HIGHWAY RESEARCH CIRCULAR

Number 141 Subject Areas: Highway Design, Bridge Design March 1973

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Committee on Geometric Highway Design

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PREFACE

A part of the current activity of the Geometric Highway Design Committee is to gather information on the use of physical models in the geometric design of highways. The information presented in this circular is a summary of results of a questionnaire circulated in April 1970 to highway departments and consulting engineer firms in the United States and Canada.

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL NATIONAL ACADEMY OF SCIENCES - NATIONAL ACADEMY OF ENGINEERING
2101 CONSTITUTION AVENUE, N.W. WASHINGTON, D.C. 20418

HIGHWAY DESIGN MODELS

This circular is a result of the questionnaire, "The Use of Physical Models in Geometric Highway Design," which was sent to 60 Highway Departments in the United States, Canada and Puerto Rico and to 131 consulting engineer firms in the United States and Canada. The response was excellent and returns were received from 55 Highway Departments and 78 consultants. About 10 percent of the responders made frequent use of models and about half of the responders made occasional use of models. The greatest use of models was for display or public presentation purposes. It is apparent that many agencies and organizations are aware of the great value of this type model and make use of them even though they are costly.

Design models are defined as models which are used primarily for design purposes and typically are not complete insofar as cosmetic details of color, shrubbery, terrain, buildings, etc., are concerned. Presentation models are those that "look like" the proposed situation to the layman. There is, however, great potential benefit to the designer in building and using design models. During the recent regional "Dynamic Design for Safety" seminars, sponsored by the Institute of Traffic Engineers and the Federal Highway Administration, it became apparent that there is relatively little use being made of "design" models. The reasons for this appear to be:

1. The belief that the cost is quite high.

2. The belief that expert "Model Makers" are needed for constructing the models.

3. Lack of information on modeling techniques, materials and scales.

4. Lack of information concerning the ways in which models can aid the designer, ways in which one can view the model from the driver's viewpoint, ways of photographing the model from various viewpoints.

This circular is aimed at providing information on some of the above points of concern. The attached Bibliography was obtained to a great extent from responses to the questionnaire.

One of the simplest yet most effective types of design model is the urethane profile model. In this model the roadway profiles are cut from 1/4 inch to 1/2 inch thick sheets of foamed urethane which cost about $0.40 per board foot. This material can be readily cut with an inexpensive sharp bladed knife. The uses and construction techniques are fully described in literature (1,6,12). The profiles can be easily attached to a styrofoam base using common pins. If desired, roadway surfaces can be placed on top of the profiles by using plastic, cardboard, matboard, etc.

The Material Cost:

Fifty to one hundred dollars will stock an organization with styrofoam bases and urethane sheets for a substantial number of models.

The Construction Cost:

If roadway or interchange profiles are available, individuals with no previous model experience can construct in a matter of hours a several-mile section of 400 (1" = 400') or 500 scale alignment profile. A complex interchange of 40 to 50 scale can be completed in two to three man-days.

Scales:

Recent research (13) indicates that 400 or 500 scale alignment models should have an exaggerated vertical scale of about 10:1 (i.e., 1" = 40' or 1" = 50') while 100 scale models should have an exaggerated vertical scale of about 5:1. Interchange models generally should be built to 40 or 50 scale or larger. Models of these scales or larger require no vertical scale exaggeration.

Uses:

The small scale alignment models can be effectively used in studying alignment coordination problems, general fit to the terrain, bridge visual problems, independent alignment visual problems, etc. These models do not require roadway surfaces on the urethane profiles (1).

Larger scale models are usually required for interchanges, and roadway surfaces will ordinarily be needed for realism. The interchange models (6) can be effectively used: to determine the length and position of structures, retaining walls, piers, and guardrails; to determine the proper location of signing for adequate driver response time; to assure that fills, structures, etc., do not obstruct the driver's view of signs or ramp terminals, etc.; and to determine cut or fill slopes.

Viewing the Models:

One can, of course, view the design model from various vantage points and get a feel for the total problem. In some instances the eye can be placed close to the roadway giving a driver's eye view. In most cases, however, a modelscope is necessary in order to get a realistic driver-view. A modelscope is a small periscope-like device which allows one to view the road from a small lens at eye level above the roadway surface. A camera can be attached (6,12,13) to the modelscope and a series of slides or motion pictures can be taken.

To the committee's knowledge there is only one modelscope generally available in the United States. It is distributed by:

* HCI Sales Corporation
145 E. 16th Street
New York, N. Y. 10003

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* The mentioning of proprietary products in Highway Research Board publications does not imply their endorsement by the Board or by the National Academy of Sciences.

The cost of the model 98 with camera adapter is about $330. Another modelscope is currently under development through the efforts of:

* William C. Hamilton
Howard, Needles, Tammen and
Bergendoff
Consulting Engineers
551 W. Lancaster Avenue
Haverford, Pennsylvania 19041

It is the committee's opinion that a modelscope is absolutely essential if one is to take advantage of the potential benefits of design models.

In order to take full advantage of models the designer should not be hindered by the lack of those materials suggested. However, he will find that sheets of urethane make his task infinitely easier. He should be innovative and look for quick, easy and inexpensive solutions to solve his problem. For example, an entire interchange model need not be constructed if only a portion needs study. This can often be done in less than an hour!

Mr. Ronald C. Holmes, Jack E. Leish and Associates, Evanston, Illinois, and Mr. William Hamilton, Howard, Needles, Tammen and Bergendoff, Consulting Engineers, contributed the following sample uses of models.

SAMPLE USES OF MODELS

The following three problems demonstrate the value of visual model investigations and the ease with which the designer can conduct the investigations.

DESIGN PROBLEM 1 - Highway Overpass Model

It is frequently desirable to study the effects that 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 visually affect the design?" are difficult to answer from the plans alone. Hence, models can be an effective design aid.

A location was modeled which had a problem not readily apparent from plan and profile. 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. The resulting effect was that the center pier appeared to be in the middle of one of the approaching roadways until one was within approximately 500' of the structure (Figure 1). From viewing a 16 mm movie of the situation, taken from the driver's vantage point, and from comments made by several laymen, this location was noted to be confusing, particularly at night. In effect, the unfamiliar driver was asked to drive on "faith," i.e., faith that the pier was not actually in the roadway.

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Figure 1. Actual location
(backslopes 2:1 at structure).

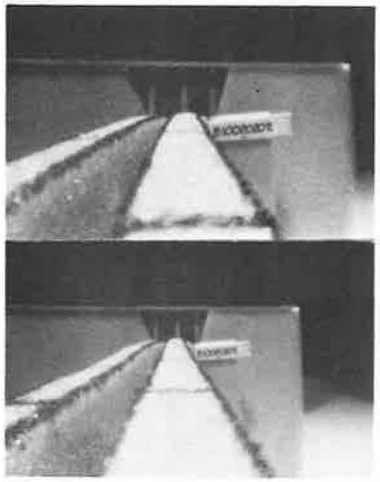


Figure 2. Overpass model
(H: 1 in. = 100 ft,
V: 1 in. = 20 ft,
exaggerated backslopes).

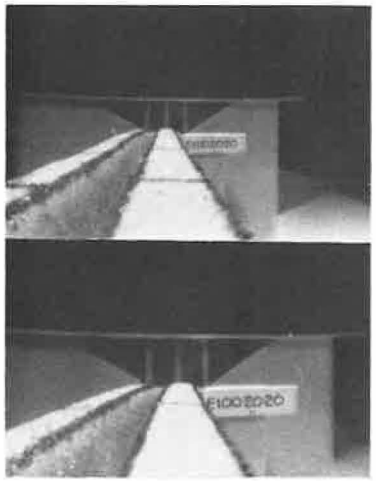


Figure 3. Overpass model
(H: 1 in. = 100 ft,
V: 1 in. = 20 ft,
backslopes 2:1).

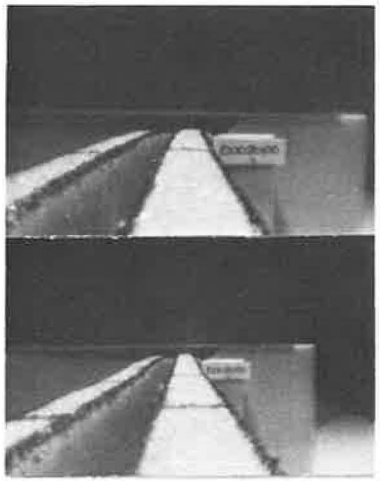


Figure 4. Overpass model
(H: 1 in. = 100 ft,
V: = 100 ft).

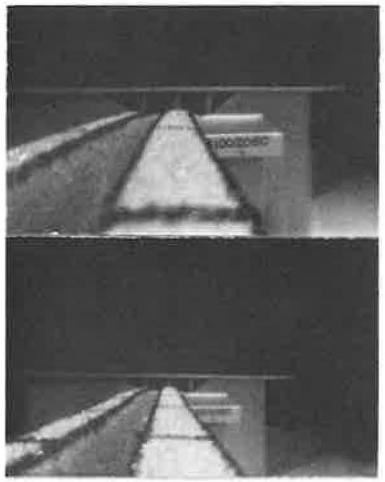


Figure 5. Overpass model
(H: 1 in. = 100 ft,
V: 1 in. = 50 ft,
backslopes 2:1).

Four 100 scale models were built with vertical scales as shown in Figures 2-5. Note that each model, regardless of vertical scale, clearly shows the problem: the center pier appears to lie in the middle of the approaching roadway. The structure and roadway opening, however, appear most realistic in Figures 4 and 5.

DESIGN PROBLEM 2 - Stage Set Model

Occasionally it is desirable to prepare quick and accurate visual space studies for possible commercial joint use under an interstate highway.

To minimize the physical encroachment of Interstate Highway I-77 on a residential section of Charleston, West Virginia it was decided to carry the highway through this area on structure 20 feet above the community. This also was to allow for possible joint use below. Since the adjoining community was to be razed and rebuilt as medium density garden apartments it was suggested that the joint use activities to be considered should consist of structured recreational areas and/or small commercial establishments (Figures 6 and 7).

To visually understand the potential joint use area and make it possible for prospective merchants to understand it a study model was prepared. The only section of the model that required detailing was the space beneath the highway essential to the study. This included round concrete columns, steel box, and the flat underside of the roadway deck.

To examine this model from the point of view of the community, the decision was made to use a 35 mm camera with a 28 mm wide angle lens. This required a large model to accommodate the camera. The scale chosen was 1/8" = 1', producing a model about 12 feet long. Because of the model's large scale, it was possible to purchase its components at a lumber yard. Materials required were:

1. 1/2" homosote for the roadway deck
2. 1/2" x 3/4" wood strips for the steel boxes
3. 5/8" doweling for the columns.

A nearby playground was used to accommodate the model. Holes 5/8" in diameter were drilled in the earth with a conventional brace and bit and the columns were erected in the holes (Figure 8). The roadway deck with the boxes nailed to it was then placed on the columns and the basic study model was ready for investigation (Fig.9).

The camera was used to record various views of the proposed joint use areas. Since the original goal was to produce reasonably believeable perspective drawings of these spaces extreme detail was not needed anywhere in the model. Black and white negatives were adequate for projecting on rear view screens to quickly trace into drawings (Figures 10, 11, 12, 13).

Result of the Study:

By using this "Stage Set Model" technique, reasonably accurate perspectives were prepared which allowed the engineer, client and residents to view the proposed highway design from a realistic vantage point. Also, it was not necessary to save or transport the model once the photographs were taken and the sketches were complete.

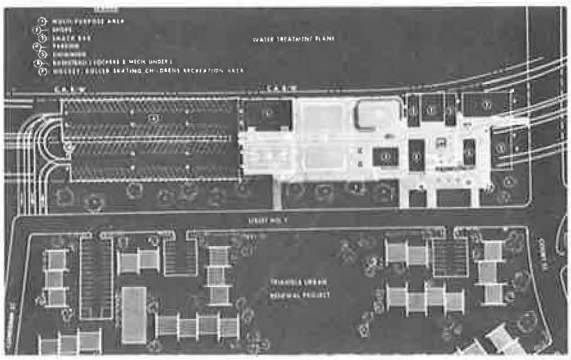


Figure 6. Plan of joint use area.

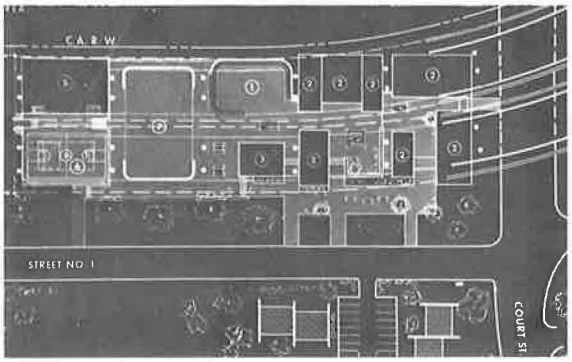


Figure 7. Commercial area.

Figure 8. Setting columns.

Figure 9. Adding bridge deck.

Figure 10. Under deck view of model.

Figure 11. Under deck view of model.

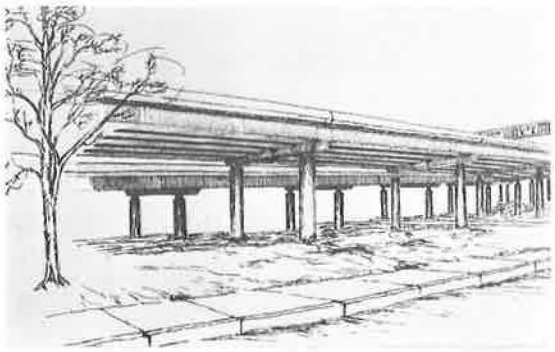


Figure 12. Rendering from Figure 10.

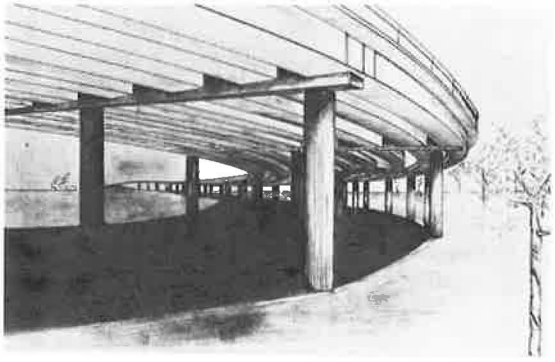


Figure 13. Rendering from Figure 11.

DESIGN PROBLEM 3 - Fin Model

Frequently it is desirable to determine the motorist's visual experience on an exit ramp from a major highway.

Highway engineers in Charleston, West Virginia were concerned about the motorist's and resident's view of an 80 foot rock wall proposed to be cut into the south side of the valley. This cut was to permit I-77 to pass through Charleston without seriously disrupting its central business district. The visual concern became acute when an exit ramp was introduced plunging deeper between the rock cut and the main line. It was at this time that a visual study was initiated (Figure 14).

The technique used for the proposed study was a "FIN MODEL." A "FIN MODEL" is composed of a series of cardboard planes cut to conform to the cross sections of an area to be studied. The fins, in this case painted black and edged with white tape, were then arranged in proper sequence and horizontal alignment (Figures 15, 16, 17). A camera was then placed between them and views were recorded of the proposed ramp and rock cut from the driver's vantage point as he moved down the exit (Figures 18, 19, 20, 21, 22).

Two single lens reflex cameras were used successfully in this study as follows:

(1) A Pentax Spotmatic equipped with a 28 mm lens.

(2) A Nokon F equipped with a 20 mm lens.

Regardless of the camera used the lens used should provide as great a depth of field as possible. This can be achieved easiest through a wide angle (20, 28, or 35 mm) lens or a modelscope. The 20 mm lens in this instance tended to exaggerate the foreground.

Once the model was photographed the engineer was then able, by projecting the slides on a rear view screen, to quickly trace reasonably believable and accurate perspectives. With adjustments to these perspectives possible design alternatives could also be evaluated (Figure 23).

Result of the Study:

No serious visual problems from the motorist's point of view were found with the cut itself. However, it was found that as the motorist moved down the exit his left-hand view as he approached the turn at the bottom of the ramp was not adequate to allow a smooth driving maneuver. Also, by forcing the motorist to enter the city through the cut his visual awareness of the city was interrupted and the orientation continuity was destroyed. The resulting design decision was to change the geometry and carry the exit ramp over the main stream of I-77, thus eliminating all sight problems. This whole study, including the time to construct the model, only took two days and about four hours of the engineer's time. The fins were easily stored in the event further investigation was necessary.

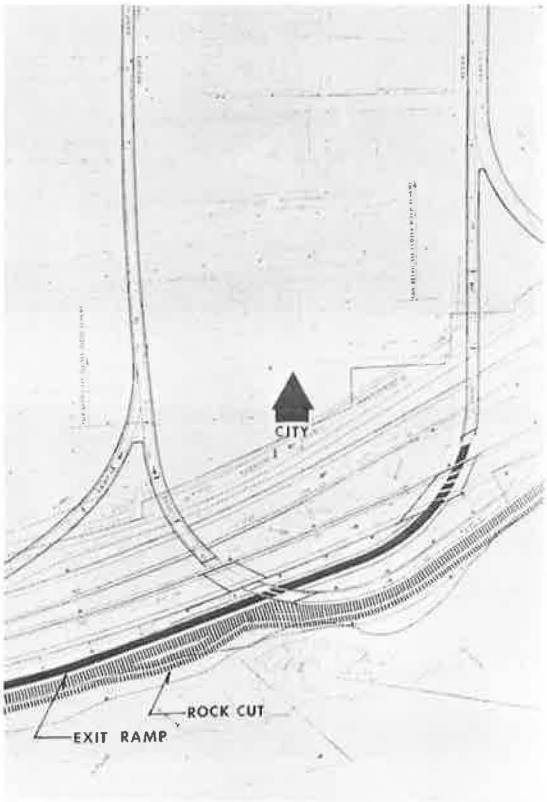


Figure 14. Study area.

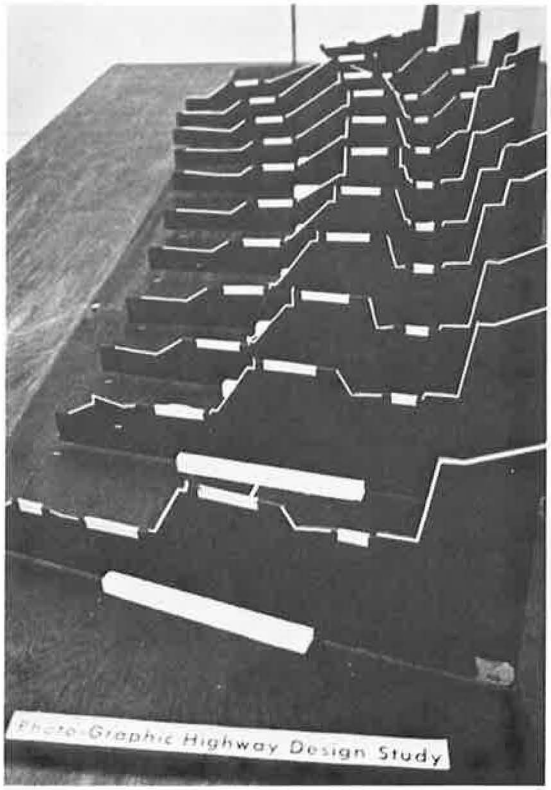


Figure 15. Fin model.

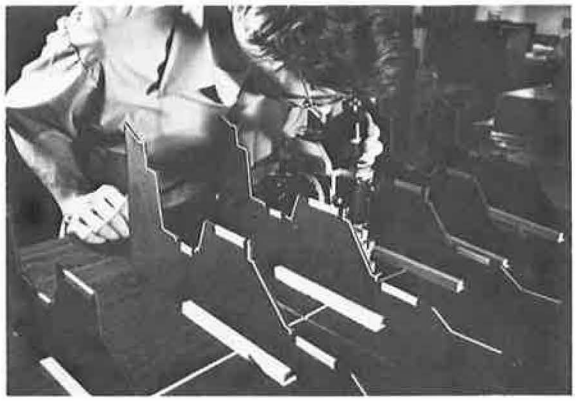


Figure 16. Viewing ramp with 35-mm camera.

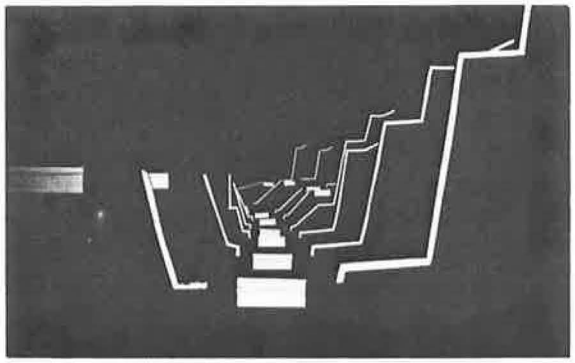


Figure 17. Aerial view of exit ramp.

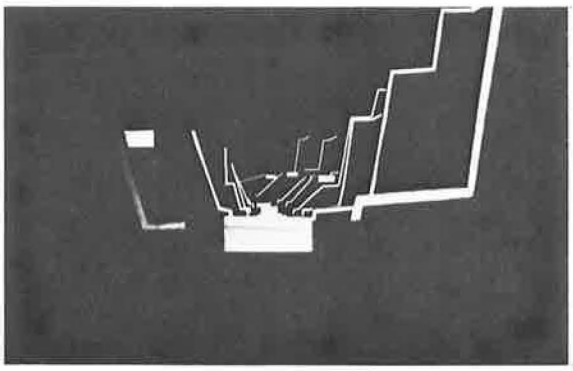


Figure 18. Driver's view of exit ramp.

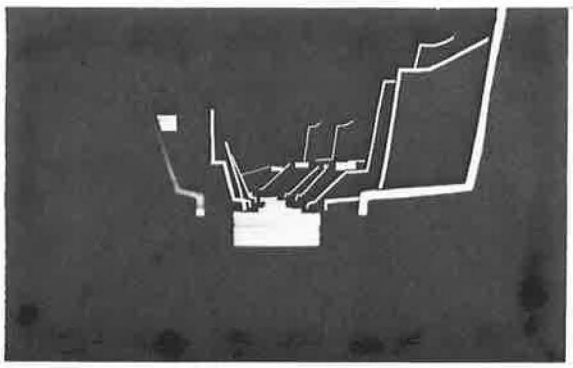


Figure 19. Approaching curve.

Figure 20. Beginning of curve.

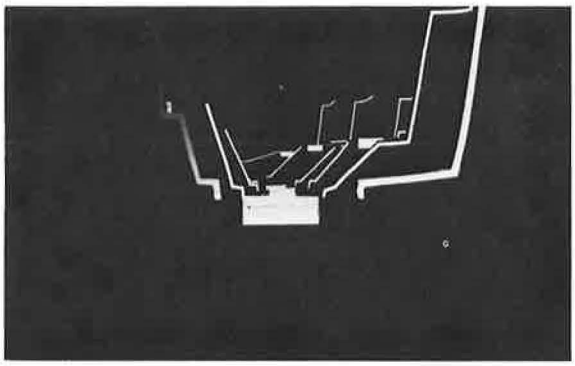


Figure 21. In curve.

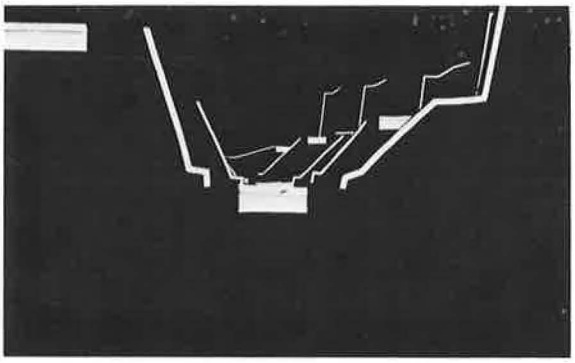


Figure 22. In curve.

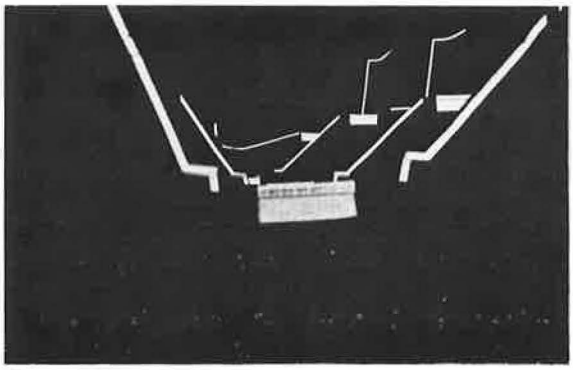
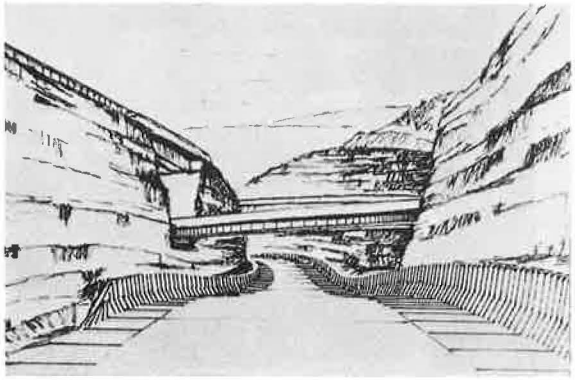


Figure 23. Rendering of ramp from fin view.



Conclusion:

It is hoped that some who have not previously made use of design models will now try them. It is also hoped that additional information has been provided to those who have used design models in the past.

The Committee proposes to publish future circulars dealing with details of uses, construction and photography and specific information provided by a number of responders to the questionnaire. Readers are encouraged to contribute brief, but explicit discussions and illustrations reflecting experience in modeling techniques for use in future publications.

Material should be sent to:

Dr. Bob L. Smith
Department of Civil Engineering
Seaton Hall
Kansas State University
Manhattan, Kansas 66506

REFERENCES

FROM THE HIGHWAY RESEARCH BOARD COMMITTEE A2A02 QUESTIONNAIRE ON THE USE OF PHYSICAL MODELS IN GEOMETRIC HIGHWAY DESIGN

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(SUMMARY OF 130 REPLIES TO QUESTIONNAIRE AND COMMENTS)

Highway Research Board
Committee D-A2, Geometric Highway Design

QUESTIONNAIRE

Please Return to:

Dr. Bob L. Smith
Kansas State University
Seaton Hall
Manhattan, Kansas 66502

Identification

Organization _____

_____

Prepared by _____
Title _____
Date _____

If you desire that your replies to this questionnaire be held in confidence, please check [ ]

THE USE OF PHYSICAL MODELS IN GEOMETRIC HIGHWAY DESIGN

1. Do you make any use of models in highway design?

[16] Frequently [63] Occasionally

[33] Seldom [18] Never

2. What type of models do you use? (Please check appropriate boxes)

[ ] (a) none

[72] (b) detailed scale models

[49] (c) scale models with a lesser degree of detail (no buildings, trees, etc.)

[37] (d) simple models showing alignment and profile only (no topography)

* [77] (e) photographs (obliques, verticals, retouched photos, etc.)

[ ] (f) other (please include a brief description) _____

Renderings

Perspectives - hand, electronic

Scaled vehicles

Motion Pictures

Aerial Mosaics

* 21 used photographs only

QUESTIONNAIRE

3. For what purpose do you make use of models? (Please check appropriate boxes.)

/96/ (a) Presentation of future highway designs to lay groups as a public information service. (Use at Public Hearings)

/72/ (b) The designers use the models as an aid in the actual design and as an aid in evaluating alternative designs.

/ / (c) Other (Please include a brief statement of the use) _____

zoning, structures, movies, feasibility,

condemnation cases, court suits.

4. What do you consider a usual basis for justification of model construction?

/82/ (a) complex interchange

/48/ (b) unusual topography (or geology)

/49/ (c) comparison of proposed to existing facilities

/ / (d) other (please indicate) redesign, public relations,

location, safety, legal, rest areas.

5. For which of the following design features do you find models useful in evaluating alternatives? (Please check appropriate boxes.)

/64/ (a) alignment

/31/ (b) sight distance

/42/ (c) grading

/33/ (d) safety

/89/ (e) aesthetics

/47/ (f) structures

/16/ (g) signing and lighting

/72/ (h) compatibility with environment

/72/ (i) impact on area traversed

/ / (j) other _____

QUESTIONNAIRE

6. What scales do you normally use for each type of evaluation checked in question 5?

	horizontal	vertical		horizontal	vertical
a.	1" = 8	1" = 8	f.	1" = 20-500	20-40
b.	1" = 10-500	1" = 2-100	g.	1" = 20-1600	20-110
c.	1" = 20- 50	1" = 20-50	h.	1" = 40-200	40-50
d.	1" = 20-100	1" = 5-50	i.	1" = 50-200	5-50
e.	1" = 20-200	1" = 5-500	j.		

7. What materials do you normally use (e.g. plywood, styrofoam, urethane, clay, etc.)?

For roadways Above and others, wire, etc.

For topography "

Other "

8. The development and construction of models is done by

/16/ Full time "model making" staff - - - approximate number /2-3/

/71/ Regular staff who are designated to work on models from time to time - - - approximate number /2-3/

/26/ Outside Agency (Please Identify)

/15/ Exclusively Outside

QUESTIONNAIRE

9. Do you as a matter of normal procedure, identify costs for materials and labor

   a. In estimating before undertaking construction of a model?

      43 Yes 26 No

   b. After completion of a model?

      29 Yes 30 No

10. Based upon type, scale, materials, purpose, etc., can you provide your approximate unit cost (i.e. per square foot) for models you have constructed?

    $10 - $400 depending on scale, detail, materials, use.

11. Do you favor increased use of models or do you believe that the use of computers in plotting perspectives of the highway will make models unnecessary?

    Models: 57 Yes 4 No

    Perspectives: 4 Yes 2 No

    Both: 27 Yes 1 No

12. General comments

    a. Is cost of models justified?

       3 No

       remainder Yes

    b. What has been the reaction when models were used for the various purposes indicated in Question No. 3?

       Nearly all - favorable to excellent

       One - poor

13. If you have any reports or descriptive material which you have developed, published or unpublished, would you please forward a copy of same with this questionnaire. If such material will be sent later, please check box ☐.

QUESTIONNAIRE

14. Other Comments

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