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Commission on Pile Research

Recommendations for Pile Driving Tests with Subsequent Load Testing

Stockholm 1980

rapport 59

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This report has been prepared by the Load Testing Group, a working group within the Commission on Pile Research

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REPORT 59

PREFACE

These recommendations replace the earlier Reprints and Preliminary Reports No. 11 "Recommendations for Pile Driving Test and Routine Load Testing of Piles" issued by the Commission on Pile Research. These new recommendations describe a number of different methods of load testing and combinations of methods, so that it will be possible to satisfy different purposes of load testing. The recommendations apply principally to types of piles normally used in Sweden.

A new method of evaluating the "ultimate load" of a pile, which differs from that contained in the earlier recommendation, is proposed. The method is independent of the shape of the load-settlement curve and gives an unambiguous value of the load at failure for a moderate settlement of the pile head, but even so, sufficient for failure to occur normally along the sides of the pile and under the tip of the pile.

The concept creep load has also been introduced into the recommendations and this is judged as giving a better characteristic value of the bearing capacity of a pile. This creep load is equivalent to the earlier concept yield load.

The recommendations have been prepared by the "Test Loading Group", a working group within the IVA Commission on Pile Research, the members of which were:

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Stockholm March 1980

RECOMMENDATIONS FOR PILE DRIVING TESTS WITH SUBSEQUENT LOAD TESTING

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SYMBOLS

A = pile cross-sectional area

a = linear dimension, mm (= 20 + D/20)

D = pile diameter or equivalent pile diameter

d = initial curvature of pile

δ = settlement of the pile head

δ_B = settlement of the pile head at ultimate load

E = modulus of elasticity of the pile

L = length of the pile

ΔL = elastic compression of the pile

P = load applied on the pile head

ΔP = additional load applied on the pile head

Q_B = evaluated ultimate load on the pile

Q_K = evaluated creep load on the pile

r_{min} = minimum bending radius

RECOMMENDATIONS FOR PILE DRIVING TESTS WITH SUBSEQUENT LOAD TESTING

1 INTRODUCTION

1.1 General

The type of pile to be used in the foundation of a building can normally be decided on the basis of the results of a geotechnical investigation. This applies particulary to end-bearing piles, i.e. piles which transmit the main part of the load through the pile tip to rock or to soil capable of bearing the load. If there is doubt of the level at which piles can achieve sufficient end-bearing capacity or in cases where friction piles are to be used, i.e. piles which transmit the main part of the load to the surrounding soil by means of friction or adhesion along the sides of the pile, it is often desirable to carry out pile driving tests, possibly in combination with load testing.

Pile driving tests are used to determine the necessary length of end-bearing piles for a certain structure, the drivability in soil or to determine the level at which friction piles will stop, calculated using a dynamic pile-driving formula.

Load testing is used during the design stage to determine the necessary length of friction piles, and to check the bearing capacities of piles already driven during the construction work.

Checking of the bearing capacity by test loading is required, for example, in the use of heavily loaded piles in accordance with the Swedish Building Code SBN-80, Pile class A, when the bearing capacity cannot be verified in any other way. In such cases, load testing may be required on piles supporting completed structures.

These recommendations describe how pile driving tests with subsequent load testing should be carried out. The planning and implementation of pile driving tests and load testing should be adapted to the soil and load conditions considered and should be supervised by a geotechnical engineer with experience in this field. The methods described below should be followed as far as possible. This facilitates comparisons between experience gained from other pile driving and load testing programmes, which provides the best opportunity for assessing the method of performance and bearing capacity of the pile.

To increase the accumulated knowledge of the behaviour of piles, it is desirable that one copy of the results obtained from each pile driving test and load test be sent to the IVA Commission on Pile Research, where the results are summarised for different purposes at regular intervals. A copy of the geotechnical investigations should also be appended to the test loading results and sent to:

Commission on Pile Research
c/o Swedish Geotechnical Institute,
S-581 01 LINKÖPING 1
Sweden

1.2 Brief description of different methods of load testing

The methods of load testing most frequently used in Sweden are:

- o Load testing with a constant rate of penetration[1)]
- o Load testing with stepped load increments[2)]
- o Cyclic load testing
- o Long-term loading with constant load
- o Combinations of the above methods.

In principle, load testing can be carried out in two ways. The deformation or settlement can be regulated and the required load recorded, or the load may be regulated and the deformation caused by the load recorded (see Figs. 1.1 and 1.2).

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1) Corresponds to the European C.R.P. method = Constant Rate of Penetration

2) Corresponds to the international ML method = Quick Maintained Load test

Load testing carried out in accordance with the regulated deformation principle is performed with a constant rate of penetration. The pile head is pressed down at a certain predetermined low rate of penetration and the force required to achieve this is measured.

In stepped load increment tests, a certain constant load is applied and the settlement caused by this load is recorded. When settlement has ceased or after a certain predetermined time (15 min - 24 h) the load is increased in accordance with a predetermined plan.

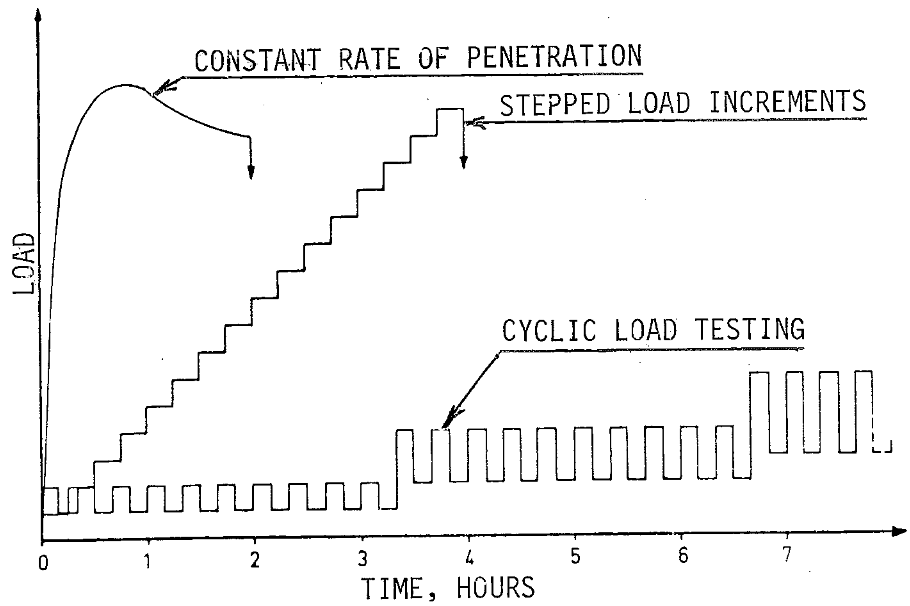

Fig. 1.1 Load-time curves, showing the difference between various methods of load testing (not to scale).

The new load is maintained and the deformation is recorded as described above. The load increments are often equal in size and are 5 - 10% of the calculated ultimate load.

Cyclic load testing can be used to investigate the effect of repeated loading and unloading of piles. The load is increased in a number of stages, as is the case with stepped load testing, but in contrast to the stepped loading method, the load is not kept constant but is varied systematically between a maximum load, which is maintained for a certain time and half of this load, which is maintained for an equally long time. This cycle is repeated 20 times, for example. A complete load test may thus last 15 - 20 hours.

To investigate certain long-term effects, such as the risk of failure due to bending of a pile as a result of lateral deformation that increases with time, or the bearing capacity of a friction pile in clay during slow deformation, the load can be maintained constant for a long period and is known as long-term loading. The long-term load is normally selected as the calculated permanent load to be placed on the pile, multiplied by a suitable factor of safety.

It may be advisable to carry out load testing using a method which consists of a combination of the above procedures to study a special property of a pile. The load testing may be carried out, for example, as stepped loading up to approx. 75% of the calculated ultimate load and then continued with a constant rate of penetration. In other cases, testing by stepped load increments or a constant rate of penetration may be followed by cyclic load testing at relatively high loads.

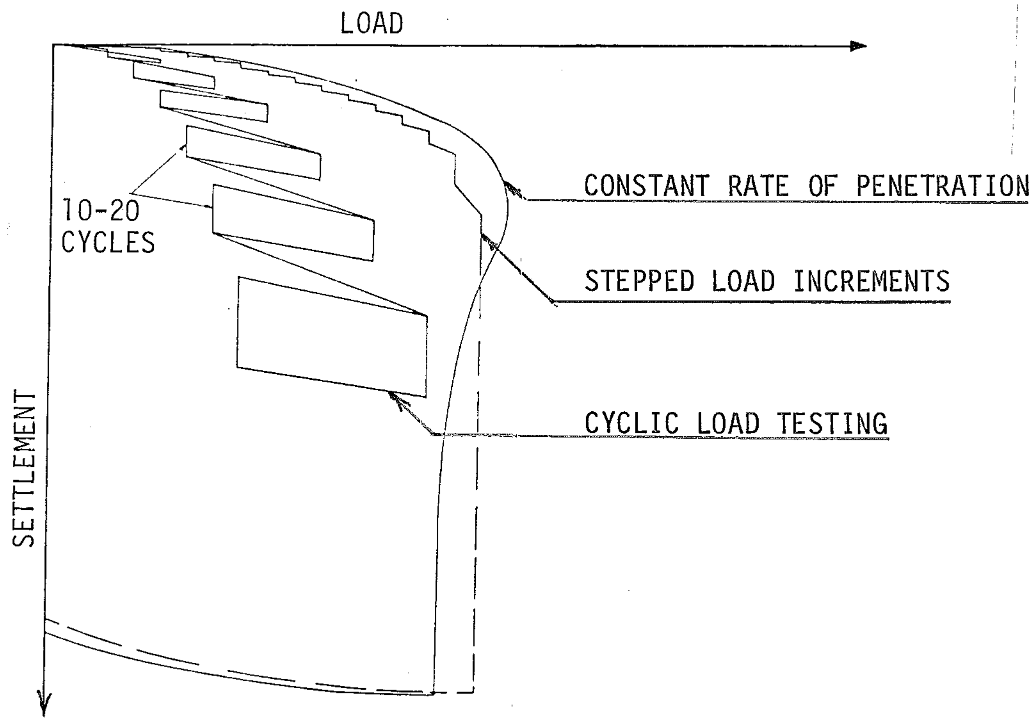

Fig. 1.2. Load-settlement curves (working curves) showing the results from different methods of load testing (not to scale).

The load and movement of the pile head is recorded during each test loading. Further information about the mode of operation or force distribution in the pile can be obtained by measuring the compression of the pile as well as the movement of the pile head. The compression of parts of the pile may also be measured using special equipment. The pile can also be fitted with a vibrating wire strain gauge, for example, to determine the force in certain sections of the pile.

1.3 Choice of load testing method

Pile driving tests, with subsequent load testing, are relatively expensive. It is therefore important that they be carried out by experienced personnel so that all valuable information will be recorded. The costs of pile driving tests and load testing are made up approximately as follows:

Piles, driving of piles and reaction piles or providing other reaction arrangement	60%
load testing including transport and setting up of equipment	25%
evaluation and reporting	15%

The scope of the measuring and testing programme affects the total costs only a little, so the measuring programme should be prepared so as to obtain the maximum possible amount information for interpreting the method of operation and bearing capacity of the pile.

The previous Section contained a brief description of a number of different methods of load testing a pile. The method chosen for a particular investigation will depend on a number of factors, such as:

- The problem; checking the bearing capacity, determination of the required length of pile or the mode of operation of the pile, the effect of repeated loading and unloading.

- Availability of loading equipment and reaction arrangements.

- Scope of settlement and deformation measurements and the type of measuring equipment.

It should be pointed out that the load-settlement relationship obtained using different methods of load testing do not agree with one another (Fig. 1.2) and that there is a difference between the ultimate load and the creep load (see Sections 6.3 and 6.4). Unfortunately, no systematic comparisons on full-scale piles tested using different methods have been carried out, but half-scale pile tests have been carried out (Bergdahl & Hult, 1979).

If the failure criteria proposed in these recommendations are taken into account, half-scale tests on friction piles in sand show:

- that the ultimate load determined from load-settlement curves for stepped loading and cyclic loading and unloading are, on average, 93% of the ultimate values obtained from constant rate of penetration tests.

- that the creep load determined from cyclic loading and unloading and stepped loading is, on average, 80% of the ultimate load obtained from constant load of penetration tests.

It can be noticed from half-scale tests carried out on friction piles in clay at Skå Edeby:

- that the ultimate load determined from cyclic loading and unloading or stepped loading is, on average, 90% of the value obtained from constant rate of penetration tests

- that the creep load determined from cyclic loading or stepped loading is, on average, 78% of the ultimate load determined from constant rate of penetration tests

It should also be pointed out that the tests have also shown that there are differences between the results of tests carried out at the same site and in the same manner on identical piles. These difference may be of the same order of magnitude as the differences described above.

Load testing with a constant rate of penetration gives a continuous graph of the load-settlement relationship for the pile, even during the phase which shows the behaviour of the pile after the soil around the pile has failed. This gives a good picture of the mode of operation of the pile in the soil. The method is fast (it takes approximately 2 h), however, this may make it difficult to find time to take exhaustive measurements during the course of the test. This method requires the use of an electric pump which can be preset to give a small and constant flow of oil.

When many deformation gauges or other measuring instruments must be read and automatic recording equipment is not available, stepped loading is a suitable method for testing piles. And the advantage of the method is that the rate of settlement during the latter part of each load increment is a valuable addition to the information to be evaluated when determining the permissable load on the pile. Load testing can be carried out using a simple hand pump. If the rate of settlement is to be determined, such as for the evaluation of the creep load, a pump with automatic pressure control and accurate pressure measurement is required (cf. Section 4.33).

Cyclic load testing is used occasionally on piles that will be used to support structures subjected to large live loads, e.g. bridges.

The use of combinations of methods may occasionally be desirable. For example, a stepped load testing may be concluded by using a constant rate of penetration. If the loading device should be found inadequate, so that the pile cannot be loaded to failure, it is advisable to complete the test by cyclic loading. The settlements measured during these load cycles provide information for assessing how close the maximum available load is to the ultimate or creep load.

GEOTECHNICAL INVESTIGATIONS IN CONJUNCTION WITH PILE DRIVING TESTS AND SUBSEQUENT LOAD TESTING

2.1 General

The geotechnical investigations carried out before pile driving tests, with subsequent load testing, must be such that the lengths of test piles and any reaction piles can be calculated. This requires the determination of the soil composition and firmness through the entire depth of soil affected by an envisaged pile foundation. The investigation must be carried to a greater depth if loose soils, especially cohesive soil, is suspected below the envisaged pile tip level.

The Commission on Pile Research Working Group for Soil Investigations is at present preparing recommendations for geotechnical investigations for use in piling work of different kinds. When the recommendations have been published, they should replace the text below.

For descriptions of items of equipment and methods, refer to the Swedish Geotechnical Society Standard (1979) for probing, the Swedish Geotechnical Society: "Proposed geotechnical laboratory recommendations (LABAN)[1], the Bygg manual (1972) Chapter 178, and the "Geotechnical Site Manual" published by AB Jacobson & Widmark (1973).

2.2 Probing

The Swedish dynamic probing test (standard method A is the most suitable) is normally carried out when the use of end-bearing piles is envisaged. During this test, the friction along the sides of the rods should be measured using a torque wrench or slip-coupling. Method B may be chosen when the depth to firm layers is less than 15 - 20 m, but not in firm clay such as boulder clay. In cases where soft clay rests directly on firm moraine or rock, light motor percussion soundings may also be used. Soil-rock drilling (percussion drilling) may be required in soil containing stones and boulders.

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1) Under preparation. Parts 2 - 7 (of 10) have been published as information sheets by the National Swedish Institute for Building Research (SIB) (see References).

Cone penetration testing or weight sounding to a firm bottom layer is normally carried out during investigations for friction piles in clay.

Weight sounding, cone penetration testing and dynamic probe testing, using method A, to a firm bottom layer are used in investigations for friction piles in gravel, sand and silt.

At great depths to firm bottom (above 30 - 40 m) and in silty soil and firm clay, a high resistance to penetration (200 - 300 blows/0.2m or above) may be obtained with dynamic probing equipment, without the point having reached a firm bottom layer. A check should be made, using either an increased height of fall or an extra heavy hammer. In such cases, consideration should be given to supplementing the investigation by soil-rock drilling (percussion drilling).

2.3 Sampling

Sampling in conjunction with pile driving tests and load testing should include the taking of sufficient samples to obtain a clear picture of the soil profile, even under the pile tip level, if possible. Undisturbed samples should be taken in cohesive soil, whereas disturbed or remoulded samples are adequate in friction soil. Where end-bearing piles are envisaged, the demands on sampling must be decided in each individual case.

2.4 Laboratory testing

The soil type and water content of all samples should be determined.

For friction piling in clay, the shear strength, sensitivity, the liquid limit as determined by the Swedish fall cone test, the bulk density and compression properties of the samples should also be determined. It is also necessary to investigate the compression properties of soil under the pile tip level for settlement calculations.

2.5 In-situ testing

For friction piles in clay, it is advisable to determine the shear strength by vane tests.

As a supplement to the probing and sampling described above, it may occasionally be advisable, in the case of friction piles in sand to determine the strength and deformation properties by carrying out pressiometer tests, particularly in conjunction with large piling works.

2.6 Reporting

The geotechnical investigations should be reported in accordance with the Swedish Geotechnical Society "Signs and symbols on boring drawings", pages 1 - 4. The geotechnical investigation should normally be appended to the pile driving test and load testing report.

3 PILE DRIVING TESTS FOR LOAD TESTING

Before pile driving tests are carried out, a decision should be taken on whether or not test piles or any of the reaction piles should be included in the foundations. A suitable location for pile driving tests and load testing should be selected on the basis of this decision and the results of the geotechnical investigation. In conjunction with this decision, the need to redrive reaction piles after the completion of load testing should be assessed.

3.1 The design of test piles

The design of test piles, including any joints and shoes should be shown on a drawing.

Test piles of concrete or steel should generally be provided with inspection pipes. In prefabricated concrete piles, an inspection pipe should be a pipe of 42±1 mm internal diameter, cast in the centre of the pile. The pipe should be a seamless precision steel pipe to DIN 2391, to permit the taking of inclinometer measurements with acceptable precision. In certain cases, a welded precision pipe, made with special dimensional accuracy to DIN 2319, may be used. Refer also to the Swedish National Road Administration "Directives for piling works" TB 108 1976-12.

3.2 Measuring test piles

3.21 Measuring the length and marking test piles

The length of test piles and pile segments must be measured to an accuracy of ± 10 mm. In conjunction with this measurement, test piles should be marked at every metre or 0.2 of a metre, depending on how the driving resistance is to be recorded. The length should be measured, starting from the extremity of the pile tip, so that the depth of the pile tip below ground level or other reference plane can be determined at any time during the course of driving.

3.22 Measuring the perimeter

The perimeter or cross-sectional dimensions of wooden or concrete test piles or segments of test piles (when concrete piles are used as cohesion piles) should be measured, with a measuring accuracy of $\pm$ 5 mm of the perimeter every second metre, but more frequently when there are irregularities in the cross-sectional area. Any non-structural projecting corners must be removed first.

3.23 Measuring the initial curvature

The initial curvature of a test pile or pile segment must be measured in certain cases as it is of importance to the results of pile driving tests and load testing. The initial curvature must always be measured in the case of timber test piles. In the case of precast concrete or steel piles, measurement of the initial curvature is not generally necessary provided that a visual inspection of the pile or pile segment does not indicate this need. The angle of the joint facing-plates in relation to the longitudinal axis of the piles must always be checked. Refer to relevant requirements for acceptable values of curvature and initial angle deviation across joints.

Initial curvature must be measured as follows (see Fig. 3.1). Place the piles on two supports located 0.2 times the length of the pile (L) from each end of the pile. Mark the centreline of the upper surface of the pile at each end. Stretch a steel wire tightly between these marks. Then measure the horizontal deviation (d) of the steel wire from the centreline and record the direction of the deviation (to the left or to the right) in relation to the longitudinal axis of the pile. Turn the pile through 90° and repeat the procedure.

Place round timber piles so that the greatest deviation from a straight line between the top and the base can be measured. Precast concrete piles should be placed so that the first series of measurements is taken on the side which has not been contained by formwork. Marking should be carried so that measurements are taken in two planes at right-angles to one another.

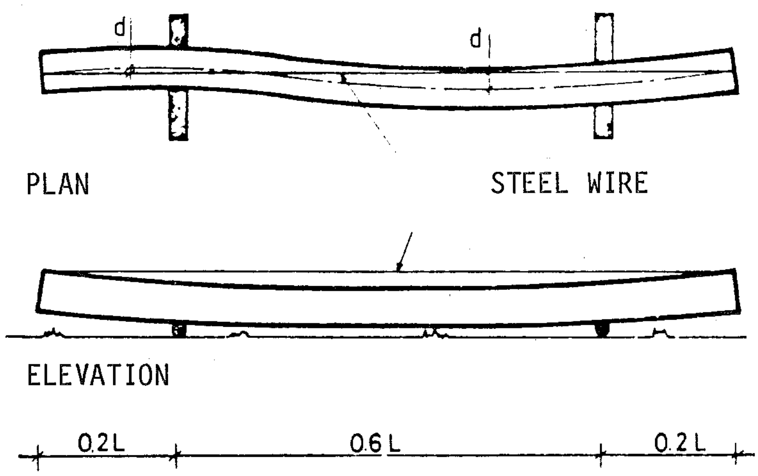


Fig. 3.1. Principle for measuring initial curvature. The distance d should be measured.

It is advisable to report measured deviations on a drawing.

3.3 Driving test piles

Test piles are normally driven vertically.

If a test pile to be used as a friction pile or end-bearing pile is driven before reaction piles or anchor bars, the test pile must be redriven. But friction piles in clay must not be redriven, as the bearing capacity is reduced if redriving is carried out after a certain time.

3.31 Recording of data

A driving log must be kept for every test pile. It is often also advisable to keep logs when driving reaction piles. Forms of the type shown in Appendix 3.1 should be used. Information at the head of the form should also be entered carefully. (The form may be ordered in pads of 50 sheets from Ingenjörsventenskapsakademien, Biblioteket, Box 5073, S-102 42 Stockholm, Sweden.)

3.32 Driving log

Pile penetration should be recorded throughout the whole course of driving. Any preboring through fill, the dry crust or frozen soil must be noted in the log, together with the depth to which preboring has been carried out, and the cross-sectional dimensions of the preboring tool used. The log must also show the depth to which the pile sinks under its own weight and under that of the pile plus the hammer. If the pile is driven through soft soil, through which it sinks a great deal per blow, it is advisable to record the number of blows for each metre of penetration. When the driving resistance increases, the number of blows should be recorded per 0.2 m of penetration by the pile, as this is the normal procedure.

When the driving resistance, using a normal hammer and height of fall, amounts to approx. 100 blows per 0.2 m of penetration, it is advisable, as a comparison, to also record the penetration of the pile achieved during a series of 10 blows, by making marks on the pile, for instance. Pile driving should always be concluded by recording the pile penetration for between 3 and 5 series of 10 blows (cf. "Swedish Building Code 1975, Approval Rules No. 1975:8 Piles"). Appendix 3.1 shows an example of a driving log completed in accordance with the description above. One advantage of this method of recording is that after the results have been shown in graphical form (see the example in Appendix 3.2), a good picture is obtained of the whole driving operaton and a direct comparision can be made with the results from the geotechnical investigation.

Alternatively, in conformity to earlier practice, the driving resistance may be recorded as the penetration of the pile per series of 10 or 50 blows. An example of this method of recording is shown in Appendix 3.1 A (pile driving log) and Appendix 3.2 A (blow count graph).

The depth of the pile tip below ground level should be entered on the pile driving log at the same time as the driving resistance is recorded. For this, the length measurements earlier marked on the pile should be used. (Note: the depth of the pile tip must not be calculated as a sum of the penetration measured for series of 10 or 50 blows.) When driving has been concluded, the level of the pile head must be determined by levelling. The level of the pile tip below the datum level used on site may then be entered in the driving log.

During driving, the insertion of each new packing in the pile driving helmet and the use of any follower must be entered in the log. The time at which driving is started and concluded and the time for any breaks during driving must be noted. Any other observations made during the course of driving, such as when hammer rebound occurs, or when a new pile segment is added, must be entered in the remarks column. Any deviation from a straight line across the joint must be measured and noted in conjunction with the fitting of an additional pile segment. Results from redriving must also be entered.

3.3 Rebound measurements

Rebound must be measured for end-bearing and fricton piles in sand when driving to refusal or during the conclusion of driving. To do this, fix a sheet of hard, glossy paper or cardboard on the pile, using suitable tape or strong rubber bands. Place a horizontal, unyielding plank on edge in front of the pile, on supports which are independent of the pile-driver and any support on which it may be resting, so that the vertical movements of the pile during a blow can be recorded on the paper by moving a pencil along the plank. Interpretation of the rebound diagram is facilitated if the pencil is drawn quickly back and forth across the paper between each blow (see Fig. 3.2 and Appendix 3.3.). The diagram should be signed by the person who has prepared it, and other data of the type shown in Appendix 3.3 should be entered. The complete diagram or a direct copy of it should appended to the documents.

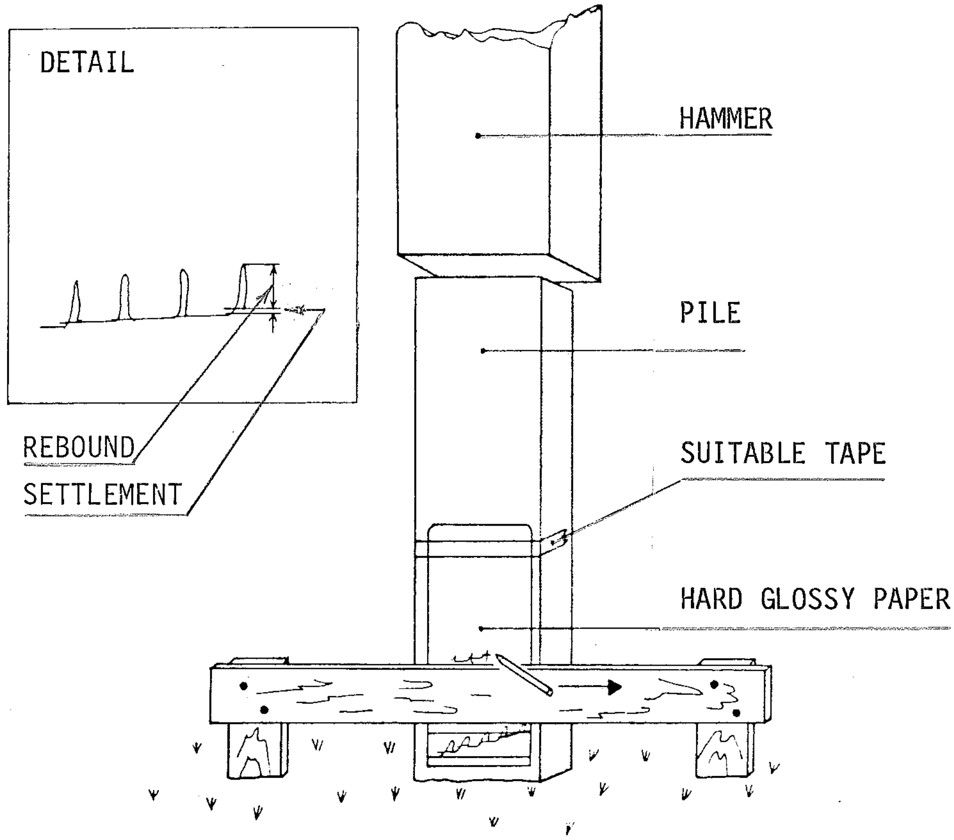


Fig. 3.2 Principle for measuring pile rebound.

In recent years, other methods have also been developed for measuring the bearing capacity and mode of operation of a pile during driving by means of accelerometers and strain gauges, such as the Case method. The measurements can be carried out during test piling, as a supplement to the measurements described above, especially in cases where the mode of operation of the pile is difficult to assess.

3.34 Measuring the curvature of driven piles

The curvature of a pile can normally be checked after driving, using a 1.8 m long steel-pipe gauge (see "Swedish Building Code 1975, Approval Rules No. 1975:8 Piles"). But checks made with gauges only permit the detection of sharp bends (bends with small radii). Inclinometer measurements should be carried out to obtain an accurate check on the curvature of a pile. These measurements must be made at a number of points along the inspection pipe in the pile (cf. Section 3.1). The maximum angle of inclination of the pile is recorded at each measuring point, together with the bearing of this inclination.

Alternatively, the angle of inclination of the pile may be measured in two directions at right angles to one another. The radius of curvature of the pile or the change in inclination over a certain length of the pile may be then calculated from these values. The shape of the pile in the ground can be calculated by carrying out a cumulative calculation on the results. Inclinometer measurements should always be made by personnel thoroughly familiar with the equipment.

When assessing the curvature of a pile after driving, the change in angle across a joint should always be separated from the curvature of the pile segments. Evaluation of the test results should also be related to the intended applied load on the pile, the soil conditions, etc.

3.4 Reporting of test piling results

The driving operation should be presented as a graph, as shown in Appendix 3.2 or 3.2A, depending on how the driving has been recorded.

The graph should show the driving work (the number of blows per 0.2 m of penetration or the penetration of the pile per blow) as a function of the depth. It may be necessary to change the scale of the graph as the pile approaches refusal and the driving resistance increases. The graph should also include a curve of the total number of blows, together with other observations that have been noted in the driving log, in accordance with Section 3.32 'Driving log'. The results of penetration measurements made during concluding series of blows and results of check-driving and redriving should be entered at the level of the pile tip in the graph. The driving graph should also indicate the pile designation, depth of the pile tip, the weight of the hammer, the height of fall and the date. Rebound diagrams should be prepared in accordance with Appendix 3.3 and the evaluated results should be entered at relevant levels in the driving graph.

The locations of piles in plan and in section should be reported on the geotechnical drawings. Where possible, driving graphs should also be shown on these drawings.

4 ARRANGEMENTS FOR LOAD TESTING

4.1 Test piles

Test piles and the driving of test piles are described in Chapter 3, 'Pile driving tests for load testing'.

4.2 Provision of reaction devices

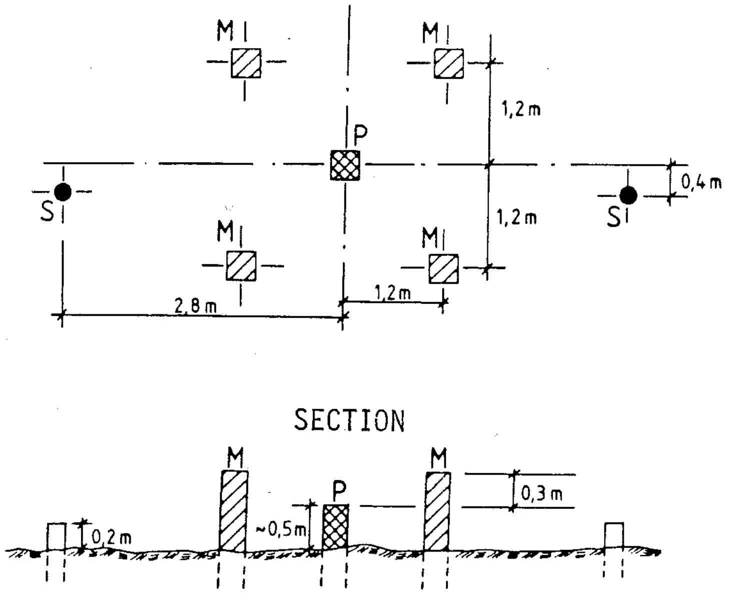
4.21 General

Reaction arrangements are usually provided so that test loading can be carried out to at least three times the greatest load that the pile can be expected to be subjected to in the structure. But it is desirable to be able to load friction piles in clay and sand to failure of the soil. The design of reaction devices should take into account a certain eccentricity of the load and relevant safety demands.

4.22 Reaction piles

Reaction devices for jacks used in test loading may be arranged in various ways. Reaction piles of timber, concrete or steel are usually used.

The number of reaction piles and their lengths are dependent on the layout of the test loading arrangement and the required reaction force. If several reaction piles are used, it may occasionally be necessary to achieve coordination by using a system of beams. The reaction piles should be designed so that the required reaction force is achieved with a certain margin of safety (factor of safety: 1.3 - 1.5), because of the unpredictability of the withdrawal or pull-out resistance of piles, uneven distribution of the load between the reaction piles, etc. In loose sand, for example, the pull-out resistance is only half of the skin friction encountered when forcing the same pile into the ground (Bergdahl & Wennerstrand, 1976). The load testing configuration to be used must be defined before the test piles are driven, so that the piles are suitably located (see Fig. 4.1). The centre-to-centre distance between reaction piles and the



P = TEST PILE

M = REACTION PILE

S = SUPPORT FOR MEASURING BEAM (2" x 4" TIMBER)

Fig. 4.1. Example showing the locations of the test pile and reaction piles in relation to one another.

test pile should not be less than 1.5 m. A greater distance is desirable in the case of friction piles in sand. (According to a theoretical study by Poulos (1974), the distance should be approx. 10 times the pile diameter, D.) If possible, the reaction piles should be driven before the test piles. A driving log as described in 3.32 above should normally be kept. Steel sheet piling may be used to provide the reaction force instead of reaction piles.

4.23 Anchor bars

A reaction force may also be provided by means of anchor bars to rock or possibly into soil. Anchors in rock should be set vertically and at least 1.5 m from the test pile. The bars should be prestressed against sleepers, for example, or a stack of beams, until a sufficiently large force is built up so that any lateral forces encountered during load testing can be absorbed during the whole test by the friction between the sleepers and the soil. Alternatively, the lateral forces may be taken up by sheet piling or short piles.

4.24 Kentledge

In certain cases, it may be advisable to arrange kentledge by placing steel girders and concrete piles as a reaction load on a stack of heavy cross-timbering etc., located at a reassuring distance from the test pile (preferably more than 1.5 m). The steel girders and concrete piles should be placed so that their centre of gravity is directly above the test pile. The stability of the kentledge against tipping and ground failure should be checked. Combinations of reaction piles and kentledge may also be employed.

4.25 Existing structures

Load testing is occasionally carried out only after part of the building or the whole building has been built, in which case, the building can be used to provide the reaction force. Special arrangements may be required to withstand the very large local forces applied to the building. This applies particularly to older buildings.

4.3 Equipment for load testing

4.31 Jack

The jack should be of the hydraulic type, with little internal friction, and must have an adequate stroke and load capacity in relation to the pump. It must be calibrated together with the pump and pressure gauge to be used in the test, unless a pressure cell is to be used.

4.32 Bearing arrangements

A spherical bearing arrangement must be fitted above or below the jack to limit the friction in the jack as a result of eccentric loading. Rubber plates may also be used, but in this case, the risk of non-axial loading of the jack must be observed.

If load testing is carried out on a raked pile, the test load must be applied axially to the pile and movements must also be measured in the direction of the longitudinal axis of the pile.

4.33 Pump

Pumping equipment should be chosen, taking into account the method of load testing.

When the pile is loaded to achieve a constant rate of penetration, a special pump that provides a constant and, within certain limits, controllable flow of oil will be required.

A hand-operated or motor-driven pump may be used for stepped loading. But if the rate of settlement is to be determined with precision, a pump with automatic pressure regulation will be required.

The pump used for cyclic loading and constant loading over a long period should be motor driven and equipped with a pressure-maintenance device, such as the photocell type, fitted to a precision pressure gauge. The interval between switching on and switching off should not exceed 1 - 2% of the applied load.

4.34 Pressure gauge

A precision pressure gauge with a large dial should be used and the measuring precision should be better than 2% of the measuring range.

4.35 Pressure cell

A pressure cell located on the pile head should be used to determine the applied load, because the friction in the jack can often involve considerable error if the applied load is calculated from the measured oil pressure. The measuring precision of the pressure cell should be better than 2% of the calculated ultimate load.

4.36 Beams and dial gauges for measuring the vertical movement of the pile head

The vertical movements of the pile head must be measured with at least two dial gauges mounted on a measuring beam.

The dial gauges must be placed on alternate sides of the test pile and equidistant from the centre of the pile. The dial gauges should be graduated in tenths of a millimetre, preferably hundredths, and should generally have a stroke of at least 50 mm, so that the minimum number of resettings is required during the course of a test. Resetting should be achieved by inserting gauge blocks of suitable size between the tip of the dial gauge and the surface on which the tip rests.

The measuring beam must be supported completely independent of the reaction piles and the loading devices (possibly on special support piles). The length of the measuring beam should be such that its supports can be located at least 1.5 m from the closest reaction pile. The measuring beam must be protected from changes in temperature during the test loading, by being covered with a tarpaulin, for instance, which does not touch the measuring beam.

In the event of doubt as to the pull-out strength of reaction piles or anchor bars, their vertical movement must be measured using dial gauges or a levelling instrument.

The movement of the pile tip can be measured in a pile equipped with an inspection pipe (see 4.4 below).

4.4 Special equipment

4.41 Measuring the settlement of a test pile

The possibility of measuring the movement of the pile tip during test loading should be utilised by inserting a bar through the inspection pipe to the tip of the pile.

At least one more measuring point is required if information is required to achieve a better assessment of the load distribution in the pile, i.e. the proportion of the load carried by the pile tip and the skin friction, and the distribution of the skin friction along the pile. The compression of the pile can be measured at an upper part and a lower part of the pile, using a pipe fitted with an expansion fixture at its lower end (Broms & Hellman, 1968). This pipe surrounds the bar used to measure movements at the pile tip. With a knowledge of the modulus of elasticity of the pile, it is then possible to calculate the approximate average stress in the different parts of the pile, using the results of measurements (Fig. 4.2).

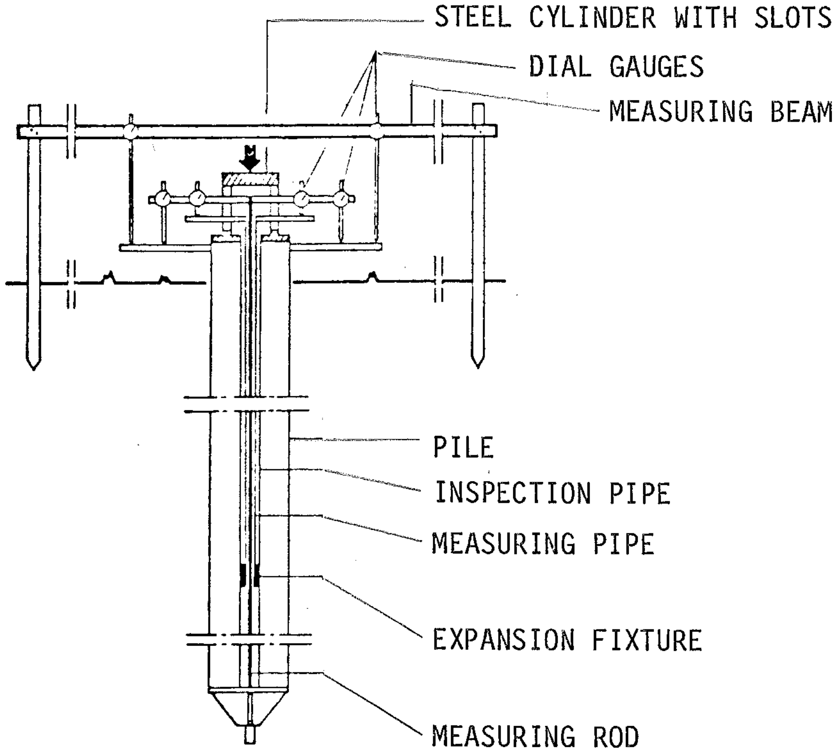


Fig. 4.2. Principle of the arrangement for measuring the settlement and compression in different parts of the pile.

The rod to the pile tip and the pipe with the expansion fitting should project about 0.1 m above the head of the pile (the rod slightly more than the tube). Horizontal yokes should be secured to the pipe and to the rod, and dial gauges should be inserted between the yokes and the head of the pile. A special device, such as a steel cylinder with slots in the side, is then placed on the pile to transmit the load from the jack to the head of the pile.

There are other systems which can be used to take the same type of measurements.

4.42 Measuring the load in a test pile

The pile may be fitted with electric transducers for accurate calculation of the load in certain sections of the pile. Such transducers, resistance transducers or vibrating-wire transducers, register the deformation of the pile over a short distance and provide more accurate values of the load and the load distribution in the pile than deformation measurements made using pipes and rods. However, the evaluation of these results is also based on the modulus of elasticity of the pile material.

Correct values of the load in the pile can only be obtained using special, accurate, pile load gauges, which measure the load independently of the modulus of elasticity of the pile. One such gauge, which also measures the bending moment in the pile, is described by Fellenius and Haagen, 1970.

4.5 Report on the testing equipment

Information on the equipment used, the configuration, execution, etc., which may be of value in evaluating the load test, should be documented, preferably also with photographs.

The report should show the arrangement used to provide a reaction force for the jack. The configuration, with dimensions, is best reported by means of a sketch. It is of particular importance to show where and how the soil was loaded by the reaction equipment (tensile or compressive stresses).

If reaction piles have been used, the report should show how these have been designed and, if they have been joined, how and at what level the joints are located. Reaction pile driving logs must be appended. The logs must show whether the reaction piles have been driven before or after the test pile, the distance from the test pile and the depth to which they have been driven.

The equipment used to apply the load, including the serial number or other identification must be specified, together with the maximum error in the measurement of the magnitude of the load. The method of supporting the measuring beam and movement gauges must also be reported. If special measurements have been made, using expansion transducers or strain gauges, for instance, these should be described in detail.

5 TECHNICAL RECOMMENDATIONS FOR THE EXECUTION OF LOAD TESTING

5.1 Time between installation and load testing

Friction piles in coarse grained soil and end-bearing piles may normally be load tested one day after driving.

In the case of other piles, the time at which load testing should be carried out must be determined taking into account the material of the pile and the soil as well as the time schedule for the remainder of the construction works. The bearing capacity of a friction pile in clay varies with time because the disturbed clay closest to the pile gradually recovers its strength (reconsolidates). The interval between driving and load testing should normally be chosen so that the greater part of the strength recovery has taken place when the load testing is carried out. In cases where the piles will be subjected to a large part of their design load shortly after installation, this must be taken into account when choosing the time for load testing.

The relatively high permeability of timber piles permits them to act as vertical drains, so that they achieve strength recovery of the soil faster than steel and concrete piles. Steel and concrete piles in close groups have a slower rate of bearing capacity recovery than corresponding isolated piles.

Friction piles of timber should not normally be load tested before one month has elapsed after driving and the corresponding figure for friction piles of steel or concrete is 4 - 6 months. If there is uncertainty as to the rate of bearing capacity recovery with time, repeated load testing may be carried out.

5.2 Required load

Load testing of piles in conjunction with design work should normally be carried to failure of the soil. Load testing, as a method of checking the bearing capacity of a pile, should normally be carried to three times the intended permissible load on the pile.

5.3 Measuring the movement of a pile

During the course of load testing, the axial movement of the pile should be measured with dial gauges. The movement is calculated as the average of the dial gauge readings. If a considerable difference (1 - 2 mm) occurs between the dial gauge readings as the result of non-axial loading during the course of load testing, the load testing must be stopped and measures taken to centre the load.

In certain cases, it may be necessary to measure lateral (horizontal) movements of the pile in addition to axial (normally vertical) movements.

Dial gauges etc. must be protected against the sun, rain and wind during load testing.

5.4 Load testing record

A record must be kept during load testing and this should show the load applied (pressure cell or pressure gauge readings), the settlement of the pile head and the compression of the pile (as dial gauge readings) and the times for the readings. All readings must normally be taken at the same time. In certain cases, a decision may be taken to read the dial gauges over a certain period, such as a minute, but it is then important that the gauges are read in the same order throughout the entire test. Weather conditions and other observations which may affect results, such as lateral displacement of the pile head, must be noted in the load testing record.

An example of a load testing record is shown in Appendix 5.1.

The load-settlement curve for the test pile (pile head) should be drawn preliminarily as the test proceeds. This will facilitate assessment of results, e.g. when the ultimate load has been reached and how far the load testing should be carried.

5.5 Methods of load testing

5.51 Load testing with a constant rate of penetration

The method is usually employed to determine the ultimate load and mode of operation of a pile.

Load testing is carried out by forcing the pile into the ground so that the rate of vertical movement measured at the head of the pile is constant. It is advisable to record the force required and the magnitude of the movement every second minute. The interval between the readings should be reduced in the case of rapid changes in load, e.g. when testing short end-bearing piles.

End-bearing piles should be loaded until failure or until the maximum available load has been applied.

Skin-friction bearing piles (friction piles) should normally be loaded to achieve at least 60 mm of settlement. If possible, friction piles in clay should be forced approx. 20 mm into the ground after the maximum required load has been reached. But if a friction pile in clay is to be load tested several times, loading should be discontinued as soon as the maximum load has been reached, i.e. when the load becomes constant or tends to fall.

The rate of penetration is normally chosen at approx. 0.5 mm/min. But in the case of short end-bearing piles, it is advisable to reduce the rate of penetration to approx. 0.1 mm/min to permit the required readings to be taken. When loading has been discontinued, the pile should be unloaded and the load and rebound measured as follows:

The load is reduced quickly by reducing the pressure in the jack. Unloading is interrupted for 1 - 2 min, i.e. the time required for the rebound to become stationary and to permit reading of the dial gauges when the load has fallen to approx. 75, 50, 25, 10 and 5% of the maximum applied load. The rebound is measured when the load reaches zero and 5, 15 and 30 minutes after unloading and, if possible, also after a longer interval.

No unloading should carried out during the course of load testing, provided that nothing occurs that justifies discontinuing the test, e.g. a noticeable change in the inclination of the pile.

5.52 Load testing with stepped load increments (known as the Quick Maintained Load Test (ML method)).

This method is designed to permit determination of the ultimate load and creep load on the pile.

In this method of testing, the load is increased every fifteen minutes by a constant amount, approx. 5% of the estimated ultimate load, generally rounded off to an even 10, 20, 50 or 100 kN. Dial gauges are read 3, 6, 9, 12 and 15 min after application of a new load increment has been started. A new load increment is applied immediately after the 15 min reading.

To be able to evaluate the creep load, load measurement and maintenance of a constant load must be carried out with great accuracy. Moreover, during the application of the load increment, the load must at no time exceed the load which will later be maintained constant.

Loading should be discontinued at the same deformations as apply to load testing at a constant rate of penetration (see 5.51).

Unloading is also carried out in accordance with 5.51.

5.53 Cyclic load testing

This method is designed to permit the determination of the creep load on the pile, as defined below.

Load testing is carried out by alternating the load between a high load and a low load. The high load is generally twice the lower one. Each load is maintained for 10 min, measured from the time of starting to apply a load change. One cycle comprises a period with a high load, directly followed by a period with low low and is thus of 20 minutes duration.

In the case of large loads, when changing between a low and a high load may take 2 or 3 minutes, it may be necessary to extend the duration of a cycle to 30 to 40 minutes. The cycle duration, which should be identical for all cycles during the entire load testing, should be sufficiently long for movements of the pile to have stopped before the next load is applied.

It is advisable to measure and record pile settlement at the head of the pile every second minute.

The number of cycles in each range of loads should be at least 10, until the high load has reached half of the estimated ultimate load, at which point the number should be increased to at least 20. It is important that the number of loads is not too few, especially when the load approaches the creep load.

The procedure is repeated with increasing loads. Suitable load increments are: 2/16 - 1/16; 4/16 - 2/16; 6/16 - 3/6; 8/16 - 4/6.... of the estimated ultimate load.

During the course of load testing, the settlement of the pile head should be plotted as a function of the number of load cycles, as shown in Section 5.6 (N.B. Log graph paper is required).

The creep load is regarded as having been exceeded when this curve starts moving down after a number of cycles (between 1 and 20). At lower loads, this curve will be concave upwards, or straight.

When the creep load has been exceeded, the load should be removed in accordance with 5.51.

The method demands great accuracy. The load changes should be applied at as even a rate as possible. It is important to make a load change carefully so as not to exceed a load increment and not to fall below a load reduction. The load must be maintained constant during the application of high loads and low loads. If this is not observed, the curve on log graph paper described above will be irregular and the change in slope may be difficult to interpret. If the load is exceeded in any cycle, the number of cycles must be increased until the curve again shows a clear tendency, and the "excessive" load should be used as a high load. N.B. The downward concave part of the curve can occur only during the final load cycles in a series.

5.54 Long-term load testing

Long-term load testing is designed to check the creep of the pile.

Depending on the conditions, load durations of the magnitude one day up to six months or a year may be required. During loading for one day, a load at approximately the creep limit is chosen. This load is assessed on the basis of results from load tests with stepped load increments (5.52), cyclic loading, (5.53) or constant rate of penetration tests (5.51). Load durations of 1 - 2 months per load step are required to determine the creep process caused by bending of the pile.

Load control and the necessary measurements are carried out as nearly continuously as possible, so that the influence of load changes outside the pile, such as the result of variations in the groundwater table are recorded. If this is not possible, a brief unloading to approx. 10% of the long-term load should be carried out for four hours, for example, at, say two-monthly intervals.

The course and magnitude of the deformations should be studied and it should be possible, by means of measurements taken in the inspection pipe of the pile, to assess any bending of the pile.

5.55 Combinations of methods of load testing

Different methods of load testing are often combined. The most frequently used combinations are described below.

5.551 Stepped load increments combined with constant rate of penetration loading.

During load testing with stepped load increments, a transition to constant rate of penetration loading is carried out in the vicinity of the ultimate load. This provides a continuous and detailed load-settlement curve from which the mode of operation of the pile can be assessed.

Load testing is carried out in accordance with 5.52 until the load under which the head of the pile sinks approx. 0.1 - 0.2 mm/min during the later part of a 15-minute period is reached. The pile is then loaded to achieve a constant rate of penetration of 0.5 mm/min and load testing is completed by unloading in accordance with 5.51.

5.552 Constant rate of penetration loading or stepped load increments combined with cyclic loading.

If the reaction force is inadequate or if the jack or pump capacity is insufficient to reach the ultimate load of the pile, the pile is loaded to achieve a constant rate of penetration or in steps, up to the highest available load, in accordance with 5.51 or 5.52 and is then subjected to at least 20 load cycles in accordance with 5.53, between 100% of the highest available load and 50% of it. Final unloading is carried out in accordance with 5.51.

5.553 Stepped load increments, or loading to achieve a constant rate of penetration in combination with day-long constant loading, when the ultimate load is not reached.

Load testing is carried out in accordance with 5.52 or 5.51, up to the highest available load. When the ultimate load is not reached using one of these methods, the pile is unloaded in accordance with 5.51 to approx. 25% of the applied load and is then loaded for short periods (2 - 3 min), to the estimated creep load, in principle, in accordance with 5.42 and Fig. 5.3. Automatic pressure maintenance devices are connected (see 4.33). Readings are taken initially at 15 - 60 min intervals and may then be extended to 6 - 8 h intervals (readings should be taken at the 1/3 points of the load period). After the final reading, the pile is unloaded in accordance with 5.51.

5.6 Reporting of load testing results

To determine the ultimate load (see Section 6.3), the results of load testing with a constant rate of penetration, stepped load increments and cyclic loading should be reported in the form of load-settlement curves (working curves) in accordance with the examples shown on Figs. 5.1 and 5.2. The settlement values from readings after 15 min are used for stepped load increments. For cyclic loading, the settlement after 10 minutes of the first load application of a new, higher load are used. The unloading part of the working curve should also be reported. If the vertical movement of the pile tip has been determined, it should be plotted in the same graph as a function of the load on the head of the pile.

The load should be set out along the horizontal axis and the settlement of the pile head (and pile tip) along the vertical axis, using a load scale of 10 kN = 1 mm and a linear settlement scale of 1 mm measured = 2 mm on the graph. The scales may be varied in exceptional cases, but the relationship between them must be maintained. This facilitates comparison between results from different load tests.

In addition to the working curve, the "column line" should be specified, i.e. the line corresponding to the elastic compression of the pile, if the entire pile had stood freely in air. For this, the following modulii of elasticity should be used unless other values have been shown to be more correct: concrete 30 000 MPa, timber 10 000 MPa, steel 210 000 MPa.

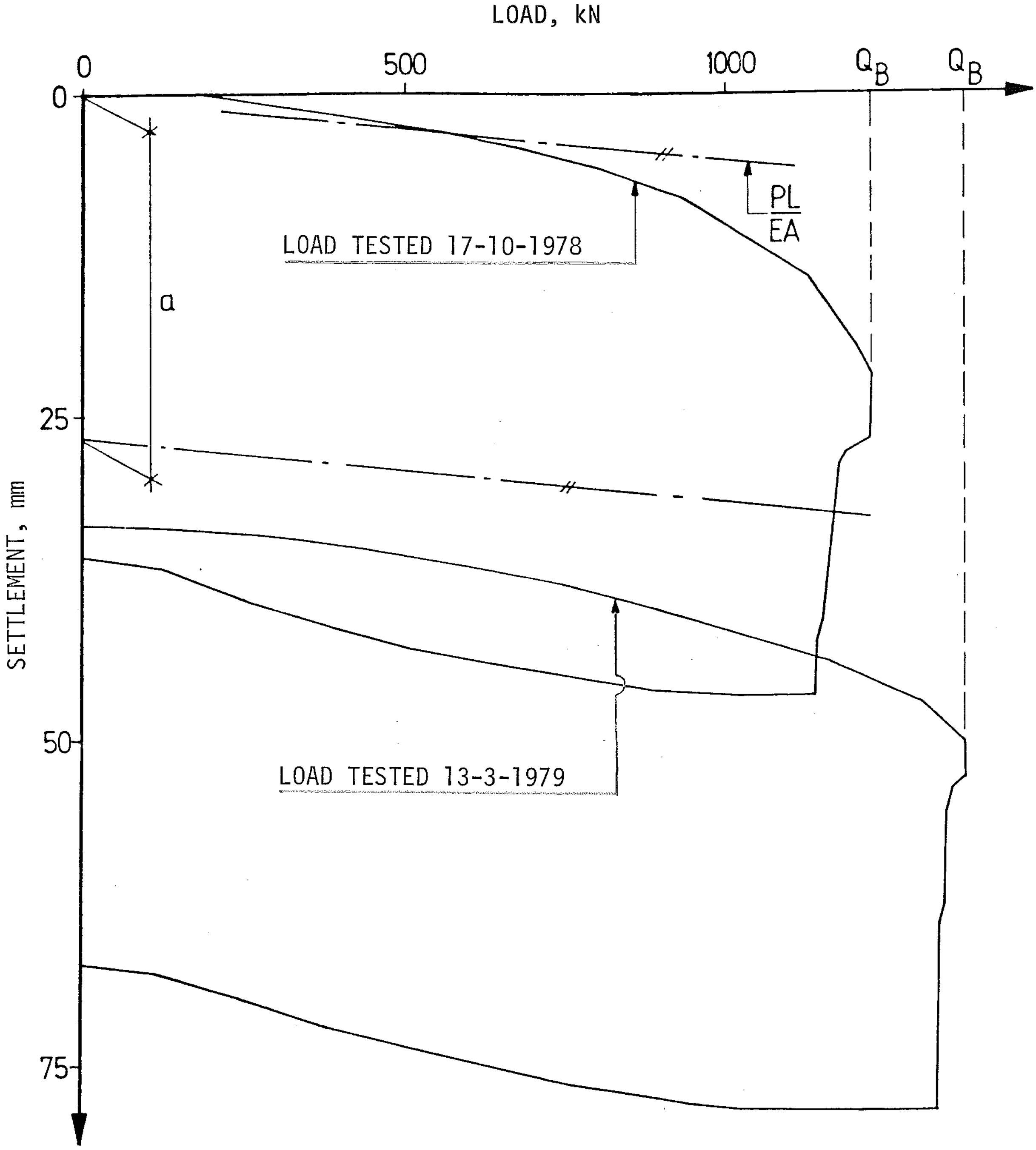
To determine the creep load (Section 6.4) from load testing using stepped load increments, the creep should be plotted under the latter part of the load steps (for example, the settlement taking place between the readings taken 9 - 15 or 12 - 15 min after application of the load) as a function of the applied load, in accordance with Fig. 5.3.

In cyclic load testing, the creep load is determined from a graph in which the settlement of the pile head is plotted as a function of the number of load cycles (see Fig. 5.4). In the graph, the settlement of the pile head is plotted at the higher load in each cycle immediately before the load is reduced to the lower load. The settlement is plotted downwards to a linear scale along the vertical axis and the number of load cycles is plotted along the horizontal axis to a logarithmic scale.

Curves are occassionally also drawn to show the settlement under the lower load of each load cycle.

In addition to the load testing results, the report should also provide information on the test pile: material, dimensions, length of embedment and driving and load-testing dates and times, and the soil profile should also be shown schematically. Any measurements taken while driving the pile to refusal or rebound measurements should also be reported.

The evaluated ultimate or creep load should be marked on the working curve or in the reporting graph.



PILE: Top segment of precast concrete, 20.0 m, C450
Bottom segment of timber, 18.1 m, O_{sp} = 134 mm
Total length 38.1 m
PILE DRIVEN: 15-06-1978
PILE LOAD TESTED: 17-10-1978 and 13-03-1979

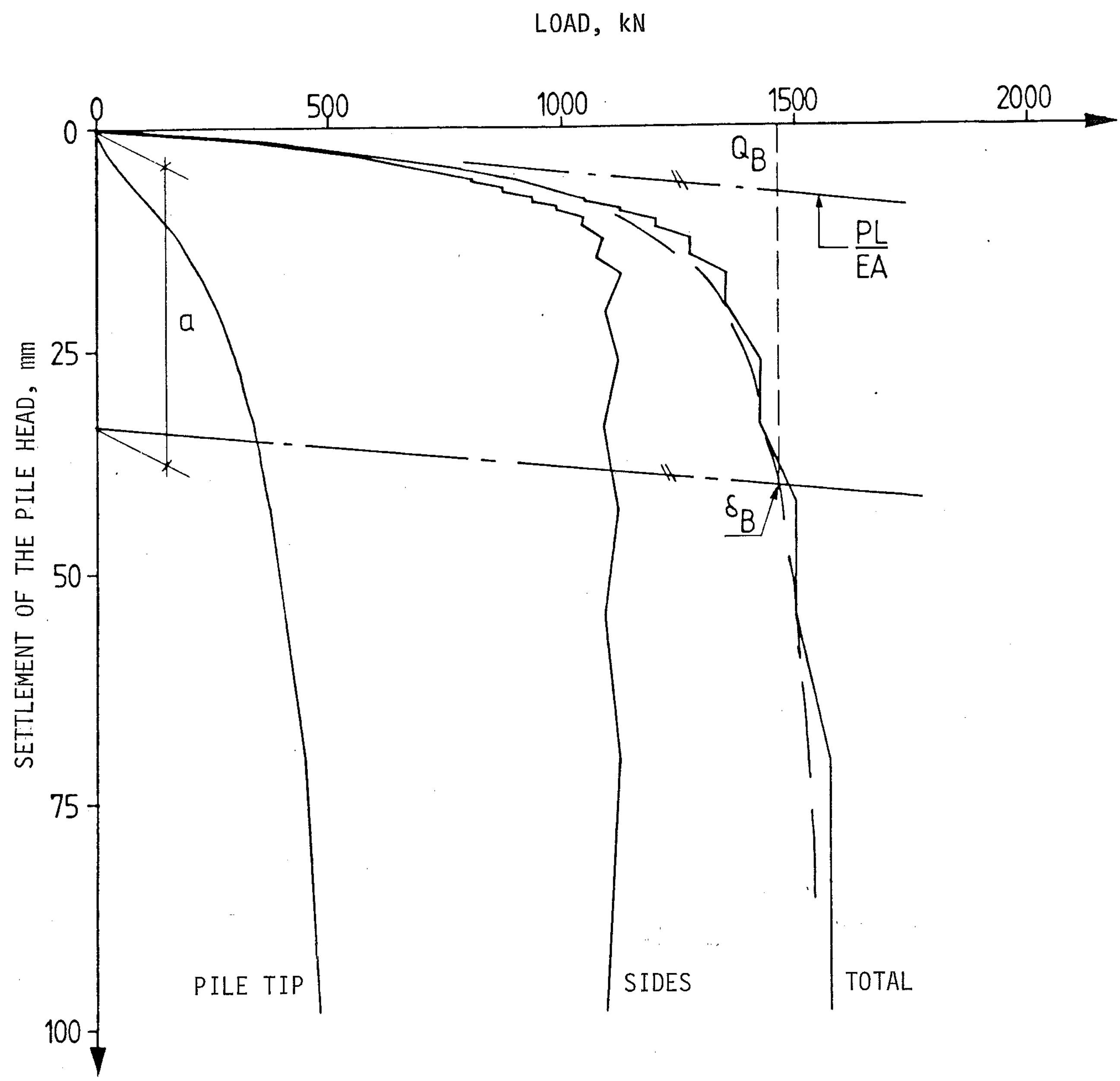
SOIL PROFILE: 0 - 2 m Dry crust
2 - 55 m Firm clay
55 - 60 m Friction soil

E6 HIGHWAY MALMÖ - GOTHENBURG
SECTION: ÅSKLOSTER - FRILLESÅS

ULTIMATE LOAD: 4 months after driving, 1230 kN
9 months after driving, 1380 kN

Load testing of piles at bridge N 582. Test pile 2

Fig. 5.1. Example of results (working curves) reported from load testing with a constant rate of penetation



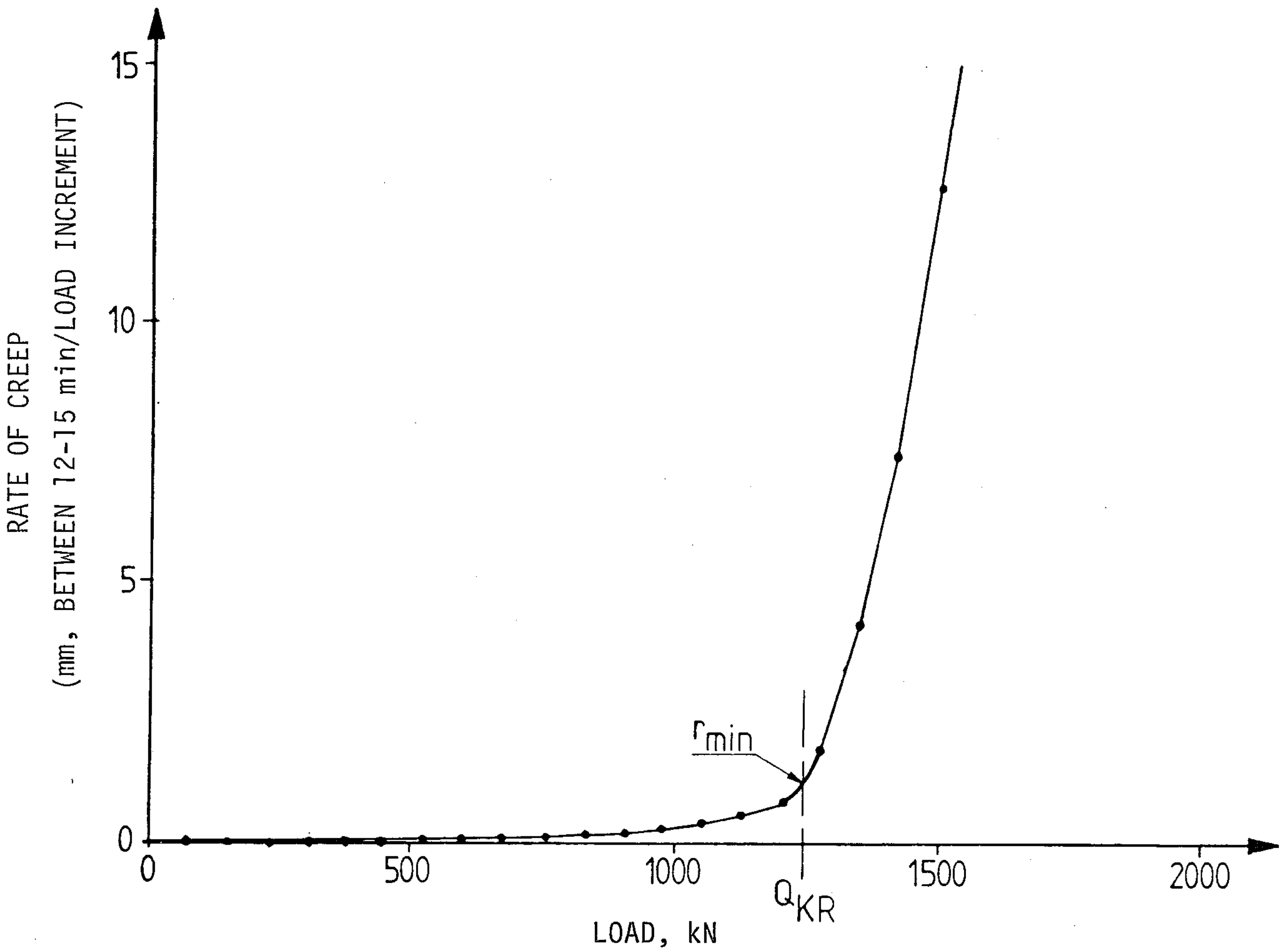
PILE: Precast concrete, 270 x 270 mm, L = 11.0 m
PILE DRIVEN: 10-02-1978
PILE LOAD TESTED: 28-03-1978

SOIL PROFILE: 0 - 4 m Organic silt
4 - 21 m Sand

EVALUATED ULTIMATE LOAD: 1440 kN

BRIDGE OVER NYA KARLVIKSVÄGEN
LULEÅ MUNICIPALITY

Fig. 5.2. Example of results (working curves) reported from load testing with stepped load increments



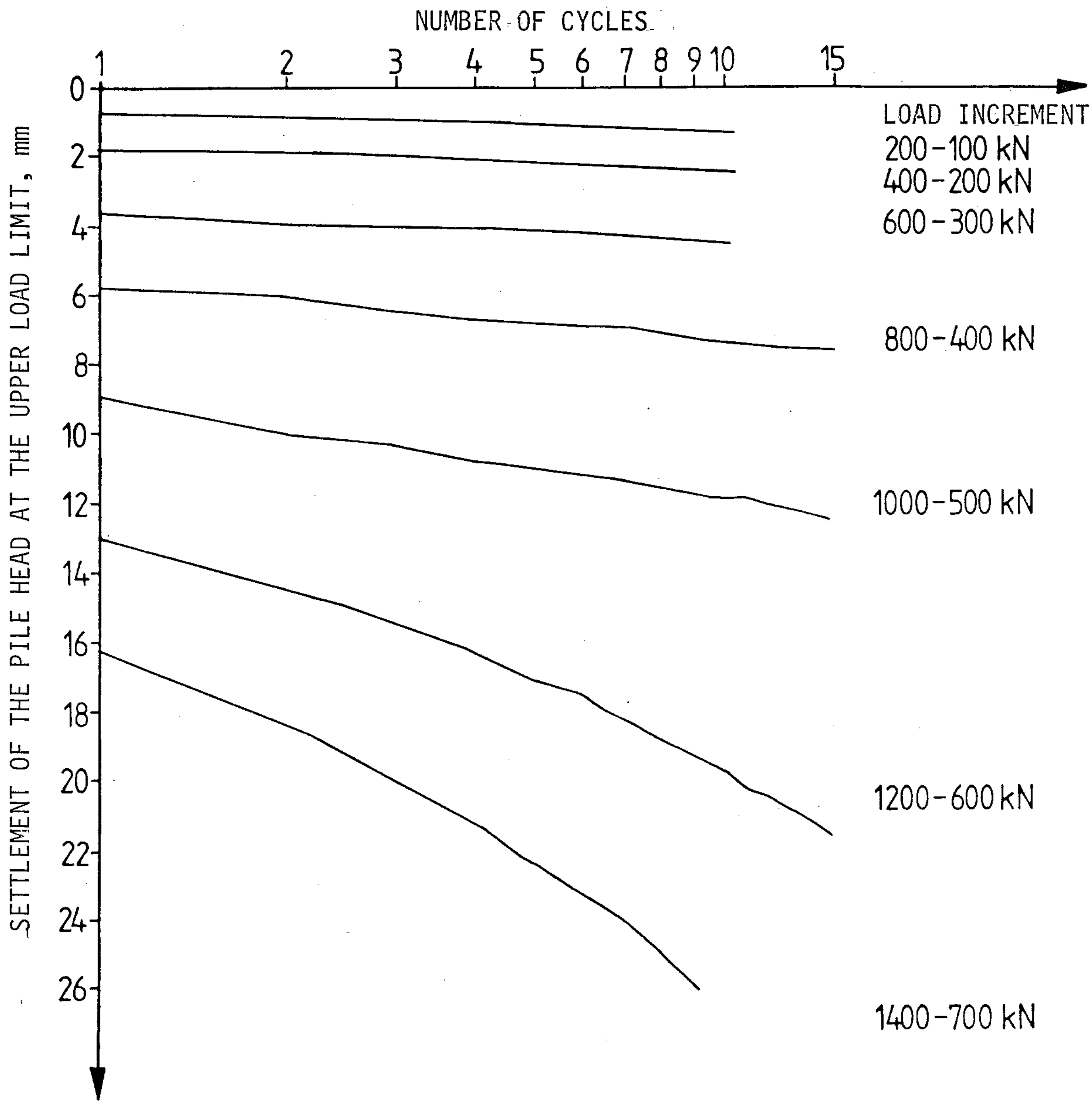
PILE: Precast concrete, 270 x 270 mm, L = 11.0 m
PILE DRIVEN: 10-02-1978
PILE LOAD TESTED: 28-03-1978

SOIL PROFILE: 0 - 4 m Organic silt
4 - 21 m Sand

EVALUATED CREEP LOAD: 1250 kN

BRIDGE OVER NYA KARLVIKSVÄGEN
LULEÅ MUNICIPALITY

Fig. 5.3. Example of reported "creep load" curve from load testing with stepped load increments



PILE: precast concrete, 250 x 250 mm, L = 24.87 m
PILE DRIVEN: 21-01-1977
PILE LOAD TESTED: 20-05-1977

SOIL PROFILE: 0 - 6 m Fine sand
6 - 16 m Coarse silt
16 - 30 m Silt
below 30 m Boulder clay

BRIDGE OVER DALÄLVEN
AT DUVÅKER
Results of load testing
Test pile No. 5

EVALUATED CREEP LOAD: 1000 kN

Fig. 5.4. Example of results reported from cyclic load testing

6 INTERPRETATION OF LOAD TESTING RESULTS

6.1 General

As stated earlier, load testing of piles is carried out during the planning stage to determine the lengths of friction piles, and is carried out during construction to check the bearing capacities of end-bearing piles and friction piles.

In the first case, the starting point is the known load of the structure and the fact that the strengths of the pile materials must be utilised to the maximum, if possible. Load testing results are used in this connection for determining the "bearing capacity" of a pile of a certain length in the soil. In cases when the mode of operation of the pile and the soil is unclear, this can also be assessed from load testing results (cf. Section 6.2). The "bearing capacity" of a pile in soil may be expressed as an ultimate load or as a creep load.

> The ultimate load of a pile is the load at which failure is reached along the sides of the pile and under the tip.
>
> The creep load of a pile is the maximum load that can be applied without incurring greatly increased deformation under continuous loading or repeated loading and unloading.

The "bearing capacity" (ultimate load, creep load) of a pile as defined above cannot generally be determined unambiguously from load testing results. A number of criteria have therefore been developed for determining ultimate or creep loads from load testing results.

The "bearing capacity" of piles often cannot be reached when the bearing capacities of piles are being checked by means of load testing, for practical and economic reasons. In this connection, the upper load limit and criteria for approval must be determined for each individual project. This may be achieved, for example, by studying the load-settlement curve for one or more piles that have been tested to a greater load than the other piles (possibly test piles).

6.2 Assessing the mode of operation of a pile

The shape of a working curve from a load test that has been carried to failure in the soil can often be used to assess the mode of operation of a pile, i.e. whether it acts as an end-bearing pile, as a friction pile in clay or sand. The mode of operation of a pile is compared with what can be expected, on the basis of the results of the geotechnical investigation.

Fig. 6.1 shows some typical working curves obtained by testing with a constant rate of penetration. Different intermediate shaped working curves may be obtained, especially in alternating types of soil and in intermediate soil.

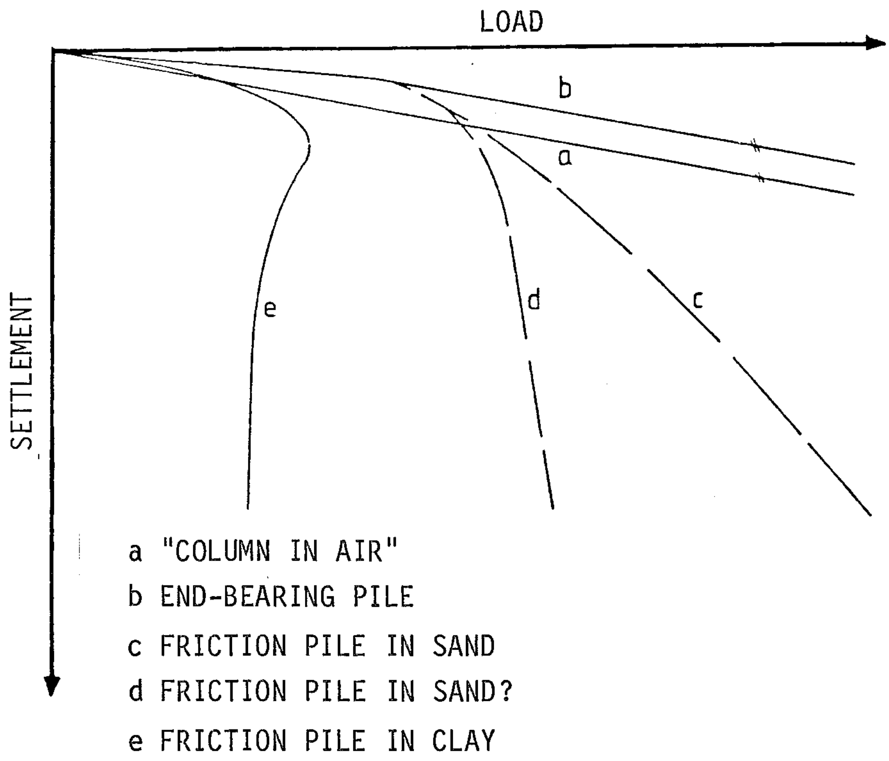


Fig. 6.1 Typical working curves for piles with different modes of operation (tested at a constant rate of penetration).

Column

Assume that a pile stands freely in air, with the pile tip on an immovable support. The working curve will then follow a straight line, a "column line", the slope of which is dependent on the cross-sectional area and length of the pile and on the modulus of elasticity of the pile, according to the formula: $\Delta L = \frac{P\,L}{E\,A}$, (the risk of bending is assumed to have been eliminated).

End-bearing pile (the tip rests on a solid support)

The pile is surrounded by soil, so that a part of the load is transmitted to the soil through the skin or sides of the pile. Thus, the vertical movements of the pile head will be less than for a corresponding pile in air (curve b).

Friction pile in sand

The pile is completely surrounded by friction soil and the bearing capacity of the pile tip forms only a part of the total bearing capacity of the pile. The working curve will then have the appearance of curve c or curve d, depending on the length of the pile and the proportion of the total bearing capacity borne by the pile tip.

Friction pile in clay

The pile is completely surrounded by cohesive soil. The appearance of the working curve will then be approximately that of curve e. The load forcing the pile into the ground will reach a maximum and then decrease with increased penetration, until a residual value is reached and this is dependent on the sensitivity of the soil in which the pile is driven and other factors.

Distribution of the bearing capacity between the tip and the sides of the pile

A reliable determination of the distribution between the bearing capacity of the tip of a pile and its sides is only possible if the pile is fitted with a tip-force gauge and, if load testing with subsequent test pulling-out of the pile is carried out, since the pile is normally not free of stress when load testing is started. Test pulling-out is not necessary if the tip-force gauge is not affected during driving of the pile.

By measuring the compression of the pile during load testing, it is possible to assess from which load the entire load increment is carried by the pile tip (Fig. 6.2).

The ratio $\Delta L/\Delta P$ (the compression of the pile in relation to the applied load increment) increases as the bearing capacity along the sides is gradually mobilised, but then becomes almost constant, since the pile force from continued load increments is transferred directly to the pile tip. This constant final value of the ratio is theoretically equal to L/EA for the tested pile, where L is the length of the pile, E is the modulus of elasticity and A is the cross-sectional area of the pile. The load above which the ratio $\Delta L/\Delta P$ is constant forms an upper limit for the skin-friction bearing capacity of the pile.

The skin-friction bearing capacity of a pile is normally less, since the pile is not free of stress when load testing is started.

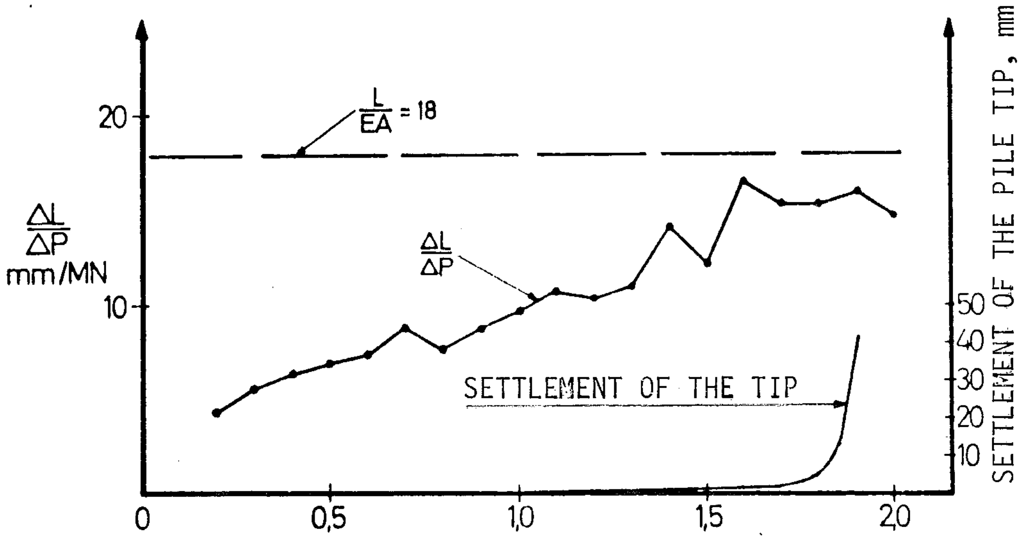


Fig. 6.2. The elastic compression of a pile in relation to the applied load increment, and the settlement of the pile tip as a function of the applied load. (Load testing for the Lärje-Sävenäs railway bridge at Säveån.)

If the compression is measured in different parts of the pile, further information on the distribution of the bearing capacity between the tip and the sides is obtained (cf. Fellenius (1969) and (1980) and Leonards & Lovell (1978)).

6.3 Determination of the ultimate load on a pile

The working curve (load-settlement curve) obtained from load testing is used as the basis for determining the ultimate load on a pile. In those cases (e.g. friction piles in clay) when a maximum value of the load is obtained, the ultimate load on the pile is given as the greatest load that can be carried by the pile, provided that the settlement is then less than the ultimate settlement, δ_B, as defined below (see also Fig. 5.1).

However, the working curve often shows no maximum value, but the load increases with increasing settlement. This is common in friction piles in sand. The ultimate load[1] of a pile is determined in these cases as the load under which the pile head settles $_B$ in accordance with the following formula:

$$\delta_B = a + \frac{P\,L}{E\,A}$$

where $a = 20 + \frac{D}{20}$ (mm)

D = the diameter (mm) of the pile tip or, in the case of non-circular cross-sections, the diameter of a circular cross-section of the same cross-sectional area (for square cross-sections, D = 1.13 x the length of the cross-section of the pile).

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1) The criterion which was earlier common in Sweden is known as the 90% rule. According to this, the ultimate load is the least load under which the settlement is twice that obtained under 90% of the same load. This criterion has been found unsuitable in many cases because the shape of the working curve has meant that the criterion cannot be satisfied despite a large total settlement.

$\frac{P\,L}{E\,A}$ = the compression of the pile when it is loaded as a column (mm)

E = the modulus of elasticity of the pile in accordance with Section 5.6.

A greater load is normally required to mobilise the tip resistance of a pile than is required to mobilise the skin friction of a pile. The settlement of the pile head (δ_B) required to achieve failure in soil both at the tip and along the sides has therefore been adopted so that the necessary movement of the tip is achieved. The compression of the pile is normally less than $\frac{P\,L}{E\,A}$ because the force vector to the tip and skin resistance does not affect the entire pile. However, for long friction piles in sand, the above definition achieves the desired increase in δ_B, so that the growth in bearing capacity as a result of increased stresses in the soil is included.

The simplest method of determining the ultimate load is to draw the "column line" on the working curve so that it cuts the deformation axis at the settlement 'a' mm. The ultimate load is then noted as the intersection between the "column line" and the working curve (see Fig. 5.2).

The ultimate load may be determined from the working curve for all of the methods of testing described above, but it should be noted that there is a certain difference between the results (cf. Section 1.3). On average, it can be assumed that the ultimate loads determined from stepped load increment tests and cyclic testing are 90% of the ultimate load determined by constant rate of penetration tests.

6.4 Determination of the creep load of a pile

The determination of the creep load of a pile is relevant in connection with load testing with stepped load increments or with cyclic load testing.

In load testing with stepped load increments, the settlement of the pile head during the latter part of each step, advisably during the interval 9 - 15 or 12 - 15 min of a 15 min load period, is plotted as a function of the applied load (creep curve, cf. Fig. 5.3). A noticeable increase in the rate of creep can generally be observed above a certain load. The load at which the creep curve deflects most (minimum radius of curvature) is defined as the creep load of the pile.

In cyclic load testing, the settlement of the pile head is reported as a function of the number of load cycles on log graph paper, in accordance with Section 5.6. The creep load is regarded as having been exceeded when the course of settlement of the pile as plotted in the graph becomes concave downwards (cf. Fig. 5.4). As loading is carried out in stages of approx. 1/8 of the ultimate load, the creep load can be easily exceeded if the upper load limit is increased. This makes the determination inaccurate as an assessment must be made of how near the load has been to the creep limit during the last and second last load stages. The load-settlement curves for these tests should therefore also be plotted and the ultimate load determined as above.

6.5 Comparison between the creep load and ultimate load of a pile

As mentioned in Section 1.3 and indicated by the definitions above, there is a certain difference between the creep load and ultimate load of a pile. The creep load may normally be assumed to be 80% of the ultimate load determined from constant rate of penetration tests.

In the evaluation of a load test result, this should the creep load (where this is possible) and the ultimate load, and a study of their relation to one another. A large difference between these values may indicate that the pile is bent, for example.

7 TO BE OBSERVED WHEN SELECTING THE PERMISSIBLE LOAD

The permissible load for a pile is determined so that adequate safety against failure in the soil or in the pile materials is obtained and so that settlement and differential settlement do no exceed acceptable values.

Acceptable safety against failure in the soil and against failure in the pile materials is normally obtained from standards applicable to the structure:

Swedish Building Code: SBN 80, issued by the National Swedish Board of Building and Planning, 1980

Swedish Building Code 1975, Approval Rules No. 1975:8 Piles, issued by the National Board of Physical Planning and Building, 1975

Bridge Standards, TB 103, issued by the Swedish National Road Administration, 1976

Directives for piling works, TB 108 issued by the Swedish National Road Administration, 1976

Piles for Swedish State Railway tracks and buildings. Directives and instructions. (SJ FT 541.1:11.1), 1979

In assessing the permissible load for piles in a pile group, the degree to which the load-tested pile represents the pile group should be taken into account in respect of the scope of the geotechnical investigations and the driving resistance of the piles. The number of load tested piles in relation to the total number of piles should also be taken into account.

Acceptable values of the magnitude of the expected settlement and differential settlement should be determined in consultation with the designer of each project. For calculation of pile group settlement, refer to Broms (1973), Torstensson (1971) and Vesic (1977).

Negative skin friction forces resulting from settlement of the soil around a pile in relation to the pile may cause settlement of groups of friction piles. Particular attention should be paid to the settlement of large groups of friction piles.

8 REPORTING ON PILE DRIVING TESTS WITH SUBSEQUENT LOAD TESTING

8.1 General

The results of pile driving tests and load testing should be presented in a report prepared by the engineer responsible for the project. In addition to the results from load testing, the report should also contain such information as may be of importance for understanding the conditions for pile driving tests and load testing, and information of importance to the further design and construction of the structure. The following Section is a check list as a guide to writing a report. Refer also to the part on reporting in each section.

8.2 Checklist for reporting on pile driving tests with subsequent load testing

1. Client

2. Job, preconditions

3. Structure, test site

4. Objective of pile driving tests, load tests

5. Geotechnical investigation (brief description, the whole geotechnical investigation should be appended to the report)

6. Brief decription of soil and groundwater conditions

7. Test piles, reaction piles, other reaction arrangements
   type, joints, inspection pipe, pile length (circumference, curvature) location

8. Driving of test piles, reaction piles
   date and time, driving equipment (type of pile driver, weight of hammer, height of fall, type of dolly)
   driving procedure, refusal criterion

9. Results from driving of test piles, reaction piles
   surveying of test piles, reaction piles, (measurements in grid system, level of the pile head, actual pile length, pile rake)
   driving graph
   rebound measurements
   other observations (settlement/rise of pile or soil, compaction effect, comparison with geotechnical investigations)

10. Test loading
    date and time
    type of test loading
    equipment for test loading
    reaction arrangements

11. Results of test loading
    test loading graph
    interpretation of test loading results

12. Recommendations for the selection of
    pile type and length
    refusal criteria
    permissable load on piles

13. Further investigations

A copy of the report on test piling and test loading should be sent, for information, to: The Commission on Pile Research, c/o Swedish Geotechnical Institute, S-581 01 LINKÖPING 1, Sweden

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GLOSSARY OF WORDS USED IN APPENDICIES 3.1 - 3.1A

ANM. Anmärkning	= Remarks
Antal slag	= Number of blows
Arbetsplats	= Site
Armering	= Reinforcement
Avstånd från pålspets	= Distance from the pile tip
Avvikelse från räta linjen	= Deviation from a straight line
Betongpåle	= precast concrete pile
Bilaga	= Appendix
Blad nr	= Page No.
Detalj	= Detail
Diam.	= Diameter
Dimension	= Dimension
Djup	= Depth
Dubbel part	= Double fall
Dygn	= Day
Enkel part	= Single fall
Enl. stand. ritn. el. dyl.	= As per standard drwg. or suchlike
Fabrikat och typ	= Make and type
Fallhejare	= Hammer
Företag	= Company
Hejarens fallhöjd	= Height of fall of hammer
Hejarvikt	= Weight of hammer
Inspektionsrör	= Inspection pipe
Knekt	= Follower
Längd	= Length
Material	= Material
Mellanlägg typ	= Type of packing
mm/slag	= millimetre/blow
Nivå	= Level
Omkrets	= Circumference

Per serie	= Per series
Profil	= Section
Protokollförare	= Log kept by
Påle nr	= Pile No.
Pålhuvudets nivå	= Level of the pile head
Pållängd efter kapning	= Length of pile after cutting
Pållängd i jord	= Length of pile in the soil
Pållängd vid slagning	= Length of pile during driving
Pålningsprotokoll	= Driving log
Pålskarv	= Pile joint
Pålsko	= Pile shoe
Pålspetsens nivå	= Level of the pile tip
Referensplan(markyta el.dyl.)	= Reference plane (ground surface or similar)
Sjunkning i mm för slagen	= Penetration in mm for ... blows
Slagdyna typ	= Type of dolly
Slagen den	= Driven on (date)
Slagningsprotokoll	= Driving log
Stålpåle	= Steel pile
Summa	= Total
Tillv. den	= Cast on (date)
Toppdiameter	= Diameter at tip
Tryckluftshammare	= Pneumatic hammer
Träpåle	= Timber pile
Tvärsnitt	= Cross-sectional area
Uppmätning av provpålen	= Measurements of test pile
Vikt	= Weight
Ålder vid slagningen	= Age at time of driving
Övriga anteckningar	= Other notes

Enter notes on the following in the remarks column:

Preboring with preboring tool through fill or dry crust
Removal of clay plug
Penetration of the pile under its own weight
Penetration of the pile under its own weight plus weight of hammer
Insertion of new packing in the dolly
Any obstacles in the soil
Whether the pile is withdrawn and re-placed
Jointing or splicing
Any raking of the pile which occurs or measurement of prescribed rake
Any damage to the pile
Where follower has been fitted
Time at which driving is commenced, concluded and any breaks
Time at which rebound measurements are carried out
Time at which the gauge is inserted into the inspection pipe
Time when rebound is observed

Företag: ROAD CONSTRUCTION CONSORTIUM — Blad nr: 1

PÅLNINGSPROTOKOLL — PÅLE NR 1

ARBETSPLATS: BRIDGE OVER VALLEY AT ÅKÖPING

Detalj: WESTERN ABUTMENT — Slagen den 12 / 8 1978

☒ Betongpåle — Dimension 270x270 mm — Armering 4 ϕ20mm — Inspektionsrör 42 mm i.d. SEAMLESS

☐ Stålpåle — Profil

☐ Träpåle — Toppdiameter

Tillv. den 30 / 6 1978

Ålder vid slagningen 42 dygn

$\sigma_{K\,28}$ 54.3 MPa ~~kp/cm²~~ (enl. intyg)

Pålsko ROCK SHOE, STUD MARKED SPS, 134 HF4

Pålskarv STIFF IN BENDING, HERKULES TYPE

(enl. stand. ritn. el. dyl.)

☐ Fallhejare — Hejarvikt 3 x) ton — ☒ Enkel part — ☐ Dubbel part

☐ Tryckluftshammare. Fabrikat och typ

☐ Knekt — material — tvärsnitt cm² — längd cm — vikt ton

☐ Lerpropp — diam. cm — djup m

Slagdyna typ OAK — vikt 0.55 ton

Mellanlägg typ

Pållängd vid slagning 12.04 + 12.07 + 10.10 + – = 34.21 m

Pållängd efter kapning – m — Pållängd i jord: 32.85 m

Pålhuvudets nivå + 9.46 — Pålspetsens nivå – 24.75

Referensplan (markyta el. dyl.) GROUND LEVEL — Nivå + 8.10

ANM.

28-DAY CUBE STRENGTH = 50.0 MPa

x) 4 t WHEN DRIVING TO REFUSAL

PILE DRIVER: LANDSVERK KL-250

NOT CUT

UPPMÄTNING AV PROVPÅLEN

Avstånd från pålspets m	Omkrets mm ~~cm~~	Avvikelse från räta linjen mm ~~cm~~	Avstånd från pålspets m	Omkrets mm ~~cm~~	Avvikelse från räta linjen mm ~~cm~~
0.3	1280		30.0	1295	- 4
2.0	1280	+ 2	32.0	1300	0
4.0	1300	+ 4	34.0	1300	–
6.0	1285	+ 2	2.0 x)		0
8.0	1295	- 4	4.0		+ 2
10.0	1280	0	6.0		- 2
12.0	1260	–	8.0		0
14.0	1265	+ 2	10.0		0
16.0	1290	+ 2	14.0		- 4
18.0	1280	+ 4	16.0		- 3
20.0	1295	+ 2	18.0		- 2
22.0	1275	0	20.0		+ 2
24.0	1280	–	22.0		+ 2
26.0	1290	0	26.0		+ 2
28.0	1275	- 2	28.0		- 4

Övriga anteckningar (Måttuppgifter för pålspets och skarvbeslag, om ritningar saknas. Ev. felaktigheter, vinkelavvikelser vid fastgjutning av pålspets och skarvbeslag).

JOINT FITTINGS HAVE BEEN CAST WITHOUT JOINT ANGLE DEVIATION

x) AFTER TURNING THROUGH 90°

30.0	– 4
32.0	+ 1

SLAGNINGSPROTOKOLL

Blad nr

Hejarens fallhöjd cm	Antal slag per serie	Antal slag summa	Sjunkning i cm för slagen	Pålspetsens djup under referensplan	Anmärkning	Hejarens fallhöjd cm	Antal slag per serie	Antal slag summa	Sjunkning i cm för slagen	Pålspetsens djup under referensplan	Anmärkning

I anmärkningskolumnen bör följande iakttagelser antecknas:

Förpålning med pryl genom fyllningslager eller torrskopa.
Upptagning av lerpropp.
Påles sjunkning för egen vikt.
Påles sjunkning för egen vikt+hejare.
Inläggning av nytt trämellanlägg i slagdynan.
Eventuella hinder i jorden.
Om påle i sådana fall dras upp och sätts på nytt.
Skarvning.
Uppkommen pållutning eller kontrollmätning av fastställd pållutning
Uppkomna skador på påle.
Påsättning av knekt.

Tid.
Slagningens början och slut samt ev. avbrott.
Fjädringsmätning.
Kontroll genom lodning i påle med inspektionsrör.
Hejarstuds.

________________den / 19___

____
Protokollförare

FOA Repro 1972.02 300 bl à 50 ex

SLAGNINGSPROTOKOLL

Blad nr 1

Hejarens fallhöjd m	Antal slag per serie	Antal slag summa	Sjunkning i mm för slagen	Pålspetsens djup under referensplan m	Anmärkning	mm/Blow
0.3	48		2000	6L	START 07.55	42
	12	60	2000	2.0		167
	70	130	11200	4.0	-JOINTING	131
	12	142	800	13.2		60
	17	159	1000	14.0		66
	20	179	"	15.0		50
	18	197	"	16.0		55
	20	217	"	17.0		55
	23	240	"	18.0		43
	25	265	"	19.0		40
	23	288	"	20.0		43
	28	316	"	21.0		46
	60	376	"	22.0		17
	82	456	"	23.0		12
	67	525	"	24.0		15
	62	587	"	25.0		16
	50	637	"	26.0		20
	30	667	"	27.0		17
	30	697	500	27.5	JOINTING,	17
	100	797	1000	28.0	BREAK FOR 1H	10
	85	882	1000	29.0	NEW PACKING	5.4
	50	932	260	30.0		5.3
	"		260	30.26		5.2
	"	1032	230	30.52		4.6
	"		210	30.75		4.2
	"	1132	180	30.96		3.7
	"		170	31.14		3.4
	"	1232	120	31.31		2.2
	"		110	31.43		2.3
	"	1332	130	31.54		2.5
	"		130	31.67		2.6
	"	1432	170	31.80		2.7
	"		100	31.97		2.7
	"	1532	120	32.07		2.4
	"		100	32.19		1.9
	"	1632	90	32.29		1.7
	"		70	32.38		1.5
	50	1732	80	32.45		1.5
				32.53		

Hejarens fallhöjd m	Antal slag per serie	Antal slag summa	Sjunkning i mm för slagen	Pålspetsens djup under referensplan m	Anmärkning	mm/Blow
0.3	50	1782	80	32.53	HAMMER	1.5
	"		60	32.61	REBOUND	1.3
	"	1882	60	32.67	CHANGED TO	1.1
	"		80	32.73	4t HAMMER	1.0
	"	1982	20	32.81	REBOUND	0.4
	"	2032	10	32.83	MEASUREMENT	0.2
0.4	"	2082	10	32.84	FINISH 10.00	0.2
				32.85	REBOUND	
					MEASUREMENT	
					CHECKED WITH	
					GAUGE TO 33.89m	
					REDRIVING	
0.3	50		10		15-8-1978	
0.4	"		15			0.3
	"		10		REBOUND	0.2
	"		10		MEASURED	0.2
				32.80		

I anmärkningskolumnen bör följande iakttagelser antecknas:

Förpålning med pryl genom fyllningslager eller torrskopa.
Upptagning av lerpropp.
Påles sjunkning för egen vikt.
Påles sjunkning för egen vikt+hejare.
Inläggning av nytt trämellanlägg i slagdynan.
Eventuella hinder i jorden.
Om påle i sådana fall dras upp och sätts på nytt.
Skarvning.
Uppkommen pållutning eller kontrollmätning av fastställd pållutning
Uppkomna skador på påle.
Påsättning av knekt.

Tid.
Slagningens början och slut samt ev. avbrott.
Fjädringsmätning.
Kontroll genom lodning i påle med inspektionsrör.
Hejarstuds.

ÅKÖPING den 15/8 1978

Pål Mätare
Protokollförare

Företag:	Blad nr:

PÅLNINGSPROTOKOLL

PÅLE NR

ARBETSPLATS: ____________________

Detalj: ____________________

Slagen den ___ / ___ 19___

☐ Betongpåle — Dimension ________ Armering ________ Inspektionsrör ________

☐ Stålpåle — Profil ________

☐ Träpåle — Toppdiameter ________

Tillv. den ___ / ___ 19___

Ålder vid slagningen ________ dygn

$\sigma_{K\,28}$ ________ kp/cm² (enl. intyg)

Pålsko ________

Pålskarv ________
(enl. stand. ritn. el. dyl.

ANM.

☐ Fallhejare Hejarvikt ____ ton ☐ Enkel part ☐ Dubbel part

☐ Tryckluftshammare. Fabrikat och typ ________

☐ Knekt material ________ tvärsnitt ________ cm² längd ________ cm vikt ________ ton

☐ Lerpropp diam. ________ cm djup ________ m

Slagdyna typ ________ vikt ________ ton

Mellanlägg typ ________

Pållängd vid slagning ____ + ____ + ____ + ____ = ____ m

Pållängd efter kapning ____ m Pållängd i jord: ____ m

Pålhuvudets nivå ▽ ________ Pålspetsens nivå ▽ ________

Referensplan (markyta el. dyl.) ________ Nivå ▽ ________

UPPMÄTNING AV PROVPÅLEN

Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Övriga anteckningar (Måttuppgifter för pålspets och skarvbeslag, om ritningar saknas. Ev. felaktigheter, vinkelavvikelser vid fastgjutning av pålspets och skarvbeslag).

Blanketten är utgiven av IVA:s Pålkommission, Box 5073, 102 42 Stockholm. Ifylles enligt IVA:s pålkommission,
Anvisningar för provpålning och provbelastning, särtryck och preliminära rapporter nr 11.

APPENDIX 3.1A

Företag: VÅGBYGGEN AB | Blad nr: 1

PÅLNINGSPROTOKOLL

PÅLE NR 12

ARBETSPLATS: VIADUCT AT SLAGBY

Detalj: SOUTHERN ABUTMENT

Slagen den 25 / 10 1978

[X] Betongpåle — Dimension 270 x 270 mm — Armering 4 φ 20 mm — Inspektionsrör 42 mm i.d. SEAMLESS

[ ] Stålpåle — Profil

[ ] Träpåle — Toppdiameter

Tillv. den 20 / 9 1978

Ålder vid slagningen 39 dygn

$\sigma_{K\ 28}$ 55.3 (enl. intyg) MPa ~~kp/cm²~~

Pålsko ROCK SHOE, STUD MARKED SIS 2090

Pålskarv STIFF IN BENDING, ABB JOINT

(enl. stand. ritn. el. dyl.)

[X] Fallhejare — Hejarvikt 4 ton — [X] Enkel part [ ] Dubbel part

[ ] Tryckluftshammare. Fabrikat och typ

[ ] Knekt — material — tvärsnitt cm² — längd cm — vikt ton

[ ] Lerpropp — diam. cm — djup m

Slagdyna typ — vikt 0.45 ton

Mellanlägg typ

Pållängd vid slagning 10.30 + 10.10 + 10.05 + = 30.45 m

Pållängd efter kapning - m — Pållängd i jord: 30.02 m

Pålhuvudets nivå ▽ +11.83 — Pålspetsens nivå ▽ -18.82

Referensplan (markyta el. dyl.) GL — Nivå ▽ +11.40

ANM.

28-DAY CUBE STRENGTH = 50.0 MPa

PILE DRIVER: ÅKERMAN 750

RAKE: 8:1

NOT CUT

UPPMÄTNING AV PROVPÅLEN

Avstånd från pålspets m	Omkrets mm ~~cm~~	Avvikelse från räta linjen ~~cm~~ mm	Avstånd från pålspets m	Omkrets mm ~~cm~~	Avvikelse från räta linjen ~~cm~~ mm	Övriga anteckningar (Måttuppgifter för pålspets och skarvbeslag, om ritningar saknas. Ev. felaktigheter, vinkelavvikelser vid fastgjutning av pålspets och skarvbeslag).
0.3	1015	-	30.0	1005		JOINT FITTINGS CAST WITHOUT JOINT ANGLE DEVIATION
2.0	1010	0				
4.0	1020	0	x) 2.0		0	
6.0	1010	+2	4.0		0	x) AFTER TURNING THROUGH 90°
8.0	1015	+3	6.0		+2	
10.0	1020	-	8.0		0	
12.0	1000	0	12.0		+4	
14.0	995	-4	14.0		+3	
16.0	995	-3	16.0		+3	
18.0	1000	-4	18.0		0	
20.0	995	-	22.0		0	
22.0	1005	0	24.0		-3	
24.0	1005	-3	26.0		+2	
26.0	1010	-2	28.0		-2	
28.0	1005	+1				

SLAGNINGSPROTOKOLL

Blad nr

Hejarens fallhöjd cm	Antal slag per serie	Antal slag summa	Sjunkning i cm för slagen	Pålspetsens djup under referensplan	Anmärkning	Hejarens fallhöjd cm	Antal slag per serie	Antal slag summa	Sjunkning i cm för slagen	Pålspetsens djup under referensplan	Anmärkning

I anmärkningskolumnen bör följande iakttagelser antecknas:

Förpålning med pryl genom fyllningslager eller torrskopa.
Upptagning av lerpropp.
Påles sjunkning för egen vikt.
Påles sjunkning för egen vikt+hejare.
Inläggning av nytt trämellanlägg i slagdynan.
Eventuella hinder i jorden.
Om påle i sådana fall dras upp och sätts på nytt.
Skarvning.
Uppkommen pållutning eller kontrollmätning av fastställd pållutning
Uppkomna skador på påle.
Påsättning av knekt.

Tid.
Slagningens början och slut samt ev. avbrott.
Fjädringsmätning.
Kontroll genom lodning i påle med inspektionsrör.
Hejarstuds.

________________ den / 19____

____
Protokollförare

FOA Repro 1972.02 300 bl à 50 ex

SLAGNINGSPROTOKOLL

Blad nr 1

Hejarens fallhöjd m (~~cm~~)	Antal slag per serie	Antal slag summa	Sjunkning i ~~c~~m för slagen	Pålspetsens djup under referensplan m	Anmärkning	BLOWS / 0.2m	Hejarens fallhöjd m (~~cm~~)	Antal slag per serie	Antal slag summa	Sjunkning i ~~c~~m för slagen	Pålspetsens djup under referensplan m	Anmärkning
0.4	21		1.0	GL	START 7.45	4	0.4	38	1600	0.2	15.6	16^{55} HOURS
	46	67		1.0		9		55	1655	0.2	15.8	07^{55} HOURS
	61	128		2.0		12		35			16.0	
	72	200		3.0		14		48				
	69	269		4.0		14		50				
	71	340		5.0		14		42				
	80	420		6.0		16		43	1873			
	75	495		7.0		15		51			17.0	
	75	570		8.0		15		46				
	108	678		9.0		22		42				
	20	698		10.0	JOINTING			40				
	27							38	2090			
	28							40			18.0	
	20							38				
	20	798						35				
	30			11.0				35				
	26							37	2275			
	25							35			19.0	
	27							36				
	28	935						36				
	28			12.0				35				
	25							85	2505			
	27							65			20.0	JOINTING
	30							85				NEW PACKING
	30	1075						70				
	33			13.0				65				
	32							65	2855			
	33							70			21.0	
	37							65				
	37	1247						60				
	38			14.0				65				
	42							60	3175			
	38							55			22.0	
	28							60				
	44	1437						60				
	40			15.0				65				
	43							75	3490			
0.4	42	1562		15.6			0.4	80	3570	0.2	23.0 / 23.2	

CONTD. ON PAGE 2

I anmärkningskolumnen bör följande iakttagelser antecknas:

Förpålning med pryl genom fyllningslager eller torrskopa.
Upptagning av lerpropp.
Påles sjunkning för egen vikt.
Påles sjunkning för egen vikt+hejare.
Inläggning av nytt trämellanlägg i slagdynan.
Eventuella hinder i jorden.
Om påle i sådana fall dras upp och sätts på nytt.
Skarvning.
Uppkommen pållutning eller kontrollmätning av fastställd pållutning
Uppkomna skador på påle.
Påsättning av knekt.

Tid.
Slagningens början och slut samt ev. avbrott.
Fjädringsmätning.
Kontroll genom lodning i påle med inspektionsrör.
Hejarstuds.

__________ den / 19___

____
Protokollförare

Företag:	Blad nr:

PÅLNINGSPROTOKOLL

PÅLE NR

ARBETSPLATS: ______________________

Detalj: ______________________

Slagen den / 19____

- [ ] Betongpåle — Dimension ________ Armering ________ Inspektionsrör ________
- [ ] Stålpåle — Profil ________
- [ ] Träpåle — Toppdiameter ________

Pålsko ________

Pålskarv ________
(enl. stand. ritn. el. dyl.

Tillv. den / 19____

Ålder vid slagningen ________ dygn

$\sigma_{K\,28}$ ________ kp/cm² (enl. intyg)

ANM.

- [ ] Fallhejare   Hejarvikt ____ ton   [ ] Enkel part   [ ] Dubbel part
- [ ] Tryckluftshammare. Fabrikat och typ ________
- [ ] Knekt   material ________   tvärsnitt ________ cm²   längd ________ cm   vikt ________ ton
- [ ] Lerpropp   diam. ________ cm   djup ________ m

Slagdyna typ ________ vikt ________ ton

Mellanlägg typ ________

Pållängd vid slagning ____ + ____ + ____ + ____ = ____ m

Pållängd efter kapning ____ m   Pållängd i jord: ____ m

Pålhuvudets nivå ▽________   Pålspetsens nivå ▽________

Referensplan (markyta el. dyl.) ________ Nivå ▽________

UPPMÄTNING AV PROVPÅLEN

Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Övriga anteckningar (Måttuppgifter för pålspets och skarvbeslag, om ritningar saknas. Ev. felaktigheter, vinkelavvikelser vid fastgjutning av pålspets och skarvbeslag).

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Anvisningar för provpålning och provbelastning, särtryck och preliminära rapporter nr 11.

Företag: VÅGBYGGEN AB

Blad nr: 2

PÅLNINGSPROTOKOLL

PÅLE NR 12 CONTD.

ARBETSPLATS: VIADUCT AT SLAGBY

Detalj: SOUTHERN ABUTMENT

Slagen den / 19

☐ Betongpåle — Dimension ___ Armering ___ Inspektionsrör ___

☐ Stålpåle — Profil ___

☐ Träpåle — Toppdiameter ___

Tillv. den / 19

Ålder vid slagningen ___ dygn

$\sigma_{K\ 28}$ ___ kp/cm² (enl. intyg)

Pålsko ___

Pålskarv ___
(enl. stand. ritn. el. dyl.

ANM.

☐ Fallhejare Hejarvikt ___ ton ☐ Enkel part ☐ Dubbel part

☐ Tryckluftshammare. Fabrikat och typ ___

☐ Knekt material ___ tvärsnitt ___ cm² längd ___ cm vikt ___ ton

☐ Lerpropp diam. ___ cm djup ___ m

Slagdyna typ ___ vikt ___ ton

Mellanlägg typ ___

Pållängd vid slagning ___ + ___ + ___ + ___ = ___ m

Pållängd efter kapning ___ m Pållängd i jord: ___ m

Pålhuvudets nivå ▽ ___ Pålspetsens nivå ▽ ___

Referensplan (markyta el. dyl.) ___ Nivå ▽ ___

UPPMÄTNING AV PROVPÅLEN

Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Övriga anteckningar (Måttuppgifter för pålspets och skarvbeslag, om ritningar saknas. Ev. felaktigheter, vinkelavvikelser vid fastgjutning av pålspets och skarvbeslag).

Blanketten är utgiven av IVA:s Pålkommission, Box 5073, 102 42 Stockholm. Ifylles enligt IVA:s pålkommission,
Anvisningar för provpålning och provbelastning, särtryck och preliminära rapporter nr 11.

SLAGNINGSPROTOKOLL

Blad nr

Hejarens fallhöjd cm	Antal slag per serie	Antal slag summa	Sjunkning i cm för slagen	Pålspetsens djup under referensplan	Anmärkning	Hejarens fallhöjd cm	Antal slag per serie	Antal slag summa	Sjunkning i cm för slagen	Pålspetsens djup under referensplan	Anmärkning

I anmärkningskolumnen bör följande iakttagelser antecknas:

Förpålning med pryl genom fyllningslager eller torrskopa.
Upptagning av lerpropp.
Påles sjunkning för egen vikt.
Påles sjunkning för egen vikt+hejare.
Inläggning av nytt trämellanlägg i slagdynan.
Eventuella hinder i jorden.
Om påle i sådana fall dras upp och sätts på nytt.
Skarvning.
Uppkommen pållutning eller kontrollmätning av fastställd pållutning
Uppkomna skador på påle.
Påsättning av knekt.

Tid.
Slagningens början och slut samt ev. avbrott.
Fjädringsmätning.
Kontroll genom lodning i påle med inspektionsrör.
Hejarstuds.

________________den / 19___

____
Protokollförare

FOA Repro 1972.02 300 bl à 50 ex

SLAGNINGSPROTOKOLL

Blad nr 2

Hejarens fallhöjd m	Antal slag per serie	Antal slag summa	Sjunkning i m för slagen	Pålspetsens djup under referensplan m	Anmärkning
0.4	85	3655	0.2	23.2	BREAK 30 MIN
	80				
	80				
	85	3900			
	90			24.0	
	85				
	80				
	70				
	70	4295			
	75			25.0	
	70				
	65				
	70				
	70	4645			
	75			26.0	
	70				
	70				
	65				
	70	4995			
	75			27.0	
	80				
	85				
	85				
	80	5400			BREAK 15 MIN
	95			28.0	
	85				
	85				
	75				
	75	5815			
	90			29.0	
	154	6069	0.2	29.2	
0.4	152	6221	0.1	29.4	N.B. 304 BL/0.2m
0.2	300		50*)	29.51	*) PENETRATION 1 mm
0.6	10		2*)	30.01	
"	10		3*)		REBOUND
"	10		3*)		MEASURED
				30.02	CHECKED WITH
					GAUGE TO 30.18m
					FINISH 11.40

Hejarens fallhöjd m	Antal slag per serie	Antal slag summa	Sjunkning i m för slagen	Pålspetsens djup under referensplan m	Anmärkning
0.5	50		7		REDRIVING
0.6	10		2		1-11-1978
	10		3		REBOUND
	10		2	38.01	MEASURED

I anmärkningskolumnen bör följande iakttagelser antecknas:

Förpålning med pryl genom fyllningslager eller torrskopa.
Upptagning av lerpropp.
Påles sjunkning för egen vikt.
Påles sjunkning för egen vikt+hejare.
Inläggning av nytt trämellanlägg i slagdynan.
Eventuella hinder i jorden.
Om påle i sådana fall dras upp och sätts på nytt.
Skarvning.
Uppkommen pållutning eller kontrollmätning av fastställd pållutning
Uppkomna skador på påle.
Påsättning av knekt.

Tid.
Slagningens början och slut samt ev. avbrott.
Fjädringsmätning.
Kontroll genom lodning i påle med inspektionsrör.
Hejarstuds.

SLAGBY den 1 / 11 1978

Pål Mätare
Protokollförare

FOA Repro 1972.02 300 bl à 50 ex

Företag:	Blad nr:

PÅLNINGSPROTOKOLL

PÅLE NR

ARBETSPLATS: ______

Detalj: ______

Slagen den / 19___

☐ Betongpåle — Dimension ______ Armering ______ Inspektionsrör ______

☐ Stålpåle — Profil ______

☐ Träpåle — Toppdiameter ______

Pålsko ______

Pålskarv ______
(enl. stand. ritn. el. dyl.

Tillv. den / 19___

Ålder vid slagningen ______ dygn

$\sigma_{K\,28}$ ______ kp/cm² (enl. intyg)

ANM.

☐ Fallhejare   Hejarvikt ___ ton   ☐ Enkel part   ☐ Dubbel part

☐ Tryckluftshammare. Fabrikat och typ ______

☐ Knekt material ______ tvärsnitt ______ cm² längd ______ cm vikt ______ ton

☐ Lerpropp diam. ______ cm djup ______ m

Slagdyna typ ______ vikt ______ ton

Mellanlägg typ ______

Pållängd vid slagning ___ + ___ + ___ + ___ = ___ m

Pållängd efter kapning ___ m   Pållängd i jord: ___ m

Pålhuvudets nivå ▽______   Pålspetsens nivå ▽______

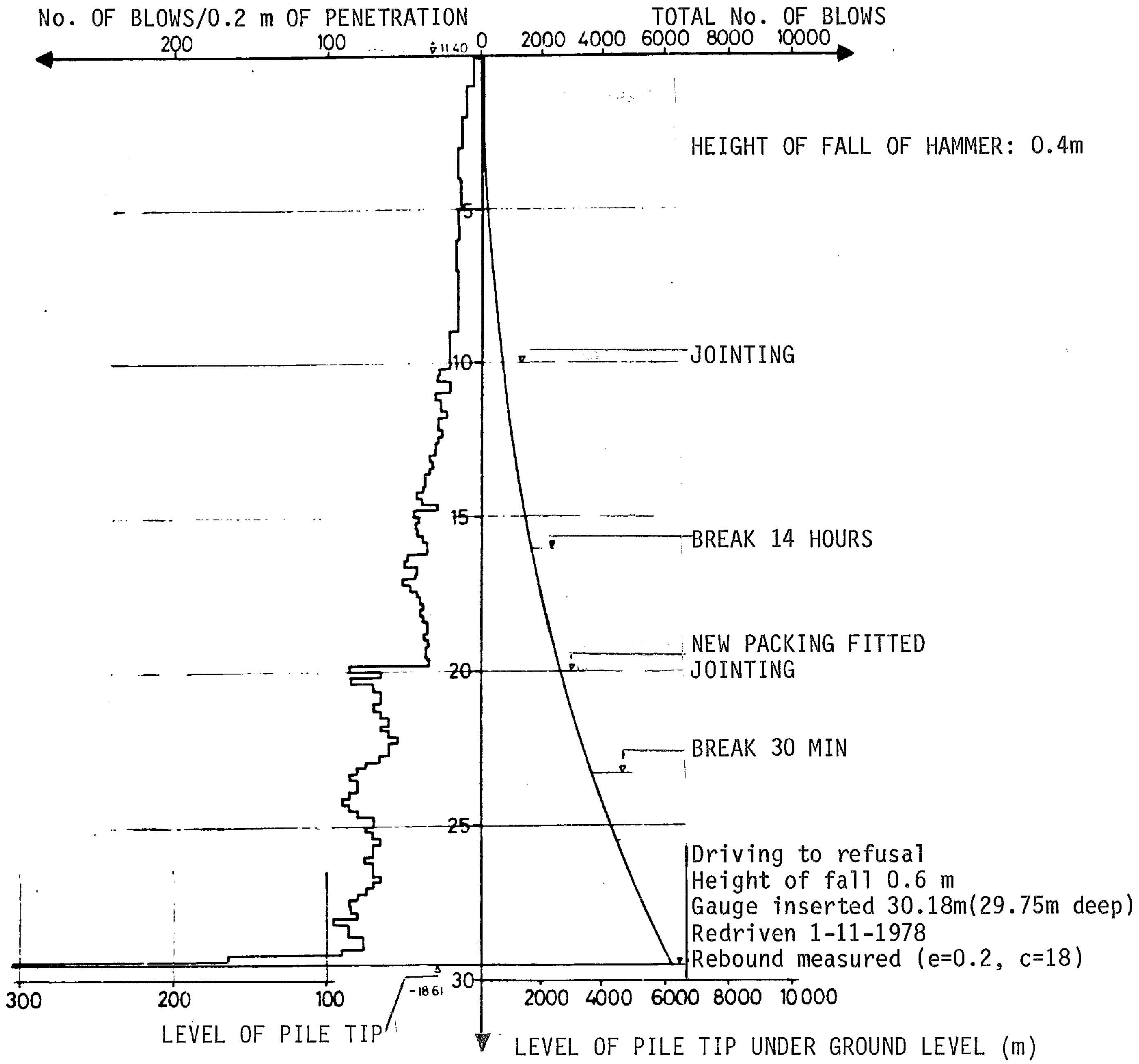
Referensplan (markyta el. dyl.) ______ Nivå ▽______

UPPMÄTNING AV PROVPÅLEN

Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Avstånd från pålspets m	Omkrets cm	Avvikelse från räta linjen cm	Övriga anteckningar (Måttuppgifter för pålspets och skarvbeslag, om ritningar saknas. Ev. felaktigheter, vinkelavvikelser vid fastgjutning av pålspets och skarvbeslag).

Blanketten är utgiven av IVA:s Pålkommission, Box 5073, 102 42 Stockholm. Ifylles enligt IVA:s pålkommission,
Anvisningar för provpålning och provbelastning, särtryck och preliminära rapporter nr 11.

PRECAST CONCRETE PILE, 270 x 270 mm, WITH ROCK SHOE
LENGTH WHEN DRIVEN: 10.30 + 10.10 + 10.05 = 30.45 m
RAKE: 8:1
WEIGHT OF HAMMER: 4 t supported in single fall
DRIVEN: 25-10-1978
REDRIVEN: 1-11-1978
GROUND LEVEL: +11.40



DRIVING TO REFUSAL (5 series of 10 blows)

Height of fall, m	0.6	0.6	0.6	0.6	0.6
Penetration, mm/blow	0.2	0.3	0.3	0.2	0.2
Rebound, mm	20	21	19	18	17

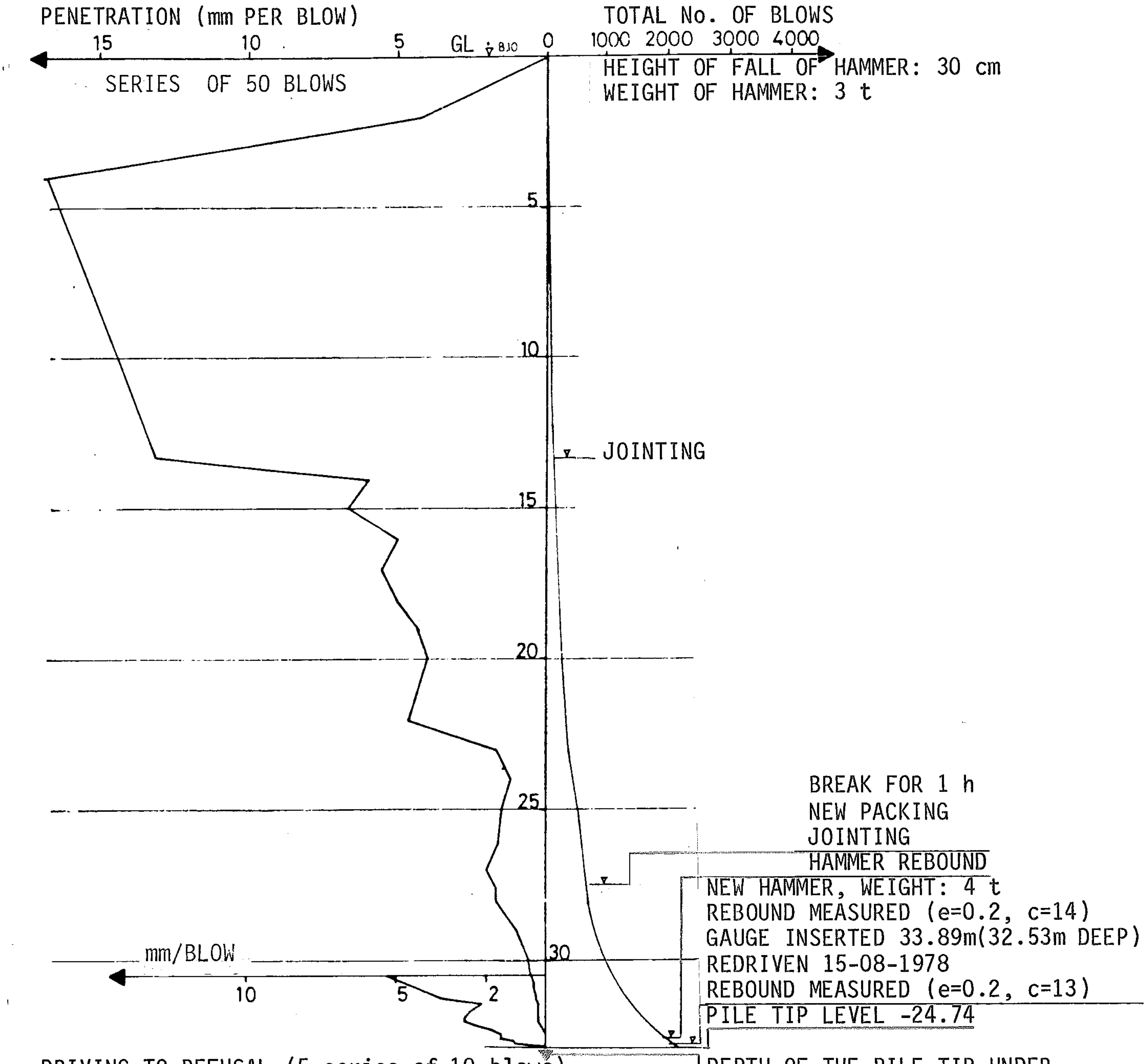
REDRIVING (5 series of 10 blows)

Height of fall, m	0.6	0.6	0.6	0.6	0.6
Penetration, mm/blow	0.2	0.3	0.2	0.3	0.2
Rebound, mm	18	19	19	18	18

VÄGBYGGEN AB
VIADUCT AT SLAGBY
SOUTHERN ABUTMENT
PILE No. 12
PILE DRIVING GRAPH

Appendix 3.2 Example of a pile driving report graph for penetration measured as the number of blows per 0.2 m.

PRECAST CONCRETE PILE, 270 x 270 mm, WITH ROCK SHOE
LENGTH WHEN DRIVEN: 12.04 + 12.07 + 10.10 = 34.21 m
VERTICAL PILE
WEIGHT OF HAMMER: 3 t supported in single fall
FOLLOWER NOT USED
DRIVEN: 12-08-1978
REDRIVEN: 15-08-1978
GROUND LEVEL: +8.10



DRIVING TO REFUSAL (5 series of 10 blows)					
Height of fall, m	0.3	0.3	0.4	0.4	0.4
Penetration, mm/blow	0.4	0.2	0.2	0.3	0.2
Rebound, mm	14	13	15	13	14

REDRIVING (5 series of 10 blows)					
Height of fall, m	0.3	0.3	0.3	0.3	0.3
Penetration, mm/blow	0.3	0.2	0.2	0.3	0.2
Rebound, mm	15	13	14	15	13

ROAD CONSTRUCTION CONSORTIUM
BRIDGE OVER VALLEY AT ÅKÖPING
WESTERN ABUTMENT
PILE No. 1
PILE DRIVING GRAPH

Appendix 3.2A Example of a pile driving report graph for penetration measured as the penetration per series of blows.

REBOUND MEASUREMENT

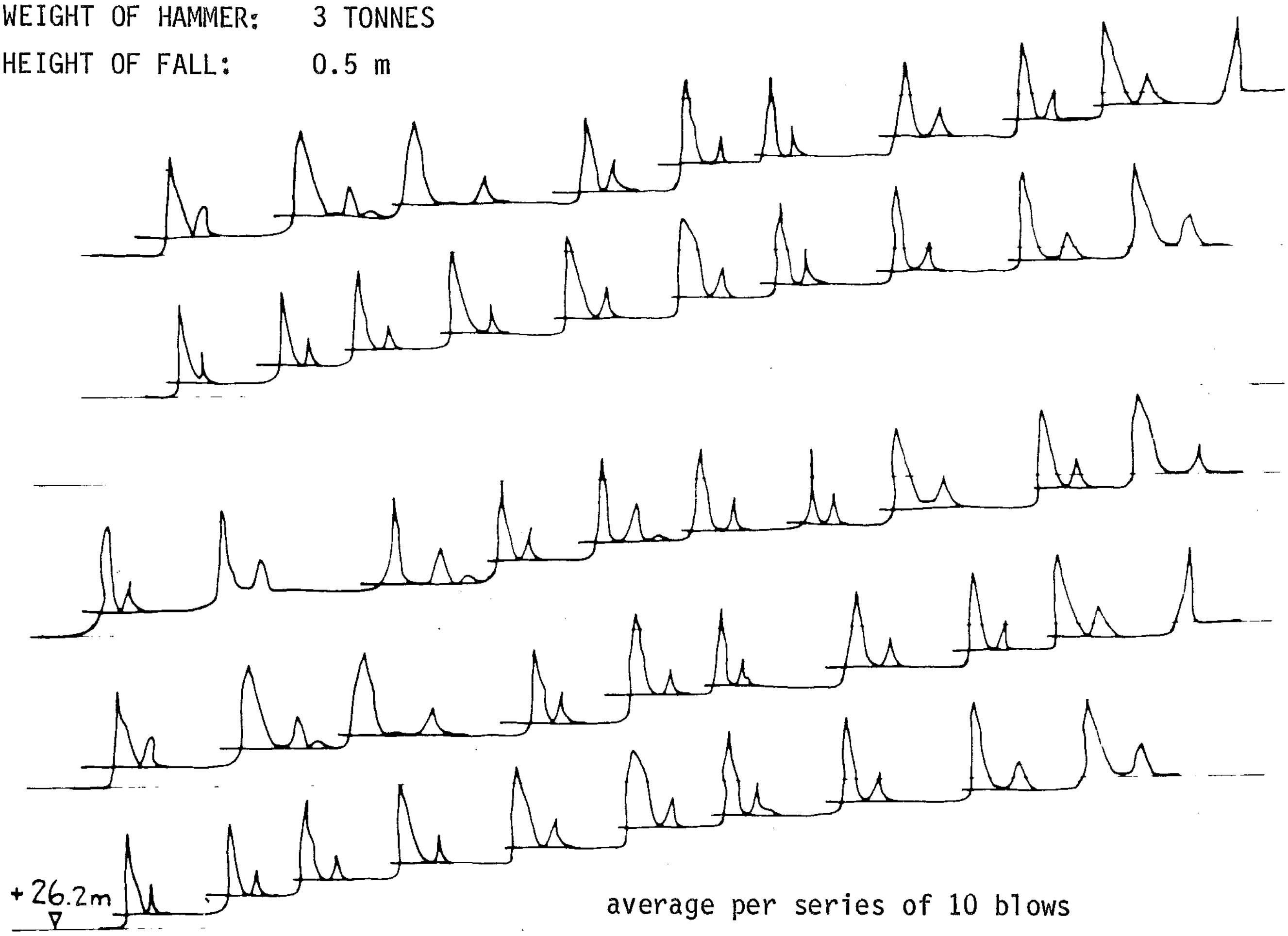
SITE: BROBYGGET PILE No: 3

PART OF STRUCTURE: CENTRAL SUPPORT

DEPTH OF PILE TIP: 26.3 m

WEIGHT OF HAMMER: 3 TONNES

HEIGHT OF FALL: 0.5 m



average per series of 10 blows

REBOUND (mm/blow)	11.0	11.0	11.0	11.5	11.0
PENETRATION (mm/blow)	1.9	2.0	2.1	1.9	2.0

PLACE: SLAGSTA DATE: 23-11-1978

Appendix 3.3 Example of a rebound measurement report

Appendix 5.1

COMPANY	PAGE

LOAD TESTING RECORD

PILE No.

Site: ______________________

Structure: ______________________

Test pile: ______________________ Driven: ______________________

Total length: ______________________ Load tested ____ - ____ - 19 ____

Length of pile in ground ____________ Weather: ______________________

Method of load testing: ____________

TIME	LOAD APPLIED		PILE HEAD				PILE TIP				LATERAL MOVEMENT Remarks
	Measured	kN	DIAL 1	DIAL 2	Mean	Move-ment	DIAL 1	DIAL 2	Mean	Move-ment	

Appendix 5.1 Load testing record form

PUBLICATIONS BY THE COMMISSION ON PILE RESEARCH

Translated titles. Publications with number in brackets are out of print. Unless otherwise stated the papers are written in Swedish.

BULLETINS

Bull. No. 1 Driving tests with pile shoes equipped with rock tip.
B Fellenius, 1963

(2) Pile driving test for bridges in connection with the construction of Europe road No 6 through Gothenburg.
B Fellenius and W Pejrud, 1964.

3 Comparison between bending moment, radius of curvature and width of cracks in concrete piles driven through soft clay to sloping rock surface at Tingstadsleden, Gothenburg.
B Fellenius, 1964

(4) Pile testing for railway bridge at Vannas.
B Fellenius, 1964

(5) Methods of calculating the lateral deflection and the ultimate capacity of laterally loaded piles (English summary).
B Broms, 1965

6 The ultimate capacity of piles subjected to inclined loads (English summary).
B Broms, 1965

7 Calculation of the bearing capacity of vertical piles. (English summary)

8 Driving of piles to sloping rock surface at the fortlet Lejonet, Gotenburg (English summary).
W Pejrud, 1965

9 The influence of reinforcement and its pretension stress and the hammer drop height on the cracking of concrete piles (English summary).
S Sahlin, 1965

10 The bearing capacity of reinforced concrete piles driven to bedrock (English summary).
H Granholm, 1966

11 The bearing capacity of slender concrete piles supported by a sloping rock surface (English summary).
B Broms, 1965

Bull. No. 12 The dynamic strength of unreinforced model concrete piles. Results from a preliminary study (English summary)
S Sahlin and L Hellman, 1966

13 The bearing capacity of pile groups (English summary)
B Broms, 1967

14 Stresses, cracks and fatigue when driving reinforced model concrete piles (English summary)
B-G Hellers, 1970

15 Bearing capacity of sloping rock surface loaded by a rock tip (English summary)
S-E Rehnman, 1968

16 Dynamic stresses in steel piles. Results from field tests (English summary)
G Fjelkner, 1970

17 The strength of rock tips. Results from static load tests (English summary)
S-E Rehnman, 1970

18 Negative skin friction on piles in clay
I. Some results of a full scale test
II. General views and design recommendations
(In English)
B H Fellenius, 1971

19 Damping of stress waves in piles during driving. Results from field tests
Gunnar W Fjelkner - Bengt B Broms, 1972

REPRINTS AND PRELIMINARY REPORTS

No 1 Lectures given at the annual meeting Oct. 25, 1965

2 Load tests on end bearing concrete piles in Ostra Nordstaden, Gothenburg
G Hellstrom, 1965

3 Bearing capacity of sloping rock surface
S-E Rehnman, 1966

(4) Lectures given at the annual meeting Nov. 14, 1966

5 Results from pile testing in Gothenburg Central Station (English summary)
B Fellenius, 1955

6 On driving end bearing piles to refusal
L Hellman, 1967

No 7 Investigation on refusal chriteria when driving steel piles with pneumatic hammers (Report No I)
G Fjelkner, 1967

8 Industrial manufacturing of concrete piles
K Sundberg and A Forsell, 1968

9 Computor analysis of shock wave measurements (Report No I)
L Vilander, 1968

10 Refusal chriteria when driving steel piles with pneumatic hammers (Report No II)
G Fjelkner, 1968

11 Recommendation for pile driving and load testing of piles
Swedish Pile Commission, 1968 (in English)

12 Allowable load on deep end bearing concrete piles in Ostra Nordstaden, Gothenburg. Final Report. (English summary)
G Hellstrom, 1968

13 Resulting stresses in driven prestressed concrete piles
B-G Hellers, 1968

14 Lectures given in Halmstad Nov. 17, 1967
B Broms, G Sundberg, P Moller and T Blomdahl, 1968

(15) Statistics of driven piles in Sweden 1962 and 1966
B H Fellenius, 1968

16 Bearing capacity of friction piles in sand. Results of load tests (English summary)
S Hultsjo and J Svensson, 1969

17 A computer program for shock wave measurements (Report No II)
L Vilander, 1969

18 A new pile-force
B H Fellenius and T Haagen

Negative skin friction for long piles driven in clay (in English)
B H Fellenius and B Broms, 1969

19 Computer calculations of shock wave propagation in piles using variations of model parameters (Report No III)
L Vilander, 1969

(20) New Building Code on Piles. Lectures given at the meeting April 25, 1969
G Astrom, E Sandegren, P Sahlstrom, 1969

21 Negative skin friction on piles in clay. A literature survey (in English)
B H Fellenius, 1969

No 22 Modulus of elasticity for precast piles (English summary)
B H Fellenius and T Eriksson, 1969

The bearing capacity of friction piles. Results from field tests in Canada (English summary)
B H Fellenius, 1969

23 The bearing capacity of piles in an elastic medium considering the body stresses in the pile material (English summary)
S Bernander and I Svensk, 1969

24 Papers published at the 10th anniversity of the Pile Commission on Nov. 20, 1969

(25) Statistics of driven Piles in Sweden 1962, 1966 and 1968
Swedish Pile Commission, 1969

26 The Norwegian Pile Committee
K Flaate

The present need for pile research
B Broms, 1970

27 Report from a travel to Mexico, USA, Canada and England August 23 - September 13, 1969
B H Fellenius, 1970

28 Measuring the velocity of the drop hammer at impact
K-E Sundstrom, 1970

29 A study of the behaviour of a friction pile in sand (English summary)
A Nilsson and T Winqvist

30 Statistics of driven piles in Sweden 1962 - 1970
Swedish Pile Commission, 1971

31 Friction piles for a bridge abutment
S-E Rehnman, 1971

32 Present need for pile research in Sweden
U Bergdahl, 1971

33
1. Settlements of buildings found on shaft bearing piles in clay.
   B-A Torstensson
2. Reduction of settlements for deep foundation units.
   S Eresund
3. Deep foundation methods in Austria
   R Massarsch
4. Impressions from the London Conference on Behaviour of Piles.
   B H Fellenius

No 34 On the bearing capacity of driven piles:

1. Methods used in Sweden to Evaluate the Bearing Capacity of End-Bearing Precast Concrete Piles.
   B Broms and L Hellman
2. Discussions at the Conference Behaviour of Piles, London, 1970
   B H Fellenius, B Broms and G Fjelkner
3. Bearing Capacity of Piles Driven into Rock. With Discussion.
   S-E Rehnman and B Broms
4. Bearing Capacity of Cyclically loaded Piles
   B Broms
5. Bearing Capacity of End-Bearing Piles Driven to Rock.
   S-E Rehnman and B Broms, 1971

35 Load testing of piles according to the Polish regulations (in English)
B K Mazurkiewicz, 1972

36 Investigation of conventional driving helmets.
M Laine, 1972

37 Approximative determination of the bending stiffness of a pretensioned, partially cracked concrete section.
G Hellers, 1973

38 Statistics of driven piles in Sweden 1962 to 1972.
Swedish Pile Commission, 1973

39 Compilation of bending tests on spliced and unspliced precast concrete piles.
B Kvist and P Sandin, 1973

40 Studies of shock waves passing a helmet composed of a number of plate springs.
B Larsson, 1973

41 On corrosion of steel with particular reference to precast concrete piles.
B H Fellenius, 1974

42 Piles in clay. - A geotechnical review on the pile problems in Gothenburg.
B Fellenius, 1974

43 Soil movements at pile driving in clay - Results from model tests.
R Massarsch, 1974

44 Pile driving and load tests of piles for Silo 68 in Köping.
U Bergdahl and A Nilsson, 1974

REPORTS

No 45 The need of pile research in Sweden.
U Bergdahl, 1974

46 Root-piles. Small-diameter injected borepiles.
A Frank, 1975

47 Cast in-situ piles - commonly used installation procedures.
K R Massarsch, 1975

48 Statistics of driven piles in Sweden 1962 - 1974.
Swedish Pile Commission, 1975

49 Soil movements caused by pile driving close to an old stone masonry - Results of stereo photography measurements (English summary)
K R Massarsch, G Ivmark, 1975

50 Pile foundation in the USSR (Partly in English)
Swedish Pile Commission, 1976

51 Soil movements caused by pile driving in clay (in English)
K R Massarsch, 1976

52 The urgency of research projects concerning piles and piling in Sweden 1975 - Result of an enquet
U Bergdahl, G Ivmark, 1977

53 Statistics of driven piles in Sweden 1962-1976
Swedish Pile Commission, 1978

54 Pile groups with lateral earth resistance and fixed pile heads
H Bredenberg, B Broms, 1978

55 Bending stiffness of rail piles - Results of bending tests
E Ottosson, 1979

56 Load tests on friction piles in sand.
Field tests with different test procedures
U Bergdahl - G Hult, 1979

57 Swedish Building Code 1975
Chapter 23.6 Pile Foundations
Swedish Building Code 1975
Approval Rules No 1975:8 Piles
Translated by B Broms, 1979

58 Recommendation for cast in situ piles
Design, installation and control of digged cast in situ piles, 1979

59 Recommendation for pile driving and load testing of piles
Swedish Pile Commission

OTHER REPORTS

Report 99 Driving and test loading of long concrete piles. Test at Gubbero, Gothenburg. (Published by the Swedish Council for Building Research, English summary).
Swedish Pile Commission, 1964.

The reports of the Swedish Commission on Pile Research can be ordered from Swedish Geotechnical Institute, S-581 01 Linköping, Sweden.