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THE OFFSHORE DILATOMETER

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ABSTRACT

The Marchetti dilatometer test has found widespread use as an onshore soil investigation tool in many parts of the world. A modified dilatometer which can be used offshore and which includes a pore pressure sensor has now been developed at NGI. Onshore calibration tests show that the new device gives results similar to those obtained with the onshore Marchetti dilatometer.

The offshore dilatometer can be run interchangeably with other in situ tools and can be penetrated into the soil both from the sea bed and from the bottom of a borehole. The device has been used in several offshore soil investigations in water depths ranging from 67 to 282 m. The test results can be interpreted in terms of a number of important soil parameters. The authors recommend that the offshore dilatometer be used as a supplement to cone penetration tests and laboratory tests on obtained samples.

INTRODUCTION

The dilatometer was developed in Italy for onshore use by Marchetti (1980) in the seventies. The dilatometer test has the great advantage of being a simple and rapid test (e.g. 30 m profiling in 3-4 hours) and the repeatability of the test results is good. As a supplement to (or replacement of) cone penetration tests and sampling (with subsequent laboratory tests), the dilatometer has become a valuable instrument that is now widely used onshore in many parts of the world - particularly in Europe and North America. In 1985, NGI modified the onshore equipment for application offshore. The offshore dilatometer is smaller than the onshore device because of the inner diameter of the drill pipe through which the dilatometer is lowered when the test is run in the downhole mode. The modified dimensions of the offshore device were selected with the assistance of Dr. S. Marchetti. The offshore dilatometer was equipped with a filter located on the opposite side of the centre of the membrane so that pore pressure could be measured continuously. This opens up new possibilities for interpretation of the results relatively to the original Marchetti device.

This paper describes the equipment and procedures used for offshore dilatometer testing. Onshore calibration tests of the offshore dilatometer are reported as well as some results from testing in deep waters in the North Sea. Future trends for engineering use of the new dilatometer in offshore soil investigations are also discussed.

TEST EQUIPMENT AND PROCEDURE

As mentioned in the introduction the offshore dilatometer is smaller than the onshore Marchetti device to fit inside the standard drill pipe used offshore.

Figure 1 compares the dimensions of the Marchetti and NGI offshore dilatometer tips. The dilatometer for offshore use has a 77 mm wide and 16 mm thick blade and a 54 mm diameter expansion membrane. For Marchetti's dilatometer tip the corresponding dimensions are : 95 mm, 14 mm and 60 mm. Pore pressure can be measured continuously through a 20 mm o.d./10 mm i.d. ring plastic filter located on the opposite side on the side of the centre of the membrane.
For the onshore Marchetti dilatometer, the membrane is inflated by nitrogen gas pressure supplied from the ground surface by a cable threaded through the rods. The pressure to make the membrane just start penetrating the soil (contact pressure) and the pressure necessary to move the membrane one mm into the soil (1-mm pressure) are read manually on a pressure gauge in the control box at ground surface.

The same priciple cannot be used offshore in deep waters (>100 m). For the offshore dilatometer oil pressure is used to expand the membrane. The operating pressure is generated by means of a piston pump, which movement is controlled by a DC electric motor with reduction gear. Electrical power is supplied through an electrical umbilical cable (usually the one belonging to Fugro or McClelland). A ballscrew converts the motor rotation to linear movement.

With the dilatometer down to testing depth, the motor is energised through a rheostat, and the piston moves downwards and closes the passage to the oil reservoir. Further movement of the piston causes a pressure build up on the inside of the dilatometer membrane. Power can also be supplied through a downhole battery unit.

The pressure and pore pressure are measured by vibrating wire gauges manufacutered at NGI. The signals from membrane lift-off, 1 mm expansion and pore pressures are transmitted from the blade through the cable to the data acquisition system onboard.

Figure 2 illustrates schematically the data acquisition system used so far. The frequencies from the two vibrating wire gauges are monitored continuosly on two reading units. The readings are displayed continuously in engineering units on a digital dial gauge and graphically on a chart recorder. An electrical contact behind the membrane in the dilatometer activates the printer at lift-off pressure (p_o) at a 1-mm expansion pressure (p_1). Calibration and exercising of the membrane are carried out as for the onshore Marchetti dilatometer.

OPERATION OF EQUIPMENT

The offshore dilatometer can be used interchangeably with other in situ devices such as the cone penetrometer, being pushed in from the seabed (seabed mode) from the bottom of the borehole (downhole mode) (Lunne and Lacasse, 1985; Zuidberg et al., 1986). The equipment (including electrical and mechanical connections) is designed such that it can be used with equipment from different geotechnical companies (e.g. Fugro or McClelland). The same equipment that is used to push the cone penetrometer into the ground is used for the dilatometer.

The penetration of the blade is halted every 0.2 m and readings of the membrane expansion pressure as a function of the deflection of the center of the membrane are taken continuously. Particularly the contact pressure and the 1-mm expansion pressure are recorded. Pore pressure is recorded continuously during penetration of the blade and during membrane inflation/deflation.

ONSHORE CALIBRATION TESTS

A number of tests with the offshore dilatometer were carried out at onshore sites prior to the first offshore use of the device to:

a) check the functioning of the new device in real soils. These tests supplemented laboratory tests under high pressure to simulate deep water pressures.

b) compare the results of the offshore dilatometer with the results of the onshore Marchetti device.

c) gain experience with the pore pressure measured from an interpretation point of view.

During the laboratory tests and the initial field tests, small modification were made to the equipment and the data acquisition system. The tests showed that the offshore dilatometer functioned very well and that the test was easy to run.
The tests were run at NGI's research sites in Drammen: Museumsparken with soft clay and Holmen wite loose to mesium dense sand. Details of the two test sites are given by Lunne et al. (1986). Figures 3 and 4 compare the results of the offshore and onshore Marchetti dilatometer at the two sites.

At both sites, the offshore dilatometer gave slightly higher p_o and p_1 readings than the conventional Marchetti dilatometer. The derived soil parameters compared however, very well, mainly because the difference between p_1 and p_o was approximately the same for both devices.

Further onshore testing with the offshore dilatometer at NGI's research site in Onsøy and at three sites in Vancouver, Canada in cooperation with University of British Columbia (By et al., 1987) have confirmed the above findings.

OFFSHORE EXPERIENCE

The offshore dilatometer has been used since 1985 on several extensive soil investigations in water depths ranging from 67 to 282 m. It was used in conjunction with both Fugro and McClelland's equipment in the seabed and the downhole mode. Figure 5 includes the test results of a soil investigation performed for Statoil at the Gullfaks 'C' site in 217 m water depth in the North Sea (Tjelta et al., 1986). The figure gives, in addition to the readings, p_o, p_1 and u (penetration pore pressure), the derived dilatometer parameters:

Material index, $I_d = \dfrac{p_1 - p_o}{p_o - u_o}$

Horizontal stress index, $K_D = \dfrac{p_o - u_o}{p_o'}$

Dilatometer modulus, $E_D = K(p_1 - p_o)$

where u_o = in situ water pressure prior to dilatometer insertion

p_o' = in situ effective vertical stress

K = constant function of the membrane dimensions and maximum expansion

INTERPRETATION OF TEST RESULTS

Marchetti (1980) developed empirical correlations relating the dilatometer parameters I_d, K_d and E_d to a number of soil parameters. Figure 5 shows for the Gullfaks 'C' site the following soil parameters derived using Marchetti's correlations: undrained shear strength, s_u, coefficient of earth pressure at rest, K_o, overconsolidation ratio, OCR, and constrained modulus, M_o. Updated correlations were later established by Schmertmann (1982) and Lacasse and Lunne (1988). The following geotechnical parameters can be determined with various degree of reliability (Lacasse and Lunne, 1988), based on dilatometer test results in a number of Norwegian clays and sands:

- soil stratigraphy and soil identification
- soil unit weight
- lateral stress
- overconsolidation ratio
- drained shear strength (sands)
- constrained modulus
- coefficient of consolidation

Up to now, pore pressures during penetration and during membrane expansion have been recorded and plotted but not interpreted further. It is believed that the pore pressure readings could be useful as an index to soil variability and soil permeability, and that it has a potential for interpreting the results in terms of effective stresses. In addition Robertson and Campanella (1986) proposed a method for assessing soil liquefaction and Marchetti et al. (1986) published a method for relating limit skin friction of piles in clay to dilatometer readings.

RECOMMENDATIONS FOR USE OF DILATOMETER TEST IN OFFSHORE SOIL INVESTIGATIONS

In the authors opinion, the dilatometer test should be used on important soil investigations as a supplement, to piezocone and laboratory testing rather than as a replacement.

The fact that the in situ lateral stress can be derived with reasonable reliability from the dilatometer test results is of specific interest since this important parameter cannot at present be reliably determined from either the piezocone test or any other test. In sand for instance, the interpretation of the piezocone in terms of shear strength requires the input of K_o, hence the dilatometer is a useful supplement in this case. The estimation of the constrained modulus based on the dilatometer, may also be expected to be more reliable than the modulus determined from the piezocone, especially in sands.

The method for estimating skin friction of piles in clay from dilatometer test results is promising and should increase the usefulness of the device.

AKNOWLEDGEMENT

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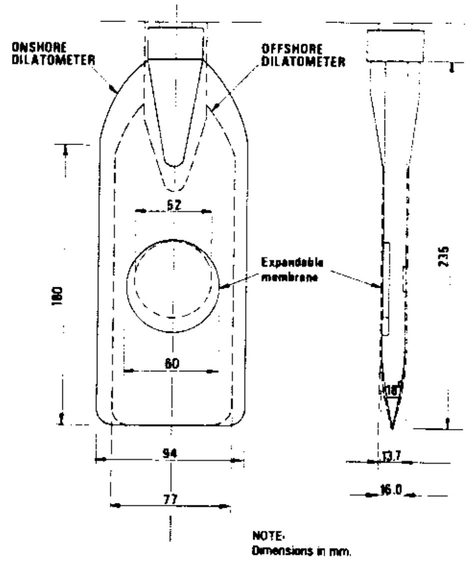

Fig. 1 Comparison of dimensions of the onshore Marchetti dilatometer and the offshore dilatometer.

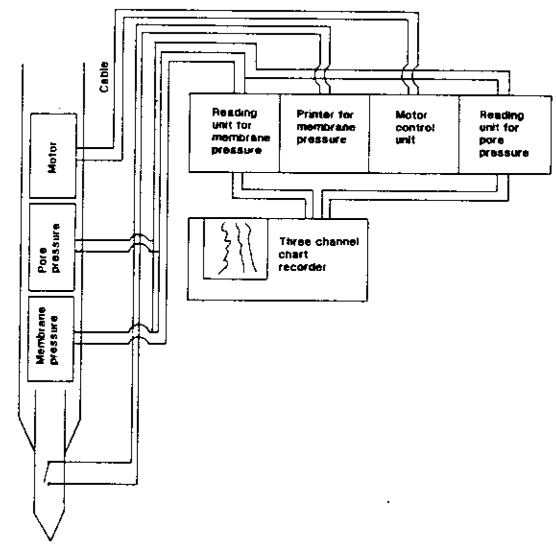

Fig. 2 Offshore dilatometer data acquisition system.

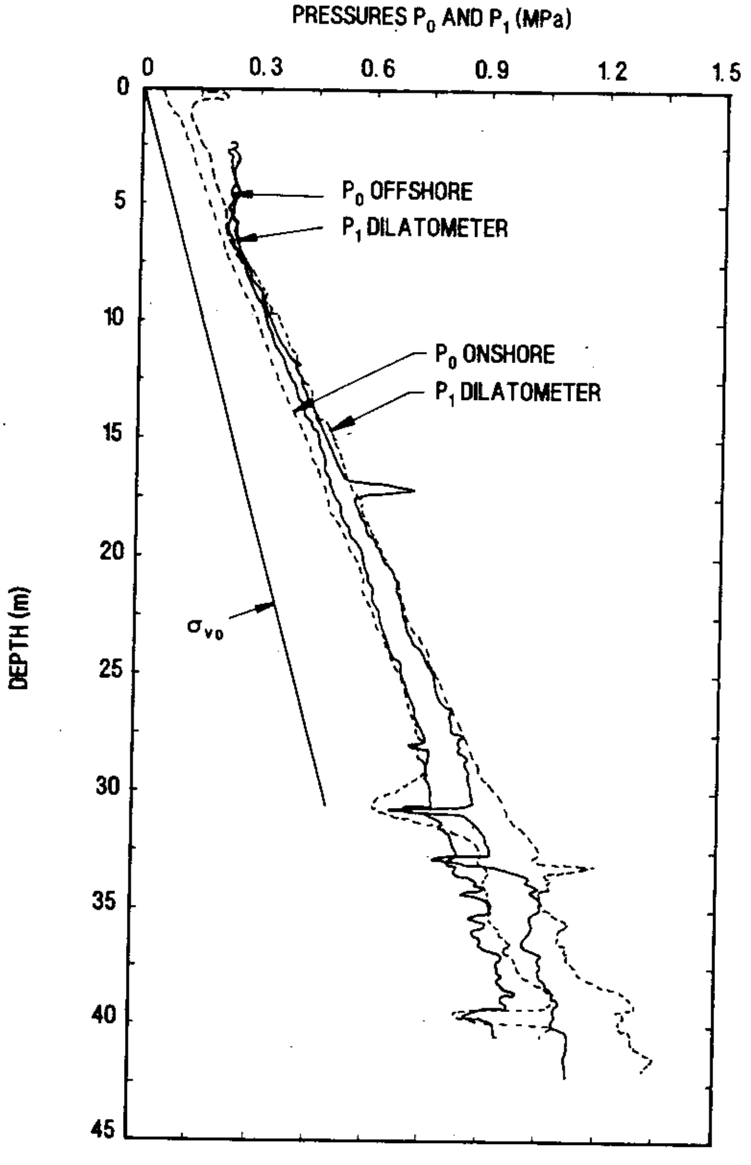

Fig. 3 Comparison between tests results with Marchetti onshore dilatometer and NGI offshore dilatometer in soft Onsøy clay.

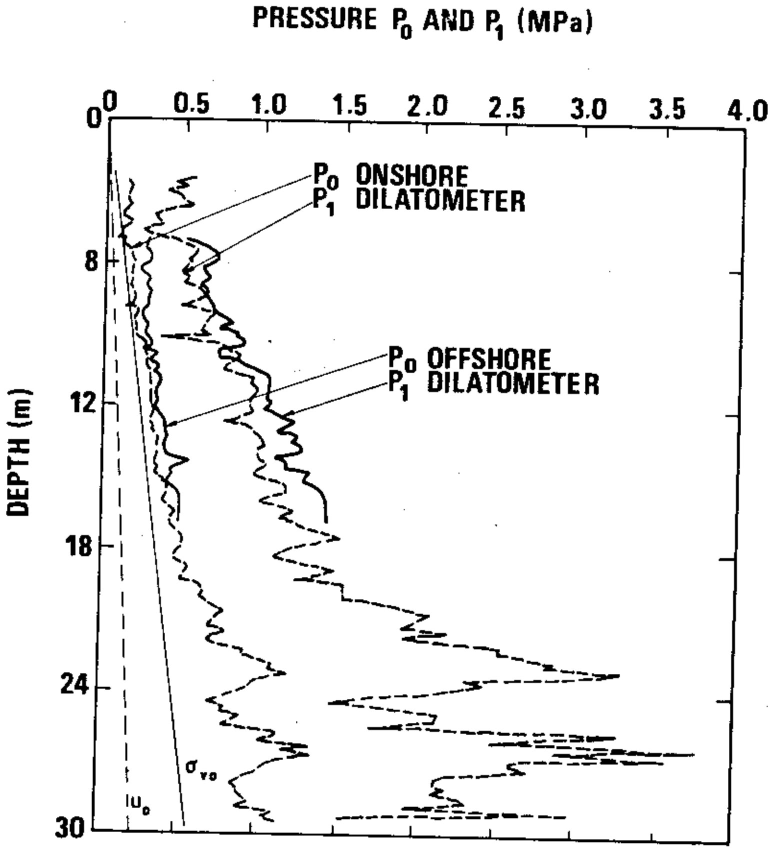

Fig. 4 Comparison between test results with Marchetti onshore and NGI offshore dilatometer in loose Drammen sand.

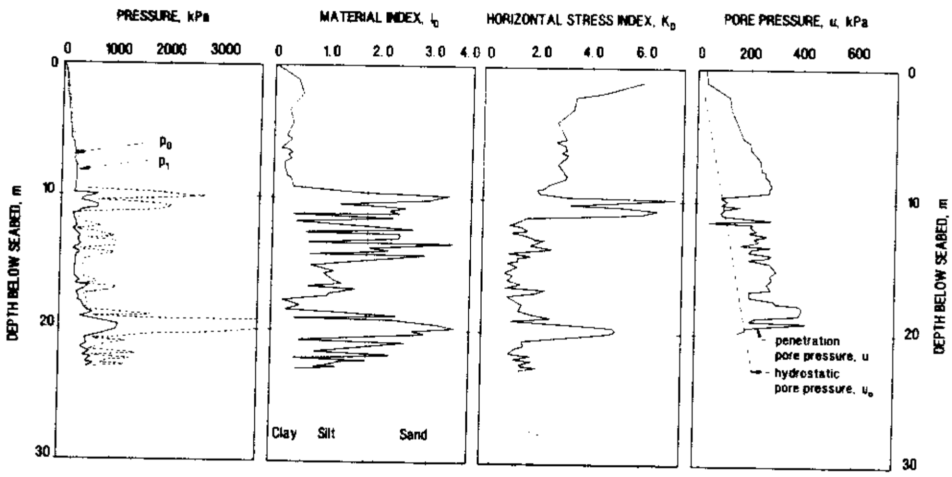

Fig. 5 Dilatometer test results from Gullfaks 'C' North Sea site.

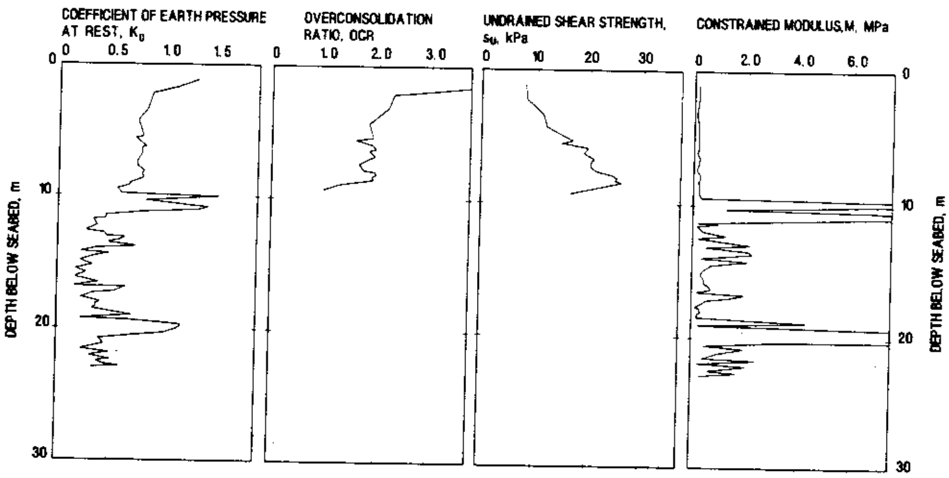

Fig. 6 Soil parameters at Gullfaks 'C' site derived using Marchetti's correlations.