Predicting Pile Capacities Using Dutch Cone Penetrometer Data

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EQUIPMENT

The first Dutch cone penetrometer purchased by the Mississippi State Highway Department was an 89-kN (10-ton) capacity model mounted on a trailer. The vertical-load reaction was accomplished by screwing an auger assembly into the soil by means of a hydraulic driven spanner at six predetermined locations (1). Sounding data, which included both point resistance and skin friction, were obtained at 1-m (3.3-ft) intervals in most cases, although, if conditions warranted closer intervals, the spacing could be reduced to as low as 0.2 m (8 in).

The second piece of equipment was a drilling unit mounted on a swamp buggy, which was modified to make penetrometer soundings and has proved a more successful piece of equipment.

FIELD PROBLEMS ASSOCIATED WITH THIS EQUIPMENT

Mississippi soils are composed of many strata of relatively thin rock or dense sands, which, when encountered, present difficult problems for performing penetrometer soundings. The thin rock layers and boulders possess extremely high point bearings and can stop the sounding. Because of the point size, a very dense, thin sand layer will appear to be infinitely thick, and many times will cause the sounding to be stopped short of the desired depth, although pile driving records indicate that piles are very little affected by these layers. Soundings also should not be attempted in sands in which the standard penetration test is consistently above 60.

Soundings with a skin friction cone should not be performed in gravel formations; instead, a point resistance cone should be used. Providing the necessary vertical reaction also presents problems.

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MODIFICATION OF PRESSURE MEASURING EQUIPMENT

The pressure measuring equipment used with the Dutch cone penetrometer was modified so that the readings could be obtained with an X-Y plotter. A pressure transducer was installed to provide an electrical output for the Y-axis of the plotter, and a linear resistor was used to provide the signal for displacement.

INTERPRETATION OF CONE PENETROMETER DATA FOR DETERMINING PILE CAPACITIES

A typical output sheet of sounding data is shown in Figure 1. The first portion of the curve is the point resistance and the second part is a combination of the point resistance and the skin friction for the friction sleeve. This plot is unique in that the point resistance and the skin friction are clearly defined. These data were reduced to unit point resistance (UPR) and unit skin friction (USF) by the formulas

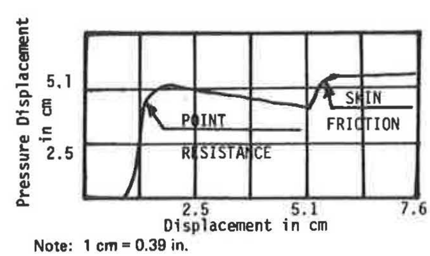
$$UPR = (YPM)(PSPI)(AOL)/(AOP) \quad (1)$$

$$USF = (YPM)(PSPI)(AOL)/(AOS) \quad (2)$$

where

UPR = unit point resistance in kilopascals,
YPM = plotter movement of the Y-axis in centimeters

Figure 1. Typical sounding.



Note: 1 cm = 0.39 in.

Table 1. Soil profile and pile capacity.

Depth (m)	Soil Type	Unit Skin Friction (kPa)	Skin Friction (kN)	Unit Point Resistance (kPa)	Point Bearing (kN)	Pile Capacity (kN)
2	Firm, stiff, gray and	73.3	104.1	2 408		423
3	tan silty clay	84.3	224	3 077		455
4	Loose, gray, medium-	73.4	328	2 919	373	701
5	grained, wet sand	47.1	395	2 863	357	752
6		79.6	508	2 574	457	965
7	Hard gray clay with	50.4	580	5 285	831	1411
8	sand seams	259		11 744		
9		290		14 773		

Note: 1 kPa = 0.145 lb/in²; 1 kN = 225 lbf; 1 m = 39.4 in.

Figure 2. Skin friction for Mississippi delta soils and soil deposited by stream flooding.

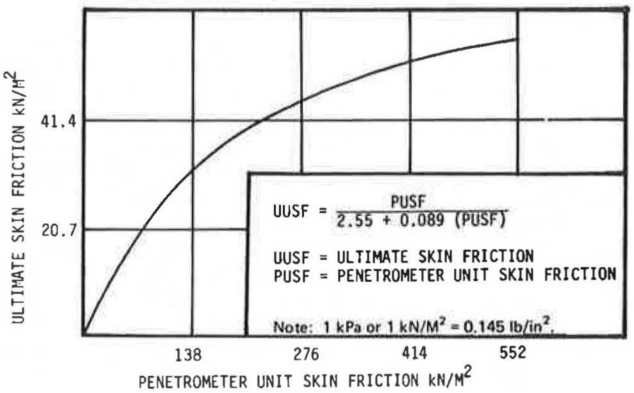


Figure 3. Skin friction for dense coarse sand, very dense sands, and clay sands.

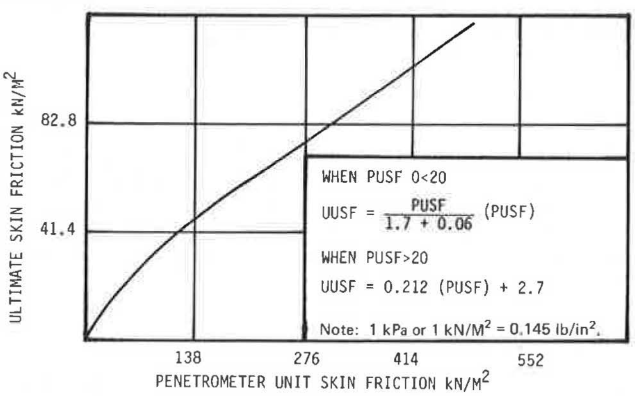


Figure 4. Skin friction for loose, medium dense, and dense fine sand, silty clay, and clayey silt soils.

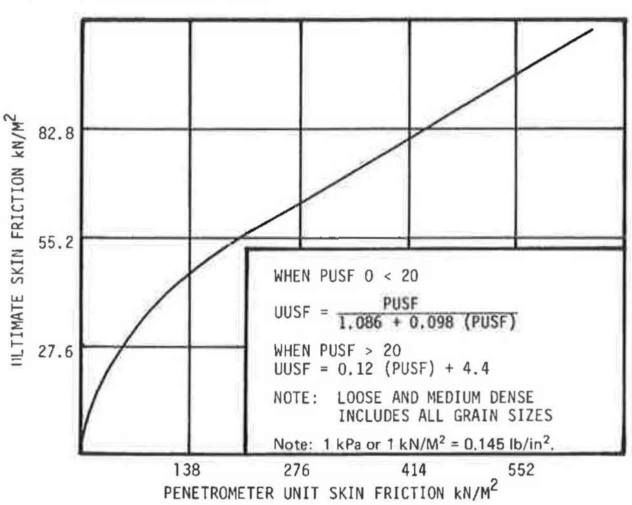


Figure 5. Ultimate point bearing in clay, sandy clay, and clayey sand soils.

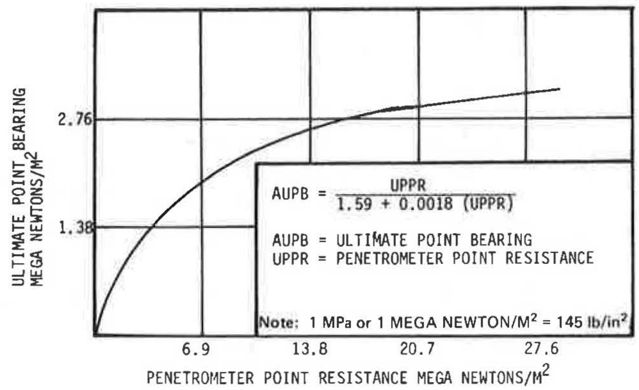


Figure 6. Ultimate point bearing in sand, silts, and silty sands.

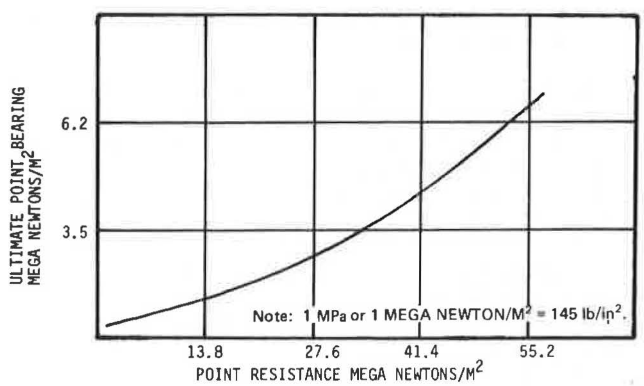
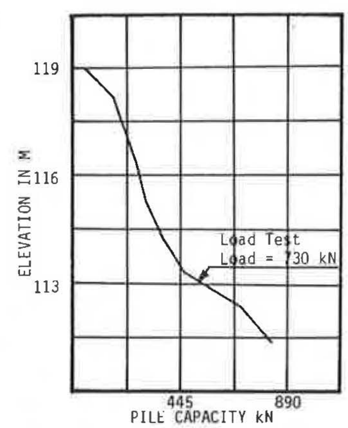
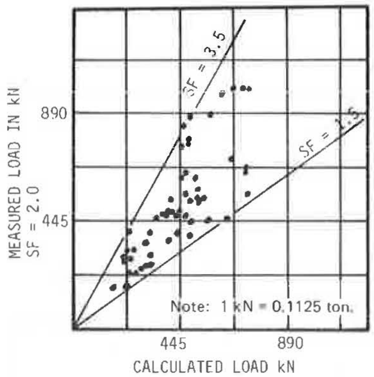


Figure 7. Pile capacity curve for 0.36-m² concrete.



Note: 1 M = 3.3 ft; 1 kN = 0.1125 ton.

Figure 8. Actual field test loads versus calculated loads.



for point resistance or skin friction,

PSPI = plotter stress per centimeter of movement from the calibration chart for the particular plotter setting,

AOL = area of the loading head in square meters,

AOP = area of the cone point in square meters,

AOS = area of the skin friction jacket in square meters, and

USF = unit skin friction in kilopascals.

The reduction of the penetrometer data for one complete sounding is given in Table 1, which also shows the bearing capacity values. The skin friction for a 1-m (3.3-ft) segment is obtained by multiplying the area of the segment by the unit skin friction for the segment. For example, for the pile in Table 1,

1. The jacket area of a meter segment of the 0.36-m (14-in) square pile is 1.42 m^2 (2204 in^2),
2. The unit skin friction for the sounding at a depth of 2 m is 73.3 kPa (10.63 lb/in^2), and
3. The skin friction for this segment is 1.42 × 73.3 kPa = 104.1 kN (23.4 kips).

The total skin friction for a pile is equal to the sum of the skin frictions of all of the pile segments.

Most theories of point-bearing failure assume that some of the soil above and below the pile tip is affected. To allow for this in the analysis, three point resistance values, the first value above, the value at, and the first value below the pile tip, were averaged. Thus, the point bearing for the 4-m depth of the pile in the above example will be (from Table 1) ⅓(3077 + 2919 + 2863) × 0.127 = 375 kN (83.9 kips).

These piles were also loaded to failure, and the measured ultimate load was then compared to the calculated load. The ratio of the calculated load divided by the measured load ranged from two to seven. However, the ratio for a particular soil or soil condition remained almost constant.

Three relationships based on soil type and soil conditions were developed for skin friction (Figures 2, 3, and 4), and two relationships were developed for point bearing (Figures 5 and 6). With these relationships, bearing capacities were calculated for 54 piles. The value of skin friction is first selected by determining the soil type either by observation of undisturbed samples or by standard penetration tests. After the soil type is determined, the appropriate skin-friction relationship is selected and the skin-friction value for the segment of pile is calculated.

For example, for the 4-m (13-ft) depth of the pile in Table 1, for which the soil type from the boring log is a loose gray silty sand,

1. The unit skin friction is 73.4 kPa (10.63 lb/in^2);
2. From the relations shown in Figure 4, the skin friction is 35.5 kPa (5.15 lb/in^2); and
3. The skin friction for the segment is 1.42 × 35.5 = 50.6 kN (11.4 kips).

The point bearing for the 4-m (13-ft) depth is determined as follows: The average for the three penetration resistances is ⅓(3077 + 2919 + 2863) = 2953 kPa (428 lb/in^2). From Figure 6, the unit point bearing is 931 kPa (135 lb/in^2), and the point bearing at this depth is 0.127 × 931 = 118 kN (26.5 kips). The pile capacity curve for this data is plotted in Figure 7.

A load test on a pile at this location that had been driven to a tip elevation of 112.9 m (370 ft) showed an ultimate load of 730 kN (82 tons). The ultimate load calculated for this tip elevation by using the cone penetrometer data was 516 kN (58 tons). If a safety factor of 2 is used for the penetrometer data, then the allowable load at this tip elevation should be 258 kN (29 tons). The actual safety factor using 258 kN (29 tons) as the allowable load will be less than 3 (730 ÷ 258), which is not considered excessive. The actual design load for this pile was 329 kN. If the pile lengths for this structure had been selected from the pile capacity curve shown in Figure 7, the tip elevation would have been 112 m (368 ft), which is very good for the overall conditions that existed at this site. Figure 8 is a plot of the measured allowable load versus the penetrometer calculated load using a safety factor of 2 for all of the piles. The lines representing safety factors of 1.5 and 3.5 are also shown on this plot, which shows that the safety factor will always be at least 1.5 but never greater than 3.5.

CONCLUSION

The Dutch cone penetrometer can be used to predict pile capacities with reasonable accuracy. Pile capacities calculated by using raw cone penetrometer data are two and seven times the actual measured capacities. The method does, however, possess some limitations for collecting sufficient soil strength data.

REFERENCE

1. G. Sanglerat. The Penetrometer and Soil Exploration. Elsevier, New York.