

A STUDY OF VERTICAL AND HORIZONTAL SCALES  
FOR HIGHWAY DESIGN MODELS

by

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## INTRODUCTION

The design of highways has been increasingly recognized as a three-dimensional problem. Persons with the ability to form the three-dimensional picture of the finished roadway in their minds simply from viewing two-dimensional plans (horizontal and vertical alinements) are indeed rare. Even if such persons were common, they would also need to possess some form of creative medium, such as artistic ability, to convey their mental picture of the roadway to others. This ability is also rare.

Techniques have been developed which allow the typical highway designer to see his roadway in three dimensions prior to its construction. One technique, an analytical approach, is the use of computer plotted perspectives (5, 6, 7). This technique is very well suited for the identification of discontinuities in the finer aspects of final design.

Other techniques involve the use of pictorial methods. One such method is the use of the Projector-Screen-Sketch-board (5). A slide is projected through the back of a piece of glass on which a sheet of transparent drawing paper is attached. The artist or engineer can make changes in a given roadway section or draw the initial section of roadway in conjunction with the surrounding landscape. Highly successful results in rendering improvements of existing roadway sections have been attained using this technique.

Another technique, one in which the content of the research was concerned, is the use of highway models. There are two basic categories of highway models--presentation models and design models. For a number of years, the presentation models have been used effectively in public hearings and consultations with local authorities. Presentation models are usually very complete with special attention given to landscaping, color, and even surrounding features such as buildings and watercourses. Because of the great detail used in these models, they have often been costly and time-consuming to construct.

Design models, on the other hand, are built without as much concern given to cosmetic details. These models are generally used as three-dimensional aids for preliminary and final design of interchanges and highway alignments.

One excellent method for the construction of design models was developed by DeLeuw, Cather and Company (2). In this method a plan sheet is attached to a three inch thick styrofoam base. Roadway profiles are accurately cut from 1/2 or 1/4 inch sheets of foamed urethane (using a sharp razor-type knife) and then "toe-nailed" to the base with ordinary straight pins. For added realism, cardboard, styrene plastic, or acetate roadways are attached to the top of the urethane profiles.

A urethane model can be constructed very quickly and with very little expense. For example, a large scale (1" = 40' or 1" = 50') urethane model of a complex interchange can be built in approximately two to four man-days at a cost of \$50.00 to \$75.00 for materials (5).

Design models can generally be classified in two categories: (1) intersection and interchange models and (2) highway alignment models (also commonly called profile models). Intersection and interchange models can be used in design for a variety of purposes. Among these are evaluation of sight distance prior to exit ramps, contour grading, signing, guard rail location, and column and abutment placement. These models are generally built at relatively large horizontal scales (such as  $1" = 40'$  and  $1" = 50'$ ) to accommodate the necessary detail inherent in interchange and intersection design.

Alignment models, on the other hand, are usually used to locate gross discontinuities in highway design. Evaluation of plan and profile coordination as well as examining losses of view of the roadway ahead are uses which are well suited to alignment models. Horizontal scales used in alignment models vary from  $1" = 100'$  for models used in final highway design to  $1" = 400'$  and  $1" = 500'$  for models used in highway planning and location.

Even though design models are not particularly expensive or time-consuming to construct, they have not been widespread in use. Two reasons can be attributed to the limited use of design models:

1. The connotation "highway design model" has often been associated with the more expensive and detailed presentation model. Design models have been categorized as "too expensive" or "too time-consuming" to build.

2. There is little literature on the use or construction of design models. Furthermore, questions such as "What can be seen from a design model?", "How do I look at these models?", and "At what scale does one build such a model?" have, for the most part, been unanswered.

The series of nationwide Seminars on Dynamic Design for Safety have been instrumental in pointing out the differences between presentation models and design models as well as illustrating the uses and construction techniques for design models. The concept of design models was enthusiastically received by the highway engineers attending the seminars (Appendix F, Reference 5).

The problem of vertical scale in design models, however, has been difficult to resolve. It has generally been thought that models with horizontal scales of  $1" = 50'$  or  $1" = 40'$  need to be built with some exaggeration in the vertical plane. At scales of  $1" = 100'$  in the horizontal plane, vertical exaggeration of five times the horizontal scale, or  $1" = 20'$ , has been used to make the model appear realistic from the driver's vantage point (5, 6).

Although numerous references show some applications of highway design models, none show convincing evidence that a model gives a true picture of the real situation. The question of scale and actual realism of models were the problems addressed in the research discussed in this paper. It was believed that by solving the scale problem and consequently showing that scale

models can truly simulate real situations, a more general, widespread use of design models would result.

All of the models built for the research were urethane models. This type of design model was considered by the author to be the best. However, there is no reason to believe that the conclusions drawn in the research could not be applied to models utilizing other materials.

The best way to view a model from the driver's vantage point is through a modelscope (a device resembling a periscope). Two modelscopes were available for the study. One was manufactured by OPTEC of London, England, and can be purchased for around \$300.00. The other modelscope was still in the development stage and will probably be marketed in the near future. Hence, an opportunity was provided to compare these two modelscopes.

## LITERATURE SURVEY

Other than the information found in two references previously mentioned (References 5 and 6), no information was found which explicitly stated the appropriate vertical scale to be used in design models at various horizontal scales. However, several references were invaluable in determining design model construction procedures and materials.

Berry and McCabe (2) present one of the best discussions on design models, especially urethane models, available to date. They mention that if a model is to be used for the purpose of contour grading it is highly desirable to construct the model with the same horizontal and vertical scales. They suggest that, since  $1" = 50'$  is the smallest practical vertical scale, models used for this purpose should be constructed at horizontal and vertical scales of  $1" = 50'$  or larger.

Porter (4) discusses the use of various mixtures of remoldable contour grading materials and application in design models. He presents a good discussion on the photographic technique using the modelscope manufactured by OPTEC of London, England.

The notes from the Seminars on Dynamic Design for Safety (5) provide an excellent synopsis on design models. This reference was extremely helpful in establishing the procedure to be used in construction of design models at various scales.

Butcher and Pearson (3) present an excellent discussion on model photography. Although they were concerned with architectural models, this reference provides considerable insight into model photography.

## PURPOSE

The purpose of the research described in this paper was to resolve scale problems and to determine the degree of realism in design models.

## SCOPE

The research was limited to the following:

1. Determination of vertical scales to be used in design models built at horizontal scales commonly used in the design of interchanges, intersections, and highways.

2. Investigation of some design applications of small scale alinement models.

## METHOD OF APPROACH

The approach taken in the solution of scale problems was an empirical one since the literature survey did not reveal any sound theoretical approach. Locations were selected and photographed at known points along the roadway from the driver's approximate viewpoint. Plans were obtained for each location and models were constructed at various scales. The models were then photographed from the same points as the actual locations using one of the two available modelscopes to place the viewpoint at approximate driver's eye level. The model photographs were compared to the location photographs to determine the vertical scale at which the model appeared most realistic.

Although the comparison of the model photographs with actual location photographs was the primary means of resolving scale problems, this was not the only means used in the research. Views with the naked eye and with the other modelscope (the one manufactured by OPTEC) were also compared to the actual location views. Unfortunately, equipment was not available to photograph views through the OPTEC modelscope. In nearly all cases, however, the scale model which appeared most realistic in the model photographs also appeared most realistic with the naked eye and with the OPTEC modelscope.

### Locations and Location Photography

The locations were selected to represent a variety of design situations. These locations included one intersection

at very flat grades, one interchange with significant grade changes, and three highway sections including one with an overpass.

These locations were photographed with a 35 mm NIKON F single lens reflex camera equipped with a NIKKOR Zoom lens. A lens setting of 86 mm appeared to give the most realistic picture of a roadway section.

### Model Photography

The NIKON F camera was also used in the model photography. The modelscope, developed under the direction of Mr. William Hamilton of Howard, Needles, Tammen, and Bergendoff, Consulting Engineers, was fitted directly to the camera body (Figures 1 and 2). A special focus screen manufactured by NIKON was utilized to let more light through the pentaprism. A cable release was used to make the time exposures.

Tests conducted by Mr. Hamilton with the modelscope and camera showed that the equivalent aperture was approximately F/90. Two flood lamps (R2 Superflood DXC, 115-120V) manufactured by Sylvania were used to light the models. A GOSSEN Lunasix lightmeter provided accurate light readings for the model photographs. Using high speed Kodak Ektachrome (ASA 125) for color slides and Kodak Plus-X Pan (ASA 125) for black and white prints, the time exposures were in the range of 1/2 to 2 seconds with the lamps two to three feet above the models. In all cases, projecting color slides of the actual location and the models simultaneously on a screen was the best means of comparing results.

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WITH PICTURES  
THAT ARE CROOKED  
COMPARED TO THE  
REST OF THE  
INFORMATION ON  
THE PAGE.**

**THIS IS AS RECEIVED  
FROM CUSTOMER.**



Figure 1. Modelscope with Attached Eyepiece

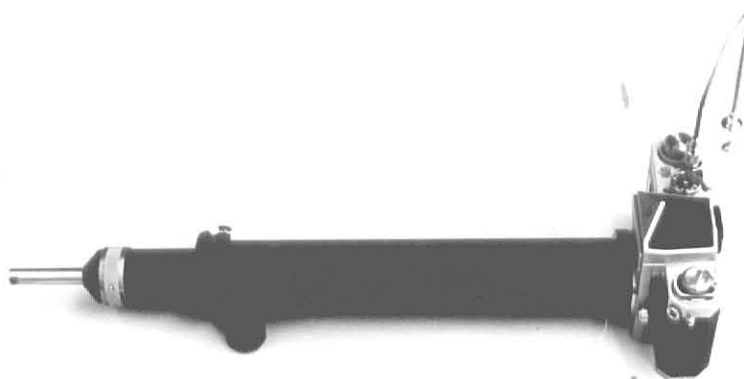


Figure 2. Modelscope Attached to the NIKON F  
Camera Body

A tripod was necessary to hold the camera and attached modelscope stationary during the time exposures. The camera was attached to the tripod such that the modelscope protruded onto the models in a horizontal position (Figure 3).

### Modelscope Limitations

The modelscope and NIKON F camera body produced clear and useful photographs. However, during the research, limitations were noted in this equipment.

The modelscope, as used in the horizontal position, placed the viewpoint above the driver's eye level. At a vertical scale of  $1" = 40'$  the viewpoint was approximately nine feet above the roadway surface. Had the modelscope been used in the vertical position, this problem would have been partially eliminated. The scale distance above the roadway surface would have been only five feet. Unfortunately, the tripod available for the study did not provide for using the modelscope in the vertical position.

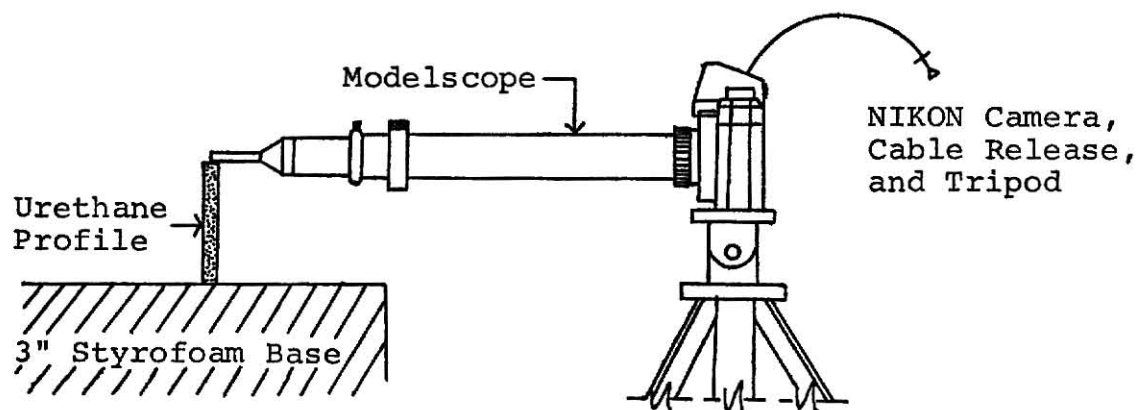


Figure 3. Modelscope Setup for Photography

Also at the relatively large scales, used in the intersection and interchange models, the modelscope seemed to give more field of view than the driver would actually have. At relatively small horizontal scales, the problem was reversed; the modelscope seemed to give less field of view than the driver would have.

In spite of these limitations, the modelscope and NIKON camera provided ease of use and consistent results. Should this modelscope be marketed, it would be recommended as the best device now available for model photographs.

The modelscope manufactured by OPTEC (Figure 4) was extremely useful for quick viewing of a model. The modelscope could be held with one hand and used to view a model in either the vertical or horizontal position (Figure 5). Although easy to use with an eyepiece, it did not lend itself as well to model photography.\* When a camera was attached to the OPTEC modelscope, light through the pentaprism of the camera was extremely dim. Hence, it was virtually impossible to see exactly what was being photographed.

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\*Although photography equipment was not available for the study, it had been available in the past. Thus, the photography limitation discussed resulted from past observations.

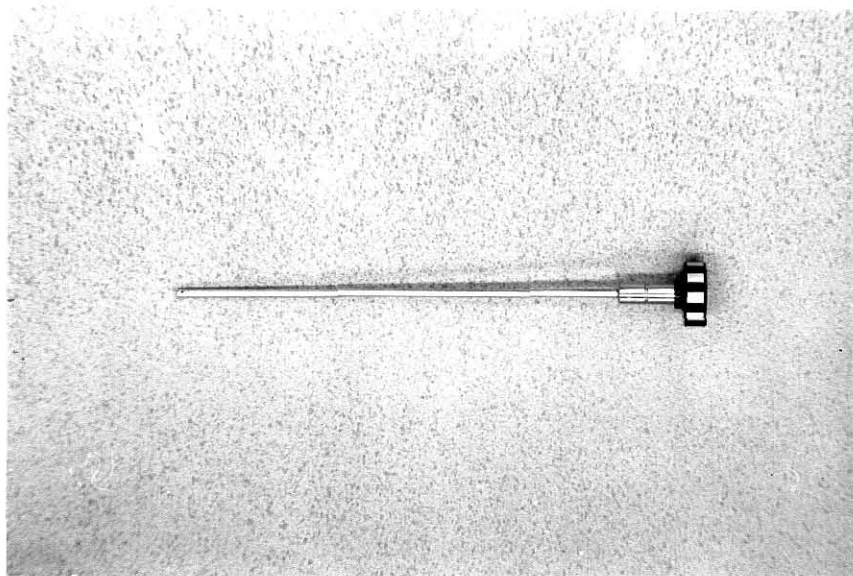


Figure 4. OPTEC Modelscope

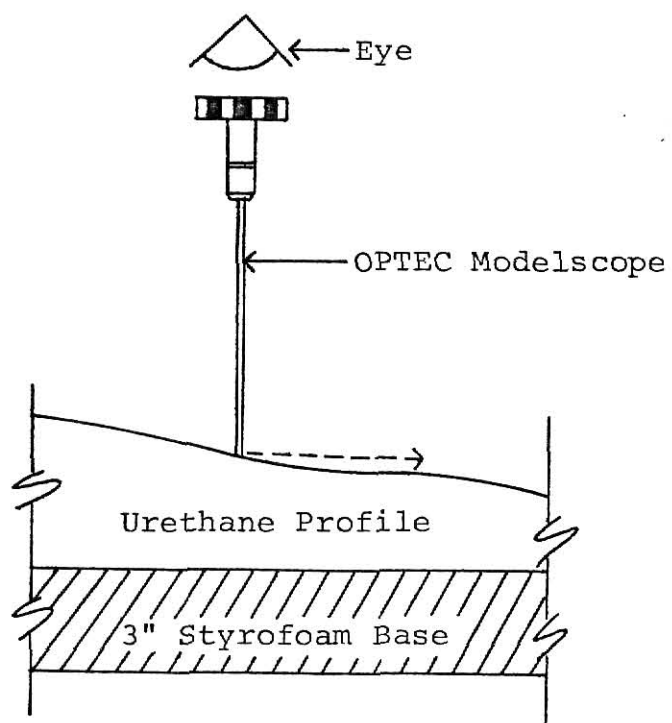


Figure 5. Use of the OPTEC Modelscope

## INTERSECTION AND INTERCHANGE MODELS

Early in the research it was deemed desirable to select locations which had operational problems caused by the geometry of the situation and not necessarily apparent in the construction plans. Thus, the use of models to locate geometric design problems could be illustrated and possibly utilized as a factor in determining the proper scales to use. Both the interchange and intersection selected for the research contained such a problem.

The interchange section consisted of an entrance ramp and an exit ramp connected by a short weaving section. A problem was apparent after construction in that the weaving section was not readily visible to drivers entering the freeway.

The intersection was of high type design with a left turn bay located on a reverse curve in one of the intersection legs. Even though the intersection was built on extremely flat grades (less than 0.72 percent), the left turn bay was not visible until the driver was nearly at the intersection.

In order to build a number of models illustrating the inherent problems, only those sections with problems were constructed. Hence, early in the research an important fact was noted. In order to view part of an interchange or intersection, it is not necessary to build the entire interchange or intersection model. Only that section which has probable design problems needs to be built.

Building a partial model as opposed to the entire model can result in a considerable time-savings. For example, consider

the interchange location used in the research. If the entire interchange had been built, the time to construct each model would have been approximately three man-days. On the other hand, each partial model was built in less than 1/2 man-day. Figures 6 and 7 illustrate two of the partial models used and show the problem areas under study.

All of the models were built with horizontal scales of 1" = 40' (40-scale) with the exception of one of the interchange models which had a horizontal scale of 1" = 50' (50-scale). These scales are commonly used in the design of intersections and interchanges.

#### Construction Procedure and Materials

The procedure used in the construction of the interchange and intersection models was essentially the same as outlined in Reference 5 and is the Appendix of this paper.

In order to view the problems at hand, roadway surfaces were considered mandatory for all the models. The surfaces were constructed complete with lane markings and curbs and attached to the top of the urethane profiles.

Two types of material were investigated in the construction of the roadway surfaces--.015 inch pressboard (a hard finish brown paper board) and 0.06 inch mat board (a durable form of cardboard). The pressboard, which was used for the intersection models, was noted to have some disadvantages. While photographing the models, the heat of the floodlamps caused the

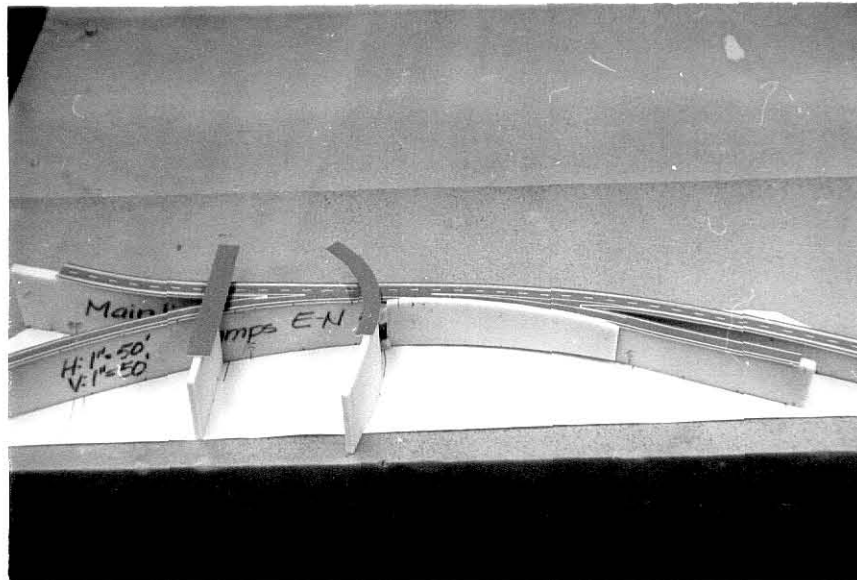


Figure 6. Partial Interchange Model

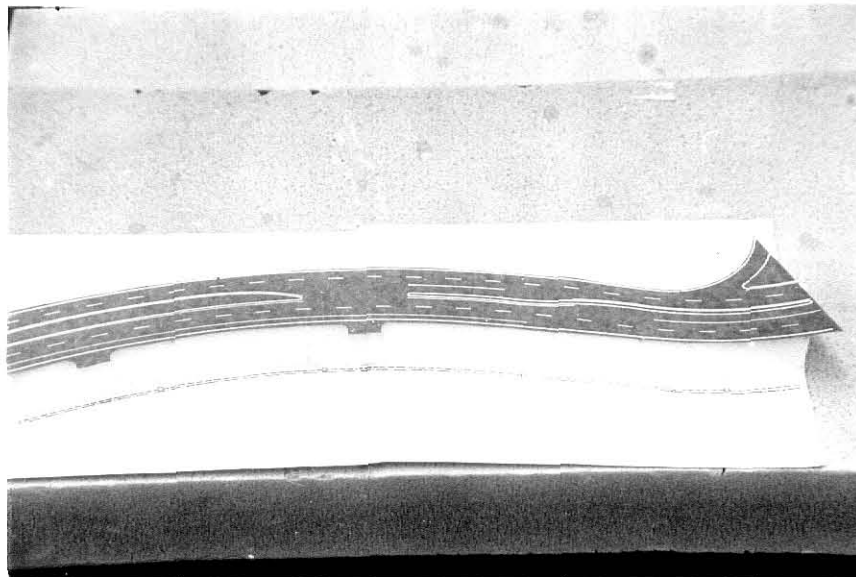


Figure 7. Partial Intersection Model

material to expand and hence appear warped. Care had to be taken prior to taking each photograph to make sure the warped appearance was not visible through the modelscope. In some instances the roadway section had to be removed and relocated to counteract the material expansion.

The pressboard was also noted to be affected by changes in temperature and humidity. After a period of time on a model, the material again became warped.

The mat board, which was used for the interchange models, was found to be quite superior to the pressboard. The material was not affected by the heat of the floodlamps and retained its form and shape even after remaining on a model for months.

Mat board was found to be readily available in a variety of colors and textures at most art, architecture, and/or engineering supply stores. A medium gray color mat board with a smooth texture was chosen for the interchange models to simulate the color and texture of concrete surfaces.

The cost of the material is minimal. A 32" by 40" sheet of mat board costs around \$1.00. In most cases, three sheets this size would be adequate to construct all roadways on a complex interchange built at 40-scale.

The following procedure was utilized for the construction of roadway surfaces with the mat board:

1. A template was cut out with scissors from a copy of the plans. Essentially this template consisted of all roadways on the plan sheet with all extraneous paper cut away. Figure 8

is an example of a template used in the construction of a partial interchange model for the research.

2. This template was taped to a sheet of mat board and one of the roadways traced out in pencil. Those lines which could not be traced because of structures were drawn after the template was removed.

3. Utilizing a mat knife (any heavily built razor-type knife works well), the roadway section was cut out by carefully following the pencil lines. Freehand cutting was found to work best for cutting on curves whereas a metal straightedge worked best for long tangent sections. Better results were obtained when two or three light cuts were used to cut through the mat board as opposed to one heavy cut.

4. Lane markings and curbs were applied with white ink and a ruling pen. Either a spline held in place with spline weights or highway curves were found to work well for markings on curves. Lane markings were made with thin lines while curbs were drawn as thick lines. It was found helpful to draw all markings and curbs in light pencil prior to drawing with white ink.

The thickness of mat board was found to closely simulate the depth of structures on the interchange models. Wooden dowels, 1/8 inch in diameter, simulated piers very realistically.

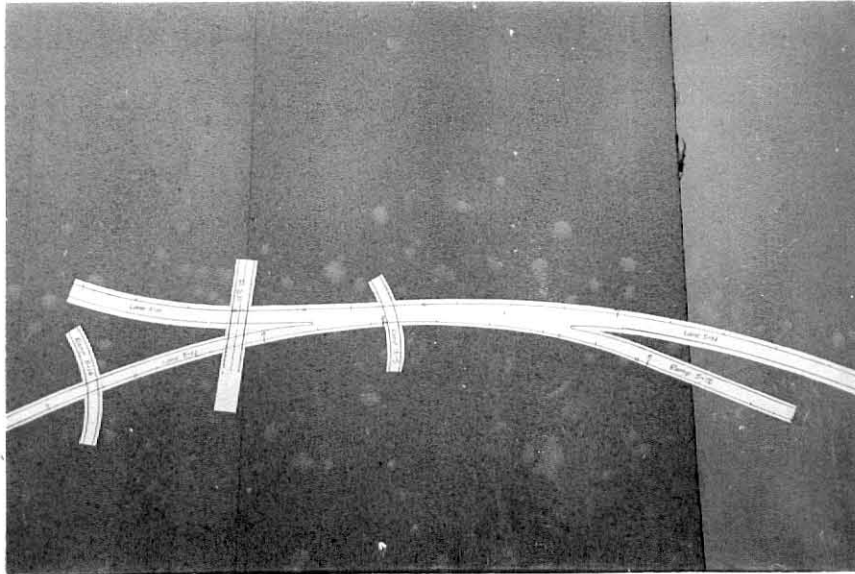


Figure 8. Roadway Template

#### Interchange Modeling Results

The most desirable interchange model is one which is constructed at natural scale, or in other words, at the same horizontal and vertical scale. Natural scale models undoubtedly produce the most realistic view of the total roadway environment and provide more realism in such design applications as contour grading and signing. One problem investigated in the research was whether or not a natural scale interchange model would appear realistic from the driver's viewpoint.

Two models were built at natural scale. One of the models was constructed at  $1" = 40'$  and the other one at  $1" = 50'$ . Both of these scales are commonly used in interchange design plans.

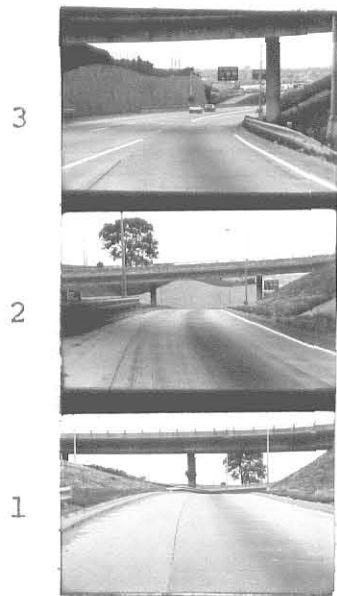
The result of this experiment was encouraging. Both models appeared to resemble the actual location from the driver's viewpoint. Figure 9A is a series of photographs taken of the actual location and Figure 9B and Figure 9C are scale model photographs with natural scales of  $1" = 40'$  and  $1" = 50'$ , respectively. These photographs were taken at approximately 200 foot intervals.

In picture 1 of Figure 9B and Figure 9C the second structure is barely visible on the horizon as it is in picture 1 of the actual location. Although the modelscope (as used in horizontal position) placed the viewpoint somewhat above the driver's actual view, the photographs give a valid indication of the vertical sight distance.

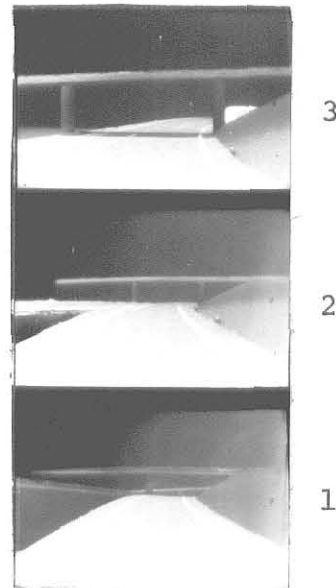
The series of photographs in Figure 9D is the result of an experiment with vertical exaggeration. The horizontal scale used in the model was  $1" = 40'$  while the vertical scale was  $1" = 20'$  (i.e., a vertical exaggeration of 2:1). In order that the backslopes would appear realistic, the structures were constructed with no exaggeration using both horizontal and vertical scales of  $1" = 40'$ .

This obviously had considerable effect on the apparent vertical sight distance. In picture 1 of Figure 9D, the second structure is completely out of view whereas this is not the case in the actual location photograph.

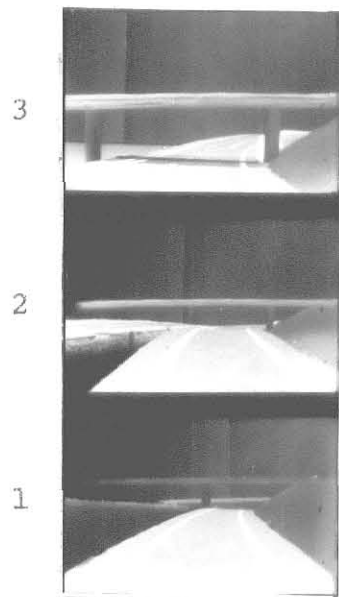
All model photographs accurately illustrate the geometric design problem inherent in this location. The views given in



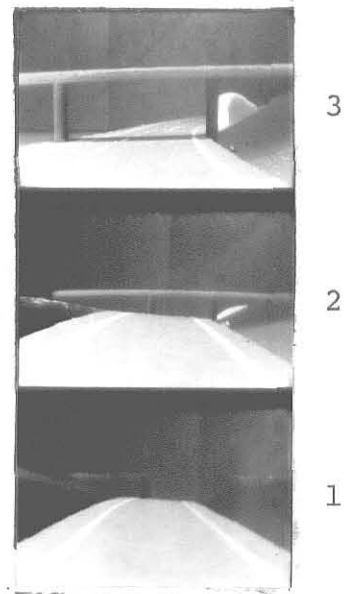
A. Actual Location  
Photographs



B. Scale Model  
Photographs,  
H: 1" = 40'  
V: 1" = 40'



C. Scale Model  
Photographs,  
H: 1" = 50'  
V: 1" = 50'



D. Scale Model  
Photographs,  
H: 1" = 40'  
V: 1" = 20'

Figure 9. Interchange Photographs

picture 2 of the actual location and all of the models give no indication that a weaving section is ahead. In picture 3, which is 200 feet farther downstream, the driver is actually in the weaving section. However, a driver unfamiliar to this location might have some difficulty distinguishing this weaving section from a typical acceleration lane. Actually, close inspection of picture 3 reveals that a right-hand off-ramp begins immediately following the structure in view. Nevertheless, a driver under normal circumstances would not have the time to make a detailed inspection of the situation ahead.

#### Intersection Modeling Results

Since intersection models are also often used to study contour grading, signing, and other related items, the best model was believed to be one with the same horizontal and vertical scale. Under this premise, the first intersection model was built with both horizontal and vertical scales of  $1" = 40'$ .

As expected, the resulting model appeared quite realistic from the driver's viewpoint. Both the actual location and model depict the leg of the intersection as very flat. Figure 10A is a series of photographs of the actual location and Figure 10B is a series of photographs of the first model. These photographs were taken at approximately 100 foot intervals.

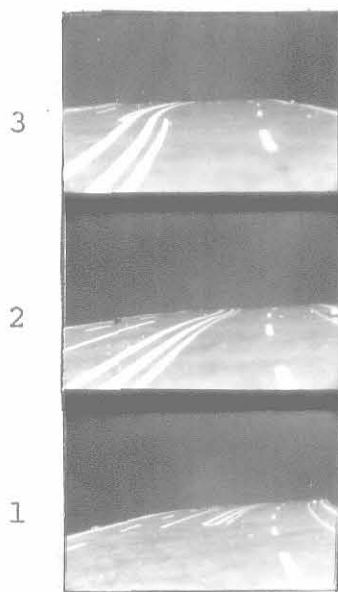
However, it was extremely difficult to accurately cut the profile used in this model. Even at the relatively large vertical scale of  $1" = 40'$ , the profile varied little from a



A. Actual Location Photographs



B. Scale Model Photographs,  
H: 1" = 40'  
V: 1" = 40'



C. Scale Model Photographs,  
10:1 Vertical Exaggeration



D. Plan Model Photographs

Figure 10. Intersection Photographs

straight line. It was noted by the author that this held true for grades less than about one percent in 40-scale models with no vertical exaggeration.

Since the profiles could not be cut with accuracy and ease, an investigation was made of two other types of models. First, models were constructed with exaggeration in the vertical scale and second, a simple plan model consisting of the roadway, alone, attached to a flat surface was investigated.

Models with vertical exaggeration. Three models were constructed with vertical exaggeration. The models were built with exaggerations of 2:1, 4:1, and 10:1. Of these models, the only one which was significantly easier to construct than the model with no exaggeration was the model with a 10:1 vertical exaggeration. Figure 10C is a series of photographs of this model.

These photographs depict a noticeable crest vertical curve prior to approaching the intersection, which is not the case in the actual location. Hence, the model was judged to be particularly unrealistic and efforts were abandoned in this area.

Plan model. This model consisted simply of the roadway surface with no urethane profile. The surface was attached to a flat piece of styrofoam and photographed. The results, which appear in Figure 10D, are essentially the same as the model built with the same horizontal and vertical scales (Figure 10B).

Both the plan model (Figure 10D) and the model built with no exaggeration (Figure 10B) portray the inherent problem of the intersection most realistically. In picture 1 the driver has no indication that a left turn bay is ahead. In picture 2, 100 feet downstream, the driver can see that something unusual is happening ahead in his lane. For some reason, unexplained to the driver, the lane appears to become wider near the intersection. Finally, the left turn bay comes into full view in picture 3. However, as the models have shown, the driver was not given adequate warning of the approaching situation.

#### Summary of Modeling Results

The results of the interchange models built with the same horizontal and vertical scales showed a high degree of realism from the driver's vantage point. Therefore, it was concluded that there is no real need to introduce vertical exaggeration in interchange models built at relatively large scales of  $1" = 40'$  or  $1" = 50'$ .

The best intersection model was the one utilizing the roadway surface only and no urethane profiles. This model appeared quite realistic and was easy to construct. In the study of an intersection with very flat grades (i.e., less than about one percent), this type of simple model would probably be sufficient.

If the profile of an intersection is dictated by the topography and the grades are greater than one percent, a

model should be constructed in the same manner as an interchange model. That is, using scales of  $1" = 40'$  or  $1" = 50'$  in the horizontal plane, urethane profiles should be constructed with the same respective vertical scale.

In order to study a particular area or problem, the entire interchange or intersection model does not have to be built. Instead, a partial model of the section in question can be constructed.

Interchange models built with some vertical exaggeration (say 2:1) have some merit. They could be used effectively in checking and correcting designs for problems involving vertical sight distance. For example, if one had reason to believe a design contained a hidden off-ramp, a partial model of the section in question could be built using vertical exaggeration. The vertical exaggeration in the model would thus act as a safety factor. Working with an exaggerated model to check and correct such a problem, one would be very likely to detect the problem prior to the actual construction of the interchange.

Intersection models with some vertical exaggeration, although of no particular benefit for the intersection location in the study, might be beneficial in other studies. If, for instance, the crown of an intersecting roadway may be thought to restrict the sight distance across an intersection, a model with some vertical exaggeration could be constructed to check and/or eliminate this apparent problem. Again this vertical exaggeration would act as a safety factor in design.

All of the conclusions drawn thus far hold true when viewing the models with the naked eye and with the OPTEC modelscope. However, the use of a modelscope was noted to be a most valuable aid in obtaining views from the driver's vantage point.

Observations were made of two different materials used in the construction of roadway surfaces--pressboard and mat board. Mat board was noted as being quite superior and hence is recommended as a good and inexpensive material to use.

## ALINEMENT MODELS

The American Association of State Highway Officials' A Policy on Geometric Design of Rural Highways (1) states:

Horizontal and vertical alinement should not be designed independently. They complement each other and poorly designed combinations can spoil the good points and aggravate the deficiencies of each. Horizontal alinement and profile are among the more important of the permanent design elements of the highway, for which thorough study is warranted. Excellence in their design and in the design of their combination increase utility and safety, encourage uniform speed, and improve appearance, almost always without additional cost.

Coordination of horizontal and vertical alinement is indeed a difficult task. The use of alinement models is a means by which the highway designer can effectively preview the effects of combining plan and profile in three dimensions.

Alinement models are generally built at horizontal scales smaller than those used in interchange and intersection models, common scales ranging from 1" = 100' to 1" = 500'. At relatively small scales, long sections of highway can be modeled in a limited amount of space. Thus, alinement models can also be used to effectively examine losses of view of the roadway ahead.

Two locations were selected and modeled for the research-- a four-lane expressway and a two-lane highway. Both of these locations had a long downgrade and short vertical curves.\*

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\*The downgrade in the four-lane location is approximately 3.5 percent while the downgrade in the two-lane location is nearly 6 percent.

These factors were considered to be the best indicators in determining the appropriate vertical scales to use in alinement models.

Numerous models of these locations were constructed. The models were constructed at two different horizontal scales-- 1" = 100' (100-scale) and 1" = 400' (400-scale).

One other location was selected and used in the research. This location was used to determine how highway overpasses should be handled in 100-scale models built with vertical exaggeration. Also, the location illustrated the utility of 100-scale models in locating design problems not apparent from the plans alone. In order to maintain the continuity of this paper, this location was handled in a separate section (see page 41).

#### Construction Procedure

Since the procedure outlined in the Appendix applies primarily to interchange models, modifications in this procedure were necessary for the alinement models. Urethane sheets of 1/4 inch in thickness were found more appropriate for the profiles than the 1/2 inch sheets.

No roadway surfaces were made for these models. Instead, black lines were drawn on the edges of the urethane with a felt tip marker to help delineate the edges of pavement. Black lines across the profile, perpendicular to the edge markings, were drawn at equal intervals to help delineate the depth of perspective. For models built at 100-scale, two inch intervals

were found appropriate. For the models built at 400-scale, one to 1-1/4 inch intervals worked best.

In order to assure that the top of the profile remained on the correct horizontal alinement, braces made of urethane were sometimes necessary, especially when the profiles were over six to eight inches high. On the 100-scale four-lane models, pieces of urethane were often inserted between the two roadways to assure the correct median width.

It was extremely difficult to cut profiles with short vertical curves in building the alinement models. It was noted that some of the vertical curves which were difficult to cut at 100-scale, were virtually impossible to cut at 400-scale. In order to construct the 400-scale models accurately, the profile had to be cut "high" and then sanded to the correct elevation. Thus, it appeared that simply constructing alinement model profiles, especially at very small scales, was one of the best ways to locate possible discontinuities in the vertical plane caused by short vertical curves.

In constructing the 400-scale models of the four-lane expressway, only one profile was used to represent all roadways. This was possible since both directions of travel had very nearly the same profile. If, however, one is modeling independent roadway alinements, two profiles would be needed to correctly simulate the situation at hand.

At 100-scale, the thickness of the 1/4 inch urethane profiles accurately simulated the true width of pavement. At

this scale, 1/4 inch represented twenty-five feet or very nearly the correct width of two twelve-foot lanes.

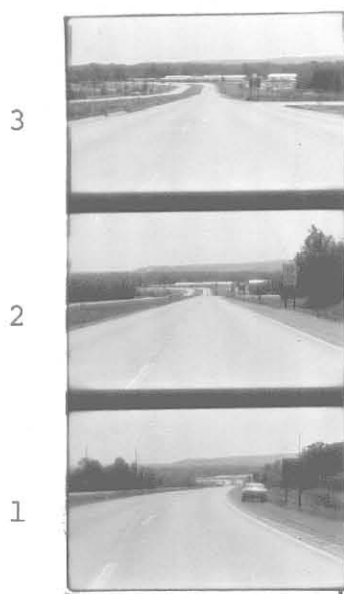
However, at 400-scale a problem existed in that the 1/4 inch thick profiles represented 100 feet in width. Efforts were made to eliminate this problem by using either narrow tape or a thick line drawn with a felt tip marker to better delineate the roadways. However, both attempts to eliminate the problem proved unsuccessful. Had 1/8 inch urethane sheets been available, the problem might have been avoided.

#### 100-Scale Modeling Results

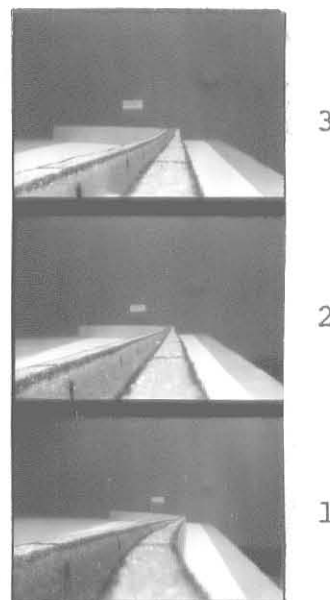
As in the intersection and interchange models, an alinement model built at natural scale was considered the most desirable. Accordingly, a 100-scale model of the four-lane expressway was constructed with no vertical exaggeration. Photographs of the actual location and the model appear in Figure 11A and Figure 11B respectively.

The resulting photographs clearly show that some vertical exaggeration is needed at 100-scale. In the model photographs the downgrade is barely noticeable. Furthermore, it was noted that cutting the profile for this model was nearly impossible due to the small vertical scale.

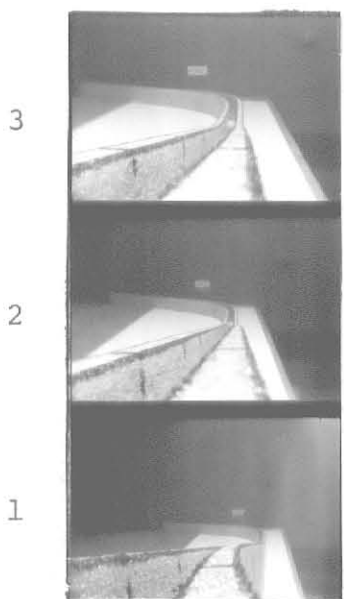
This led to the construction and investigation of two new models, one with a 5:1 vertical exaggeration and one with a 10:1 vertical exaggeration. The resulting photographs of these two models appear in Figure 11C and Figure 11D.



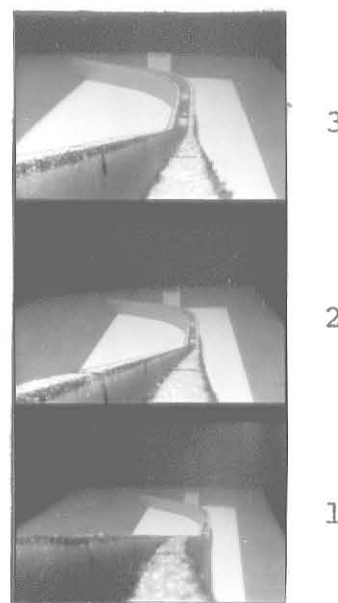
A. Actual Location Photographs



B. Scale Model Photographs, No Vertical Exaggeration



C. Scale Model Photographs, 5:1 Vertical Exaggeration



D. Scale Model Photographs, 10:1 Vertical Exaggeration

Figure 11. Four-Lane Expressway Photographs, 100-Scale Models

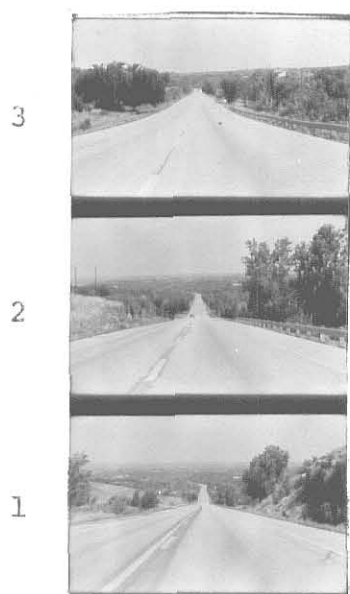
By comparing the model photographs with those of the actual location, both models resembled the actual situation closely. Close inspection of the photographs seemed to indicate that the grades in the model with a 5:1 vertical exaggeration (Figure 11C) looked more realistic than the grades in the model with the 10:1 vertical exaggeration (Figure 11D). However, no positive conclusions could be drawn from these two models alone.

The models of the two-lane location clearly indicated which vertical scale was best in 100-scale models. The models of this location were again built with 5:1 and 10:1 vertical exaggerations. Photographs of the actual location and the models appear in Figure 12.

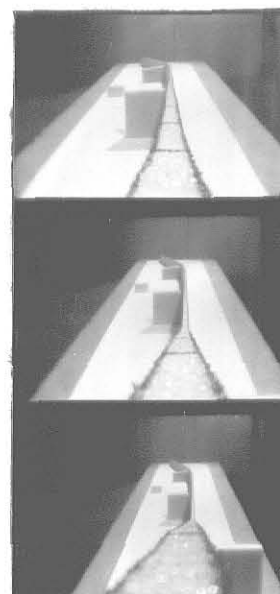
The model with 5:1 vertical exaggeration (Figure 12B) was the most realistic. The downgrade in the model with a 10:1 vertical exaggeration (Figure 12C) appears extremely steep. Also, in picture 1 of Figure 12C the crest vertical curve appears to conceal the downgrade, whereas this is not the case in both the actual location and in the model with a 5:1 vertical exaggeration.

#### 400-Scale Modeling Results

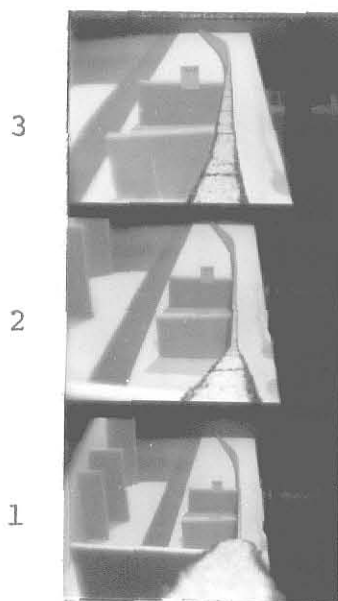
Two models of each location were built at a horizontal scale of  $1" = 400'$ . Since it was found that 100-scale models were not realistic without vertical exaggeration, no attempt was made to construct 400-scale models without vertical exaggeration. The vertical scales used were  $1" = 100'$  (4:1 vertical exaggeration) and  $1" = 40'$  (10:1 vertical exaggeration).



A. Actual Location Photographs



B. Scale Model Photographs, 5:1 Vertical Exaggeration



C. Scale Model Photographs, 10:1 Vertical Exaggeration

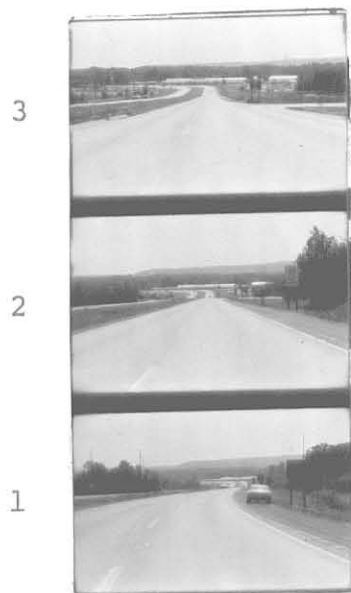
Figure 12. Two-Lane Highway Photographs, 100-Scale Models

For some reason the modelscope used to photograph the models did not seem to accurately portray what the driver actually sees. Part of the problem could have been that approximately the first 3/4 of an inch in front of the modelscope was cut off from view. Although not particularly significant in models of larger scale, this reduction of foreground in the 400-scale models represented approximately 300 feet.

Because of the apparent modelscope limitations, it was difficult to obtain model photographs which could be accurately compared with the real locations. Nevertheless, it was believed that the results were sufficient to draw conclusions of the appropriate vertical scale to use in 400-scale models. The results were even more conclusive when viewing the models with the naked eye and especially with the OPTEC modelscope.

The photographs of the two locations studied appear in Figure 13 and 14. Figure 13A is a series of photographs of the actual four-lane expressway and Figure 13B and Figure 13C are the series of photographs for the models with 4:1 and 10:1 vertical exaggerations respectively. Similarly, Figure 14A is a series of photographs of the actual two-lane highway location and Figure 14B and Figure 14C are the series of photographs of the models with respective vertical exaggerations of 4:1 and 10:1.

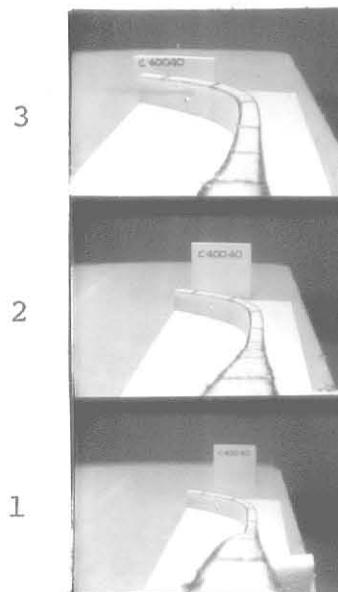
The models with a 4:1 vertical exaggeration, or vertical scale of 1" = 100', did not accurately simulate the real situations. The long downgrade in both locations simply appeared



A. Actual Location Photographs

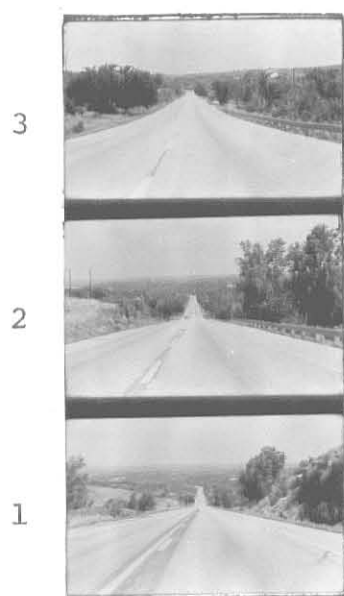


B. Scale Model Photographs, 4:1 Vertical Exaggeration

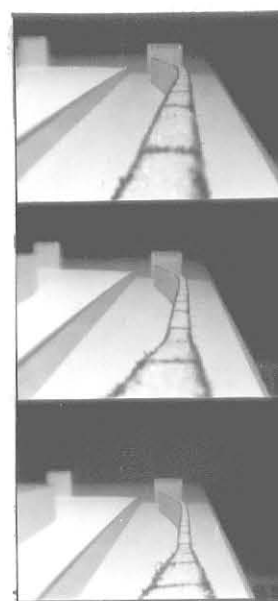


C. Scale Model Photographs, 10:1 Vertical Exaggeration

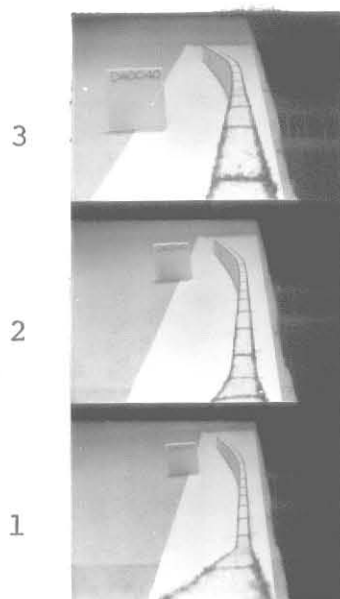
Figure 13. Four-Lane Expressway Photographs, 400-Scale Models



A. Actual Location Photographs



B. Scale Model Photographs,  
4:1 Vertical Exaggeration



C. Scale Model Photographs,  
10:1 Vertical Exaggeration

Figure 14. Two-Lane Highway Photographs,  
400-Scale Models

too flat on these models. The models with a 10:1 vertical exaggeration, on the other hand, were quite realistic. The long downgrade in both locations looked as steep on the models as in the actual situations.

#### Summary of Modeling Results

Alinement models built at 100-scale need vertical exaggeration in order to appear realistic. A vertical scale of 1" = 20', or in other words, a vertical exaggeration of 5:1 was found to be appropriate.

At 400-scale, a vertical scale of 1" = 40', or a 10:1 vertical exaggeration, was found appropriate.

All of the above conclusions hold true when viewing alignment models with the naked eye and with the OPTEC modelscope. In fact, at 400-scale the conclusions were even more obvious when using the naked eye and especially the OPTEC modelscope.

It was difficult if not impossible to cut profiles with short vertical curves, especially at 400-scale. Thus, it was concluded that simply constructing alignment model profiles, especially at very small scales, was one of the best ways to locate possible discontinuities in the vertical plane caused by short vertical curves.

## HIGHWAY OVERPASSES IN 100-SCALE MODELS

Often it is desirable to study the effects bridges, particularly overpasses, have on the roadway alignment. Questions such as "How does the bridge fit in with the overall design?," "Does the bridge appear open?," and "How does the column placement affect the design?" are difficult to answer from the plans alone. Hence, models can be an effective design aid.

When two roadways intersect and an interchange is not warranted, it is not always practical to construct a model at relatively large scales. Instead, a better solution is to construct the overpass in conjunction with an alignment model. However, when vertical exaggeration is used in an alignment model, it is difficult to build an overpass which appears realistic. This problem is often encountered in 100-scale models.

In an effort to solve the problem at 100-scale, an overpass location was chosen which had 2:1 backslopes. A model of the location was built using the appropriate vertical exaggeration of 5:1. The backslopes were constructed from urethane with a piece of mat board used to simulate the crossing structure. Wooden dowels, 1/8 inch in diameter, were used to represent the piers. Figure 15 shows a model used in the study.

The location chosen also had a problem which was not necessarily apparent in the plans. The structure crossed a four-lane highway on a crest vertical curve. Just prior to the structure, the four-lane highway began to curve to the right.

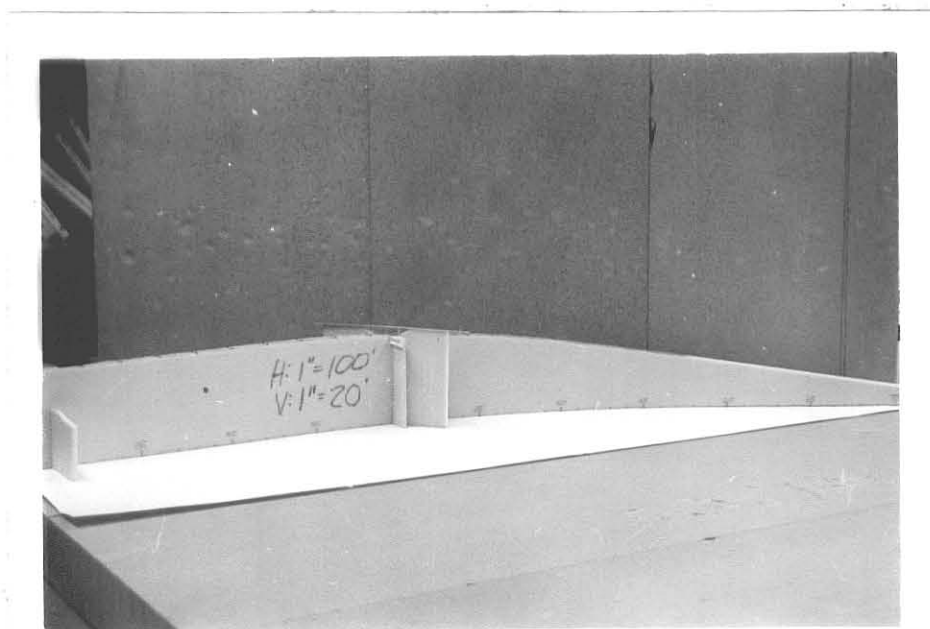
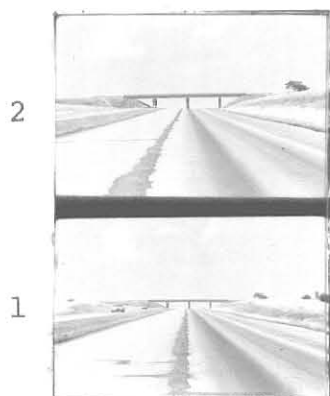


Figure 15. 100-Scale Highway Overpass Model

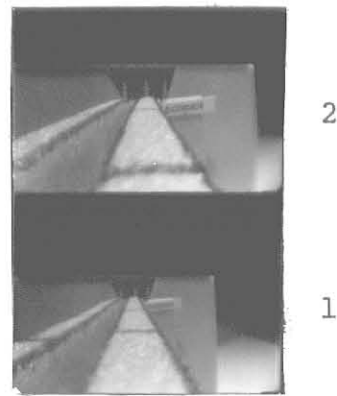
The resulting effect was that the center pier of the structure appeared to be in the middle of one of the approaching roadways.

#### Modeling Results

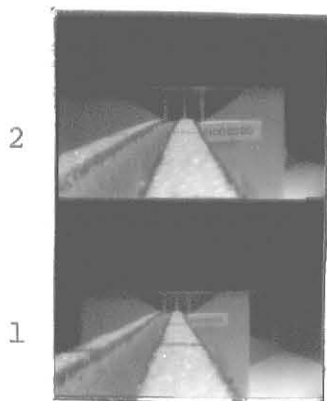
The first attempt in the problem solution was a model with the structure and backslopes built at the same scales as the four-lane alignment. That is, the structure was built with a horizontal scale of  $1" = 100'$  and a vertical scale of  $1" = 20'$ . The results of the model clearly showed that the backslopes appeared too steep. Figure 16A shows photographs of the actual location and Figure 16B shows the resulting photographs of the first model.



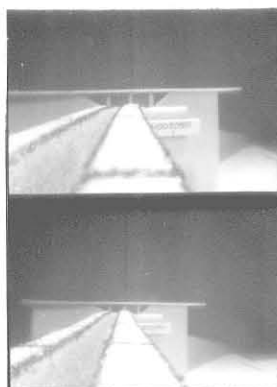
A. Actual Location Photographs



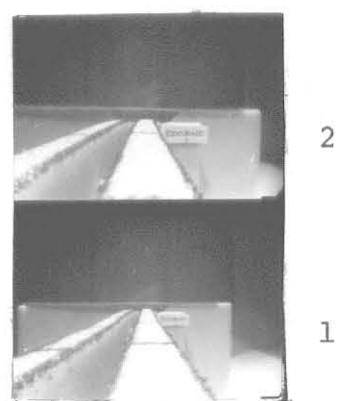
B. Overpass Model Photographs,  
H: 1" = 100'  
V: 1" = 20'  
Exaggerated Backslopes



C. Overpass Model Photographs,  
H: 1" = 100'  
V: 1" = 20'  
Backslopes 2:1



E. Overpass Model Photographs,  
H: 1" = 100'  
V: 1" = 50'  
Backslopes 2:1



D. Overpass Model Photographs,  
H: 1" = 100'  
V: 1" = 100'

Figure 16. Highway Overpass Photographs

An attempt was made to correct the steep appearance of the backslopes in the second model. The structure was kept at a vertical scale of  $1" = 20'$  while the backslopes were constructed at the true slope of 2:1. The results of this model are clearly evident in Figure 16C. The structure appeared completely out of proportion in relation to itself and to the four-lane alignment.

Better results were obtained in the third model. In this model, no vertical exaggeration was used in the construction of the structure. The effect was a very realistic model. Photographs of this model appear in Figure 16D.

Although the third model appeared very realistic when photographed through the modelscope, it appeared out of proportion when viewed with the naked eye and with the OPTEC modelscope. The vertical exaggeration used in the four-lane alignment concealed a considerable portion of the center pier in these cases. The OPTEC modelscope placed the viewpoint much closer to the surface than did the modelscope used in the photography. By standing at the end of the model, the naked eye allowed one to essentially view the model from just above the roadway surface.

Because of these apparent problems a fourth model was constructed. The structure was built with a vertical scale of  $1" = 50'$ , or a 2:1 vertical exaggeration, while the backslopes were kept at 2:1. The resulting photographs, which appear in Figure 16E, again show a very realistic model. This

model also appears very realistic when viewed with the naked eye and with the OPTEC modelscope.

It should be noted that all of the models, regardless of the scale used, clearly identified the problem at hand. The pier appeared in the middle of the approaching roadway.

### Conclusion

It was evident from the results of the first two models that using full exaggeration ( $1" = 20'$ ) in an overpass in conjunction with 100-scale models produced unrealistic and distorted effects. When the overpass was constructed with no vertical exaggeration (i.e., natural scale), it appeared very realistic with the equipment used in the photography. However, when viewing the model with the naked eye and with the OPTEC modelscope, it again appeared unrealistic.

The fourth model appeared realistic in all cases. Therefore it was concluded that the most realistic overpass to be used in conjunction with 100-scale models is one with a vertical scale of  $1" = 50'$  (2:1 vertical exaggeration) and backslopes constructed at their true slopes.

## SMALL SCALE ALINEMENT MODEL APPLICATIONS

Small scale alinement models have some distinct advantages which set them apart from the other types of models discussed in this paper. Because of the relatively small horizontal scales used in these models, such as 1" = 400' or 1" = 500', long sections of highway can be modeled in very little space. Also, the time required to build such a model is minimal. Given the plan and profile, along with the necessary materials, two persons can construct a small scale model of a four mile section of highway in less than one hour.

This section of the paper illustrates a few applications of small scale alinement models. Several hypothetical design situations were fabricated and modeled.

All of the models built were at 400-scale. Models at this scale were considered to be representative of all small scale alinement models.

### Visual Dip Models

According to Smith, Yotter, and Murphy (7), there are three primary rules for coordination of the profile and plan of a highway. These rules are as follows:

1. The P.I. of the horizontal curve and the P.I. of the vertical curve must nearly coincide (within about 10 percent of the length of horizontal curve).
2. The horizontal and vertical curves must be nearly the same length (within about 10 percent).

3. If the conditions in rule two cannot be met, the horizontal curve should slightly precede the vertical curve.

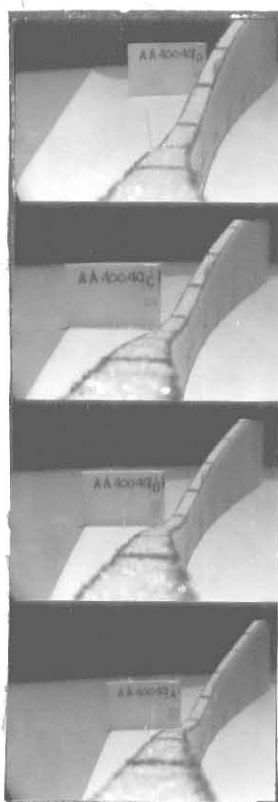
Three models were constructed to test the effectiveness of 400-scale models in indicating violations of rule two. The geometry of all the models was essentially the same with the length of vertical curve being the only variable. The geometry of the three models is summarized as follows:

Horizontal:	P.I. Sta. = 200+00 D = 1°00' $\Delta$ = 30°00' Right Length of curve, $L_H$ = 3000'
Vertical:	P.I. Sta. = 200+00 Back tangent grade, $g_1$ = -3% Forward tangent grade, $g_2$ = +3% Length of curve, $L_v$ = variable

The first model constructed had a vertical curve length of 900'. This length was slightly longer than the length recommended by AASHO (1) as the absolute minimum for a design speed of seventy miles per hour. Using this length of vertical curve, the conditions set forth in rule two were clearly violated.

Figure 17 is a series of photographs taken of the first model. The photographs depict the expected visual dip or artificial inflection most vividly. Furthermore, the dip is more apparent as the distance from the observer to the P.C. is increased, which is the same conclusion drawn in Reference 7.

To further test the effectiveness of 400-scale models, a second model was constructed. The length of vertical curve in this model was twice that of the first model, or 1800'. Although the length of vertical curve was significantly greater



D. At the P.C.

C. 500' Prior  
to P.C.

B. 1000' Prior  
to P.C.

A. 1500' Prior  
to P.C.

Figure 17. Visual Dip Model Photographs,  $L_v = 900'$

than the absolute design minimum, it still violated the conditions in rule two.

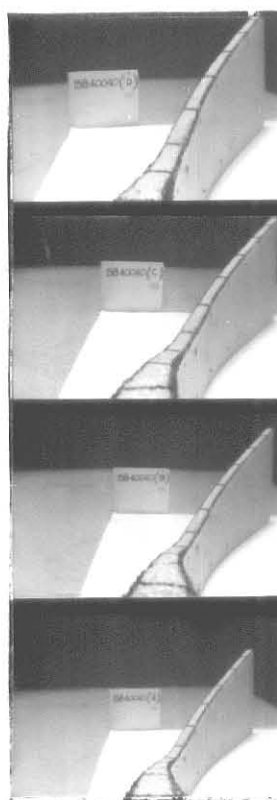
A series of photographs of the second model appear in Figure 18. Again the expected visual dip was clearly apparent, even at the P.C. of the horizontal curve.

Having established the fact that 400-scale models are sensitive to visual discontinuities caused by violations of rule two, a third model was built. This model was in keeping with the rules for coordination of plan and profile. Both the horizontal and vertical curves were 3000 feet in length. The resulting photographs appear in Figure 19. As expected, the photographs depict a much smoother and more flowing alinement with no artificial inflections or vertical dips.

#### Long Highway Alinement Models

As stated earlier, one distinct advantage of small scale alinement models is that long sections of highway can be modeled in a very limited space. To show some of the conclusions that can be derived from such models, two urethane profiles, each representing nearly four miles of highway, were constructed.

Both of these profiles utilized the same tangent grades. One of the profiles was constructed with vertical curves designated by AASHO as absolute minimums for a design speed of seventy miles per hour. The other profile was constructed with vertical curves of more generous length. These profiles were then tested on various horizontal alinements, two of which appear in this report.



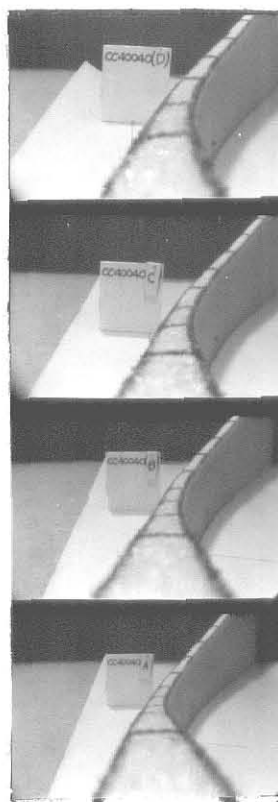
D. At the P.C.

C. 500' Prior  
to P.C.

B. 1000' Prior  
to P.C.

A. 1500' Prior  
to P.C.

Figure 18. Visual Dip Model Photographs,  $L_V = 1800'$



D. At the P.C.

C. 500' Prior  
to P.C.

B. 1000' Prior  
to P.C.

A. 1500' Prior  
to P.C.

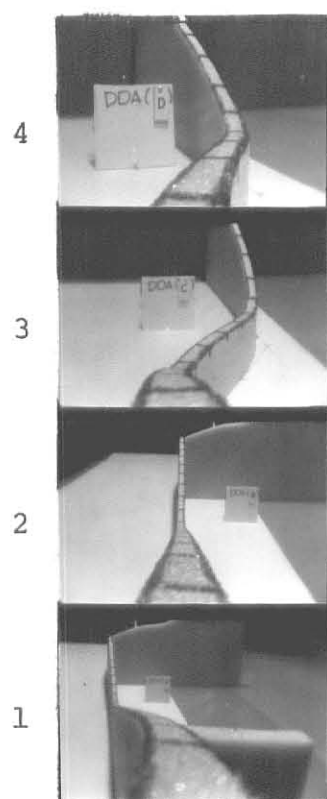
Figure 19. Visual Dip Model Photographs,  $L_v = 3000'$

In one of the horizontal alinements, care was taken to make sure the vertical curves were in phase with the horizontal curves. In other words, the P.I.'s were kept coincident. Furthermore, care was taken to keep the lengths of the horizontal curves nearly the same as the vertical curves of the more generous profile.

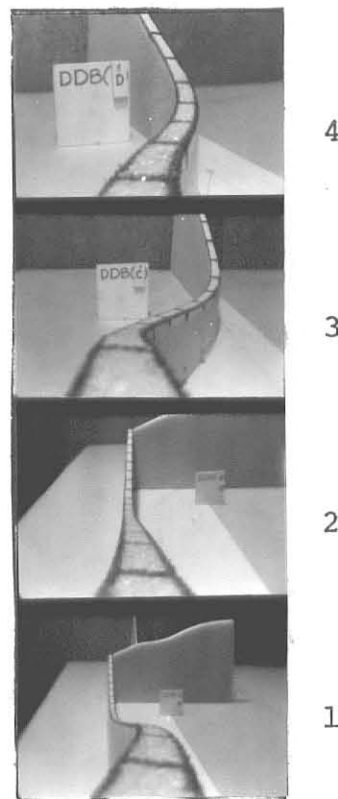
A series of photographs of both profiles fitted to the first horizontal alinement appear in Figure 20. The photographs in Figure 20A show the model with the minimum length vertical curves while the photographs in Figure 20B depict the model with the more generous vertical alinement. The photographs were taken from the same stations in both of the profile models. As expected, the model with the more generous vertical alinement appeared smooth and flowing while the other model indicated some obvious discontinuities.

Inspection of the first photograph of both of the models clearly indicates a problem that was not apparent prior to the construction of the models. A piece of urethane was cut to represent the finished ground line at a point on a crest vertical curve in both models. The roadway in both models disappears over the crest vertical curve only to reappear on the horizon in an unanticipated location. Thus, both models indicated a design error which was not apparent in the plans.

The same profiles were again used to construct another alinement. In these models no care was taken to keep the vertical curves in phase with the horizontal curves. The results of these models appear in Figure 21.



A. Profile with  
Short Vertical  
Curves



B. Profile with  
Long Vertical  
Curves

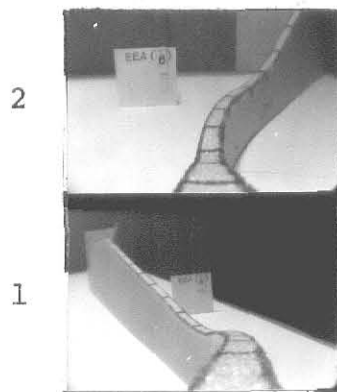
Figure 20. Long Highway Alinement Model  
Photographs, Curves in Phase

Figure 21A depicts two locations on the alinement built with the profile with short vertical curves. As expected, the photographs indicate some of the gross discontinuities of the alinement (especially note the visual dips in picture 2).

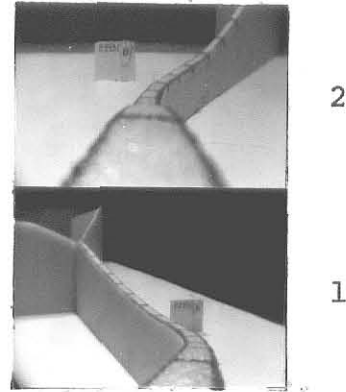
Figure 21B depicts the same two locations on the model with a more generous profile. Even though the model indicates a better design has been attained, it certainly represents a less than desirable situation, indicating the need for coordination of vertical and horizontal alinement.

### Conclusion

400-scale models appear to give valid indication of artificial inflections or visual dips. Furthermore, these small scale models allow the engineer to study the effects of roadways which disappear over crest vertical curves and reappear later on the horizon. Although many design problems can be eliminated by utilizing generous alinements in keeping with the rules for plan and profile coordination, 400-scale models, or more generally small scale alinement models, are certainly valuable in locating unexpected problems.



A. Profile with  
Short Vertical  
Curves



B. Profile with  
Long Vertical  
Curves

Figure 21. Long Highway Alinement Model  
Photographs, Curves Not in Phase

## CONCLUSION

Within the limitations imposed by the scope of the study and from the information assimilated, the following was concluded:

1. There is no real need to introduce vertical exaggeration in interchange models built at relatively large scales of  $1" = 40'$  or  $1" = 50'$ .
2. In the study of an intersection with very flat grades (i.e., less than about one percent), a simple plan model consisting of the roadway surface alone, would most likely be sufficient.
3. If the profile of an intersection is dictated by the topography and the grades are greater than one percent, a model should be constructed in the same manner as an interchange model.
4. In order to study a particular area or problem, a partial model of the intersection or interchange can be constructed as opposed to the entire model.
5. Interchange or intersection models built with some vertical exaggeration (say 2:1) can be used effectively to study problems involving vertical sight distance. The exaggeration would thus act as a safety factor.
6. Alinement models built at 100-scale need a vertical exaggeration of 5:1 (i.e., a vertical scale of  $1" = 20'$ ) in order to appear realistic.

7. Alinement models built at 400-scale need a vertical exaggeration of 10:1 (i.e., a vertical scale of 1" = 40') in order to appear realistic.

8. Since it was difficult if not impossible to cut profiles with short vertical curves, especially at 400-scale, simply constructing alinement model profiles, especially at very small scales, is one of the best ways to locate possible discontinuities caused by short vertical curves.

9. The most realistic overpass to be used in conjunction with 100-scale models is one with a vertical scale of 1" = 50' (2:1 vertical exaggeration) and backslopes constructed at their true slopes.

10. 400-scale models give valid indication of artificial inflections or vertical dips.

11. Small scale alinement models are effective in examining losses of view of the roadway ahead.

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## APPENDIX\*

The construction procedure for the urethane type model is outlined below as it would apply to an interchange.

1. Attach the plan base sheet to the styrofoam base using pins, staples or glue.
2. If the roadway profiles are plotted on profile paper, these can be stapled or pinned to the urethane sheets in preparation for cutting the profiles. If this is not the case, the profiles can be plotted directly on the urethane using a fine-pointed felt tip pen. The stationing should also be marked on the urethane with the pen (this aids in positioning the cut-out profile on the base sheet). It is not necessary to draw the profile on the urethane as a dot can be placed at profile elevation at each station mark. It is well to make each profile with scale and roadway name or designation for fast identification. One-half inch urethane sheets should be used for all profiles except the shortest radius roadways, with one-quarter inch material used for these.
3. The roadway profile can be easily cut with a sharp razor-type knife . . . . Dull blades should be replaced, as they tend to pull or tear the material.

A plastic spline, laid on its side along the drawn profile or dots, provides an excellent guide for the knife. The knife blade should be kept perpendicular to the urethane, thus insuring a square cut along the profile. The spline will need to be held in place with the fingers by one person while a second one does the cutting. Any "high points" as a result of an improper cut can easily be eliminated by sanding with a small piece of urethane.

4. It is helpful to plot the ground profile under bridges or elevated structures. This provides additional support in the model and gives a good indication of the finished ground.

In assembling sections of such elevated roadways, care must be taken to insure that the roadway surface is at the proper elevation. This can be accomplished by

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\*Source: Reference 5.

leaving the cut-out portion of urethane in place until the profile is firmly attached to the base. One-eighth inch wooden dowel rods can be inserted vertically at column locations and the dowel inserted until its top is at finish roadway elevation. It is helpful to use a metal dowel of 1/8 inch diameter to pre-form a hole for the wooden dowel in both the urethane and styrofoam. After the dowels are in place, a bit of cutting along the sides of the dowel will allow the cut-out portion of the profile to be removed.

5. The profiles are attached to the styrofoam base using straight pins, "toe-nailed." In some instances, when extra rigidity is desired, wooden dowels (sharpened in a pencil sharpener) can be inserted vertically through the profile and into the base. An assembled model can be shipped without damage if placed in proper boxing.

The 1/2 inch profiles, if handled carefully, can be bent into very sharp curves, and of course, 1/4 inch profiles can be bent to sharper curvatures. Slight vertical v-shaped cuts on the interior side of the curves, at about one inch intervals, make it easier to bend the profiles into very sharp curves. The intersecting profiles should be notched to increase the stability of the model.

6. Using 1/2 inch thick profiles makes most interchange models appear quite realistic. If, however, one wants to improve the realism very quickly, roadway surfaces can be attached to the top of the profiles.

A STUDY OF VERTICAL AND HORIZONTAL SCALES  
FOR HIGHWAY DESIGN MODELS

by

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BSCE, Kansas State University, 1971

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AN ABSTRACT OF A MASTER'S THESIS

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## ABSTRACT

The purpose of the study was to resolve scale problems and to determine the degree of realism in design models. This was accomplished by comparing models built at various scales to the actual locations they simulated.

Photographs of the actual locations were taken at known points along the roadway from the driver's approximate viewpoint. Plans were obtained for each location and scale models were constructed. These models were then photographed from the same points as the actual location using a modelscope to place the viewpoint at approximate driver's eye level. Comparing the model photographs to the location photographs was the primary means used to determine which scale models appeared most realistic.

Two categories of design models were investigated: (1) intersection and interchange models and (2) highway alignment models. The appropriate vertical scales for each type of model were determined for the horizontal scales most commonly used in design.

The specific problem of highway overpasses used in conjunction with 100-scale models with vertical exaggeration was investigated. Conclusions were made concerning the handling of overpasses in these cases.

Numerous photographs resulted from the study and were documented in the paper. Also, some applications of design models, particularly 400-scale models, were noted.