Models for Highway Design: Some Construction and Photographic Techniques

REX G. PORTER, DeLeuw, Cather and Company of Canada Limited

The first primary purpose of this research was to find, by experiment, a mixture that was suitable for design modeling of highways. Many available materials were mixed, molded, observed, photographed and evaluated for this use. The ideal mixture was found to be motor oil and asbestos powder since it stayed malleable and could be easily remolded giving a realistic impression of grading in the photographs. Further research was done using glycerine instead of oil as a wetting agent and there was no appreciable difference in the two.

The second primary purpose was to apply this mixture to an actual design problem. Two design alternatives were constructed and the modeling techniques evolved. The method proved to be fast and effective as a preliminary design aid and it provided a reliable evaluation of the scheme finally constructed. Other alternatives could be examined at small additional cost.

A secondary result that evolved from this research was valuable experience in the photographic technique, instrumental in making a visual evaluation of preliminary design alternatives. The photographs taken through the modelscope gave a realistic roadway view that a driver would see.

Models and photography provide an inexpensive design evaluation tool and contribute to an efficient and aesthetic preliminary design.

•PRIOR to this study, polyurethane had been used to form the slopes on highway design models. This method required a great deal of time to shape the polyurethane by sanding and cutting, and later adjustment was not possible. If a design change was required after completing the model and studying it through a modelscope (for a description of the modelscope and its use, see the section on "Photographic Technique"), then a new model of the changed section had to be constructed. Dry sawdust had also been used but it did not give a realistic impression of the graded surface in the modelscope photographs.

A study of materials was made in order to recommend a material or a combination of materials that lent itself to modeling at the preliminary design stage; that is, the ideal material desired could be molded easily, then reworked quickly and yet retain its shape once remolded. At this stage, modelscope analysis of problem areas of vertical and horizontal alignment and grading irregularities could be used to advantage to show up problems and provide solutions not readily seen in two-dimensional plans and profiles.

A variety of materials and binders was described, mixed and formed into test slopes to narrow down the detailed analysis to only a few possibilities. Finally, an example problem was analyzed using the recommended material and several modelscope photographs emphasized the value of this inexpensive design aid.

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GENERAL STUDY PROCEDURE

Initially, a wide range of fill materials and binders was tested in different combinations. Materials tested to be used as fill were sawdust; Ottawa sand; floorsweeping compound (sawdust); Hill & Dale modeling compound; Perma Scene modeling compound; asbestos insulating powder; Pollyfilla powder; and plastic wood. Materials used as binders were contact cement; Bulldog glue (fish base); liquid plastic varnish; rubber cement; water and Pollyfilla; lubricating oil (No. 10 grade); glycerine (liquid); and linseed oil.

The testing procedure consisted of mixing these different fill materials with various binders in varied proportions to produce a workable mixture. These mixtures were then molded into test slopes and small cubes to test shrinkage, and their appearance on drying was noted. The following observations were made:

1. proportions of components used;
2. description of mixing process;
3. wet workability in molding to shape;
4. binding power to itself and to the base;
5. dry workability in remolding by cutting, sanding, chipping, and reshaping;
6. shrinkage of mix on drying;
7. hardness of mix on drying;
8. strength when dry; and
9. relative weight of the mixes.

Color photographs were made to show the more promising mixes shaped in small sample slopes. An impression of the surface texture and coloring was noted in the photographs. After studying the relative advantages and disadvantages of each mixture tested, four promising mixes were picked for further study. They were the following:

1. Liquid plastic varnish and Hill & Dale compound.
2. A combination of $\frac{1}{3}$ by volume sawdust, $\frac{1}{2}$ by volume asbestos, and $\frac{1}{6}$ by volume Pollyfilla plus as little water as possible, to make a workable mixture.
3. Perpetually wet, malleable mix No. 1 of asbestos powder plus as little No. 10 grade lubricating oil as possible to make a workable mixture.
4. Perpetually wet, malleable mix No. 2 of asbestos powder plus as little liquid glycerine as possible to make a workable mixture.

A small scale model was made using these four mixes and a shrinkage disadvantage in using the Hill & Dale modeling compound was observed. A space developed between this mixture and the polyurethane road profiles.

Linseed oil was originally used as a binder for the asbestos to keep it malleable, but, after drying for several days, a thin skin developed on the surface and could not be remolded. This problem was not encountered using No. 10 grade lubricating oil or the liquid glycerine.

There was no appreciable difference in using liquid glycerine or lubricating oil in the malleable mixes and since the malleable type of model appeared to be the most promising material for design testing, a more complex modeling problem was attempted.

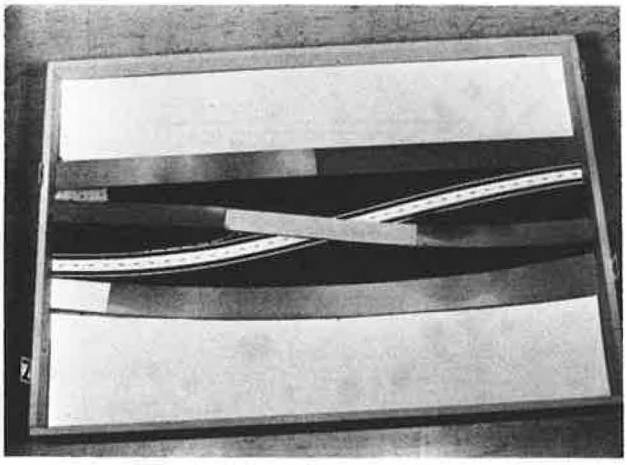
A model of a basketweave overpass on Highway 427 in Toronto, then in the final design stage, was constructed at a scale of 1 in. = 40 ft, and the malleable mix using lubricating oil was used to form the cut and fill slopes. Two retaining wall alternatives were modeled and photographed to show the advantage of this material as a design tool in pointing out visual differences in each alternative.

A detailed description of the construction technique with the recommended materials follows in the next section.

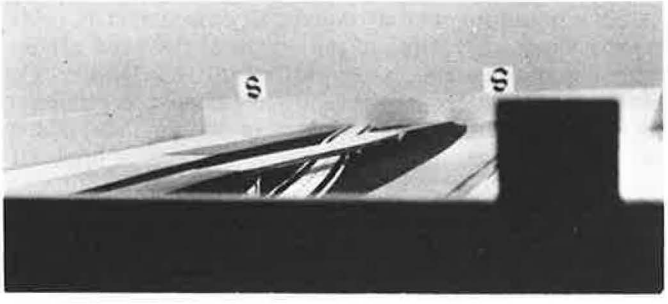
THE REMOLDABLE MODEL—A TECHNIQUE

General Setup of the Model

A 40-scale model of the southbound basketweave bridge area was constructed and two retaining wall alternatives were compared. Three oblique views of the model are shown in Figure 1.



PLAN VIEW



OBLIQUE VIEWS

Note: The letters "N" for north and "S" for south indicate in the photographs the actual sight direction.

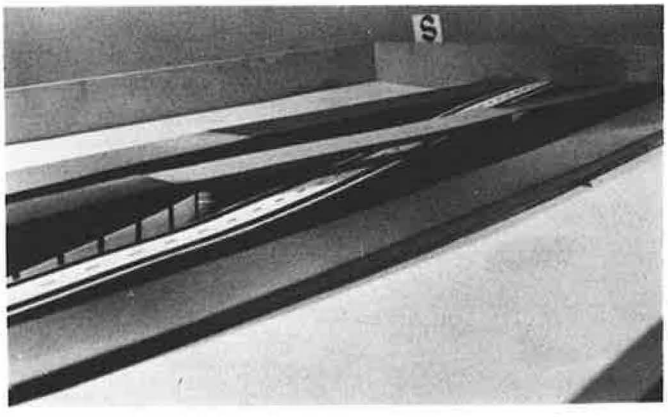


Figure 1. Overall photographs of remoldable model.

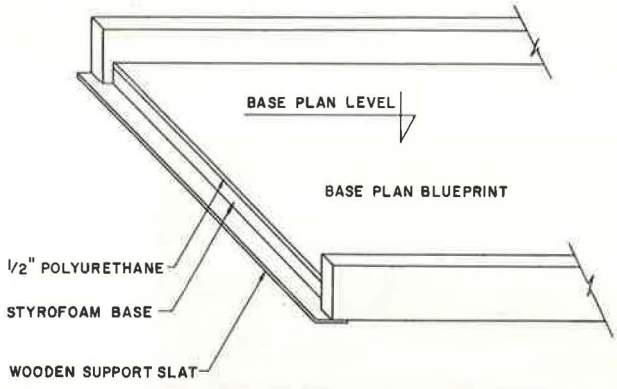


Figure 2. Cutaway view of container and base.

A wooden box 3 ft by 2 ft was constructed to fit the required area modeled at a scale of 1 in. = 40 ft. A styrofoam base was supported by wooden slats and a ½-in. piece of polyurethane was placed on this to provide a base plan elevation level at least 10 feet (to scale) below the lowest elevation in the area (see Fig. 2).

A base plan blueprint at the required scale (1 in. = 40 ft) was then set on the polyurethane sheet. Profiles of the edges of the road alignments were cut from ½-in. polyurethane and pinned along the required alignments on the base plan. The road subsurfaces were cut from ¼-in. polyurethane and pinned to the profiles. A 3.5-ft offset from the edge of shoulder was left as polyurethane subsurface since the usual minimum retaining wall offset is 3.5 feet. Areas of high fill were approximated with contours cut from ¼-in. polyurethane and then a top layer of asbestos and oil was used to make a smooth top surface (see Fig. 3 for detail drawings).

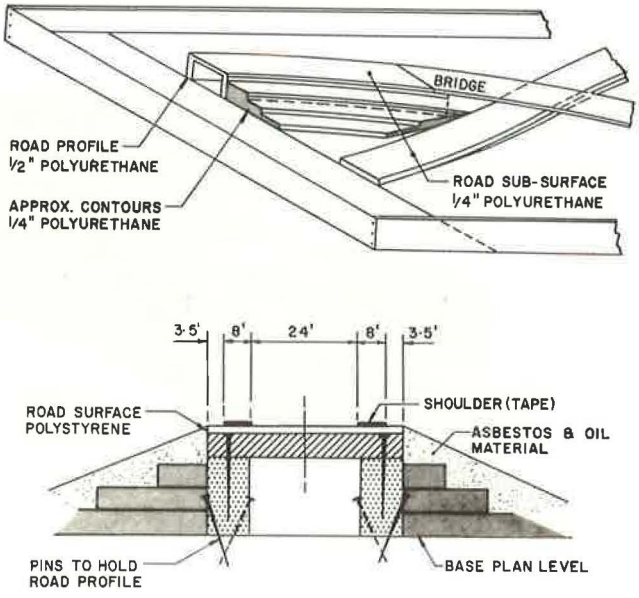
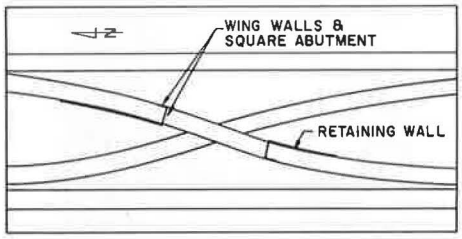


Figure 3. Contour material detail.

PLAN OF SOUTHBOUND BASKETWEAVE AREA



ALL PHOTOGRAPHS LOOKING SOUTH

SECTION

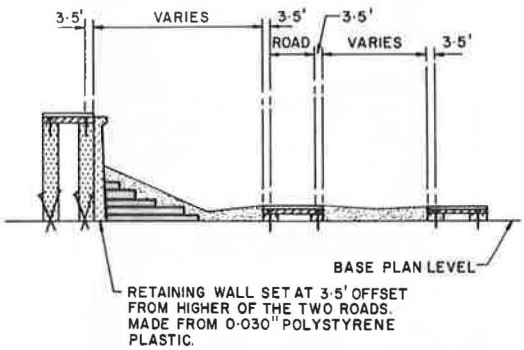


Figure 4. Retaining wall Alternative 1.

Road Surface Materials

The polyurethane road surfaces were found to be too rough when photographed by the modelscope; therefore, a smoother-textured material was required to give the effect of pavement in the photographs. Three materials were tried:

1. Cardboard (bristol board)—Since the asbestos material plus oil did come in contact with this road-surface material, the paper in the cardboard becomes saturated with the oil and, within three to four days, irregular dark patches appeared along the edges of the road. Changes in humidity also caused this material to warp.
2. 0.015-In. Polystyrene Plastic (rubber cement binder)—This material was too thin to hold a ribbon-like road shape without warping and forming undulations. Rubber cement was used as an adhesive to hold the plastic to the polyurethane and it did not dry completely. This could be due to saturation of the surface with oil, which destroys the binding effect of the rubber cement.
3. 0.030-In. Polystyrene (contact cement binder)—The contact cement formed a solvent bond with the polystyrene and dissolved the surface of the plastic; therefore, any excess contact cement on the top of the road surface could not be removed without scarring the surface. However, the bond with the polyurethane in contact with the oil-soaked asbestos was much stronger than when using rubber cement, as the contact cement is not affected by the oil. After photographing with lights, no warping was observed.

Slight undulations in profile were noticed but these did not distort the overall effect as in (2) above. In some test photographs a slight glare was observed on the surface of the road in front of the retaining walls. This was corrected by spraying the road and retaining wall surfaces with a dull lacquer (Letraset art fixative). On rephotographing this surface, the light was diffused enough so that glare was not a problem. The 0.030-in. polystyrene was recommended for future use.

Vertical lines spaced at 30-ft intervals to scale were put on the exposed face of the retaining walls to give an increased impression of depth in the photograph. A thin black tape was used.

Retaining Wall Alternative 1

A retaining wall cut from 0.030-in. polystyrene plastic was offset from the HIGHER edge of shoulder alignment by 3.5 feet (see Fig. 4). This retaining wall section was cut to the proper height and length when supported on the base plan level, and the material contoured to the proper 3:1 slopes (see Fig. 4). The asbestos and oil mixture was molded to shape very quickly and any changes in slope could be altered easily.

This alternative was photographed from different locations using a Pentax single reflex camera (see section on "Photographic Technique" for photographic details). A modelscope was attached to the camera to give an eye-level view of the road from the driver's vantage point and photographs were taken from five positions on the left-hand lane and five equivalent positions on the right-hand lane. A sequential set of photo-

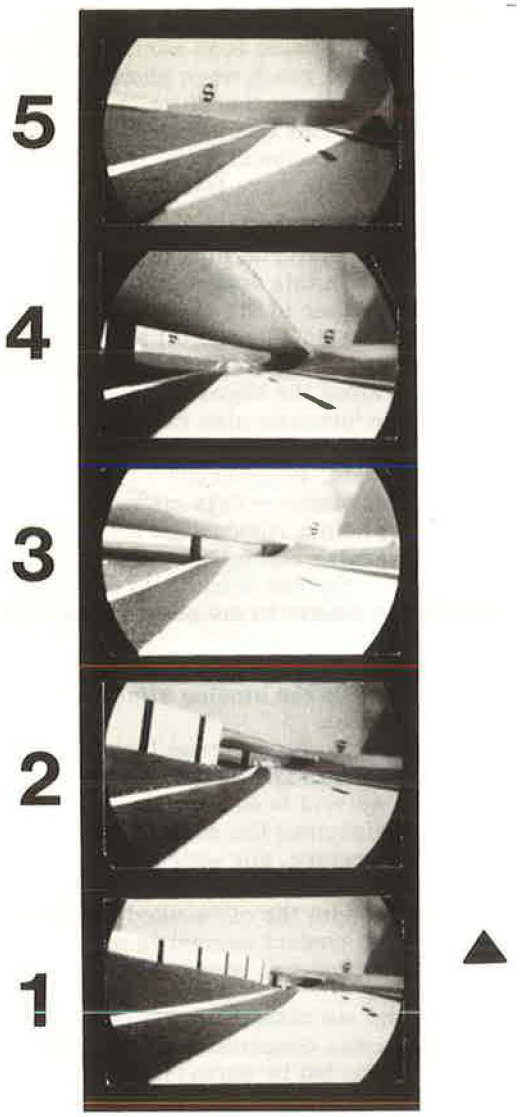


Figure 5. View driver sees from left-hand lane (Alternative 1).

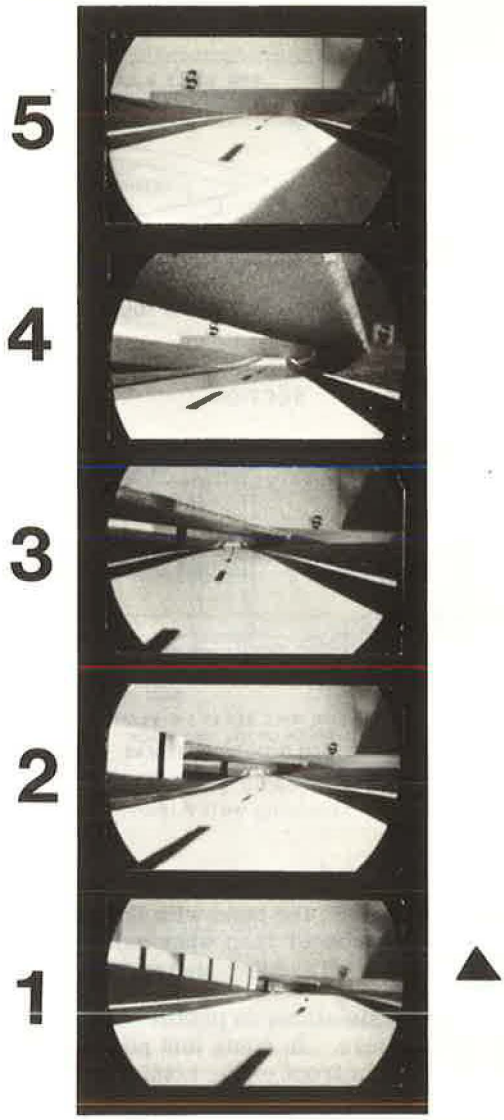


Figure 6. View driver sees from right-hand lane (Alternative 1).

graphs for the left-hand lane is shown in Figure 5 and a similar set of photographs for the right-hand lane is shown in Figure 6. The actual positions on the model from which these photographs were taken can be seen in Figure 7. The model was then changed to form the retaining wall alignment described in the next section.

Retaining Wall Alternative 2

The retaining wall used in Alternative 1 was removed and some of the malleable fill was remolded to suit the new grading. For Alternative 2 a retaining wall cut from polystyrene and resting on the base plan level was offset from the LOWER edge of shoulder alignment by 3.5 feet and curved under the bridge to fit the new grading contours (see Fig. 8). Alternative 2 was photographed from the same positions as Alternative 1 (see Fig. 7). The sequential photographs of the left-hand and right-hand lanes can be seen in Figures 9 and 10.

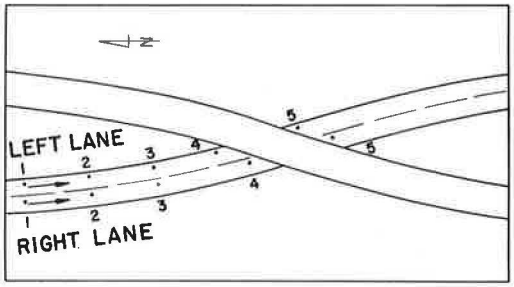
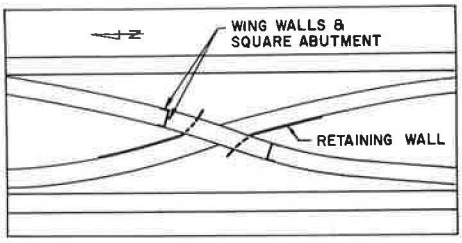


Figure 7. Position of modelscope (Alternatives 1 and 2). (Note: Numbers refer to photograph number shown in Figures 5, 6, 9, and 10).

PLAN OF SOUTHBOUND BASKETWEAVE AREA



ALL PHOTOGRAPHS LOOKING SOUTH

SECTION

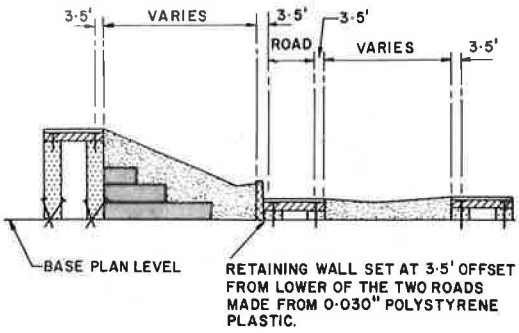


Figure 8. Retaining wall Alternative 2.

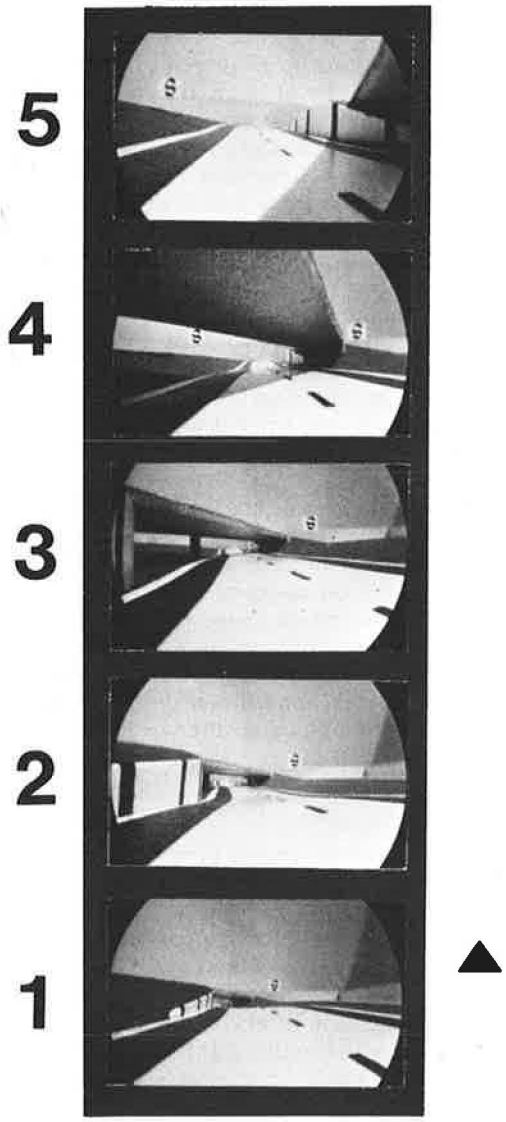


Figure 9. View driver sees from left-hand lane (Alternative 2).

A Detailed Comparison of the Two Alternatives

A comparison of the two alternatives shown in this report with respect to design criteria such as sight distance, visual aesthetics and grading irregularities, will illustrate the usefulness of this technique. In order to decide which retaining wall design is better, the engineer can now compare similar views of each alternative taken from the driver's vantage point. For example:

1. Compare photograph 1a with photograph 2a in Figure 11. There is a much wider view through the bridge in Alternative 1 than Alternative 2.
2. Compare photograph 1b with photograph 2b in Figure 11. A feeling of enclosure and lack of room for maneuvering is felt in Alternative 2 due to the retaining wall being offset close to the lower road on the left. Alternative 1 leaves a slope on the left in case of emergency and is a better design.
3. Compare photograph 1c with photograph 2c in Figure 11. Alternative 2 gives the same feeling of enclosure on the right

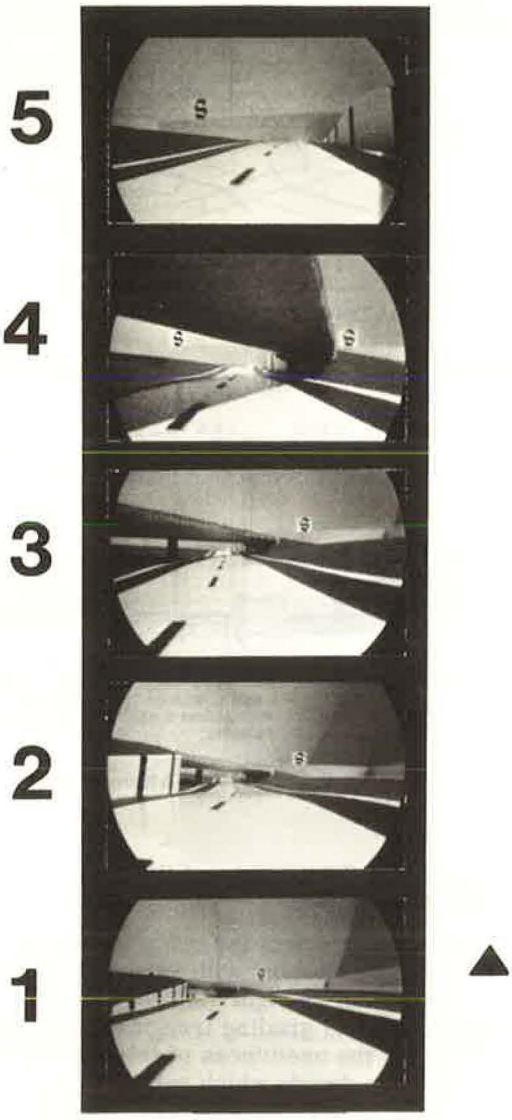


Figure 10. View drives sees from right-hand lane (Alternative 1).

as it did on the left in (2) above. Alternative 1 would be a better design.

Time and Cost Considerations

After gaining some experience in mixing and working with the recommended material, a technician can construct a small area model similar to the one tested here in two to three days. The change from Alternative 1 to Alternative 2 required one to two hours of work in cutting the new retaining walls and reforming the grading material.

Similarly, when experience has been attained in setting up the camera equipment, and after the optimum settings for the camera have been determined, one to two hours will be required to shoot 10 to 20 photographs of each alternative. Therefore, when processing time for photographs is taken into account, a comparison of preliminary schemes of a small area similar to the bridge described in the section on "Remoldable Model" at 40-scale can be completed in a matter of several days by one technician.

Material costs for this technique are inexpensive. Initially, the cost for photographic equipment (as described in the section on "Photographic Technique") is a large investment but it can be used for other purposes in any company, and most highway consulting and design firms require similar camera equipment. The modelscope is the only specialized instrument needed for this technique. Therefore, the total costs of a design model such as that described above are extremely low compared with its value as a tool in the design process. The realistic views given in the photographs indicate the confidence that can be placed on the decision of how a design will appear when constructed.

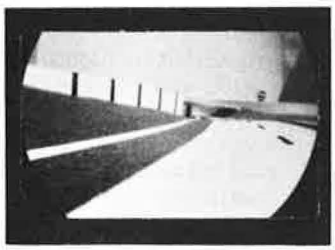
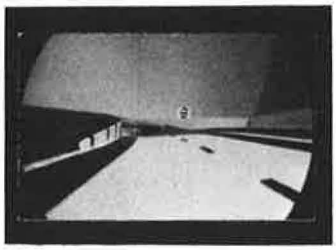
Overall Comments, Summation and Conclusion

For a working model where design changes arise during preliminary stages, a remoldable mixture of asbestos powder mixed with lubricating oil was the most satisfactory material. Road surfaces cut from 0.030 polystyrene sprayed with a dulling lacquer to prevent a glare conveyed a smooth surface in the modelscope photographs.

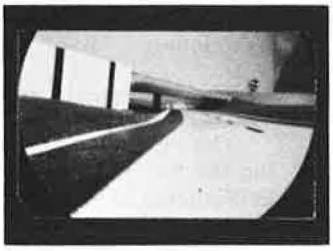
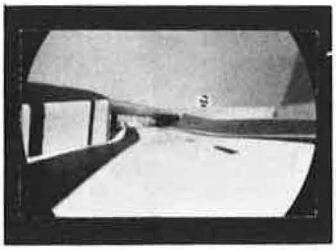
Black-and-white photographs convey a tonal contrast more effectively than do color photographs; therefore, for a comparison of alternative designs, they are recommended. However, for presentation purposes where a more realistic effect is desired, more effort could be spent on coloring the asbestos mixture and using color photographs for visual comparison. Contrast between retaining walls and road surfaces can be attained by color tinting and placing lights for shadowing effects.

Different design alternatives can be easily constructed, photographed and analyzed in three-dimensional models. In the past, two-dimensional plans and profiles or illus-

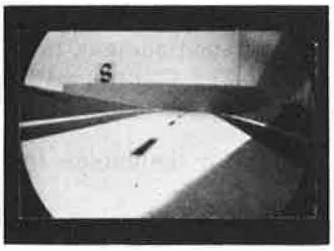
ALTERNATIVE 1 ALTERNATIVE 2

1a   2a

Position No. 1 Left-Hand Lane.

1b   2b

Position No. 2 Left-Hand Lane.

1c   2c

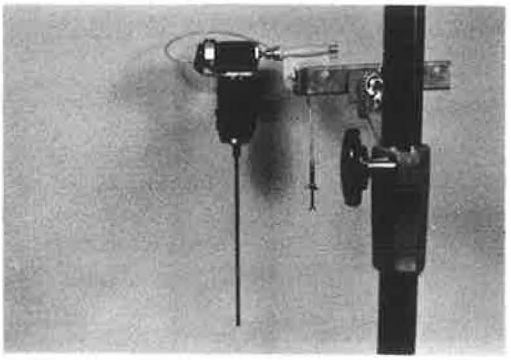
Position No. 5 Right-Hand Lane.

Figure 11. Comparison of photographs.

trations have not been enough to visualize the driver's view and sight distance difficulties in complex design proposals. Grading problems adjacent to structures such as bridges, bridge wingwalls and retaining walls can be pointed out by using this type of modeling technique. By careful analysis of the model and photographs a suitable design to overcome these problems can result in good aesthetics from the driver's viewpoint.

This type of modeling can be done at the preliminary design stage and eventually used to show the final design for presentation purposes. In this way, time spent on modeling is being utilized in the design phase towards presenting the final solution.

This particular design example points out the specific usefulness of this technique of photographic model evaluation applied to retaining wall location and grading design.



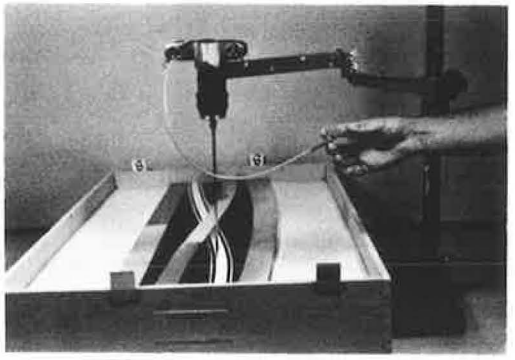


Figure 12. Photographic equipment setup.

In addition, other design evaluations that have been made using the modelscope are (a) correlation of vertical and horizontal alignment; (b) abrupt changes in horizontal and vertical alignment pointed out; (c) bridge evaluation with regard to openness, fit in the overall design and column and abutment placement; (d) sign locations to maximize driver perception and route continuity; and (e) guiderail location evaluation to minimize sight obstruction. All these uses will contribute to a better visual design by improving the driver's view of the highway.

In conclusion, the advantages of this method of design evaluation justify the relatively small costs of these modeling techniques.

THE PHOTOGRAPHIC TECHNIQUE

The equipment used in photographing the model is given below and shown in Figures 12 and 13.

The Modelscope (by OPTEC, Washington D. C., U. S. A., and London, England)—This device views the road from a small lens at eye level above the road surface. It gives an image that a driver would see sitting in a car if the height of the lens is adjusted properly to the vertical scale of the model.

The Camera—A Pentax Spotmatic 35-mm single lens reflex with a cable release.

Lens Adaptor—This was manufactured specially for the outside thread of the modelscope to fit the inside thread of the 50-mm lens.

A No. 1 Extension Ring—This extends the focal length to allow the image to fill the frame on the film.

Tele-Converter 2X—This converts the 50-mm lens on the Pentax camera to a 100-mm lens.

Vice Clamp With a Universal Socket—This is attached to the camera body and allows the camera to be leveled and also aligned so that the modelscope will be vertical. It can be purchased as an accessory to the camera.

Extension Bracket—This extends the camera over the model and can be adjusted to suit the size of the model. It was a piece of iron with a 90° bend and drilled holes to allow for additional extension pieces.

Pentax Photographic Copy Stand—This stand allows the camera to be placed over the model in any position desired to give the required view through the modelscope. It provides a rigid support to hold the apparatus and prevent movement of the scope.

The problems involved with this photographic technique are as follows:

1. Lighting is one of the most crucial factors in producing a true image of the model since the lighting intensity is greatly reduced due to the optics of the modelscope. The lighting cannot be read indirectly by a hand-held light meter nor directly by a light meter inside the automatic camera. The hand-held light meter does not record the actual amount of light coming through the scope. The automatic light meter in the

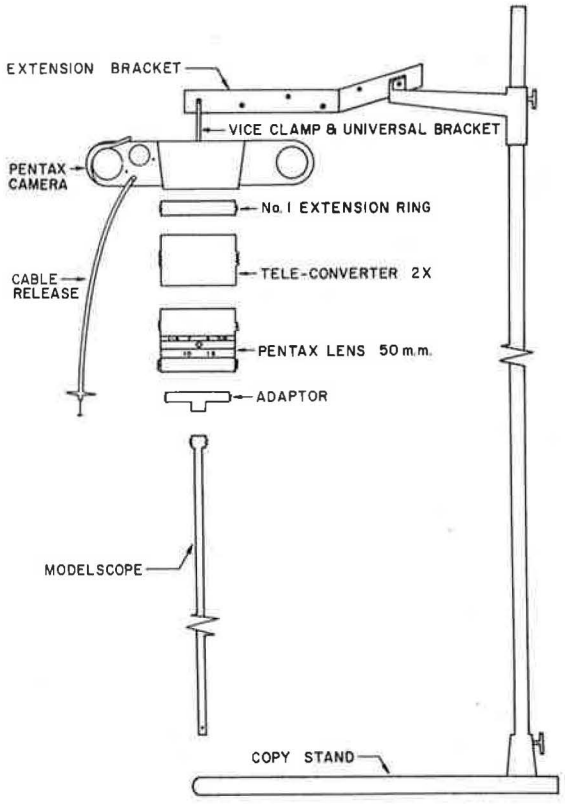


Figure 13. Equipment diagram.

camera is not sensitive enough to calibrate the available light through the scope nor is it illuminated by the light hitting the meter dial. Tests were made at different apertures and exposure times to determine the best setting for the lighting conditions. Because of the modelscope optics in combination with the camera lens arrangement a suitable depth of field chart was not available. Therefore, further investigation found that a focus adjustment on the camera ring of 12 to 15 feet was the best setting to use in this situation.

2. A possible way of avoiding these trial exposures under different lighting conditions would be to use a canon FT–QL camera. It has a booster meter attachment that is extremely sensitive to low lighting levels passing through the lens. As a visual aid, the meter is mounted on the outside of the camera.

3. Movement of the modelscope is another factor that will blur the image since long exposure times are required. Care must be taken to stop any pendulum motion of the scope. To anchor the end of the scope of the road surface before each shot, apply masking tape, with adhesive on both sides, to the position on the road where the scope is to be set, and firmly press the scope down for lateral stability.

4. In order to have the modelscope image located in the center of the negative, the modelscope must be positioned so that it is vertical. This was done by adjusting the camera position by means of the clamp and universal socket. The lens on the bottom of the scope should be square to the camera and not at a skew angle.

Black-and-white photographs were taken with Kodak Tri-X film with an A. S. A. rating of 400 using natural light. The model was set up outside on a clear sunny day and the settings used were aperture = f 2.0; exposure time = $\frac{1}{15}$th second (for all positions); and focus adjustment = 12 feet.

Color transparencies were also taken using Kodak 35-mm Ektachrome for artificial light with an A. S. A. rating of 125. The lighting was provided by three 500-watt, 3200°K lamps approximately 3 feet away from the surface of the model. The settings used were aperture = f 1.4; exposure time = 1 second (for all positions clear of a structure); exposure time = $1\frac{1}{2}$ seconds (under a structure); and focus distance = 15 feet.

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