AN EXPERIMENTAL STUDY OF SPECIAL ANCHORS IN SAND AND CLAY

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An Experimental Study of Special Anchors in Sand and Clay

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Up to the present time there has been very little material written upon the subject of special anchorages - or deadmen as they are commonly called. Intensive searches through the Engineering Index for the last few years netted only one article relating to the specific use of deadmen. This was in connection with anchoring of the back stays of a suspension bridge, a very special job. The lack of any general knowledge on the subject is unfortunate because deadmen are used quite frequently in construction and erection work. The most common examples of the use of deadmen are in the guying of power poles, derricks, and the aforementioned example of the suspension bridge. A tent peg in itself is a modified type of a deadman. Deadmen are also used in the holding of guard rails along the highways. If a problem involving the use of a deadman arises, the engineer has no books or periodicals to turn to, but must cope with the situation either from his experience or ingenuity. He hopes that the anchor selected will prove effective under the prevailing conditions.

On the other hand, possibly, the problem defies classification. Each case is unique, a new problem which must be reckoned with, and variable quantities taken into account. This, and the fact the deadman may assume such small significance as compared to new and different construction methods, may account for the fact that there has been no attempt to report any work or experiments done on anchorages.

The object, then, of this thesis is to test in the laboratory several types of deadmen under varying conditions, with the purpose of noting actions and reactions and attempting to interpret and analyze the results as observed. It being beyond the scope of the author, no attempt is being made to derive any mathematical formulae as the existence of so many variables involved, and the time factor, make the effort prohibitive. At the present time, the Michigan State Highway Department is having research work done on this phase and also the experimental phase. The author, however, is working independently on the project.

The two main points being investigated are the depth of burial of the deadman and the angle that the tie line, makes with the vertical. By varying these conditions and attempting to keep several other variable conditions constant, it is expected and hoped that some favorable results will be obtained. It is expected to bury a large deadman and pull it out later in the spring and the data from the laboratory models and the large scale deadman to be correlated, if possible.

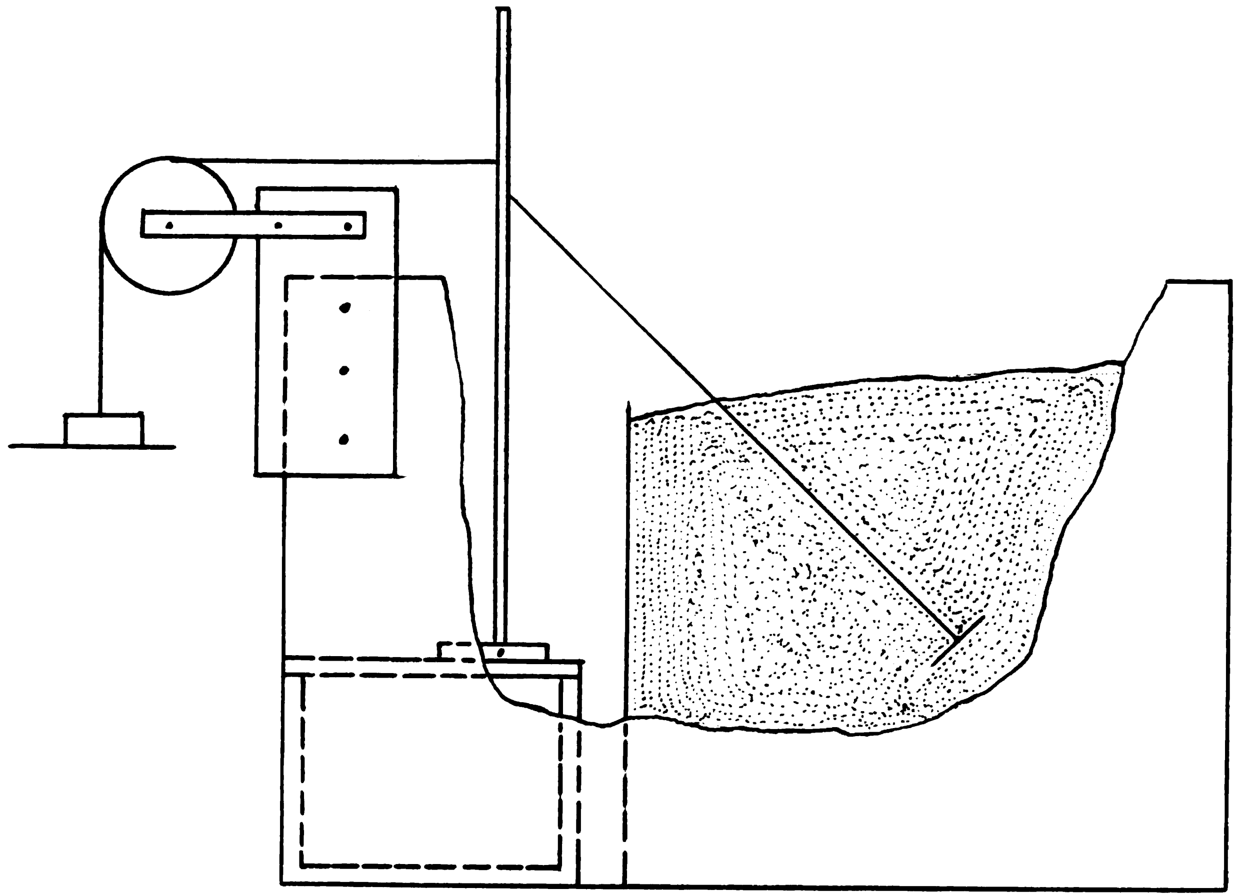
The two mediums selected for pulling out of the deadman were sand and clay, these being chosen because they are the most extreme conditions an engineer is likely to encounter. The sand, a Miami sandy loam was almost perfectly dry, having been in the warm laboratory for about three months and frequently stirred and mixed up. A series of tests was run on the dry sand, the sand was moistened, samples taken from three different places in the box and the average moisture

content of the sand computed. Tests were run on the wet sand, after which the sand was removed. The clay, a brown Miami clay loam, was substituted and the tests continued in this medium.

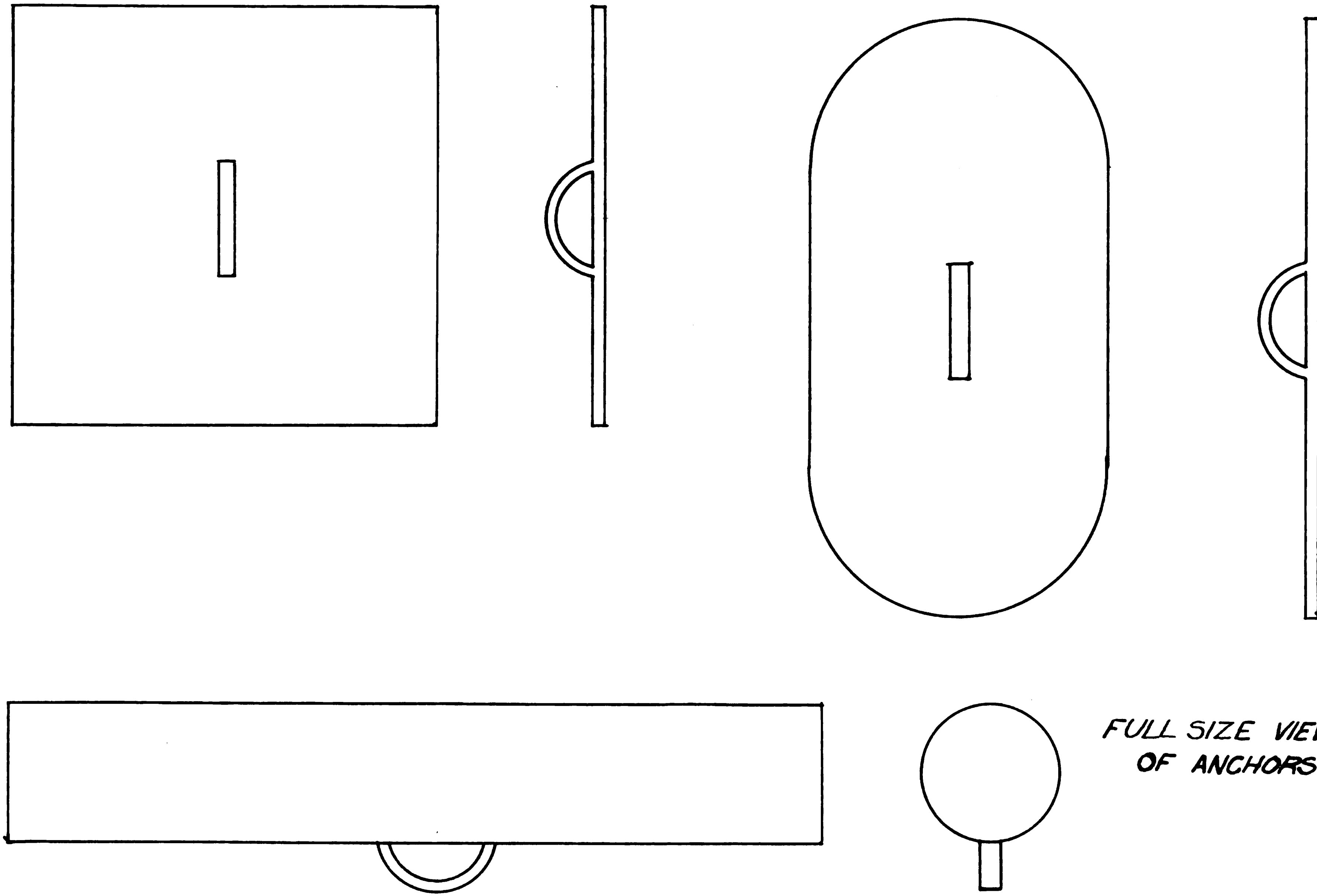
The means of testing the deadman - practically this consisted of pulling them out of the sand or clay - is shown in fig. 1. It consists of a piece of cast iron pipe, 30 inches long and 3/4 of an inch in diameter, to which the deadman are guyed. This pipe was fitted with a plug in the lower end which had a 1/4 inch hole in it for pinning to a pair of 1/16 x 1 x 1 x 3 inch angles which supported the pipe on a wooden bracket securely fastened to an inside corner of the box. Theoretically there is a little friction between the plug and the pin, but after oiling the connection, it was considered to be negligible. The pipe is free to move in a vertical plane only, traverse motion being eliminated due to the design. Holes were drilled in the pipe at different places for the attachment of hooks to which the deadmen and pulling line were fastened. An angle 1/8 x 1½ x 1½ x 8 inches was riveted with two pieces 3/32 x 1 x 6 inches to which a 2½ inch pulley was pinned with a ¼ inch pin. Again this was oiled and friction between pin and pulley was considered negligible.

The line for connecting the deadman to the pole, and pole across the pulley to the load was of the clothesline variety averaging .132 inches in diameter. The friction between the pulley and the line is assumed to be .3,[1] because

1 Analytical Methanics for Engineers, Seely & Anson, John Wiley & Sons, New York, pp. 123



CUTAWAY SCHEMATIC DRAWING OF APPARATUS.



FULL SIZE VIEW
OF ANCHORS

no spring balance delicate enough was available to determine the actual friction, and the tension in the line computed according to the familiar belt friction formula. With the tension known, it is a simple matter to determine the stress in the line holding the deadman.

The anchors used were three in number. One was a round bar of cold rolled stee, 5 3/4 inches long and 1 inch in diameter. Fitted with its hook it weighed 1.23#. The next two anchors were made of hot rolled sheet steel approximately 1/16 inch thick. One was in the shape of a square, 3 inches on a side. The other had a somewhat oval shape with the following dimensions. A square 2¼ inches on a side, with 1 1/8 inch semicircles at two opposite edges. The latter two anchors, fitted with hooks each weighed 0.23#. They were all designed to have an identical effective area of nine square inches, with only one half of the area of the round bar assumed acting in resistance to the pull. In burying the plate anchors in preparation to pulling them out, care was taken that the plate was exactly perpendicular to the line so that it would offer the greatest resistance to the load.

The sand used during the experiment had a sieve analysis of the following character.

Sample weighed 252.5 grams

		%
Weight Retained on # 4 sieve	0	0
Weight Retained on # 10 sieve	2	0.8
Weight Retained on # 20 sieve	80	32.6
Weight Retained on # 40 sieve	130.4	52.6
Weight Retained on # 60 sieve	28.7	9.8
Weight Retained on # 140 sieve	9.6	2.8
Weight Retained on # 200 sieve	1.6	0.6
Total	252.3 g.	99.2%

The clay used was a brown Miami clay loam from a borrow pit on N. Center street in East Lansing. The borrow pit is actually a small terminal moraine and is principally a very uniform clay. Time limitations made it impossible to run a mechanical analysis of the clay and determine its actual gradation.

Procedure

The anchor was placed in a depression in the sand in such a position that the depth was the required distance (either 8 or 4 inches) and that the angle made by the tie line to the pole was either 45 or 30 degrees with the vertical. Sand was then carefully placed around the deadman, making sure the plate was perpendicular to the tie line. When the sand was up to the required depth, it was compacted seventy-five blows with a round steel cylinder, two inches in diameter and weighing five and one-half pounds. The cylinder was raised one inch and allowed to fall. This compaction covered an area of one square foot directly over the anchor. A can was then placed on the loading arrangement and lead shot was poured into the can at the rate of three hundred grams per minute. This was continued until the deadman failed, failure being considered when the pipe had deviated thirty degrees from the perpendicular. In the wet sand and clay a different loading scheme was used. The loading was done with cast iron weights of the common variety put on at five minute intervals until the anchor was close to failure, and then continued with lead shot. This was done because it was impractical to load entirely with lead shot.

After having completed the dead load testing, impact loading was next considered. However, in this experiment, only one anchor, the oval plate, was loaded in dry sand. Dry sand being obviously such a poor retaining agent, the impact test was done for merely curiosity. Impact loading was accomplished thusly --- a weight of thirty to forty perc nt of the dead load was placed one inch above the loading pan and allowed to drop. Usually failure did not ensue, so the medium was recompacted twenty-five times with the compacting tool as described above and another weight selected. This was continued until failure occurred, which usually was so sudden and complete that it pulled the anchor totally from the sand or clay.

DRY SAND	DATA	0% Moisture	SHEET 1
Anchor	**Depth Inches**	**Hitch Angle Degrees**	**Dead Load Pounds**
Round Bar			
1	8"	45	16.4
2	8"	30	16.1
3	4"	45	7.5
4	4"	30	6.7
Square Plate			
1	8	45	13.2
2	8	30	12.0
3	4	45	2.6
4	4	30	7.2
Oval Plate			
1	8	45	16.9
2	8	30	6.6
3	4	45	4.4
4	4	30	2.3

DRY SAND (con)	DATA	0% Moisture	SHEET 2

Anchor	Impact Load	% of Dead Load	Stress in Anchor Line
Round Bar			
1	-	-	209 psi
2	-	-	295 psi
3	-	-	139 psi
4	-	-	198 psi
Square Plate			
1	-	-	189 psi
2	-	-	252 psi
3	-	-	93 psi
4	-	-	194 psi
Oval Plate			
1	6.9	41.2	212 psi
2	4.4	67.7	186 psi
3	3.3	75.0	107 psi
4	1.6	72.0	109 psi

	DATA		SHEET 3
WET SAND		5.4% Moisture	

Anchor	Depth Inches	Hitch Angle Degrees	Dead Load Pounds
Round Bar			
1	8	45	23.64
2	8	30	15.97
3	4	45	11.7
4	4	30	6.3
Square Plate			
1	8	45	18.64
2	8	30	17.81
3	4	45	7.4
4	4	30	7.2
Oval Plate			
1	8	45	19.84
2	8	30	12.86
3	4	45	8.00
4	4	30	6.25

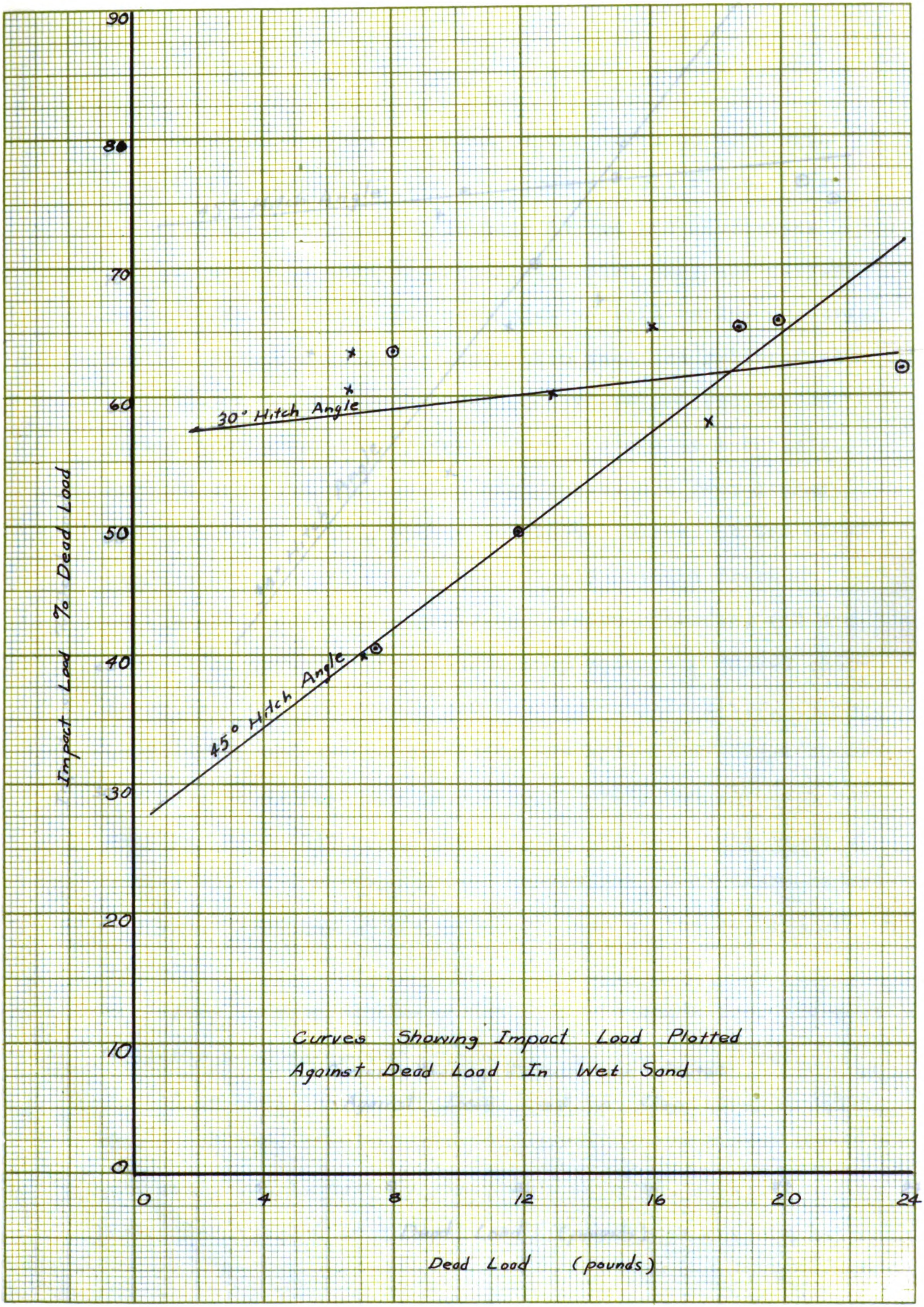
DATA SHEET 4

WET SAND (con.) 5.4% Moisture

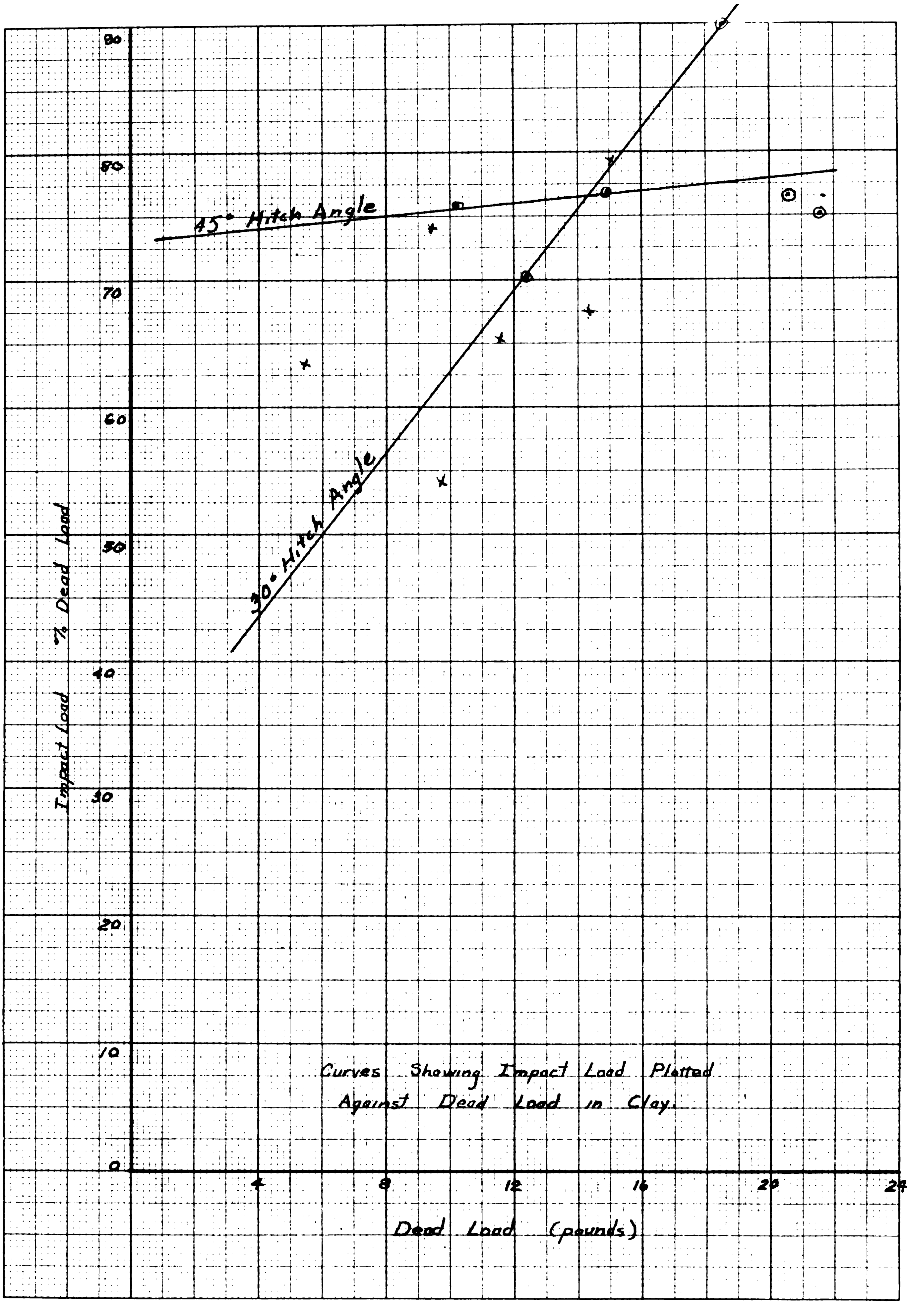
Anchor	Impact Load #	% Dead Load	Dead Stress in Line
Round Bar			
1	17	72%	252 psi
2	12	75%	294 psi
3	7	59%	177 psi
4	4.4	62%	183 psi
Square Plate			
1	14	75%	222 psi
2	12	67%	306 psi
3	3.7	50%	141 psi
4	3.6	50%	196 psi
Oval Plate			
1	15	76%	229 psi
2	9	70%	260 psi
3	5.83	73%	162 psi
4	4.67	74%	180 psi

CLAY	DATA		SHEET 5
Anchor	**Depth Inches**	**Hitch Angle Degrees**	**Dead Load Pounds**
Round Bar			
1	8	45	20.6
2	8	30	15.0
3	4	45	12.33
4	4	30	9.87
Square Plate			
1	8	45	18.5
2	8	30	10.67
3	4	45	10.16
4	4	30	6.33
Oval Plate			
1	8	45	22.7
2	8	30	14.4
3	4	45	15.2
4	4	30	9.1

CLAY (con.)	DATA		SHEET 6
Anchor	Impact Load	%Dead Load	Dead Stress in Line psi
Round Bar			
1	15.86	77	238 psi
2	12.0	79	287 psi
3	8.67	70	192 psi
4	5.3	54	218 psi
Square Plate			
1	16.7	90	216 psi
2	7.0	66	246 psi
3	7.67	75	161 psi
4	4.0	63	185 psi
Oval Plate			
1	17.1	75	247 psi
2	9.5	66	283 psi
3	11.4	77	201 psi
4	6.9	74	206 psi



Impact Load % Dead Load
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
30° Hitch Angle
45° Hitch Angle
Curves Showing Impact Load Plotted Against Dead Load In Wet Sand
Dead Load (pounds)


90
80
70
60
50
40
30
20
10
0
4
8
12
16
20
24
45° Hitch Angle
30° Hitch Angle
Impact Load % Dead Load
Dead Load (pounds)
Curves Showing Impact Load Plotted Against Dead Load in Clay.

Analysis

Sand and clay were chosen as the media to work with because they represent the two opposite soil types. The textures are the prime difference in the two substances and it is due to this characteristic that they act differently under loading. The particles of soil having a coarse texture with particles no finer than sand are referred to as granular and their physical properties are recognized as being of great importance. Purely granular materials have no cohesion but develop high resistance from mechanical stability when properly confined. Clays, on the other hand, which consist of the most finely divided fraction of the soil, have the ability to develop cohesion, and are in general affected predominantly by molecular forces characteristic of microscopic and submicroscopic matter. High capillarity and low permeability are typical of clays while granular sands have negligible capillarity and are very permeable. With this comparison of the two main soil types at either end of the scale giving an insight as to their behavior under loading, let us consider some of the actions of the anchors.

From an examination of the data, it seems that the most reliable deadman in the trials run was the oval plate, buried so that the longitudinal axis is in a vertical plane. The round bar, simulating a log, performed better in the wet sand, but it must be remebered, however, that the round bar weighed approximately five times as much as the plate did, and the force of gravity cannot be neglected. While the value of the dead load testing may not seem to be too valuable, it nevertheless serves as a criteria in estimating and selecting the impact load which naturally is the most important aspect of the problem. Of the one trial run in dry sand, the impact load averaged sixty percent of the dead load while in wet sand and clay, it was considerably higher. The average impact loading for wet sand and clay was about seventy per cent of the total dead load. As was expected, the hitch angle which is most desirable to use is forty-five degrees because it has a greater horizontal component of force than a hitch angle of sixty degrees, for example. Since both horizontal and vertical components enter into the pulling, the angle which furnishes the maximum horizontal and vertical resisting force is logically the most suited - ergo, the best hitching angle to the post is forty-five degrees.

Although the experiment was run with the depth varied only twice (four and eight inches) it certainly was soon obvious that the depth is a very important factor. In almost every case the greater depth, eight inches, was the most effective, i. e., required a greater force on it to eject the anchor. Earth, in this respect, behaves somewhat like water, that is to say, the greater the depth, the greater the pressure on an object immersed or buried in it. As to the depth that is the most efficient and economical, this paper is not prepared to venture upon. These two factors, hitch angle and depth of burial, were similar in both the sand and clay.

Two interesting facts were noted in the pulling of the anchors from the sand. As was described in the method of loading, increments of weight over a period of time were used. After about the third increment was applied, when the line was very taut and had stretched its maximum, each additional increment was noted to affect the anchor. The post would move from three to six degrees from its past position showing that the anchor was moving in the sand. Apparently the sand was being confined or compacted about the anchor and when enough resistance was developed, the anchor would stop. In most cases, this took from one to two minutes, with one case, the oval plate moving for two and one-half minutes before equilibrium was again reached. The second fact noticed was that the oval and square plate, in every case; in dry and wet sand, had a tendency to rotate about the bottom edge of the anchor, so that when failure occurred, the plate was about parallel and in the same plane as the tie line. The plate anchors evidently followed the path of least resistance. Of course, this difficulty could be overcome if the anchor were fitted with attachment hooks near the top and bottom and an equal amount of tension applied to each hook.

In clay, however, different phenomena occurred. The plates showed no tendency to rotate about the lower edge, but rather pulled out equally, and in so doing, sheared off four truncated pyramids of clay, one on each side of the tie line.

Failure in sand was very slow and gradual, whereas in clay the failure was very rapid and sudden, although there was some evidence of the anchor creeping through the clay as it did in the sand. The compaction of the sand and clay was measured with a hydraulic penentrometer device and while the sand seemed quite uniform in resisting the needle throughout its depth, the clay most assuredly did not. The top one to two inches showed the results of compaction while the remaining depth showed absolutely no evidence of compaction whatsoever. If an engineer ever put a deadman in clay, it is recommended that he stabilize with sand, and put in the resulting mixture a layer at a time, and tamp firmly before putting in the next layer of clay.

Summary and Recommendations

The best anchor for sand and clay was the oval plate with the round bar second and the square plate last. The best hitching angle was found to be forty-five degrees. The depth is a factor which may have limitations as to location and economy, but the greater the depth, the more is required to pull the deadman from the earth. Dry sand is a poor medium for holding anchors for it develops less mechanical stability than wet sand. When sand is wet to any intensity, the outer sand may dry out quite readily, but the inner sand stays wet for quite a period of time. If a deadman is to be anchored in clay, it should be stabilized with something, preferably sand if readily obtainable, and tamped around the deadman in layers to assure complete compaction.