

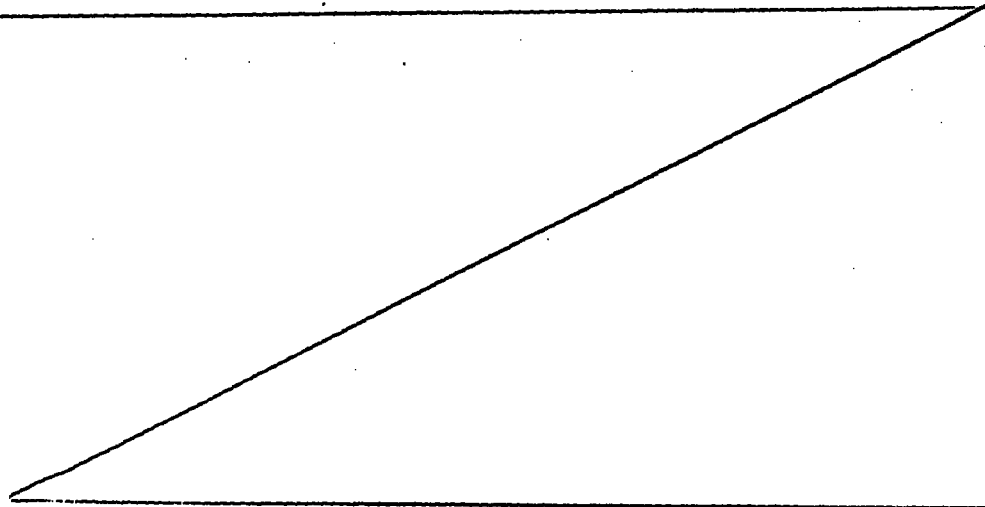
METHOD OF AND APPARATUS FOR MEASURING
SKIN FRICTION

5 The present invention relates to a method of
and apparatus for measuring skin friction, which is
necessary for determining the dimensional and
configurational specification of piles on which to
found structures.

10 The bearing capacity of foundation piles
comprises two components, point resistance and skin
friction. The former represents the bearing capacity
exhibited at the lower end of a pile placed in a ground
against a force in the axial direction of the pile,
while the latter represents the bearing capacity
against frictional resistance between soil or ground
15 and the pile, along the pile shaft. In designing a
structure to be built on foundation piles, it is
extremely important to evaluate the point resistance
and the skin friction, and in designing foundation
piles economically advantageously, it forms an
20 important subject to appropriately evaluate these two
components of the bearing capacity of foundation piles.

In the art of geotechnical engineering, how to
appropriately evaluate the bearing capacity of piles is
an important subject, and there have been a variety of

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studies made, seeking to give a satisfactory solution to this subject, but there has not yet been established such a method which is relatively simple and yet by which the bearing capacity of piles, particularly the skin friction thereof, can be determined at a high accuracy.

In determining the skin friction, it is today generally practiced to find the soil constant of the ground at the intended construction site and find the skin friction by calculation based on the soil constant found. For soil constants, employed are N values (blow counts found by the standard penetration test according to JIS A 1219) and q_u values (unconfined compressive strength values found according to JIS A 1216). However, what the N value represents is a soil characteristic parameter under a dynamic condition and involves an essential difference from the skin friction, which is a kind of shear strength under a static condition. Then, with the q_u value, this represents the shear strength of soil under an undisturbed condition. However, when subjected to driving-in of a pile, soil becomes disturbed and its property undergoes a change.

Therefore, by any of today methods of determining the skin friction based on N values or q_u values, it is infeasible to attain a satisfactory accuracy in the determination. Further, whereas in order to evaluate the

skin friction at accuracy it is necessary to take into consideration each of the degree of disturbance which soil has undergone as a result of driving of a pile thereinto, degrees to which the soil restores its original condition as time lapses, and the influence on the friction resistance of a difference in the surface roughness of piles, these factors cannot be taken into account according to the evaluation methods making use of N values or q_u values. Therefore, according to the evaluation methods under reference, it often tends to result in under-evaluating the skin friction and, in designing piles, placing more stress than necessary on safety.

A further known method of measuring the skin friction of piles comprises a loading test method according to ASTM D3966, according to which a load is applied on a pile driven in a ground and the determination is made of any displacement in the axial direction of the pile to evaluate the skin friction. This test method can provide a bearing capacity value of the pile itself and is therefore advantageous in the light of the accuracy, but it involves the need of a large scale installation and is costly and time-consuming to operate, therefore it in practice is extremely difficult to operate the test frequently. In addition, it generally is that the test

is terminated as soon as the design bearing capacity is satisfied, when it is likely even in the case of this test method that the determination of the skin friction made lacks accuracy, and this is so because as
5 indicated above the design bearing capacity is usually conservatively set.

It is therefore a primary object of the present invention to obviate above indicated various difficulties in the prior art methods of evaluation of
10 the skin friction of foundation piles.

It also is an object of the invention to provide a method of and apparatus for determining the skin friction of foundation piles at a high accuracy without the need of operating a costly and time-
15 consuming loading test.

According to one aspect of the invention there is provided a method of measuring skin friction, comprising the steps of:

forming a hole in the ground for receiving a
20 casing pipe;

inserting a casing pipe of internal diameter D' into the hole;

forming below the lower or leading end of the casing pipe a measurement hole of diameter D'' ;

25 introducing into the measurement hole a skin-friction measuring device having a cylindrical testing part of outer diameter D , where D satisfies $D'' < D < D'$,

rotating the cylindrical testing part and measuring the torque arising due to the friction
30 between the surface of the cylindrical testing part and the wall of the measurement hole.

According to another aspect of the invention there is provided an apparatus for measuring skin friction, comprising:

35 a main body capable of being inserted into a

casing pipe having an inside diameter D' ;

a cylindrical testing part provided in a longitudinal central part of said main body, said cylindrical testing part being rotatable relative to said main body and having a cylindrical measurement face of diameter D which is smaller than D' but larger than the diameter D'' of a measurement hole to be formed below the lower end of the casing pipe when inserted in the ground;

a driving rod to be inserted through the casing pipe for pressing the main body into the measurement hole and for rotating the cylindrical testing part; and

a torque-measuring member connected to the top end of said driving rod.

Whereas the skin friction of piles is influenced by many factors such as the degree of soil disturbance induced by pile driving, the degree of restoration of shear strength of soil after pile driving and so forth, these factors are to a certain extent simulated by using the present invention, so that the evaluation of the skin friction can be made at a considerably higher accuracy according to the present invention than according to existing evaluation methods.

These and other features and advantages of the invention will be clearly seen from considering the following description of embodiments of the invention, taken in conjunction with the accompanying drawings.

Fig.1 is a longitudinal sectional view, taken for an illustration of the method embodying the present invention;

Fig.2 is also a longitudinal section, showing essential parts of the apparatus embodying the present invention;

Fig.3 shows a cross-sectional view, taken on line III-III in Fig.2;

Fig.4 is a longitudinal sectional view, showing essential parts of a torque-measuring device in the apparatus of the invention; and

Fig.5 is a plan view of essential parts of the torque-measuring device.

Now, with reference to the accompanying drawings, the present invention will be described in greater detail.

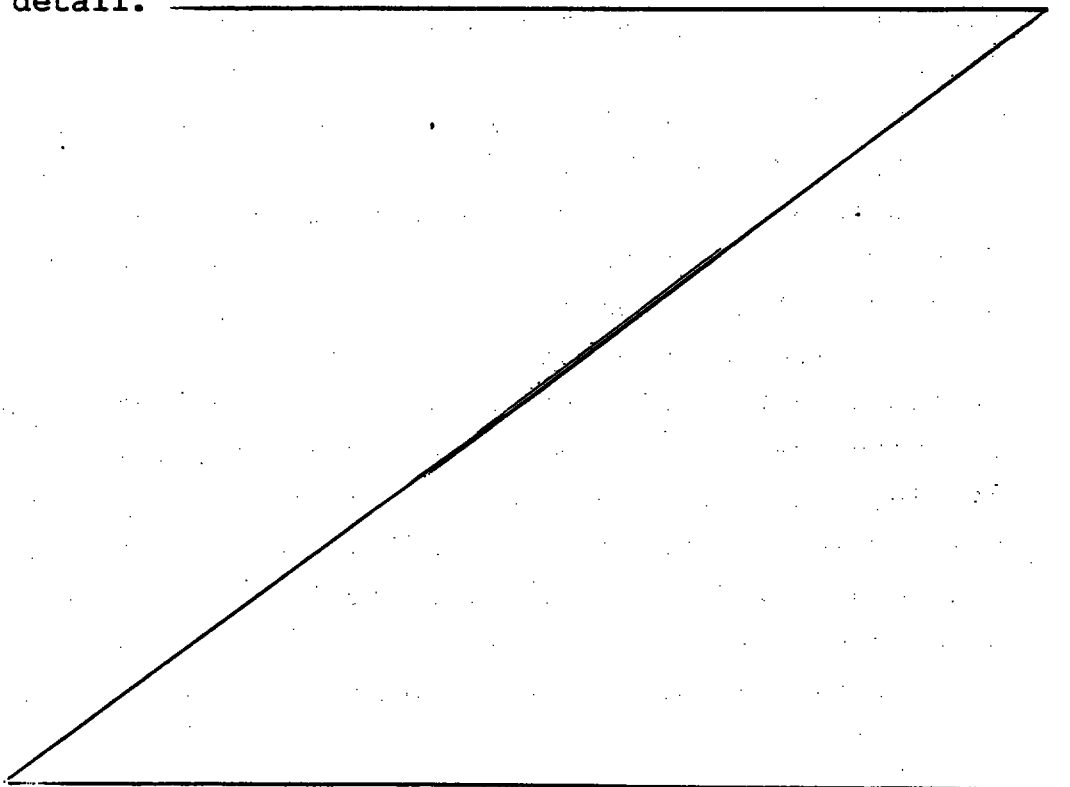
As can be best seen from Fig.1, according to the method of the invention, initially a hole 2 is drilled, using a casing pipe 1, to the prescribed depth into the ground G, and then a measurement hole 3 is formed at the bottom of the hole 2, the diameter of which is smaller than that of the hole 2 and that of a measuring device 5 later to be described. The measuring device 5, which is provided at a lower or leading end of a driving rod 4, is then introduced into the hole 3 either by hammering or by continuous pressure. By operating a driving means 8 which, in the illustrated embodiment, comprises a handle, of a loading device 7 equipped with a torque measuring member, a cylindrical testing part 6 rotatably mounted on the measuring device 5 is then rotated via the driving rod 4, and the torque required for rotating the testing part 6 is measured.

The above-mentioned measuring device 5 is for determining the skin friction, particularly of piles, and comprises a main body 9 supported at a lower or leading end portion of the driving rod 4, a guide or driving shoe 10 mounted to the lower or leading end of the main body 9, and the cylindrical testing part 6, which has a length l and is disposed above the guide shoe 10 and exposed about the peripheral face of the

main body 9.

According to the method of the invention, which is operated with use of apparatus broadly comprising the above essential members, the main body 9 is inserted into the hole 3 by the driving rod 4. The main body 9 and the guide shoe 10 are non-rotational members, while the cylindrical testing part 6 is rotatable relative to the main body 9, whereby it is feasible to rotate the testing part 6 alone, via the driving rod 4, when it is located at the prescribed depth in the ground G. The driving rod 4 is rotatably supported by guide rollers 11 disposed at a central portion inside of the casing pipe 1. Therefore, the torque required for driving or rotating the testing part 6 fixed at a leading end portion of the driving rod 4 can be without fail or error transmitted to the loading device 7.

Now, with the reference transferred to Fig. 2, the measuring device 5 will be considered in greater detail.



In the main body 9, a shaft 15 to be connected to the leading end of the driving rod 4 is rotatably supported by bearings 16, 17 and 18, and at the bottom end of the shaft 15 a support member 19 is fixed. By a key 5 20, the shaft 15 and accordingly the support member 19 are prevented from being rotated. Externally about the support member 19, the cylindrical testing part 6 is removably secured by bolts 21. At an upper portion of the main body 9, a cylinder 22 having its upper end 10 closed by a cover member 23 is removably mounted. The bearing 17, which is a thrust bearing, is pressed down by a holding metal member 24 screwed in an upper end of the main body 9, and to a lower end portion of the main body 9, a connecting member 25 is fixed by a bolt 26. To the 15 lower end of the connecting member 25, a cap member 27 is fixed by a bolt 28, and the driving shoe 10 is secured to the connecting member 25 by a bolt 29 through the cap member 27.

The apparatus of the invention broadly comprising 20 the above parts and members is operated as follows:

The force for driving the device 5 for measuring the skin friction into the hole 3 is transmitted to the shoe 10 through the driving rod 4 via the shaft 15, bearing or thrust bearing 18, and the connecting member 25, and while the guide shoe 10 is operated to shave or

chip the wall of the hole 3 to increase the diameter thereof, the measuring device 5 is driven deeper into the ground G. While the main body 9, the cylinder 22 and the guide shoe 10 are held in position in the ground G, the
5 cylindrical testing part 6 is rotated by the driving rod 4.

It will be readily understood that it is advantageous to provide a plurality of cylindrical testing part 6 different in surface roughness, so that it is feasible to replace the existing testing part 6 with
10 another as follows: First, the bolt 29 is removed, whereby the guide shoe 10 fixed to the connecting member 25 can be removed. Then, by removing the bolt 21, the existing testing part 6 fixed to the support member 19 is removed together with spacers 30 and
15 31, and may be replaced by a different part 6. The surface roughness of the cylindrical testing part 6 can be selectively suitably determined taking into consideration such as the property or characteristic of the ground G, the material of the pile to be designed and so forth.

20 In Fig. 2, the cylindrical testing part 6 has a length l between upper and lower spacers 30 and 31 therefor, but these spacers may be dispensed with by so designing the part 6 as to have a length greater than the length l by the difference corresponding to the length or
25 depth of the spacers 30 and 31.

The loading device 7 provided with a torque measuring member is for rotating the cylindrical testing part 6 and also for measuring the torque required for the rotating of the testing part 6, and it is of a mechanism as illustrated in Figs. 4 and 5.

As shown, the loading device 7 includes a support member 33 secured by a bolt 34 to an upper end portion of the driving rod 4 so as to be rotatable with the rod 4. Another support member 35, which is disposed below the support member 33, is rotatably fitted to the driving rod 4. The support members 33 and 35 abut against each other on contact surfaces C. A torque measuring spring 32 is mounted external to the support member 35, and is in contact with the head of a bolt 36 secured to the support member 35. This spring 32 is secured by a bolt 38 to a rotatory angle finding plate 37, which in turn is fixed by a bolt 39 to a gear 40 to mesh with a gear 41 and also a gear 43 on the side of a reduction gear 42, to which the handle 8 is connected.

In operation, the handle 8 is operated to rotate gears 43, 41 and 40 through the reduction gear 42, thus rotating the torque measuring spring 32 fixed to the angle finding plate 37 and resulting in rotation of the driving rod 4 via the support members 35 and 33.

Upon the above operation, between the fixing end 44 and a contact plate 45 which forms part of the spring 32 there occurs a displacement produced corresponding to the torque, which is measured by a strain gauge 46, whereby measurement of the torque can be performed.

With use of the apparatus of the present invention, measurement of the skin friction of a foundation pile is carried out as follows:

First, drilling into the ground G is performed

with the casing pipe 1 to bring its lower or leading end to the prescribed depth in the ground G, and a hole 3 having a smaller diameter than the measuring device 5 is then formed in the ground G below the lower end of the casing pipe 1. Thereafter, the device 5 mounted at a lower end of the driving rod 4 is driven into the hole 3 for skin friction determination by either pressing or hammering the rod 4. As the device 5 is thus introduced, the ground forming the wall of the measurement hole 3 is shaved or chipped away by the guide shoe 10 and the shaved-off mass of soil is received inside the shoe 10. Therefore, by the above setting of the apparatus into the ground G, it is feasible to place the measurement device at the prescribed location with no influence exerted on the strength of the ground G and to carry out the intended measurement of the skin friction accurately.

Next, the handle 8 of the loading device 7 mounted on the upper end of the casing pipe 1 will be rotated in the direction shown by R in Fig.1 to rotate the cylindrical testing part 6. The part 6 has an outside diameter D smaller than the inside diameter D' of the casing pipe 1 but larger than the diameter D" of the bore 3. The dimensional relationship among these diameters D, D' and D" is determined taking into consideration that the inside diameter D' of the casing pipe 1 should be such as to permit the skin-friction measuring device 5 to pass through the casing pipe 1 and that the diameter D" of the measurement bore 3 should be such that after a wall portion of the hole 3 is shaved or chipped away by the guide shoe 10 as prescribed, the peripheral surface of the cylindrical testing part 6 is in close contact with the wall of the hole 3. The testing part 6 can be made to contact the wall of hole 3 more closely if its diameter D is set to

be appreciably greater than the outside diameter of the main body 9 of the measuring device 5.

According to the present invention, not only the torque M required for the rotation of the testing part 6 but also an angle of rotation are measured by the measuring member or instrument attached to the loading device 7. The skin frictional stress, τ , is calculated according to the following equation:

$$\tau = \frac{M}{\pi(D^2/2 \times l)}$$

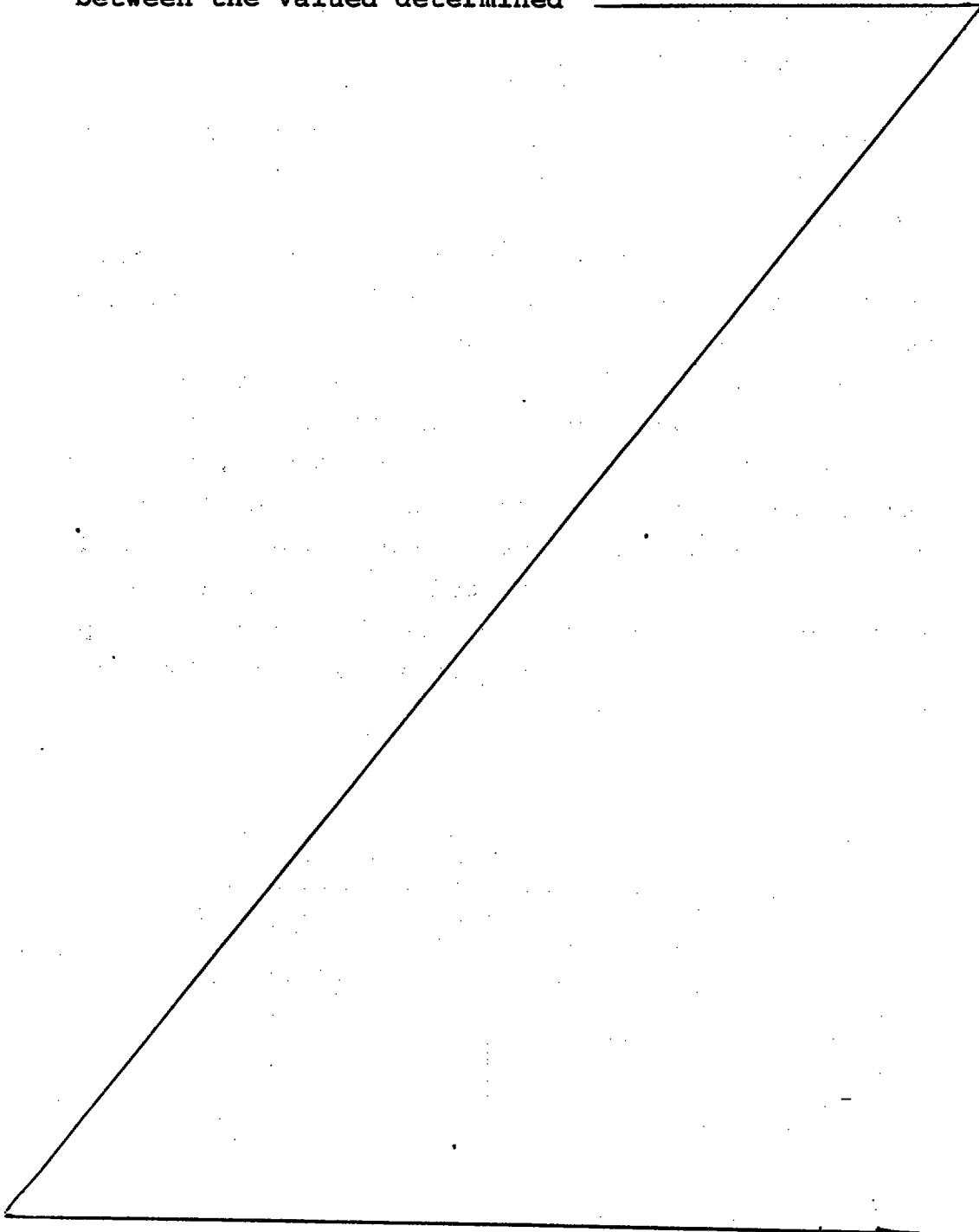
wherein D is the outside diameter of the cylindrical testing part 6 and l is the length or depth of the device 6.

With use of τ values obtainable as above, determination can be advantageously made of the pile skin friction by using appropriate values such as the length, diameter and material of foundation piles.

The following Table is entered for a comparison of skin friction values found according to (a) the method of the present invention on the one hand, (b) the loading test method on the other hand, and (c) the calculation method based on soil constants (N values or q_u values), in connection with three piles A-1, A-2, and A-3 for respective measuring methods above.

Pile No.	Skin Friction		
	Method (a)	Method (b)	Method (c)
A - 1	220 tf	195 tf	104 tf
A - 2	160	160	83
A - 3	315	280	158

As seen from the above Table, the skin friction values determined according to the currently practiced calculation method based on soil constants [Method (c)] are all considerably lower than those
5 determined by each of the Methods (a) and (b), and at the same time, there lies a close correspondence between the valued determined



according to the present invention [Method (a)] and those determined by the loading test method [Method (b)], therefore it is seen that the measurement method according to the invention can provide skin friction values at a high accuracy and is advantageous from practical points of view.

As described in detail above, the present invention is advantageous in respect of the following.

The invention does not require any large scale installation, therefore it can be readily applied in ordinary or routine soil investigations.

Also, now that cylindrical testing parts of different surface roughness conditions are interchangeable according to the invention, it advantageously is feasible to evaluate the effect of a change in the surface roughness of piles on the skin friction.

Further, the cylindrical testing part being so structured as to be rotatable, it is feasible to determine not only the skin frictional stress values (τ) but also the angle of rotation and it therefore is possible to evaluate stress-strain characteristics between the piles and soil or ground.

Moreover, the measurement apparatus of the invention is designed to well stand hammering, so that it can be effectively utilized in connection with hard soil such as Pleistocene soil and even Tertiary soft rock.

CLAIMS:

1. A method of measuring skin friction, comprising the steps of:

forming a hole in the ground for receiving a casing pipe;

inserting a casing pipe of internal diameter D' into the hole;

forming below the lower or leading end of the casing pipe a measurement hole of diameter D'' ;

introducing into the measurement hole a skin-friction measuring device having a cylindrical testing part of outer diameter D , where D satisfies $D'' < D < D'$,

rotating the cylindrical testing part and measuring the torque arising due to the friction between the surface of the cylindrical testing part and the wall of the measurement hole.

2. A method as claimed in claim 1, wherein a guide shoe of outer diameter larger than D'' but no larger than D is provided at the lower or leading end of the skin-friction measuring device, the guide shoe shaving away the wall of the measurement hole as the skin-friction measurement device is introduced, so that the cylindrical testing part is pressed tightly into the measurement hole.

3. A method as claimed in claim 1 or 2, wherein said cylindrical testing part is at a location spaced from the bottom of said measurement hole.

4. Apparatus for measuring skin friction, comprising:

a main body capable of being inserted into a casing pipe having an inside diameter D' ;

a cylindrical testing part provided in a longitudinal central part of said main body, said cylindrical testing part being rotatable relative to said main body and having a cylindrical measurement



* C L H S *

face of diameter D which is smaller than D' but larger than the diameter D" of a measurement hole to be formed below the lower end of the casing pipe when inserted in the ground;

5 a driving rod to be inserted through the casing pipe for pressing the main body into the measurement hole and for rotating the cylindrical testing part; and

10 a torque-measuring member connected to the top end of said driving rod.

5. Apparatus as claimed in claim 4, wherein the main body is provided at its lower end with a cylindrical guide shoe for shaving away the wall of the measurement hole.

15 6. Apparatus as claimed in claim 4 or 5, wherein the cylindrical testing part has an outside diameter appreciably greater than the outside diameter of the main body.

20 7. Apparatus as claimed in claim 4, 5 or 6, wherein the cylindrical testing part is mounted with a spacer disposed on at least one of its upper and lower sides.

25 8. Apparatus as claimed in any of claims 4 to 7, wherein said cylindrical testing part is replaceable with a comparable part having a different surface roughness.

30 9. Apparatus as claimed in any of claims 4 to 8 and including a means for driving the driving rod, wherein a spring is mounted between the driving rod and the driving means and an arrangement is made such that the torque required for the rotation of the cylindrical testing part is determined based on the displacement of said spring.

35 10. Apparatus as claimed in claim 9, wherein the driving means comprises a handle.



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11. A method as claimed in claim 1 and substantially as hereinbefore described with reference to, and as shown in the accompanying drawings.

12. Apparatus as claimed in claim 4 and
5 substantially as hereinbefore described with reference to, and as shown in the accompanying drawings.



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