AN EXPERIMENTAL INVESTIGATION OF MICHIGAN STATE HIGHWAY GUARD RAIL ANCHORAGES

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An Experimental Investigation of Michigan State Highway Guard Rail Anchorages

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by

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PREFACE

For many years the Michigan State Highway Department has been using specifications for guard rails that, for the most part, have not been designed or proven by tests. Their specifications are the outgrowth of the ideas and practice of field men. The Highway Department recognizes the need for an investigation of the present design and it is in conjunction with the Department that I am undertaking the experimental study of guard rail anchorages. This study is of course a small but important part of the design picture. Due to the experimental nature of this portion of the investigation it was deemed impractical to undertake more of the design.

I would like to acknowledge and thank Mr. E. A. Finney and Mr. L. D. Childs of the Michigan State Highway Department for their cooperation and advice in this project. Also I would like to thank Dr. R. Thurm for translating the German reference to me.

AN EXPERIMENTAL INVESTIGATION OF MICHIGAN STATE HIGHWAY GUARD RAIL ANCHORAGES

In selecting a thesis subject it seemed to me best to select one of some practical value. Having heard that the State Highway Department has allowed students to work on some of their projects for thesis work, I investigated and found that they had a number of such projects. I had in mind at the time the idea of doing some type of experimental work, so was attracted to this particular study of guard rail anchorages.

PURPOSE

The purpose of this investigation is to determine experimentally the resistance to pull out of various types of anchors with the end view in mind of having values for the redesign of the guard rail. The anchor with a high value of pull out resistance consistent with economy will of course be used in the design and later in the recommendation for the standardization of the specifications.

HISTORY

D. C. Hubbard, research engineer for A. B. Chance Co., has made a very extensive study of the holding power of various special anchors, made by his company, in various types of soil. The anchors tested were patent metal anchors such as screw, expanding, rock, pyramid cone types. While these anchors have little application to guard rail anchors in Michigan, the methods and conclusions will give an insight into what has been done in the way of testing anchors.

Full scale anchors were buried in from 3 - 7 feet of various type soils varying from marshes to rock. By means of a pole, block and tackle, strong spring scales and a caterpillar tractor for power, the anchors were pulled out at an angle of 45°. In this manner "Maximum Soil Holding Strength", defined as the point at which the anchor started pulling out, of the different anchors in varying soil conditions was found. Excellent graphs and tables were made from these values. Further it was learned that the values decreased approximately 15% for depths of one foot less than given in the tables and 10% less for the second foot. In other words, the pull out values do not vary lineally with the depth of burial. The shallower depths were found to be more susceptible to creepage. The moisture content of the soil type was found to be a factor more important than a fine division of soils within the classification bracket. They recognized a 15% variation in their values due to the variance of soil conditions.

An article in German entitled, "Soil Resistance of Anchor Plates", by Dr. Wilhelm Buchholz, when partially translated proved very interesting and suggested some methods used by the author. Dr. Buchholz tested different sizes of square plates at depths 1 - 4 feet with a horizontal pull through a wall. His use of photographs and layers of colored sand were the features utilized in the author's tests. His photographic results are presented and compared with my results in the data section of this paper.

"An Experimental Study of Special Anchors in Sand and Clay", a thesis by R. T. Haggerstrom, contained much valuable information as it dealt with tests very similar to mine. He used three types of anchors of a small scale and a pulley and weight pulling system. His variables were soil types, sand and clay; depth of burial, 8 inches and 4 inches; angle of pull out, 60° and 45°. Angle of pull out of 45° was found to be best while the greater depth proved to have greater pull out value as might have been expected. Experimenting with impact loads, he found clay to be more resistive than the sand.

This was the background from which the following was decided: The tests would be done with scale model anchors of the type given in the Michigan State Highway Specifications plus some other shapes of the same cross sectional area. Further the tests would be run under the worst conditions encountered in highway fills, i.e. dry sand. A highway shoulder section to scale in the relative position of actual conditions would also be used. The use of colored sand for determining sand movement and the use of photographs for recording was thought to be of value in the tests. Keeping in mind the methods and findings of the above investigators, the following apparatus and procedure was evolved.

APPARATUS

Figure 1 shows general views of the apparatus that was built. The box has interior dimensions 3 feet by 4 feet by 28 inches, which was governed by the scale 3 inches = 1 foot, that was deemed suitable for use. The observation port was a 3/8 inch thick plate of glass. Opposite the port an angle iron bracket was attached to accomodate the pulley arrangement. Holes in the vertical legs were for adjusting the angle of pull out to 45°. In one corner (nearest pulley bracket) strap iron brackets were fastened inside the box to receive vertically the vibrating arm of

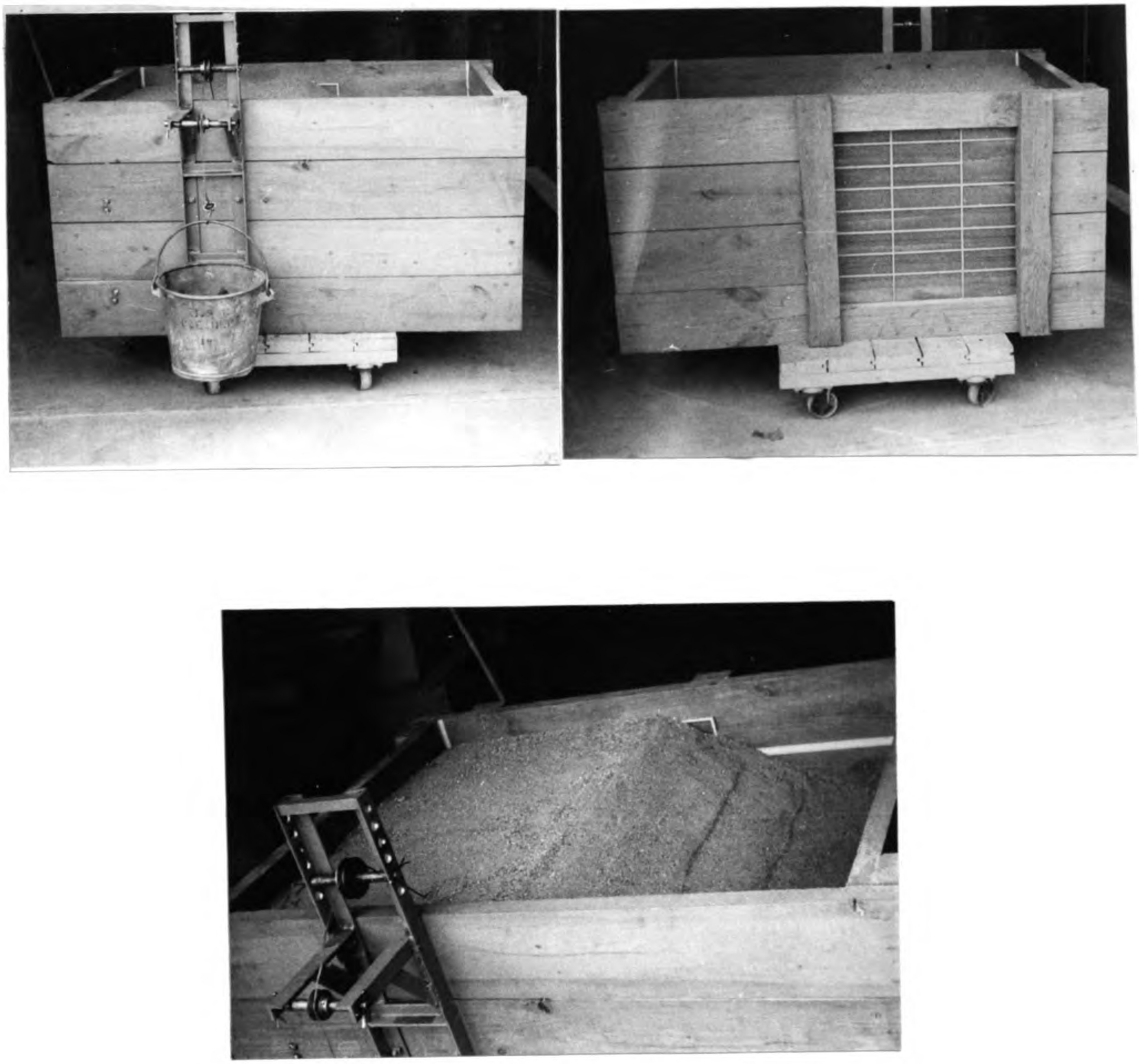


Figure 1. General views of apparatus.

a portable vibrator. This vibrator was of the type used to vibrate concrete into place. A 3/8 inch flexible cable with a bucket attached completed the apparatus. The whole was placed on a dolly for portability.

MATERIALS

Shown in Figure 2 are the type anchor that were studied. They were made of concrete, compressed red fiber board (hereafter referred to as plate), and wood as enumerated below:

	Type	Scale Dimensions	Area	Weight
a	Square - Concrete	6" x 6" x 1-1/2"	36 sq.in.	4-1/2#
b	Circular - Concrete	1-5/8" x 6.78" Dia.	"	5-1/2#
c*	Circular - Plate	1/2" x 6.78" Dia.	"	1-1/2#
d	Oval - Plate	1/2" x 7.15" x 3.92" Dia.	"	1-1/2#
e	Log	15" x 2-1/2" Dia.	37.5 sq.in.	2-1/4#

* Not shown in photographs of Figure 2.

Anchors (a) and (e) are scale models of anchors as specified by the Michigan State Highway Department.

The sand in which tested was a well graded sand described locally as Boichot Sand. Colored sand was made by adding fabric dye to Boichot Sand with small amounts of water and then drying in an oven.

PROCEDURE

The bottom of the box was covered with sand to a depth of approximately 4 inches. The anchor with cable attached was then placed in such a manner that the cable angle would be 45°. Layers of sand of 3 inches

a. Square Concrete

b. Log

c. Circular Concrete

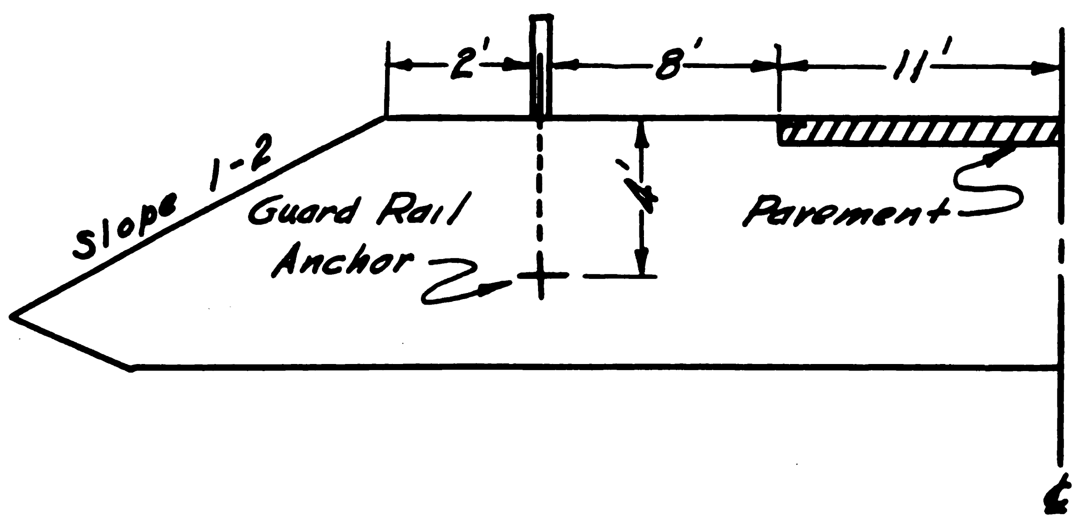
d. Oval Plate

Figure 2. Views showing types of anchors used.

were added with wedges of colored sand placed at the port and at the point where the shoulder section would cut after filling. See Figure 2a. This was then vibrated for one minute. The purpose of vibrating was to partially compact the sand but most important to create uniform conditions from one test to another. This process was repeated until 12 inches of sand covered the center of gravity of the anchor. After three pull outs proved the lack of movement at the glass port (Anchor buried within 6 inches of the plate glass.) and with the colored sand in the shoulder section of very little use in showing movement there, the use of colored sand was abandoned and the procedure modified as follows. The anchor was

Figure 2a. Views showing colored sand in shoulder section and in the glass port.

located as before and the sand added by layers until approximately covering center of gravity of anchor by 15 inches. The whole was then vibrated for 15 minutes for the same purpose as before. The surface of the sand was smoothed over with 12 inch covering (vibration settled sand from 2 to 3 inches) then covering c.g. of anchor. A cut was then made to scale to represent a shoulder section of highway with a slope of 1:2. See Figure 3.



*Typical Highway Cross Section
Showing Location of Guard Rail*

Figure 3.

The anchor was then ready to be pulled, which was accomplished by adding weight to the bucket end of the cable. Lead shot was poured at the rate of 0.8 pounds per second until 25 pounds (amount of shot available) had been added. This was allowed to remain undisturbed for from 1 to 2 minutes when, if no movement had occurred, the shot was replaced with lead weights and the shot again poured. After several tests an initial load of 200 pounds was used. Creepage was measured by a mark on the cable. This process was repeated until failure occurred. Failure was very apparent with a rapid cable movement of 6 - 10 inches resulting in the weight bucket resting on the floor.

The following measurements were observed:

1. Displacement of anchor in direction of cable.
2. Displacement of sand (recorded photographically).
3. Force to disturb the anchor.

DATA

Anchor Tested

Log type.

Conditions

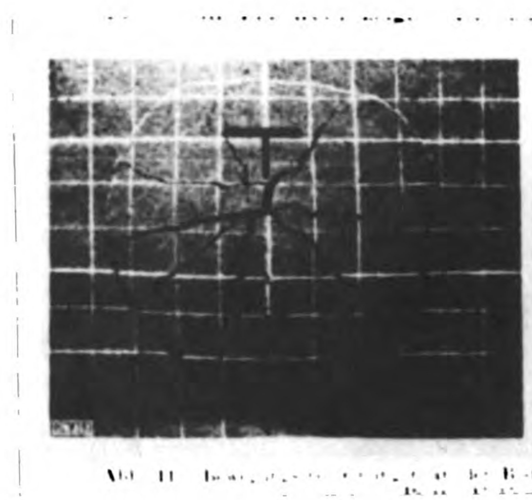
Longitudinal axis horizontal and at 90° to cable.

No.	Creepage Inches	Final Movement Inches	Moisture Content of Sand	Dead Weight Required for Failure
1	3-1/8	3	1.68%	285.5 #
2	---	7	Air Dried	361.0 #
3	---	-	" "	353.5 #
4	---	-	" "	409.5 #
			Mean*	375

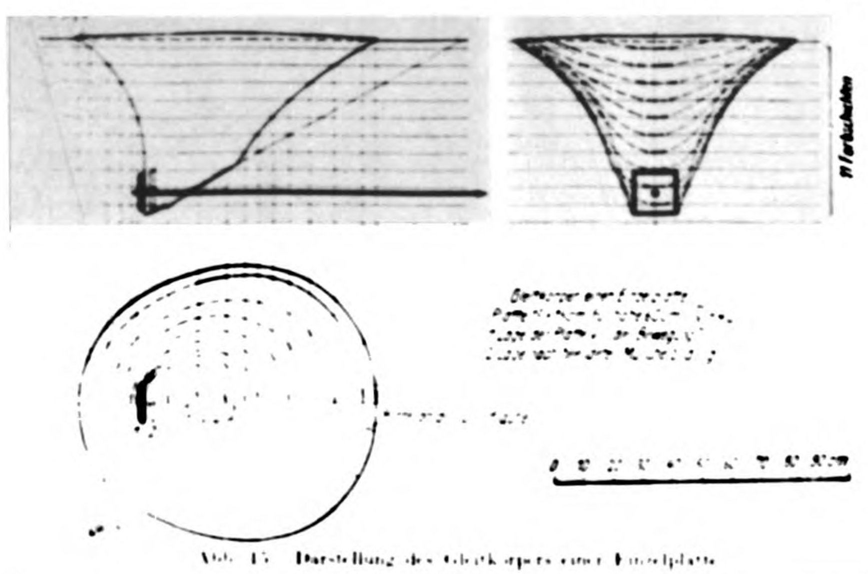
Remarks

* Test No. 1 was run in damp sand as a pilot test and was not used in computing the mean pull out force. This was the only test in which, due to the moisture content, cracks occurred. The photograph of this is shown in Figure 4 and compared to photographs taken by Dr. Buchholz. It is interesting to note from this comparison the influence of the shoulder section. Also from his diagram another striking similarity may be observed. The center of our oval upheaval was displaced 4 inches in the direction of pull from the point of burial. When anchor was uncovered the end toward shoulder had twisted about 1 inch up and toward the pull in all tests with log type. The tests in dry sand produced no creepage with failure occurring rapidly with no warning while the shot was being poured. See Figure 7 for disturbance pattern set up in dry sand.

a. Cracks in shoulder section Log type anchor pull out.



b. Photograph by Dr. Buchholz showing cracks caused by pulling square anchor plate horizontally.



c. Diagram by Dr. Buchholz showing shape of cone of influence. Though his pull was horizontal of cone of influence appears to be similar.

Figure 4.

DATA (continued)

Anchor Tested

Square Concrete.

Conditions

Axis horizontal; face at 90° to cable; all tests in air dried sand.

No.	Final Movement Inches	Dead Weight Required for Failure
1	6-1/2	275.0 #
2	---	313.0 #
3	---	279.5 #
	Mean	289 #

Remarks

From Figure 5 it can be seen that the shoulder was disturbed only slightly. Failed as shot was being poured. Anchor had not turned in a horizontal plane as did the log type.

Figure 5. Views showing the typical pattern caused by pulling square concrete anchor.

DATA (continued)

Anchor Tested

Circular Concrete.

Conditions

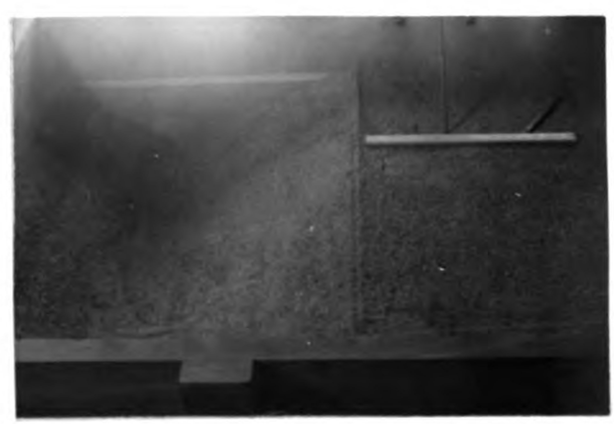
Circular face 90° to cable; all tests in air dried sand.

No.	Final Movement Inches	Dead Weight Required for Failure
1	9-3/4	360.5 #
2	---	328.5 #
3	---	306.5 #
	Mean	331

Remarks

Upheaval pattern is shown in Figure 6. Anchor failed a few seconds after the completion of shot pouring in tests No. 1 and 2 while failure occurred while pouring in test No. 3. Anchor did not turn in a horizontal plane.

a. Typical disturbance pattern set up pulling circular concrete anchor.



b. View showing surface before pulling. 15" ruler is shown in these pictures.

Figure 6.

DATA (continued)

Anchor Tested

Circular Plate.

Conditions

Circular face 90° to cable; all tests in air dried sand.

No.	Final Movement Inches	Dead Weight Required for Failure
1	9	376.0 #
2	-	343.0 #
3	-	309.0 #
	Mean	342 #

Remarks

Disturbance pattern is practically identical to that of the circular concrete type shown in Figure 6. Pull out values of these two types compare very well. The three tests pulled out as shot was being poured and showed no tendency to turn in the horizontal plane.

Anchor Tested

Oval Plate.

Conditions

Longitudinal axis horizontal; oval face 90° to cable; all tests in air dried sand.

No.	Final Movement Inches	Dead Weight Required for Failure
1	8-1/4	331 #
2	---	453 #
3	---	396 #
4	---	443 #
	Mean	405 #

Remarks

Due to wide variation of first three tests a fourth test was run. Tests 2, 3, and 4 failed a few seconds after completion of shot pouring. End toward shoulder tended to twist up and toward pull as did the log type. All anchors tended to ride up toward surface rather than along 45° line on pulling. This was indicated by final position of the cable-angle with horizontal had decreased from 45°.

Figure 7. Typical disturbance pattern set up by pulling oval type anchor. This was very similar to pattern made by the log type.

4

3

3

2.

Resistance to

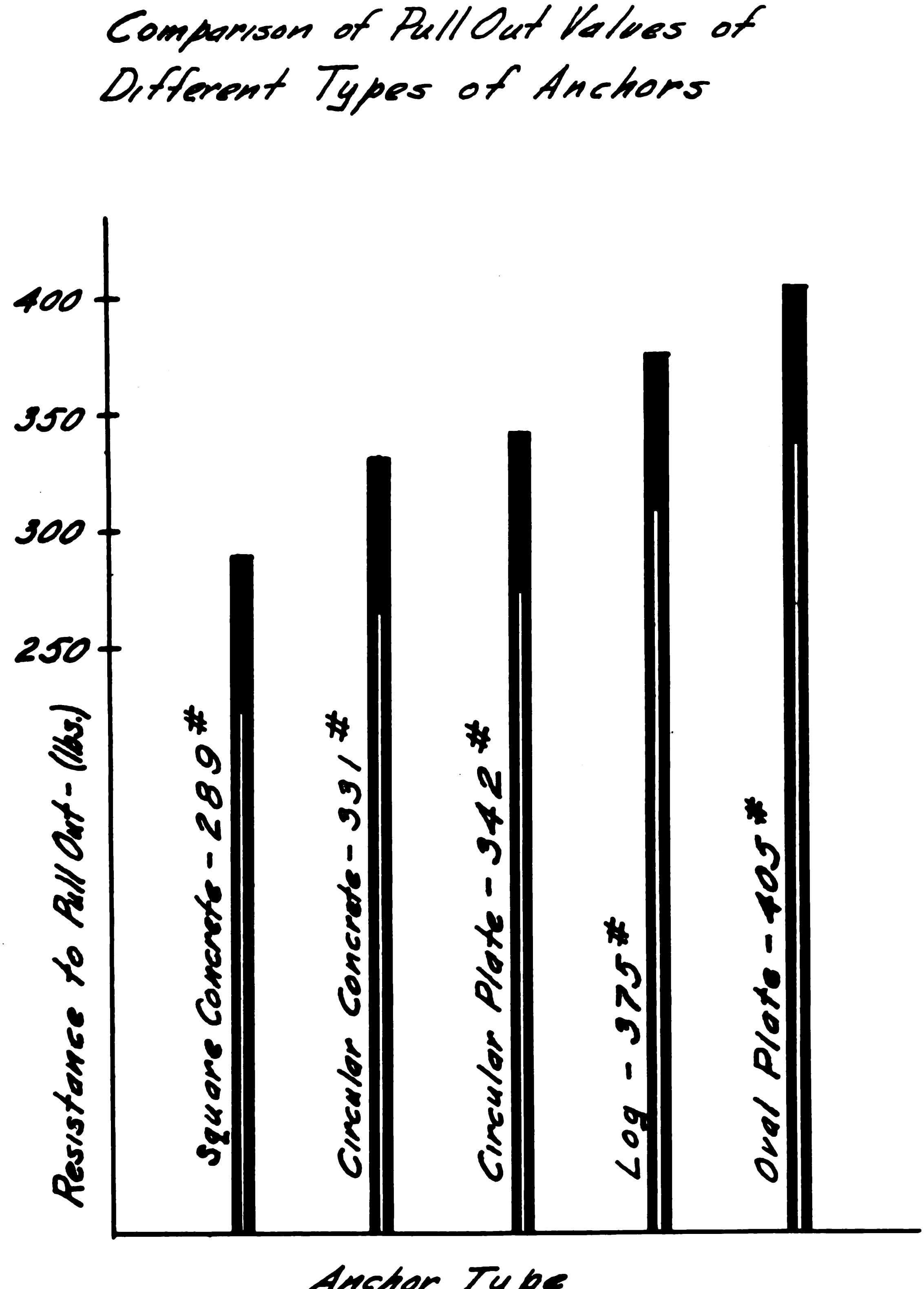

Comparison of Pull Out Values of
Different Types of Anchors
400
350
300
250
Resistance to Pull Out - (lbs.)
Square Concrete - 289#
Circular Concrete - 331#
Circular Plate - 342#
Log - 375#
Oval Plate - 405#
Anchor Type

Figure 8

SUMMARY

The bar graph of Figure 8 gives us a picture of the holding power of the various types of anchors. The relative values of the oval plate, log and square shape are in agreement with the findings of R. T. Haggerstrom. It is obvious that the pull out values would vary directly with the cross sectional area and depth of burial and, since they were constant for our tests, the explanation for the behavior concerns coefficient of friction, weight, or shape of the anchors. Coefficient of friction and weight factors may be immediately eliminated by examination of the anchors, their weights and pull out values. Shape alone then stands as the determining factor. In this vein four curves were plotted with pull out force as ordinate. The abscissi were moment of inertia, perimeter, length to width ratio, and finally simply length (horizontal dimension as buried). The latter curve (see Figure 9) was the only one to give a curve of value. This curve suggests that there is an optimum shape or length of anchor. Even if the log type (last point on curve) were discounted, and the curve assumed to continue upward, the length of an anchor would be limited by practicality. A study of the economics of the problem would undoubtedly show a rectangular type to be most feasible.

Full scale tests have not been conducted. The small scale tests, however, give us a prediction of the relative values of the larger anchors. As to what these values might be would only be a guess at this time, since factors such as weight may enter the full scale tests. Since the Highway Department plans to continue these small scale tests and correlate them with the full scale tests, I would recommend the following:

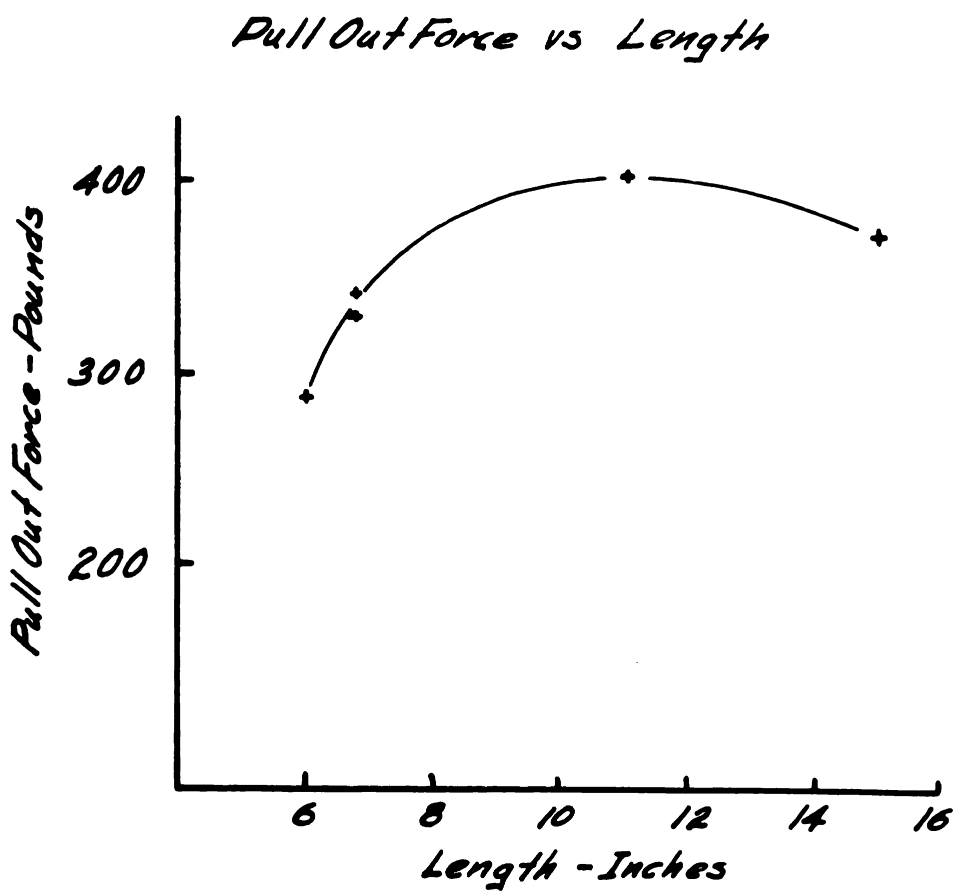

Pull Out Force vs Length
400
300
200
Pull Out Force - Pounds
6
8
10
12
14
16
Length - Inches

Figure 9

1. Investigation of different rectangular plates of equal area.
2. The use of moist sand.
3. Rearrange pulley bracket so that cone of influence may be observed at the glass port by means of colored sand.

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