable Data not complete balance on tape	June 27, 1973 1 - 17.9 lb car on near trackway 500 lb accelerating weight V 33 ft/sec

TABLE C-4 (continued)

Test Run 27 1/8" cable Data not complete, balance on tape	June 27, 1973 1 - 17.9 lb car on near trackway 300 lb accelerating weight V 28 ft/sec
Test Run 28 1/8" cable marker signal not working chain jumped, vehicle hit stop	June 28, 1973 1 - 17.9 lb car on near trackway 300 lb accelerating weight V 28 ft/sec
Test Run 29 1/8" cable Ran out of paper on center recorder	June 28, 1973 1 - 17.9 lb car on near trackway 600 lb accelerating weight V = 41.5 ft/sec
Test Run 30 1/8" cable broke chain and two bearings	June 28, 1973 2 - 17.9 lb cars 650 lb accelerating weight V = 37 ft/sec
Test Run 31 1/8" cable	June 28, 1973 2 - 17.9 lb cars 200 lb accelerating weight V = 20 ft/sec
Test Run 32 1/8" cable	June 28, 1973 2 - 17.9 lb cars 400 lb accelerating weight V = 28.7
Test Run 33 1/8" cable	June 28, 1973 1 - 13.25 lb car on near trackway 400 lb accelerating weight V = 31.5
Test Run 34 1/8" cable	June 28, 1973 1 - 13.25 lb car on near trackway 300 lb accelerating weight V = 30.5
Test Run 35 1/8" cable	June 28, 1973 1 - 13.25 lb car on near trackway 630 lb accelerating weight V = 40.5 ft/sec

TABLE C-4 (continued)

Test Run 36 1/8" cable	June 28, 1973 1 - 9.1 lb car on near trackway 630 lb accelerating weight V = 43 ft/sec
Test Run 37 1/8" cable	June 28, 1973 1 - 9.1 lb car on near trackway 652 lb accelerating weight V = 46.2 ft/sec

Note: All velocities V shown are average velocity of vehicle through test span.

Note: The data set from the Phase III Moving Load Tests may be found in Appendix C of Reference 11, SVS Guideway Studies, Volume III, Dynamic Tests of a Cable Stayed Guideway.

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APPENDIX D

Recorders:

Sanborn 150
Model 152-10013
Serial number 366

Sanborn 150
Model 154-100B
Serial number 2063

Sanborn 150
Model 154-100B
Serial number 2034

Tape Recorder (Data Tape VR 3300)
Consolidated Electrodynamics
Type 12-305A
Serial number 14065

Accelerometer
Bruel & Kjaer Type 4314
Serial number 117921

Charge Amplifier
Kistler Model 566
Serial number 1364

Transducer Converter
Sanborn 592-300
Serial number 294-351

LVDTs

Schavitz	E200	E300
Serial numbers	5318	4422
	5320	4423
	5321	
	5322	
	5323	
	5325	
	5326	
	5327	
	5328	
	5334	

Frequency Analyzer
Spectral Dynamics
Model 330 Spectroscope

TESTING OF THE SUSPENDED VEHICLE SYSTEM

SCALE MODEL

by

Barry Wilton Stanley

(ABSTRACT)

A 1/24th scale model of the SVS (Suspended Vehicle System) guideway was constructed, instrumented, and tested. The model simulated five 250-ft-spans of the cable-stayed guideway for high-speed mass transportation type vehicles. Model vehicles consisting of single bogeys and single cars were designed and used during the test program. A falling weight type propulsion device was used to propel the model vehicles across the guideway at speeds up to 46 ft/sec.

The middle span of the guideway was instrumented with LVDTs to measure deflections and an accelerometer to detect vibrational frequencies. The output of ten LVDTs was recorded on either a Sanborn strip chart recorder or a magnetic type recorder. The accelerometer supplied a signal to a real-time frequency analyzer.

The testing program consisted of both static and dynamic phases. Static tests were used to determine the behavior of the structure to dead loads. Free vibration tests indicated the fundamental structural frequencies,

and moving load tests measured the response of the system to moving vehicle conditions. Although no theoretical analysis is presented, an analysis was carried out independently by other researchers and used as a basis of comparison.

The results of the static testing indicated that the structure behaved in a linear manner with respect to loading. When compared with calculated values, the static test data gave higher deflections and this indicated a "softer" guideway than was predicted.

The dynamic part of the test program consisted of free vibration tests and moving load tests. The free vibration tests were used to detect the natural frequencies of the guideway and the results compared well with predicted values. Actual guideway operation was simulated in the moving load tests. Some dynamic amplification was noted at higher vehicle speeds but resonance conditions were not detected.