HIGHWAY DESIGN MODELS: SCALES AND USES

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One solution to the problem of depicting a three-dimensional highway design in other than a two-dimensional form is through use of models and model photographic equipment. This paper shows the results of research aimed at resolving the problems of scale and realism in highway design models and illustrates the use of modelscopes for photographing and viewing design models. Examples are given of designs modeled to represent a variety of situations including an intersection at flat grade, an interchange with significant grade changes, and straight highway sections.

•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 highway in their minds simply from viewing two-dimensional plans (plan, profile, and cross sections) 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 physical problem is slowly being solved through the development of successful computer graphics programs (7, 8, 9), the production of more sophisticated model photographic equipment, and the availability of a greater range of model-making materials (5).

The major problems that still remain before proper visual evaluations can be made are to convince clients that these studies are indeed necessary and need not be a massive budgeting item; to demonstrate to the designer that he can readily build design models for such visual studies (or that he can have the models built economically and quickly); and to make the techniques, materials, and equipment for building, viewing, and analyzing design models readily available.

The models that are the subject of this paper are termed "design" models, i.e., models built without much concern for cosmetic details. Design models are generally used as three-dimensional aids for preliminary and final highway design.

LITERATURE

The series of nationwide seminars on Dynamic Design for Safety (7) has been instrumental in pointing out the differences between presentation models and design models and in illustrating the uses and construction techniques for design models. The concept of design models was enthusiastically received by the highway engineers attending the seminars.

Berry and McCabe (2) and Porter (6) present excellent discussions on the construction and uses of design models, especially urethane models. Butcher and Pearson (3) present an excellent discussion on model photography. Although they were concerned with architectural models, they provide considerable insight into model photography.

METHOD OF APPROACH

The approach taken in the solution of scale problems was an empirical one inasmuch as the literature survey revealed no 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 built and 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. Model photographs and color slides were compared to the location photographs and color slides to determine the vertical scale at which the model appeared most realistic.

Although the comparison of model photographs and 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, the Optec modelscope, and color slides were also compared to the actual location views.

Locations and Location Photography

The locations were selected to represent a variety of design situations. These locations included one intersection at a very flat grade, one interchange with significant grade changes, and two highway sections.

The locations were photographed with a 35-mm Nikon F single-lens reflex camera equipped with a Nikkor zoom lens. A camera setting of 86 mm appeared to give the most realistic picture of a roadway section.

Model Construction

The models were constructed of profiles cut from ½- or ¼-in. sheets of foamed urethane. The profiles were then pinned to a styrofoam base. Detailed procedures for constructing urethane models at various scales are given elsewhere (2, 6, 7).

The urethane models were inexpensive and easy to construct. For example, a large scale (1 in. = 40 ft) model of a complex interchange can be built in 2 to 4 man-days at a cost of \$50 to \$75 for materials (7).

Model Photography and Viewing

The Nikon F camera was also used in the model photography. The modelscope, developed under the direction of William E. Hamilton of Howard, Needles, Tammen and Bergendoff, was fitted directly to the camera body (Fig. 1). A special focus screen manufactured by Nikon was utilized to let more light through the pentaprism.

A tripod was used to hold the camera and attached modelscope stationary during the time exposures, and a cable release was used for the time exposures.

The camera was attached to the tripod such that the modelscope protruded onto the models in a horizontal position (Fig. 1). This was possible because only partial models were made for this study. When models of, say, a complex interchange are photographed, it is usually necessary to arrange the tripod so that the modelscope will be vertical By doing this, the modelscope can be inserted at many points in the model. It is possible to provide a moving picture of a driver's trip through the model interchange by using either a 35-mm slide camera or a movie camera (4).

The modelscope manufactured by Optec (cost about \$300) was extremely useful for quick viewing of a model. The modelscope was held with one hand and used to view a model in either the vertical or horizontal position (Fig. 2). The Optec modelscope can be readily used for photographing models.

INTERCHANGE MODELS

A location was selected that had operational problems, caused by the geometry of the situation, that were not readily apparent in the construction plans. The interchange section consisted of an entrance ramp and an exit ramp connected by a short weaving section. After construction, it was apparent that the weaving section was not readily visible to drivers entering the freeway.

To build a number of models illustrating the inherent problems, we constructed only the problem section. Hence, early in the study, an important fact was noted: To view part of an interchange did not require that the entire interchange model be built. In many cases, only the section that has probable design problems needs to be built.

Building a partial model (Fig. 3) as opposed to the entire model can result in a considerable time savings. For example, if the entire interchange had been built, the

time to construct each model would have been approximately 3 man-days, whereas each partial model was built in less than $1/2$ man-day.

All of the models were built with horizontal scales of 1 in. = 40 ft (40-scale) with the exception of one model that had a horizontal scale of 1 in. = 50 ft (50-scale).

Construction Procedure and Materials

The procedure used in the construction of the interchange model was essentially the same as outlined at the seminars on Dynamic Design for Safety (7).

To view the problems at hand required roadway surfaces for all the interchange models. The surfaces were constructed complete with inked lane markings and curbs and were attached to the top of the urethane profiles.

Two types of material were investigated for the construction of the roadway surfaces, 0.015-in. pressboard (a hard-finish brown paper board) and 0.06-in. matboard (a durable form of cardboard). The matboard was superior to the pressboard. It was not affected by the heat of floodlamps and retained its form and shape even after remaining on a model for months.

Interchange Modeling Results

The most desirable interchange model is one that is constructed at natural scale or, in other words, at the same horizontal and vertical scale. Natural scale models produce the most realistic view of the total roadway environment and provide more realism in such design applications as contour grading, retaining wall studies, and signing (2, 6). One problem investigated in the research was whether the roadway in a natural scale interchange model would appear realistic from the driver's viewpoint.

Two models were built at natural scale, one at 40-scale and the other one at 50-scale.

The result of this experiment was encouraging. Both models closely resembled the actual location from the driver's viewpoint. Figure 4 shows series of photographs taken of the actual location (Fig. 4a) and of the scale models (Figs. 4b and 4c). These photographs were taken at approximately 200-ft intervals.

In picture 1 of Figure 4b and Figure 4c, 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 vertical sight distance.

The series of photographs in Figure 4d is the result of an experiment with vertical exaggeration. The horizontal scale used in the model was 1 in. = 40 ft, whereas the vertical scale was 1 in. = 20 ft (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 in. = 40 ft. This obviously had considerable effect on the apparent vertical sight distance. In picture 1 of Figure 4d, 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 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 ft farther downstream, the driver is actually in the weaving section. However, a driver unfamiliar with this location might have some difficulty distinguishing the weaving section from a typical acceleration lane. Actually, close inspection of picture 3 reveals that a right 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 Model

An at-grade intersection was also modeled. The intersection was a high type of design with a left-turn bay located on one of the intersection legs. Even though the

Figure 1. Setup for model photography.

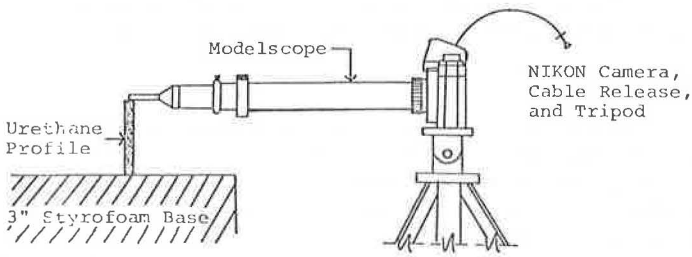


Figure 2. Use of Optec modelscope.

Figure 3. Partial interchange model.

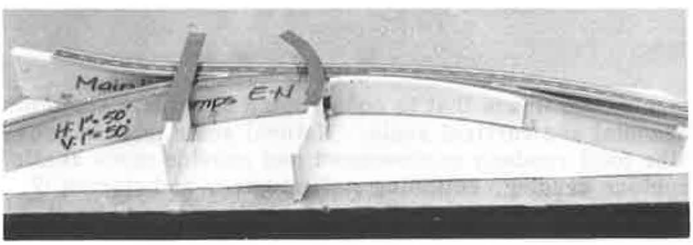
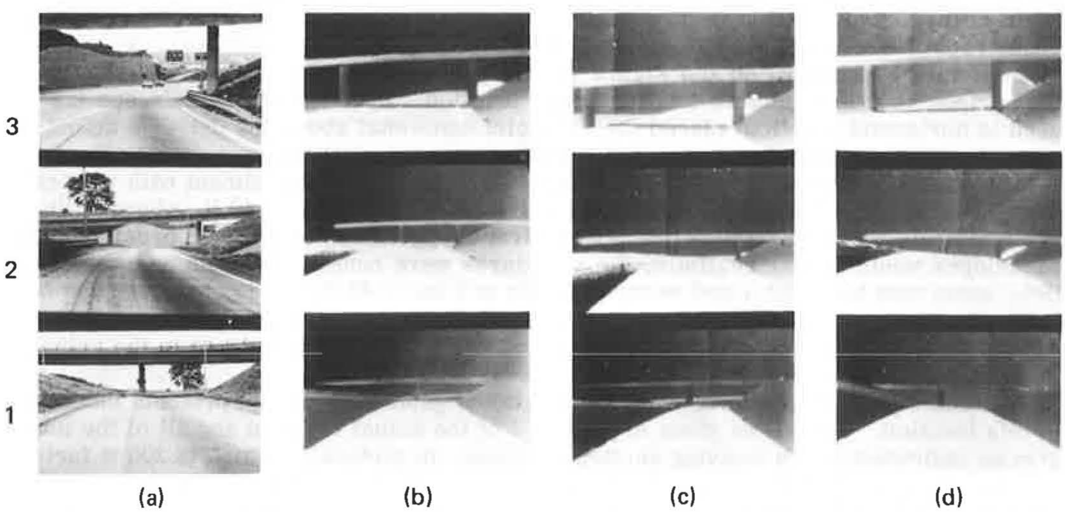


Figure 4. Photographs of (a) actual interchange location, (b) 40-scale model, (c) 50-scale model, and (d) 40-scale model with 2:1 vertical exaggeration.



intersection was built on a very flat grade (about 0.5 percent), the left-turn bay was not visible until the driver was nearly at the intersection.

Forty-scale models were built with vertical exaggeration of 2:1, 4:1, and 10:1 and with no vertical exaggeration. A plan model was also built; i.e., no urethane profile was constructed. The plan model very effectively showed the design problem. For intersections with grades of less than 1 percent, examination of plans at, say, 40-scale with a modelscope or the eye near the pavement surface works quite well. For greater grades or grade changes, one should use the scales recommended for interchange models.

ALIGNMENT MODELS

Coordination of horizontal and vertical alignment is an important but extremely difficult task (1). Using alignment models enables the highway designer to effectively preview the effects of combining plan and profile in three dimensions.

Alignment models are generally built at horizontal scales smaller than those used in interchange and intersection models; commonly used scales range from 1 in. = 100 ft to 1 in. = 500 ft. At relatively small scales, long sections of highway can be modeled in a limited amount of space. Note also that only urethane profiles (without roadways) are used in these models. Alignment 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. Numerous models of these locations were constructed at two horizontal scales, 1 in. = 100 ft (100-scale) and 1 in. = 400 ft (400-scale).

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

100-Scale Modeling Results

As in the intersection and interchange models, an alignment 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. However, the results clearly indicated that vertical exaggeration was needed at this scale. Not only were profiles difficult to plot and cut at 100-scale, but also the grades in the location simply appeared too flat on the model.

Models were built with 5:1 and 10:1 vertical exaggerations. The resulting photographs of the models of the two-lane highway location are shown in Figure 5.

The model with 5:1 vertical exaggeration (Fig. 5b) was the most realistic. The downgrade in the model with a 10:1 vertical exaggeration (Fig. 5c) appears extremely steep. Also, in picture 1 of Figure 5c, the crest vertical curve appears to conceal the downgrade, whereas this is not the case in either the actual location or the model with 5:1 vertical exaggeration. Note in Figure 5 that picture 1 of each series was taken from the same highway stationing; the same is true for pictures 2 and 3.

400-Scale Modeling Results

Two models of each location were built at a horizontal scale of 1 in. = 400 ft. Because 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. Vertical scales of 4:1 and 10:1 exaggeration were used. Figure 6 shows series of photographs of the actual two-lane highway location and the models with vertical exaggerations of 4:1 (Fig. 6b) and 10:1 (Fig. 6c).

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

simply appeared too flat on these models. The models with 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.

SMALL-SCALE ALIGNMENT MODEL APPLICATIONS

Small-scale alignment models have some distinct advantages that 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 in. = 400 ft or 1 in = 500 ft, 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 4-mile section of highway in less than 1 hour.

This section of the paper illustrates a few applications of small-scale alignment 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 alignment models.

According to Smith, Yotter, and Murphy (9), there are three primary rules for coordination of the profile and plan of a highway. These rules are as follows:

1. The point of intersection (PI) of the horizontal curve and that of the vertical curve must nearly coincide (within about 10 percent of the length of horizontal curve), i.e., the curves should be "in phase."
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:

Item	Value
Horizontal	
PI station	200+00
D, deg	1
Δ, deg	30 right
Length of curve, ft	3,000
Vertical	
PI station	200+00
Back tangent grade, percent	-3
Forward tangent grade, percent	+3
Length of curve	Variable

The first model constructed had a vertical curve length of 900 ft, which is slightly longer than the length recommended by AASHO (1) as the absolute minimum for a design speed of 70 mph. Using this length of vertical curve clearly violated the conditions set forth in rule two.

Figure 7a shows 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 point of curvature (PC) is increased, which is the same conclusion drawn by Smith, Yotter, and Murphy (9).

To further test the effectiveness of 400-scale models, we constructed a second model. The length of vertical curve L_v in this model was twice that of the first model, 1,800 ft. Although L_v was significantly greater than the absolute design minimum, it still violated the conditions in rule two.

A series of photographs of the second model is shown in Figure 7b. Again, the expected visual dip was clearly apparent, even at the PC of the horizontal curve.

Figure 5. Photographs of (a) actual two-lane highway and of 100-scale model with (b) 5:1 vertical exaggeration and (c) 10:1 vertical exaggeration.

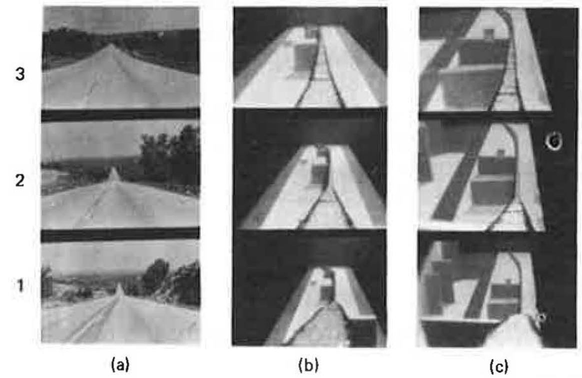


Figure 6. Photographs of (a) actual two-lane highway and 400-scale models with (b) 5:1 vertical exaggeration and (c) 10:1 vertical exaggeration.

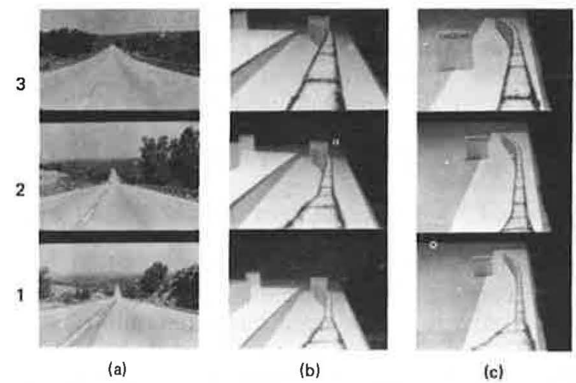
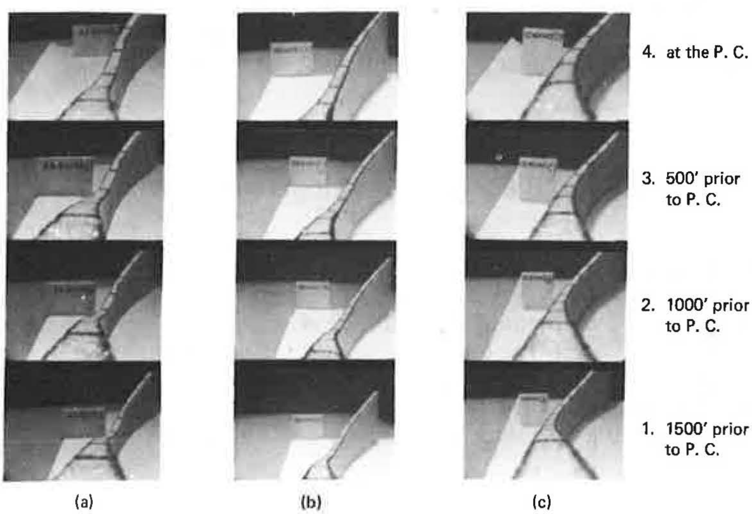


Figure 7. Photographs of visual dip models with L_v equal to (a) 900 ft, (b) 1,800 ft, and (c) 3,000 ft.



Having established the fact that 400-scale models are sensitive to visual discontinuities caused by violations of rule two, we built a third model. This model was in keeping with the rules for coordination of plan and profile. Both the horizontal and vertical curves were 3,000 ft long. The resulting photographs are shown in Figure 7c. As expected, the photographs depict a much smoother and more flowing alignment with no artificial inflections or vertical dips.

Similar studies were made with the vertical and horizontal curves being both in and out of phase. The visual discontinuities in the out-of-phase case were very apparent and agreed with similar studies that used computer graphics (9). The models also graphically indicated problems involving "losses of sight" of the roadway.

CONCLUSIONS

The following was concluded from this study:

1. There is no real need to introduce vertical exaggeration in interchange models built at 40-scale, 50-scale, or larger.
2. In the study of an intersection with very flat grades (i.e., less than about 1 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 if the grades are greater than 1 percent, a model should be constructed in the same manner as an interchange model.
4. To study a particular area or problem requires that only a partial model of the intersection or interchange be constructed rather than 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. Alignment models built at 100-scale need a vertical exaggeration of 5:1 (i.e., 1 in. = 20 ft) in order to appear realistic.
7. Alignment models built at 400-scale need a vertical exaggeration of 10:1 (i.e., 1 in. = 40 ft) in order to appear realistic.
8. Because it was difficult if not impossible to cut profiles with short vertical curves, especially at 400-scale, simply constructing alignment model profiles, especially at very small scales, is one of the best ways to locate possible discontinuities caused by short vertical curves.
9. 400-scale models give valid indication of artificial inflections or vertical dips.
10. Small-scale alignment models are effective in examining losses of view of the roadway ahead.
11. Modelscope devices are essential for studying small scale models from the driver's vantage point.
12. Photographs (especially color slides) of design models, taken through the modelscope, are of great aid in studying a wide variety of highway design problems.
13. Design models are versatile, economic, and significant aids to the highway designer.

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