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FEDERAL HIGHWAY ADMINISTRATION

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FEDERAL HIGHWAY ADMINISTRATION
F. C. TURNER, Administrator

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A suburban setting and median landscaping provide a wonderland garden to motorists on the Alvernon Way, Tucson, Ariz. (Photo courtesy of City of Tucson.)

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U.S. DEPARTMENT OF TRANSPORTATION
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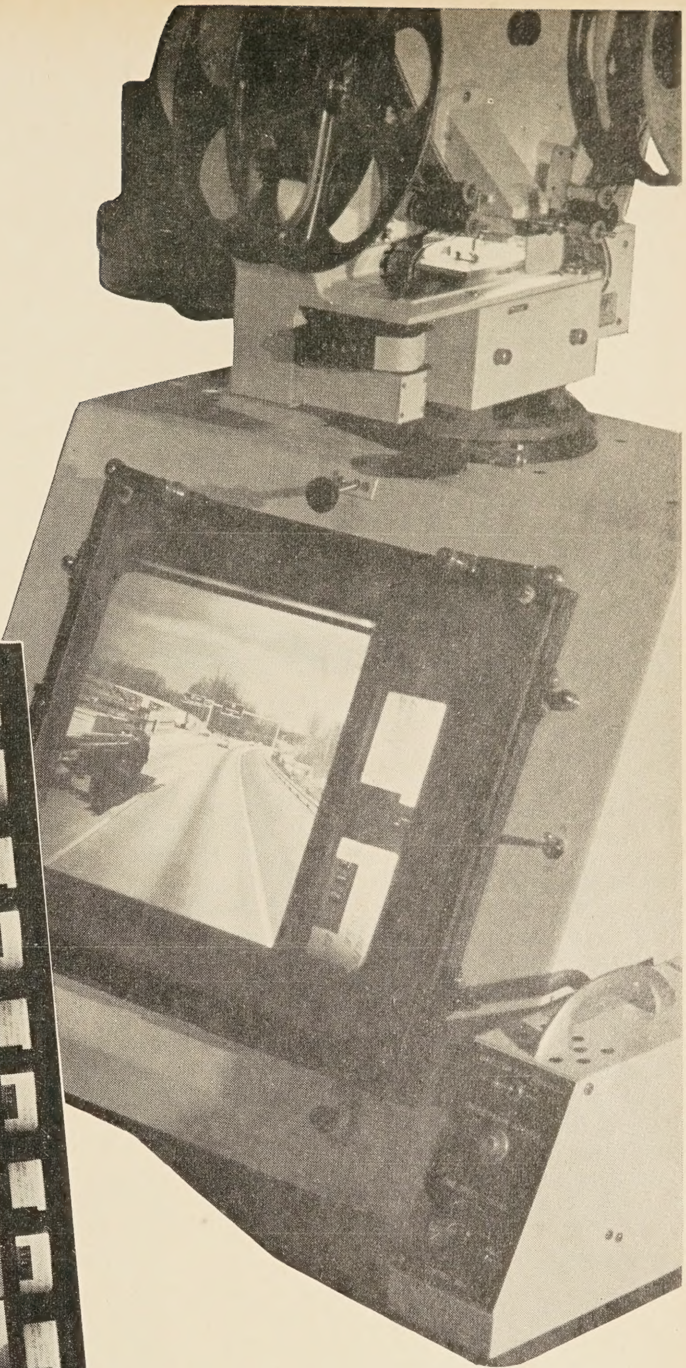
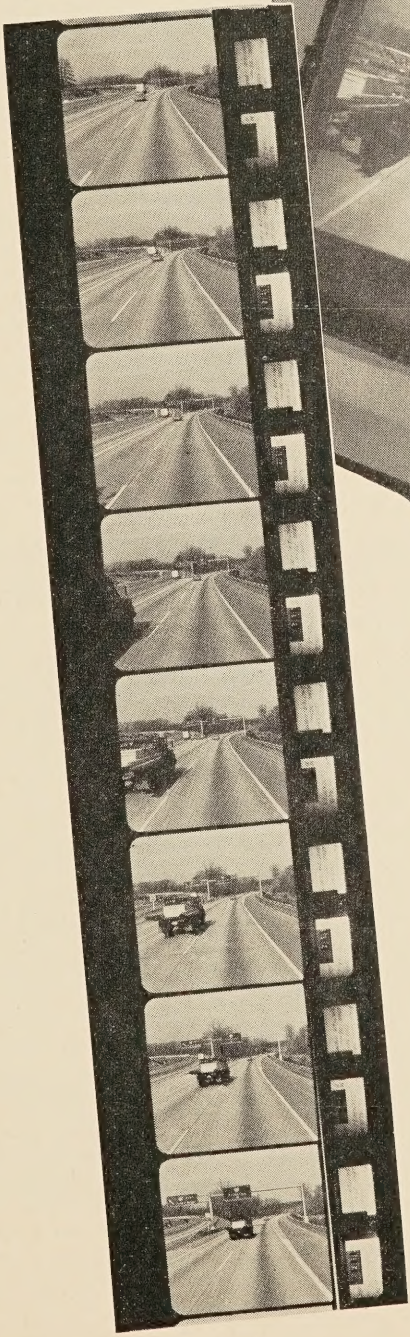
Photologging—An Aid to Highway Engineering

Reported by [1] **WILLIAM T. BAKER and JAMES C. WILLIAMS, Highway Engineers Programs Division**





Photologging, a photographic process that can be used to acquire visual data on the highway and roadside (a photolog) has captured the interest of highway officials and engineers in many State highway departments. Because of this interest the study reported in this article was conducted to evaluate this rather new technique and to determine what types of equipment are suitable for the purpose, as well as what problems are likely to be encountered by those intending to produce photologs.

To distinguish between the different types of cameras and other equipment used in the study, equipment names and model numbers are given. The mentioning of any product is not to be construed as an endorsement of that product, as comparisons of the different makes of equipment were not intended.

BY THE OFFICE OF TRAFFIC OPERATIONS

Introduction

A relatively new data-gathering method has been developed during the last several years to help highway engineers acquire visual information about the highway and its environment. The technique, known as photologging, is a photographic process in which pictures of the highway are taken at equal increments of distance from a moving vehicle to produce a static pictorial record, or *photolog*, of the highway cross section.

A photolog is not a motion picture of the highway. Motion pictures are produced by exposing a certain number of film frames in a given increment of time—24 frames per second for normal motion. Photolog pictures are usually based on distance traveled, rather than on time. If a series of pictures taken at intervals of 1/100 of a mile is desired, the frame rate would be 1 per second when the camera is traveling at about 36 miles per hour. So that the vehicle carrying the camera does not have to maintain a fixed speed, a device that actuates the camera at the proper increment of distance traveled can be attached to the vehicle odometer.

Because of requests for photologging information from State highway departments interested in filming their highways, a study was conducted by the Federal Highway Administration to evaluate this new technique. The objectives of the study were (1) to show application of this technique to the Interstate Highway System by producing a photographic record of I–495, the 65-mile Capitol Beltway

[1] Also published in the July 1970 issue of *Traffic Engineering*.

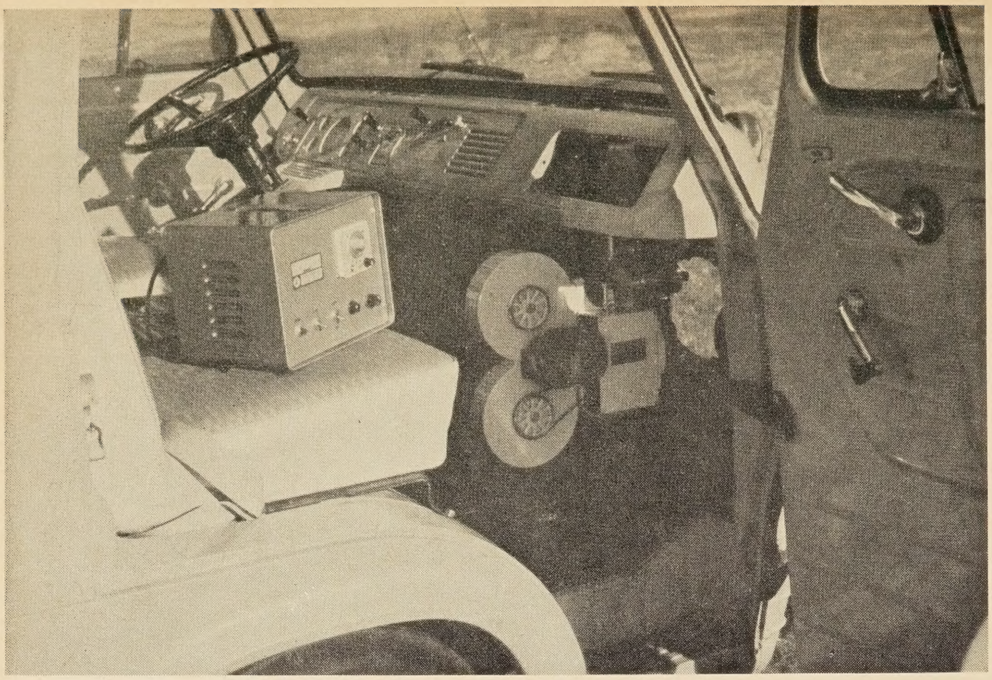


Figure 1.—Camera installed on floor mount.

around the metropolitan area of Washington, D.C., and (2) to provide knowledge about the equipment and the methods required to film the highway and its environment from a moving vehicle, thus enabling the Federal Highway Administration to offer assistance to the States. Technical support was given by the equipment manufacturers whose products were used in the study.

At present, highway organizations in about 20 States are considering a photolog of their highway systems. In at least four of these States, equipment has been purchased and work soon will be underway. Although the technique was first used in Iowa in 1959, Oregon was the first State to film its highway system completely and to use the photolog in day-to-day operations.

Procedure

The scope of the study included searching out cameras and viewing equipment that would be suitable for producing a photolog; for taking pictures from different mounting heights and angles so that overall views of highway cross sections could be evaluated; and for determining, through actual filming, the problems likely to be encountered by those who contemplate producing a photolog of a highway system. It was beyond the scope of the study to perfect camera mounts, to design a vehicle exclusively for photologging, or to perfect instrumentation for the secondary optical sy tem to provide data on each film frame. Accordingly, camera-vehicle configurations were of a temporary nature, and the design of permanent photologging schemes was left to those who plan to film on a regular operational basis.

During the project approximately 800 feet of 35mm. film was used to photograph the Capitol Beltway, I–495, that encircles the Washington, D.C. metropolitan area. An additional 900 feet of 35mm. test film was used to evaluate different camera positions, travel speeds, and lighting conditions.

A photolog consisting of short segments of film was also produced to illustrate the following components of the highway system:

- Rural railroad grade crossings (Fairfax County, Va.).
- Arterial streets (U.S. 1 and U.S. 236, Alexandria, Va.).
- Typical parkway (George Washingtor Memorial Parkway, Va.).
- Urban streets (Wisconsin and Pennsyl vania Avenues, Washington, D.C.).
- Two-lane State highway filmed with th camera facing opposite to the direction o travel (Route 123, Fairfax County, Va.).
- Complex interchange with old desig standards (I–95, U.S. 350, through the *Mixin Bowl*, Arlington County, Va.).
- Two interchanges (I–95 and I–495, Va. I–495 and I–270S, Md.).

Photographic equipment

Both the 16mm. and the 35mm. film forma are suitable for photologging; however, th 35mm. film format was used in the study re ported here because of its superior picture The frame area of most 35mm. film is ap proximately 2½ times as large as that of th 16mm. film, providing better resolution an definition.

The following photographic equipment wa used:

Camera systems

- Robot Motor-Recorder 24 ME Camera
- Automax G-2 Cine/Pulse Camera.
- Flight Research Model 207 Multidat Camera.

Portable video tape system

Sony Portable Videocorder Kit DVK-240
Videocorder Duplicator CV-2200
Video Monitor CVM-2200

The Robot Camera had a 100-foot day light-loading film magazine, a shutter speed c 1/250 of a second, a 35mm.-wide angle len and a secondary optical system capable c photographing an external data display.

The Automax Camera was an older Mode G-2 with a 100-foot film magazine, a shutte speed of 1/500 of a second, and a 28mm.-wid angle lens. Unlike the other two cameras

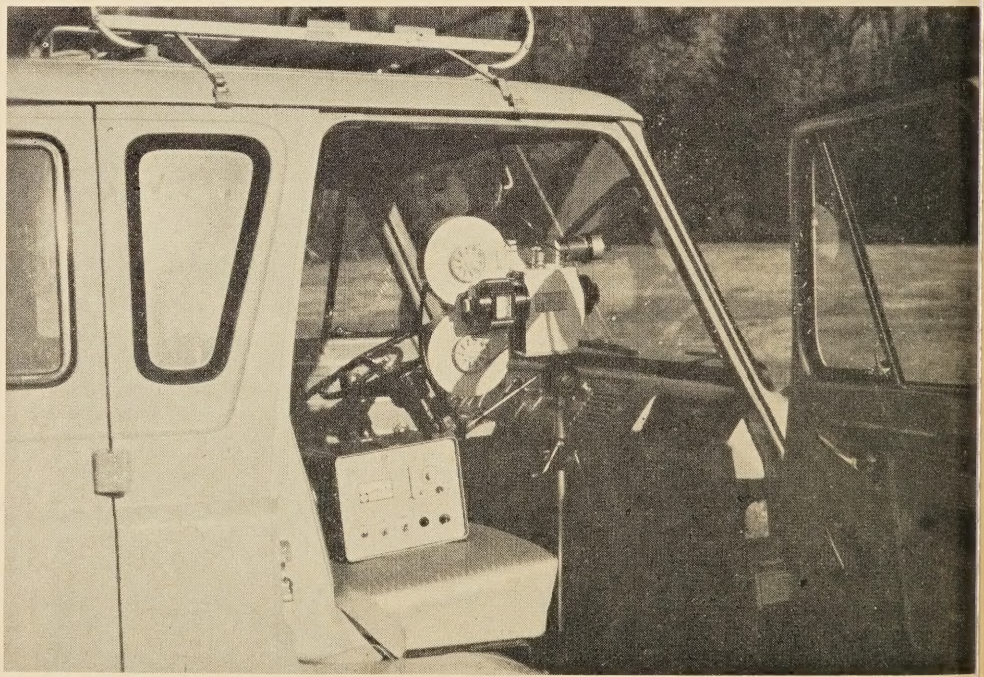


Figure 2.—Camera installed on driver's-eye mount.

Figure 3.—Camera installed on roof mount.

his particular camera was equipped with an ntervalometer (time actuating mechanism) and could not be actuated by any other means. The Automax had a data box, containing a counter and a clock, attached to the camera body, and used a secondary optical system to record data on each picture frame.

The Flight Research Camera had a 400-foot film magazine, a shutter speed of 1/500 of a second, a 28mm.-wide angle lens, automatic exposure control, pin registration, and a data box containing a counter and recording plate. Pin registration is an internal mechanism that accurately positions each frame in the same location on the film pressure plate. Although pin registration is not necessary for photologging, it may be a desirable feature if the camera is used for other purposes.

The Sony video unit had a 20-minute tape recorder, automatic exposure control, and a 16–64mm. zoom lens.

The instrumentation recorded by the secondary optical systems of the cameras was not perfected, as it was sufficient to know that each camera could record identification data and accurately position it on each frame.

Camera position

Three camera positions were evaluated: floor mount at the headlight height (fig. 1), tripod mount at the driver's eye height (fig. 2), and roof mount (fig. 3).

The floor-mounted position was used to determine whether sufficient information to perform pavement life studies could be obtained; the driver's eye height to determine whether the driver's eye view of the highway was significant, and whether features of the highway environment, not otherwise observed at the lower mounting height, could be seen; and the roof mount to learn whether more physical features of the highway and its environment, than were available from lower positions, could be seen.

The same section of highway was photographed from all three positions for each test run so that comparisons could be made. The test runs also provided information as to which camera features were necessary for photologging. After the test runs were completed and the results reviewed, a single camera and a single viewing position were selected to film the Capitol Beltway.

Film

The film used was Eastman Kodak Color Negative Film, Type 5254, which has an ASA rating of 100 for 3,200 K (indoor) lighting. For use outdoors, a No. 85 or 85B Wratten filter was required for proper color balance. The filtration lowers the ASA rating to 64.

Vehicle

A 1963 Ford Econoline Van (fig. 3) was used as the test vehicle. A speedometer impulse unit was connected to the regular odometer in the vehicle to provide an electrical impulse to actuate the camera at 1/100-mile intervals. The vehicle was equipped with a roof-mounted portable generator that provided 115-volt alternating current for camera operation.

Speeds of 30, 40, and 50 miles per hour were maintained for each test run to determine the combined effect of vehicle speed and camera shutter speeds on picture clarity. Camera alinement was changed for the different test runs as follows:

- Straight ahead and level.
- Straight ahead and 5° down.
- 10° to the right and 5° down.
- 10° to the right and level.

As a result of the test runs, it was determined that a camera mounted on the roof of the vehicle, positioned 10° to the right and 5° down, provided the best coverage of all highway features. A driving speed of 40 m.p.h. was selected for filming the Beltway.

Viewers

There are two principal types of film viewers and three basic 35mm. film formats—full-frame, square, and half-frame. The popular full-frame format—the one used most for color slides—has a picture size of 24mm. by 36mm. The picture size of the square format is 24mm. by 24mm., and that of the half-frame format is 18mm. by 24mm. The one type of viewer, primarily used to read microfilm, simply advances film either manually or mechanically past an optical system and accepts any of the three film formats. The other type of viewer, more properly classified a projector, usually incorporates a shutter and controls that advance the film to produce the effect of motion. This type accepts the half-frame film format only.

Film produced in the study was evaluated on the Kodak Recordak Motormatic Reader, Model MPG, and the Vanguard Motion Analyzer, Model M-35C. These two viewers respectively represent the two principal types mentioned above. Although the Kodak viewer is primarily designed for microfilm use, it works as well with normal 35mm. or 16mm. transparency film. The distinguishing features of the two viewers are:

Kodak viewer

- 16mm. or 35mm. roll film, either reel or magazine.
- Automatic threading.
- Variable speed film advance—forward or reverse.
- Wall projection (by removing the rear projection screen).

Vanguard Motion Analyzer

- Single-frame pull-down for each picture.
- Variable speed film advance—forward or reverse.
- Operation with or without a shutter at various speeds (shutter operation produces motion).
- Frame counter synchronization with milepost data on film.
- Wall projection (by placing head on projection base).
- Availability of variety of accessories.

Results

Cameras

Each of the three camera systems took excellent pictures. Figures 4, 5, and 6 respectively show how much of the roadway can be seen in the half-frame format when 38mm., 25mm., and 20mm. lenses are used. The data provided by a secondary optical system are omitted from these photographs, as the portion of the frame devoted to identification data varies according to the camera system and the particular requirements of the user.

Although no comparison of the different camera systems was attempted, the Flight Research Camera was selected to film the Capitol Beltway, primarily because of two important features: automatic exposure control and large capacity film magazine. The other two cameras can be purchased with these features, but the models obtained for this project did not have them.

A larger film capacity requires less film-handling time and shorter periods of vehicle downtime. When taking a picture every $\frac{1}{100}$ of a mile at an average running speed of 50 miles per hour, a 1,000-foot magazine in the half-frame format provides approximately 160 miles of filming in $3\frac{1}{2}$ hours.

As shown in figure 7 the Beltway film had identification data at the right of each frame. This is probably the least desirable location for the data, as the view of the environment to the right is the most critical. When the data appear across the top or bottom of the frame (upper left hand corner on one of the cameras), the picture is approximately 20 percent wider.

Black and white portable video recording on the type of equipment tested does not seem practical for photologging for several reasons. The image quality does not permit signs to be read until the photolog vehicle is very close to them; the video operates tape continuously as the vehicle proceeds down the highway and records more data than is necessary for photologging; and the playback equipment cannot be stopped to extract data on a frame-by-frame basis without a significant loss of picture quality. Moreover, the recorder does not have the reel capacity to record pictorial data that normal photographic-film cameras do; consequently, vehicle downtime for tape changing is considerably greater.

Camera position

Like other aspects of photologging, the best camera position depends on what the primary use of the film is to be. If the photolog is to be used basically to provide a static record of the highway geometry and environment, the camera position should be about roof height. According to the test films, this height gave the best overall coverage of the Capitol Beltway; usually, all guardrail and sign bases in the median and side ditches were clearly visible.

On the other hand, if the photolog is to depict the highway from a driver's eye viewpoint, then it would be necessary to photograph from this height. Pictures taken from the roof position present the viewer with a different perspective from that of a lower camera position. For example, if film taken at roof level were used to evaluate ramp merging areas, the camera, because of its increased height above the ground, would see a merging situation before the driver would.

The floor mount seemed least desirable of the three positions. Pictures of the pavement taken from this position were no better than those taken from the driver's eye height or roof height. The overall coverage of the highway was minimal and the total perspective of the highway environment was not in balance.

Film

Color negative film is recommended for photologging because of its high quality reproduction capabilities and its economic advantages. This film is readily accessible and can be processed routinely by most film

Figure 4.—Half frame format, 38mm. lens.

Figure 5.—Half frame format, 25mm. lens.

Figure 6.—Half frame format, 20mm. lens.

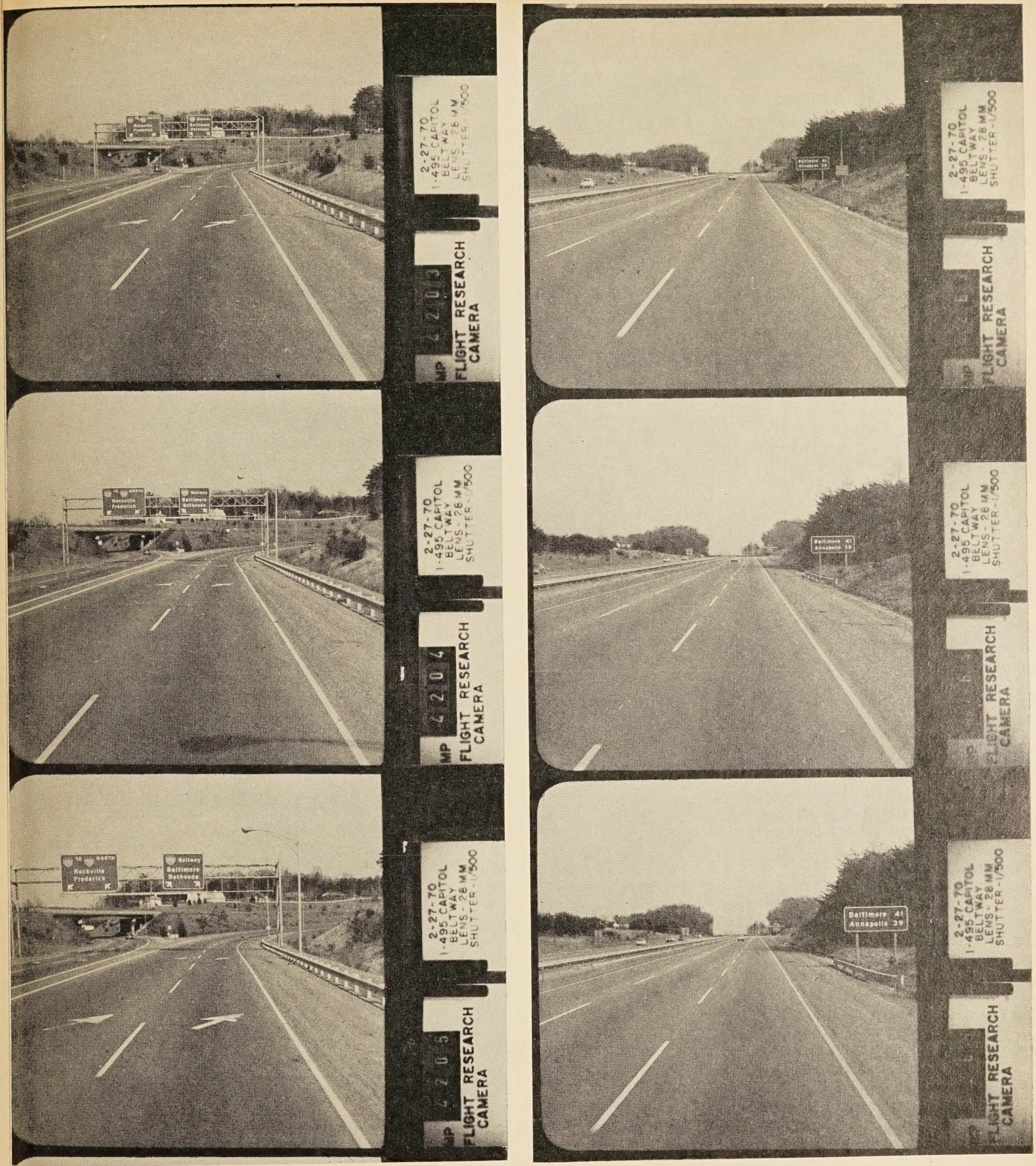


Figure 7.—Segments from photolog of Capitol Beltway.

laboratories using standard processing techniques. It is suitable for limited or extensive production of prints, and it provides an ideal film speed index range for photologging—ASA 64 in daylight with filtration.

So that each quantity of film submitted to the processing laboratory provides reasonably accurate color rendition and exposure, one or two photographs of an 18-percent standard gray card, which is available from most camera stores, should be taken before each film run.

Vehicle

Because better accuracy is obtained when the camera is actuated by means of a distance measuring device, rather than a time actuating mechanism, or intervalometer, the photolog vehicle should have sufficient power to travel at varying speeds. The speed traveled should be governed only by the prevailing traffic conditions. Other features necessary for the photolog vehicle are air conditioning for film preservation and for the comfort of the operators; a darkroom or a light-tight area in which film can be loaded and unloaded; safety warning devices, flashing yellow light, flags, etc.; and portable electrical power supply for camera operation.

On the Capitol Beltway, to obtain a photolog of a clear roadway ahead, it was necessary to drive 10 to 15 miles per hour less than the average traffic speed. At faster speeds the photolog vehicle was forced to pass other vehicles, and some details of the physical highway features were lost. Driving at the average traffic speed often positioned the photolog vehicle behind a truck.

Viewers

Like the camera equipment, the choice of viewers depends on the principal use of the film. A unique feature of the Kodak viewer used in the study reported here is that either 16mm. or 35mm. film can be loaded into magazines for automatic film pickup and threading. These magazines are easily labeled for filing. However, if motion is desired a projector like the Vanguard Motion Analyzer must be used. The Vanguard single frame mechanism, which is operated by a push-button, quickly pulls down each frame into view and facilitates viewing when data is to be extracted one frame at a time. A grid for extracting measurements can be overlayed on the viewing screen of either of the two viewers tested.

In Oregon, the only State in which photologging is a standard operating procedure, a Kodak viewer that handles 16mm. film only has been used successfully. In Oregon, a photolog is used primarily for inventorying and accident location work, in which effect of motion when viewing a stretch of highway is not important.

Costs

If color negative film is used and several thousand miles of highway are photographed at 1/100-mile intervals, it is estimated that a 35mm. half-frame photolog can be produced for approximately $3.00 per one-way mile of the highway. This cost, which includes the cost of the original color negative and one print, comprises the costs of the following items:

Item	*Cost per mile*	*Basis*
Vehicle	$0. 15	Estimated for a small truck, on the basis of *Cost of Operating an Automobile*, February 1970, Bureau of Public Roads
Labor	. 25	2 men @ $9,000 per year
Subsistence	. 08	2 men @ $10 per day
Deadheading	. 15	30% of the above 3 items
Camera equipment	. 20	$10,000 camera system, 50,000 mile amortization
Film and processing	1. 90	1 original, 1 print
Administrative overhead	. 27	10% of all items above
Total	3. 00	

Each additional print costs 59 cents per mile.

Film and processing is the most costly single item. For an original and four prints, film and processing constitute about 80 percent of the total per mile cost.

No special discounts were obtained for processing negatives and making work prints. However, the buying and processing of large quantities of film on a competitive basis undoubtedly would result in more economical prices.

The cost of film, negative processing, and one print amounted to a little less than 2 cents per picture. Each print thereafter costs approximately one-half cent per picture.

Other Uses of Equipment

Only recently has ground-based photography been used to any extent as a data-gathering tool in the highway field. Although the photographic equipment in the project reported here was tested only for its application to photologging, it can also be used for other highway functions. The cameras can be used whenever there is a need to take many pictures, reliably, by remote actuation. One application might be the filming of vehicle lateral placement by mounting the camera in a static position and actuating it by road tubes or an intervalometer. Two of the three cameras tested could also be operated in the cine mode to film motion pictures.

Another application could be the gathering of traffic data that usually requires use of mechanical traffic counters and field surveys. The cameras, again, could be mounted in a static position and remotely actuated to record pictorially from a single location traffic volume, vehicle speed, passenger occupancy, license numbers, and vehicle classification. From inexpensive black and white film, processed to negative only, a keypunch operator could extract the dat from the screen of the viewing equipmen previously described, advancing each fram by a foot pedal.

Conclusions

As a result of giving formal photologgin presentations to Federal, State, and loc highway agencies, as well as to others associ ated with highway-information requirements many written comments and suggested use were received. These uses, together wit those of photologs in Oregon and in th Federal Highway Administration's Washing ton office, are reflected in the following list c activities in which photologging can be a aid:

- Studying highway accident locations.
- Inventorying and evaluating traffic cor trol devices.
- Answering inquiries from the public.
- Conducting certain special researc studies.
- Providing historical records.
- Utilizing historical records as a basis i estimating damage to highways due t natural disasters.
- Determining effectiveness of junkyar screening.
- Locating scenic overlooks.
- Determining compliance of billboard sig regulations.
- Aiding highway administrators in publi hearings.
- Determining sight distances.
- Obtaining sufficiency ratings.
- Studying the effectiveness of variou landscape designs.
- Public relations' efforts—driver and pul lic education.
- Locating snow fencing.
- Evaluating the adequacy of roadsic lighting.
- Studying use and occupancy permits fc utilities.

The film and viewing equipment has bee used by personnel of the Office of Traff Operations, Federal Highway Administratio to support research on diagrammetric signin and in discussions on signing principles an techniques. In addition to the uses liste above, it is believed that photolog film wi have a large potential for use in advance planning and programing for project prioritie Because decisions must be made years i advance to develop work programs, the visu representation of sections of highway und study can be an important aid in any decisio making process.

Although much of the study concerned th application of photologging to the Interstat Highway System, the following importar findings resulted from evaluation of sho segments of urban film:

- Camera should be alined at least 20° t the right so that smaller signs in urban are can be observed.
- Manual actuation of the camera may b more practical than the distance impulsir

(*Continued on p. 91*)

Soil-Portland Cement Thickness Design—Summary of Current Practices

Highway Research Board Committee A2J04, Soil-Portland Cement Stabilization, *sponsored a conference session on soil-cement thickness design at the January 1970 annual meeting. In an effort to bring together the latest information, the authors conducted a survey and compiled a summary on current practices for thickness design of soil-cement or cement-stabilized materials. This summary was presented and discussed at the conference session.*

In this article the content of the questionnaire used in the survey is presented, and the authors review the current practices of agencies concerned with thickness design and construction of cement-stabilized layers for pavements.

Reported by [1] **DONALD G. FOHS** and **EARL B. KINTER,** Highway Research Engineers, Materials Division

BY THE OFFICE OF RESEARCH

Introduction

THE procedures for thickness design of cement-stabilized layers for pavements currently in use in the United States are summarized in this article. The summary is based on information obtained from a survey in which 75 copies of a questionnaire were distributed by the Highway Research Board to agencies concerned with highway design and construction, including all State highway departments, 16 county highway departments, four Federal agencies, and two consultants. The counties to which the questionnaire was sent were selected to provide good geographical coverage of the country.

Although thickness design was the primary concern, it was realized that few agencies actually have a specific thickness-design procedure or method. Consequently, the scope of the questionnaire was broadened to include the different factors that affect design and construction of pavements featuring cement-stabilized layers. Considered, for example, were (1) the ability of construction equipment to mix and compact soil-cement in-place, which was assumed to affect designed thickness, and (2) methods for measuring strength properties and incorporating them into a pavement design procedure, as these are likely to be required by organizations that have no specific thickness design procedures. Also, the questionnaire was intended to identify any distinct preferences for particular types of cement treatment, and the locations of the cement-treated layers in pavement structures.

[1] Prepared for conference session on *Soil-Cement Thickness Design*, 49th Annual Meeting of Highway Research Board, January 1970.

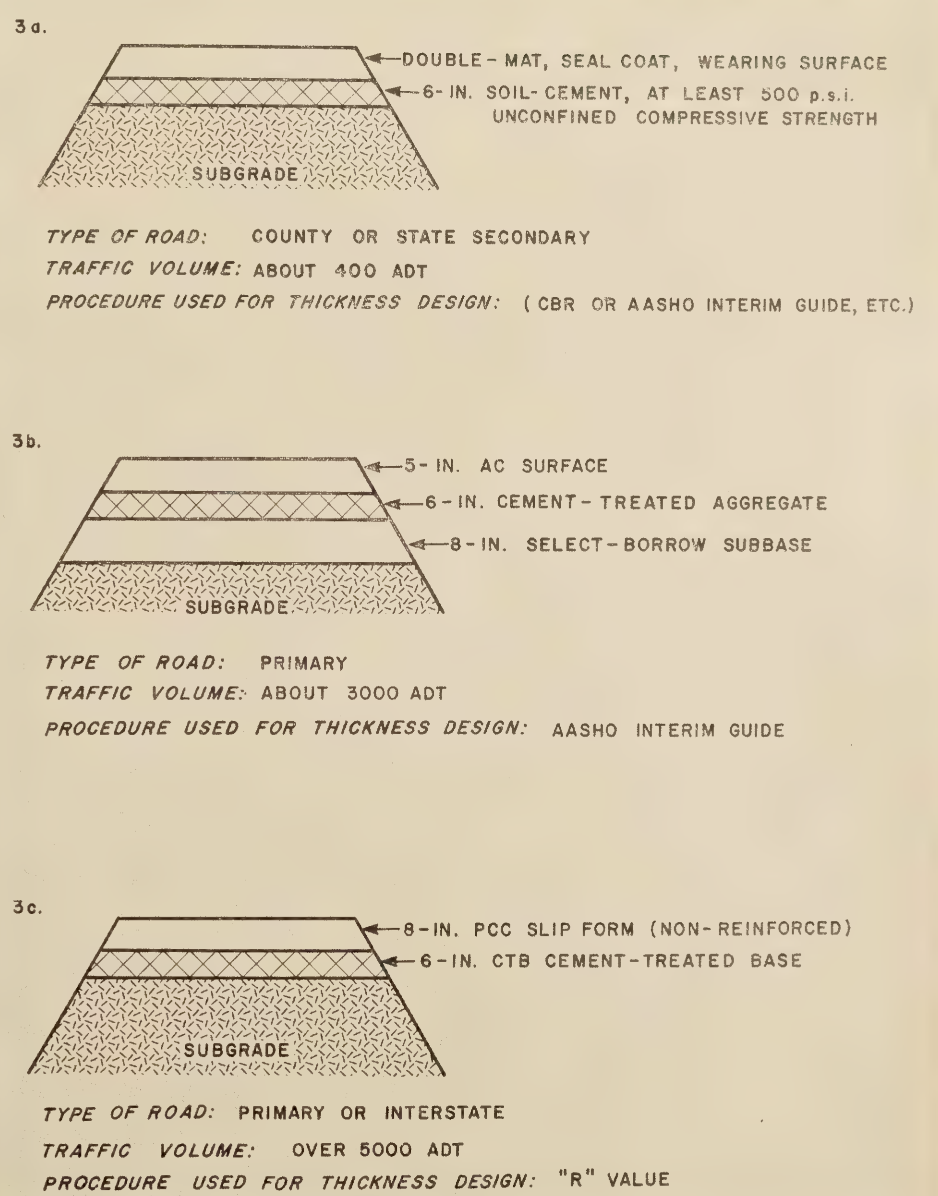


Figure 1.—Questionnaire example sheet, question 3, current practices of soil-portland cement thickness design.

Table 1.—Usage of cement-treated material, 1966–68

State [1]	Usage in 1,000 square yards								
	1966			1967			1968		
	S-C	CMS	CTA	S-C	CMS	CTA	S-C	CMS	CTA
Alabama	40	--------	312	160	--------	400	156	--------	505
Arizona	--------	--------	45	--------	--------	576	--------	--------	1,384
Arkansas	400	--------	--------	400	--------	--------	250	--------	--------
California	--------	--------	6,750	--------	--------	8,108	--------	--------	8,860
Colorado	--------	--------	100	--------	--------	--------	--------	--------	2
Georgia	1,668	--------	--------	3,537	--------	--------	4,164	--------	--------
Hawaii	--------	--------	188	--------	--------	43	--------	--------	154
Idaho	--------	--------	--------	--------	--------	136	--------	--------	543
Illinois	386	--------	--------	127	--------	--------	143	--------	--------
Iowa	2	--------	--------	--------	126	124	--------	130	10
Kentucky	264	69	--------	--------	628	--------	--------	--------	--------
Louisiana	17,653	--------	--------	5,292	--------	--------	3,194	--------	--------
Maryland	400	--------	2,500	45	--------	550	70	--------	550
Mississippi	--------	--------	--------	6,008	--------	--------	4,650	--------	--------
Missouri	880	--------	20	--------	--------	--------	140	--------	--------
Montana	--------	--------	200	--------	--------	50	--------	--------	--------
Nebraska	--------	--------	--------	--------	--------	--------	--------	--------	(2)
Nevada	339	--------	--------	385	--------	--------	379	--------	--------
New Hampshire	13	--------	29	15	--------	--------	--------	--------	59
New Mexico	--------	--------	2,940	--------	--------	2,178	277	--------	895
New York	100	--------	--------	--------	--------	--------	85	--------	--------
North Carolina	23	59	133	24	--------	61	12	10	64
Ohio	--------	--------	--------	--------	--------	--------	--------	--------	561
Oklahoma	408	--------	--------	413	--------	--------	381	--------	--------
Oregon	--------	--------	3	--------	--------	11	--------	--------	140
Pennsylvania	356	--------	--------	--------	--------	--------	403	--------	--------
Rhode Island	--------	--------	--------	27	--------	--------	--------	--------	--------
South Dakota	--------	--------	220	--------	--------	184	--------	--------	229
Texas	--------	[3] 8,400	--------	--------	[3] 5,600	--------	--------	[3] 6,800	--------
Utah	--------	--------	111	--------	--------	1	--------	--------	190
Virginia	3,500	--------	267	4,000	--------	300	3,750	--------	246
Washington [4]	--------	--------	--------	--------	--------	--------	--------	--------	--------
West Virginia	--------	--------	--------	--------	--------	126	--------	--------	--------
Wisconsin	--------	--------	--------	1,140	--------	--------	1,600	--------	--------
Wyoming	383	--------	--------	--------	--------	--------	39	--------	22

[1] Eight States—Alaska, Connecticut, Indiana, Kansas, Michigan, Minnesota, New Jersey, and Puerto Rico—returned questionnaires but indicated no cement-treated materials used.

Six others—Delaware, Maine, South Carolina, Tennessee, Vermont, and the District of Columbia—did not return questionnaires.

Two States—Florida and North Dakota—reported that soil-cement was used but indicated no amounts.

One State—Massachusetts—indicated that a soil-cement project is to be constructed in 1970.

[2] Subbase.

[3] Represents total square yards of all three types of cement-treated materials.

[4] Return indicated that CTA was used as a subbase for 0.75-foot PCC pavement and as a base for 0.25–0.60-foot AC pavement.

Table 2.—Location and type of cement-treated layer in pavement structure

State	Flexible pavement		Rigid pavement
	Base	Subbase	Subbase
Alabama	S-C	--------	CTA
Arizona	--------	CTA	CTA
Arkansas	S-C	--------	S-C
California	CTA	--------	CTA
Colorado	--------	--------	CTA
Florida	--------	S-C	S-C
Georgia	S-C	--------	S-C
Hawaii	CTA	--------	CTA
Idaho	CTA	--------	CTA
Illinois	S-C	--------	--------
Iowa	S-C, CTA	S-C	--------
Kentucky	--------	S-C, CTA	--------
Louisiana	S-C	--------	S-C
Maryland	S-C, CTA	S-C	S-C
Mississippi	S-C, CMS, CTA	CMS, CTA	S-C, CMS, CTA
Missouri	S-C	--------	CTA
Montana	CTA	--------	CTA
Nebraska	--------	--------	S-C
Nevada	S-C	--------	S-C
New Hampshire	S-C	--------	--------
New Mexico	CTA	S-C, CTA	CTA
New York	S-C	--------	--------
North Carolina	S-C, CTA	CMS	CTA
Ohio	--------	--------	CTA
Oklahoma	S-C	--------	S-C
Oregon	CTA	--------	CTA
Pennsylvania	S-C	--------	--------
Rhode Island	S-C	S-C	--------
South Dakota	CTA	--------	CTA
Texas	S-C, CTA	S-C	S-C, CTA
Utah	--------	--------	CTA
Virginia	S-C	S-C, CTA	S-C, CTA
Washington	CTA	--------	--------
West Virginia	--------	--------	CTA
Wisconsin	--------	--------	S-C
Wyoming	S-C, CTA	CTA	--------

Table 3.—Pavement structures and design information for secondary roads

State	Surfacing	Base course	Subbase	Cement-treated-layer design procedure	Pavement design procedure	Traffic volume: ADT	Traffic volume: 18K equivalent
						Number	
Alabama	DBST	6-in. S-C, $q_u > 650$ p.s.i.	None	Experience	AASHO guide	400	
Arizona	3-4-in. AC	4-6-in. aggregate	4-6-in. CTA		do		
Arkansas	DBST	6-in. S-C	3-in. select borrow	Experience	do		
California	AC surface	(1)	(2)	California method	California method	(3)	(3)
Georgia	DBST	6-in. S-C	None				
Illinois	2-3-in. AC	6-8-in. S-C	None	Illinois method	Illinois method	301-800	
Iowa	2-3-in. AC	6-7-in. S-C, 6-8-in. CTA	do	Equipment capabilities.	AASHO guide	200-1,000	
Louisiana	TBST	8½-in. S-C	do	(4)	do	1,000	
	1.5-5-in. AC	8½-in. S-C	do	(4)	do	100-5,000	
Mississippi	DBST	6-in. S-C	5-in. aggregate	Experience	do	1,000	
		8-in. S-C	5-in. aggregate	do	do	1,000-5,000	
Missouri	3-4-in. AC	6-7-in. S-C	None	do			
New Hampshire	SBST	6-in. S-C, $q_u > 300$ p.s.i.	12-in. gravel	AASHO guide	AASHO guide	700	
New York	1½-in. AC	6-in. CTA	12-in. gravel	Experience	Experience	150	
North Carolina	SBST	6-in. S-C	None	do	do	500	
Oklahoma	DBST	6-8-in. S-C, $q_u > 250$ p.s.i.		Oklahoma method	Oklahoma method	300-1,000	
Oregon	4-in. AC	12-in. CTA	None	R-value	R-value	1,750	
Rhode Island [5]	3-in. AC	6-in. S-C	8-in. S-C	Experience	Experience	6,000	
South Dakota	1½-in. AC	6-in. CTA, $q_u > 650$ p.s.i.	None		AASHO guide		
	1-in. AC	4-in. CTA, $q_u > 550$ p.s.i.	do		do		
Texas	DBST	6-8-in. CTA, $q_u > 400$ p.s.i.	(6)	Experience	(7)	100-20,000	
	3-in. AC	6-8-in. S-C, $q_u > 500$ p.s.i.	(6)	do	(7)	100-20,000	
Virginia	DBST	6-in. S-C	None	do	Virginia method	400	

[1] CTA thickness determined by California pavement design procedure.
[2] Variable aggregate thickness.
[3] All ranges.
[4] Experience and equipment capabilities.
[5] Experimental project designed to determine effectiveness of cement-treated material to prevent detrimental effects of frost action.
[6] Aggregate select borrow or lime treated subgrade.
[7] Texas triaxial class.

Table 4.—Pavement structures and design information for primary roads

State or other organization	Surfacing	Base course	Subbase	Cement-treated-layer design procedure	Pavement design procedure	Traffic volume: ADT	Traffic volume: 18K equivalent
						Number	
Alabama	4-in. AC+DBST	6-in. CTA, $q_u > 350$ p.s.i.	4-12-in. select borrow		AASHO guide	3,000	
Arkansas	8-in. PCC [1]	6-in. CTA	6-in. select borrow	Experience	do		
California	AC variable	CTA variable	Aggregate variable	California method	California method [2]		
	PCC	0.45-ft. CTA	0.5-foot aggregate	do	do	6,000	
Florida	PCC	6-in. S-C		Experience	Experience		
	AC		6-in. or 12-in. S-C	do	AASHO guide		
Iowa	3-in. AC	AC variable	6-in. CMS	do	do		
Kentucky	6½-in. AC	11-in. CTA (2.5% by weight)		CBR	CBR	2,000	
		5-in. dense graded aggregate	6-in. S-C (10% by vol.)	CBR	CBR	1,500	
Louisiana	5-13-in. AC	6-8½-in. S-C	None	Experience	AASHO guide		
	8-in. PCC	6-in. S-C	0-6-in. select borrow	do	do		
Maryland	4½-in. AC	6-in. S-C, $q_u > 450$ p.s.i.	12-in. sand capping	do	Maryland method [3]	15,000	
		4-in. CTA (dense graded)	6-in. dense graded aggregate+6-in. CMS.	do	do	4,000	
Mississippi	4-in. AC	8-in. S-C	8-in. granular material	do	AASHO guide	3,000-4,000	
	8-in. PCC [4]	6-in. S-C	6-in. granular material	do	CBR	(5)	
	8-in. PCC [1]	6-in. S-C		do	do	(5)	
Missouri	6-10-in. PCC	4-6-in. CTA		do			
Nebraska	8-9-in. PCC [6]	3-in. CTA		do			
Nevada	3½-4¾-in. AC	6-8-in. S-C	6-12-in. granular material		AASHO guide	5,000	
New Mexico	AC variable	Treated or untreated	CTA variable		R-value		
North Carolina	3-in. AC	8-in. CTA		Experience	AASHO guide	1,500	
	6-in. AC	7-in. crushed aggregate	6-in. CMS	do	do	7,000	
Ohio	9-in. PCC [6]	4-6-in. CTA					
Oklahoma	4½-in. AC	6-8-in. S-C, $q_u > 250$ p.s.i.	Sometimes required	Oklahoma method [3]	Oklahoma method [3]	1,200-7,200	
Oregon	4-in. AC	10-in. CTA	6-in. lime treated subgrade.	R-value	R-value	5,650	
Pennsylvania	2-3-in. AC	6-8-in. S-C or CTA	6-in. select borrow	Experience	AASHO guide		
South Dakota	1½-2-in. AC	6-in. CTA, $q_u > 250$ p.s.i.			do		
Texas	8-in. PCC [1]	4-8-in. CTA or S-C		Experience	do		
Utah	9-in. PCC [4]	4-in. CTA	4-in. select borrow	AASHO guide	do		
Virginia	4½-7½-in. AC	4-6-in. aggregate	6-in. S-C (mixed in place)	Experience			20-400
	8-in. PCC [4]	6-in. CTA (4% by weight)		do	Virginia method		400
Washington	4-7-in. AC	6-in. CTA	(7)	Washington method			
County of San Diego Engineer Department	3½-in. AC	6½-in. CTA (6½% cement)	11½-in. select borrow	R-value	R-value	1,600	
	4-in. AC	6-in. CTA, $q_u > 400$ p.s.i.		(8)	(8)	6,000	

[1] Continuously reinforced.
[2] Hveem stabilometer is basic test.
[3] CBR is basic test.
[4] Plain.
[5] Variable.
[6] Reinforced.
[7] When required for working platform.
[8] Standard section.

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Table 5.—Pavement structures and design information for Interstate roads

State [1]	Surfacing	Base course	Subbase	Cement-treated-layer design procedure	Pavement design procedure	Traffic volume: ADT	Traffic volume: 18K equivalent
						Number	
Alabama	9–10-in. PCC [2]	6-in. CTA, $q_u>350$ p.s.i.	12-in. improved subgrade		AASHO guide	5,000	
	8-in. PCC [3]	6-in. CTA, $q_u>350$ p.s.i.	12-in. improved subgrade		do	5,000	
Arizona	4–6-in. AC	6-in. aggregate untreated	9–15-in. select borrow [4]		do		
	9-in. PCC [2]	4–6-in. CTA	4–6-in. select borrow		AASHO guide and PCA		
Georgia	10-in. PCC [2]	6-in. S-C		Georgia method [5]	Georgia method		
	6-in. AC	8–10-in. S-C	Select borrow variable	do	do		
Hawaii	4-in. AC	8-in. CTA	10-in. select borrow	R-value	R-value	44,200	
	9-in. PCC [2]	4-in. CTA	6-in. select borrow	PCA	PCA	44,200	
Nevada	4¾-in. AC	8-in. S-C	6–24-in. (Class B)		ASAHO guide	45,000	
	8-in. PCC [2]	4–6-in. S-C, $q_u>750$ p.s.i.		PCA	PCA		1,760
New Hampshire	5½-in. AC	6-in. CTA, $q_u>400$ p.s.i.	12-in. gravel [6]	AASHO guide	AASHO guide	19,116	
New Mexico	AC variable	Black base variable	Select borrow variable [7]	R-value	R-value		
	8-in. PCC [2]	6-in. CTA			AASHO guide		
North Carolina	9-in. PCC [2]	4-in. CTA			do	10,000	
		6-in. CMS			do	9,000	
Oklahoma	8-in. PCC [2]	6–8-in. S-C, $q_u>250$ p.s.i.			Oklahoma method [9]	15,000	
Oregon	8-in. PCC [8]	4-in. CTA	5-in. crushed aggregate		PCA	23,000	
Virginia	9½-in. AC	6-in. CTA	6-in. S-C (10% by vol.)	Experience			400
Wyoming	4-in. AC	6-in. S-C	Aggregate variable		AASHO guide		

[1] Arkansas, California, Iowa, Louisiana, Nebraska, Texas, and Utah use same structures and designs as described for primary roads. (See table 4.)
[2] Plain.
[3] Reinforced.
[4] An additional subbase of 4–6-in. CTA is placed on subgrade.
[5] Quick triaxial compression is basic test.
[6] An additional subbase of 24 inches of sand is placed on subgrade.
[7] An additional subbase of 6 inches of soil-cement is placed on subgrade.
[8] Continuously reinforced.
[9] CBR is basic test.

Abbreviations

The following abbreviations are used in the tabular material, tables 1–10, in which the questionnaire responses are summarized:

AASHO—American Association of State Highway Officials
AC—Asphaltic concrete
ADT—Average daily traffic
ASTM—American Society for Testing and Materials
CBR—California bearing ratio
CMS—Cement-modified soil
CTA—Cement-treated aggregate
CTB—Cement-treated base
DBST—Double bituminous surface treatment
DGA—Dense graded aggregate
F-T—Freeze-thaw
PCA—Portland Cement Association
PCC—Portland cement concrete
q_u—Unconfined compressive strength, p.s.i.
SBST—Single bituminous surface treatment
S-C—Soil-cement
TBST—Triple bituminous surface treatment
UCS—Unconfined compressive strength test
W-D—Wet-dry

Table 6.—Procedures for thickness design of cement-treated layers

State or other organization	Procedure
Alabama	Experience.
Arizona	Experience; equipment capabilities.
Arkansas	Not answered in questionnaire.
California	Rigid—experience; flexible—R-value.
Colorado	K-value.
Florida	Experience; equipment capabilities.
Georgia	Quick triaxial design procedure.
Hawaii	R-value.
Idaho	R-value.
Illinois	Relative strength coefficient.
Iowa	Equipment capabilities.
Kentucky	CBR.
Louisiana	Experience; equipment capabilities.
Maryland	Experience; equipment capabilities.
Mississippi	Experience; AASHO guide.
Missouri	Experience.
Montana	Not answered in questionnaire.
Nebraska	Experience.
Nevada	CBR; AASHO guide.
New Hampshire	AASHO guide.
New Mexico	AASHO guide.
New York	Experience; frost; soil type; drainage.
North Carolina	Experience.
Ohio	PCA for rigid pavement; none used for flexible pavement.
Oklahoma	Substitution in CBR design procedure.
Oregon	Flexible—R-value; rigid—CBR.
Pennsylvania	Experience.
Rhode Island	Equipment capabilities.
South Dakota	AASHO guide.
Texas	Experience; equipment capabilities.
Utah	Relative strength coefficient; CBR.
Virginia	Equipment capabilities.
Washington	Gravel equivalencies.
West Virginia	Gravel equivalencies.
Wisconsin	Experience.
Wyoming	Relative strength coefficient; experience.
Federal Aviation Administration	Gravel equivalencies.[1]
U.S. Navy	Gravel equivalencies; experience.
U.S. Corps of Engineers	CBR.
Caddo Parish, La	Experience of PCA agent.
San Diego County, Calif	Gravel equivalencies.

[1] Equivalencies: 1 in. of S-C=1 in. of gravel—1 in. of CTA=1.5 in. of gravel.

Content of Questionnaire Used in Survey

The questionnaire used in the survey was designed to gather information required for the summary. To eliminate problems that could have arisen from differences in nomenclature, the agencies were asked to observe the following definitions of terms in completing the questionnaire:

Soil-cement.—A mixture of pulverized soil, portland cement, and water, which upon compaction at optimum moisture content to standard density (as determined by AASHO T 134 or ASTM D 558, or equivalent) forms a hard, durable structural material meeting PCA brushing-loss and strength criteria or other acceptable criteria.

Cement-modified soil.—A mixture of soil and cement containing sufficient cement to reduce plasticity and modify the gradation to meet applicable soil specifications, but insufficient to produce a material meeting the PCA or other acceptable criteria for soil-cement.

Cement-treated aggregate.—A mixture of granular soil material and cement containing sufficient cement to reduce plasticity and modify the gradation to meet applicable specification for base course for flexible pavements or sul base course for rigid pavements.

The following questions made up the ques tionnaire (space was included to permit answei to be written in):

Question 1a.—Does your organization us any of the above materials in the constructio of rigid or flexible pavements _____ yes _____ n(

Table 7.—Thickness limits of cement-treated layers

State or other organization	Soil-cement				Cement-modified soil				Cement-treated aggregate			
	Actual		Practical		Actual		Practical		Actual		Practical	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Alabama	8	4	8	4	--------	--------	--------	--------	8	4	8	4
Arizona	--------	--------	--------	--------	--------	--------	--------	--------	6	4	7	3
Arkansas	8	6	8	6	--------	--------	--------	--------	--------	--------	--------	--------
California	--------	--------	--------	--------	--------	--------	--------	--------	10.8	4	11.4	4.8
Colorado	--------	--------	--------	--------	--------	--------	--------	--------	12	4	8	4
Florida	12	6	12	6	--------	--------						
Georgia	10	6	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Hawaii	--------	--------	--------	--------	--------	--------	--------	--------	--------	4	6	4
Idaho	--------	--------	12	6	--------	--------	12	6	6	4	12	6
Illinois	8	6	8	6	--------	--------	--------	--------	--------	--------	--------	--------
Iowa	7	6	8	4	--------	6	8	6	8	6	--------	4
Kentucky	6	6	6	6	--------	--------	--------	--------	8	5	8	5
Louisiana	9	6	10	6	--------	--------	--------	--------	--------	--------	--------	--------
Maryland	6	6	6	6	6	6	6	6	4	3	4	3
Mississippi	8	5	10	4	--------	--------	--------	--------	--------	--------	--------	--------
Missouri	7	6	8	6	--------	--------	8	4	6	4	6	4
Montana	--------	--------	--------	--------	--------	--------	--------	--------	4.8	4.2	6	3
Nebraska	--------	3	--------	3	--------	--------	--------	--------	--------	--------	--------	--------
Nevada	10	6	8	6	--------	--------	--------	--------	--------	--------	--------	--------
New Hampshire	--------	--------	--------	--------	--------	--------	--------	--------	--------	3	--------	6
New Mexico	6	6	6	6	--------	--------	--------	--------	6	4	6	4
New York	6	6	10	6	--------	--------	--------	--------	--------	--------	--------	--------
North Carolina	8	6	8	6	8	6	8	6	8	4	8	4
Ohio	--------	--------	--------	--------	--------	--------	--------	--------	6	4	--------	4
Oklahoma	8	6	8	6	--------	--------	--------	--------	--------	--------	--------	--------
Oregon	--------	--------	--------	--------	--------	--------	--------	--------	8	4	--------	4
Pennsylvania	8	6	8	6	--------	--------	--------	--------	--------	--------	--------	--------
Rhode Island	8	6	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
South Dakota	--------	--------	--------	--------	--------	--------	--------	--------	6	4	8	4
Texas	8	6	8	4	--------	--------	--------	--------	8	6	8	4
Utah	--------	--------	--------	--------	--------	--------	--------	--------	4	4	4	4
Virginia	6	--------	6	--------	--------	--------	--------	--------	6	--------	6	--------
Washington	--------	--------	--------	--------	--------	--------	--------	--------	8	6	8	5
West Virginia	6	4	6	4	--------	--------	--------	--------	8	4	8	4
Wisconsin	6	6	6	6	--------	--------	--------	--------	--------	--------	--------	--------
Wyoming	--------	6	--------	6	--------	6	--------	6	--------	4	--------	4
Federal Aviation Administration	--------	6	--------	6	--------	--------	--------	--------	--------	6	--------	--------
U.S. Navy	12	4	--------	--------	12	4	--------	--------	8	6	--------	--------
U.S. Corps of Engineers	10	4	6	3	24	4	6	3	24	4	6	3
Caddo Parish, La.	8	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
San Diego, Calif.	12.5	5.3	12.5	4.8	12.5	5.3	12.5	4.8	12.5	5.3	12.5	4.8

If no, please sign and date questionnaire and return to Donald G. Fohs.

Question 1b.—If yes, approximately how much of each material was used during the last 3 years?

	1966 (sq. yd.)	*1967 (sq. yd.)*	*1968 (sq. yd.)*
Soil-cement	______	______	______
Cement-modified soil	______	______	______
Cement-treated aggregate	______	______	______

Question 2.—Where in the pavement structure is the cement-stabilized layer located?

	Flexible pavement		*Rigid pavement*
	Base	*Subbase*	*Subbase*
Soil-cement	______	______	______
Cement-modified soil	______	______	______
Cement-treated aggregate	______	______	______

Question 3.—Briefly describe the typical pavement structures featuring cement-stabilized materials and supply the indicated information for each type of structure. Use extra sheets if necessary and please identify the descriptions as 3a, 3b, etc. (See example sheet, fig. 1.)

Question 4.—If the thickness of any of the cement-stabilized layers was not arrived at by using a pavement design procedure, what factors determined the thicknesses selected for construction? (e.g., experience, equipment capabilities, etc.). *NOTE*—When applicable please identify your replies with the example numbers you have used in 3 (e.g., 3a, 3b, or 3c, etc.).

Question 5.—What are the maximum and minimum thicknesses (inches) actually used for the three types of cement-stabilized layers and, given current construction equipment and technology, what do you consider the practical maximum and minimum thickness to be?

Type	*Actual*		*Practical*	
	Maximum	*Minimum*	*Maximum*	*Minimum*
Soil-cement	______	______	______	______
Cement-modified soil	______	______	______	______
Cement-treated aggregate	______	______	______	______

Question 6a.—How are strength properties measured for the compacted cement-stabilized materials? (Test method)

Question 6b.—How are the strength properties of the compacted cement-stabilized materials incorporated into the design of the pavement structure? (For example—gravel equivalent, structural coefficient, CBR, etc.)

Question 7.—What correlations or equivalencies have you established for cement-stabilized materials? (For example—one State considers 1 inch of CTB to be equal to 1.75 inches of gravel; another assigns a structural coefficient of 0.15 to a soil-cement base having an unconfined compressive strength greater than 300 p.s.i.)

Question 8.—Do you have any current research with the objective of developing a thickness design for cement-stablized materials, and what is the anticipated nature of the design procedures?

Question 9.—Please include any further comments concerning soil-cement thickness design.

Questionnaire Responses

Responses to individual questions are discussed in the succeeding paragraphs, although not in the same order as the questions appeared in the questionnaire.

General use of cement stabilization (question 1a)

According to the ratio of questionnaires returned to those distributed—57 returned out of 75 distributed—there is considerable interest in cement stabilization, as well as in thickness design. From the 44 questionnaires

Table 8.—Strength test methods and procedures for incorporating strength properties into pavement design

State or other organization	Test method	Procedures for incorporation
Alabama	UCS	Relative strength coefficient.
Arizona	UCS	Do.
Arkansas	None; 95% density required	
California	UCS; stabilometer	Flexible—gravel equivalent; rigid—K-value.
Colorado	Plate bearing	K-value.
Florida	UCS	
Georgia	Triaxial compression	Relative strength coefficient.
Hawaii		Gravel equivalencies.
Idaho	UCS	Do.
Illinois	UCS	Relative strength coefficient.
Iowa	UCS	Relative strength coefficient.
Kentucky	Density	Dense-graded aggregate equivalencies.
Louisiana	UCS	Relative strength coefficient.
Maryland	W-D; UCS	Gravel equivalencies.
Mississippi	UCS	Relative strength coefficient.
Missouri	UCS	None.
Montana	UCS	Gravel equivalencies.
Nebraska	UCS	Not considered structurally.
Nevada	UCS	Relative strength coefficient.
New Hampshire	UCS	Do.
New Mexico	UCS	Relative strength coefficient.
New York	UCS	Experience.
North Carolina	UCS	Relative strength coefficient.
Ohio	Not measured	K-values according to PCA.
Oklahoma	UCS	Gravel equivalencies.
Oregon	UCS [1]	Gravel equivalencies; K-value—PCA.
Pennsylvania	UCS	Relative strength coefficient.
Rhode Island	UCS	Do.
South Dakota	UCS	Do.
Texas	UCS; cohesiometer	Minimum strength.
Utah	UCS	California bearing ratio.
Virginia	UCS	Relative strength coefficient.
Washington	CCS	Gravel equivalencies.
West Virginia	UCS; stabilometer; cohesiometer	
Wisconsin	UCS	
Wyoming	UCS; stabilometer (CTA)	Relative strength coefficient.
Federal Aviation Administration	UCS	Gravel equivalencies.
U.S. Navy	UCS	None. Minimum strength required.
U.S. Corps of Engineers	W-D; F-T; UCS	California bearing ratio.
Caddo Parish, La.	Density	
San Diego County, Calif.	UCS; stabilometer	Gravel equivalencies.

[1] After 12-cycle wet-dry or freeze-thaw.

returned by State highway departments, i was determined that 36 States either hav used cement-stabilized material on past proj ects, are using it at present, or plan to use i on future projects.

Two counties and three Federal agencie indicated that they now use cement-stabilize material or have used it in the past. Becaus of the limited use of cement-treated material by the counties and the specialized use b the Federal agencies, the replies of thes organizations are discussed later, after th discussions of the responses to the question

Trends in usage (question 1b)

The amounts of cement-treated materia used during the last 3 years are listed i table 1. It is shown by the data in the tabl that the amounts of cement-stabilized ma terial used in 1966 and 1967 were almo identical—about 50 million square yards. Th amount used in 1968 decreased about 2 percent from the amounts used in the previous years. It is difficult to assess th significance of this information because fiv of the 36 States using cement-treated materia account for most of the reported use, and an change in policy by any one of the five woul markedly influence the reported totals. On State-by-State basis, the data indicate tha use of cement-stabilized material in the la 3 years has significantly decreased in Louis ana, Mississippi, and New Mexico. It is als indicated that soil-cement is used mo prevalently in the Southeast, and cemen

Table 9.—Correlations or equivalencies established for cement-treated materials

State or other organization	Coefficient or equivalency
Alabama	$q_u>650$, $a_2=0.23$; $400<q_u<650$, $a_2=0.20$; $q_u<400$, $a_2=0.15$.
Arizona	CTA, $a_2=0.25$; 1-in. CTA=2-in. granular base.
Arkansas	S-C, $a_2=0.20$.
California	$q_u=750$, 1-in. CTB=1.7-in. gravel; R=80, 1-in. CTB=1.2-in. gravel.
Colorado	None.
Florida	None.
Georgia	S-C, $a_2=0.30$.
Hawaii	$q_u>400$, 1-in. CTA=1.5-in. gravel.
Idaho	Traffic index>7.0, 1.5 in.=1 in.; 6.3>TI>5.5, 1.75 in.=1 in. TI<5.4, 1 in.=2.00 in.
Illinois	$300<q_u<650$, $0.15<a_2<0.23$.
Iowa	CTA: $q_u>300$, $a_2=0.20$; S-C: $q_u>300$, $a_2=0.15$; CMS: $q_u>100$ $a_3=0.10$.
Kentucky	1-in. S-C=1-in. DGA; 1-in. CTA=1-in. crushed DGA.
Louisiana	$q_u>300$ p.s.i., $a_2=0.15$.
Maryland	1-in. S-C or cement-treated DGA=2-in. untreated DGA.
Mississippi	$q_u>500$, $a_2=0.20$.
Missouri	1-in. CTA=1½-in. DGA; 1-in. S-C=1¼-in. DGA.
Montana	$a_2=0.15$.
Nebraska	None.
Nevada	$400<q_u<750$, $a_2=0.20$; $q_u>750$, $a_2=0.23$.
New Hampshire	1-in. CTA=2-in. gravel.
New Mexico	CTA: Class A, $a_2=0.23$; Class B, $q_u>300$, $a_2=0.17$; Class C, $a_2=0.12$.
New York	None.
North Carolina	6-in. S-C=8-in. crushed stone; CTA, $a_2=0.20$; S-C $0.15<a_2<0.20$; CMS, $0.10<a_2<0.15$.
Ohio	None.
Oklahoma	1-in. S-C=: 1-in. soil asphalt; 1-in. DGA; 1-in. fine aggregate black base; 2-in. select borrow; ¾-in. aggregate black base.
Oregon	$q_u>1{,}000$ p.s.i., 1-in. CTA=1.8-in. crushed stone.
Pennsylvania	CTA, $a_2=0.30$; S-C, $a_2=0.20$.
Rhode Island	None.
South Dakota	$q_u<400$, $a_2=0.15$; $400<q_u<650$, $a_2=0.20$; $q_u>650$, $a_2=0.23$.
Texas	1-in. S-C=1-in. gravel.
Utah	$300<q_u<600$, $a_2=0.14$; $q_u>600$, $a_2=0.17$.
Virginia	CTA=1 × AC; CTA on subgrade=0.6 × AC; S-C=0.4 × AC.
Washington	$q_u>850$, 1-in. CTA=1.74-in. gravel.
West Virginia	1-in. CTA=1.65-in. gravel.
Wisconsin	None.
Wyoming	Depending on q_u, $0.15<a_2<0.25$.
Federal Aviation Administration	1-in. macadam=1-in. S-C; 1-in. S-C=1.5-in. crushed stone, caliche.
U.S. Navy	1-in. S-C=2-in. gravel (rigid); 1-in. S-C=1.3-in. gravel (flexible).
U.S. Corps of Engineers	S-C yields CBR 50-80.
Caddo Parish, La.	None.
San Diego County, Calif.	1-in. Class A CTA=1.7-in. gravel; 1-in. Class B=1.5-in. gravel; 1-in. Class C=1.2-in. gravel.

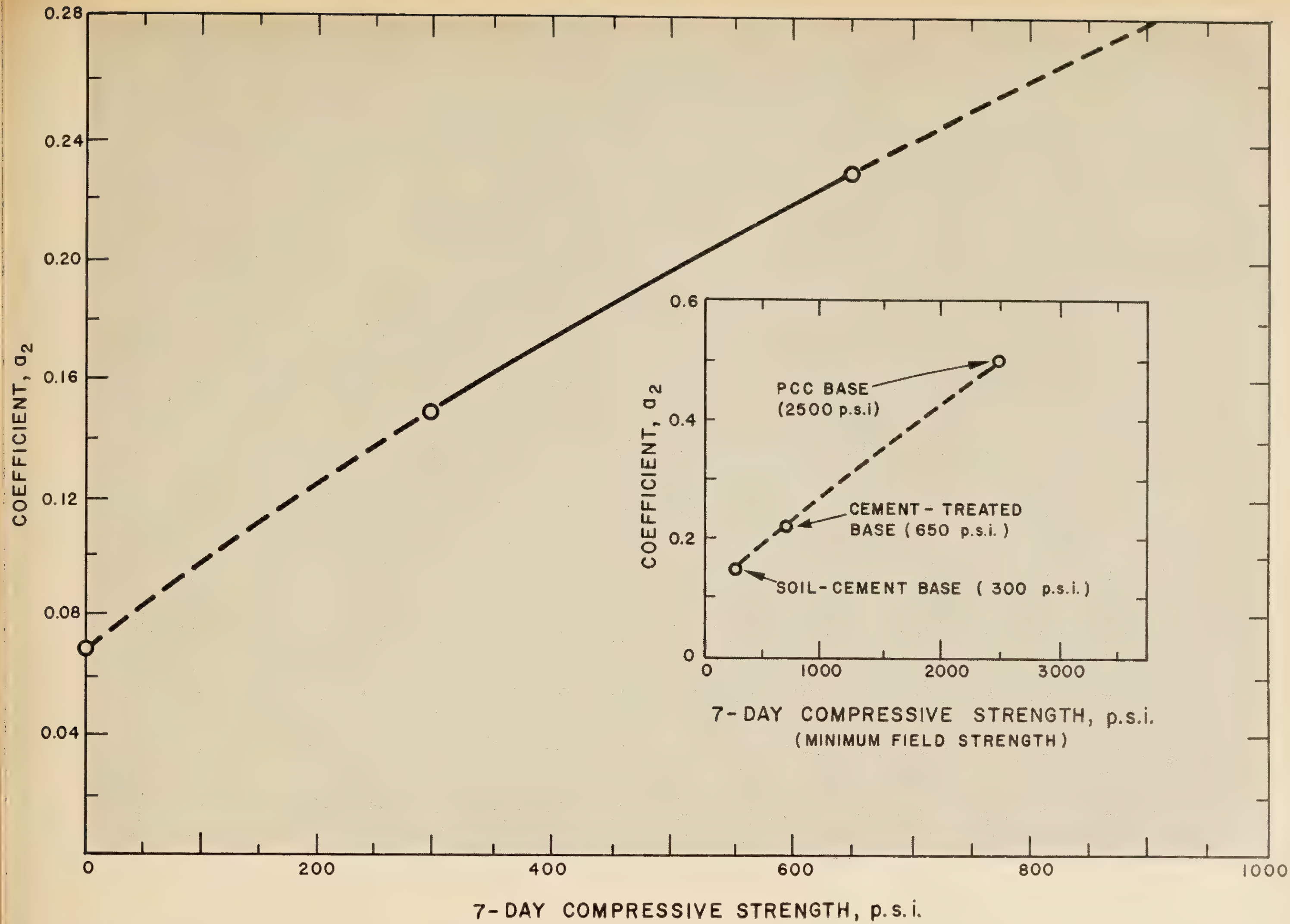

Figure 2.—Relationship between compressive strength and coefficient of relative strength, Illinois Division of Highways (from final report NCHRP Project No. 1–11).

treated aggregate more widely in the Southwest.

Type and location of treated material (question 2)

The amounts of cement-treated materials, their locations in the pavement structure, and descriptions of the pavement structures involved are given in tables 1–5. As shown in table 2, treated material is divided almost equally between soil-cement and cement-treated aggregate. Use of cement-modified soil was reported in only two States. According to tables 1–5, soil-cement is used largely as a base course in secondary roads, whereas cement-treated aggregate serves more frequently as a base for flexible pavements on primary and Interstate highways and as a subbase for rigid pavements.

Procedures for thickness design (question 4)

Thickness design procedures are listed in table 6. Of the 33 States responding to the question concerning thickness design, 15 indicated that layer thickness was dictated by experience or equipment capabilities, and 18 stated that an analytical procedure was used. The majority of the States using an analytical procedure for thickness design indicated that they used the AASHO *Interim Guide for the Design of Flexible Pavement Structures,* in which coefficients of relative strength are used to determine required layer thickness. The States using the AASHO procedure derive the coefficients from values of unconfined compressive strength.

In four States the R-value procedure rather than the AASHO guide is used. Other design procedures, based on California bearing ratio, triaxial strength, or modulus of subgrade support, were also mentioned as being used, but to a lesser extent.

Thickness limits (question 5)

Question 5 requested information on the range of thicknesses actually constructed and the maximum and minimum thicknesses considered practical in the various States. This question was included because past experience would be expected to influence future thickness design. As indicated in table 7, the majority of agencies regard 8 inches and 6 inches as the practical maximum and minimum thicknesses for soil-cement and 8 inches and 4 inches for cement-treated aggregate. Although, as is well known, use of a 6-inch thickness is virtually universal, it is shown in table 7 that 8-inch layers are also common. In two States the maximum layer thickness is 12 inches, in one State 10 inches, and in another 9 inches.

Strength measurements for pavement design (question 6)

In nearly all the States, it was indicated that strength properties of cement-treated materials are evaluated. In the 32 States where strength is measured, 30 highway departments use an unconfined compressive strength test, one uses a triaxial test, and another a plate-bearing test.

In the AASHO interim guide the coefficients of relative strength have been correlated with unconfined compressive strength. Highway departments in 16 States indicate that they assign a coefficient of relative strength to incorporate strength properties into their pavement design procedures. Equivalent gravel factors, rather than coefficients of

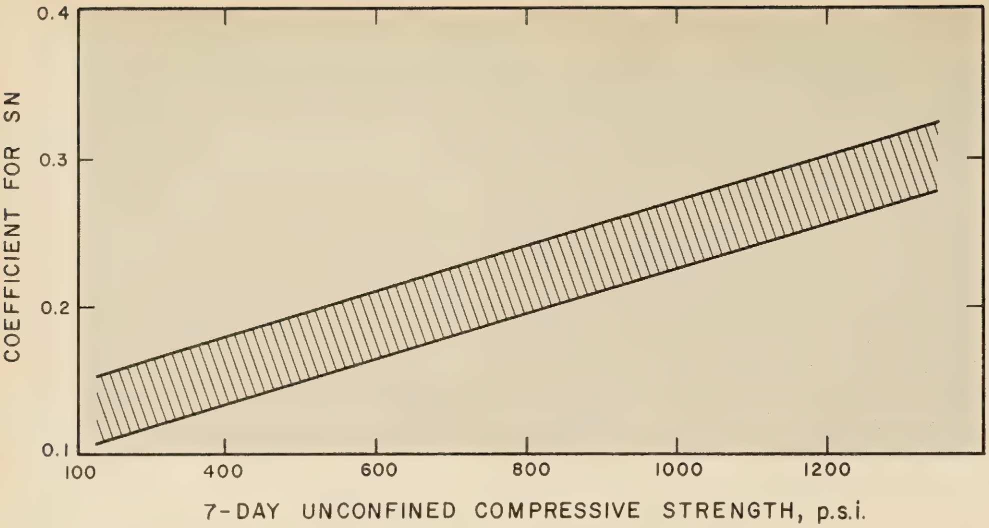

Figure 3.—Relationship between compressive strength and coefficient of relative strength, Texas Highway Department (from final report NCHRP Project No. 1–11).

relative strength, are used in 10 other States. A method in which unconfined compressive strength properties are used to arrive at the structural coefficient of cement-treated base has been developed in Arizona, but such factors as gradation, plasticity index, method of mixing (central plant or in-place), and thickness of asphaltic concrete cover are also used to develop the coefficient.

Correlations and equivalencies (question 7)

The relative strength coefficients or equivalent gravel factors used in the different States are listed in table 9. Some highway departments have adopted the unconfined compressive strength criterion developed from the AASHO road test—that is, for cement-treated material (not soil-cement), a coefficient of 0.23 is used when the unconfined compressive strength is more than 650 p.s.i., 0.20 when the strength is between 650 and 400 p.s.i., and 0.15 when the strength is less than 400 p.s.i.

A modified form of the AASHO criterion is used in other States. For example, in Illinois and Texas,[2] the variation in structural coefficient for cement-treated materials as a function of 7-day unconfined compressive strength has been established. This relationship for Illinois is shown in figure 2. The upper point of the curve represents the cement-treated sand-gravel base used in the AASHO road test; the lower point, the same sand and gravel material without cement; and the intermediate point, a material with the minimum compressive strength required for durable soil-cement base. In Texas (fig. 3) it has been demonstrated that for a given unconfined compressive strength, a range of coefficients, rather than a single value, may be assigned.

Initially, the Arizona State Highway Department adopted the structural coefficient values established by the AASHO road test and used them as a guide to establish values for their own construction materials. However, after the new values were used to evaluate the pavement structure of several projects, it was decided that the coefficients should be revised. Although lower coefficients were established for most materials, after a considerable amount of study and research, the coefficients for cement-treated base were higher. The method used in Arizona to develop the structural coefficient for cement-treated base is summarized in table 10.

Pavement structures (question 3)

In question 3, descriptions of typical pavement structures featuring cement-stabilized materials were requested. The information supplied in the responses is given in tables 3, 4, and 5 for secondary, primary, and Interstate highways, respectively. The typical pavement structure most frequently described for secondary highways (table 3) consists of a 6-inch soil-cement or cement-treated aggregate base course placed directly on the subgrade and surfaced with 3 inches of asphaltic concrete or with a double bituminous surface treatment. However, it was indicated in several States, that the structure includes select borrow or aggregate subbase.

In table 4, it is shown that thicker asphaltic concrete surfaces are provided for primary roads. Compared to secondary highways, primary structures more frequently include subbases. A comparison of tables 3 and 4 indicates that cement-treated aggregate more frequently serves as a base course for primary roads, whereas soil-cement is more frequently used as a base for secondary roads.

According to tables 4 and 5, similar flexible pavement structures usually are used for primary and Interstate highways—about 4 inches of asphaltic concrete surface, 6 inches of cement-treated aggregate base, and 8 inches of granular subbase placed directly on untreated subgrade. On Interstate highways a thicker subbase is often used, the subgrade is stabilized, or an additional subbase is provided.

County highway departments

Cement-treated materials are used in only two of the 10 counties responding to the questionnaire—Caddo Parish, La., and San Diego County, Calif. One project using cement-treated materials has been constructed in Caddo Parish; it consists of a 7-mile section of roadway with an 8-inch soil-cement base and a triple bituminous surface treatment. Respondents in San Diego County indicated that they have used cement-treated aggregate and soil-cement for base course, and California Department of Highways procedures (R value) for thickness design.

Federal agencies

Three of the four Federal agencies solicited—the Federal Aviation Administration, Naval Facilities Engineering Command, and Army Corps of Engineers—responded to the questionnaire and indicated that they used cement-stabilized materials for pavement construction. A response was not received from the Department of Housing and Urban Development.

(*Continued on p. 91*)

Table 10.—Method for arriving at coefficient of relative strength for cement-treated base

[Arizona State Highway Department—from final report NCHRP Project No. 1–11]

Condition	Amount to be added to base coefficient 0.12 [1]
Mixing:	
Central plant	0.05
Road mix	0.00
Passing No. 8 sieve—30–65 percent	0.01
Passing No. 4 sieve—45–75 percent	0.02
Strength:	
More than 500 p.s.i.	0.07
300–500 p.s.i.	0.05
Less than 300 p.s.i.	0.00
Plasticity index—nonplastic	0.01
Thickness of asphaltic concrete over CTB:	
4 inches	0.01
6 inches	0.02

[1] The coefficient used for design is arrived at by adding to 0.12 (the base coefficient for CTB) the values in column 2 as appropriate for a given condition. Example—structural coefficient for cement-treated base that is to be plant-mixed, is nonplastic and is to have 6 inches of asphaltic concrete cover is—0.12+0.05+0.01+0.02=0.20.

[2] *Evaluation of AASHO Interim Guides for Design of Pavement Structures* by B. F. McCullough, C. J. Van Til, B. A. Vallerga, and R. G. Hicks, Final Report NCHRP Project 1-11 (in review stage, December 1969).

BY THE OFFICE OF DEVELOPMENT

Photogrammetry for Highway Planning, Location and Design— Review of Current Methods

Reported by [1] **JESSE R. CHAVES**
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Some of the ways in which aerial photogrammetry is used for highways and some of the problems associated with large scale map compilation are discussed in this summary of photogrammetric practices. The author reviews procedures for route selection and topographic mapping, and discusses the more recent technique of strip analytical aerial triangulation using wide angle photography in terms of highway engineering needs.

Introduction

WITHIN the last 15 years aerial photogrammetric engineering has become an established discipline in many highway organizations. Not only has photogrammetry helped improve the overall efficiency of highway planning, location, and design, but, in the last 5 years, the application of computational photogrammetry has increased the accuracy of photogrammetric surveys for highways and has helped reduce survey costs. The development of the Stereo Image Alternator system has enabled the use of color photographs in double projection instruments for mapping.

In this summary, established photogrammetric practices are outlined, as are particular problems associated with photogrammetry in highway applications. New techniques that have excellent potential and areas that need further development are included in the discussion. Currently, in research and development, at least four areas are being emphasized in connection with photogrammetry: Development of efficient terrain data acquisition systems for highway design; production of large scale orthophotographs for use in highway planning and location studies, and in right-of-way acquisition; development of computer graphics systems for automating map compilation; and development of integrated computer systems for optimizing photogrammetric computations.

[1] Presented at the Tenth Annual Photogrammetry Short Course, University of Illinois, Urbana, Ill., June 1-12, 1970.

Route Selection and Topographic Mapping

Selecting highway corridors

In the selection of highway corridors, which is the preliminary reconnaissance phase of highway location, available photo indexes, aerial photographs, topographic quadrangle maps, and other maps are used. Stereoscopic vertical aerial photographs at scales of 1:20,000–1:60,000 and quadrangle maps at scales of 1:24,000, 1:62,500, or 1:250,000 for the area of interest between given terminal points are examined. Rarely would special topographic mapping be required at this stage, as possible corridors through which highways can be located may be 2–20 miles wide.

The principal basis for corridor selection is the study of aerial photographs and maps and the use of available planning information, such as census surveys and origin and destination surveys. Because the area covered is usually extensive, only general information would be considered—major land use, topographic features, and river crossings; adverse soil and ground conditions, such as swamps or landslides; potential areas of scenic interest or potential recreation sites; existing transportation system, such as highways, railroads, and airports; and major potential sources of construction materials. When compared with recent photographs, old aerial photographs will reveal past land use and show major trends in land use.

Selecting route alternatives

In the next phase of reconnaissance each route corridor is examined to determine which route or routes within it are the most practical.

Photographs and maps used in the previous phase are usually adequate for this purpose, but they are studied and analyzed in somewhat greater detail. Particular attention is paid to fitting the alinements to the topography within curvature and grade constraints; avoiding excessive rise and fall, bedrock excavation, and high-cost or productive farmland; minimizing property severance and disturbance to trees or other natural features; number and size of grade separation structures and bridges; and needed transportation service to communities with minimum disruption to residences, public buildings, public utilities, etc. Individual route alternatives are delineated on the aerial photographs and on the maps.

Selecting optimal route

After the route alternatives have been delineated, they must be compared to determine the optimal route. For this comparison, the third phase of reconnaissance, larger scale photography and mapping may be required for critical segments of selected routes or for the entire length of the more feasible routes. The larger scale photographs and maps, also permit earthwork volumes and construction costs to be estimated, and construction and maintenance problems to be considered. Reconnaissance route topographic maps may range in scale from 1 inch: 1,000 feet to 1 inch: 200 feet with contour intervals from 20 feet to 5 feet. The scale and contour interval selected depends on the ruggedness of topography and the intensity of land use. Usually these maps are compiled at a scale of 400 or 200 feet: 1 inch with a 10-foot or 5-foot contour interval respectively. Corresponding photography scales are 1:24,000 and 1:12,000, assuming a 5-diameter enlargement from photograph to map.

Preliminary survey

As a result of the comparative analysis, the optimal route is selected and recommended. After public hearings have been held and the proposed route has been approved, a preliminary survey is initiated. Large scale route topographic maps with scales of 200 feet: 1 inch to 40 feet: 1 inch and contour intervals of 5 feet to 1 foot are compiled for detailed location and design. The map scale and contour interval selected depend on the nature of the topography, the intensity of land use, and the accuracy required.

Procedures Leading to Map Compilation

Mapping in the preliminary survey stage

In the preliminary survey for detailed location and design, the following steps apply to large scale topographic mapping:

- Assemble and verify all available horizontal and vertical ground control data along the approved route. These data are available from the U.S. Coast and Geodetic Survey, from the U.S. Geological Survey, and from other sources for some routes.
- Plan and indicate on appropriate maps photographic flight lines along the route, considering for each model the relief-height to flight-height ratio imposed by the limitations of certain photogrammetric plotters.
- Plan horizontal and vertical ground control distribution along the route. This includes the basic control traverse, which should originate and close on first or second order station markers that are part of the National survey network established by the U.S. Coast and Geodetic Survey. In control planning, the method of providing supplemental control—by ground methods or by analytical or analog aerial triangulation—should be considered.
- Place photographic targets on all basic horizontal and vertical control points and on a reasonable number of supplemental control points to assure reliable and accurate mapping and subsequent engineering measurements.
- Photograph the route to be mapped according to the flight plan using a precision aerial camera and high performance lens.
- Perform a basic control survey using an electronic distance measuring instrument and precision theodolite and leveling instruments. Accurately adjust horizontal and vertical traverses.
- Perform a supplemental ground control survey required for mapping or alternatively perform analytical or analog aerial triangulation to provide positions and elevations of supplemental control points.
- Compile topographic maps, and field edit or complete as necessary.

The steps involved in map compilation are discussed in the following paragraphs.

Assembling control data

In addition to published information—triangulation diagrams, control leveling index maps, and description lists of control points of the Coast and Geodetic Survey and Geological Survey—the U.S. Army Topographic Command in Washington, D.C., maintains a ground-control-data bank. The Topographic Command has informal cooperative agreements to exchange horizontal-control data with Federal, county, and municipal agencies and with State highway and private organizations. The data bank is maintained on magnetic tape and updated periodically. Annually or upon request a tape containing all the available control data for a given area is forwarded on loan to the cooperating organization. In turn, the organization sends a tape containing all existing control data or new data to the Topographic Command to update the central-data bank. Vertical-control data is not included in the data bank and the quality of horizontal-control data is not indicated.

The Coast and Geodetic Survey (1)[2] has also initiated a geodetic data bank on magnetic tape for newly surveyed horizontal control that will be available to interested users, although the data will not include descriptive information concerning the geodetic points.

Planning photographic flight

Flight lines should be planned to adequately cover the mapping band and to allow sufficient tolerances for flight-line position and aircraft altitude. Displacement of images on large scale photographs of rugged topography may be sufficient to cause gaps in coverage unless endlap is increased. The normal requirement for the average endlap is between 57 and 6[illegible] percent. If one or more negatives in a flight strip exceeds a minimum of 55 percent or maximum of 68 percent, the photographs may be rejected. In rugged-relief areas the 68-percent limit can be relaxed to insure complete stereoscopic coverage (*2*).

When Kelsh-type plotters are used for large-scale mapping, the relation between map scale and relief-height to flight-height (h/H) ratio must be considered for each model of a flight strip because of the limitation in measuring range of these plotters. Sometimes the h/H may control the largest feasible map scale. For a Kelsh instrument using 6-inch focal length photography and 5:1 projection ratio the h/H must not exceed ¼. For example, topographic maps at a scale of 50 feet to 1 inch are desired; but because the plotter projection ratio is 5:1, aerial photographs must be taken at a scale of 25[illegible] feet to 1 inch (1:3,000). From the relationship $S=f/H$, the required flight height for a 6-inch camera can be computed:

$$\frac{1}{3{,}000}=\frac{0.5}{H}$$

$$H=1{,}500 \text{ feet}$$

[2] Italic numbers in parentheses identify the references listed on p. 87.

Therefore, the maximum relief that can be ıeasured in any model is 1,500/4 o $h=375$ 'eet, where H is taken from the low point in :he model.

Image motion, or image smear during :xposure, is another problem associated with ow-flight photography. The naked eye can ›ften discern the results of image motion on ırge-scale photographs by the apparent ɿidening of photographic target legs oriented 'erpendicular to the flight line. Brandenberger *3*) has stated that for precision photogram-ıetry the image motion during exposure on he film negative should be less than 25 ıicrometers; accordingly, the following ɔrmula is given for computing the allowable ıaximum exposure time (Tmax) in seconds:

$$\text{Tmax}=\frac{0.00009.H}{f.v}$$

Vhere,

H=flight height, meters

f=focal length of camera, meters

v=aircraft ground speed, kilometers per hour

:xample—compute Tmax for the following conditions:

iven:

Photograph scale=1:3,000

Camera focal length=6 inches

Flight height=1,500 feet

Aircraft ground speed=150 m.p.h.

$H=(1{,}500\text{ ft.})\ (0.3048)=457.2$ meters

$f=(6\text{ in.})\ (.0254)=0.152$ meter

$v=(150\text{ m.p.h.})\ (1.6093)=241.4$ Km. per hour

$$\text{Tmax}=\frac{(0.00009)\,(457.2)}{(0.152)\,(241.4)}=.00112\text{ second}$$

his formula can also be rearranged to com-ıte the minimum allowable flight height for given minimum exposure time.

lanning control distribution

The basic control points are planned length-ise along the route at intervals of 1,200–000 feet, and permanent station markers are ɜed on them. If supplemental control is to › obtained by field surveys, control distri-ıtion should provide at least three horizontal ıd five vertical control points in each model '). Preferably four of the supplemental con-ol points are located near each corner of the odel and the fifth near the center. Semi-ɜrmanent station markers are used on these ıpplemental control points.

There are no hard and fast rules regarding ıe density and distribution of ground control r photogrammetric bridging. Many factors fluence the accuracy of bridged supplemental ›ntrol—how completely systematic errors 'e removed, accuracy of primary control, ght height, extent of photographic target-g, topography, and quality of orienting and easuring each bridged model. Accuracy re-ıirements and a knowledge of the attainable 'idging quality determine the density of 'ound surveyed points. Typical analog bridg-g of large-scale photographs is as follows: Two horizontal and four vertical control points in the first model of each flight strip; there-after, one horizontal and two vertical control points in every fourth model and in the last model of the strip. For analytical aerial triangulation, the control in the first model of the flight strip can be reduced to one hor-izontal and two vertical control points, as absolute orientation of the first model is not necessary.

Photographic targets

The design of photographic targets and their placement on survey control markers have undergone considerable experimentation. It is recognized that control premarking is essential in accurate large-scale mapping for location and design. Many State highway organizations base target designs on mapping experience to develop targets that best suit their particular conditions. There are several target designs (*2*) that are recommended for large-scale map-ping. The following criteria are incorporated in all suitable target designs: symmetrical shape; adequate size for specific scale of pho-tography; and sufficient contrast between design components or between the target and its background to be sharply recorded on the aerial negative. Designs with white target centers are usually avoided because of elevation-exaggeration effects in the stereo-scopic model.

Aerial photography

Prescribed flight lines, endlap, and flight altitude all should be maintained while the route is being photographed. The aerial camera should be equipped with a high-resolution, low-distortion lens; detailed specifications for the aerial camera and film are given in the Reference Guide Outline (*2*). Dimensionally stable film bases must be used, as an unstable film base is the most frequent cause of model deformation.

Basic control

Second- and third-order control surveys can be readily performed with modern electronic distance-measuring equipment, precision the-odolites, and levels. Usually, second order or better horizontal surveys and third order or better vertical surveys are preformed. The importance of accuracy becomes apparent when it is realized that the basic control survey is the basis for all subsequent engineer-ing measurements, including design and con-struction staking of the highway facility. Conventional computer programs are available that adequately perform traverse adjustments, as well as a weighted least squares traverse adjustment program that takes into account the accuracy of the measured distances and angles (*4*).

Supplemental control

In some State highway organizations, sup-plemental control for mapping is obtained by ground surveys. Because the cost of a ground survey constitutes 40–70 percent of the total cost of a photogrammetric survey, analog and analytic aerial triangulation have been used more extensively in recent years.

Since 1964 a number of computer programs for analytical strip aerial triangulation have been published by the U.S. Coast and Geodetic Survey (*5*, *6*) and by the National Research Council (N.R.C.) of Canada (*7*, *8*). More recently, Karara and Marks (*9*) and Wong (*10*) have published modified versions of the Coast and Geodetic Survey programs. The programs of Karara and Marks (*9*) have provisions for linking the strip coordinate computation with the strip adjustment so that ground coordinates can be computed in a single pass. The modified programs also permit the use of spike fiducials (open centers) in the corners of the photograph. Wong's programs (*10*) also include subroutines to perform semianalytical aerotriangulation by the in-dependent model method. Strogis and Chaves (*11*)[3] have modified the N.R.C. strip triangu-lation program (*7*) to include an image coordinate refinement program (*12*) primarily for small computer applications. Another computer program, recently developed (*13*), reduces stereocomparator measured data for photographs with side fiducials. The output of this program is designed for input to the N.R.C. triangulation program (*7*).

Accuracy of results obtained by strip aerial triangulation for large-scale mapping varies according to type of measuring equipment; scale of photographs and number of fiducials; and accuracy, density, and distribution of ground control. For example, in an experiment in construction staking, the California Division of Highways used both analog and analytical methods to bridge five models at a scale of 1:6,000. Five horizontal and 10 vertical control points were used to adjust the strip and to compute the position and elevation of 312 targeted construction-control points. Photographs were taken with a 6-inch aerial camera and bridged with both a stereo-comparator and a first order analog in-strument. The standard errors of the test points for the analytically computed horizontal and vertical coordinates were ±0.24 and ±0.28 ft. respectively. Standard errors from analog bridging were ±0.7 and ±0.5 for the horizontal and vertical coordinates respectively.

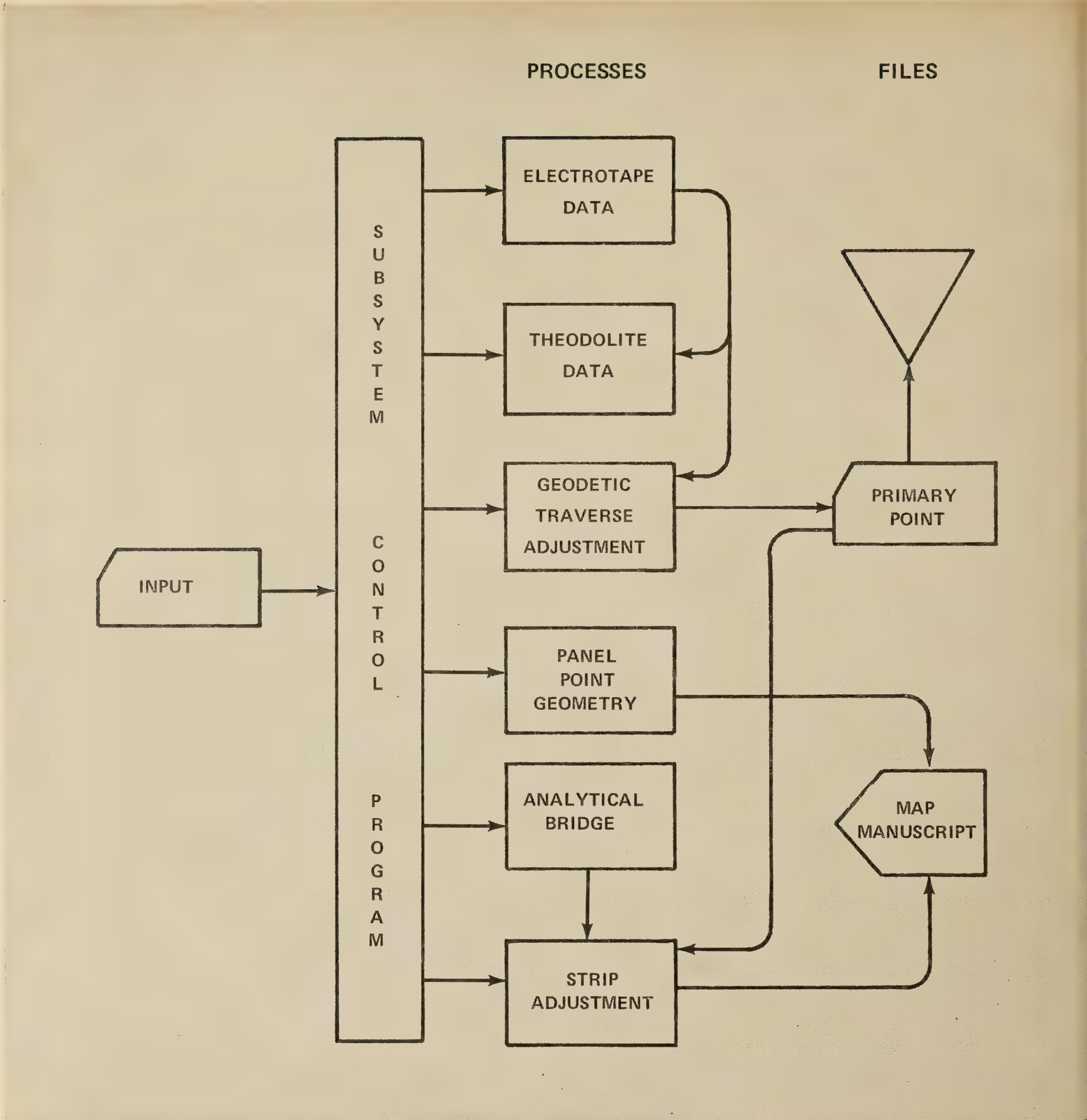
The Reference Guide Outline (*2*) contains specifications and accuracy requirements for analog and analytical aerial triangulation.

Map compilation

The accuracy of topographic maps com-piled by photogrammetric methods may be affected by many factors, some of which are as follows:

- Errors in the ground control survey.
- Errors in photographic identification of ground control.
- Image motion during exposure.
- Poor calibration of the aerial camera or plotting instrument.
- Film distortion caused by film develop-ment and drying.
- Camera malfunction, such as vacuum failure, at the instant of exposure, causing deformation of the negative.

[3] A subsequent revision has added the N.R.C. strip adjust-ment program so that ground coordinates can be computed in a single pass (unpublished TIES Computer Program R-0300).



Photogrammetric control subsystem.

- Poor distribution of ground control in a model.
- Operator's inability to measure stereoscopic model with precision.
- Incomplete lens distortion compensation in the stereoscopic model.

According to specifications (*2*) governing topographic map accuracy, 90 percent of the elevations determined from solid line contours should be within $\frac{1}{2}$ contour interval or better, and the remaining 10 within one contour interval. In determining compliance, contour shift tolerance has the effect of lowering the vertical accuracy and is not permitted. On steeper slopes where intermediate contours may be omitted, vertical accurancy is based on the index contours. Similarly 90 percent of all planimetric features tested should be within $\frac{1}{40}$ of an inch of their true positions and none should be misplaced by more than $\frac{1}{20}$ of an inch.

As in the manufacturing industry, qualit control procedures in map production prever a defective product and give the highway eng neer confidence in the maps he uses. Becaus organizations may lack sufficient field su vey personnel to conduct field surveys fo testing maps, map checking can be dor in a two phase procedure. First, selecte models in a flight strip are reviewe and analyzed photogrammetrically by rese ting the models in a plotter using the sam ground control data. Models that are borderline or fail to meet specifications are further checked by field profiles and traverses. This two step procedure enables organizations to check maps for completeness as well as for accuracy and usually to ascertain the causes for errors or deficiencies. The California Division of Highways developed the procedure in the mid-1950's to test a large volume of mapping that was performed under contract (*14*). Details and specifications are available (*2*) for testing maps by field surveys and photogrammetric methods.

Photogrammetric Cross Sections

Measuring terrain cross sections by photogrammetric methods to compute highway earthwork quantities is now a well established procedure in many State highway organizations. In some States, however, organizations still obtain cross-section data by ground surveys. Photogrammetric plotting instruments for measuring cross sections are usually equipped with scalers or digitizers to measure and automatically record elevations and offset distances perpendicular to the highway centerline. Earthwork quantity computations are determined by combining original terrain cross-section data either with design template cross sections or with the *as built* roadway and terrain. Cross sections are usually measured at intervals of 50 feet, 100 feet, or at other intermediate points along the centerline, as required. Cross sections can be measured directly in a stereoscopic model or *stripped* from topographic maps.

The accuracy required depends on the intended use of the cross sections. For example, to compare highway route alternatives, preliminary quantities can be computed and the terrain data obtained from reconnaissance topographic maps, because high accuracy is not required for route comparisons. However, cross sections obtained for determining earthwork quantities in designing horizontal alinement, grades, and slopes, must be accurate, as highway projects are advertised on the basis of design quantities. Payment to the construction contractor is sometimes based on design quantities. Payment also may be based on *as built* quantities, which are computed from post construction final cross sections and which must be accurate to insure equitable payment to the contractor.

Vertical systematic error in the model or map is one of the most serious sources of error in determining earthwork quantities by photogrammetric methods, and specifications (*2*) for photogrammetrically measured cross sections include the algebraic mean of these errors at randomly measured spot elevations, test profiles, and cross sections. The influence on measured cross sections of systematic vertical error in a model can be removed by indexing on field elevations along the centerline at each cross section. This adjustment is applied to all points on a given cross section and requires that the position of the centerline be known before photographs are taken. Large-scale topographic maps free of systematic vertical errors provide for greater flexibility and enable the design engineer to position the designed alinement and obtain earthwork quantities without delay.

Photogrammetric and Integrated Computer Systems

A recent trend to develop integrated computer and photogrammetric systems has occurred both outside and within the highway engineering field to procure the data more efficiently and optimize the computations required in engineering work.

Under the sponsorship of the Federal Highway Administration, the Texas Highway Department is developing an integrated Design Subsystem that is part of a larger comprehensive Total Integrated Engineering System (TIES). A generalized flow chart of a portion of the Roadway Segment of the Design Subsystem, called Photogrammetric Control, is included in the accompanying illustration, which shows individual computer processes (subroutines) and data flow between individual processes and the computer storage file. The computed output from this subsystem is used primarily to compile large-scale topographic, planimetric, and right-of-way maps, and a computer file of primary traverse points remains available for input to other programs in the Design Subsystem.

The Nistri Analytical Plotter (AP/C) is an example (*15*) of another type of system in which photogrammetric instruments are integrated on-line with digital computers. Konecny (*16*) has extended this concept by interfacing an Analytical Plotter with an IBM 360/50 system. Eventually, such a system will automatically produce orthophotographs while simultaneously digitizing a model. The model, strip, or ground coordinates can be stored directly on a magnetic tape or any peripheral device for use by other programs in an integrated system. Alternatively some digital recording device, such as a magnetic tape unit, could be linked to the photogrammetric instrument for directly storing the coordinates of terrain points without a direct link to a large computer.

O'Connell (*17*) has reported on another system in which a Stereomat is linked to an IBM 1,800 computer to produce large-scale orthophotographs and simultaneously to digitize stereoscopic models for use in highway route location studies. The terrain coordinates were used as inputs to other programs for computing and plotting preliminary data for route location analysis.

Summary and Conclusion

During the last 6 years great strides have been made in the use of wide angle photography for strip analytical aerial triangulation in highway mapping. Superwide photography seems to have great potential for photogrammetric bridging, and its application needs to be fully evaluated. Semianalytical and block aerial triangulation also should be tested in terms of highway engineering needs. The application of photogrammetry in cadastral surveys for highway right-of-way acquisition has yet to be fully exploited, and the development of an efficient semiautomated system for producing orthophotographs and acquiring terrain data for engineering use has but begun. Computer graphics systems are needed to improve the efficiency of maps used in highway engineering. There is also need to develop and evaluate close range photogrammetric systems for making engineering measurements. Two areas in which some work has been done are the measurement of retaining wall movements and deflections and the measurement of microprofiles of highway pavement surfaces for characterizing resistance to skidding.

REFERENCES

(*1*) *Requirements for a Geodetic Graphic Data Bank*, by R. O. Williamson, Proceedings of the 1970 Symposium on Computational Photogrammetry, The American Society of Photogrammetry, January 1970, p. 229.

(*2*) *Reference Guide Outline—Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways*, prepared by the Photogrammetry for Highways Committee of the American Society of Photogrammetry, U.S. Department of Transportation, Federal Highway Administration, 1968.

(*3*) *Analysis and Evaluation of Aerial Triangulation Procedures and Instrumentation*, by A. J. Brandenberger, Final Report, Phase 3, The Ohio State University Research Foundation, July 1963.

(*4*) *Traverse Adjustment by Weighted Least Squares*, by R. L. Kenngott, C. H. Sells, Inc., Civil Engineers and Surveyors, Pleasantville, N.Y., 1967.

(*5*) *Three-Photo Aerotriangulation*, by M. Keller, and G. C. Tewinkel, Technical Bulletin No. 29, Coast and Geodetic Survey, U.S. Department of Commerce, February 1966.

(*6*) *Aerotriangulation Strip Adjustment*, by M. Keller and G. C. Tewinkel, Technical Bulletin No. 23, Coast and Geodetic Survey, U.S. Department of Commerce, August 1964.

(*7*) *An Introduction to Analytical Strip Triangulation With a Fortran Program*, by G. H. Schut, AP-PR 34, National Research Council of Canada, December 1966.

(*8*) *A Fortran Program for the Adjustment of Strips and of Blocks by Polynomial Transformations*, by G. H. Schut, AP-PR 33, National Research Council of Canada, February 1968.

(*9*) *Analytic Aerial Triangulation for Highway Location and Design*, by H. M. Karara, and G. W. Marks, Photogrammetry Series No. 22, University of Illinois, July 1969.

(*10*) *Three Computer Programs for Strip Aerotriangulation*, by K. W. Wong, Photogrammetry Series No. 20, University of Illinois, August 1969.

(*11*) *Electronic Computer Program for Analytical Strip Triangulation*, by G. Strogis, and J. R. Chaves (TIES Computer Program R-0200) U.S. Department of Transportation, Federal Highway Administration, 1970.

(*Continued on p. 91*)

The Third Base for the Federal Highway Administration's Contract Price Index

BY THE OFFICE OF HIGHWAY OPERATIONS

Reported by EDWIN L. STERN
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CHANGES in contract prices for highway construction in the United States, on a national basis, have been measured and published as a price index since 1933, and available data extends back to 1922.

The index, known officially as *Price Trends for Federal-Aid Highway Construction*, was originally based on the 5-year period from 1925 to 1929, and was described in detail in the July 1933 issue of PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 14, No. 5.

As indicated by the title of this index, the trends are based on data from Federal-aid contract awards. Investigations have indicated, however, that prices on non-Federal-aid highway construction are substantially the same as those on Federal-aid work. The trends, therefore, are considered to reflect prices for all highway construction.

In 1961, under the leadership of the Bureau of the Budget, the Federal Government endeavored to establish all indexes published by Federal agencies on a uniform 1957–59 base period, beginning January 1, 1962. Accordingly, the Public Roads highway construction price index on the new base period was described in the October 1961 issue of PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 31, No. 10, and in the November 1961 issue of the *American Road Builder*.

By Bureau of the Budget Memorandum of March 31, 1970, to the Heads of Executive Departments and Establishments, the year 1967 was established as the standard reference base period for general-purpose index numbers prepared by Federal agencies until further notice. The Bureau of the Budget ruled that the new base period should be instituted as soon as practicable but generally no later than the date of issuance of January 1971 indexes. The highway construction contract price index, based on 1967 quantities and prices, will begin with the third quarter 1970 issue.

The design of the 1967 base index will remain essentially the same as that of the 1957–59 base index. The weightings of highway construction major items or operations have changed somewhat during the past 10 years but not nearly as much as the changes that occurred during the previous 30 years. In the 1920's and early 1930's roads still conformed largely to natural terrain. There were steep grades, comparatively short bridges over waterways, and few tunnels. Compared to quantities for grading and structures, quantities for base and surfacing work were therefore high. Highway geometrics for the last several years have changed this relationship. A comparison of the percentages or weights based on costs of the indicator items in the index during the different periods are shown in table 1.

A comparison of quantities and costs based on one-third of the 1957–59 (3-year period) quantities at 1957–59 unit prices and total 1967 quantities at 1967 unit prices are shown in table 2. Figure 1 is a graphical representation of the trends on the 1967 base. As shown, trends for the later years, plotted quarterly, are more definable than on previous representations because three-quarter moving averages are being used.

Annual figures from 1950 through 1967 and quarterly figures from 1968 to present are shown in table 3. Quarterly figures from 1962 through 1967, both actual and three-quarter averages, are available from the Federal Highway Administration on request.

Table 1.—Percentage comparison of indicator items

Item	1925–29 quantities at 1925–29 prices	1925–29 quantities at 1957–59 prices	1957–59 quantities at 1957–59 prices	1957–59 quantities at 1967 prices	1967 quantities at 1967 prices
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Excavation	36	24	34	37	39
Surfacing:					
Portland cement concrete	48	54	15	13	15
Bituminous concrete	----------	----------	16	14	14
Total surfacing	48	54	31	27	29
Structures:					
Reinforcing steel	5	7	6	5	6
Structural steel	2	3	11	12	9
Structural concrete	9	12	18	19	17
Total structures	16	22	35	36	32
Total highway	100	100	100	100	100

Table 2.—Comparison of quantities and costs

Item	1957–59 base			1967 base			Increase	
	⅓ quantity	Unit price	Cost	Quantity	Unit price	Cost	Quantity	Cost
	Thousands		*Thousands*	*Thousands*		*Thousands*	*Percent*	*Percent*
Excavation cu. yds.	1, 213, 962	$0. 420	$509, 864	1, 656, 655	$0. 541	$896, 250	36. 5	75. 8
Surfacing:								
Portland cement concrete sq. yds.	51, 651	4. 377	226, 076	79, 942	4. 428	353, 983	54. 8	56. 6
Bituminous concrete tons	37, 172	6. 658	247, 491	51, 230	6. 466	331, 254	37. 8	33. 8
Total surfacing	----------	----------	473, 567	----------	----------	685, 237	46. 3	44. 7
Structures:								
Reinforcing steel lbs.	735, 626	0. 1292	95, 043	981, 587	0. 1308	128, 392	33. 4	35. 1
Structural steel do.	860, 487	0. 1946	167, 451	885, 235	0. 2467	218, 387	2. 9	30. 4
Structural concrete cu. yds.	4, 861	54. 18	263, 369	5, 572	70. 30	391, 682	14. 6	48. 7
Total structures	----------	----------	525, 863	----------	----------	738, 461	14. 4	40. 4
Total highway	----------	----------	1, 509, 294	----------	----------	2, 319, 948	32. 2	53. 7

Table 3.—Price trends for Federal-aid highway construction

[1967 base] [1]

Year	Common excavation: Average contract price per cubic yard	Common excavation: Index	Surfacing: Portland cement concrete: Average contract price per square yard	Surfacing: Portland cement concrete: Index	Surfacing: Bituminous concrete: Average contract price per ton	Surfacing: Bituminous concrete: Index	Surfacing: Surfacing index	Structures: Reinforcing steel: Average contract price per pound	Structures: Reinforcing steel: Index	Structures: Structural steel: Average contract price per pound	Structures: Structural steel: Index	Structures: Structural concrete: Average contract price per cubic yard	Structures: Structural concrete: Index	Structures: Structures index	Composite index
1950	$0.32	59.1	$3.62	79.9	$5.89	91.8	85.9	$0.099	75.9	$0.129	52.3	$42.62	60.7	60.2	66.6
1951	0.40	75.1	3.92	86.5	7.33	114.2	100.5	0.119	91.6	0.176	71.5	50.72	72.2	74.8	81.8
1952	0.43	79.9	4.19	92.5	6.98	108.8	100.7	0.119	92.0	0.178	72.3	52.24	74.4	76.3	84.1
1953	0.40	75.1	4.07	89.8	6.53	101.8	95.9	0.121	93.4	0.172	70.1	52.82	75.2	76.2	81.0
1954	0.38	71.4	3.98	87.9	5.97	93.0	90.5	0.112	86.3	0.159	64.5	50.15	71.4	71.3	76.4
1955	0.35	65.6	3.96	87.4	6.07	94.6	91.0	0.110	84.8	0.157	64.0	50.01	71.2	70.8	74.3
1956	0.40	74.9	4.26	94.0	6.58	102.6	98.3	0.127	97.5	0.212	86.1	53.74	76.5	82.7	84.0
1957	0.42	78.6	4.34	95.8	6.75	105.2	100.6	0.134	103.5	0.228	92.6	55.98	79.7	87.4	87.7
1958	0.43	80.3	4.41	97.4	6.67	104.0	100.7	0.129	99.5	0.186	75.7	54.10	77.0	79.9	85.6
1959	0.40	74.7	4.40	97.1	6.58	102.6	99.9	0.126	96.8	0.169	68.6	53.00	75.4	76.4	82.0
1960	0.39	73.2	4.33	95.6	6.37	99.3	97.5	0.119	91.7	0.167	67.7	51.72	73.6	74.3	80.1
1961	0.41	75.5	4.20	92.7	6.35	98.9	95.9	0.115	88.5	0.165	67.1	53.38	76.0	74.9	80.7
1962	0.45	82.9	4.28	94.4	6.28	97.9	96.2	0.113	86.7	0.166	67.7	54.62	77.7	75.8	83.8
1962	0.45	82.6	4.17	94.2	6.32	95.9	97.2	0.113	86.2	0.167	67.6	53.88	76.6	75.6	84.3
1963	0.45	82.6	4.24	95.7	6.48	100.1	97.9	0.114	87.1	0.182	73.8	57.31	81.5	80.2	86.4
1964	0.46	84.8	4.16	93.9	6.26	96.8	95.3	0.112	85.7	0.193	78.1	57.71	82.1	81.5	86.9
1965	0.47	87.4	4.34	97.9	6.50	100.5	99.2	0.124	94.5	0.200	81.1	59.63	84.8	85.4	90.3
1966	0.52	96.5	4.50	101.7	6.44	99.6	100.7	0.127	97.2	0.224	90.7	63.22	89.9	91.4	96.1
1967	0.54	100.0	4.43	100.0	6.47	100.0	100.0	0.131	100.0	0.247	100.0	70.30	100.0	100.0	100.0
1968:															
First quarter	0.54	98.9	4.70	106.1	6.71	103.8	105.0	0.133	101.8	0.252	101.9	72.14	102.6	102.3	101.8
Second quarter	0.57	105.0	4.78	107.8	6.82	105.5	106.7	0.131	100.3	0.233	94.5	69.75	99.2	98.0	103.3
Third quarter	0.52	96.9	4.73	106.8	6.76	104.6	105.7	0.129	98.7	0.260	105.2	72.51	103.1	103.0	101.4
Fourth quarter	0.67	123.1	5.07	114.6	6.82	105.5	110.2	0.133	102.0	0.250	101.2	74.15	105.5	103.6	113.1
Average	0.56	102.6	4.79	108.1	6.77	104.7	106.4	0.131	100.5	0.249	100.8	71.81	102.1	101.5	103.4
1969:															
First quarter	0.57	105.7	4.38	98.9	6.83	105.6	102.1	0.135	103.4	0.268	108.7	75.35	107.2	107.0	105.1
Second quarter	0.61	112.8	4.59	103.7	7.13	110.3	106.9	0.136	103.8	0.277	112.2	79.91	113.7	111.5	110.6
Third quarter	0.59	108.3	5.35	120.9	6.76	104.5	113.0	0.148	113.2	0.373	151.0	80.90	115.1	125.4	115.1
Fourth quarter	0.57	105.4	5.48	123.7	7.51	116.2	120.1	0.158	121.2	0.323	131.0	89.04	126.7	127.0	116.6
Average	0.59	108.5	4.87	110.0	7.01	108.4	109.3	0.143	109.6	0.316	128.1	81.34	115.7	118.3	111.8
1970:															
First quarter	0.63	115.7	4.83	109.0	7.51	116.1	112.4	0.150	114.9	0.295	119.5	86.77	123.4	120.8	116.4
Second quarter															
Third quarter															
Fourth quarter															
Average															
Previous quarter base [2]															
1969:															
First quarter		85.9		86.3		100.1	92.7		101.4		107.4		101.6	103.3	92.9
Second quarter		106.6		104.8		104.4	104.6		100.4		103.3		106.1	104.3	105.3
Third quarter		96.1		116.6		94.8	105.7		109.1		134.6		101.2	112.4	104.1
Fourth quarter		97.3		102.3		111.2	106.3		107.0		86.8		110.1	101.3	101.3
1970:															
First quarter		109.8		88.1		99.9	93.6		94.8		91.2		97.5	95.1	99.8
Second quarter															
Third quarter															
Fourth quarter															
Three-quarter moving average															
1968:															
First quarter	0.54	100.2	4.67	105.4	6.72	103.9	104.7	0.134	102.5	0.242	98.2	72.54	103.2	101.6	102.0
Second quarter	0.54	100.4	4.74	106.9	6.76	104.6	105.8	0.131	100.2	0.249	100.7	71.36	101.5	101.0	102.2
Third quarter	0.56	104.1	4.80	108.5	6.80	105.2	106.9	0.131	100.1	0.248	100.5	71.70	102.0	101.2	104.0
Fourth quarter	0.56	103.9	4.65	105.0	6.80	105.2	105.1	0.132	100.9	0.259	104.9	73.76	104.9	104.2	104.3
1969:															
First quarter	0.61	112.2	4.59	103.7	6.98	108.0	105.8	0.135	103.3	0.268	108.6	77.32	110.0	108.4	109.1
Second quarter	0.59	109.6	4.73	106.8	6.92	107.0	106.9	0.140	106.7	0.313	127.0	79.20	112.7	115.9	110.8
Third quarter	0.59	109.2	5.01	113.2	7.06	109.2	111.3	0.145	110.9	0.324	131.2	82.65	117.6	120.5	113.4
Fourth quarter	0.59	109.4	5.18	117.0	7.17	110.9	114.0	0.152	116.0	0.336	136.0	85.27	121.3	124.7	115.6
1970:															
First quarter															
Second quarter															
Third quarter															
Fourth quarter															

[1] Base for composite index, 1967, involves 1,656,655,000 cubic yards of roadway excavation, 79,942,000 square yards of portland cement concrete surfacing with an average thickness of 8.7 inches, 51,230,000 tons of bituminous concrete surfacing, 981,587,000 pounds of reinforcing steel for structures, 885,235,000 pounds of structural steel and 5,572,000 cubic yards of structural concrete.

Index figures for 1950 through 1962 are simple mathematical conversions from the 1957–59 base to the 1967 base. They were derived from the previously computed figures, using 1957–59 base quantities and prices, dividing the figures for each year by the figures for the year 1967, and multiplying by 100. Revisions for 1962 and figures subsequent thereto are computed from 1967 base quantities and prices.

Prices for portland cement concrete surfacing reflect adjustments to base period thickness in each State and do not include costs for reinforcing steel and joints.

[2] Index for each quarter as compared with 100.0 for each preceding quarter.

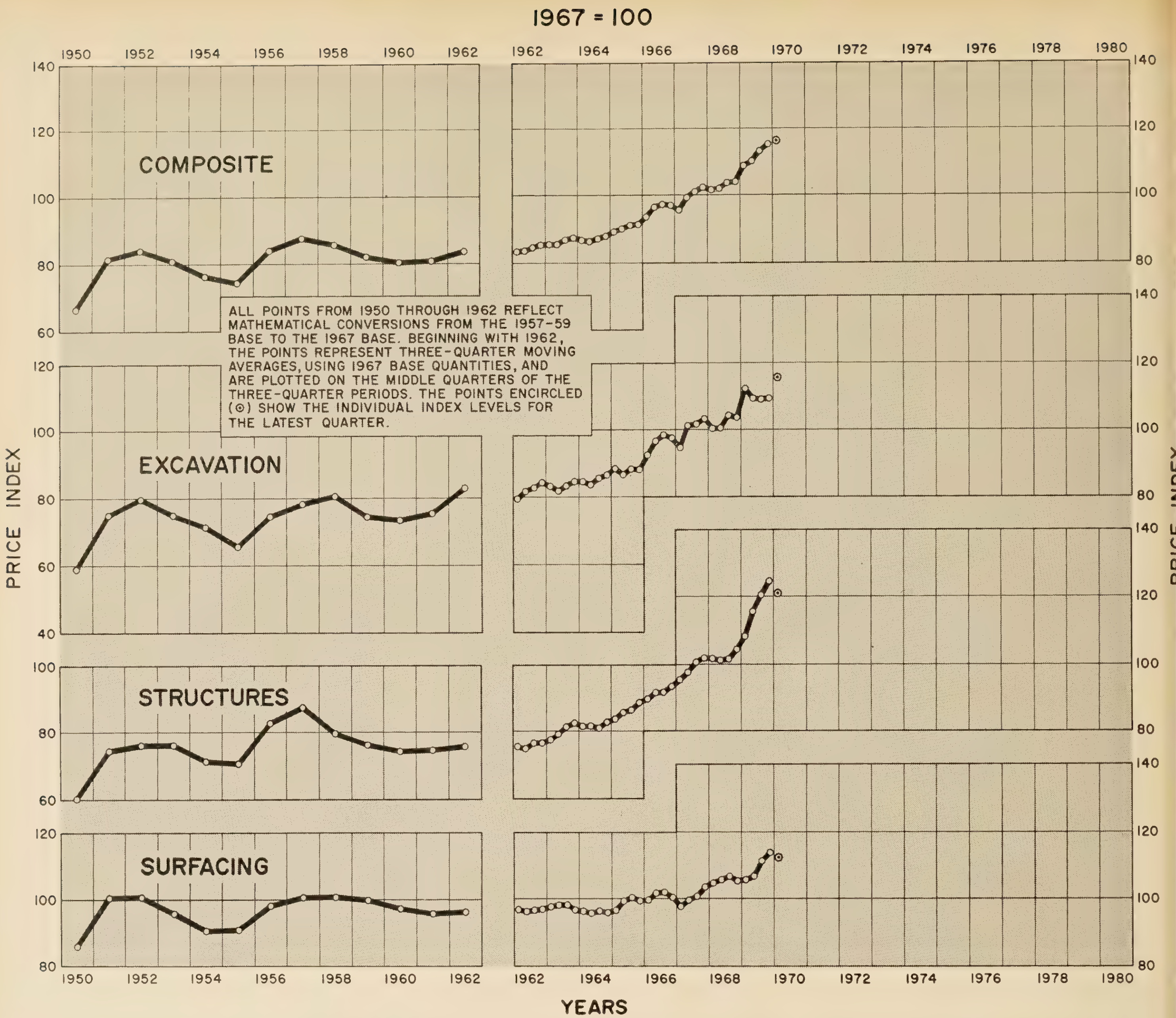


Figure 1.—Price trends for Federal-aid highway construction.

New Publications

The Federal Highway Administration has recently published three documents. These publications may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, prepaid. The following paragraphs give a brief description of each publication and its purchase price.

Quality Assurance in Highway Construction

Quality Assurance in Highway Construction (50 cents a copy) contains a reprint of an article published in six parts in the February–December 1969 issues of PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 35, Nos. 6–11. These parts, together, form a comprehensive report of the results of research on highway quality assurance in the last 6 years; they have been combined in a single report to facilitate use of the information by those in the highway field who are concerned with controlling the quality of highway construction.

The material in this report is a significant contribution to the *literature* on current highway construction and the ability to measure it. Highway builders and inspectors should find it a valuable stepping stone to similar examination of their construction. State highway personnel who participated in the research have gained valuable experience on construc tion quality and have used it to evaluat their sampling and testing methods an procedures.

The report illustrates the importance o random samples in the measurement proces and the benefits of control charts in the dail routine of projects inspection.

Bridge Inspector's Training Manual

Bridge Inspector's Training Manual, 197 ($2.50 a copy) provides guidelines for th training of bridge inspectors. It is not intende to provide a complete treatment of bridg

(*Continued on p. 91*)

Photologging

(*Continued from p. 74*)

system because of the increased number of signs and other traffic control devices.

Following a presentation of the Capitol Beltway film, representatives of one major city estimated that traffic control devices could be inventoried from a photolog more quickly than by the ususal field-crew-survey method and would result in substantial savings. Their last inventory in 1965 required 10 men working 1 year to obtain data by Polaroid cameras at a cost of 25 cents per picture. It was estimated that a photolog could produce such data for less than 5 cents per picture, and could be accomplished by two men in a relatively short period of time. The 35mm. negatives, processed in roll form, are more amenable to data reduction than Polaroid prints, as negatives can be projected on a viewing screen.

A photolog will not replace actual on-site inspections for obtaining detailed analyses of roadway geometrics or terrain. However, it has been found in Oregon that routine jobs, such as answering inquiries from the public and pinpointing accident locations from accident reports, can be performed in the office and reduce travel costs and nonproductive travel time.

Soil-Portland Cement Thickness Design

(*Continued from p. 82*)

In the Federal Aviation Administration, a 6-inch soil-cement base course is used for basic-utility-type airports that serve aircraft weighing less than 8,000 pounds. A 6-inch cement-treated aggregate base course has also been used for facilities that serve aircraft with *critical weights* of 110,000 pounds on a dual landing gear. Several equivalencies for soil-cement and cement-treated aggregate have been established by the agency. For example, a given thickness of soil-cement is considered equivalent to the same thickness of aggregate or macadam subbase when used for pavements serving aircraft with gross weights of more than 30,000 pounds. The same equivalencies apply to bases used for pavements that serve aircraft with gross weights of less than 30,000 pounds. In base courses, 1 inch of cement-treated aggregate is considered equal to 1½ inches of crushed aggregate, caliche, lime-rock, shell, penetration macadam, or emulsified-asphalt aggregate base course. The Federal Aviation Administration also indicated that in some embankment sections, subgrade soil is modified with cement to depths of 12 inches or more, in layers.

The Naval Facilities Engineering Command estimated that, in the last 3 years, 1½ million square yards of soil-cement and 600,000 square yards of cement-treated aggregate have been used in construction. This agency has estimated that for rigid pavement base, 1 inch of cement-treated aggregate is equivalent to 2 inches of gravel, and that for flexible pavement base, 1 inch of cement-treated aggregate is equivalent to 1.33 inches of gravel. These estimates are based on experience.

The Corps of Engineers has used cement-stabilized materials extensively, having constructed total thicknesses of as much as 24 inches, in 6-inch layers. Equivalent CBR values have been used to incorporate strength properties into their design procedure. For example, material defined as stabilized subgrade is assigned a CBR value of 50, soil-cement subbase a CBR value of 50–80, and soil-cement base a CBR value of 80 or more. When the cement content is less than that required to meet their criteria for durable soil-cement, the measured CBR values are used in the design procedure.

Conclusions

The following conclusions are based on an overall analysis of questionnaire responses:

• Soil-cement is used more frequently as a base course in secondary roads, and cement-treated aggregate more frequently as a base for flexible pavements of primary and Interstate highways and as a subbase for rigid pavements.

• In the majority of organizations, experience and equipment capabilities dictate the thickness of cement-stabilized layers.

• The practical maximum layer thickness for cement-stabilized material is regarded by most organizations to be 8 inches.

• Nearly all the agencies use an unconfined compressive strength test to evaluate the strength properties of cement-stabilized mixtures.

• For thickness design, most highway departments use the correlations between unconfined compressive strength and coefficients of relative strength determined in the AASHO road test. These coefficients are used directly in the AASHO *Interim Guide for the Design of Flexible Pavement Structures*, or are converted to equivalent gravel factors for use in CBR or other pavement-design methods.

Photogrammetry

(*Continued from p. 87*)

(*12*) *Aerotriangulation: Image Coordinate Refinement*, by M. Keller and G. C. Tewinkel, Technical Bulletin No. 25, Coast and Geodetic Survey, U.S. Department of Commerce, March 1965.

(*13*) *Electronic Computer Program for Stereocomparator Coordinate Reduction*, by J. R. Chaves (TIES Computer Program R-0100) U.S. Department of Transportation, Federal Highway Administration, March 1970.

(*14*) *Photogrammetric Map Checking*, by G. P. Katibah, Photogrammetry and Aerial Surveys, Developments and Applications—1961, Highway Research Board Bulletin 312.

(*15*) *Proceedings of the Second International Photogrammetric Conference in Ottawa on the Analytical Plotter*, National Research Council of Canada and Canadian Institute of Surveying, April 1963.

(*16*) *The Analytical Plotter AP-2C and Its Interfacing With an IBM 360–50 System*, by G. Konecny, presented at the 1969 Symposium on Computational Photogrammetry, State University of Forestry, Syracuse, N.Y.

(*17*) *Applying Stereomat Orthophotographs to Highway Route Location*, by R. O'Connell, Consulting Engineer, November 1969, pp. 118–122.

New Publcations

(*Continued from p. 90*)

inspection. This manual is a guide both for instruction and for the conduct of bridge inspections.

Chapter I of this manual outlines, in general terms, the primary duties of the bridge inspector, the essential requirements for the training of bridge inspectors, and the prerequisite qualifications for individuals selected for such training. Chapter II provides a simplified classification of bridge types and a rudimentary explanation of simple mechanics. Chapter III explains the planning of a bridge inspection operation and the use of an inspection field book. Chapter IV describes the methodology and the procedural sequence to be followed in conducting a bridge inspection. Chapter V instructs, informs, and guides the bridge inspector so as to enable him to recognize the various kinds of bridge deterioration, to pinpoint their location, and to categorize and describe their severity. Chapter VI contains a brief discussion of methods for reporting inspection results and making recommendations.

Hydraulics of Bridge Waterways—Second Edition

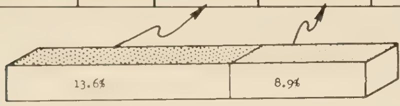
Hydraulics of Bridge Waterways, Bulletin No. 1 in the Hydraulic Design Series, 1970 ($1.25 a copy), is a 111-page revised edition of the 1960 publication. It presents simplified methods for computing backwater caused by bridges. These methods were developed from extensive model tests and actual measurements of flow on streams with wide flood plains. New material includes information on partially inundated superstructures, the proportioning of spur dikes at bridge abutments, and supercritical flow under a bridge together with examples.

The nature of the new bulletin is indicated by the chapter titles: Computation of backwater; difference in water level across approach embankments; configuration of backwater; dual bridges; abnormal stage-discharge condition; effect of scour on backwater; superstructure partially inundated; spur dikes; flow passes through critical depth; preliminary field and design procedures; illustrative examples; and discussion of procedures and limitations of method.

This publication is intended to provide, within the limitations described, a means of computing the effect of a given bridge upon the flow of the stream it is proposed to span.

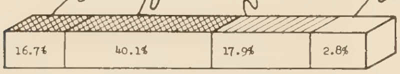
APPALACHIAN DEVELOPMENT HIGHWAY SYSTEM

STATE	TOTAL DESIGNATED SYSTEM MILEAGE	OPEN TO TRAFFIC: ADEQUATE SEGMENTS- NO APPALACHIA FUNDS EXPENDED	OPEN TO TRAFFIC: INADEQUATE SEGMENTS- IMPROVED WITH APPALACHIA FUNDS	OPEN TO TRAFFIC: TOTAL
GEORGIA	89.0	2.6	-	2.6
KENTUCKY	582.6	163.7	73.0	236.7
MARYLAND	82.2	4.1	10.0	14.1
NEW YORK	260.0	29.5	15.9	45.4
NORTH CAROLINA	199.1	1.3	20.6	21.9
OHIO	295.0	93.0	17.3	110.3
PENNSYLVANIA	489.8	58.1	25.8	83.9
TENNESSEE	332.9	12.8	12.9	25.7
VIRGINIA	204.1	25.0	76.0	101.0
WEST VIRGINIA	423.6	9.9	12.4	22.3
TOTAL	2,958.3	400.0	263.9	663.9



OPEN TO TRAFFIC
22.5%

STATE	WORK IN PROGRESS: UNDER CONST.	WORK IN PROGRESS: ENG'R AND R-O-W	WORK IN PROGRESS: LOCATION STUDIES UNDERWAY OR COMPLETED	WORK IN PROGRESS: TOTAL UNDERWAY	NO LOCATION WORK UNDERTAKEN
GEORGIA	14.2	72.2	-	86.4	-
KENTUCKY	73.1	239.7	33.1	345.9	-
MARYLAND	7.7	32.9	-	40.6	27.5
NEW YORK	85.5	98.6	18.1	202.2	12.4
NORTH CAROLINA	46.4	93.5	26.3	166.2	11.0
OHIO	40.6	119.7	22.1	182.4	2.3
PENNSYLVANIA	43.4	166.6	195.9	405.9	-
TENNESSEE	61.7	143.4	71.5	276.6	30.6
VIRGINIA	12.9	13.9	76.3	103.1	-
WEST VIRGINIA	109.7	205.9	85.7	401.3	-
TOTAL	495.2	1,186.4	529.0	2,210.6	83.8



WORK IN PROGRESS 74.7%

ABOVE TABLES EXCLUDE LOCAL ACCESS ROADS

STATUS OF IMPROVEMENT AS OF JUNE 30, 1970


U.S. GOVERNMENT PRINTING OFFICE: 1970

PUBLICATIONS of the Federal Highway Administration

A list of articles in past issues of Public Roads *and title sheets for volumes 24–35 are available upon request from the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20591.*

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

Accidents on Main Rural Highways—Related to Speed, Driver, and Vehicle (1964). 35 cents.

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and A New Graphical Evaluation Chart (1962). 25 cents.

America's Lifelines—Federal Aid for Highways (1969). 35 cents.

Analysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System (1969). $1.00.

A Book About Space (1968). 75 cents.

Bridge Inspector's Training Manual (1970). $2.50.

The Bridge to Your Success (1969). 45 cents.

Calibrating & Testing a Gravity Model for Any Size Urban Area (1968). $1.00.

Capacity Analysis Techniques for Design of Signalized Intersections (Reprint of August and October 1967 issues of PUBLIC ROADS, a Journal of Highway Research). 45 cents.

Construction Safety Requirements, Federal Highway Projects (1967). 50 cents.

Corrugated Metal Pipe (1970). 35 cents.

Creating, Organizing, & Reporting Highway Needs Studies (Highway Planning Technical Report No. 1) (1963). 15 cents.

Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems, 1968. 45 cents.

Federal-Aid Highway Map (42x65 inches) (1970). $1.50.

Federal Laws, Regulations, and Other Material Relating to Highways (1970). $2.50.

Federal Role in Highway Safety, House Document No. 93, 86th Cong., 1st sess. (1959). 60 cents.

The Freeway in the City (1968). $3.00.

Freeways to Urban Development, A new concept for joint development (1966). 15 cents.

Guidelines for Trip Generation Analysis (1967). 65 cents.

Handbook on Highway Safety Design and Operating Practices (1968). 40 cents.

Supplement No. 1 (Nov. 1968). 35 cents.

Supplement No. 2 (Nov. 1969). 40 cents.

Highway Beautification Program. Senate Document No. 6, 90th Cong., 1st sess. (1967). 25 cents.

Highway Condemnation Law and Litigation in the United States (1968):

Vol. 1—A Survey and Critique. 70 cents.

Vol. 2—State by State Statistical Summary of Reported Highway Condemnation Cases from 1946 through 1961. $1.75.

Highway Cost Allocation Study: Supplementary Report, House Document No. 124, 89th Cong., 1st sess. (1965). $1.00.

Highway Finance 1921–62 (a statistical review by the Office of Planning, Highway Statistics Division) (1964). 15 cents.

Highway Planning Map Manual (1963). $1.00.

Highway Research and Development Studies Using Federal-Aid Research and Planning Funds (1969). $1.50.

Highway Statistics (published annually since 1945):

1966, $1.25; 1967, $1.75; 1968, $1.75.

(Other years out of print.)

Highway Statistics, Summary to 1965 (1967). $1.25.

Highway Transportation Criteria in Zoning Law *and* Police Power and Planning Controls for Arterial Streets (1960). 35 cents.

Highways and Human Values (Annual Report for Bureau of Public Roads) (1966). 75 cents.

Supplement (1966). 25 cents.

Highways to Beauty (1966). 20 cents.

Highways and Economic and Social Changes (1964). $1.25.

Hydraulic Engineering Circulars:

No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965). 55 cents.

No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965). 65 cents.

No. 11—Use of Riprap for Bank Protection (1967). 40 cents.

No. 12—Drainage of Highway Pavements (1969). $1.00.

Hydraulic Design Series:

No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970). $1.25.

No. 2—Peak Rates of Runoff From Small Watersheds (1961). 30 cents.

No. 3—Design Charts for Open-Channel Flow (1961). $1.50.

No. 4—Design of Roadside Drainage Channels (1965). 65 cents.

Identification of Rock Types (1960). 20 cents.

Increasing the Traffic-Carrying Capability of Urban Arterial Streets: The Wisconsin Avenue Study (1962). Out of print—(Request from Federal Highway Administration).

The 1965 Interstate System Cost Estimate, House Document No. 42, 89th Cong., 1st sess. (1965). 20 cents.

Interstate System Route and Log Finder List (1963). 10 cents.

Joint Development and Multiple Use (1970). $1.50.

Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 3d ed. (1970). $3.75.

Landslide Investigations (1961). 30 cents.

Manual for Highway Severance Damage Studies (1961). $1.00.

Manual on Uniform Traffic Control Devices for Streets and Highways (1961). $2.00.

Part V only of above—Traffic Controls for Highway Construction and Maintenance Operations (1962). 25 cents.

Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems, House Document No. 354, 88th Cong. 2d sess. (1964). 45 cents.

Maximum Safe Speed for Motor Vehicles (1969). $1.00.

Modal Split—Documentation of Nine Methods for Estimating Transit Usage (1966). 70 cents.

Motor Carrier Safety Regulations (1968). 45 cents.

National Driver Register. A State Driver Records Exchange Service (1967). 25 cents.

National Highway Needs Report, H. Comm. Print 90–22 90th Cong. 2d sess. (1968). 25 cents. Supplement 10 cents.

The National System of Interstate and Defense Highways (1969). 15 cents.

Overtaking and Passing on Two-Lane Rural Highways—a Literature Review (1967). 20 cents.

Presplitting. A Controlled Blasting Technique for Rock Cuts (1966). 30 cents.

Proposed Program for Scenic Roads & Parkways (prepared for the President's Council on Recreation and Natural Beauty), 1966. $2.75.

Quality Assurance in Highway Construction. (Reprinted from PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 35, Nos. 6–11, 1969). 50 cents.

Reinforced Concrete Bridge Members—Ultimate Design (1969). 45 cents.

Reinforced Concrete Pipe Culverts—Criteria for Structural Design and Installation (1963). 30 cents.

Road-User and Personal Property Taxes on Selected Motor Vehicles (1970). 65 cents.

(Continued on reverse side)

Publications of the Federal Highway Administration—Continued

Role of Economic Studies in Urban Transportation Planning (1965). 65 cents.
The Role of Third Structure Taxes in the Highway User Tax Family (1968). $2.25.
Second Annual Highway Beauty Awards Competition (1969). 50 cents.
Specifications for Aerial Surveys and Mapping by Photogrammetrical Methods for Highways (1968). $1.25.
Standard Alphabets for Highway Signs (1966). 30 cents.
Standard Land Use Coding Manual (1965). 50 cents.
Standard Plans for Highway Bridges:
Vol. I—Concrete Superstructures (1968). $1.25.
Vol. II—Structural Steel Superstructures (1968). $1.00.
Vol. III—Timber Bridges (1969). 75 cents.
Vol. IV—Typical Continuous Bridges (1969). $1.50.
Vol. V—Typical Pedestrian Bridges (1962). $1.75.
Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (1969). $3.50.
Standard Traffic Control Signs Chart (as defined in the Manual on Uniform Traffic Control Devices for Streets and Highways). 22 x 34, 20 cents—100 for $15.00. 11 x 17, 10 cents—100 for $5.00.
Study of Airspace Utilization (1968). 75 cents.
Traffic Safety Services, Directory of National Organizations (1963). 15 cents.
Transition Curves for Highways (1940). $2.50.
Ultrasonic Testing Inspection for Butt Welds in Highway and Railway Bridges (1968). 40 cents.