METHOD OF DETERMINING DRIVEN FRICTION PILE CAPACITIES

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Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7
This invention relates generally to the art of determining friction pile capacities, and more particularly to the determination of driven friction pile capacities by analysis of the soil into which the pile is to be driven.

Prior procedures for ascertaining the safe loading for a pile have typically involved driving test piles into the soil, and ascertaining how much load each pile will carry. This procedure, however, has many disadvantages. The necessary driving of the test piles is not only a costly but a time consuming operation. Pile driving equipment is difficult to transport to the site, as well as costly to secure, and when tests of various sites are being made for the purpose of plant location, the necessity of having pile driving equipment at hand for each test results in substantial costs as well as time consumption. Further, having made a test with pile driving equipment, it is invariably some considerable time before the actual operation of driving foundation piles for the structure to be erected will begin, and the pile driving equipment accordingly remains idle at the site during this time, or must be taken away for other work, and then later brought back. For these and other like reasons, the described procedures are inherently cumbersome, time consuming and costly.

The general object of the present invention is to provide a method for the determination of the capacity of a driven friction pile by analysis of the soil, without the necessity of driving test piles. Various types of driven friction piles are in current use, and modifications of the general method provided by the invention may be made depending upon the particular type of pile to be used. In each instance, however, shear and friction tests are made on sample cores of soil taken from different depths at the site where the pile is to be located. In one typical form of the invention, these shear and friction tests are made in each instance with the soil under a surcharging pressure duplicating the pressure on the soil at the depth from which core was taken. From the data thus obtained, the support of the soil on the pile at each depth may be determined, and simple summation yields the total supporting force of the soil on the pile.

The invention will be best understood from the following description of the method as adapted to selected typical types of piles, reference for this purpose being had to the accompanying drawing, in which:

Fig. 1 is a chart illustrative of the process of the present invention;

Fig. 2 is a longitudinal section through the sample core contained within a plurality of sampler rings;

Fig. 3 shows a method of taking a shear test with the core and sampler rings of Fig. 2;

Fig. 4 shows the method of taking a friction test;

Fig. 5 is a cross section of an H-beam pile indicating one method of failure;

Fig. 6 is a cross section of an H-beam pile indicating another method of failure; and

Fig. 7 shows, with some exaggeration of taper, a tapered type of displacement pile.

The general method of the present invention is applicable to various types and shapes of piles. A steel H-beam is illustrative of one type of pile to which the invention is applicable, and the invention will first be described in that specific adaptation, from which the application of the invention to other similar pile problems will be understood.

Using any suitable or conventional core sampling device, sample cores of soil are obtained from different depths at the site of the projected structure. The coring device used should, however, be capable of taking cores which are substantially undisturbed, so that they will be in their original natural condition when subjected to subsequent tests. These cores may be taken at suitable depth intervals, depending upon the nature and variations in character at successive levels of the soil encountered. Where the soil is highly uniform, cores may be taken every several feet, and when highly variable may be taken continuously. This will of course depend upon actual conditions encountered in the field, the type of pile, the ultimate load the pile is to carry, etc. as will be understood.

Fig. 2 shows a typical cylindric core 10 contained within a series of concentric sampler rings 11, which engage one another end to end. Preferably, these rings are initially contained within the core taking tool (not illustrated) and the core is forced up inside them as it is cut by the bit. Or the core may be forced into the set of rings after being taken from the soil. Selected samples from different depths of interest are then subjected to shear and to friction tests.

The shear test is preferably made as follows: The core 10, still within the three rings 11, is placed between two plungers 12, preferably, though not necessarily, composed of a suitable water porous stone, so as to permit escape of moisture from the core, and dimensioned to slide inside the sampler rings 11 (see Fig. 3). End
pressure \( P \) is exerted on these plungers in a measured amount such as to surcharge the core with exactly the pressure of the soil at the depth from which that particular core was taken. The necessary surcharge is readily calculated, being equal to the average density of the soil multiplied by the depth. End pressure is not exerted on the rings themselves. With the usual pressures in the natural location, the core is sheared along a plane or planes transverse to the direction of application of the end pressure. This is preferably accomplished, as illustrated in Fig. 3, by applying a shearing force \( S \) to the middle sample ring to move it transversely of the longitudinal axis of the core.

This shearing force is gradually increased until the core shears, the shear planes being indicated in the figure at \( i \). Any suitable testing machine may be used. The applied force at which the core is sheared is accurately measured, and the maximum shear strength of the soil sample tested is then equal to that applied force divided by twice the cross-sectional area of the core.

An advantage in shearing the core at two planes simultaneously instead of one is that possible variable conditions are better averaged, and also that there is then no unbalanced turning moment on the central section of the core.

A friction test is next made on soil from the same depth, and the same sample core is then used in making the shearing test. This test is conveniently and preferably used for this purpose. If the pile is to be of steel, for example, a disk of steel \( 15 \) is placed between the two disks \( 10a \) of soil, against the two previously sheared surfaces \( 10b \) of the latter, as in Fig. 4, and the same surcharging procedure is used. As will be evident, the surcharging pressure is the same as the pressure that will be exerted in a normal direction against the surface of the \( H \)-section pile at the depth in question. A force \( S \) is then applied to the steel disk in a direction transverse of the axis of the core, and is gradually increased until the disk slides across the surfaces \( 10b \) of the core. The applied force at which the disk begins to slide is accurately measured, and the friction strength of the soil sample tested is then equal to that applied force divided by twice the cross-sectional area of the core. The fact that the core disks \( 10a \) are contained and supported within the rings \( i \) and between the plungers \( 12 \), and the fact that the disk \( 16 \) is confined between the two surfaces \( 10b \) of the two core disks \( 16a \), and hence has a sliding face on each side, make for ease, convenience and accuracy in the performance of this friction test.

We have thus ascertained, for any given depth and character of soil, both the shear strength of the soil, and the friction strength of the soil in contact with the pile material, the effects of the natural soil pressure at the depth having been taken fully into account through application of the surcharge during both the shear and the friction tests. Of course, if the effects of increasing soil pressures on shear and friction for the soil at hand are already known from available data or previously taken tests, both the shear and the friction tests may be made without instants using surcharging pressure, and the results then modified to account for soil pressure. However, in the case of the special measurements of the particular, or like, samples must at sometime be made under the natural soil pressure. And by making the tests with the soil sample under a pressure duplicating soil pressure at the depth from which the sample was taken, procedures and calculations are simplified, and accuracy of results assured.

Such pairs of shear and friction tests are made on a number of sample cores taken from a number of depths in the earth, and results for each test thus having been obtained. The number of cores taken and tested will, of course, depend upon the changes in type and condition of soil, and upon the required accuracy of results.

Fig. 1 is a chart illustrative of a typical, though somewhat simplified, practical condition. At the left of the chart is a "log" column \( 20 \) showing the nature of the soil for 30 ft. of depth, as revealed by inspection of core samples. The first 10 ft. are indicated as composed of sand clay, the next 10 ft. as composed of sandy clay, and the lower 10 ft. as composed of hard clay. Immediately to the right of log column \( 20 \) is shown the type of pile to be driven, in this instance a steel \( H \)-beam. And further to the right is a graph showing the relation between depth, plotted on one axis, and shear and friction strengths, plotted on the horizontal axis.

The curves \( 30 \) and \( 31 \) represent shear strength and friction strength of the several soils at increasing depths. By inspection of these curves, it will be seen that for the first 10 ft. of depth, through the "soft clay" region, the shear and friction strengths of the soil are substantially the same, both increasing gradually with increasing depth. For the next 10 ft. of depth, in the "sandy clay" region, the soil is much stronger in shear than in friction, the friction strength curve being nearly an extension of the curve for the first 10 ft., while the shear strength curve shows a substantial increase for this region. For the lower 10 ft. of depth, in the "hard clay," the curves reveal increases in friction strength as well as in shear strength, as compared with the sandy clay region, the shear strength of the soil again substantially higher than the friction strength. Throughout the entire 30 ft. of depth, both the shear and friction strengths increase gradually owing to increasing soil pressure. The more force divided by twice the cross-sectional area of the core.

The slopes of the curves within constant soil regions indicate the effects of increasing soil pressure with depth, and the different slopes of the curves in the different soil regions demonstrate that the result of increasing soil pressure may be influenced by the nature of the soil.

Now there are two ordinary ways in which an \( H \)-section steel pile may fail. First, it may fail along the planes indicated by the dotted lines \( 34 \) in Fig. 5, which represent a failure by frictional slippage along exterior flange surfaces \( 35 \), and a failure by shear of the soil along planes \( 38 \) defined by the longitudinal edges \( 37 \) of the flanges of the pile. With failure of this type, the soil inside the planes \( 36 \) moves with the pile. Second, the pile may fail by frictional slippage along all surfaces of the pile, the dotted lines \( 39 \), as indicated by dotted lines \( 39 \) in Fig. 6. In the latter case, the soil remains stationary, and the pile moves down through it.

Whether the soil will fail in one or the other of these two ways is determined from the shear and friction tests made as above described, and pile axial and end load tests.
ted in pounds per square foot against depth in feet, and since in the example given these values increase substantially uniformly for each 10 ft. of depth, the resulting pressures may be computed at any time, and the shear and friction failure points for the average depth of 5 ft. may be used. Accordingly, it is noted from the graph that both the friction failure point and the shear failure point are 160 pounds per sq. ft. for a depth of 5 ft. From this it is inferred that for the first 10 ft., the loading will be equal to the area of the planes 35, times the friction failure factor of 160 pounds per sq. ft. Assuming the area of the two planes 35 for the first 10 ft. to be 20 sq. ft., this loading will be $20 \times 160 = 3,200$ pounds. For shear failure along the planes 36, the loading will be equal to the area of the two planes 38, which may also be 20 sq. ft., times the shear failure factor of 160 pounds per sq. ft., or 3,200 pounds. Calculations might also be made for friction failure along all surfaces, as in Fig. 6, though it is obvious that for the first 10 ft., the failure will be along the planes 35 and 36, as in Fig. 5, since the friction and shear failure factors are the same, and the area is much greater in the case of Fig. 6. Thus by these calculations the loading that will cause failure for the first 10 ft. of pile is $2 \times 3,200$ pounds or 6,400 pounds.

Similar calculations are next made for the second 10 ft. of pile. The soil conditions are now changed, the soil of the second 10 ft. being much stronger in shear, as shown by the curves in Fig. 1, and calculations reveal that the pile will fall in this region entirely by friction slippage in the manner represented in Fig. 6. For this 10 ft. section of the pile the average friction failure value is 500 pounds per sq. ft. The loading for friction failure, in the manner of Fig. 6, is then equal to 500 times the area of the friction surfaces, or $500 \times 60 = 30,000$ pounds. Calculation for failure in the manner of Fig. 5 gives a substantially higher total loading, so that it is known that failure will occur in the manner of Fig. 6, with a loading of about 30,000 pounds.

For the lower 10 ft. of pile, the average friction failure value is 1180 pounds per sq. ft., while the average shear failure value is about 3,650 pounds per sq. ft. Calculations for friction failure, in the manner of Fig. 6, give a maximum loading of 70,800 pounds, whereas calculations for failure in shear assumed may be taken as typical of a class of piles including straight sided piles, and piles having offsets, or sections of progressively reduced diameter or cross-section. The latter may be treated as the equivalent of tapered piles, calculations based on the hypothesis that the tapered end may be taken as divided into a series of smaller tapers, the offset sections giving results to close approximation, which may be adjusted slightly as dictated by the experience of the designer. The straight sided type of pile is also calculated the same as a tapered pile, though certain adjustments of the values obtained may be made, as will be evident to those skilled in the art. The pile here shown is also indicated as vertically fluted, though such fluting may be disregarded in practice. The piles of this class have the common characteristic of failure by frictional slippage rather than by shear. However, the lateral or normal pressure of the soil on the pile is a function of the strength of the soil in shear, and both shear and friction soil tests are again made for the entire depth the pile is to be driven.

It is found, both experimentally and from theoretical considerations, that the normal or lateral pressure of the soil on a tapered pile, driven pile, owing to the lateral compression of the soil by the pile, is equal to the shear strength of the soil at the depth under investigation, the factor approximately equal to $n$. Accordingly, in accordance with the present invention, a series of shear tests are made for progressively increasing depths, with the sample cores under endwise pressures equal to the natural soil pressures at the depths from which they were obtained, the procedure being the same as in the first described form of the invention. The shear strength value for each depth is then multiplied by $n$ to give the lateral pressure of the soil that will exist as a pressure normal to the pile when the pile is driven. The value so found is then taken as the surcharging pressure for the sample core from that depth during the making of the friction test, which otherwise is made the same as in the first described form of the invention.

From the data so obtained, the friction strength of the soil on the pile may be plotted against depth. Assuming soil conditions to be again as represented in column 20 of Fig. 1, the frictional support of the soil on the first 10 ft. of depth is then calculated, and this is done by multiplying the average friction strength of the soil by the area of the first 10 ft. (ascertained as above stated) by the surface area of the first 10 ft. of the pile, which gives the loading of the first 10 ft. of pile at which failure is imminent. This is repeated for the second and third 10 ft. sections, and the results summed up to yield the load capacity of the pile as a whole, i.e., that at which failure is imminent. Again, a safe loading may then be taken between 50% and 80% of the load capacity value as so obtained.

It has been stated above that the displacement type of pile (represented by Fig. 9) fails characteristically by frictional slippage. Of course, while this holds good in all ordinary instances, it is possible for any pile to fail by shear if the shear strength of the soil is less than the friction strength, which it may sometimes be in very soft or wet clays. In such a case as is referred to the soil may shear all around the pile, the pile dragging a layer of soil downwardly with it.

As mentioned above, the tapered pile here instanced is illustrative of various types of driven piles which displace the soil laterally, and which ultimately fail by friction failure along its surfaces. The designer may make various refinements in the method to suit specific pile shapes,
but in all instances of a driven, soil displacement pile, of the present classification, the general method described will be followed.

The two general types of piles here given as typical examples have in common the taking of shear displacement tests, friction tests on sample cores from selected depths by surcharging a sample core from each selected depth with a longitudinally applied end pressure approximating the natural pressure of the soil at that selected depth, shearing the core along a plane parallel to the line of application of said end pressure while said surcharging pressure is maintained, measuring the force required to so shear the core, ascertaining the shear strength of the sample by dividing said force by the area of the sheared surface, applying a test plate composed of a pile simulating material to a face of the sample core from said selected depth, surcharging said sample core with the same end pressure as before, applied in a direction normal to the plane of said test plate, sliding said test plate on said sample core face in a direction at right angles to the direction of application of said surcharging pressure while said surcharging pressure is maintained, measuring the force required to so slide the test plate on said core sample face, ascertaining the friction strength of the sample by dividing said force by the area of contact between the test plate and the sample core exposed to the direction of sliding, and determining the load capacity of successive longitudinal segments of the pile for failure in either of two ways, whichever indicates the lesser loading for failure, and which comprise (a) taking the product of the average friction strength of the soil and the friction strength of the sample core taken from the depth corresponding to said pile segment, and (b) taking the product of the area of any shear planes along the pile segment along which the soil may shear and the friction strength of the core sample taken from the depth corresponding to said pile segment, and adding to the last product the product of the area of any shear planes along which frictional slippage will occur along with shear at said shear planes and the friction strength of said sample core taken from the depth corresponding to said pile segment, and determining the load capacity of the pile as a whole by summation of the pile segment load capacities.

2. The steps in the art of predicting driven friction pile capacities that comprise, obtaining samples of soil from progressively deeper depths in the earth, and making shear and friction tests on sample cores from selected depths by surcharging a sample core from a selected depth with an end pressure approximating the natural pressure of the soil at the selected depth, shearing the core along a plane normal to the line of application of said end pressure while said surcharging pressure is maintained, and measuring the force required to so shear the core, ascertaining the normal pressure which will be exerted against the sides of the pile for said selected depth by reference to said shearing force, applying a test plate of pile simulating material to a transverse face of a sample core from said selected depth, surcharging said sample core with a longitudinally applied end pressure approximating said normal pressure, sliding said test plate on said sample core face in a direction normal to the direction of application of said surcharging pressure while said surcharging pressure is sustained, measuring the force required to so slide the test plate on said core sample face, ascertaining the capacity of segments of the pile by taking the product of the area of each pile segment in frictional contact with the soil and the force per unit area required to slide the test plate on the sample core taken from the depth corresponding to said pile segment, and ascertaining the total pile capacity by summation of the capacities of the pile segments.

3. The method of predicting driven friction pile capacities that comprises, ascertaining by a procedure including a physical soil sample shear test the average shear strength of the soil into which the pile is to be driven when the soil is under natural soil pressure, ascertaining by a procedure including a physical soil sample friction test the average friction strength of the soil and the area of the pile in friction contact with the soil, (b) taking the product of the average shear strength of the soil and the area of any shear surfaces about the pile along which the soil may shear, and adding to the last product of the average friction strength of the soil and the area of any shear surfaces about the pile along which frictional slippage may occur accompanying said shear at said shear surfaces.

4. The method of predicting driven friction pile capacities that comprises, ascertaining by a procedure including a physical soil sample shear test the average shear strength of the soil into which the pile is to be driven when the soil is under natural soil pressure, ascertaining by a procedure including a physical soil sample friction test the average friction strength of the soil in contact with pile material when the soil is under natural soil pressure, and ascertaining the load capacity of the pile for failure in either of two ways, whichever indicates the lesser loading for failure, and which comprise (a) taking the product of the average friction strength of the soil and the area of the pile in friction contact with the soil, and (b) taking the product of the average shear strength of the soil and the area of any shear surfaces about the pile along which the soil may shear, and adding to the last product of the average friction strength of the soil and the area of any shear surfaces about the pile along which frictional slippage may occur accompanying said shear at said shear surfaces.

5. The method of predicting driven friction pile capacities that comprises, ascertaining by a procedure including a physical soil sample shear test the average shear strength of the soil into which the pile is to be driven when the soil is under natural soil pressure, ascertaining the average lateral soil pressure which will be exerted normally against the sides of the pile by reference
to the average shear strength of the soil, ascertaining by a procedure including a physical soil sample friction test the average friction strength of the soil in contact with the pile material when the soil is under pressure approximating said average lateral soil pressures, said surcharging pressure being sustained in said pile segment and said surcharging pressure being sustained and the load capacity of the pile by taking the product of the area of the pile in frictional contact with the soil and said average friction strength of the soil.

A method of predicting driven friction pile capacities that comprises, obtaining samples of soil from progressively deeper depths in the earth, making a shear strength determination on a sample from each of a plurality of different selected depths by surcharging the sample from each selected depth with a pressure approximating the natural soil pressure at that depth, and shearing said sample along a plane normal to the line of application of the surcharging pressure while said surcharging pressure is sustained, making a friction strength determination on said sample from each of said plurality of selected depths by applying a test plate of pile-simulating material to a plane face of the sample from each selected depth, surcharging said sample with a pressure applied normally to said plane face of said sample and approximating the soil pressure which will be exerted normally against the sides of the pile at said selected depth, and sliding said test plate on said sample face in a direction at right angles to the direction of application of said surcharging pressure and taking the product of the average friction strength of said sample obtained from the friction strength determinations, and the area of the pile segment in friction contact with the soil, and (b) taking the product of the average shear strength of the soil between the depth limits of the samples, as found from the friction strength determinations, and the area of any shear surfaces about the pile segment along which the soil may shear and adding to the last product the product of the average friction strength of the soil between the depth limits of the pile, as found from the friction strength determinations, and any areas of the pile segment along which frictional slippage may occur accompanying said shear at said shear surfaces, and determining the load capacity of the pile as a whole by summation of the pile segment load capacities.

The method of predicting driven friction pile capacities that comprises, obtaining samples of soil from progressively deeper depths in the earth, making a shear strength determination on a sample from each of a plurality of different selected depths by surcharging the sample from each selected depth with a pressure approximating the natural soil pressure at that depth, and shearing said sample along a plane normal to the line of application of the surcharging pressure while said surcharging pressure is sustained, ascertaining the load capacity of successive longitudinal segments of the pile, each such segment having upper and lower depth limits which include between them at least one of said selected depths, by applying a test plate of pile-simulating material to a plane face of the sample from each selected depth, surcharging said sample with the same surcharging pressure as employed in the shear strength determination, applied normally to said plane face of said sample, and sliding said test plate on said sample face in a direction at right angles to the direction of application of said surcharging pressure while said surcharging pressure is sustained, ascertaining the load capacity of successive longitudinal segments of the pile, each such segment having upper and lower depth limits which include between them at least one of said selected depths, for failure in either of two ways, whichever indicates the lesser loading for failure, and which comprise (a) taking the product of the average friction strength of the soil between the depth limits of the segment, as found from the friction strength determinations, and the area of any shear surfaces about the pile segment along which the soil may shear and adding to the last product the product of the average friction strength of the soil between the depth limits of the pile, as found from the friction strength determinations, and any areas of the pile segment along which frictional slippage may occur accompanying said shear at said shear surfaces, and determining the load capacity of the pile as a whole by summation of the pile segment load capacities.

The method of predicting driven friction pile capacities that comprises, obtaining samples of soil from progressively deeper depths in the earth, making a shear strength determination on a sample from each of a plurality of different selected depths by surcharging the sample from each selected depth with a pressure approximating the natural soil pressure at that depth, and shearing the sample along a plane normal to the line of application of the surcharging pressure while said surcharging pressure is sustained, ascertaining the lateral soil pressure which will be exerted normally against the sides of the pile for said selected depth by reference to the shear strength of the soil as determined by making a friction strength determination on a sample from each of said selected depths by applying a test plate of pile-simulating material to a plane face of a sample from each selected depth, surcharging said sample with a pressure applied normally to said plane face of said sample and which approximates said lateral soil pressure for said depth, and sliding said test plate on said sample face in a direction at right angles to the direction of application of said surcharging pressure and taking the product of the average friction strength of said sample obtained from the friction strength determinations, and the area of the pile segment in frictional contact with the soil, and determining the load capacity of the pile as a whole by summation of the pile segment load capacities.

The method of predicting driven friction pile capacities that comprises, obtaining samples of soil from progressively deeper depths in the earth, making a shear strength determination on a sample from each of said plurality of selected depths by applying a test plate of pile-simulating material to a plane face of the sample from each selected depth, surcharging said sample with the
lected depths by shearing said sample and adjusting for natural soil pressure at the selected depth, making a friction strength determination on a sample from each of said plurality of selected depths by sliding a test plate of pile-simulating material on a plane face of the sample and adjusting for the soil pressure which will be exerted normally against the side of the pile at the selected depth, ascertaining the load capacity of successive longitudinal segments of the pile, each such segment having upper and lower depth limits which include between them at least one of said selected depths, for failure in either of two ways, whichever indicates the lesser loading for failure, and which comprise (a) taking the product of the average friction strength of the soil between the depth limits of the segment, as found from the friction strength determinations, and the area of the pile segment in friction contact with the soil, and (b) taking the product of the average shear strength of the soil between the depth limits of the segment, as found from the shear strength determinations, and the area of any shear surfaces about the pile segment along which the soil may shear, and adding to the last product the product of the average friction strength of the soil between the depth limits of the pile, as found from the friction strength determinations, and any areas of the pile segment along which frictional slippage may occur accompanying said shear at said shear surfaces, and determining the load capacity of the pile as a whole by summation of the pile segment load capacities.

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