INVESTIGATION OF SOIL DAMPING ON FULL-SCALE TEST PILES

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ABSTRACT

Bearing capacity is predicted and compared with field load test results for six full-scale test piles. A computer program for studying piling behavior by wave equation analysis is used to develop soil damping parameters. These soil damping parameters are used in a mathematical model which describes the damping characteristics of the soil.

For the four test piles which were embedded entirely in highly plastic clay, a recommended value for the friction damping parameter and the point damping parameter is established. The point damping parameter is investigated for two test piles which were embedded in clay with the tips in sand. The point damping parameter for piles with the tip in sand is found to be larger than the recommended value for piles embedded entirely in clay. A recommended value for the point damping parameter in sands is not established because of the limited amount of field data available for this study.

SUMMARY

This investigation was conducted during the fourth year of a five year study on "Bearing Capacity for Axially Loaded Piles." The applicability of two different mathematical models which describe soil damping characteristics is evaluated for use in wave equation analyses of piling behavior. A wave equation computer program is used to predict pile bearing capacity, and the predicted capacity is compared with field load test data from full-scale test piles. Wave equation analyses of four full-scale test piles embedded entirely in highly plastic clay soils indicate that an average value of $J' = 0.2$ seconds per foot for the friction damping and a point damping parameter of $J = 0.15$ seconds per foot may be used with the mathematical model having a velocity exponent of 1.0.

Two additional test sites are analyzed where the test piles were embedded predominantly in a highly plastic clay, but the pile tips were embedded in sand. Using the mathematical model with a velocity exponent of 1.0 and a point damping value of 0.15 seconds per foot, extremely high values of friction damping are needed to achieve agreement between predicted and actual bearing capacity. However, if a friction damping value of 0.20 seconds per foot is used, point damping values of 0.95 seconds per foot and 1.55 seconds per foot are obtained.

The analysis of these two test piles with tips embedded in sand indicates that a value of point damping much greater than 0.15 seconds per foot is required for agreement between predicted and actual bearing capacity. However, additional test data are needed to verify this trend.

IMPLEMENTATION STATEMENT

This is a technical progress report which presents the results of an investigation which was conducted to develop soil damping parameters. These soil damping parameters are needed for use with the one-dimensional wave equation computer program to predict the bearing capacity of an axially loaded pile.

Implementation of the results obtained in this study should be limited to piles which are embedded entirely in highly plastic clay soils. A value of J' = 0.2 seconds per foot for the friction damping parameter and a point damping parameter of J = 0.15 seconds per foot are recommended for use with the mathematical model having a velocity exponent of 1.0. The values of point damping for piles driven through a highly plastic clay layer into sand determined in this study should not be used until further verification has been obtained from additional field tests. Future field tests should include the measurement of point load through instrumentation. The initial static load tests should be conducted at the time of driving, and the ten-day static load tests should be conducted concurrently with a redriving of the test piles. This procedure will allow predicted values of bearing capacity and soil set-up to be correlated with the actual values obtained in the field.

Implemented results from this study should be used concurrently with existing design procedures pending further verification by additional field tests on full-scale piles.

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INTRODUCTION

Present Status of the Question. - Dynamic pile driving formulas have been in use for many years to predict the load carrying capacity of a pile. Unfortunately, these formulas are dependent upon simplifying assumptions which greatly reduce their accuracy and restrict their application. Isaacs (4)* is credited with first proposing the occurrence of longitudinal wave transmission in a pile during driving. Because the solution is extremely complex, little effort was made to expand this theory until 1960 when Smith (10) presented a numerical solution to the wave equation and a mathematical model to simulate pile-soil interaction. Smith described the total soil resistance mobilized during dynamic loading in the following manner:

$$R_{u_{dynamic}} = R_{u_{static}} [1 + (J \text{ or } J') V] \qquad (1)$$

where R_u = dynamic or static soil resistance, pounds;

J = a damping constant for the soil at the point of the pile, seconds per foot;

J' = a damping constant for the soil along the side of the pile, seconds per foot;

V = the instantaneous velocity of a point on the

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*Numbers in parentheses refer to the references listed in Appendix I.

(The citations on the following pages follow the style of the Journal of Soil Mechanics and Foundation Division, ASCE.)

pile at a given time, feet per second.

During the past six years, considerable research has been directed toward determining representative damping parameters for various types of soils. Initial laboratory studies were conducted by Reeves, Coyle, and Hirsch (9). These studies involved the use of a dynamic loading apparatus to determine damping characteristics of saturated sands subjected to impact loading. Coyle and Gibson (3) extended the laboratory investigation and correlated damping parameters with common soil properties such as void ratio for sands and liquidity index for clays. These investigations showed that the damping parameter as determined in the laboratory was not constant for the range of velocities considered. However, a constant laboratory damping parameter was obtained by modifying the Smith equation as follows:

$$R_{u_{dynamic}} = R_{u_{static}} [1 + (J \text{ or } J') V^N] \qquad 0<N<1.0 \qquad (2)$$

where N = a power to which the velocity, V, must be raised for J or J' to be constant.

Tests were later performed by Korb and Coyle (5) and Raba and Coyle (8) on model piles in clay. Using the modified Smith equation, Korb and Coyle investigated both tip damping, J, and friction damping, J'. For piles in clay, a value of N = 0.35 was recommended for use with a constant friction damping parameter of J' = 1.25 seconds per foot, and a value of N = 1.0 was recommended for use with a constant point damping parameter of J = 0.15 seconds per foot.

In 1970, Bartoskewitz and Coyle (2) obtained static and dynamic field test data on two instrumented piles in clay. Using the damping parameters recommended by Korb and Coyle for wave equation analyses, Bartoskewitz and Coyle compared predicted bearing capacity with measured bearing capacity for these two instrumented piles. The predicted bearing capacity was approximately 30 percent less than the bearing capacity measured during the pile load tests. This rather large discrepancy between measured and predicted pile capacity suggested that a value be determined for friction damping which would reduce the error. Using an N value of 0.35 in the wave equation analyses, values of friction damping required to give agreement between predicted and actual pile bearing capacity were J' = 0.535 seconds per foot for test pile No. 1 and J' = 0.67 seconds per foot for test pile No. 2.

These results indicated that the friction damping parameter corresponding to an N value of 0.35 was not a constant for the clay soils at this test site. Bartoskewitz and Coyle attempted to relate friction damping with some soil classification property, but their findings were inconclusive. It was also observed that an infinite number of combinations of J' and N could be used to achieve agreement between predicted and actual pile bearing capacity. At this point in the research program, it became apparent that information was needed concerning the relationship between the friction damping parameter, J', and the velocity exponent, N.

Objectives. - The objectives of this investigation are:

a. To obtain static and dynamic field test data on full-scale instrumented piles from the literature.

b. To determine, by using the field test data and the one-dimensional wave equation analysis, the soil damping parameters required to achieve agreement between predicted and actual pile bearing capacity.

c. To evaluate the applicability of two different mathematical models used to describe the damping characteristics of the soil with the one-dimensional wave equation analysis.

INVESTIGATION OF FRICTION DAMPING ON PORT ARTHUR TEST PILES

General. - The computer program developed by Lowery, Hirsch, and Samson (7) for solving the one-dimensional wave equation using Smith's (10) numerical method is employed in this investigation. Any future mention of a wave equation analysis or solution refers to an analysis or solution obtained by using this computer program.

Analysis of Friction Damping at Time of Driving. - In November, 1969, two instrumented piles were driven and load tested near Port Arthur, Texas. Both piles were 16-in. OD, 3/8-in. wall thickness, steel pipes and were driven by a Link Belt 520 diesel hammer. Test pile No. 1 had a total length of 67 ft and was driven to an embedded depth of 64 ft. Test pile No. 2 had a total length of 78 ft and was driven to an embedded depth of 74 ft. Both piles were statically load tested at approximately two hours after driving and again 11 days after driving. Strain gages at the head and tip of each pile made it possible to measure both tip load (RUP) and total soil resistance (RUT) for each pile. Complete data on the static load tests have been reported by Bartoskewitz and Coyle (2).

With the exception of the friction damping parameter, J', and the velocity exponent, N, the soil parameter values used in this investigation are those recommended by Korb and Coyle (5) and by Bartoskewitz and Coyle (2). These values are:

$$Q_{side} = 0.10 \text{ inch}$$

$$Q_{point} = 0.10 \text{ inch}$$

$$J_{point} = 0.15 \text{ seconds per foot}$$

$$N_{point} = 1.0$$

where Q = the maximum elastic soil deformation, or quake. Values of RUP and RUT used were those measured during the static load test.

By using the wave equation computer program and by setting RUT equal to the static load capacity of the pile at time of driving, it was possible to determine the friction damping parameter, J', corresponding to a particular value of the velocity exponent, N. For example, the static soil resistance of Port Arthur test pile No. 1 was 46.2 tons two hours after driving. The point resistance measured from strain gages was nine tons. These values were used for RUT and RUP respectively.

In order to develop the curve shown in Fig. 1, several values of J' were selected for a value of N = 0.2, and the corresponding driving resistances were computed using the wave equation program. The wave equation computer program calculates the permanent set of the pile caused by one blow of the hammer. The reciprocal of the permanent set yields the driving resistance in blows per unit of net pile movement. Since the actual blow count for the last increment of driving was known, the J'

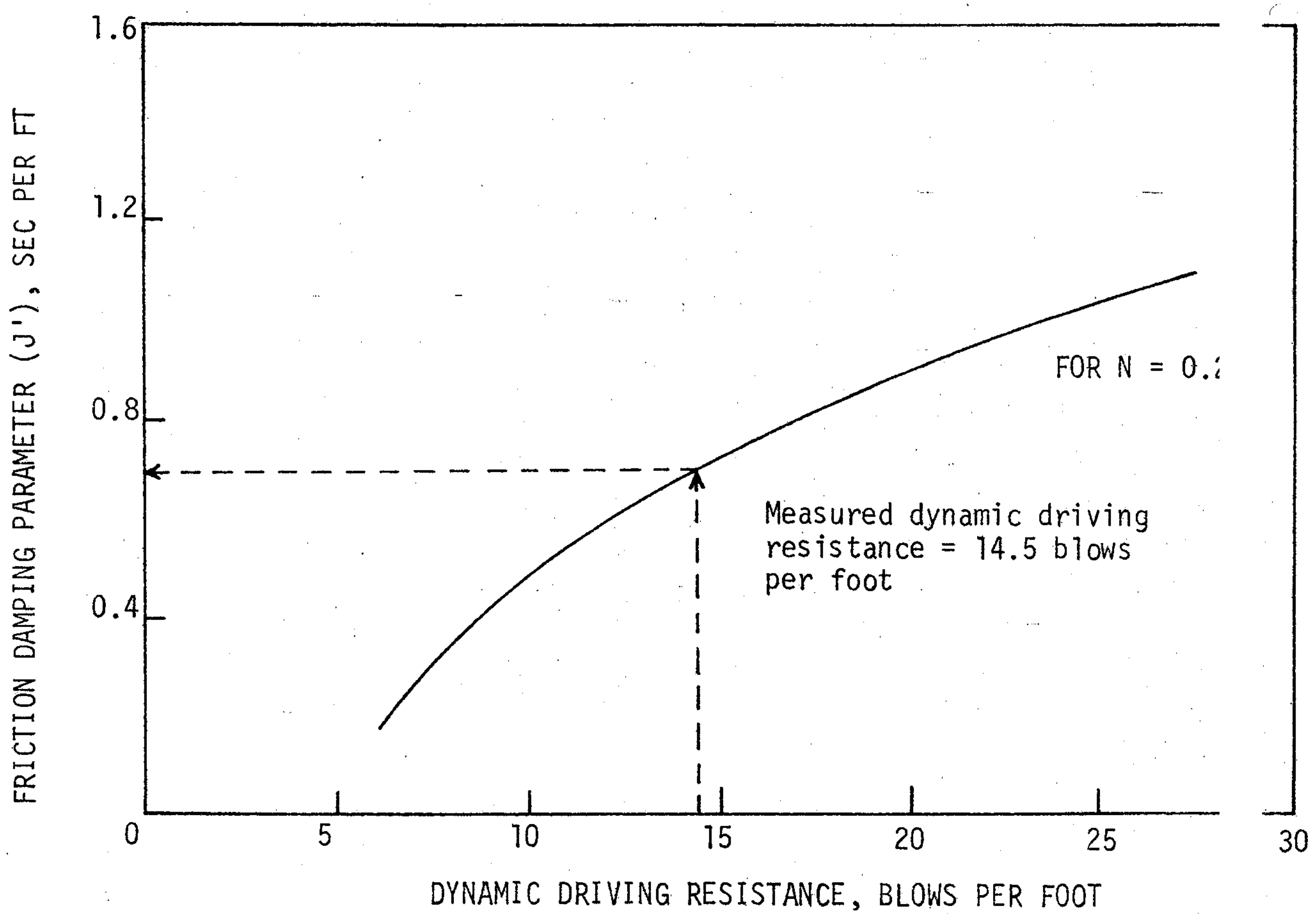

FIG. 1. - FRICTION DAMPING PARAMETER VERSUS DYNAMIC DRIVING RESI NCE

FOR PORT ARTHUR TEST PILE NO. 1

value corresponding to N = 0.2 and RUT = 46.2 tons can be determined. For the recorded driving resistance of 14.5 blows per foot, the corresponding J' was determined to be 0.70 seconds per foot. This procedure was repeated for values of N = 0.4, 0.6, 0.8, and 1.0. For each value of N, there is a unique value of J' which forces agreement between the predicted static soil resistance and the static soil resistance measured in the field. It was then possible to plot each unique value of J' with the corresponding N value for Port Arthur test pile No. 1 as shown in Fig. 2.

Port Arthur test pile No. 2 was analyzed in the same manner. The average blow count for the last several feet of driving was recorded as 16 blows per foot, and RUT was measured to be 50.1 tons. The procedure used to develop a relationship between the side friction damping parameter and the velocity exponent was identical to that used for pile No. 1. The curve relating J' to N for Port Arthur test pile No. 2 is also presented in Fig. 2.

Fig. 2 illustrates the relationship between J' and N for the range of N values between 0 and 1.0. For the Port Arthur test piles, J' approaches a constant value of approximately 0.17 seconds per foot as N increases to 1.0. However, as the value of N is decreased, the two curves tend to diverge. For example, according to Bartoskewitz and Coyle (2), if N = 0.35, J' = 0.535 seconds per foot for test pile No. 1 and J' = 0.67 seconds per foot for test pile No. 2. Thus, it appears that at the time of

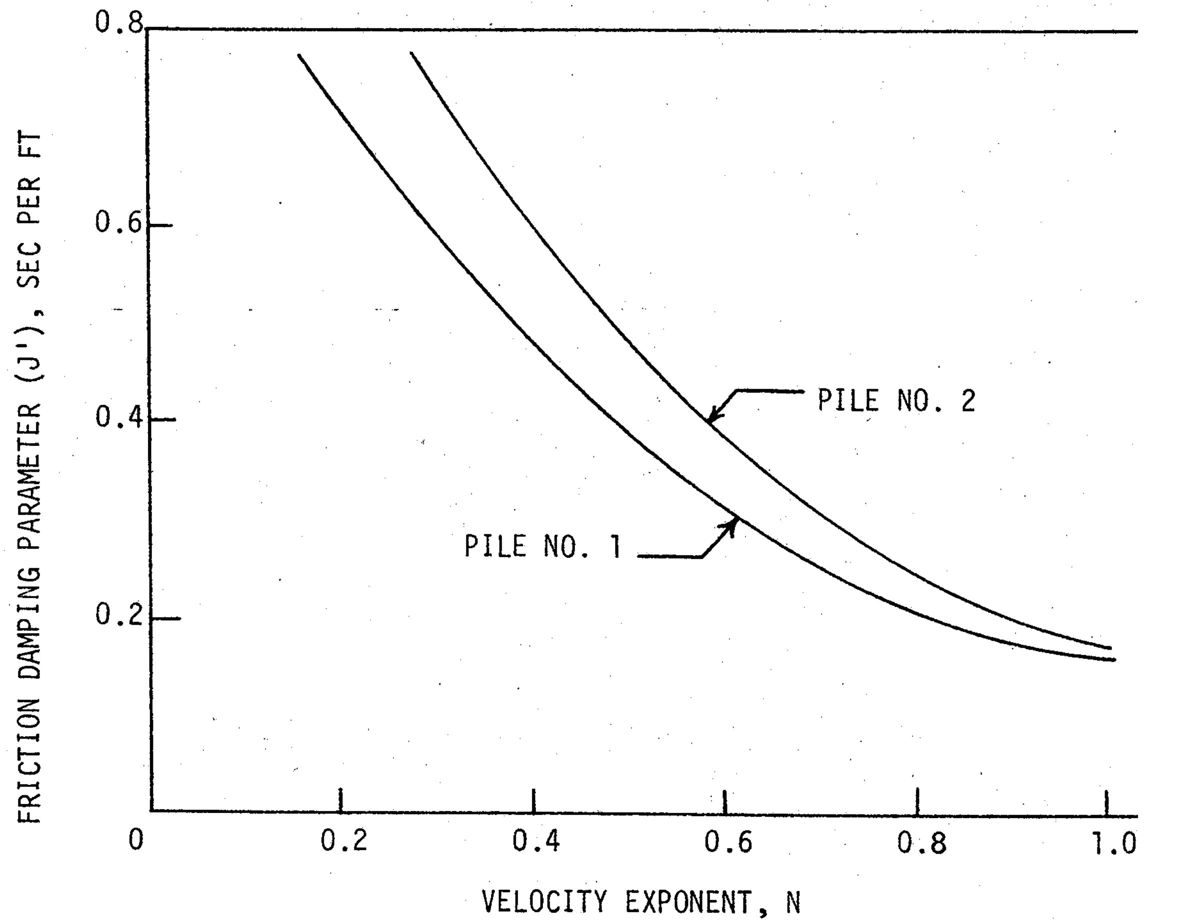

FIG. 2. - FRICTION DAMPING PARAMETER VERSUS VELOCITY EXPONENT FOR PORT ARTHUR TEST PILES AT TIME OF DRIVING

driving, the friction damping parameter is fairly constant for a value of N = 1.0 but is not constant for values of N less than 1.0.

Analysis of Friction Damping 11 Days after Driving. - The Port Arthur piles were statically load tested and redriven a second time 11 days after installation. The difference in the hammer-pile-soil system between the time the piles were first driven and the time the piles were redriven after 11 days was due to set-up occurring in the clay. This set-up increased the static soil resistance and decreased the RUP/RUT ratios. For example, RUP/RUT for Port Arthur test pile No. 1 at time of driving was 0.195, but when the pile was redriven after 11 days, RUP/RUT was 0.050. By using the same procedure described previously, curves relating the friction damping parameter versus driving resistance were obtained for both piles. The average blow count for pile No. 1 was 72 blows per foot; and for pile No. 2, 182 blows per foot. Knowing these blow counts, it was possible to develop curves relating J' and N as shown in Fig. 3. Comparing Figs. 2 and 3, it is observed that for any value of N, the corresponding J' is higher at the time of the 11-day test than at the time of driving. For example, Port Arthur test pile No. 1 at time of driving has a J' value of 0.17 seconds per foot corresponding to N = 1.0. After 11 days, the J' value corresponding to N = 1.0 is 0.44 seconds per foot. This increase in J' is due to the set-up which occurs in clays.

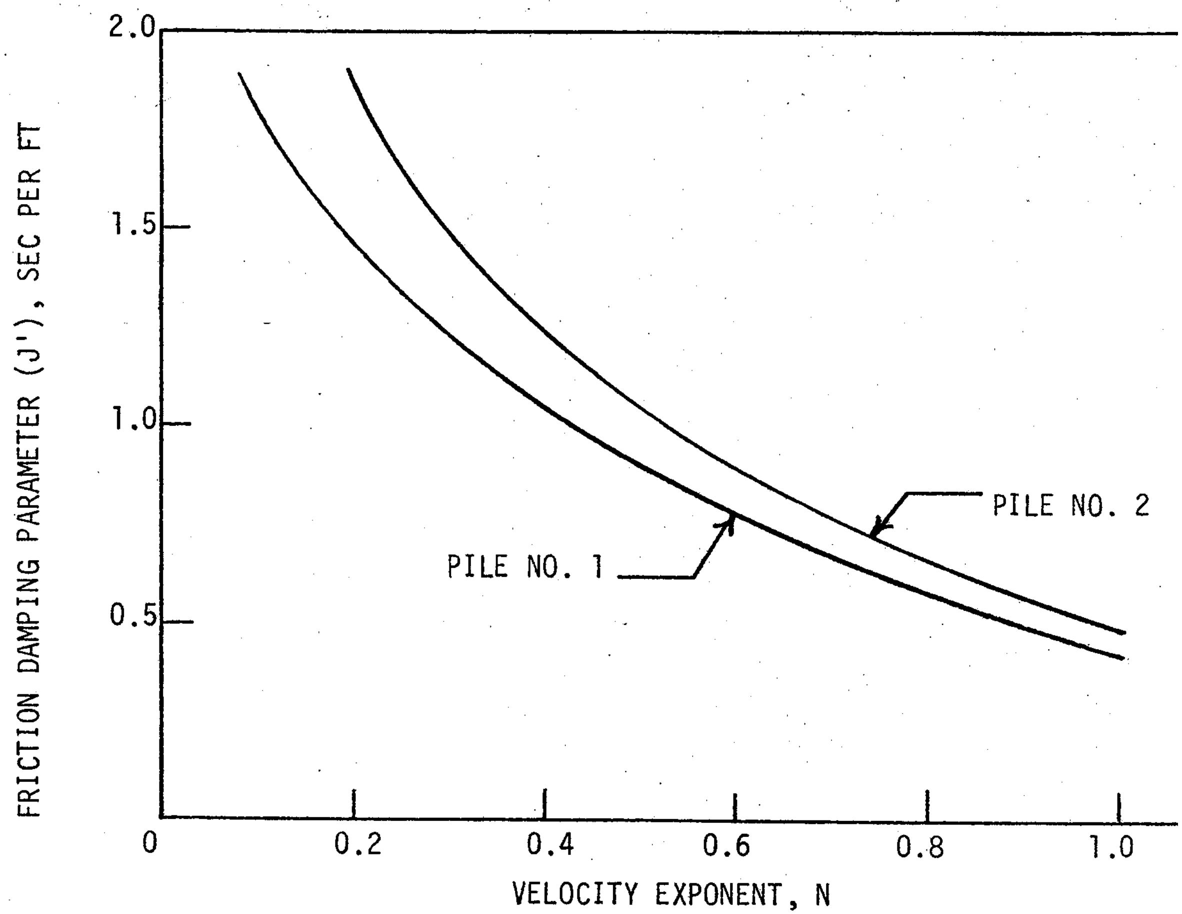

FIG. 3. - FRICTION DAMPING PARAMETER VERSUS VELOCITY EXPONENT FOR PORT ARTHUR TEST PILES AFTER 11 DAYS

Therefore, it is apparent that values for J' obtained at the time of driving will not apply after set-up has occurred.

ADDITIONAL CASE STUDIES OF PILES ALL IN CLAY

General. - Results from the Port Arthur test piles indicated that for piles all in clay, J' is approximately 0.17 seconds per foot when N = 1.0. However, additional data were needed on full-scale pile load tests to determine if this value of the friction damping parameter would be applicable in the same type of soil at other locations. Records of test piles driven at Beaumont, Texas and at Chocolate Bayou, along the Texas Gulf Coast were analyzed. Both of these piles were statically load tested at least ten days after driving. Thus, it was necessary to estimate the amount of set-up which had occurred so that the static soil resistance at time of driving could be determined.

Only by performing a static load test immediately after a pile is driven and then again after soil set-up has occurred can the amount of set-up be determined exactly. However, this method is impractical because of the time and expense incurred in conducting two separate tests.

Bartoskewitz and Coyle (2) report a soil set-up of 2.16 and 2.43 for the Port Arthur piles; i.e., the static load capacity of pile No. 1 at the end of 11 days was 2.16 times the static load capacity of the pile at the time of driving; and for pile No. 2, the static load capacity increased by a factor of 2.43 between time of driving and 11 days after driving. Tomlinson(11) has presented data in the form of bearing capacity versus time curves from which a set-up factor of approximately 2.0 was suggested. Therefore, in this investigation a set-up factor of 2.0 was used in the absence of conclusive static load test data.

In reviewing the original Port Arthur data reported by Bartoskewitz and Coyle (2), it was concluded that no change in point resistance with time should be expected. For Port Arthur pile No. 1, the point resistance decreased from nine tons at time of driving to five tons at 11 days, and the point resistance at pile No. 2 increased from eight tons at time of driving to ten tons at 11 days. Thus, there appeared to be no trend in the change of point resistance with time, and it was concluded that in clay soils point resistance should be considered to remain constant with time.

For the cases in which point resistance was not known, it was assumed to remain constant, and a set-up factor of 2.0 was applied to side friction. For example, at the time the static load test was performed, the Chocolate Bayou test pile had a total static soil resistance of 120 tons and a point resistance of 20 tons. Assuming that the point resistance remained constant and that the side friction increased by a factor of 2.0, the static soil resistance at the time of driving was 70 tons (20 tons plus half of 100 tons). Therefore, RUP/RUT at time of driving was 20/70 or 28.6%.

Beaumont Test Pile. - Data obtained from a pile load test conducted at Beaumont, Texas have been reported by Airhart, Hirsch, and Coyle (1). This pile was a 16-in. OD, 3/8-in. wall, 53-ft long steel pipe driven into predominantly clay soils by a Delmag D-12 hammer. The average blow count for the last several feet of driving was 28 blows per foot, and the pile was tested 13 days after driving. The maximum static test load applied on the pile was 120 tons, and the tip resistance was measured to be 18 tons. Keeping the point resistance constant and reducing the side friction by a factor of 2.0, RUT at time of driving was calculated to be 18 tons plus 102 tons/2.0 = 69 tons. RUP/RUT = 18/69 or 26.1%. Knowing these values of RUP and RUT and using the soil parameters determined previously, a wave equation analysis was performed in which the friction damping parameter, J', was varied between 0 and 1.6 seconds per foot; and the velocity exponent, N, was varied between 0 and 1.0. The curve of J' versus N is shown in Fig. 4, and it is observed that for N = 1.0, J' = 0.22 seconds per foot.

Chocolate Bayou Test Pile. - Lowery, Edwards, and Hirsch (6) reported results of a static load test conducted at Chocolate Bayou on the Texas Gulf Coast. This instrumented pile was a 16-in. square precast concrete pile 40-ft long. The pile was driven into predominantly clay soils to an embedded depth of 33 ft by a Link Belt 520 hammer. The average blow count the last several feet of driving was 24 blows per foot, and the pile was

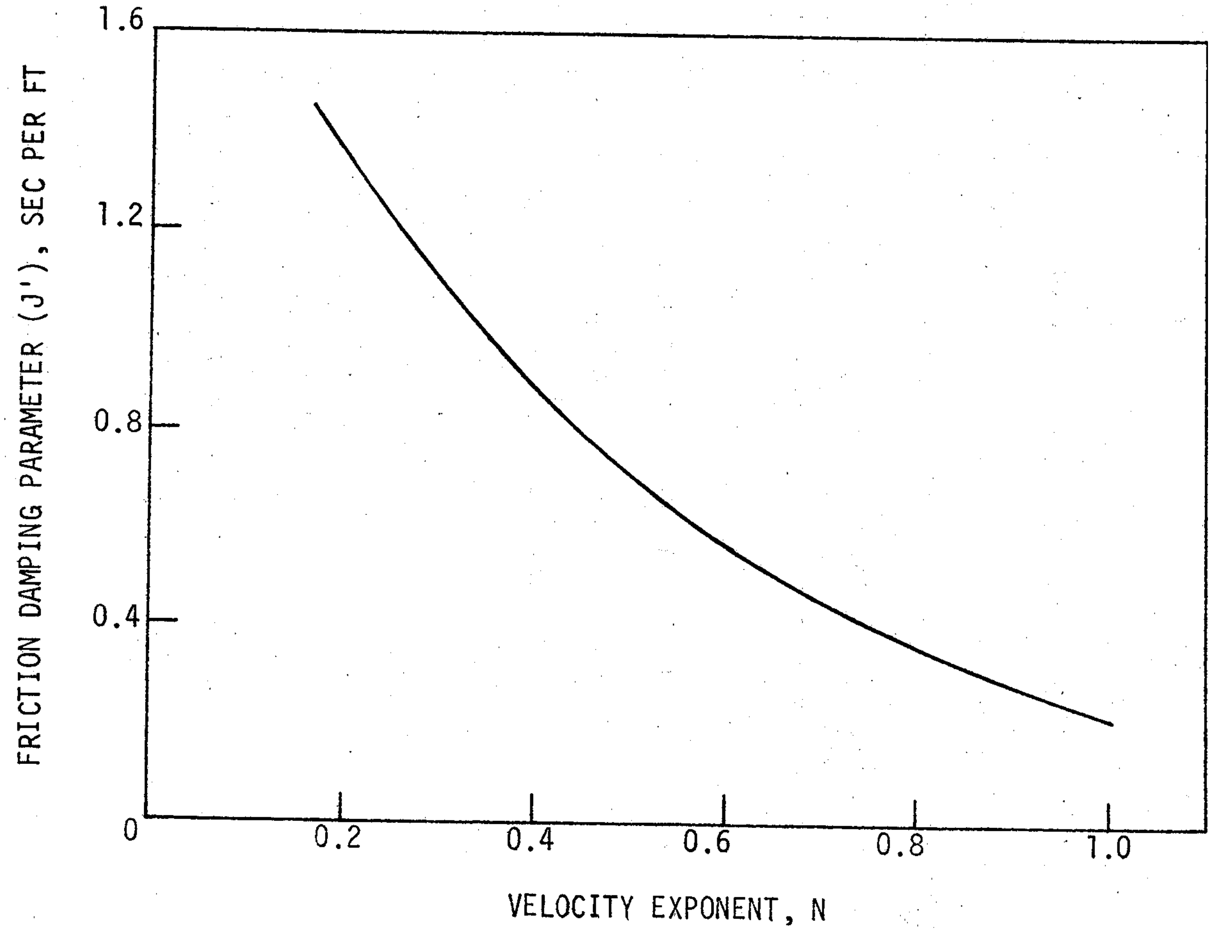

FIG. 4. - FRICTION DAMPING PARAMETER VERSUS VELOCITY EXPONENT FOR BEAUMONT TEST PILE

load tested 45 days after driving. The maximum static load applied to the pile was 120 tons; the point resistance was measured to be 20 tons. Since the pile was not tested immediately after driving, it was again necessary to assume a set-up of 2.0 for side resistance, while the point resistance was assumed to remain constant. RUT was found to be 20 tons plus 100 tons/2.0 = 70 tons. RUP/RUT = 20/70 or 28.6%. Following the same procedure described for the Beaumont pile, the curve of J' versus N shown in Fig. 5 was obtained. For N = 1.0, the corresponding J' was found to be 0.26 seconds per foot.

Discussion of Results. - The relationships between J' and N for the four test piles investigated are summarized in Fig. 6. These relationships were developed for values of N between 0 and 1.0. It is observed from Fig. 6 that for an N value of 1.0, the friction damping parameter converges to an average value of 0.20 seconds per foot. In each case, the piles were driven into predominantly highly plastic clay soils. Therefore, the following soil parameter values are recommended for piles driven entirely into highly plastic clays:

Friction damping, J' = 0.20 seconds per foot,

Point damping, J = 0.15 seconds per foot,

Velocity exponent, N = 1.0.

By recommending a value of N = 1.0, it is implied that Smith's equation, Eq. 1, need not be modified and should remain:

$$R_{u_{dynamic}} = R_{u_{static}} [1 + (J \text{ or } J') V].$$

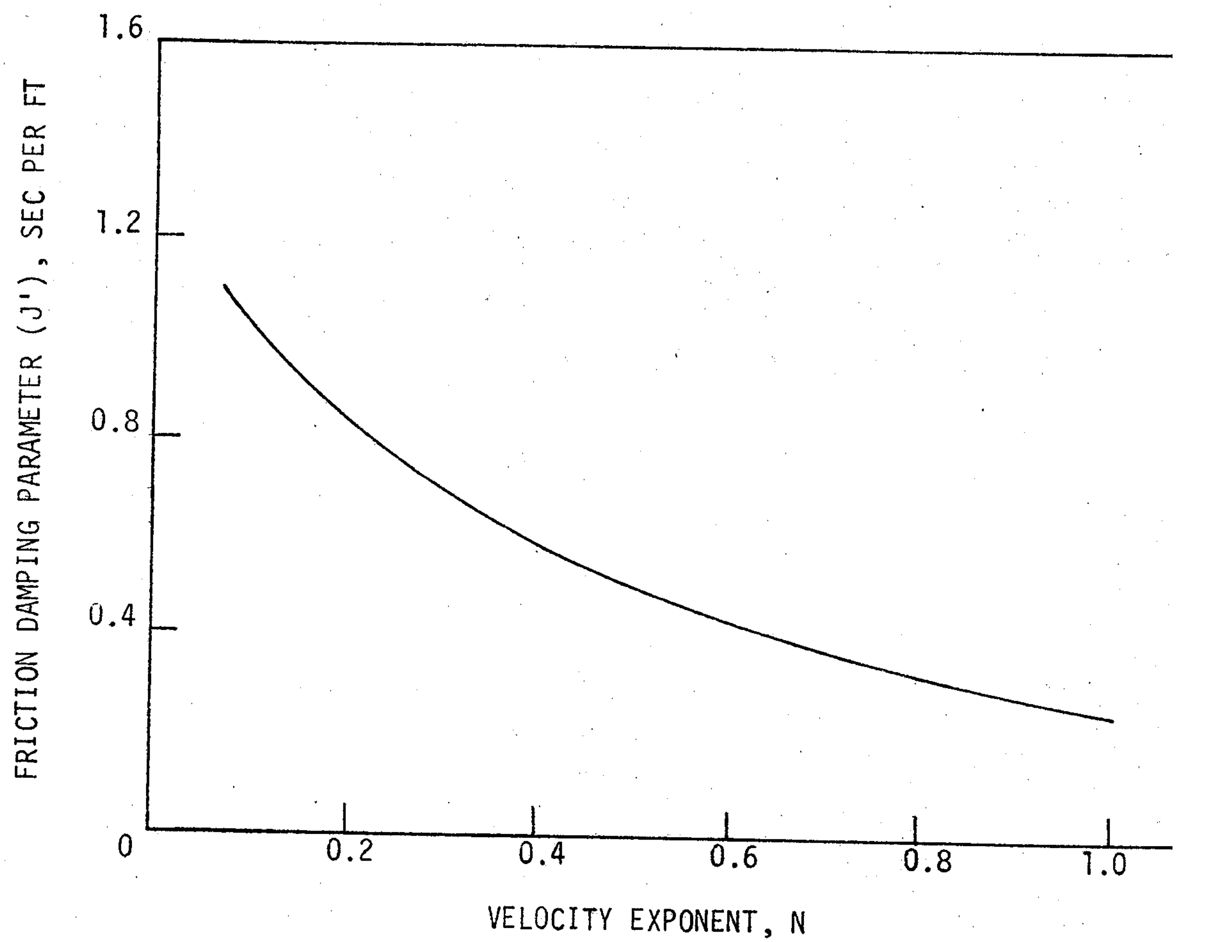

FIG. 5. - FRICTION DAMPING PARAMETER VERSUS VELOCITY EXPONENT FOR CHOCOLATE BAYOU TEST PILE

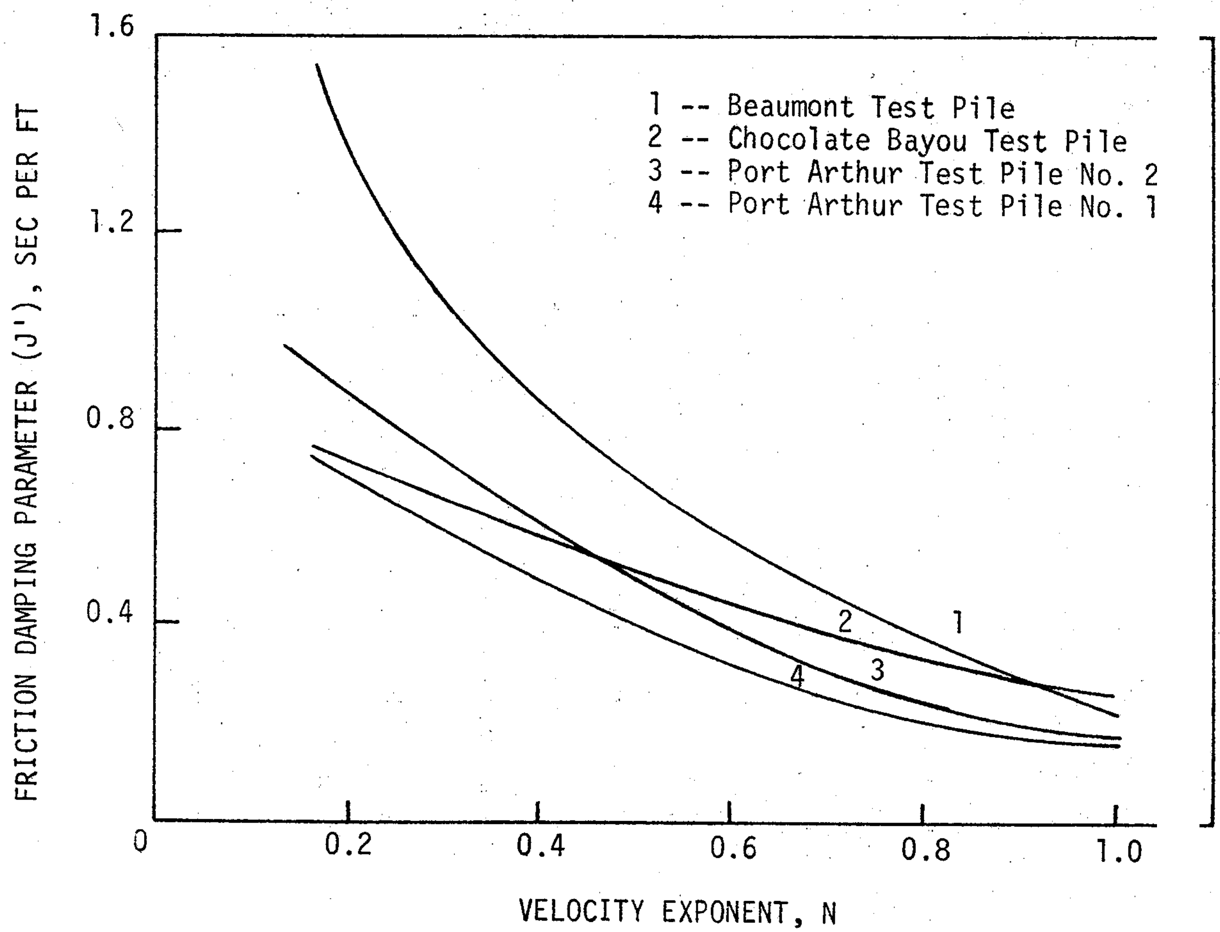

FIG. 6. - FRICTION DAMPING PARAMETER VERSUS VELOCITY EXPONEN

FOR PILES ALL IN CLAY

The soil parameter values listed above were used with the wave equation computer program to determine predicted bearing capacity for the four piles previously discussed. In order to estimate the static soil resistance, the following procedure was employed. By using the above soil parameters and by varying RUT, a curve of RUT versus dynamic driving resistance was obtained. Fig. 7 shows the relationship between static soil resistance and dynamic driving resistance for Port Arthur test pile No. 1. Entering the graph with the known blow count of 14.5 blows per foot, the corresponding predicted RUT was determined to be 41.0 tons. The RUT actually measured during the static load test was 46.2 tons; thus, the error between the predicted and actual bearing capacity is -5.2 tons/46.2 tons or -11.2%. This procedure was repeated for each of the four test piles investigated, and the results are summarized in Table 1.

Table 1. - Error in Predicting Static Soil Resistance Caused by Using an Average Value of J'

Test Pile Location	Measured Soil Resistance (tons)	Predicted Soil Resistance (tons)	Error (%)
Port Arthur No. 1	46.2	41.0	-11.2
Port Arthur No. 2	50.1	46.4	- 7.4
Beaumont	69.0	73.0	+ 5.8
Chocolate Bayou	70.0	76.0	+ 8.6

The maximum difference between predicted and actual bearing

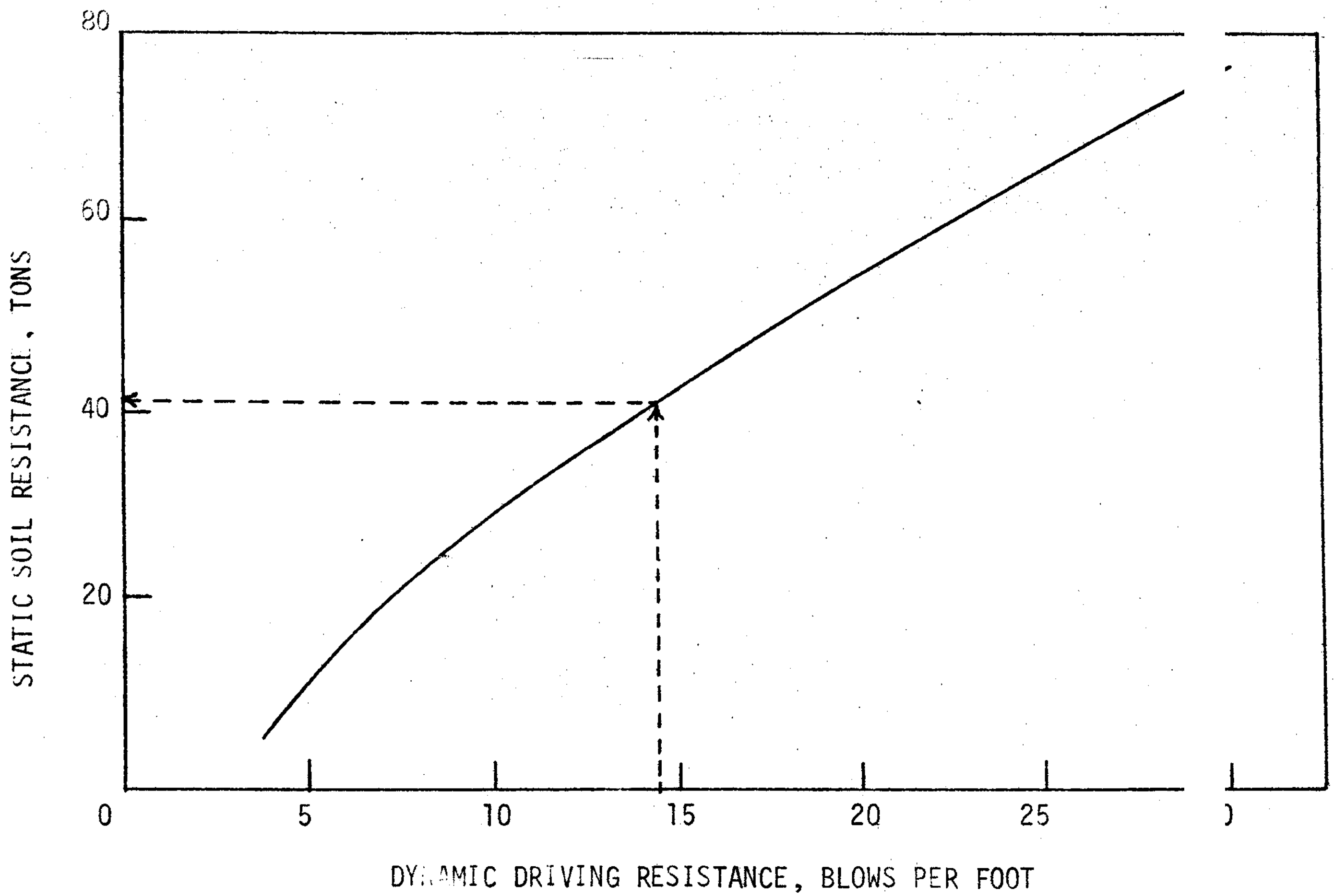

FIG. 7. - SOIL RESISTANCE VERSUS DYNAMIC DRIVING RESISTANCE FC

PORT ARTHUR TEST PILE NO. 1

capacity is in the order of plus or minus ten percent which is considered acceptable agreement.

CASE STUDIES OF PILES IN CLAY WITH TIPS IN SAND

General. - Additional test pile records were located in which the piles were driven through an extensive upper clay layer and into several feet of sand. These test pile sites were located at St. Charles Parish, Louisiana and at Victoria, Texas. The clay soils which provided side resistance during load testing were very similar to the clay soils found at the sites presented previously. However, the tip resistances of the piles driven several feet into sand were much higher than the tip resistances of piles driven entirely into clay.

As was the case in the Beaumont and Chocolate Bayou test piles, the load tests at Victoria and St. Charles Parish were conducted a minimum of ten days after the pile was driven. Thus, the determination of soil resistance at time of driving was required.

On May 10, 1971, the Texas Highway Department drove a 16-in. square prestressed concrete pile on Park Road 22 near Corpus Christi, Texas. The pile was instrumented by TTI for research purposes. The soil profile indicated that the test pile was embedded almost entirely in sand. Load tests were conducted immediately after driving and again ten days after driving. Strain gages at the head and tip of the pile made possible the measurement of total static soil resistance and tip resistance. At time of driving, the total static soil resistance was 147 tons, and the tip resistance was 109 tons. Ten days later the static load test was repeated, and the total resistance was 156 tons with a corresponding tip load of 108 tons. These unpublished data indicate no change in tip resistance with time for pile tips embedded in sand. Therefore, it is believed that ultimate point resistance should be considered to remain constant with time for piles embedded in sand. In this study, point resistance was assumed to remain constant, and a set-up of 2.0 was applied to side friction in the clay layer.

Victoria Test Pile. - Static load tests on an instrumented test pile at Victoria, Texas have been reported by Lowery, Edwards, and Hirsch (6). The 45-ft long 16-in. square precast concrete pile was driven to an embedded depth of 30 ft by a Vulcan No. 1 hammer. The pile was driven through predominantly clay soils, and the tip was embedded 4 ft into sand. For the last foot of driving, the blow count was observed to be 395 blows per foot. The static load test was conducted 45 days after driving. Results from the static load test indicated a total static soil resistance of 200 tons, and measurements from the strain gage at the tip of the pile indicated a tip load of 128 tons. Therefore, the side resistance was 200 tons minus

128 tons or 72 tons. Assuming the point resistance remained constant with time and applying a set-up of 2.0 to side friction, the static resistance at time of driving was calculated to be 128 tons plus 72 tons/2.0 = 164 tons. RUP/RUT = 128/164 or 78.0%.

Following the same procedure used in analyzing the test piles embedded entirely in clay, relationships were developed between the friction damping parameter, J', and the velocity exponent, N, for a range of N values from 0 to 1.0. The curve of J' versus N shown in Fig. 8 indicates that for a value of N = 1.0, the corresponding value of J' is 2.75 seconds per foot. This value of J' is extremely high compared with the average J' of 0.20 seconds per foot determined from test piles embedded entirely in clay. There is no apparent reason for the high friction damping parameter as the clay soils at the Victoria site were very similar to those encountered in Port Arthur, Beaumont, and Chocolate Bayou.

St. Charles Parish Test Pile. - A wave equation analysis was also performed on unpublished load test data obtained from the Louisiana Department of Highways. The test pile was a 91-ft long 54-in. diameter precast concrete pile with a 5-in. wall thickness. A Raymond 8/0 hammer was used to drive the pile to its embedded depth of 89 ft. The soil profile was similar to that encountered at the Victoria site; the pile was driven through the upper clay layer and embedded 4 ft in sand.

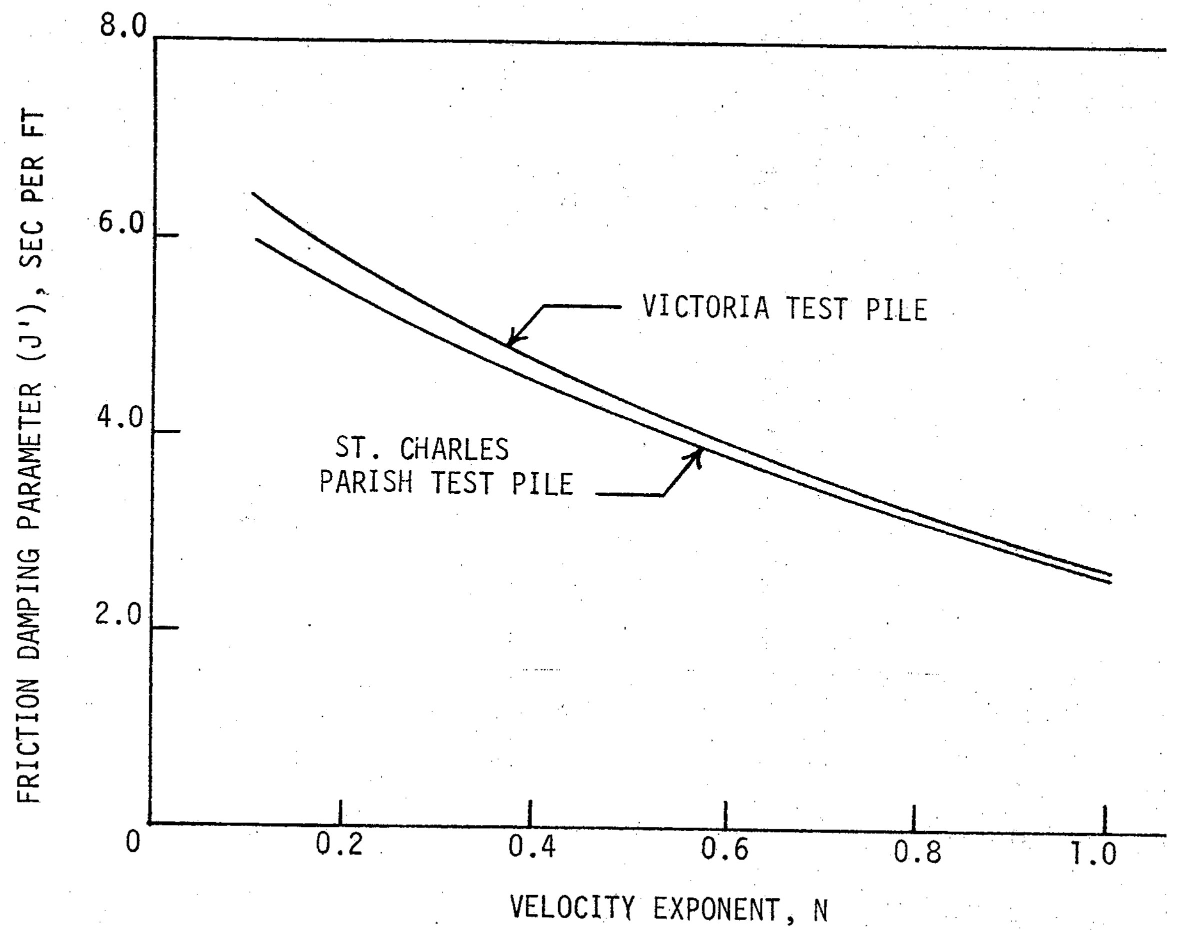

FIG. 8. - FRICTION DAMPING PARAMETER VERSUS VELOCITY EXPONENT F

VICTORIA AND ST. CHARLES PARISH PILES

Because the pile was not instrumented, a static analysis was carried out to determine the distribution of soil resistance on the pile. The total static soil resistance was measured to be 625 tons, and the side resistance obtained from a static analysis was found to be 233 tons. Thus, the point resistance was 625 tons minus 233 tons or 392 tons. Assuming the point resistance remained constant with time and applying a set-up of 2.0 to the side resistance, RUT was calculated to be 392 tons plus 233 tons/2.0 or 509 tons. The ratio RUP/RUT = 392/509 or 77.2%. The wave equation computer program was used to determine the relationship between friction damping and the velocity exponent, and the curve of J' versus N for the St. Charles Parish test pile is plotted in Fig. 8. It is observed that for a value of N = 1.0, the corresponding value of J' is 2.74 seconds per foot. Again, this value is considered to be very high for the clay soils through which most of the pile was driven.

Discussion of Results. - Although the Victoria and St. Charles Parish test piles were driven into predominantly clay soils, the last 4 ft of the piles were embedded in sand. Values of friction damping corresponding to an N value of 1.0 were 2.75 seconds per foot and 2.74 seconds per foot respectively. These high values were not expected since it seems logical that the friction damping parameter should remain constant in the same type of soil.

The significant difference between the Victoria and

St. Charles Parish test piles and the piles embedded entirely in clay is the high RUP/RUT ratios resulting from the pile tips being driven into sand. It is possible that the value of the friction damping parameter for the Victoria and St. Charles Parish test piles is approximately 0.20 seconds per foot as indicated from the analysis of piles embedded all in clay. Furthermore, it is possible that by driving the pile tips into sand and creating high RUP/RUT ratios, the point damping parameter is no longer equal to 0.15 seconds per foot. For this reason, further investigation was directed toward the relationship between the point damping parameter, J, and the ratio RUP/RUT.

INVESTIGATION OF POINT DAMPING PARAMETER

General. - An investigation of the point damping parameter, J, was also conducted using the wave equation program. Results from the friction damping investigation presented earlier indicate that a value of N = 1.0 and a corresponding value of J' = 0.20 seconds per foot should be used for piles embedded entirely in highly plastic clays. Since the Victoria and St. Charles Parish soils fall in this category, those values were used in the study of point damping. With the exception of the point damping parameter, all other parameters were the same as those used in the friction damping investigation. The point damping parameter, J, was varied from 0 to 2.0 seconds per foot, and the corresponding N value remained a constant value of 1.0.

Method of Analysis. - By setting RUT equal to the static load capacity of the pile at time of driving and by using the soil parameters described above, it was possible to determine the value of J corresponding to a particular ratio of RUP/RUT. For example, the total static soil resistance for the St. Charles Parish test pile at time of driving was calculated to be 509 tons with a point resistance of 392 tons. Using these values for RUT and RUP respectively and using an initial value of J = 0.5 seconds per foot, the wave equation program was used to compute the driving resistance in blows per unit of net pile movement.

This procedure was repeated for values of J = 1.0, 1.5, and 2.0 seconds per foot. A graph of J versus dynamic driving resistance for the St. Charles Parish test pile is shown in Fig. 9. Since the actual blow count for the last increment of driving was known, Fig. 9 was used to determine the required J value corresponding to an RUT of 509 tons. For a recorded driving resistance of 235 blows per foot, the corresponding point damping parameter was found to be 1.55 seconds per foot. Thus, the value of the point damping parameter corresponding to the RUP/RUT value of 77.2% was 1.55 seconds per foot.

This procedure was repeated for the Victoria test pile, with RUP/RUT = 78.0%, and a J value of 0.95 seconds per foot was obtained. The graph of J versus dynamic driving resistance for the Victoria test pile is shown in Fig. 10.

Discussion of Results. - From the friction damping investigation, it seems possible that a relationship exists between the point damping parameter and RUP/RUT. However, results from the St. Charles Parish and Victoria test piles do little to substantiate this premise. Values of friction damping were determined which give agreement between predicted and actual pile bearing capacity. For approximately the same value of RUP/RUT, 0.78, the corresponding values of J were far apart, 1.55 seconds per foot for the St. Charles Parish test pile and 0.95 seconds per foot for the Victoria test pile. It should be noted, however, that both J values were much higher than the J value of 0.15

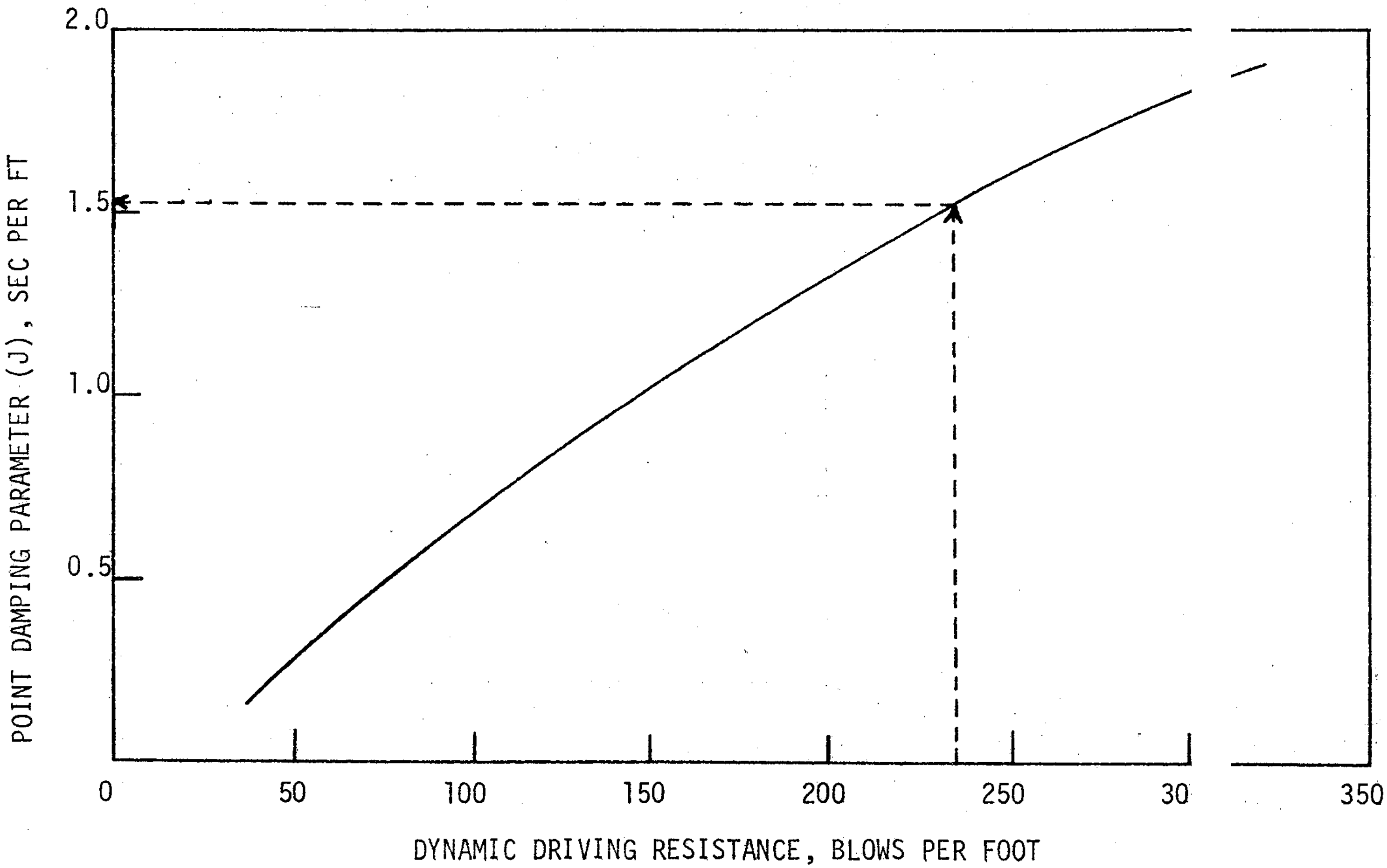

FIG. 9. - POINT DAMPING PARAMETER VERSUS DYNAMIC DRIVING RESISTANCE FOR ST. CHARLES PARISH TEST PILE

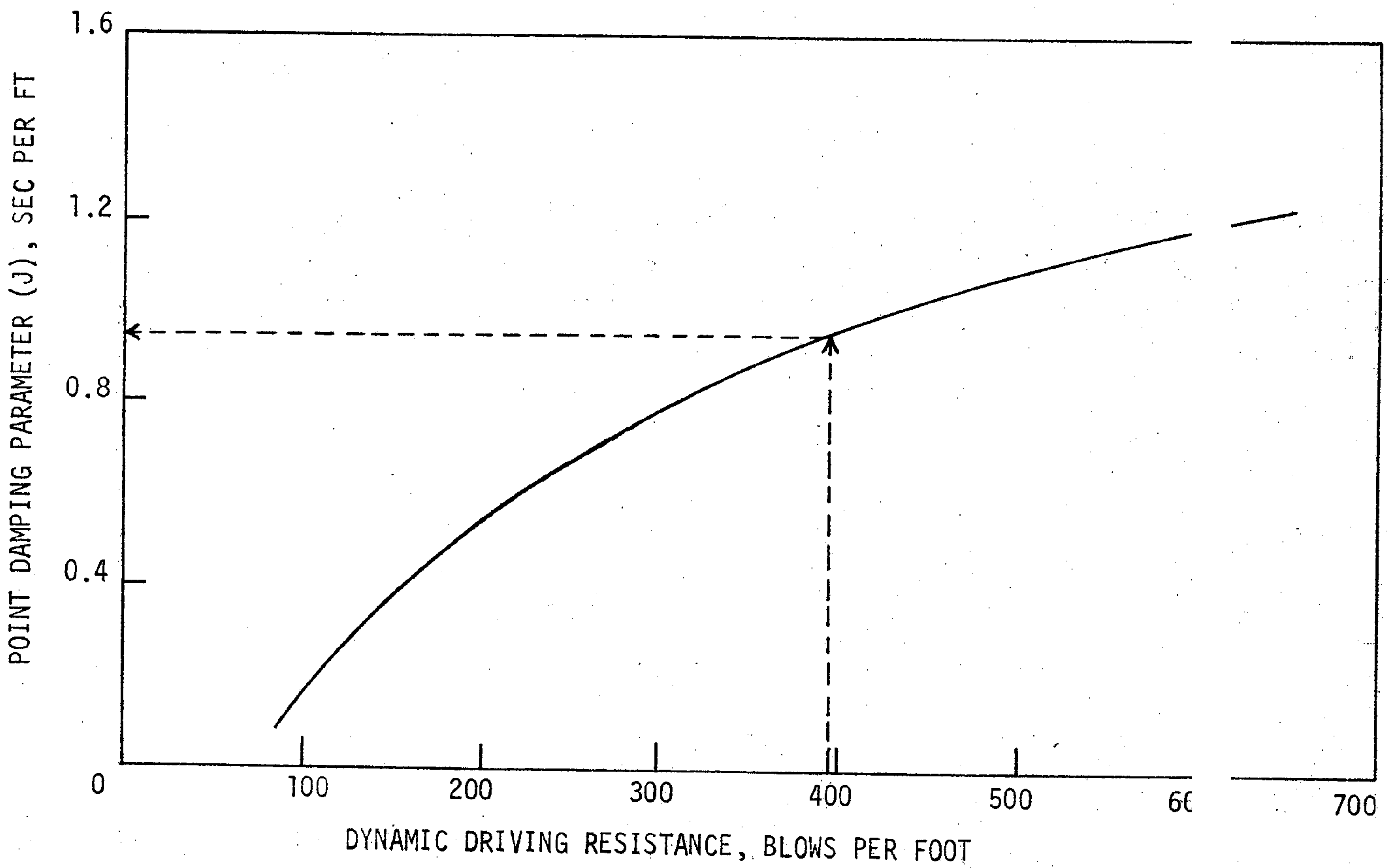

FIG. 10. - POINT DAMPING PARAMETER VERSUS DYNAMIC DRIVING RESISTANCE FOR VICTORIA TEST PILE

seconds per foot used in the friction damping investigation. Too few test piles were analyzed to completely discount the possibility that a relationship between point damping and RUP/RUT exists. Additional data for piles driven primarily into clay and embedded in sand are needed before definite conclusions can be drawn as to what effect, if any, RUP/RUT has on the point damping parameter.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions. - The primary objectives of this investigation were twofold. First, using the wave equation computer program, an investigation was made to determine the soil damping parameter required to achieve agreement between predicted and actual pile bearing capacity. Second, the results achieved in the first objective were used to determine which of two mathematical models better describes the friction damping characteristics of the soil.

Based on wave equation analyses of the Port Arthur, Beaumont, and Chocolate Bayou test piles at time of driving, the following conclusions can be made for piles embedded entirely in highly plastic clays:

1. Smith's mathematical model better describes the total soil resistance during dynamic loading; i.e., the velocity, V, should be raised to a power of N = 1.0.
2. A value of 0.20 seconds per foot should be used for the friction damping parameter and a value of 0.15 seconds per foot for the point damping parameter.
3. Differences in pile materials and pile geometry do not seem to affect the friction damping parameter.

Based on wave equation analyses of the St. Charles Parish and Victoria test piles at time of driving, the following observations are made for piles driven through a layer of highly plastic clay with tips founded in sand:

1. For the case in which a point damping parameter, J, of 0.15 seconds per foot was used, unreasonable values of the friction damping parameter, J', were obtained; i.e., J' = 2.74-2.75 seconds per foot.
2. Using a value of J' = 0.20 seconds per foot as determined in the friction damping investigation, higher values of point damping were obtained; i.e., J = 0.95 seconds per foot and 1.55 seconds per foot.

The attempt to determine a relationship between point damping and RUP/RUT yielded inconclusive results. However, for the limited number of cases analyzed, there are indications that a value of point damping much greater than 0.15 seconds per foot is required for piles with tips founded in sand.

Recommendations. - The various pile analyses presented in this study are based on piles driven primarily into clay soils. There is great need for additional field test data obtained from instrumented piles driven entirely into cohesionless materials and instrumented piles driven through an upper clay layer with their tips embedded in cohesionless soils.

It is recommended that future pile tests include a measurement of the tip resistance whenever possible.

Where practical, future static load tests should also be conducted as soon after driving as possible to evalute soil parameters at time of driving. A second static load test should be conducted concurrently with redriving the pile a minimum of ten days after initial driving. Data from the second static load test will be useful in evaluating soil parameters after set-up has occurred.

A great deal more field test data on instrumented piles is needed in order to thoroughly evaluate the friction and point damping parameters in all soils and combinations of soils.

APPENDIX I. - REFERENCES

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APPENDIX II. - SUMMARY OF INPUT DATA

Port Arthur Test Piles

Site No. 1

Hammer Properties

Type: Link Belt 520 diesel

Ram velocity: 14.70 fps

Ram weight: 5.07 kips

Anvil weight: 1.18 kips

Adapter weight: 1.05 kips

Capblock stiffness: 108,500 kips/in.

Cushion stiffness: 18,600 kips/in.

Capblock coefficient of restitution: 1.0

Cushion coefficient of restitution: 0.8

Pile Properties

Type: 16-in. OD, 3/8-in. wall, steel pipe

Pile length: 67 ft

Embedded depth: 64 ft

Segment length: 5 ft

Segment weight: 0.313 kip

Segment stiffness: 9,080 kips/in.

Soil Properties

Static soil resistance: 92.4 kips

Point resistance: 18.0 kips

Final blow count: 14.5 blows/ft

Site No. 2

Hammer Properties

Type: Link Belt 520 diesel

Ram velocity: 15.16 fps

Ram weight: 5.07 kips

Anvil weight: 1.18 kips

Adapter weight: 1.05 kips

Capblock stiffness: 108,500 kips/in.

Cushion stiffness: 18,600 kips/in.

Capblock coefficient of restitution: 1.0

Cushion coefficient of restitution: 0.8

Pile Properties

Type: 16-in. OD, 3/8-in. wall, steel pipe

Pile length: 78 ft

Embedded depth: 74 ft

Segment length: 5 ft

Segment weight: 0.313 kip

Segment stiffness: 9,080 kips/in.

Soil Properties

Static soil resistance: 100.2 kips

Point resistance: 16.0 kips

Final blow count: 16 blows/ft

Beaumont Test Pile

Hammer Properties

Type: Delmag D-12 diesel

Ram velocity: 21.10 fps

Ram weight: 2.75 kips

Anvil weight: 0.816 kip

Adapter weight: 0.597 kip

Capblock stiffness: 31,500 kips/in.

Cushion stiffness: 18,600 kips/in.

Capblock coefficient of restitution: 1.0

Cushion coefficient of restitution: 1.0

Pile Properties

Type: 16-in. OD, 3/8-in. wall, steel pipe

Pile length: 53 ft

Embedded depth: 50 ft

Segment length: 5 ft

Segment weight: 0.290 kip

Segment stiffness: 8,780 kips/in.

Soil Properties

Static soil resistance: 138 kips

Point resistance: 36 kips

Final blow count: 28 blows/ft

Chocolate Bayou Test Pile

Hammer Properties

Type: Link Belt 520 diesel

Ram velocity: 11.63 fps

Ram weight: 5.07 kips

Anvil weight: 1.18 kips

Adapter weight: 1.30 kips

Capblock stiffness: 108,500 kips/in.

Cushion stiffness: 18,600 kips/in.

Capblock coefficient of restitution: 0.8

Cushion coefficient of restitution: 0.5

Pile Properties

Type: 16-in. square precast concrete

Pile length: 40 ft

Embedded depth: 33 ft

Segment length: 5 ft

Segment weight: 1.378 kips

Segment stiffness: 33,100 kips/in.

Soil Properties

Static soil resistance: 140 kips

Point resistance: 40 kips

Final blow count: 24 blows/ft

Victoria Test Pile

Hammer Properties

Type: Vulcan No. 1 steam

Ram velocity: 12.80 fps

Ram weight: 5.00 kips

Adapter weight: 1.00 kip

Capblock stiffness: 1,492 kips/in.

Cushion stiffness: 1.736 kips/in.

Capblock coefficient of restitution: 0.5

Cushion coefficient of restitution: 0.5

Pile Properties

Type: 16-in. square precast concrete

Pile length: 45 ft

Embedded depth: 30 ft

Segment length: 5 ft

Segment weight: 1.20 kips

Segment stiffness: 37,600 kips/in.

Soil Properties

Static soil resistance: 328 kips

Point resistance: 256 kips

Final blow count: 395 blows/ft

St. Charles Parish Test Pile

Hammer Properties

Type: Raymond 8/0 steam

Ram velocity: 12.94 fps

Ram weight: 25.00 kips

Adapter weight: 6.00 kips

Capblock stiffness: 9,600 kips/in.

Cushion stiffness: 5,180 kips/in.

Capblock coefficient of restitution: 0.8

Cushion coefficient of restitution: 0.5

Pile Properties

Type: 54-in. cylinder precast concrete, 5-in. wall

Pile length: 91 ft

Embedded depth: 89 ft

Segment length: 5 ft

Segment weight: 4.19 kips

Segment stiffness: 77,800 kips/in.

Soil Properties

Static soil resistance: 1,018 kips

Point resistance: 785 kips

Final blow count: 235 blows/ft