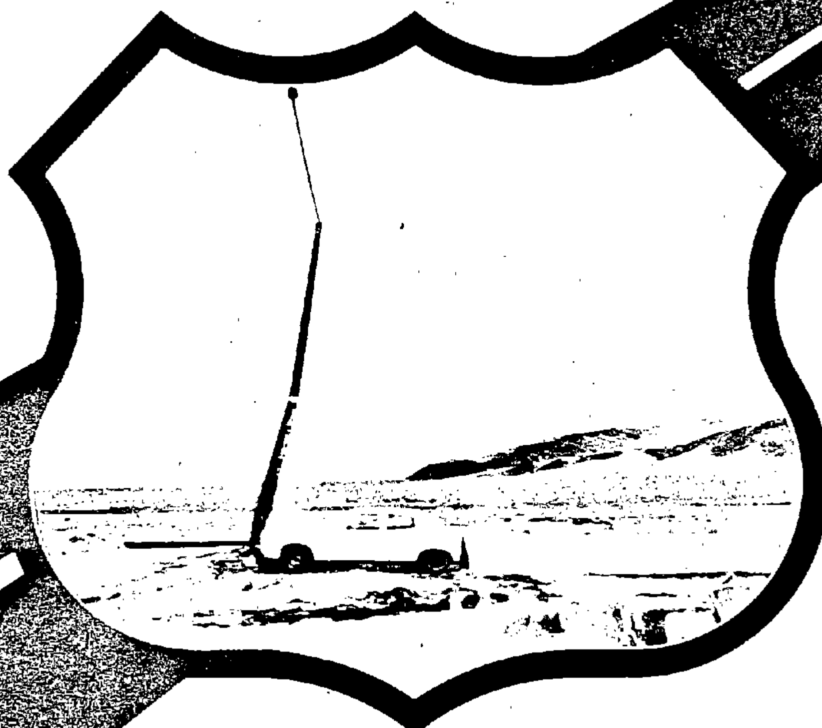
Report No. FHWA/RD-81/501

"CAPTIVE COLUMN" CRASH TESTS

March 1981
Final Report



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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Implementation Division
Washington, D.C. 20590

FOREWORD

This report describes a new concept in structural supports, the "Captive Column," which has the distinctive characteristics of being light weight, and having a high resistance to bending. One of the possible applications for this support is as a luminaire pole. The purpose of the tests conducted were to explore the functioning of the support when impacted by a 4500 lb (2025 kg) automobile. The test showed that the pole fractured at the base even when breakaway connections were not provided and caused little damage to the vehicle. The Captive Column is a proprietary item, fabricated and marketed by Light Structures and Devices Co., Quincy, California.

The testing was done and the report prepared by the Nevada Department of Transportation, Carson City, Nevada. Copies of the report are being distributed in accordance with the numbers agreed upon between each Regional Office and the Implementation Division for normal report distribution. Additional copies are available from the National Technical Information Service, Sringfield, Virginia, 22161.

For additional information, please contact the Federal Highway Administration, Office of Development, Implementation Division, (HDV-21), Washington, D.C. 20590.

Milton P. Criswell
Director,
Office of Development

NOTICE

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16. Abstract

Under contract No. DOT-FH-11-9606 the Nevada Department of Transportation (NDOT) conducted crash testing to study the capability of "Captive Column" light standard appurtenances under controlled conditions. The studies were precursors of actual on site studies and dealt with applicability under nearly ideal conditions and controlled crash guidance. Further testing will be completed under field study conditions (actual). The "Captive Column" was utilized to verify crashability. The tests were to simulate an actual automobile impact at a level angle. Two tests were run at a speed of 20 mph (8.9 m/x) and two at 40 mph (17.9 m/s) using slip bases and fixed bases. The lower section of the column broke away clean at the base and traveled with the vehicle, riding up and over the hood and top of the vehicle leaving marks at striking points. The "Captive Column", under conditions as ideal as possible, reacted exceptionally well, giving a favorable indication to test further. Tests will continue in actual service areas to further determine proper function.

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PREFACE

Vehicular accidents involving light standards are historically hazardous due.to the structure itself and the designed purpose for which it was intended. Use of such structures is the determining factor for their position in respect to roadways. For the strength required to support a luminaire, a metal standard requires a mass of steel or metal alloy which is strong, as light as possible, and yet, yielding to impact.

The "Captive Column" light standard luminaire pole is a completely new idea in light standard structures. It was tested for crashability and observed to determine its reactions. Under the assumed test conditions, the pole responded in a satisfactory manner.

Tests were conducted for the Nevada Department of Transportation (NDOT) by the Nevada Automotive Test Center (NATC), a division of Hodges Transportation Inc. The test center performed all test functions in a prompt, accurate, and professional manner yielding satisfactory results worth notable acclaim.

The NDOT wishes to thank, in addition to the NATC and Hodges Transportation Inc., Light Structures and Devices for a product worthy of the time and effort to build and test, in the interest of improved and innovative devices. Also, NDOT wishes to acknowledge the Federal Highway Administration for their cooperation and guidance in the effort aimed at achieving a successful test and a worthwhile outcome.

SUMMARY OF REPORT

Objectives

Tests were conducted to determine the ability of the "Captive Column" luminaire poles to survive an automobile crash at two different speeds on two different base types. Also, to observe its fall after being struck, and its position in relation to roadway traffic interference. The "Captive Column" light standards are constructed of three rods of steel positioned as an equilateral triangle tapering from 16" (40 cm) at the base to 6" (15 cm) at the top. The rods are held apart by balsa wood pieces and then wrapped with wire. An outer skin of fiberglass covers the entire structure, save the ends. In comparison to existing light standards (Figure 25) the "Captive Column" light standard is considerably lighter and therefore, much easier to handle.

Procedure

Four "Captive Column" luminaire poles were to be tested in a series of crashes. The crashes were observed by officials from several agencies as well as filmed in slow motion, regular 16 mm film frame motion, and still photos. A railing was constructed of lumber on a level plane aimed at the base where the poles were mounted (Figure 2 and 3). The lumber constructed rails fit within the wheelbase of the test vehicle and rubbed on the inside of the tires which guided the vehicle on approach. The test vehicle was pushed to the impact area by a pickup truck (Figure 9) which disengaged prior to the end of the railing. The test vehicle, after being pushed, traveled the remainder of the railing distance on its own, then left the guide rails and "free wheeled" approximately

Twenty feet (20') (6 m) to the impact target (Figure 10). After striking the poles, the test vehicle traveled two car lengths from the impact area to a sand pit which slowed, then stopped the vehicle (Figure 28). All four runs were made in the same manner; two were run at 20 mph (8.9 m/s) with two different base attachments (fixed and breakaway), two were run at 40 mph (17.9 m/s) with two different base attachments (fixed and breakaway) (Figures 5, 6, 7 and 8).

Results

Each of the four runs gave similar results in that the "Captive Column" luminaire poles all sheared or broke loose at the base and the poles all twisted off the base in a clockwise direction (Figures 12, 16, 20, 24 and 33). Each pole was struck at approximately 1'9" (5,25 dm) above the base at a zero degree angle. The speeds of the runs were as close to the 20 mph (8.9 m/s) and 40 mph (17.9 m/s) requirement as could be achieved using the methods outlined in the procedure. Following each run the damage assessed was marked clearly to identify it in subsequent trials (Figures 11, 15, 19 and 23). The same test vehicle was used in each of the four runs with vehicle damage exceptionally light, consisting in most cases of light marks and scratches on the hood or trunk deck. In the final run the test vehicle sustained no damage whatsoever.

Recommendations

To supplement data gathered during the current tests, an in-service evaluation of installations in the field under actual service conditions is recommended. These tests would be to evaluate durability, sturdiness in winds, and practicality under other field conditions. Additional crash testing should be performed to determine acceptability under current American Association of State Highway and Transportation Officials (AASHTO) criteria.

CHAPTER I

Background

Contracts between Nevada Department of Transportation (NDOT) and Federal Highway Administration (FHWA), Light Structures and Devices, and Hodges Transportation Inc. were entered into during 1979 for the testing of four "Captive Column" luminaire poles. The poles, constructed by Light Structures and Devices in Quincy, California were delivered to the Nevada Automotive Test Center near Fort Churchill, Nevada by NDOT prior to December 11, 1979. Tests were conducted at the test center on December 20, 1979. Tests were performed in accordance with the National Cooperative Highway Research Program Report #153 (NCHRP) "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances".

The "Captive Column" light standards used in the crash test have not to this point been tested in the manner outlined in this report. Literature on the subject is nonexistent and therefore, different and heretofore, unexplored areas and results are being experienced. This report outlines the first crash testing of the "Captive Column" light standard, and therefore is unique in that respect.

Objectives

The three major objectives in testing the "Captive Column" structures were:

1. To test four "Captive Column" design luminaire poles mounted on fixed and standardized breakaway bases through use of vehicle impact tests, to determine the poles' characteristics during the impact sequence.

2. To recommend future action to be taken in regard to use of the "Captive Column" design for highway roadside application.

3. To prepare documentation of crash test results.

A general objective involved the determination of whether the test light standards ("Captive Columns") would fall in a designed manner doing little or no damage to the impact vehicle and its occupants and to evaluate the trajectory and final resting place of the light standards or any detached elements with respect to other traffic.

<u>Description of "Captive Column" Light Standard</u>

The "Captive Column" light standard used in this test measured 28' (8.4 m) in length, with a base dimension of 16" (40 cm) and a 6" (15 cm) cross section measurement at the top (Figure 26 and 27). Core elements consisted of three rods ½" (1.25 cm) in diameter which extended the full length of the pole, and balsa wood boards, with the grain running perpendicular to the axis of the pole; buttressed at their ends, the balsa wood boards held the steel rods apart equidistant from the central axis of the pole. Internal core elements (balsa wood and steel rods) were wrapped by hi-tensil, 0.018" (0.045 cm) diameter wire, with pre-tension in captive column geometry. The core elements with the wire wrapping were covered with an outer skin of fiberglass cloth and polyester resin painted with lacquer. Prior to the application of the fiberglass outer layer, the pole weighed approximately 75 lbs. (33.75 kg).

At the test site the mast arms and a dummy weight, resembling a luminaire fixture, were attached to the top of the light standard before it was erected on the foundation base. The mast arm consisted of a 2" (5.0 cm) square steel tube 12' (3.6 m) in length, weighing 30 lbs. (13.5 kg) with an attached dummy weight of 35 lbs. (13.75 kg) substituting for a luminaire. When raised into position the luminaire (dummy weights) were 32' (13.75 kg) above the ground. Base plates weighed 33 lbs. (14.85 kg) for the fixed type and 55 lbs. (24.75 kg) for the slip base type (Figures 5, 6, 7 and 8).

Since the "Captive Column" light standard is a 3-dimensional truss-like structure, the elements operate in tension or compression without bending forces. The design bending moment for a 28' (8.4 m) luminaire support requires a total cross section of only 0.59 square inches (3.686 sq. cm) for all three rod elements. The cross sectional areas were of such dimension and strength to be a minimal resistant force and therefore, sheared easily.

CHAPTER II

Test Methodology

The suggested testing procedure in NCHRP #153 involved two tests for "Breakaway or Yielding Supports" for light standards. The recommendation in Test No. 1 was for a vehicle weighing 4,500 lbs. (2,025 kg) and a speed of 40 mph (17.9 m/s). In Test No. 2 the recommendation was for a 2,250 lb. (1,012.5 kg) vehicle to impact the standard at 20 mph (8.9 m/s). It was recommended by Nevada DOT to modify the tests due to costs; thus, the smaller vehicle test was not attempted at this time. The crash test was performed in the following manner:

> The tests for both speeds (20 mph and 40 mph)(8.9 m/s and 17.9 m/s) were accomplished using a vehicle weight of 4,500 lbs. (2,025 kg). Each test speed involved an impact of the vehicle into the light standard mounted first on a slip base and then on a fixed base.
>
> All standards were impacted at a zero degree angle, which theoretically produced the maximum resisting force. The test vehicle was pushed along wood guide rails, at approximately 5 mph (2.2 m/s) faster than test impact speeds to a point approximately three-car lengths from the light standard. The pushing vehicle disengaged from the test vehicle at this point. The test vehicle continued down the guide rails until approximately twenty feet (20') (6.0 m) from impact, at this point the guide rails ended and the vehicle "free wheeled" to impact. Vehicle braking was accomplished by means of a sand pit of very loose and dry sand, which started two-car lengths beyond the impact point (Figure 28).

The test vehicle was a 1973 AMC Ambassador four-door sedan payloaded to 4,510 lbs. (2,029.5 kg). The pushing vehicle was a 1976 Chevrolet one-half ton (.45 metric ton) pickup.

CHAPTER III

Data Collection

The test events in the four runs performed were recorded on film. A high speed camera was positioned at a 90° angle to the left of the oncoming track of the test vehicle at a distance of 78' (23.4 m) from the impact point (Figure 28). The high speed camera recorded each event at 1,000 frames per second. A 16 mm camera was positioned 193' (57.9 m) beyond the impact point, facing the oncoming test vehicle. The front view camera recorded each event at 64 frames per second. A third camera, a 16 mm hand held unit was filming at 24 frames per second and followed each run in its entirety. The hand held camera was filming from the left hand side of the approaching vehicle and near the end of the guide rails at a safe distance.

Still photos were also used to show positions of vehicles, light standards, base plate bolt fractures, vehicle damage and other pertinent data.

A transit was used to plot positions of the mast arm and light standard following crash testing. A tape measure was used in conjunction with the transit for designating relative positions. Positions of articles were photographed in relation to the base.

Vehicle speeds at the time of release, were determined through the use of the pushing vehicle's speedometer which had been calibrated the morning of the tests. A calibrated tachometer had also been installed in the impact vehicle to record its speed. The impact vehicle's speed was determined at the point of impact by using the high speed camera film and measurements marked on the impact vehicle and on the ground, and comparison with the tachograph card.

CHAPTER IV

Results

In run No. 1, the test vehicle traveled at a speed of 22.4 mph (9.96 m/s). The light standard was mounted on a slip base and was impacted at 1'9" (5.25 dm) above the base. A breakaway bushing was found 4'9" (14.25 dm) directly forward of the base. The light standard was fractured 2'8" (7.2 dm) above the point of impact. The remainder of the light standard appeared to be intact. The test vehicle came to rest 46'10" (14.05 m) from the point of impact. Damage to the test vehicle was insignificant with the only noticeable damage being paint smudges on the leading edge of the hood, on the right front of the roof and on the right rear of the trunk lid (Figures 11 and 13). These smudges were from the light standard when it passed over the top of the vehicle and were not damage to the vehicle paint. There were also two small dents in the test vehicle; one was approximately 1½" (3.75 cm) long and 1/8" (0.31 cm) deep at the forward edge of the roof on the driver's side, and the other approximately 1/2" (1.25 cm) long and 1/8" (0.31 cm) deep in the windshield molding above the driver's seat. The base of the standard hit the trunk lid of the vehicle as the vehicle passed under the standard, but it caused no damage other than the paint smudge.

The kinetic energy at impact of run No. 1 was 75578.62 ft. lbs. (10,449.12 m.kg.). The momentum change was 658.07 ft. lbs./sec. (90.98 m.kg/sec.) after impact.

Following the test run, measurements were taken to show the point of rest for the light standard (Figure 29). The following positions were noted:

1. The top of the light standard was 12'6" (3.75 m) forward of the base and 53° to the left of the base.
2. The bottom of the light standard was 32'9" (9.83 m) forward of the base and 1° to the right of the base.
3. The top of the luminaire arm was 1'3" (3.75 dm) directly to the rear of the base.

In run No. 2, the test vehicle was traveling at 24.0 mph (10.67 m/s) and impacted the standard 1'10" (5.5 dm) above the base, which was a fixed base. After breaking away from its base the light standard was pushed 16'5" (4.93 m) by the test vehicle before rotating up and over the test vehicle. All rods affixed to the base plate separated above the top retaining nut. The light standard was fractured at a point 2'10" (8.5 dm) above the impact point with a second fracture occurring 14' (4.2 m) from the top of the light standard (Figure 14). The second fracture occurred as a result of the impact and not as a result of striking the ground. The second fracture was also noted to be at the point which connects the top and bottom sections of the column. The second fracture did not separate the two column halves and the column fell as a unit structure. Of the three base plate nuts, with the remaining rod portion intact, only the one on the left rear attachment (farthest from impact) was still secured tightly. The forward bolt (left front) and the right center bolt were loose in their mounting.

The test vehicle came to a stop 47'4" (14.2 m) from the point of impact. Damage to the vehicle consisted only of paint smudges on the front of the hood, on the right front of the hood and on the left rear of the trunk lid. There were no dents in the test vehicle (Figures 15 and 17).

The kinetic energy at impact of run No. 2 was 86769.97 ft. lbs. (11,966.38 m.kg.). The momentum change was 584.05 ft. lbs./sec. (80.75 m.kg/sec.) after impact.

The light standard, following test run No. 2 was in the following described position as defined by the measurements given (Figure 30):

1. The top of the standard was 10'6" (3.15 m) forward of the base and 25^{o} to the left of the base.
2. The bottom of the standard was 38'5" (11.53 m) forward of base and 35^{o} to the left of the base.
3. The top of the luminaire arm was 11'7" (3.48 m) to the left of the base and almost parallel with the base.

Run No. 3 was made at 38.1 mph (16.93 m/s) and the light standard was mounted on a slip base. The light standard was impacted by the test vehicle 1'9" (5.25 dm) above the base (Figure 18). The extreme right bolt of the slip base sheared off at impact and upon examination it appeared that the nut securing the breakaway bushing had been tightened to the point that the bushing could not rotate, thus putting all impact energy directly into the base plate bolt. The light standard, after separating from the base plate, was pushed 21' (6.3 m) by the test vehicle before it rotated up and over the vehicle. The light standard was fractured at a point 4'4" (13.0 dm) above the point of impact. The remainder of the column appeared to be intact.

The test vehicle came to a stop 55'4" (16.6 m) from the point of impact. There were only two small paint smudges in the center of the hood and one on the right front of the roof of the test vehicle following impact (Figures 19 and 21).

The kinetic energy at impact of run No. 3 was 218673.83 ft.lbs.

(30,232.75 m.kg.). The momentum change was 560.49 ft. lbs/sec. (77.49 m.kg/sec.) after impact.

Position measurements taken after the test run was made, revealed the light standard to be in the configuration outlined below (Figure 31):

1. The top of the light standard was 12'9" (3.83 m) forward of the base and 52° to the left of the base.
2. The bottom of the light standard was 31'5" (9.43 m) forward of the base and 9° to the right of the base.
3. The top of the luminaire arm was 2'10" (8.5 dm) from the rear of the base.

In run No. 4 the light standard was mounted on a fixed base and the test vehicle speed was 39.9 mph (17.73 m/s). The impact point was 1'9" (5.25 dm) above the base of the standard (Figure 22). The front rod of the light standard was stripped out of the threads of the bottom retaining nut upon impact and was later determined not to have been seated to the same depth as the other two rods. The other two rods were sheared off over the retaining nuts as in the previous test at 20 mph (8.9 m/s). The light standard was fractured at a point three feet (3') (9.0 dm) above the impact point. The remainder of the standard appeared to be intact. The test vehicle pushed the light standard 14'11" (4.48 m) off the base before it rotated up and over the vehicle.

Following the test vehicle halt in the sand pit, examinations revealed no damage was sustained (Figure 23). Viewing films at a later date confirmed the suspicion that the standard had not touched the test vehicle in any way following impact. The test vehicle came to rest in run No. 4 at a point 62'9" (18.83 m) from the point of impact.

The kinetic energy at impact of run No. 4 was 239,824.07 ft. lbs. (33,156.88 m.kg.). The momentum change was 537.05 ft. lbs/sec. (74.25 m.kg/sec) after impact.

The standard's point of rest following the test indicated the measurement position as outlined below (Figure 32):

1. The top of the light standard was 16'7" (4.98 m) forward of the base and 45° to the left of the base.
2. The bottom of the light standard was 34'4" (10.3 m) forward of the base and 5° to the right of the base.
3. The top of the luminaire arm was 3'4" (10.0 dm) directly left of the base.

Upon completion of the four impact tests, the fiberglass covering on light standard four was cut away approximately three feet (3') (9.0 dm) above the point where the standard was fractured from the impact (Figures 4 and 24). Upon examination it was noted that the structure wire binding the rod and frame together did not unravel as a result of the impact, nor were any of the rods broken.

Two persons picked up the downed "Captive Column" luminaire and carried it to the truck for transportation back to the shop area.

CHAPTER V

Analysis

The slip and fixed bases separated from the stationary base plate in a satisfactory manner at both impact speeds.

The "Captive Column" light standard, with 35 lbs. (15.75 kg) of weight on the luminaire arm, landed in approximately the same position after each impact, regardless of the base used or speed of impact (Figure 33). The resting position of the light standard after impact would have created an insignificant hazard to oncoming or following vehicles.

The test vehicle, after each impact, continued in a straight trajectory and did not veer to the right or left until it came to a stop in the braking pit.

The light standard did insignificant damage to the test vehicle, regardless of which base was used or the speed at the time of impact (Figures 11, 15, 19 and 23). Damage done could have been corrected with rubbing compound in most cases. There was no damage to the bumper, grill, headlights or windshield of the test vehicle after all four impacts (Figure 23).

The light standard could be erected and mounted on the bases manually by six to eight men in approximately five minutes (Figure 1).

Due to the manner of construction as well as material type, the light standard was easily handled prior to testing and following each crash. With the mast arm and dummy weights attached, the entire structure weighs approximately 150 lbs. (67.50 kg.). Following an accident, in which the light standard is severed from its base attachment, removal of the light standard can be accomplished by two (2) men.

Test methodology and apparatus satisfactorily met the objectives of the test as outlined by the NDOT.

CHAPTER VI

Conclusions and Recommendations

The damage assessed following the four test runs indicates the "Captive Column" light standard will break away easily and fall, while rotating over the vehicle, with little or no damage to the impact vehicle. The "Captive Column" light standards tend to rotate in a similar fashion at both test speeds and with either a fixed or slip base attachment, falling relatively close to the path taken by the impact vehicle (Figures 29, 30 31 and 32), with little likelihood of obstructing the travel lanes, if placed properly at a roadside. It was also noted during the testing procedure that the columns are easy to handle and can be erected by an eight man crew (without the use of heavy equipment), which could be a decided advantage during installation or replacement; also, two people can remove it from the area following impact.

With information presently available from preliminary testing, it is recommended that further testing be carried out to ascertain the "Captive Column" light standard's ability to perform satisfactorily in actual "on site" conditions. Further study and input pertaining to the "Captive Column" light standard's ability to withstand winds (Figure 34), and other climatic, as well as other in-use conditions, is essential at this point.

Also, additional testing with a lighter payload vehicle and various attack angles would be desirable.

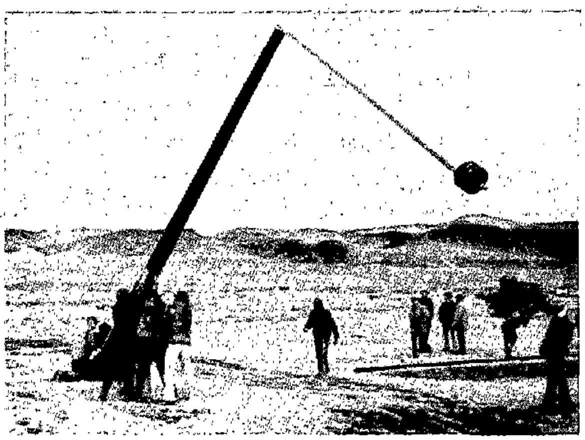

Figure 1. Light standard being lifted into place without the aid of heavy equipment.

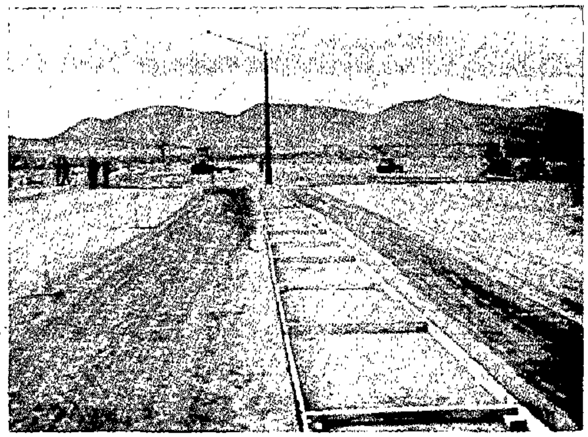

Figure 2. Light standard and layout of test area with braking area in the background (white sand area beyond tractor).

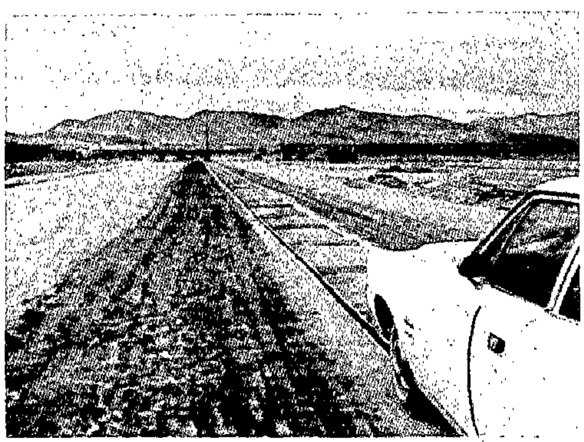

Figure 3. Full view of wooden rails used to guide vehicle (note the grease on rail sides).

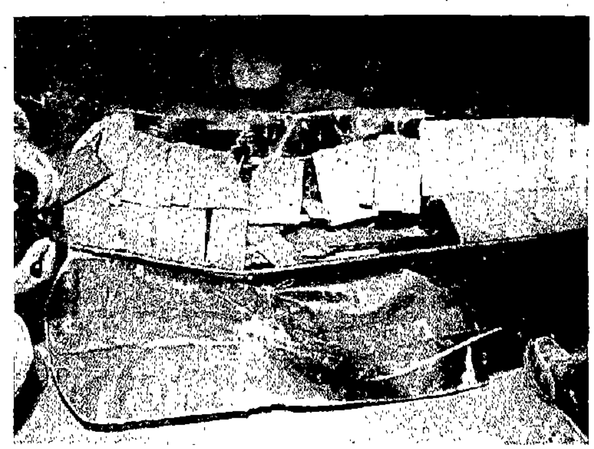

Figure 4. Internal structure following impact. The collapse was in the area of impact and did not destroy total integrity of geometric design.

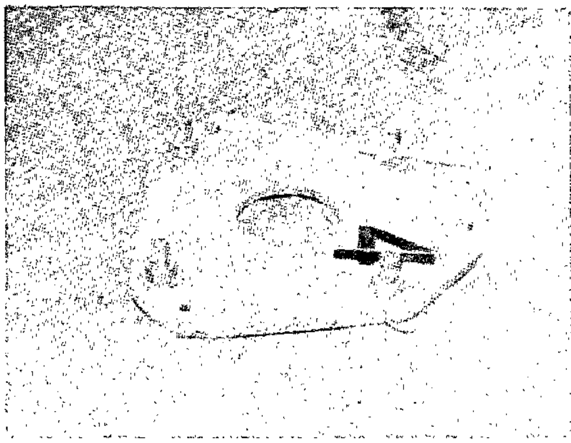

Figure 5. Base plate mounted to foundation for fixed base attachment. The three (3) bolt positions are shown on the plate.

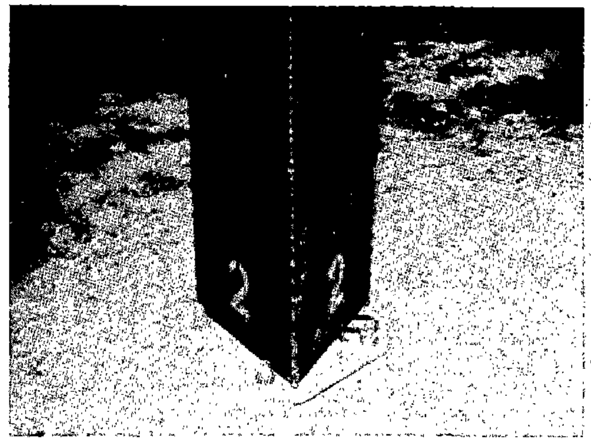

Figure 6. Fixed base attachment to "Captive Column" light standard. This type attachment was used in test runs 2 and 4.

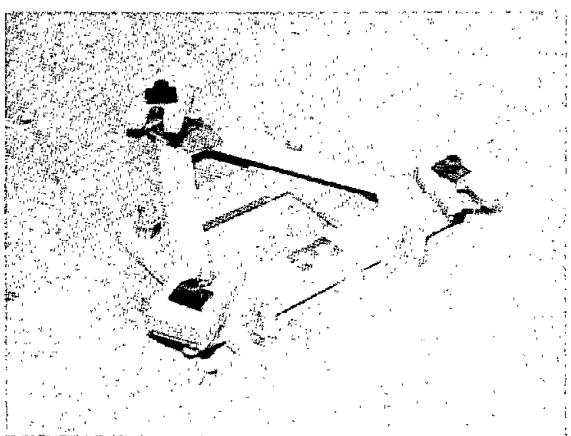

Figure 7. Base plate attachment is shown for the slip base as it appears when affixed to cement foundation by large bolts.

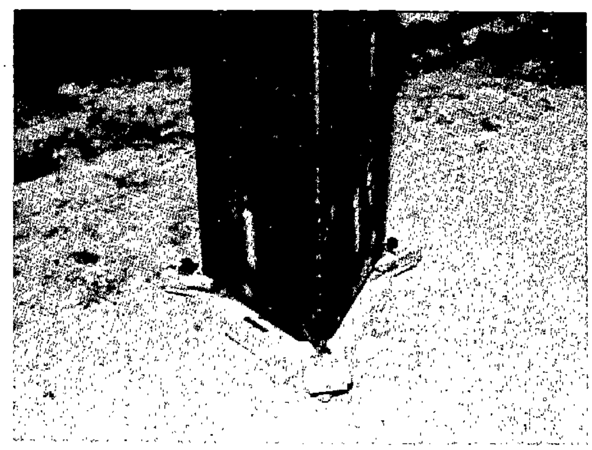

Figure 8. Slip base attached to "Captive Column" light standard. This type attachment was used in test runs 1 and 3.

Figure 9. Test vehicle prior to test run #1 with pushing vehicle behind.

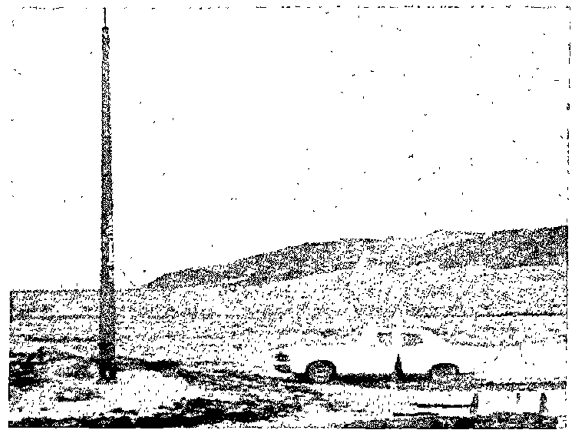

Figure 10. Test vehicle prior to impact. The test vehicle is "free wheeling" at this stage of the run.

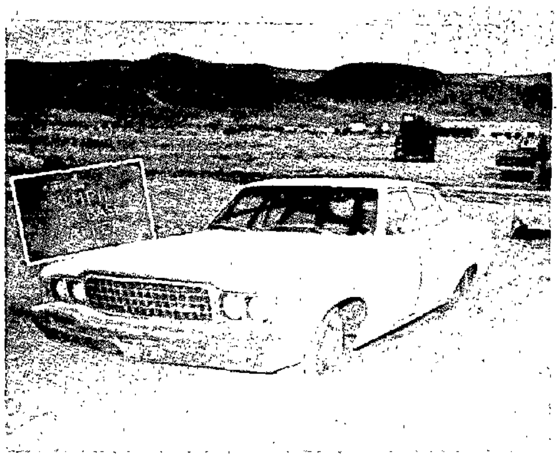

Figure 11. Test vehicle in braking area (sand pit) with fallen standard (right rear), which illustrates relative position to path of vehicle.

Figure 12. Extent of damage to light standard shown for test run #1. Note: Sheared bushing (lower left) which broke loose at impact. See text under results for explanation.

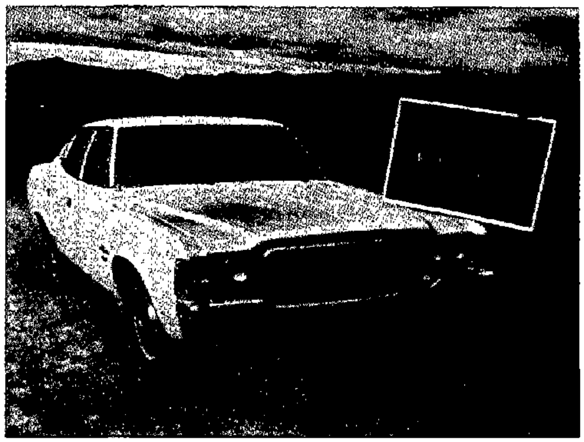

Figure 13. Test vehicle prior to test run #2. Limited amount of damage from test #1 is apparent.

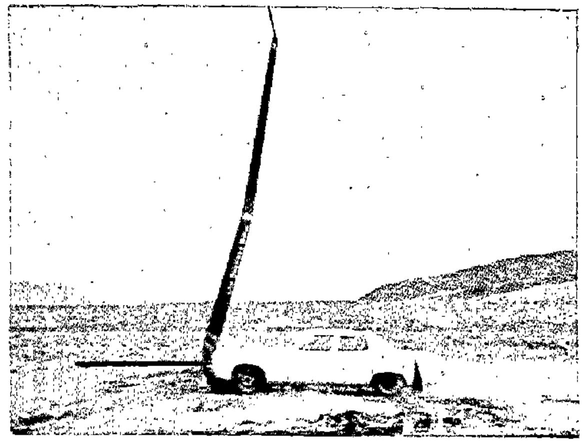

Figure 14. Impact during test run #2. Note: Fracture at midpoint in light standard. See text for explanation.

Figure 15. Test vehicle in braking area (sand pit) with guide rails in the background beyond transit tripod.

Figure 16. Extent of light standard damage shown for test run #2. Sheared rods shown at bottom of standard; also, midpoint fracture can be seen above lettering.

Figure 17. Test vehicle prior to test run #3. Vehicle damage is minimal following test #2 which was the most violent of the four test runs.

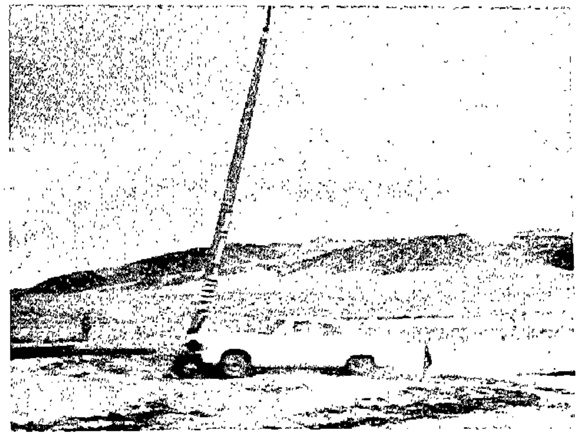

Figure 18. Impact during test run #3. Breakaway was quick in this and run #1 due to the use of a slip base in both tests.

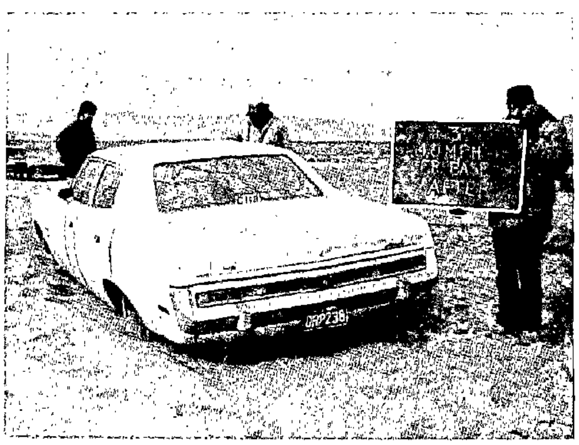

Figure 19. Test vehicle in braking area following test run #3. Damage to rear deck is shown.

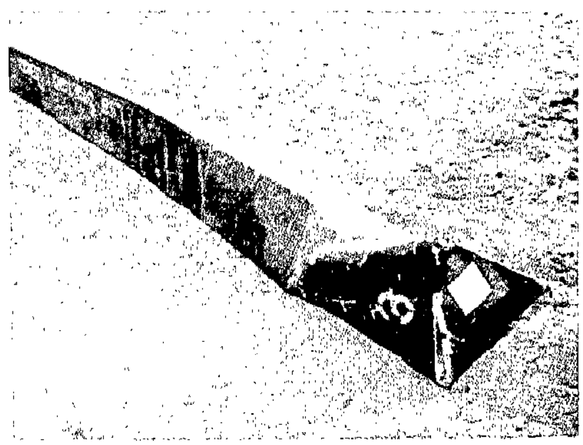

Figure 20. Extent of damage to light standard is shown to be slight. Sheared rod (lower left) with missing bushing is pictured at the bottom of light standard. See text for explanation.

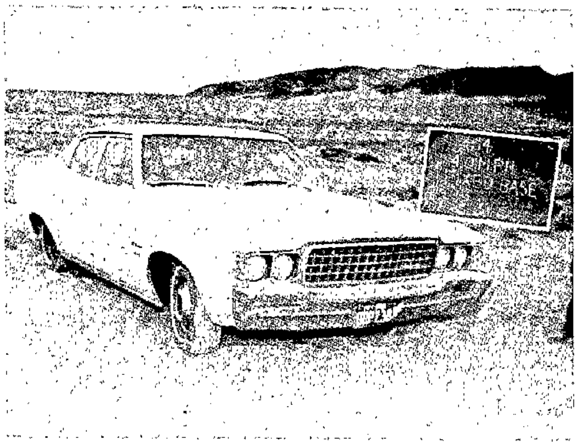

Figure 21. Test vehicle prior to test run #4. Prior test run marks circled in black to distinguish each mark made by test run number.

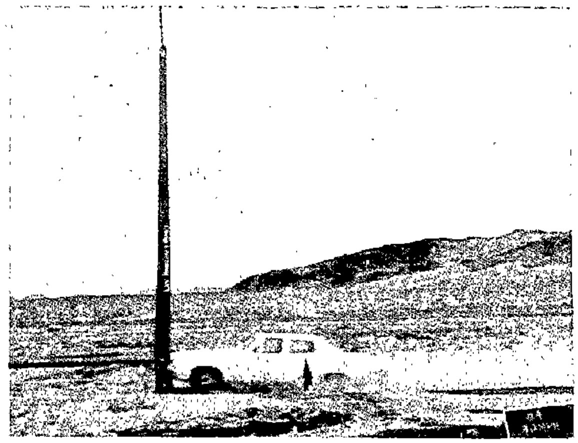

Figure 22. Impact point during test run #4. A secondary fracture did not occur on this fixed base run as it did in test run #2.

Figure 23. Test vehicle in braking area following test run #4. No new damage was noted following test run #4.

Figure 24. Extent of damage to light standard is shown to be greater on the fixed base runs than for the slip bases.

APPENDIX II

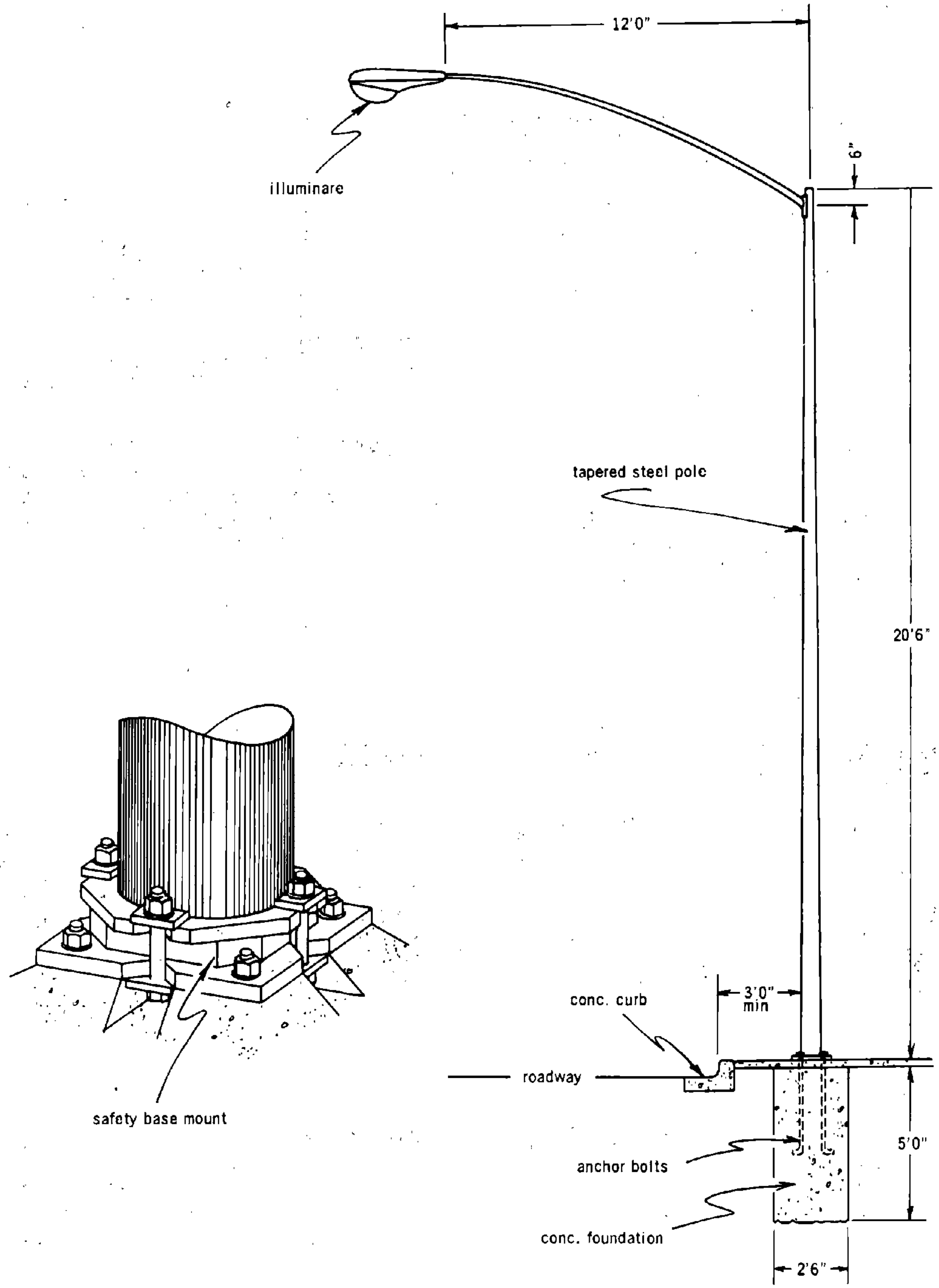

Figure 25. Type 7 light standard illuminare with safety base.

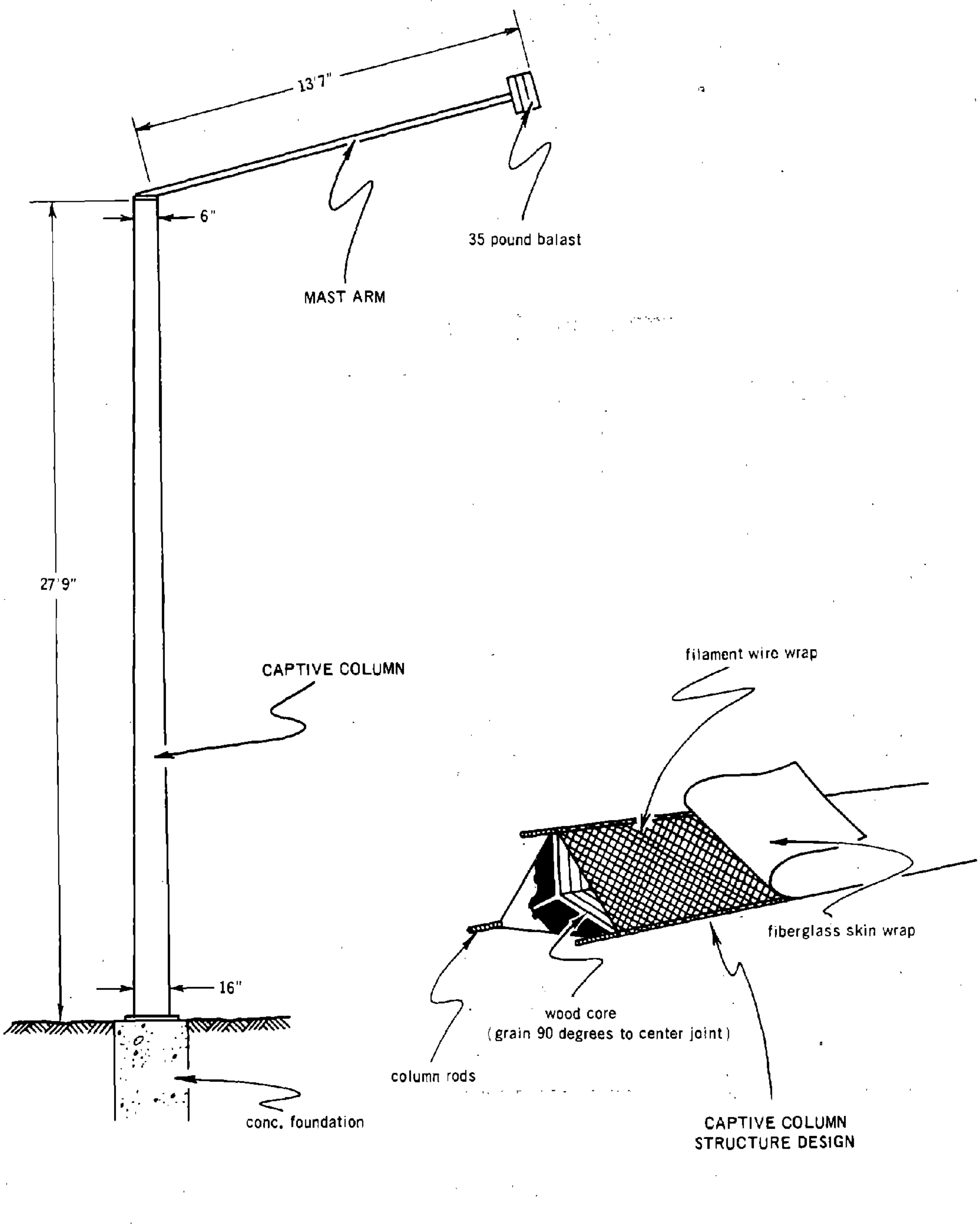

Figure 26. Light structure tested using patented Bosch Captive Column.

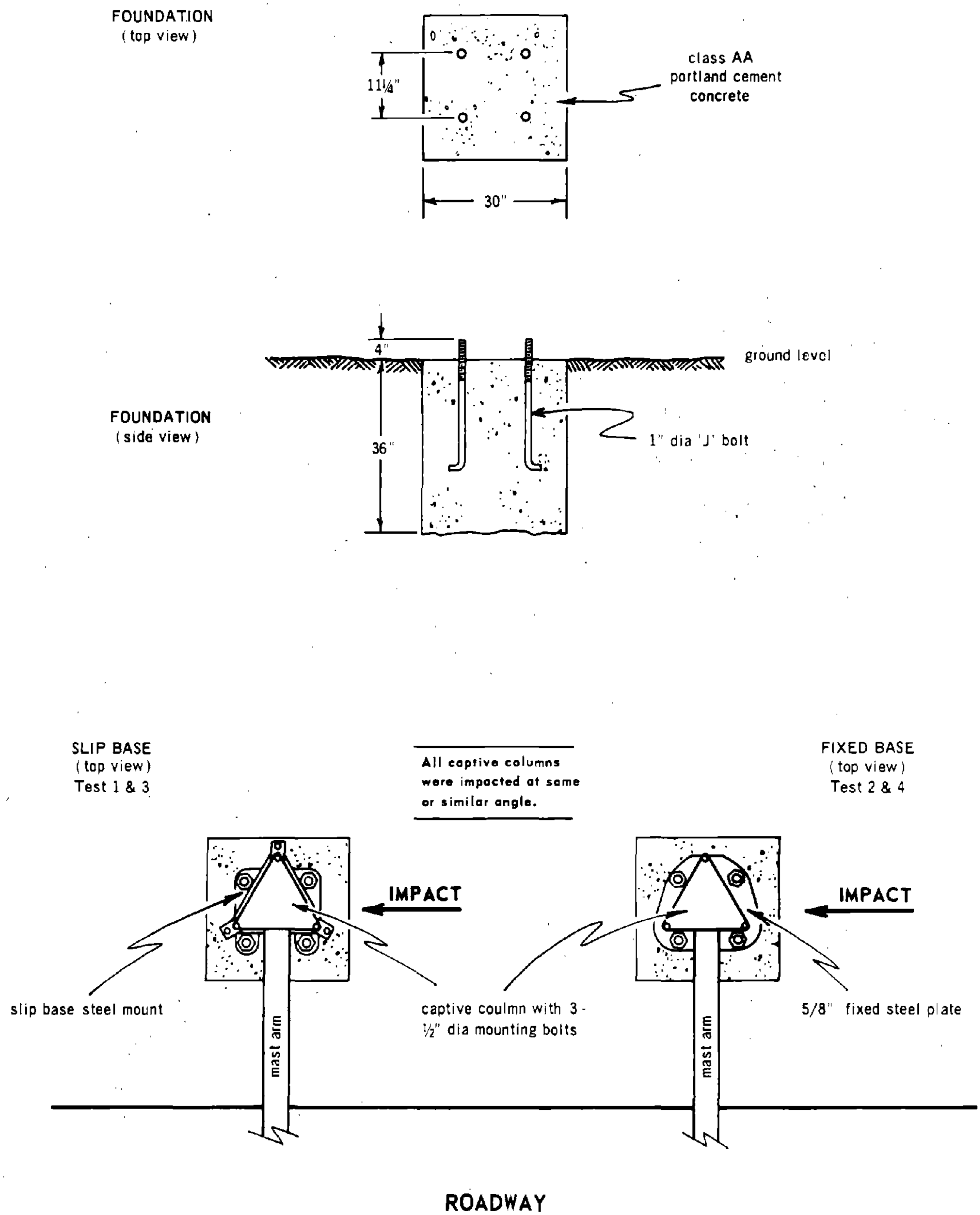

Figure 27. Test foundation and types of column base attachments.

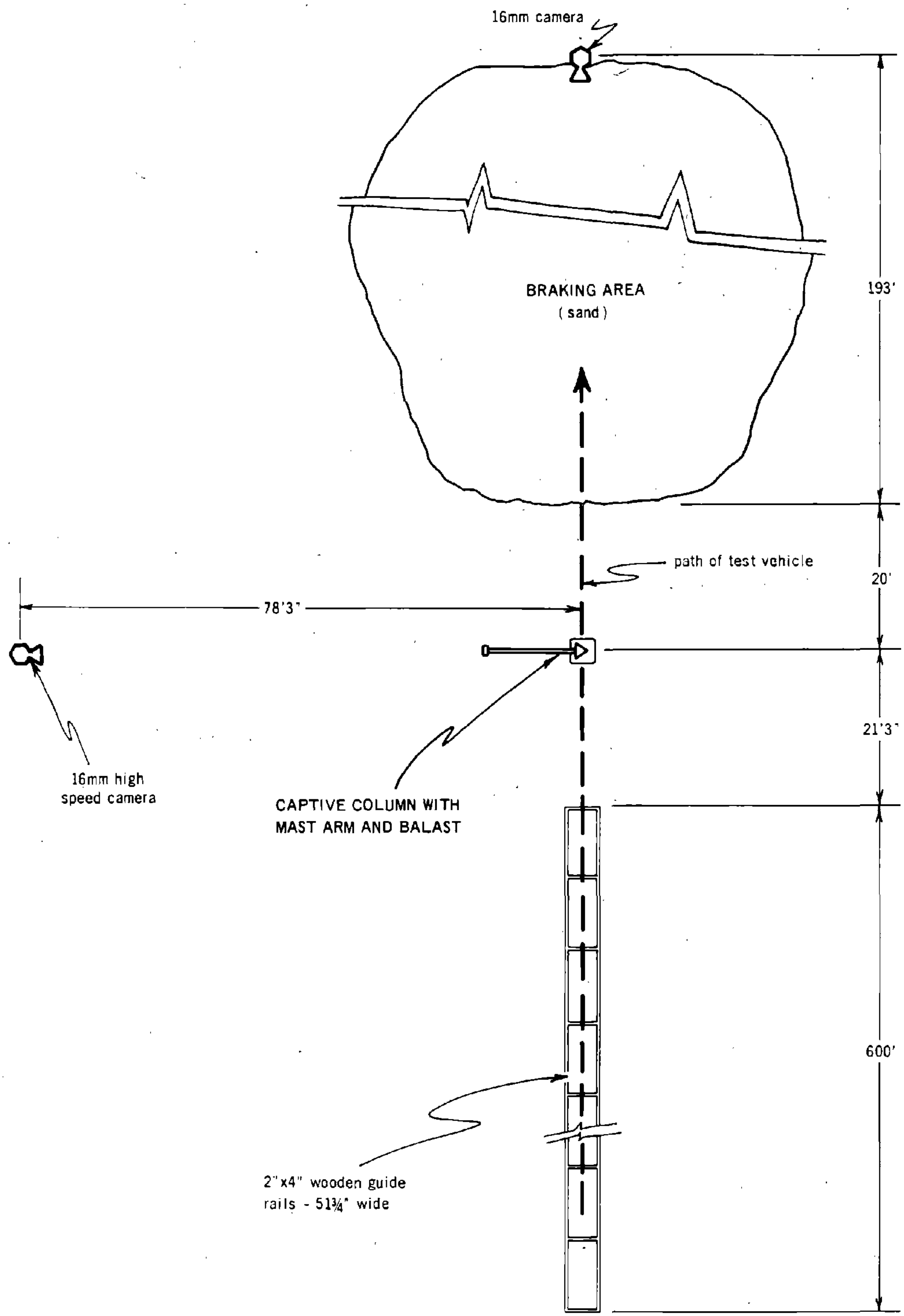

Figure 28. Layout of testing site.

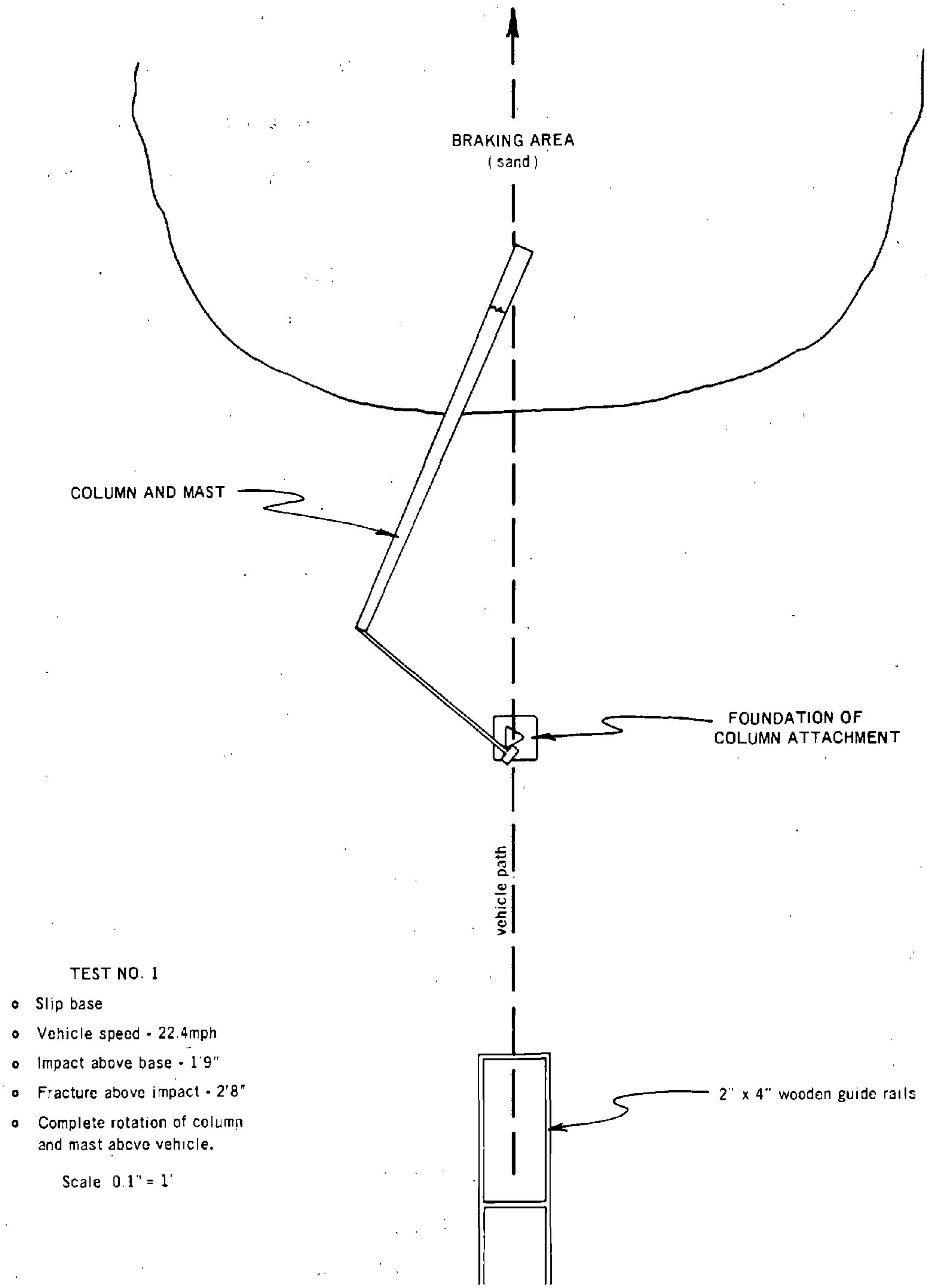

Figure 29. Resting position of column and mast after impact in test No. 1

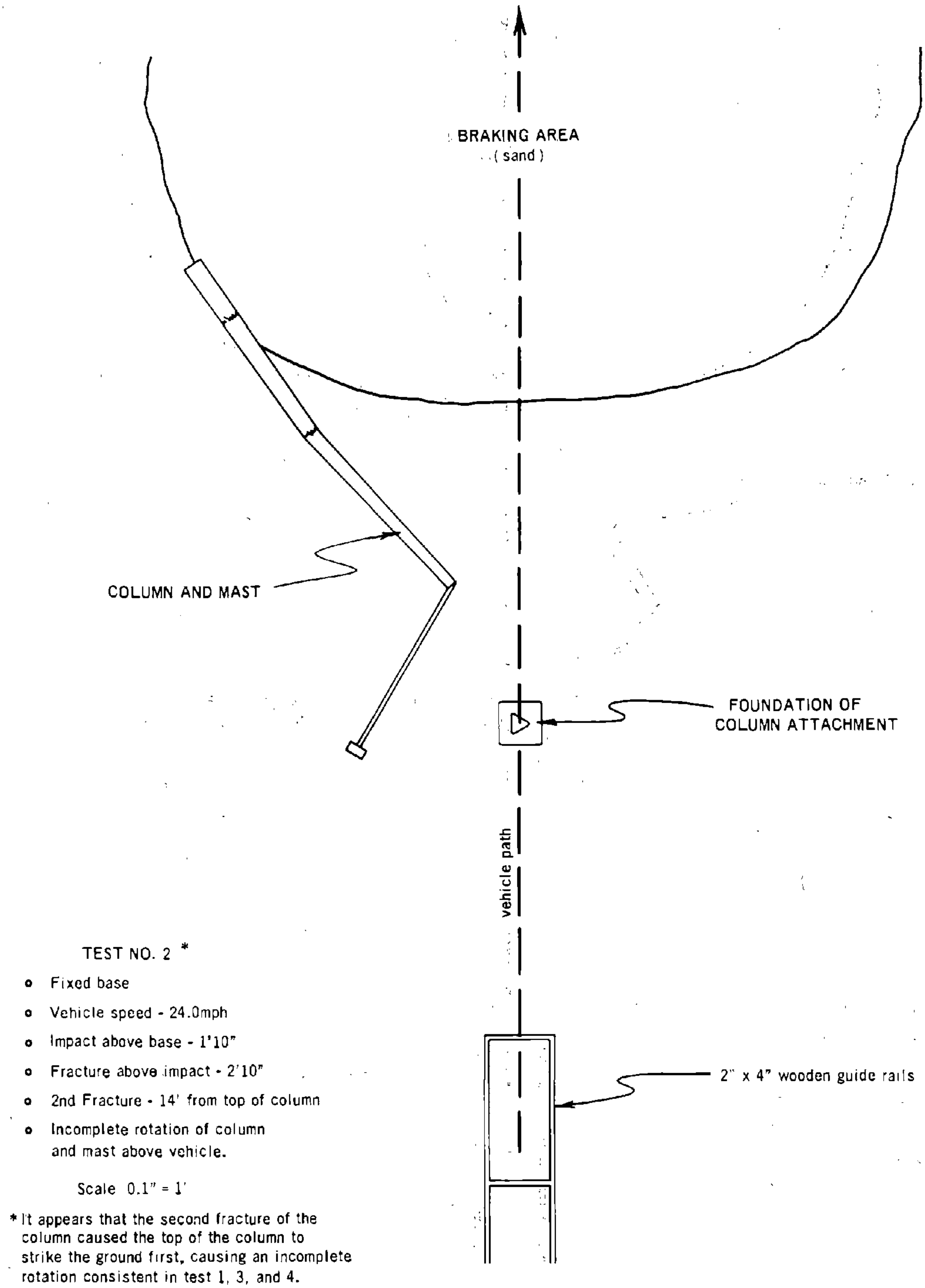

Figure 30. Resting position of column and mast after impact in test No. 2

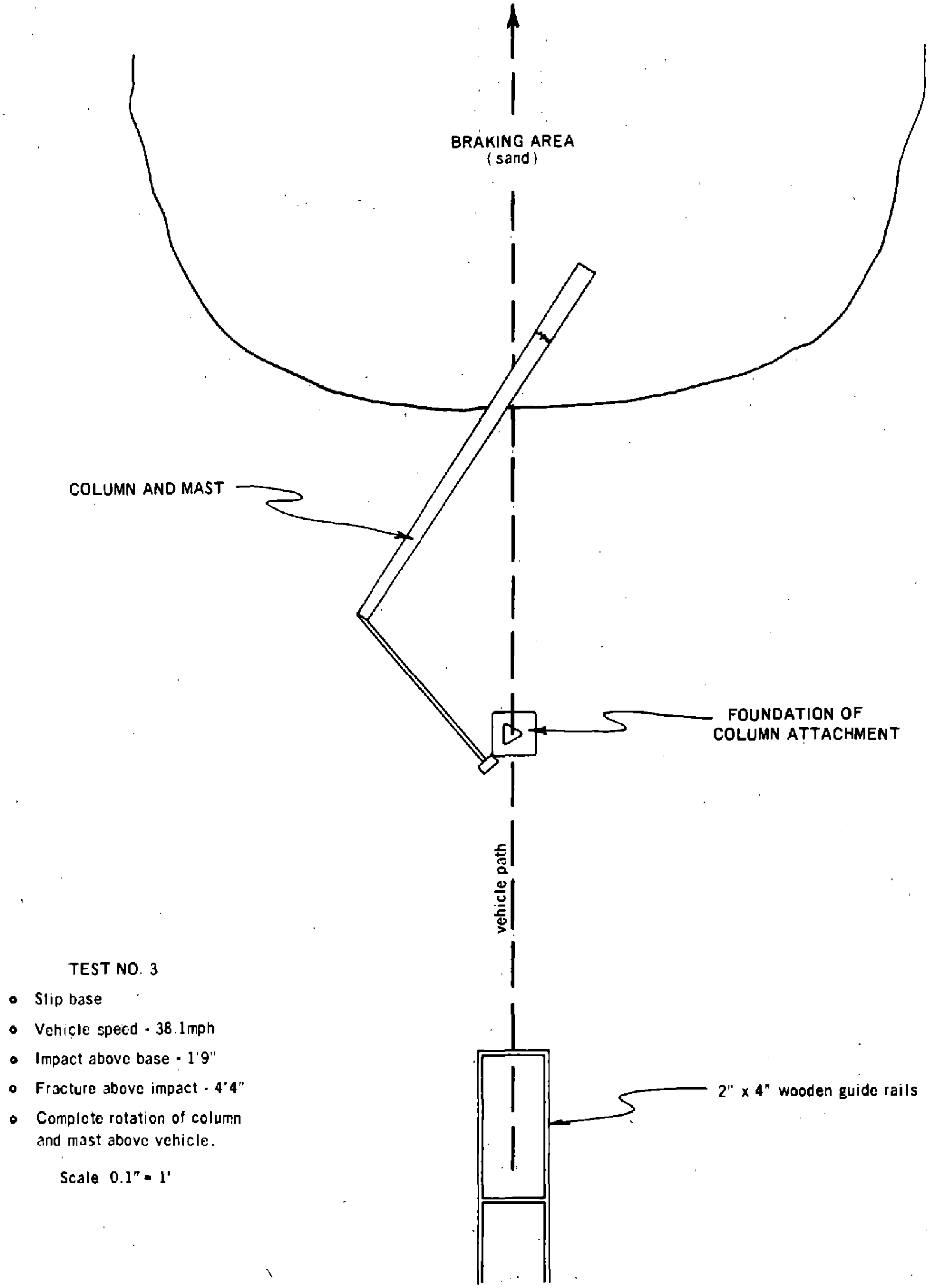

Figure 31. Resting position of column and mast after impact in test No. 3

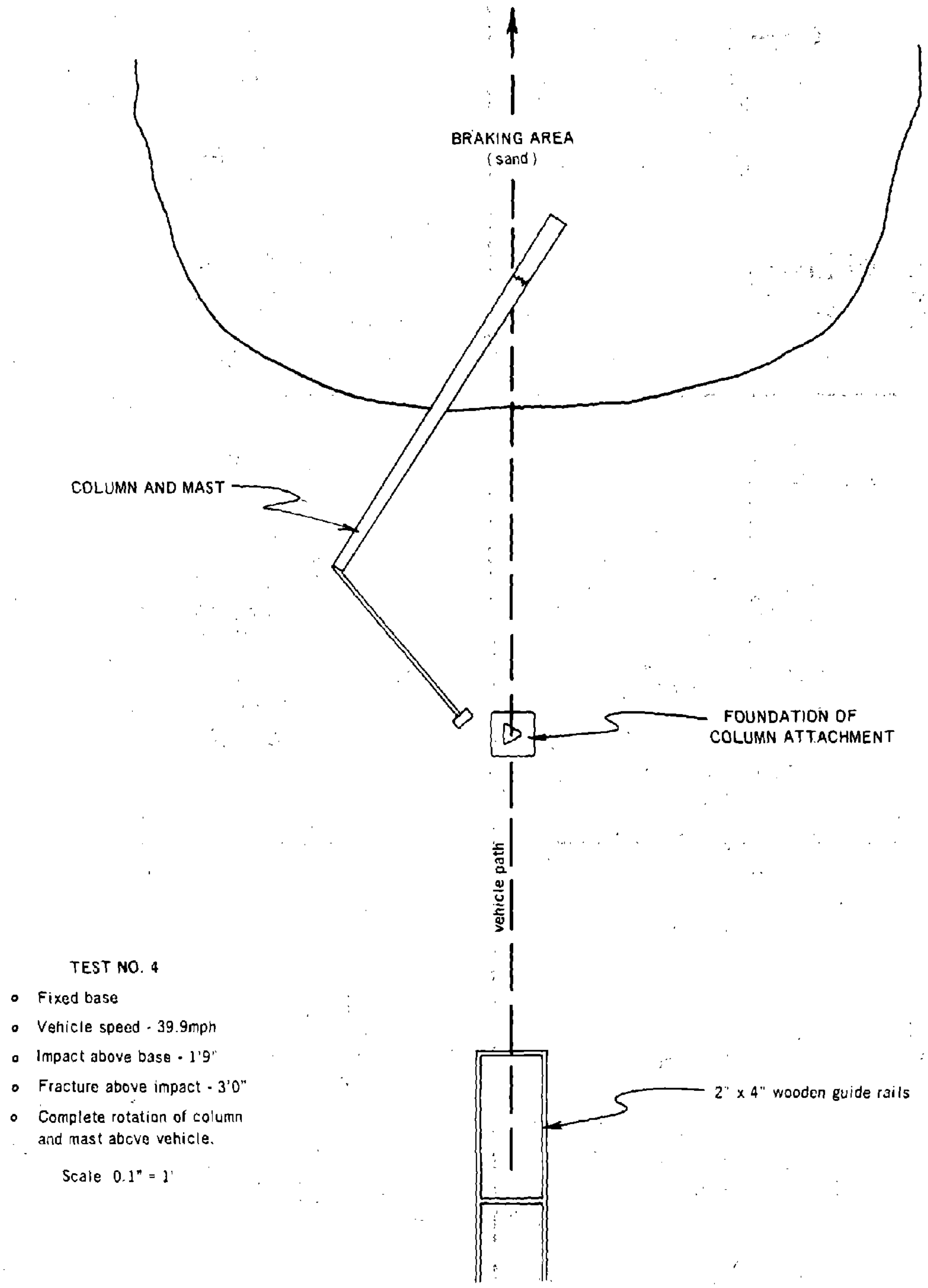

Figure 32. Resting position of column and mast after impact in test No. 4

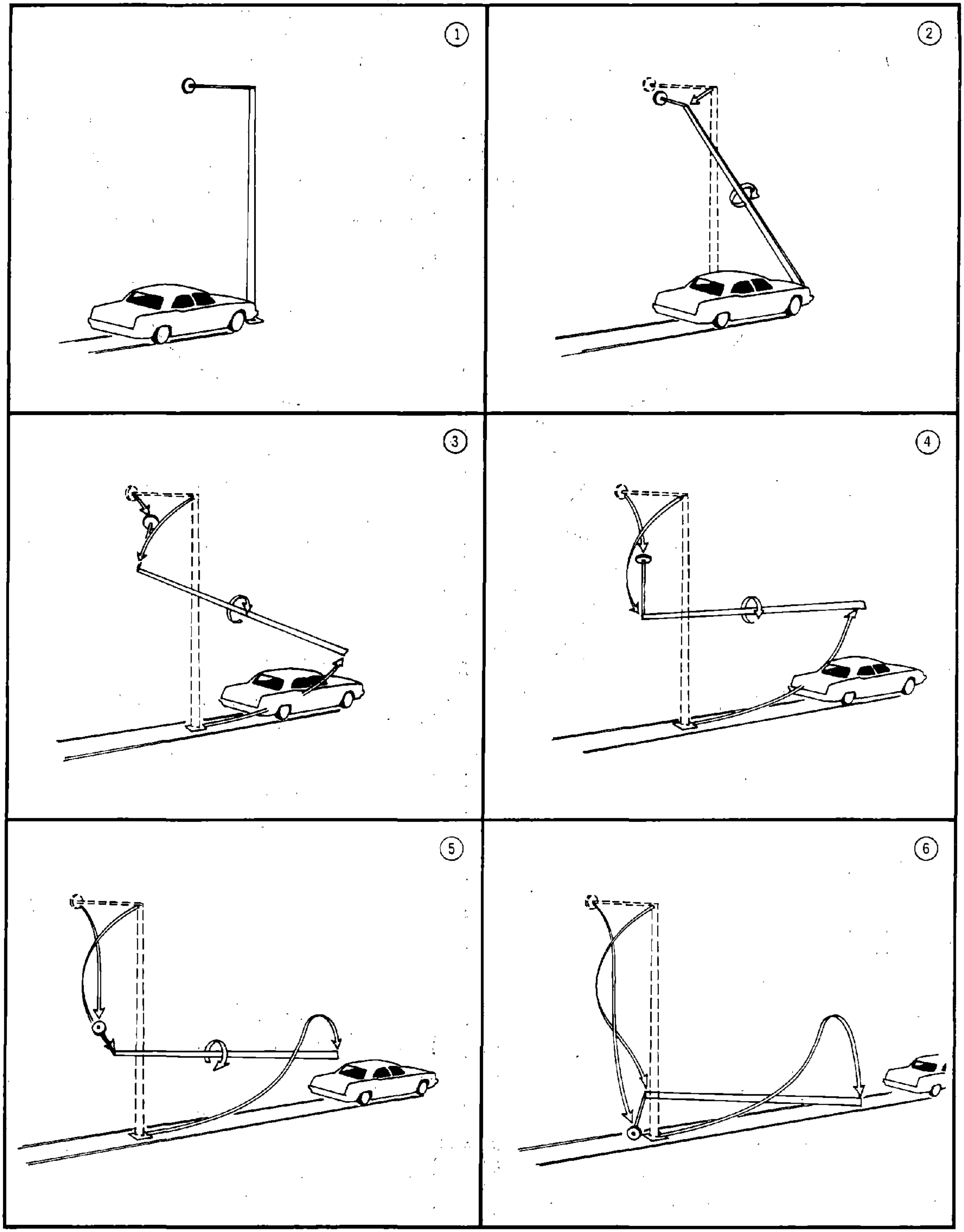

Figure 33. General direction, rotation and landing position of impacted column and mast arm.

APPENDIX III

(The following comments were submitted
to NDOT by Light Structures and Devices)

WIND LOAD AND DEFLECTION TESTING

The complete pole structures weighed 70-75 pounds (31.5-33.75 kg) without the fiberglass cover. One man can carry a captive column light standard.

The projected wind load area of the light standard is 25.7 square feet (2.31 sq.m). The drag coefficient or shape factor is taken as 1.4 (Universal Building Code data for solid towers and chimneys). AASHTO wind load specifications have recently been revised upward at 18.7 psf (91.30 kg/m^2). To test the captive column pole to this specification, we require 18.7 psf (91.30 kg/m^2) x 1.4 = 26 psf (127.82 kg/m^2) uniform load or 675 pounds (303.75 kg) total distributed load.

The captive column was mounted to a vertical test support parallel to the ground in a horizontal cantilever. In this position the top surface of the pole was divided into 1 square foot (0.09 sq.m) areas. The pole was then uniformly loaded with six-packs of beer, each weighing 5 lbs. (2.25 kg). The loading was done in five stages, with deflection measurements taken after each stage of loading. The pole was tested through a maximum static load of 28 psf (136.71 kg/m^2) (including the pole dead weight). An additional 35 pound (15.75 kg) tip load was also tested.

A series of curves showing pole deflection (beyond dead load) vs. pole height are given in Figure 34 for a range of simulated wind velocities. Maximum tip deflection was less than 5 inches

(12.5 cm) for uniform loading simulating 88 mph (39.34 m/s). Even at these wind pressures, the maximum stresses in the main chord elements are less than 50 percent of their yield strength.

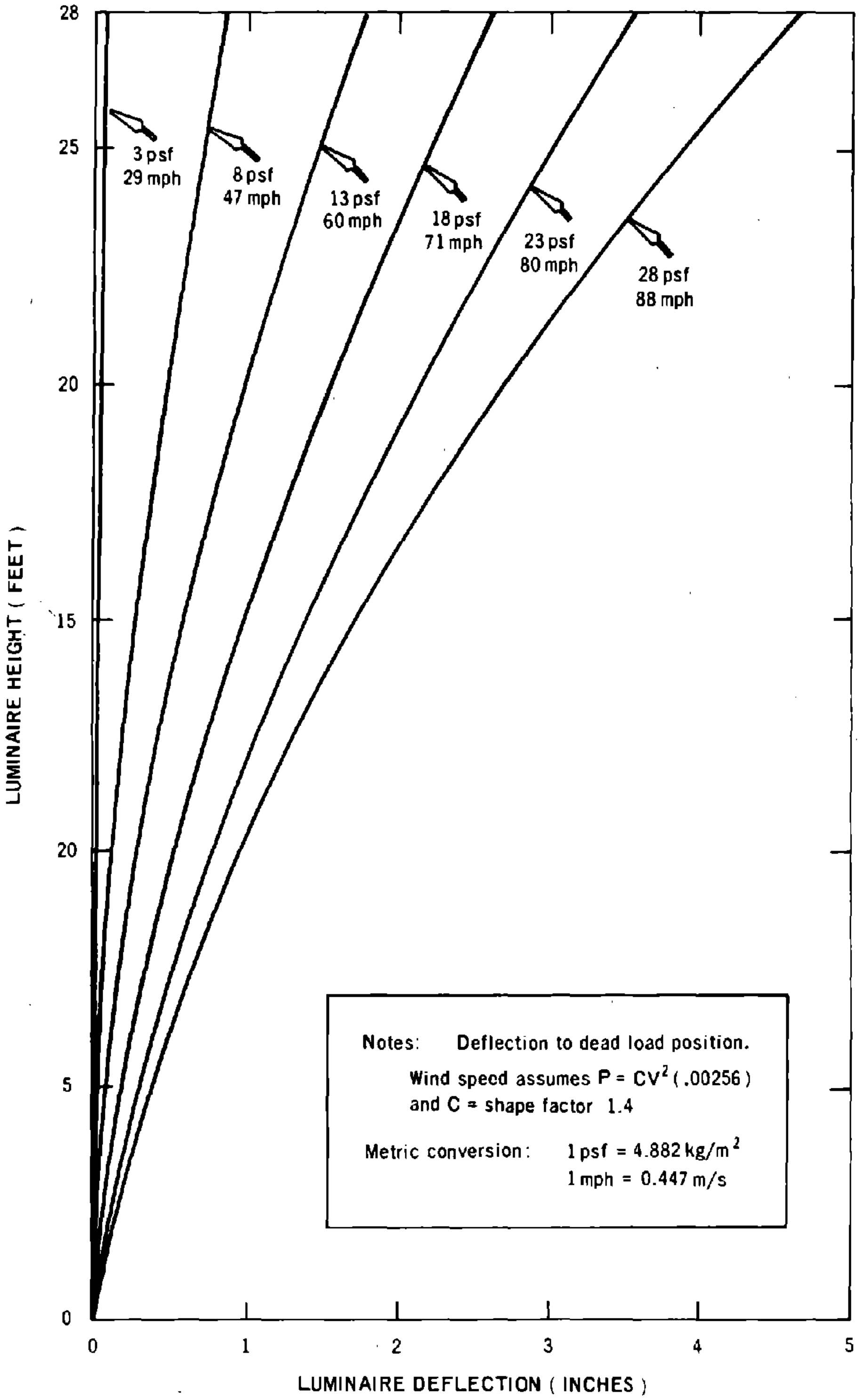

Figure 34. Pole deflection vs height for various uniform loads. (task order No. 5, light standards)

APPENDIX IV

(The following comments were submitted to NDOT by Light Structures and Devices)

RESPONSE TO COMMENTS AND QUESTIONS

During and after the crash test, questions were raised about durability and fatigue, torsional strength, vandalism and economics. We feel these questions are valid and most can be satisfactorily answered.

1. DURABILITY AND FATIGUE

This question is often raised concerning composite structures. We will consider the durability of the rod, filament, core elements, and the fiberglass jacket in turn.

Many successful composites are on the market today. The problems of bonding diverse materials and maintaining the bonds under repeated stress cycles have many solutions. Consider, for example, steel belted radial tires, racing cars, airplanes, filament wound tanks, steel braided hose, etc.

(a) The steel rods (column elements) are stress-proof steel. This type of steel has a yield strength of 100,000 p.s.i. (7,031 kg/cm^2) and an endurance limit of 63 percent of the yield strength. This means that each rod element can safely be stressed an almost infinite number of cycles without failure if the stresses are less than 63 percent of the rod's yield strength. The stresses experienced in the rods due to a uniform load of 28 lbs. per square foot (136.71 kg/m^2) (88 mph) (39.34 m/s) are less than 50 percent of their yield limit. We conclude that, since the anticipated maximum stresses are below the rod's endurance limit, an infinite number of stress cycles can be accommodated.

(b) The steel wire used for the filament elements is brass coated high-tensile steel, the same as used in many steel belted radial-ply tires. This wire has a yield strength of over 250,000 p.s.i. (17.577 kg/cm^2) and a very high endurance ratio. Due to its brass coating, this wire may oxidize with time. For in-service use we will utilize the same wire with an electro-galvanized finish (not unlike the wire used to make aircraft cable) which is quite corrosion resistant.

(c) The wood core could be treated with any number of available processes (not unlike wood poles). Due to the expected short life of these prototype poles, the fact that they were to be impacted, and the low budget for their construction, no effort was made to seal or preserve the structures for long term use.

The wooden core elements experience compression loads only. Due to the nature of the flow of forces in the captive column structure, the compressive forces on the core are small. As wood ages, its dimension perpendicular to the grain can change. However, the dimensional stability of properly dried and treated wood along the grain axis is very good.

(d) Fiberglass cloth or chopped roving set in polyester resin makes durable surface structures, as for example in car bodies and boat hulls. Fire retardant and U.V. resistant resins are available, though more costly.

General purpose resins have lifetimes of over 25 years and may show only some surface oxidation when exposed to the elements for more than 10 years.

2. <u>TORSION</u>

The 2 inch (5.0 cm) square steel tube mastarms used in these test are not sufficiently rigid for in-service use. There captive column mastarms would be employed. The tubes served adequately to place the dummy luminaire load at the Type 7 (Figure 25) Luminaire mounting location and to demonstrate the motion of the pole, arm and luminaire under impact and during and after breakaway.

The captive column can easily incorporate resistance to torsional forces such as imposed by wind forces on the luminaire and mastarm. This is a matter of design and requires incorporating sufficient strength in counter-wound helical bands of tension filament applied at appropriated wrap angles. The torsional forces are distributed through the length of both the compression core and the main chord (rod) elements.

The twisting movement caused by the whipping of the luminaire weight at impact was accommodated by the structure without damage or distortion.

3. <u>VANDALISM</u>

Many questions were raised about vandalism, mostly brought on by the thinness of the prototype's fiberglass skin. These prototype poles are easily susceptible to puncture and would not be acceptable for in-service use. However, the fiberglass skin could be applied by the chopper gun method. Up to a ¼" (0.63 cm) thick skin could be applied to the bottom 8 (2.44 m) to 10 (3.05 m) feet of the pole. This method of fiberglass and resin application is widely used in the manufacture of boat hulls, car bodies and shower stalls, all of which prove to be very durable in strength and finish. We feel this would sufficiently reduce vandalism attempts.

4. ECONOMICS

We are confident that the captive column pole can compete in the marketplace. In terms of crash worthiness, insurance companies will find they only need replace the captive column pole, rather than deal with vehicle occupant injuries and fatalities, pole replacement cost, and vehicle damage cost as associated with conventional systems. This also is economics.

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