Developments in Static Cone Penetrometering of the Seabed

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Static cone penetrometering on land, using the static ("Dutch") cone penetration test (C.P.T.) is an already widely known technique but cone penetrometering for situ investigations of the seabed is a newer technique of rapidly growing interest, especially to the offshore industry and installers of offshore structures on secure foundations. To meet the demand for soil investigation in the seabed, a complete range of new types of seabed static cone penetrometers has been developed, especially for the greater water depths.

All types are complete C.P.T. units which measure properties in situ in the seabed at various water and penetration depths necessary for the correct determination of the foundations for drilling rigs, production platforms and pipeline routes and for determining the dimensions and required penetration depth of piles. The acquisition of seabed soil samples completes the data for correct interpretation. Nowadays highly sophisticated penetrometer units are available.

In this article the various types of seabed static cone penetrometers, samplers, and other auxiliary equipment are described. They all originate from on-land penetrometers, but have been specialised to such an extent that they can be considered to be a completely new type.

This introduction does not imply that on-land penetrometers cannot be operated offshore. For shallow depths (up to 25 m) it is quite possible to use modern on-land penetrometers. For this purpose the penetrometering unit is located on a floating or moveable pontoon, or on a platform which rests on the seabed and is supplied with ballast or a stand pipe.

Diver-operated seabed static cone penetrometer HYSON-15 Tf.-UD.

The first seabed static cone penetrometer dated from 1972 and was designed by A.P. van den Berg Ingenieursburo B.V., Heerenveen. It was used for penetrometering tests supporting the construction of a harbour terminal near Bilbao. This type is still in operation in the Middle East (Gulf of Kuwait), mostly in water depths of 20-80 m.

The equipment is lowered from a ship and operated by a diver who has only to install the penetrometer tubes, because all other operations up to and including the readings are automated. It enables the performance of semi-continuous cone penetrometering in the seabed with a maximum downthrust of 150 kN (15Tf) on the overtubes and 100 kN (10Tf) on the cone down to 40m penetration depth in the seabed, depending on the soil resistance. The pulling force to recover the tubes amounts to 200 kN (20Tf). The maximum water depth at which the unit can be operated is normally 80-100 m.

To counter the reaction force, ballast or a suction anchor is used. Measuring is done electrically with a normal mechanical mantle cone and electrical measuring head, determining specific cone and total resistance (also total friction) or with an electric cone, both with automatic recording. The electrically driven hydraulic powerpack, including all electrical and hydraulic parts such as switches, valves, filters etc are mounted in a waterproof tank.

Located aboard the vessel is an operating and control panel, which has an electric two-pen recorder for automatic graphic recording of the measured values. The umbilical between this control panel and penetrometer is deployed via a constant tension winch which is part of the standard outfit. All cables for the power transmission to the electromotor and the low-voltage current for the control and measuring equipment are incorporated in the umbilical.

Seabed static cone penetrometer HYSON-25 Tf. -UA, remote controlled from on board ship

A logical development of the diver-operated HYSON -15 Tf. -UD was the construction of a new type, fully automatic in operation and remotely controlled. The unit is suitable for cone pressures up to 100 kN (10Tf) and a total downthrust of 250 kN (25Tf) while the pulling force amounts to 350 kN (35Tf). The unit is again lowered to the seabed from a ship.

The complete on-seabed cycle, from the vertical erection, pushing the first outer penetrometer tube, to the pulling of the last one, is fully automatic, on command, from aboard the ship. On board the ship is sited the advanced control and data recording equipment.

The penetrometering unit has further refinements such as reduced friction along the tubes, stowage of ballast in the moonpool when the ship is in transit and the latest types of probes and automatic measuring and data recording equipment. The complete unit has two winches with constant tension for the two umbilical cables, together with the hydraulic power system and an operator's cabin with a store for repairs and spare parts.

The HYSON-25 Tf. -UA can be supplied with the soil sampling apparatus MOSTAP-65 which is of similar construction to the WISTAP-65 described later.

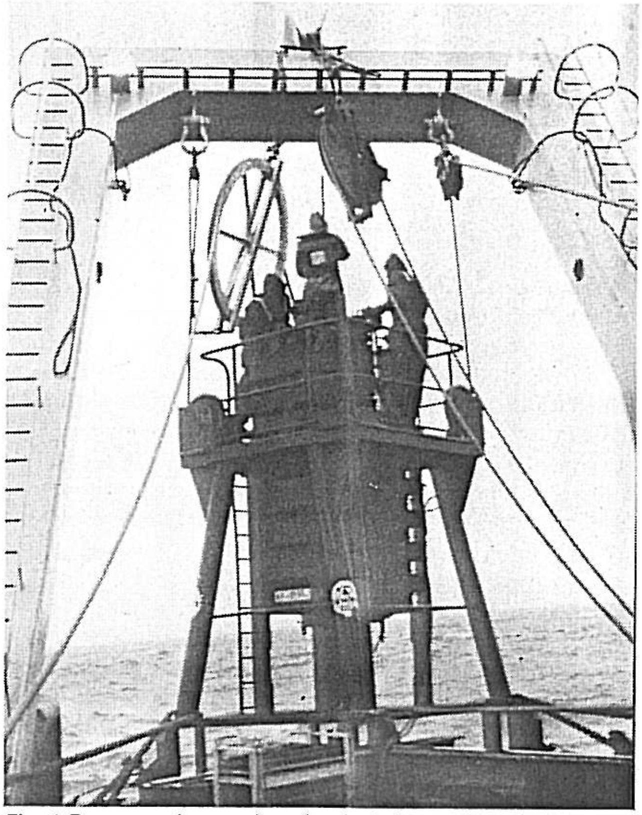

Fig. 1 Roson equipment hanging in A-frame aboard M.V.

Wireline static cone penetrometer WISONAP-10 Tf

This penetrometering unit is deployed, together with the sampling apparatus WISTAP-65, via a drill tube as is normally used in drilling/coring operations. In this technique, the cone penetrometering and sampling are done from the underside of the tubing-set. The production rate of this ingeniously designed penetrometering unit is 50-90 m/day.

The wireline penetrometer has proven itself to be a most popular seabed investigation unit and is being operated offshore in most parts of the world. This unit became operational in 1973/74 and has since been modernised and adapted to become the most advanced and accurate tool of its kind. The unit has been especially designed for operations in a normal type drilling tube, mainly 6¼"/3¼", as used for coring.

With this technique penetrometering is possible with a total force of up to 100 kN (10Tf), ie that with a cone surface of 10 cm^2 a specific cone resistance can be achieved of 1000 kgf/cm^2 where there is no skin friction. The penetrometering rate is 1.5 to 2.5 cm/sec.

The apparatus is equipped with an electrical cone with which the specific tip resistance as well as the local skin friction resistance is measured and reproduced graphically by an automatic data recorder. Multi-parameter cones are increasingly being used, allowing other measuring operations to be carried out.

The penetrometer itself is a single unit with a single-acting oil-hydraulic cylinder which has a hollow piston rod, through which the measuring conductors lead to the cone. Oil as well as water can be used as the 'driving medium'. The fluid is supplied to the penetrometer cylinder via a special umbilical cable the length of which

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depends on the preferred depth at which the penetrometering will take place and which also contains the electric current conductors which connect the electrical cone and the recorder.

The connection between penetrometer cylinder and cable is of a specially designed construction, so that the fluid cannot make contact with the electric current conductors. The cylinder is supplied with a special locking mechanism, enabling automatic fixing of the cylinder when it is passed down the inside of the drill pipe. This mechanism is automatically unlocked at the end of every full cylinder or penetrometering stroke.

Since it is single acting, the cylinder has to be forced back to its original position after each penetrometering stroke, for which purpose the cylinder has on its underside a special connection. After the cylinder has been pulled on board the vessel, the underside is connected, via a hose, to a water pump which applies the necessary pressure to restore the piston to its original position. During the penetrometering stroke the water bleeds off freely. The reaction force during penetrometering has to be delivered by the weight of the drilling tubes themselves, which has occasionally to be increased with ballast in the form of the so called "template", which is described later.

After each penetrometering stroke and after pulling the apparatus, drilling is continued until the next penetration depth has been reached. Thereafter the cycle is repeated to the preferred total depth or penetrometering value is achieved.

A hydraulic powerpack driven by an electric or diesel engine, controls the penetrometer cylinder, via the umbilical cable, during the penetrometering stroke. To check this stroke, while at the same time synchronising the paper feed on the data recorder, the hydraulic powerpack is supplied with a so called measuring or synchronising cylinder. The hydraulic powerpack also drives the constant tension winch on which the umbilical cable is stored. The winch drum is supplied with a special rotating connection for the hydraulic hose in the umbilical cable serving the hydraulic power supply. There is a special connection with the electric conductors in the umbilical.

The maximum penetration depth is 500 m below land or sea level. This is not so much determined by the available length of the umbilical, but more by physical limitations of the tubing-set eg as a result of bowing and/or current streaming in the water.

Cable vane-test apparatus WIVATAP-100

This equipment has been specially designed for soil testing in conjunction with the wireline static cone penetrometer and can also be used in the normal drilling tubes. The apparatus, which measures the shearing resistance in clays, uses the same umbilical and other accessories as the WISONAP-10 Tf.

Wireline sampling apparatus WISTAP-65

The WISTAP-65 has been designed to obtain undisturbed soil samples from soft layers in the seabed. It also is operated via normal drilling tubes of 6¼"/3¼". The apparatus originates from the MOSTAP soil sampler which these days is frequently used for the acquisition of samples from poisoned soils and polluted slimes and muds.

The WISTAP-65 can be used for on-land surveys, as well as in the seabed, as part of the penetrometering unit. The sample has a minimum diameter of 66 mm, and the sample length is 1.5 m. The rate at which the soil sampling process is carried out is normally the same as that of the penetrometering rate but is adjustable during sampling as well. The soil sampling apparatus is also in this case a single unit with a single-acting cylinder, but with a stroke of 1500 mm. The whole unit is connected to the same umbilical cable with the same locking mechanism as described before.

The apparatus consists of a mantle tube with screwable sampling mouth and a sample tube. The latter is mounted in such a way that there is space between the sample tube's outside diameter and the inside diameter of the mantle tube. In this space is located around the sampling cone, a "sample-hose", connected to a piston with a cone. This piston is directly behind the sampling mouth which is provided with a sample catcher.

By means of the hydraulic cylinder, the whole mantle tube with mouth and hose is pushed into the subsoil, 'catching' a sample from the penetrated layer. Since the piston is being kept in a fixed position, it pulls the hose out of the space between mantle and sample tube. This hose envelopes the sample tube surrounding the sample, thus resulting in proper packing of the sample.

In this way friction between sample and sample-tube is prevented. Also premature penetration of soil parts is checked since the sampling mouth is closed by the cone connected to the piston. The cone, with the piston, remains in the locked position as long as the hydraulic cylinder is inoperative. As soon as mantle tube and sample tube are pushed into the soil, the locking mechanism is released and sampling can start.

Thus, intermittently, samples are caught each time in the same cycle (as in the penetrometering cycle of the WISONAP). The sample is delivered out of the drilling tube each time, 1.5 m from its underside. After a sample has been taken, the WISTAP-65 is pulled onboard ship. The sample tube with sample is replaced by another sample tube with hose, connected to the cone with the piston and then relocated, so that the process can start again for the next 1.5 m. Sampling can then continue, starting from the depth at which the previous sampling had ended, after the drilling string is brought to the new depth.

The sample tube containing the sample is covered at both ends by means of caps, and is ready for transport to the laboratory. Air penetration or fluid escape is not possible. The WISTAP-65 is very simple to operate, since it has been developed in conjunction with the normal static cone penetration test. The samples taken are practically undisturbed.

Penetrometer type "BIRD CAGE" OT-5/1000

The rapidly expanding offshore survey activities with in situ static cone penetrometering have led to further specialised developments. An example is the patented "Bird Cage" seabed penetrometer, to be used in all those areas where the anticipated thrust can be limited to 50 kN and the penetration into the seabed is not more than 10 metres.

This type, designed for water depths up to 1000 m, is

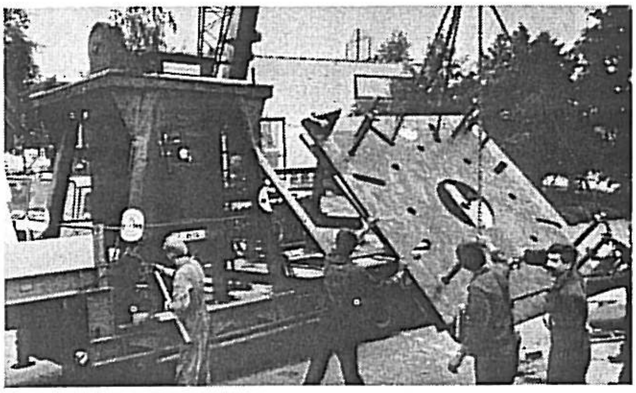

Fig. 2 Loading of Roson equipment on trailer for transport.

particularly suitable for penetrometering surveys for pipeline routes and anchoring sites.

Rotating seabed static cone penetrometer, ROSON-10/20/30 Tf

This patented, portable, seabed static cone penetrometer, fully automatically operated from onboard ship, is the result of latest research and is a compromise between the remote controlled static cone penetrometer HYSON-25 Tf UA and the Bird Cage penetrometer.

The revolutionary design, which has attracted international attention, consists of a number of driving units mounted in a conical iron frame with cardanic base plate, with which the driving components form one total unit. Down and upthrust is from 25 to 300 kN (2.5 Tf to 30 Tf) depending on the number of driving units mounted. It is suitable for water depths up to 1000 m although penetrometering by this means has so far been executed in water depths varying from 30 to 350 m.

There are two speeds in both directions: 2 cm/sec (at normal penetrometering rate) or, at choice, with the aid of speed frequency control, 0.8 cm/sec. This latter is chiefly used during pulling of the tubes, or for special penetration tests. The penetrometer mainly comprises a series of 1 to 12 ROSON units (modules) as preferred, forming a full waterproof assembly. Each ROSON unit is composed of 2 grooved discs which are electrically or hydraulically driven via a reduction gear box. Between each pair of discs the penetrometering tubes are clamped, the friction between these discs and the penetrometering tubes enabling the down- and upward movement.

The exact positioning of the penetration tubes is prepared in advance onboard ship. The penetrometering and the pulling operations are fully automatic, as is the vertical adjustment of the penetrometer on the baseplate, the so called "template". In summary, the ROSON has the following advantages:

1 A high productivity rate.
2 Penetration is continuous without intervals (the downthrust on the penetrometer tubing being applied via continuous friction-wheel modules instead of via hydraulic cylinder with a limited stroke).
3 The readings are not interrupted because of the continuous penetration and are therefore of higher quality and have more detailed data.
4 Assembly of the tubing to the required length is accelerated and can be done in advance.
5 The system is less sensitive to weather conditions. (The constant tension winches which are being used together with the ROSON, can tolerate ship motions up to 220 ft/min 70m/min.)
6 The ROSON can be used from a less sophisticated and smaller ship — for instance a supply vessel.
7 Under most circumstances the ROSON can be easily towed behind a slow-sailing ship (important for penetrometering tests for pipeline routing).
8 The system does not require a moonpool; it requires either a heavy-load crane or a compact handling frame (which can be provided with the ROSON).
9 The ROSON is modular; the system's number of friction-wheel-modules and the ballast weight can be adjusted to fit the requirements of the job.

The ROSON has a complete, automatic electrical measuring and recording system for recording cone and local skin resistance, water pressure, density etc. The outertubes are of very high quality, high strength steel, fitted with specially strengthened screw thread, allowing more downthrust.

The ROSON unit is supplied with all the necessary control equipment, umbilicals, winches, etc, as are the other seabed types but also with items not yet introduced in the other types.

The power source is fully electrical, obviating the need for hydraulics (but which are an available option). The complete part-unit construction (which may be extended by adding units) is easy to operate as a universal system and has low maintenance costs. This makes it a most attractive tool for seabed static cone penetrometering not least because of the real continuous measurements of soil properties reproduced in uninterrupted graphics.

Re-entry clamping ballast seabed frame called "RECLAB"

The re-entry clamping ballast seabed frame as incorporated in the ROSON seabed penetrometer has the following functions:

A Giving easy re-entry into the drilling tube's holes when these tubes have been lifted for operational reasons.
B Clamping the drilling tubes during cone penetrometering.
C Housing the ROSON-10/20/30 Tf, (for which the clamping part has to be removed).
D It serves as ballast (counter weight) to overcome the reaction force.
E It aids vertical positioning.

The complete assembly consists of the following parts:

1 The frame with re-entry construction.
2 Clamping system, mounted on the frame and operated and controlled with the aid of a special switch.
3 The ballast, which is determined in accordance with the reaction force as required.
4 Connections for the cable, winch, etc, as operated and integrated in previously mentioned equipment as well.

Remarks

In view of the rapidly increasing seabed penetrometering activities a standardising of the driving systems is highly desirable. The type of driving equipment used can cause deviations in measuring results. Such differences should not be tolerated in case the cause is not related to the measuring equipment itself. When such differences appear the cause should firstly be investigated in the differences between driving and ballast systems used.