Eugene Goss
COMMISSIONER OF HIGHWAYS

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT, KENTUCKY 40601

August 6, 1969

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
DIVISION OF RESEARCH
533 SOUTH LIMESTONE STREET
LEXINGTON, KENTUCKY 40508
Telephone 606-254-4475

H.3.19

MEMO TO: A. O. Neiser, State Highway Engineer
Chairman, Research Committee

SUBJECT: A Preliminary Evaluation of Mounds to Divert Wayward Vehicles away from Rigid Obstructions

A vehicle traveling 60 mph on a horizontal surface would hurtle 120 feet in the air ($V^2 = 2gh$) if the surface (pavement) turned upward in a smooth arc. Trajectory physics provides other insights relative to "ramping" upward. For instance, the ramped ends of guardrails are destined to cause an automobile to hurtle and possibly to roll if approached at 30 mph or greater. However, this is a lesser peril than being pierced by the stubbed end of the rail. Needless to say, these are fearsome situations. Moreover, crash tests have shown that a head- on collision at 30 mph with a rigid wall is likely to be fatal or cause serious injury. Vehicles do go awry at critical speeds -- whether because of mechanical failure or driver error. Anyone confronting such a situation has better chances of surviving it without suffering injury or damage if the vehicle remains upright on its wheels and does not encounter rigid obstructions. Whereas the wide median on some modern roadways provides a recovery zone or an arresting field, guardrails (fenders) deflect vehicles away from critically-steep off-road slopes. Contact with the guardrail is destined to at least damage the vehicle, but this is again considered to be a lesser peril than an excursion into unfit terrain.

Bridge piers in the median constitute an obstruction in an area which may be considered otherwise to be fit terrain. Shaped and contoured earth surrounding such obstructions presented an inviting alternative to fender-type guardrails. Shaping the mounds to permit traverse without upsetting the vehicle and also to divert the vehicle away from the pier and opposing traffic poses a design challenge.

The report submitted herewith relates the evolution of first-generation designs and presents preliminary field-tests for critical review and evaluation. At this stage, it seems that further evaluation is warranted -- and is being sought. The findings thus far are encouraging.

In conjunction with the field tests, 16 mm movies were made of each excursion. These films have been titled and duplicated and are available as a supplement to this report.

Upon viewing the raw film at an early showing, Mr. Vansant suggested that the nose of the mound be warped off-center to present a greater rightward deflecting surface and to lessen any tendency for the vehicles mounting the ridge to desend on the wrong side. This "styling" and other "warping" of the surface of the mound are illustrated with a drawing in the report.

Respectfully submitted,

Jas. H. Havens
Director of Research

JHH:slw

Attachments

cc's: Research Committee

Assistant State Highway Engineer, Research and Development
Assistant State Highway Engineer, Planning and Programming
Assistant State Highway Engineer, Pre-Construction
Assistant State Highway Engineer, Construction
Assistant State Highway Engineer, Operations
Assistant State Highway Engineer, Staff Services
Assistant Pre-Construction Engineer
Assistant Operations Engineer
Executive Director, Office of Computer Services
Executive Director, Office of Equipment and Properties
Director, Division of Bridges
Director, Division of Construction
Director, Division of Design
Director, Division of Maintenance
Director, Division of Materials
Director, Division of Photogrammetry
Director, Division of Planning
Director, Division of Research
Director, Division of Right of Way
Director, Division of Roadside Development
Director, Division of Rural Roads
Director, Division of Traffic
Division Engineer, Bureau of Public Roads
Chairman, Department of Civil Engineering, University of Kentucky
Associate Dean for Continuing Education, College of Engineering
All District Engineers

Research Report

A PRELIMINARY EVALUATION OF MOUNDS TO DIVERT WAYWARD VEHICLES AWAY FROM RIGID OBSTRUCTIONS

by

G. R. Garner
Assistant Research Engineer

and

J. B. Venable
Assistant Research Engineer

Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

August 1969

INTRODUCTION

In the summer of 1965, the first fatality report involving an interstate median bridge pier in Kentucky caused concern among state and national officials for the safety of motorists who perchance or otherwise enter upon a collision course toward an unprotected bridge pier. A consensus of opinion seemed to indicate that some form of attenuation or deflection device was necessary.

Early innovations employed various short guardrail configurations to deflect wayward vehicles from the piers. The use of small, short sections has since evolved until present methods include surrounding the bridge pier with several hundred feet of guardrail, including ramped-end treatment (see Figure 1). The use of guardrail has not been questioned from the standpoint of safety design, yet some effort has been applied by Kentucky and other states to finding an alternative approach.

From these efforts, the use of mounds to decelerate and deflect vehicles originated. It was thought that this design concept was consistent with current safety developments as well as being an economical treatment of the problem, since most of the work involved in constructing the mound can be done during grade and drain construction using natural materials available on location. These mounds have since been constructed on certain interstate projects and on all bridge locations of the Jackson Purchase (51.4 miles) and Pennyrile (56.6 miles) Parkways in Kentucky. Having found no records of accidents involving these mounds in the interim, there has been no substantial means of evaluating the effectiveness of this innovation in preventing or reducing the severity of collisions with bridge piers. Consequently, it was decided that low speed excursions over a mound might provide a basis for evaluation.

The Division of Research made a series of driver-controlled traverses at low speeds on a typical site constructed on a 60-foot median. The purpose of this report is to summarize the results obtained from these initial, low-speed tests and, in so doing, attempt to make some determination of the reliability of this particular type of earthwork. It is anticipated that these low-speed tests will be supplemented eventually by testing at higher speeds, using some form of remote guidance system in place of the human driver. Also, it must be emphasized that conclusions drawn from this report apply only to low-speed encroachments. Additional effects which may be encountered during high-speed testing can only be hypothesized at this time.

HISTORY AND DESIGN OF THE MOUND

The basic postulate supporting the use of these mounds is that they will absorb energy or slow down an encroaching vehicle while deflecting it away from the bridge pier. A "soft" encounter or a retarding digression from the roadway is presumed to be less damaging and less injurious than impacting a rigid barrier -- even at a glancing angle. The change in potential energy, due to "ramping up", is relatively insignificant; consequently, the principal retarding factor arises from ploughing into the material and rolling friction -- that is, work done on the mound at the expense of the kinetic energy of the vehicle. Foremost in its design is an attempt to postpone or defer any impact or encounter which precludes all reasonable chance of survival or escape from injury. Moreover, it seems compelling to afford all time and opportunities possible for the driver of the vehicle to recover control -- hopefully without imperiling others, but no doubt at some risk of reentering the traffic stream -- even so, the possibility of evasive action by on-coming traffic seems admissible.

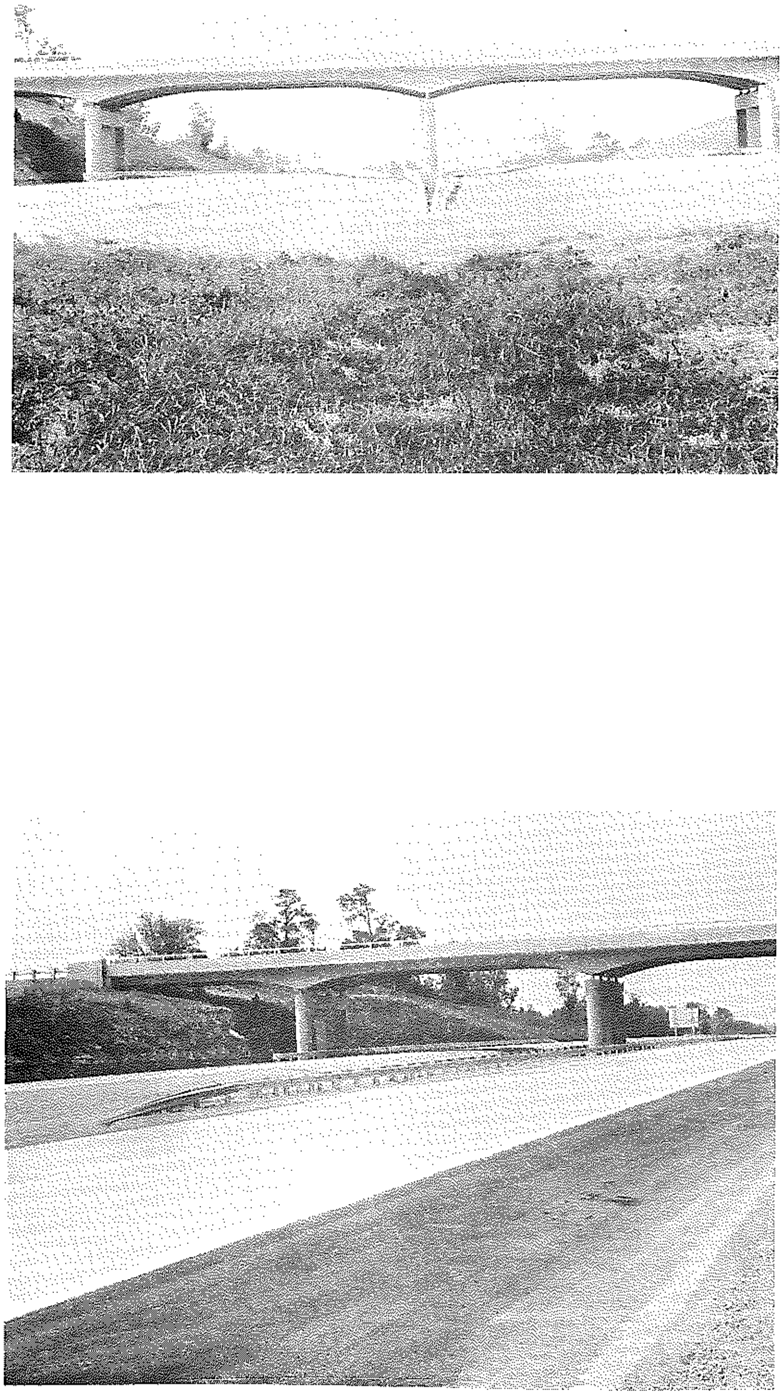


Figure 1. Typical Guardrail treatment at median bridge piers.

Figures 2 and 3 show pictures of the oblong mound design. Significant changes made in the development of this basic design are summarized chronologically in Table 1. These changes have been concerned with the length, the snub-nose effect, and the use of guardposts at the nose. The original design length was approximately 100 feet in both directions. This has since been lengthened to 250 feet in both directions. Some officials in the Department have recommended that the length be further increased to 500 feet in both directions. The nose has been somewhat modified from the original design to allow for a smoother transition between the median slope and the ramped ends. Also, the seven guardposts placed longitudinally on three-foot centers down the center of the nose slope have been eliminated.

The bulk of the mound consists of natural, available material; the top two feet are a lightly-compacted topsoil. The top foot in the immediate area between the bridge piers consists of crushed stone (shown in Figure 3). The ideal cover or mantle for the berm would be a material which would rut deeply under the wheels and(or) splash when impacted at high speed. Although sand or mucky clay would suffice in some respects, one would be subject to erosion and the other would harden when dried. A four-inch layer of wood-chip mulch -- with live shrubs -- offered a compromise scheme. This wood-chip treatment, along with the pattern of plantings such as flowering quince, is thought to enhance the energy-absorbing characteristics of the installation.

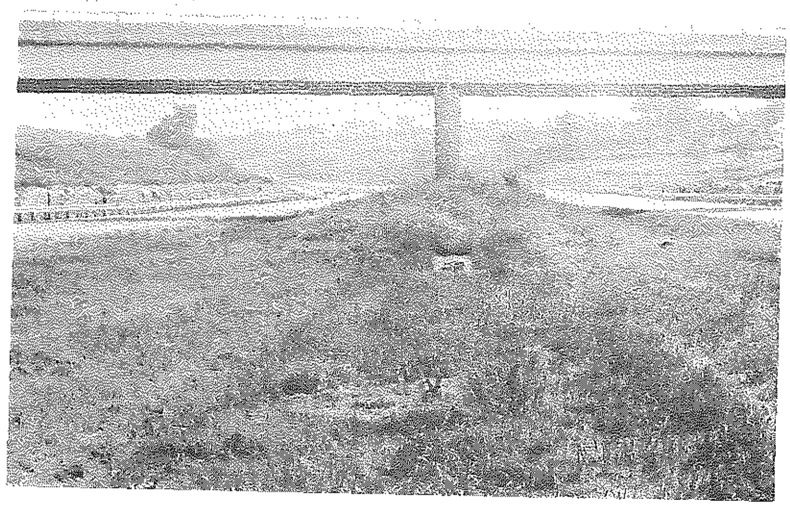
The standards used by the Department provide two designs, i.e., for 40-foot and 60-foot medians. The standard drawings in Appendix A depict the basic differences. Of paramount importance and of seemingly questionable design is the 2:1 side slope specified for 40-foot medians. A structure of this type is shown in Figure 3. It has been suggested that this 2:1 side slope is too steep and too close to the shoulder. At this stage, tests have not been conducted on this type of installation, but the implications are discussed later in this report with respect to 3:1 side slopes.

Other states have employed similar contrivances and seem to indicate a favorable degree of acceptance by both highway officials and the public. In Ohio, the mound in the median is virtually continuous for most sections where it is employed. West Virginia claims a similar design. Maryland has mounds in the median which extend 500 feet in both directions from bridge piers; Illinois has experimented with mounds of earth on either side of the approach near the pier but not around the pier itself. The degree of usage of the mound concept is not known at this time, but the interest shown by Kentucky and other states would warrant a thorough testing of earth designs at high speeds.

TEST PROCEDURES

A final decision was made by Department officials in May 1969 to test an installation on I 71 between Louisville and Carrollton. This section was scheduled to open early in July. A June test date was chosen to allow testing to be done in the absence of through traffic. A test site was chosen about six miles east of LaGrange in Henry County, where KY 146 passes over I 71. This site was in a finished condition except for the wood-chip treatment and shrubbery. It was decided that tests should not be run until the four inches of wood chips were applied. Wood chips were then placed by District 4 maintenance forces, and the site was declared ready for testing (see Figure 4).

The test vehicle chosen was a 1962 Ford Galaxie. This vehicle was a skid test car used by the Division of Research and was scheduled for replacement in the fall of 1969. This vehicle weighs approximately 4000 pounds and had its center of gravity 22 inches above pavement level. HRB procedures *(3)* for conducting crash tests on guardrails call for a test vehicle weighing 4000±200 pounds and having a center of gravity 21 inches above pavement. It was concluded, therefore, that any determinations made using this vehicle would be compatible with results using other



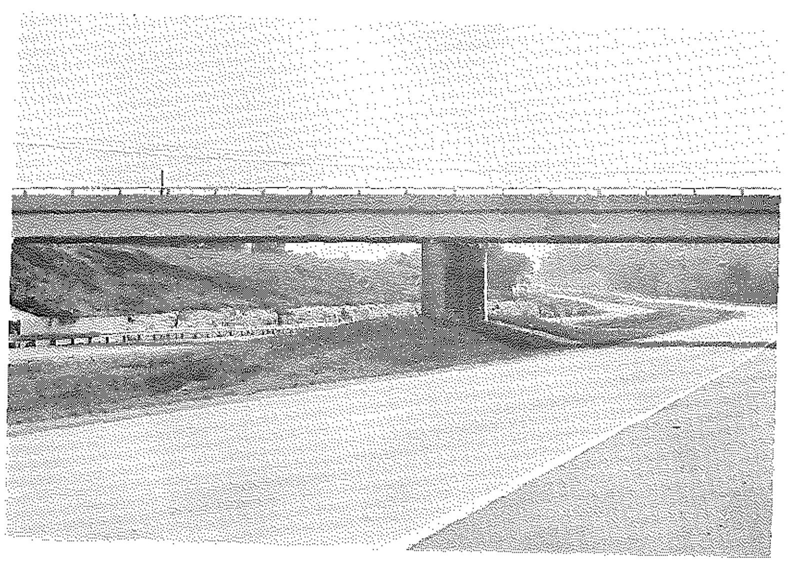


Figure 2. Typical mound on 60-foot median sections.

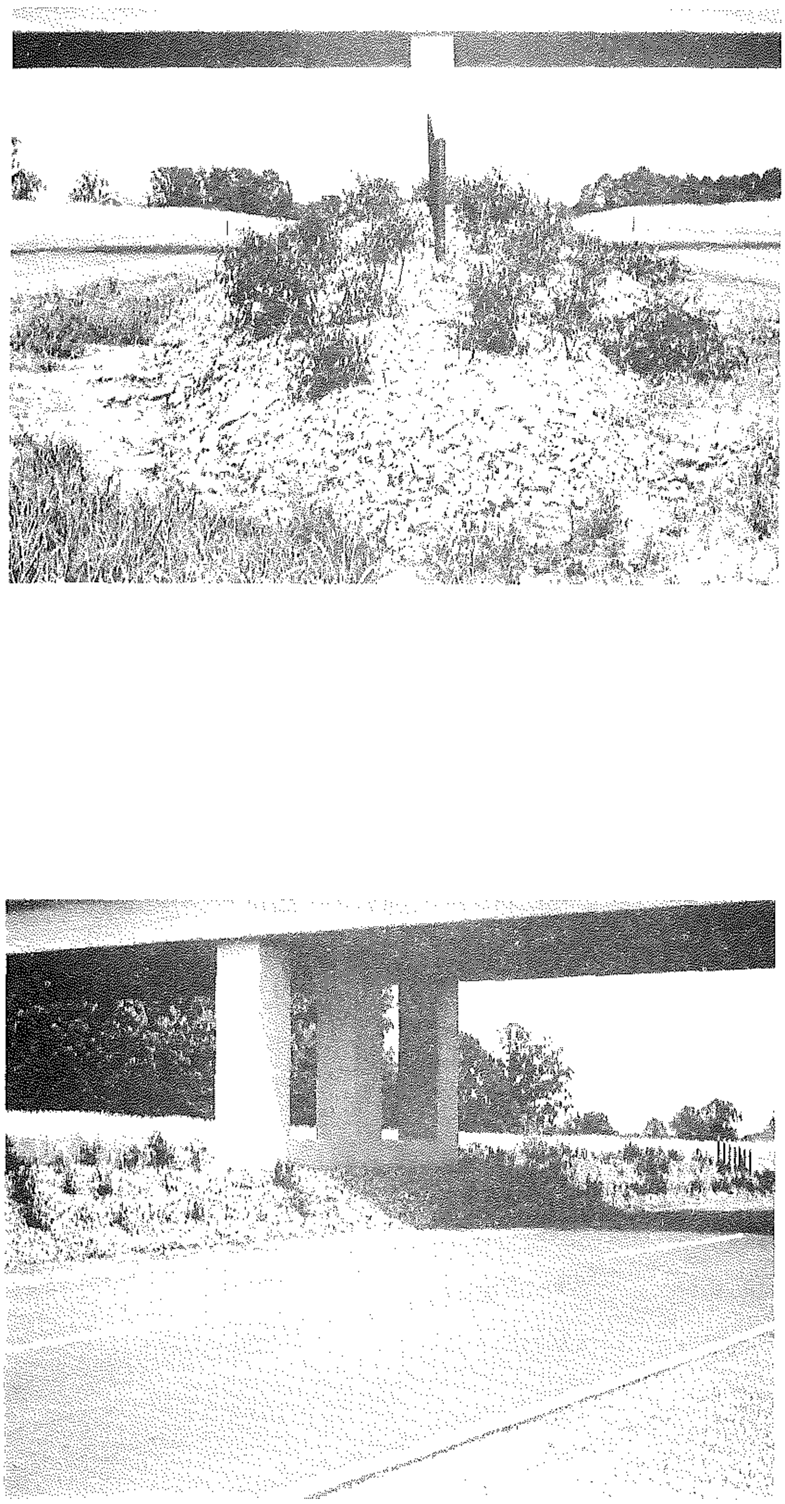


Figure 3. Typical mound on 40-foot median sections.

TABLE 1: CHRONOLOGICAL LISTING OF DESIGN REVISIONS

STANDARD DRAWING NO. (S)	DATE EFFECTIVE	DESIGN REVISIONS
17.23, 17.24, 17.25	7-20-66	Original berm design
17.23a	1-20-67	Median box inlet eliminated in cut sections
17.23b, 17.24a, 17.25a	8-5-67	Nose slope made less blunt on 60′ median berm; 7 guardposts on nose of berm deleted
17.23c, 17.24b, 17.25b	1-2-68	Berm length increased from 100′ (original design) to approximately 250′ on either side of centerline of median pier
17.23c, 17.24b, 17.25b	4-18-69	Voided and deleted

NOTE: Standard Drawings 17.23c, 17.24b, and 17.25b are shown in Appendix A standard test vehicles.

The actual testing procedure was to consist of as many runs at selected encroachment angles as would be safe or until the vehicle could no longer function properly. In attempting to set up some reliable testing procedures for these initial, low-speed tests, it was first necessary to determine some realistic encroachment angles and a maximum safe speed for each run. The test encroachment angles chosen by Research personnel were 7.5, 15, and 22 degrees. These angles were chosen in consideration of HRB recommended testing procedures for guardrails and guardposts *(3)* and encroachment angles determined from median studies by Hutchinson *(4)* and others *(1,2,7)*. HRB recommendations suggest that approach angles of 7 and 25 degrees be used. Hutchinson found for median sections in Illinois that the average angle was 7.5 degrees and that 95 percent of the encroachment angles measured were less than 22 degrees. Other agencies have conducted crash tests of varying nature at or near these angles -- to evaluate guardrails and other protective devices. In addition to these encroachment angles, it was deemed worthwhile to conduct a number of head-on runs. Since, on the average, vehicles entering the median journey about 300 feet *(4)* it seemed probable that a vehicle could approach the median pier head-on.

Having reviewed literature *(5,6)* concerning the evident danger involved while conducting tests using human-driven vehicles, it was decided that no manned runs should be conducted at speeds in excess of 30 miles per hour. The speed of the test vehicle was to proceed from very slow speeds (in five-mile-per-hour increments) until it was deemed unsafe to continue. At no time was the test procedure to be in any way hazardous or unsafe for the driver. After each run, a decision was to be made by the driver and the Director of Research as to the nature and speed of the next run.

Guidelines were laid out on the pavement with lime dust for each encroachment angle (see Figure 4). The wood chips were raked back onto the mound after each run. A movie camera was positioned such that proper photographic record of each run could be made. The movies were supplemented by slides and black-and-white prints taken from various angles.

RESULTS AND DISCUSSION

Obviously, an accurate or detailed analysis of the attenuation characteristics of this particular earth structure cannot be made as the result of this first series of low-speed tests. Yet, there does seem to be some pertinent trends or developments which suggest that further testing is needed.

Table 2 illustrates the testing sequence chosen by Research personnel. At each encroachment angle, runs were made at speeds ranging from five miles per hour to 25 miles per hour. Generally speaking, as the speed was increased, the test vehicle went higher up on the mound and travelled further before descending. An increase in the encroachment angle also caused the test vehicle to climb higher. As the speed was increased, the reentry angle became more shallow. Appendix B contains sequential pictures of each test run.

The first angle of encroachment used for testing purposes was 7.5 degrees. The first two runs at five and ten miles per hour were rather inconclusive, but the 15-mile-per-hour run showed the test vehicle beginning to dig in the berm slightly and to slide obliquely across the slope. Next, a more acute 15-degree encroachment angle was attempted. This time, at a speed of ten miles per hour, the test vehicle began to dig slightly and to slide obliquely along the slope as it lost forward momentum. At 15 miles per hour and 15 degrees, the vehicle began to plough into the bank more distinctly -- as was evidenced by the wood chips thrown up by the front bumper of the vehicle. Also, at this speed the vehicle went up to the top of the berm before descending in a sweeping arc. It was concluded at the end of this run that the test vehicle would probably collide with the pier at a speed of 20-25 miles per hour at this angle.

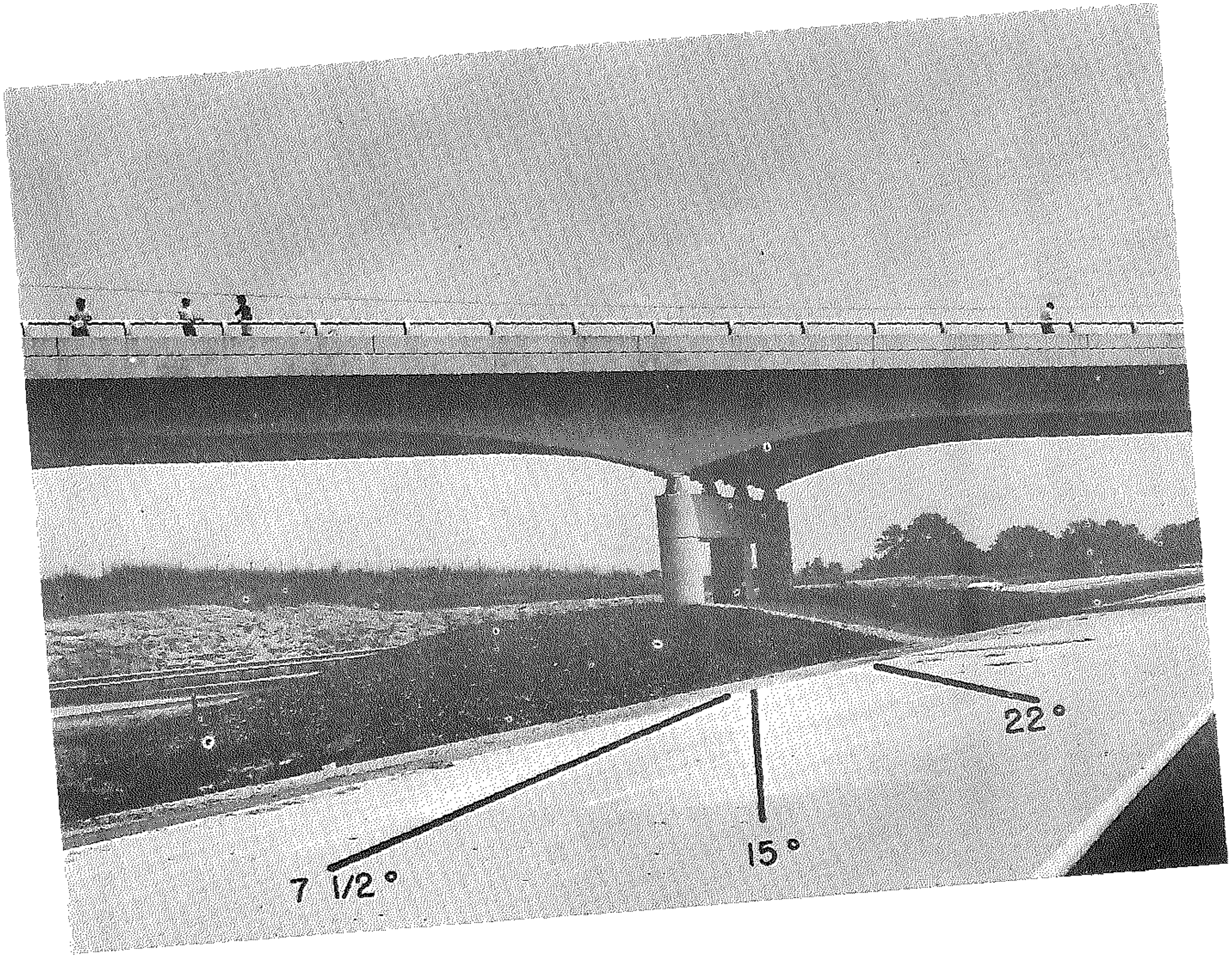


Figure 4. Site chosen for tests.

TABLE 2

SEQUENCE OF TEST RUNS ON MOUND

Speed (mph)	Angle of Encroachment (Degrees)
5	7.5
10	7.5
15	7.5
5	15
10	15
15	15
20	7.5
2@ 10	Head-On
15	Head-On
2@ 20	Head-On
25	Head-On
10	22
15	22

Since the adverse effects of the 15-mile-per-hour test run at 7.5 degrees were not as pronounced as those at 15 degrees, it was decided to make another run at the 7.5-degree encroachment angle and at a speed of 20 miles per hour. Again, the vehicle dug in the wood-chip layer and slid obliquely to the right. At this angle it was surmised that the pier would be hit if the speed were 25-30 miles per hour.

From accident reports involving automobiles colliding with bridge piers and from studies by Hutchinson *(4)* it was determined that vehicles are in the median for several hundred feet during their recovery period while involved in a median encroachment accident. In order to evaluate what effect the errant driver might experience having encroached on the median and attempting to recover, a number of "head-on" longitudinal test runs were made. At ten miles per hour, the test vehicle was stopped by the time it had reached the summit of the ramped end. At 20 and 25 miles per hour, the vehicle began to dig into the berm, and considerable bouncing was observed when the vehicle reached the top of the up-slope. In fact, the motion pictures of the tests indicate that the test vehicle was actually "airborne" at a speed of 25 miles per hour. When the test driver attempted to steer, the vehicle then descended in a sliding arc and ended up back on the roadway. It was also noted that the front bumper of the test vehicle dug into the shoulder of the roadway during the descent. After the run at 25 miles per hour, it was decided that further speed increases at a head-on approach were not advisable.

The driver noted a lack of steering control when on the mound; control faded with increasing speed. It was felt that this lack of steering control was caused largely by the wood mulch. It was also noted that the energy absorbing characteristics of the wood mulch were negligible, even though the mulch at the test site was twice the four-inch depth specified in the design. Further use of the wood mulch is therefore to be questioned.

Test runs were then made at an angle of 22 degrees and at speeds of 10 and 15 miles per hour. On both runs the test vehicle dug into the slope and slid obliquely to the right. With this steeper encroachment angle, the chances of hitting the pier at 20-25-mile-per-hour speeds seemed to be much greater. However, there is some physical improbability of a high-speed vehicle achieving a high angle of approach *(4)* . The possibility remains that, at some angle and speed and point of approach, a vehicle may impact the pier. A mathematical analysis indicates that, at approach angles of 7.5, 15, and 22 degrees and at approach points 92, 46, and 33 feet from the pier, respectively, such a collision would occur. As the approach angle is decreased, the probability of collision is decreased because the deflecting characteristics of the mound are more likely to be effective.

A theoretical analysis also indicated that a vehicle approaching a short, 100-foot long mound head-on at 70 miles per hour would hit the bridge pier while still "airborne". This hypothesis was somewhat validated by the head-on run at 25 miles per hour, during which the vehicle did become airborne. Sufficient justification can here be found to lengthen the mound to 500-feet in both directions from the bridge pier. Also the mound nose should be flattened and warped off-center to present a greater rightward deflecting surface and to lessen the tendency for vehicles to become airborne and(or) mount the ridge and descend on the wrong side. To further maximize the deflecting characteristics of the mound, it is suggested that the mound have an increasingly steeper slope near the piers in order to make it increasingly difficult for a vehicle to maintain a course toward the pier. These design improvements are illustrated in Figure 5.

SUMMARY

The findings of this report indicate that, since these tests were preliminary in nature, a more extensive testing program should be undertaken.

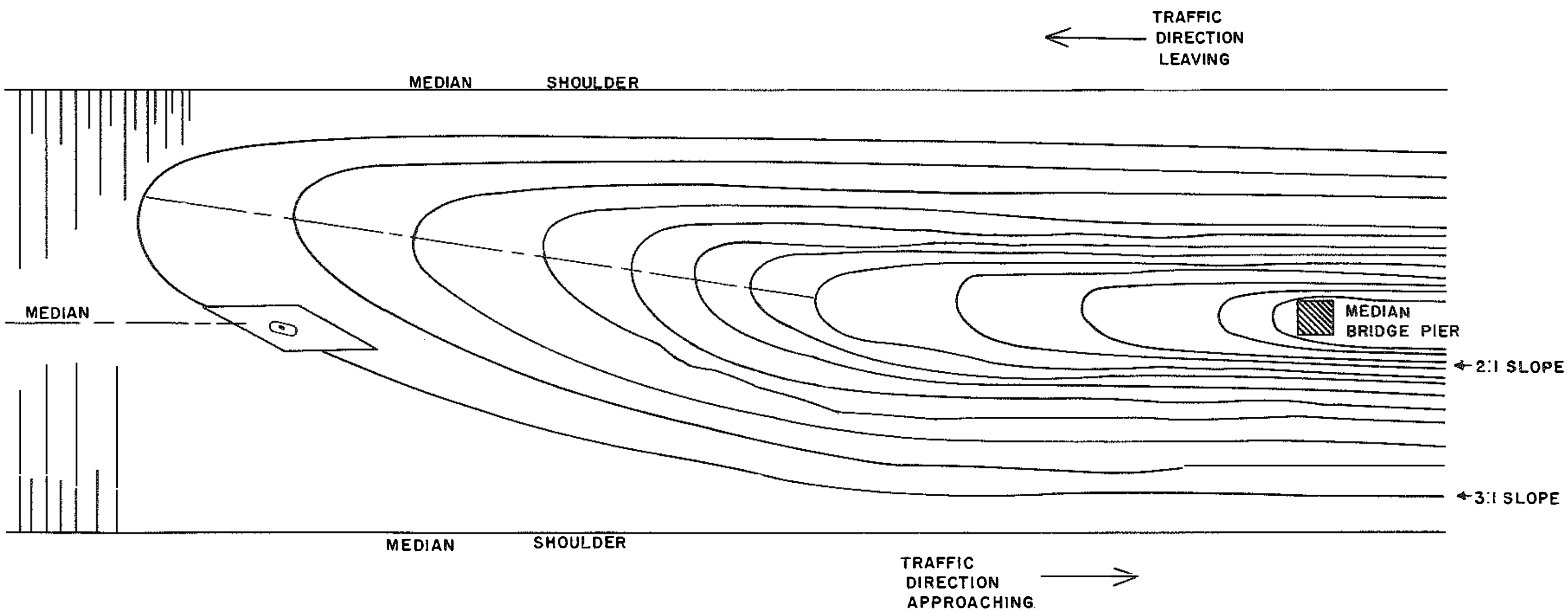


Figure 5. Proposed warped nose and variable side slopes for mound.

In addition, the following improvements in mound design are justified:

1. The mound should be lengthened to 500 feet in both directions from the bridge piers.
2. The mound nose should be warped off-center.
3. The transition from the median to the mound should be made "smoother".
4. The mound should have steeper slopes around the bridge pier (i.e. transition from 3:1 to 2:1 on the side slopes and at the same time increasing the slope of the top of the mound as illustrated in Figure 5).
5. The wood mulch should probably be deleted.

REFERENCES

1. Beaton, J. L., Nordlin, E. F., Field, R. N., *Dynamic Tests of Corrugated Metal Beam Guardrail,* **Record No. 174,** HRB, 1967.

2. Graham, M. D., Burnett, W. C., Gibson, J. L., *New Highway Barriers: The Practical Application of Theoretical Design* **Record No. 174,** HRB, 1967.

3. Highway Research Board Committee on Guardrails and Guideposts, *Proposed Full-Scale Testing Procedures for Guardrails,* **Circular No. 482,** HRB, September 1961.

4. Hutchinson, J. W., Kennedy, T. W., *Safety Consideration in Median Design* **Record No. 162,** HRB, 1967.

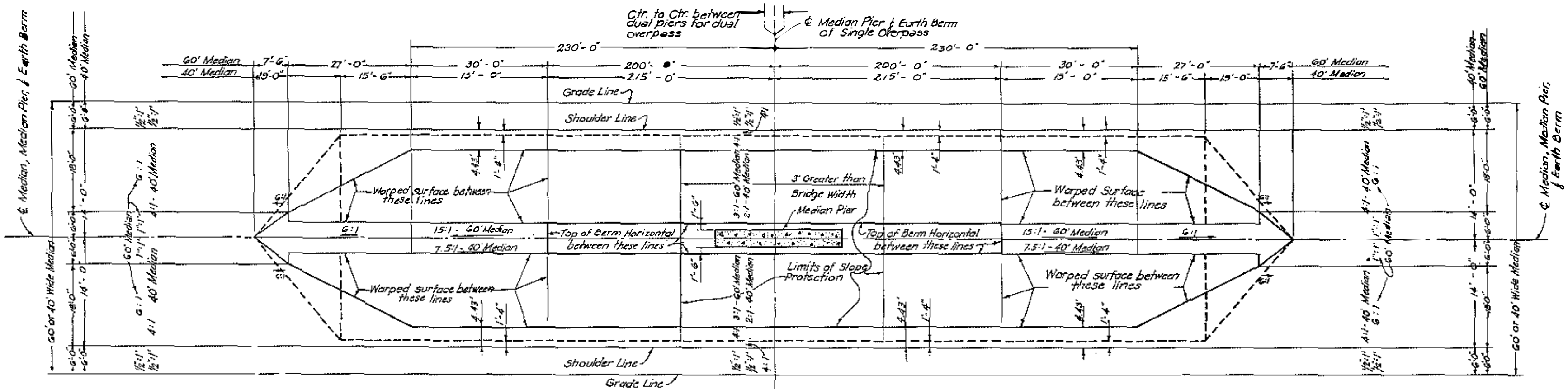
5. Severy, D. M., Mathewson, J. H., *Technical Findings from Automobile Impact Studies,* **SAE Transactions,** Vol 65, 1957.

6. Stapp, J. P., *Human Tolerance to Deceleration,* **American Journal of Surgery,** Vol 93, No. 4, 1957.

7. Stonex, K. A., *Roadside Design for Safety,* **Proceedings,** Vol 39, HRB, 1960.

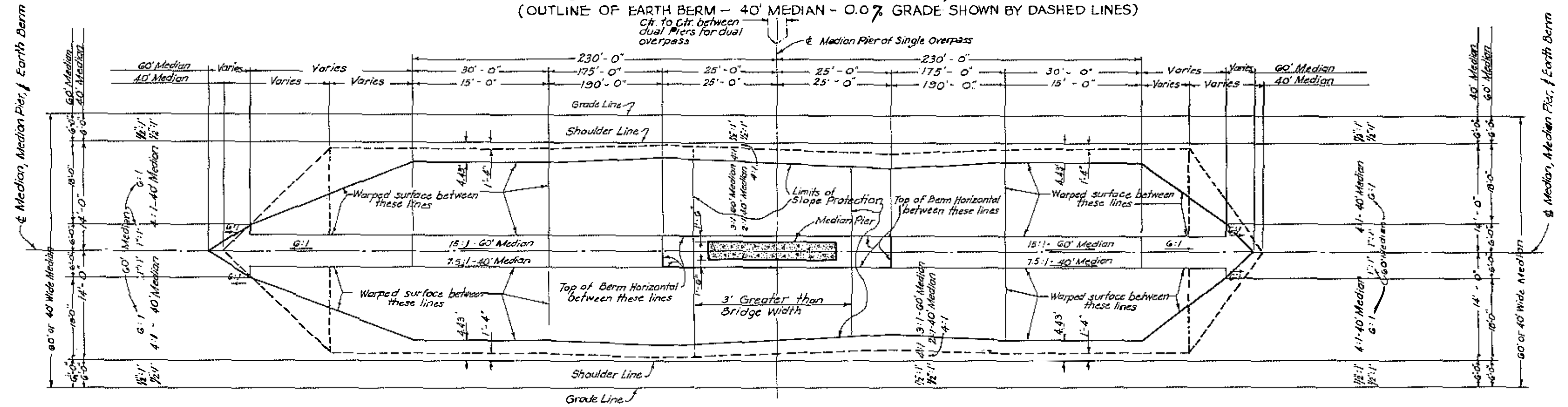
APPENDIX A

STANDARD DRAWINGS



PLAN OF EARTH BERM - 60' MEDIAN 0.0% GRADE

(OUTLINE OF EARTH BERM - 40' MEDIAN - 0.0% GRADE SHOWN BY DASHED LINES)



PLAN OF EARTH BERM - 60' MEDIAN - PLUS OR MINUS GRADE

(OUTLINE OF EARTH BERM - 40' MEDIAN - PLUS OR MINUS GRADE - SHOWN BY DASHED LINES)

NOTES: The longitudinal perforated pipe shall be constructed for the entire length of the berm at locations as indicated on Std. Dwg. No. 17.24 or 17.25 current edition.

When the earth berm restricts the normal flow of water in the median, the water shall be disposed of in the most economical manner:

(1) Single Median Box Inlet Type 2 and then away from the median.

(2) Through the berm with Single Median Box Inlet Type 2 or Median Box Type 3 on the inlet and through 15" pipe to a Median Box Type 3 at the outlet.

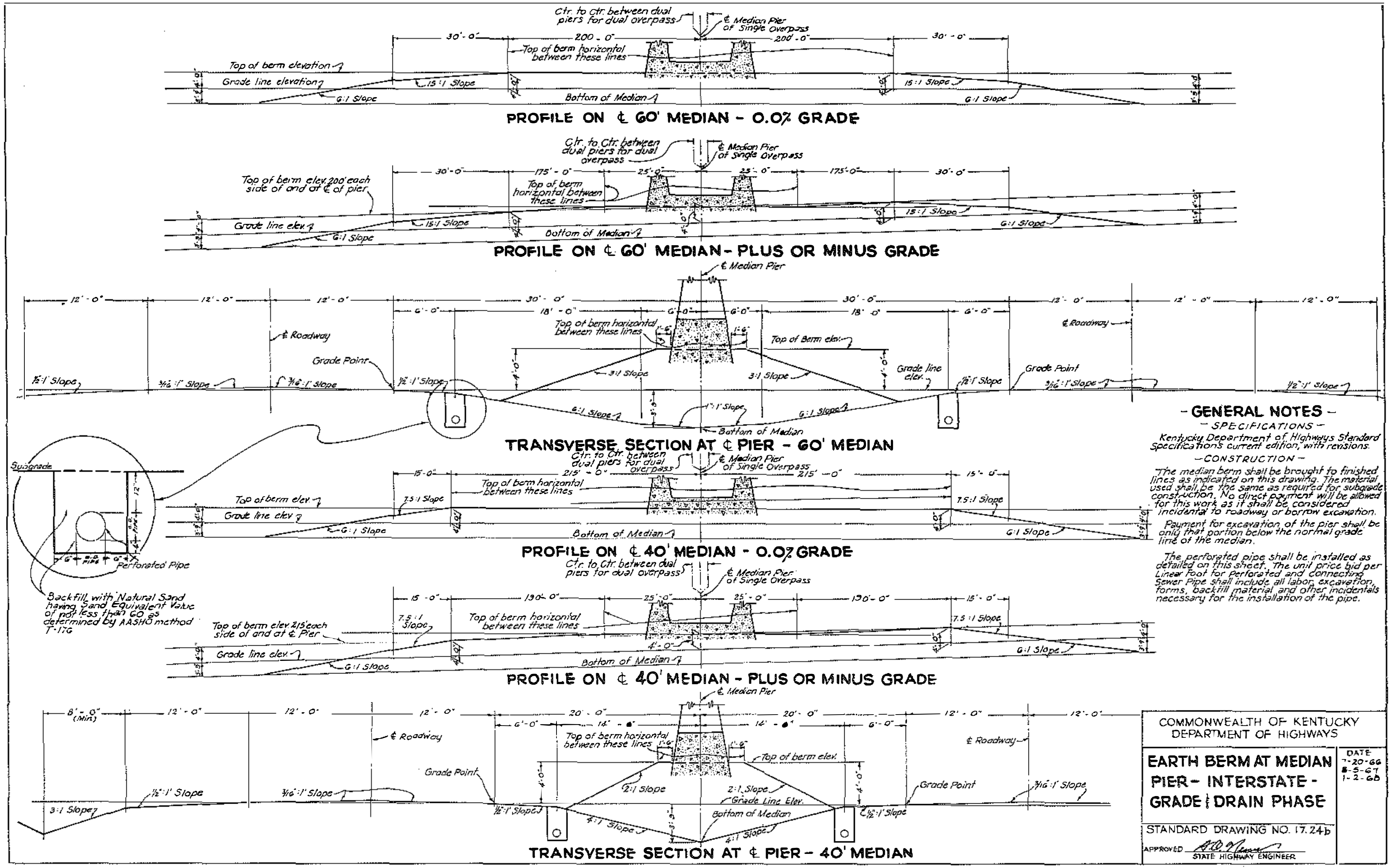
COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

PLAN OF EARTH BERM AT MEDIAN PIER - 40' & 60' MEDIANS

DATE
7-20-66
1-20-67
8-5-67
1-2-68

STANDARD DRAWING NO. 17.23c

APPROVED [signature] STATE HIGHWAY ENGINEER



- GENERAL NOTES -

– SPECIFICATIONS –

Kentucky Department of Highways Standard Specifications current edition, with revisions.

– CONSTRUCTION –

The median berm shall be brought to finished lines as indicated on this drawing. The material used shall be the same as required for subgrade construction. No direct payment will be allowed for this work as it shall be considered incidental to roadway or borrow excavation.

Payment for excavation of the pier shall be only that portion below the normal grade line of the median.

The perforated pipe shall be installed as detailed on this sheet. The unit price bid per Linear Foot for Perforated and Connecting Sewer Pipe shall include all labor, excavation, forms, backfill material and other incidentals necessary for the installation of the pipe.

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

EARTH BERM AT MEDIAN PIER - INTERSTATE - GRADE & DRAIN PHASE

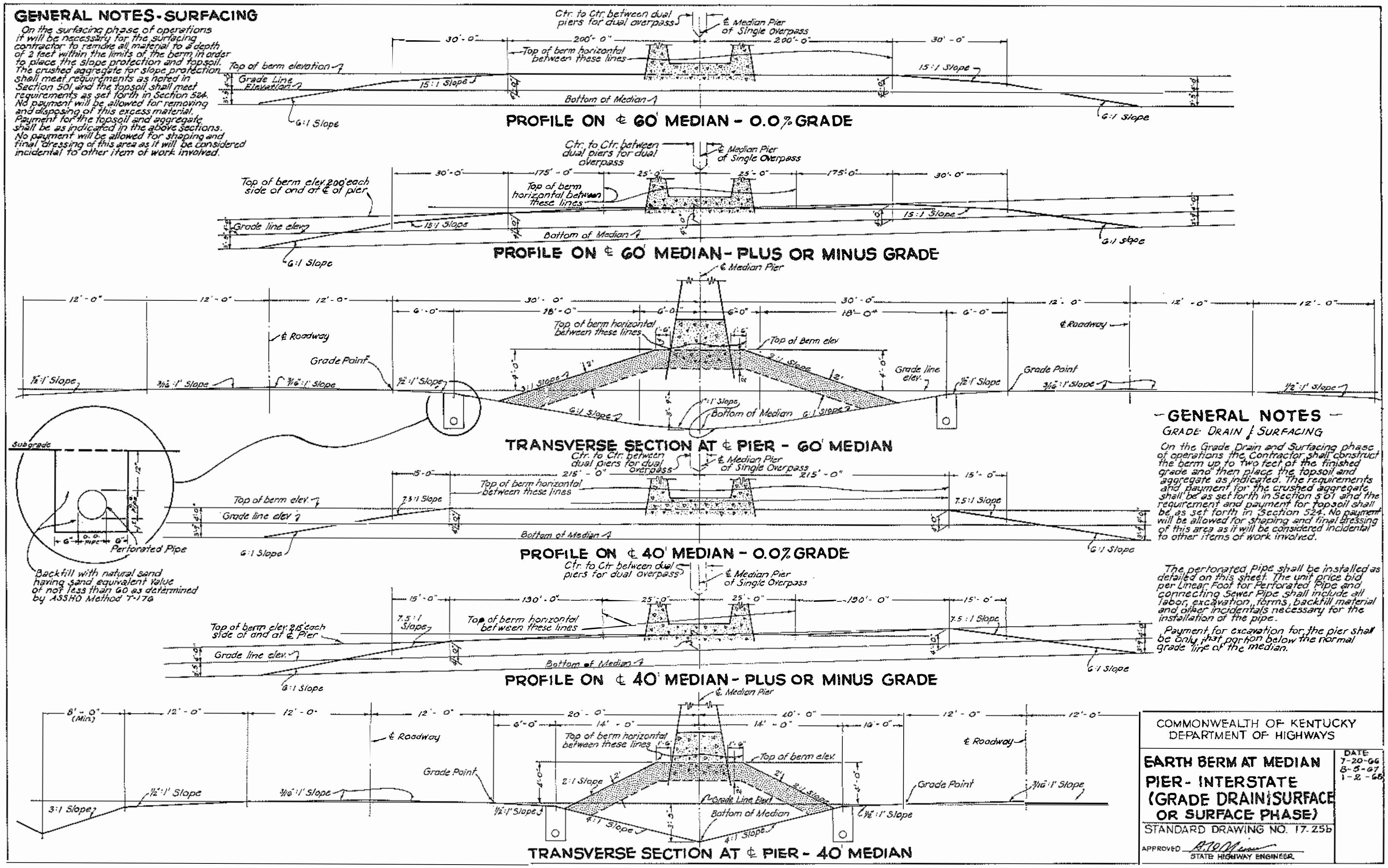
DATE
7-20-66
8-5-67
1-2-68

STANDARD DRAWING NO. 17.24b

APPROVED [signature]
STATE HIGHWAY ENGINEER

GENERAL NOTES - SURFACING

On the surfacing phase of operations it will be necessary for the surfacing contractor to remove all material to a depth of 2 feet within the limits of the berm in order to place the slope protection and topsoil. The crushed aggregate for slope protection shall meet requirements as noted in Section 501 and the topsoil shall meet requirements as set forth in Section 524. No payment will be allowed for removing and disposing of this excess material. Payment for the topsoil and aggregate shall be as indicated in the above sections. No payment will be allowed for shaping and final dressing of this area as it will be considered incidental to other item of work involved.



- GENERAL NOTES -

GRADE DRAIN & SURFACING

On the Grade Drain and Surfacing phase of operations the Contractor shall construct the berm up to two feet of the finished grade and then place the topsoil and aggregate as indicated. The requirements and payment for the crushed aggregate shall be as set forth in Section 501 and the requirement and payment for topsoil shall be as set forth in Section 524. No payment will be allowed for shaping and final dressing of this area as it will be considered incidental to other items of work involved.

The perforated pipe shall be installed as detailed on this sheet. The unit price bid per Linear Foot for Perforated Pipe and connecting Sewer Pipe shall include all labor, excavation, forms, backfill material and other incidentals necessary for the installation of the pipe.

Payment for excavation for the pier shall be only that portion below the normal grade line of the median.

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

EARTH BERM AT MEDIAN PIER - INTERSTATE (GRADE DRAIN & SURFACE OR SURFACE PHASE)

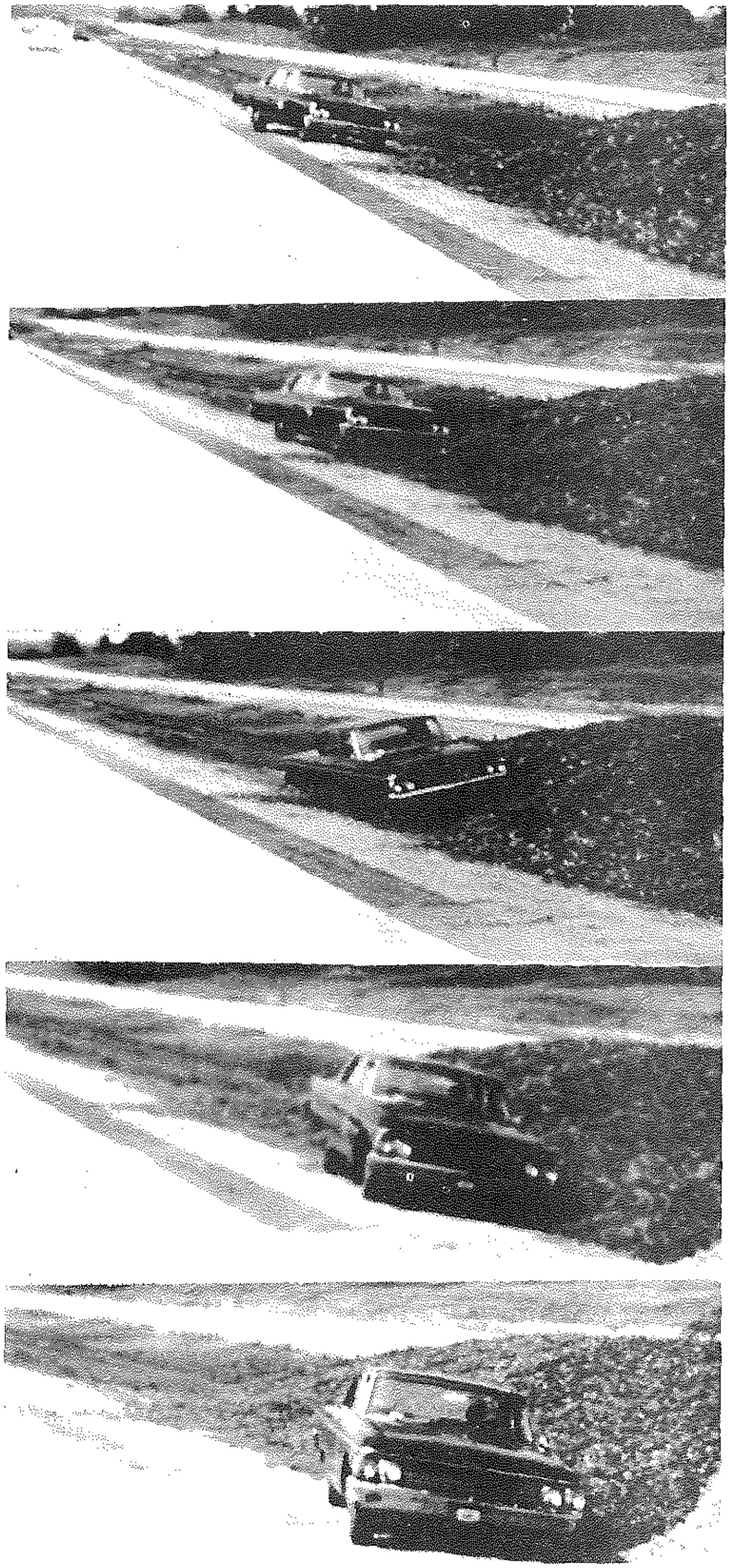
DATE 7-20-66, 8-5-67, 1-2-68

STANDARD DRAWING NO. 17.25b

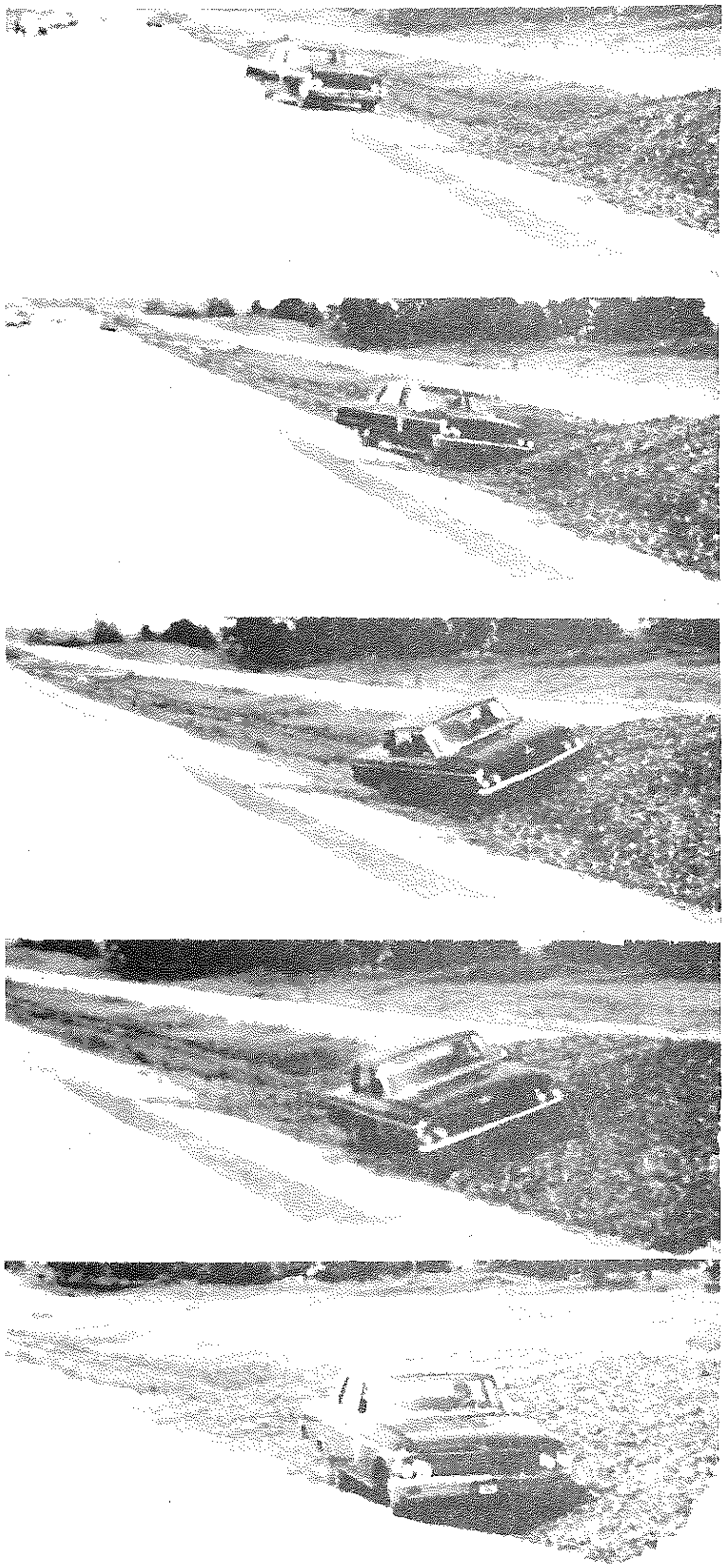
APPROVED [signature] STATE HIGHWAY ENGINEER

APPENDIX B

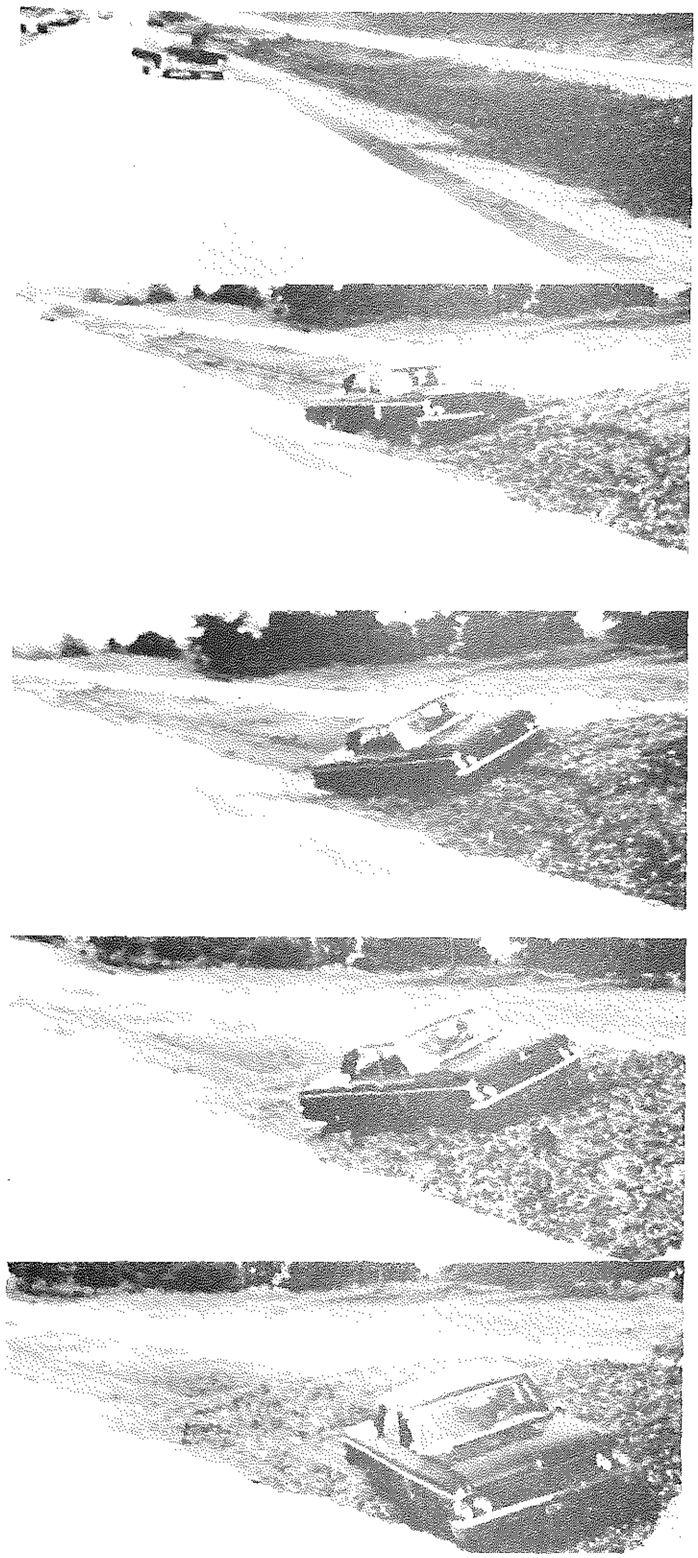
SEQUENCE PICTURES OF TEST RUNS



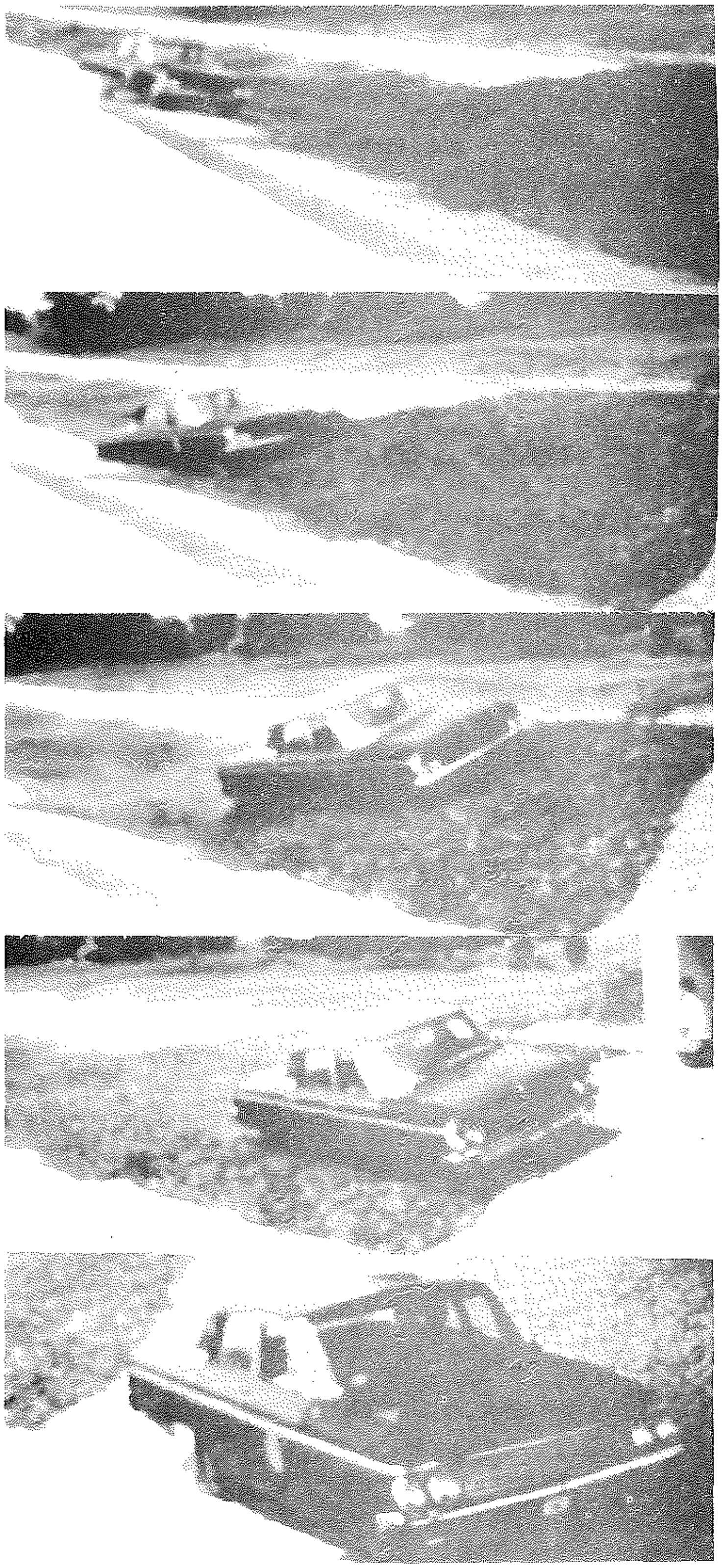
Encroachment Angle: 7 1/2°
Vehicle Speed: 5 MPH



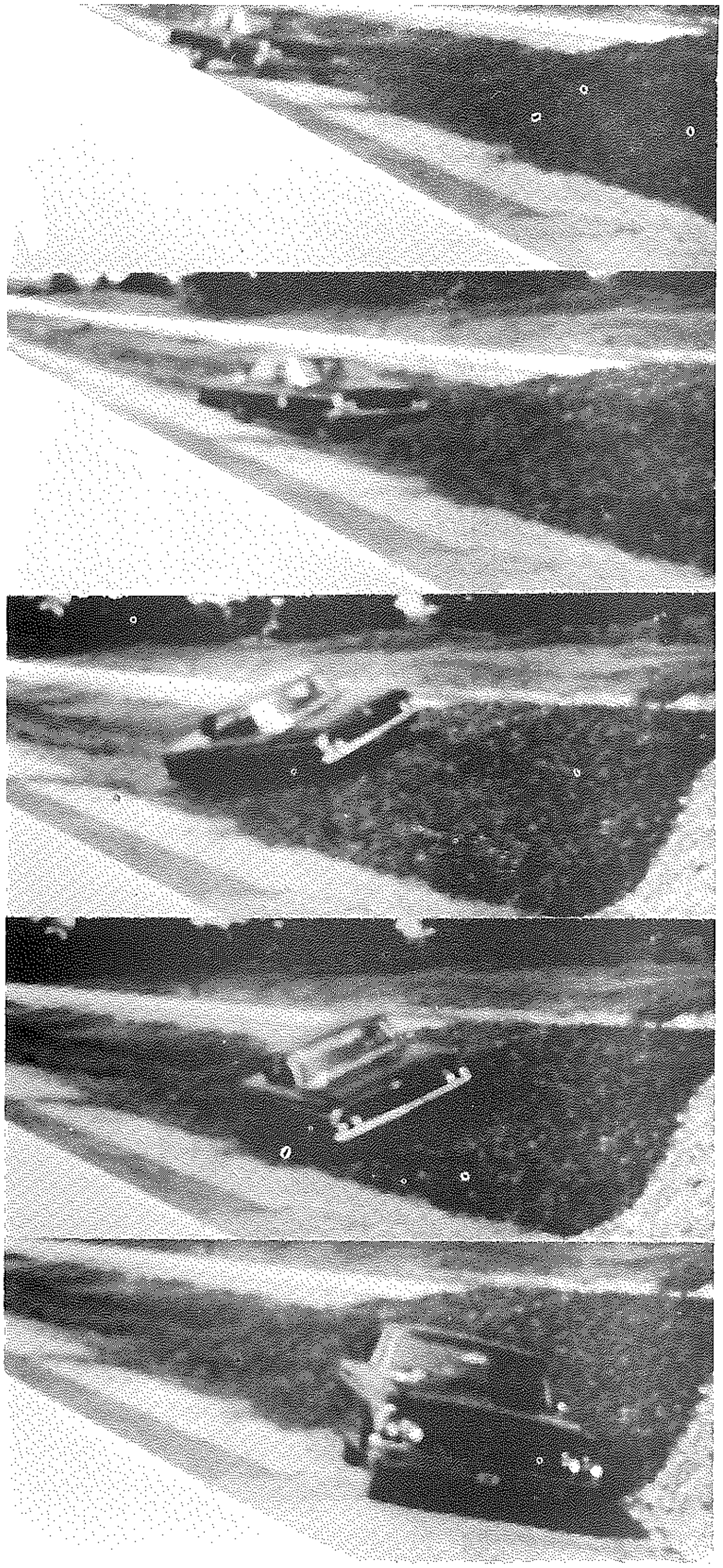
Encroachment Angle: 7 1/2°
Vehicle Speed: 10 MPH



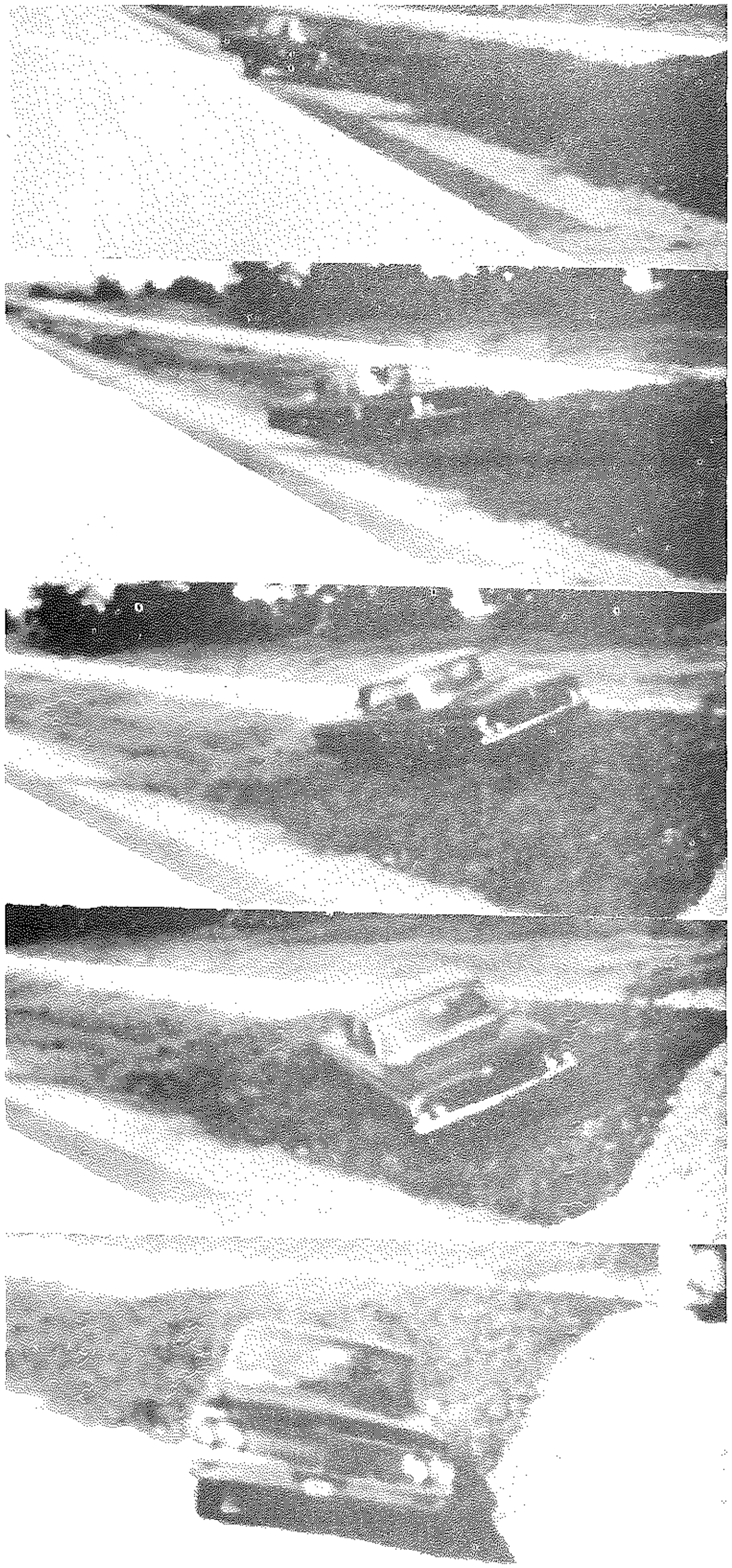
Encroachment Angle: 7 1/2°
Vehicle Speed: 15 MPH



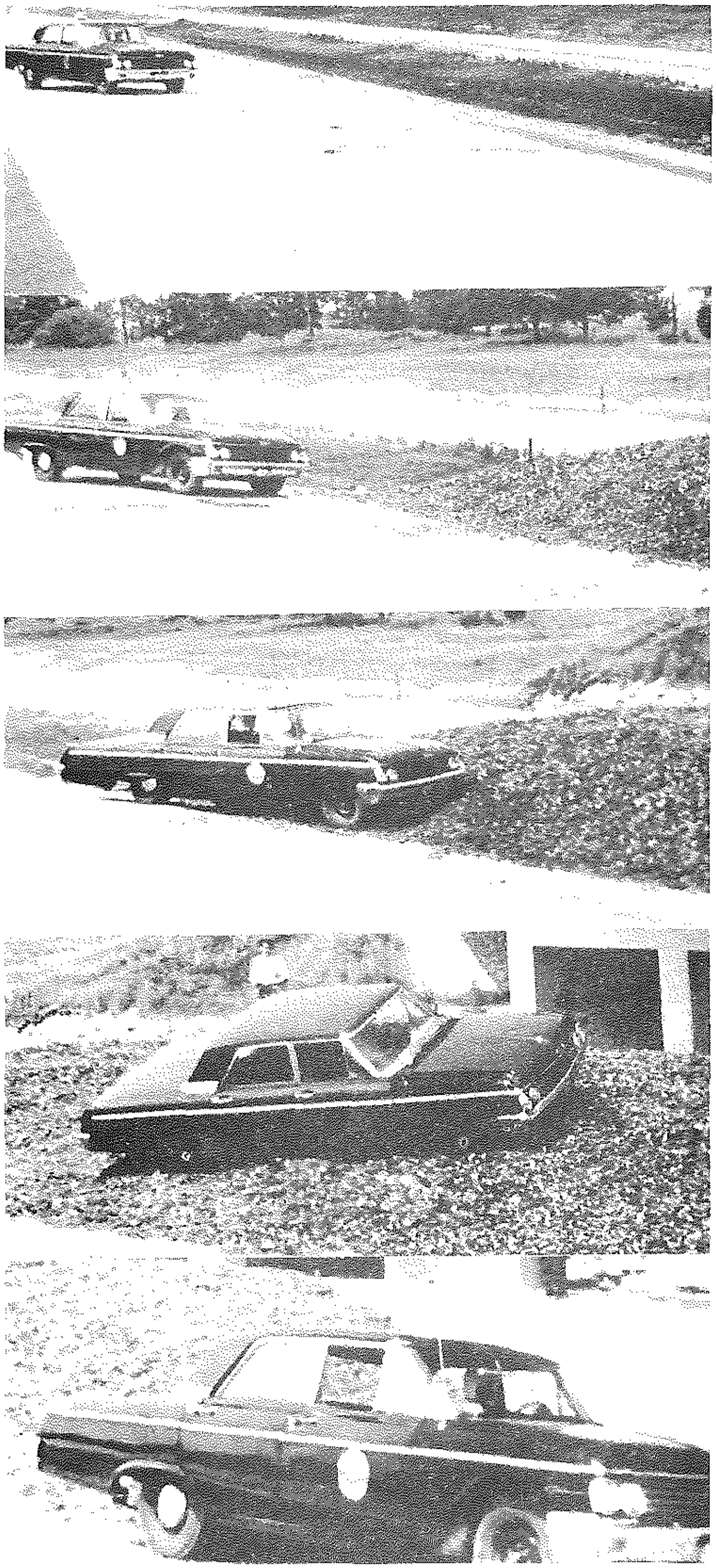
Encroachment Angle: 7 1/2°
Vehicle Speed: 20 MPH



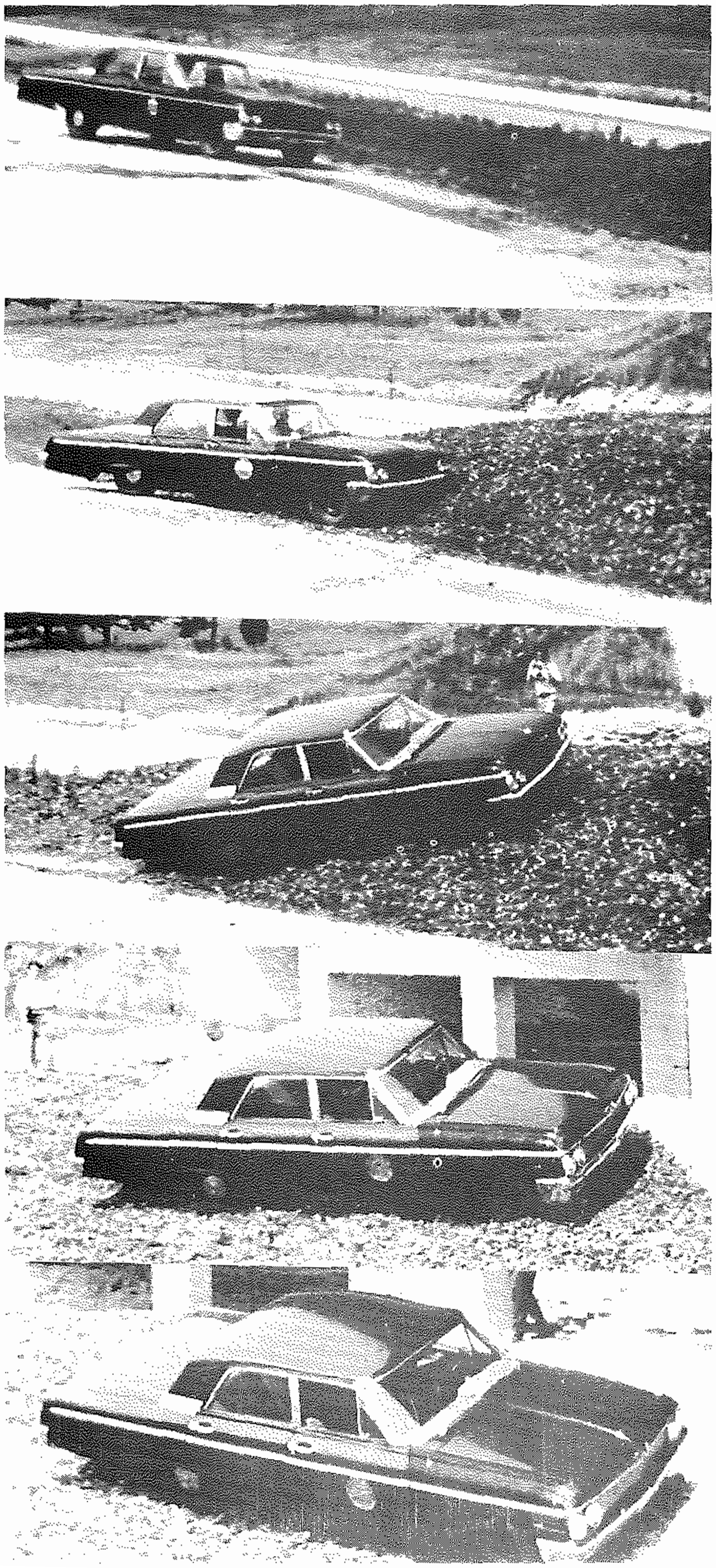
Encroachment Angle: 15°
Vehicle Speed: 10 MPH



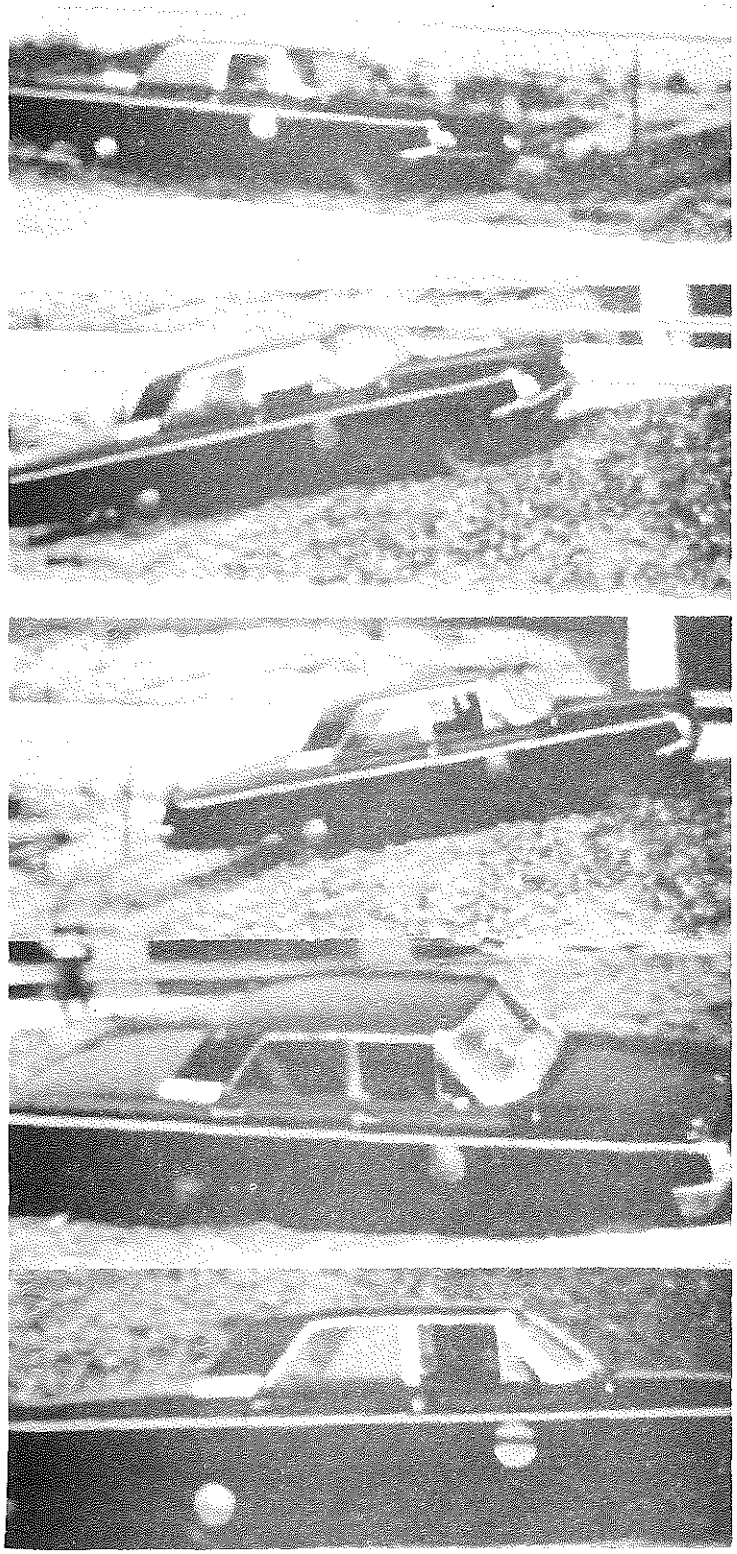
Encroachment Angle: 15°
Vehicle Speed: 15 MPH



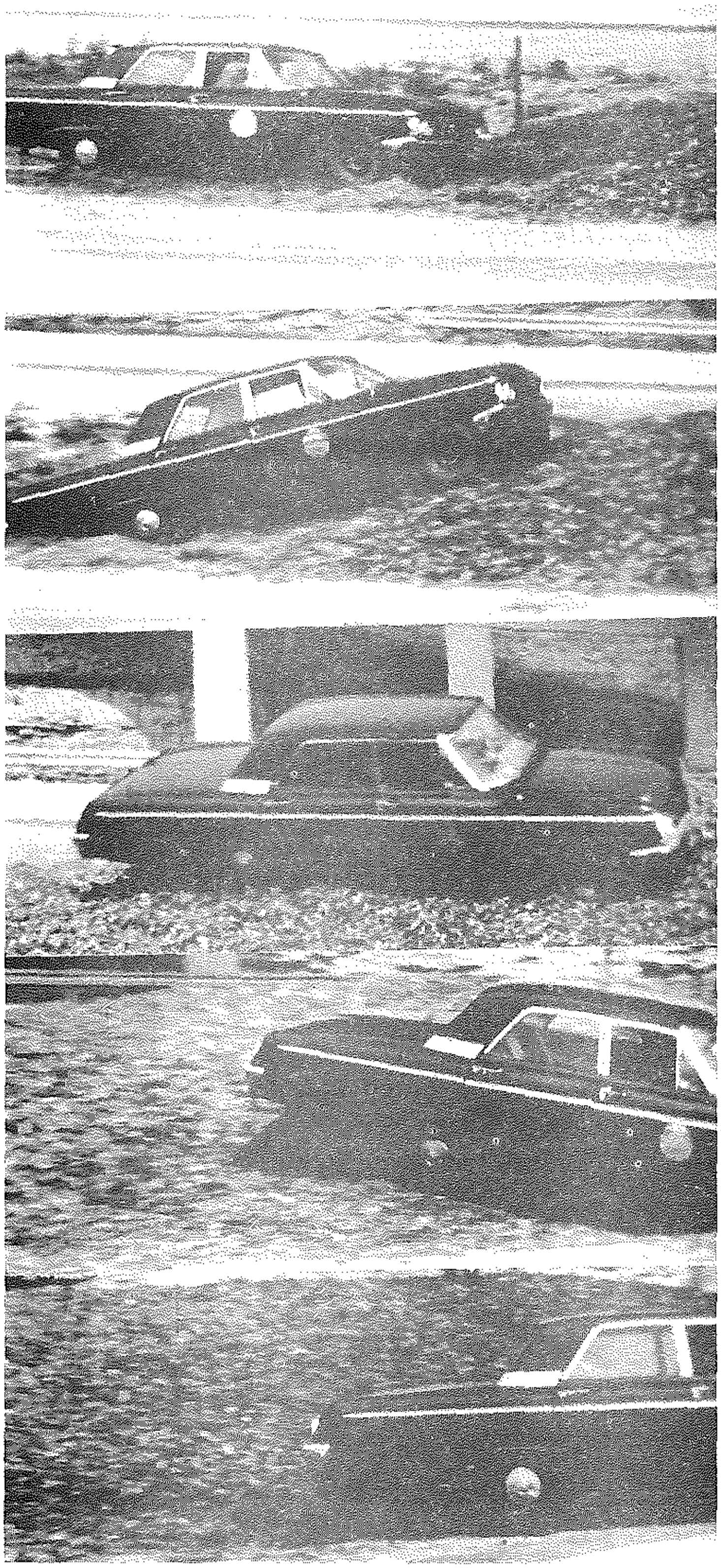
Encroachment Angle: 22°
Vehicle Speed: 10 MPH



Encroachment Angle: 22°
Vehicle Speed: 15 MPH

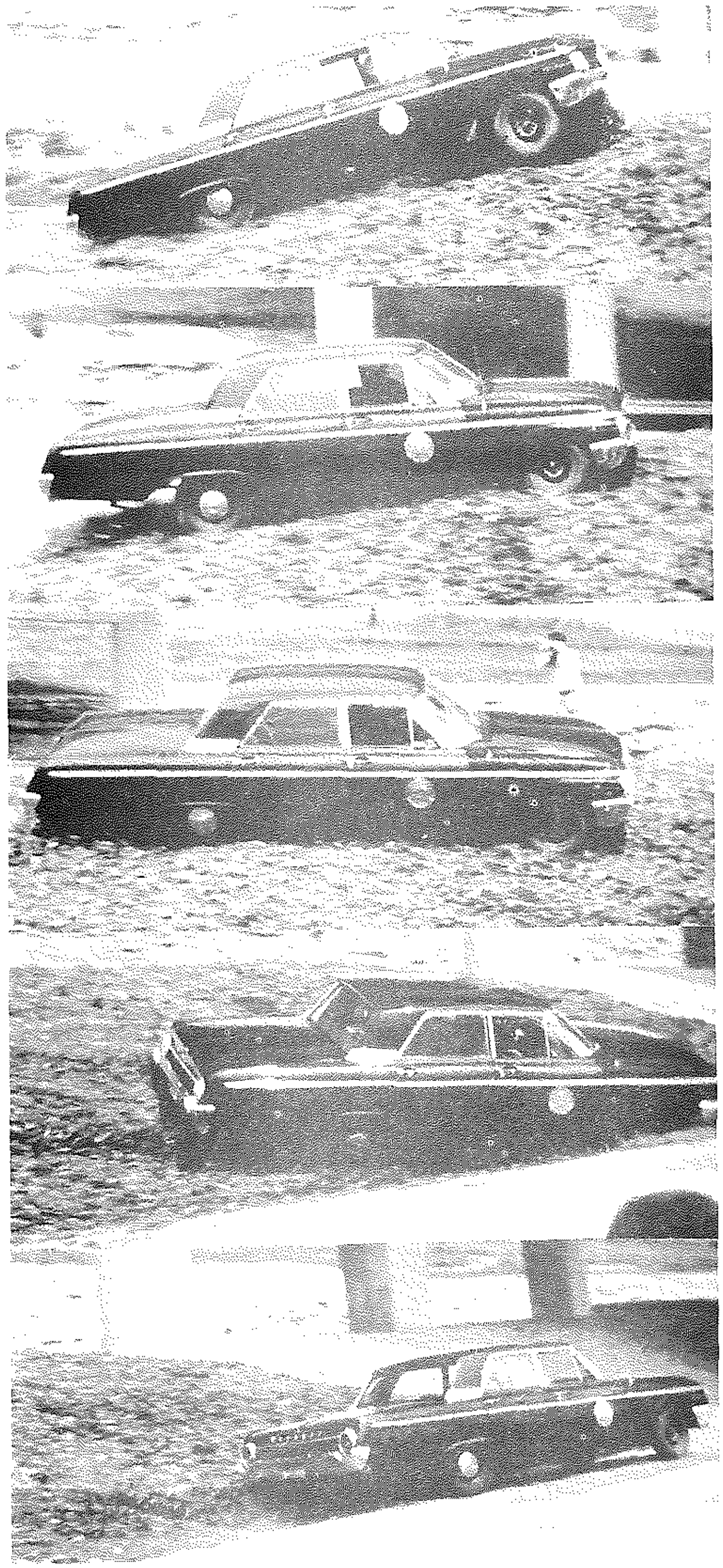


Encroachment Angle: Head On
Vehicle Speed: 10 MPH



Encroachment Angle: Head On
Vehicle Speed: 15 MPH

Encroachment Angle: Head On
Vehicle Speed: 20 MPH



Encroachment Angle: Head On
Vehicle Speed: 25 MPH