Särtryck och preliminära
rapporter nr 35

LOAD TESTING OF PILES ACCORDING TO THE POLISH REGULATIONS

B K Mazurkiewicz*

INGENIÖRSVETENSKAPSAKADEMIEN
PÅLKOMMISSIONEN

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ROYAL SWEDISH ACADEMY OF ENGINEERING SCIENCES
Commission on Pile Research

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PREFACE

Dr B K Mazurkiewicz was employed at the Swedish Geotechnical Institute as Research Associate during the period May - October 1971. Has stay at the Institute was sponsored by the Commission on Pile Research.

In Poland he is among other things occupied with pile problems. This paper, prepared during his stay presents a comparison between Swedish and Polish regulations for load testing of piles.

One of the tasks of the Commission on Pile Research is to publish also foreign experiences in this branch and therefore the Commission is very greatful to the Author for his contribution.

Stockholm, June 1972
COMMISSION ON PILE RESEARCH

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LOAD TESTING OF PILES ACCORDING TO THE POLISH REGULATIONS

B K Mazurkiewicz - Swedish Geotechnical Institute

1. Introduction

Since July 1st 1970, new regulations for piles have been enforced in Poland, PN-69/N-02482 "Foundations.Bearing capacity of piles and pile foundations". The regulations also contain rules for load testing of piles and principles for the interpretation of the test results. At the same time, the Pile Commission of the Royal Swedish Academy of Engineering Sciences, Subcommittee for Load Testing of Piles, published "Recommendation for pile driving tests and routine load testing of piles" as an unofficial complement to the Swedish regulations for piles, SNB - 1967 S 23.6 "Pålnormer, föreskrifter, råd och anvisningar angående grundläggning med pålar". These recommendations concern the preparation for and performance of routine testing of driven piles.

In this paper the main principles of the Polish Regulations are given for load testing of piles with a comparison of existing differences between the Swedish and Polish regulations which cover the same area. The emphasis is put on the Polish regulations because the Swedish can be found in "Reprints and preliminary Reports No. 11", by the Pile Commission.

2. General rules for the load testing of piles

The Polish regulations require that the bearing capacity of piles which are defined by means of statical calculation based on data from soils investigations to be verified in the field by load tests in each case. These load tests must be included in the piling project of the given structure. The pile testing project must contain a specification of the test piles, the pile testing procedure to be used, the value of maximum test load and the value of permissible settlements under the expected loads. The permissible settlements should be adequately calculated for each case in relation to the expected loads and given soil conditions.

The Swedish regulations do not stipulate such strong requirements in this respect. They state only that when more accurate information on driving conditions and bearing capacity is needed, a separate pile driving test should be performed and that normally a load test is required only in the case of high loads on piles or when friction piles are to be used. The load tests are divided in two groups: routine tests and elaborate tests. However, the regulations deal mainly with the performance of routine tests.

Both the Swedish and the Polish regulations require that an adequate soils investigation must be performed prior to the planning and execution of a pile test. The Polish regulations recommend only very generally that the soils investigation must be performed in such a way that a complete picture is obtained of the soil conditions. The Swedish regulations, on the other hand, define minimum requirements for sounding, sampling, and laboratory testing and stipulate how the soil report should be written.

The Swedish regulations recommend that the number of test piles and load tests should be decided for each case. This is fundamentally different from the rules given in the Polish regulations, which require that load tests should be carried out on a minimum of two piles in the case of uniform soil layers if the foundation consists of less than 100 piles and on one pile for every additional 100 piles. When the soil can be divided into a number of different geotechnical zones, the load tests must be carried out for at least one pile in each such zone, driven where the soil conditions are most irregular. In several cases this regulation allows a 50 % reduction in the number of test piles, for example when the piles are installed by means of bored casing pipes (e.g., Wolfholzpile), or when an accurate geotechnical profile is obtained during the boring procedure, which agrees with the profile obtained during, the soils investigation. In cases where the bearing capacity of piles is tested by means of pile driving formulae, such a reduction is also permitted.

In addition, the Polish regulations present a number of detailed rules which have no equivalents in the Swedish regulations. In buildings where the piles work in groups containing a small number of piles (up to 4), with relatively small bearing capacity (up to 25 tons per pile), a load test of the whole pile group is recommended. In addition, when there are elements in a building on piles which have very small permissible settlements the load test should be carried out on at least one pile under such conditions, for exemple, in the foundations for very precise machine installations.

The Polish regulations also define the number of test piles and their distribution in the case of piles which remain when buildings are destroyed, piles which are not used for a long time after installation, or piles which are not used according to the original intention. For these cases the regulations recommend that the loading tests should be carried out on piles placed where great loads are expected and where the worst soil conditions occur. When the piled area is less than 900 m^2 the number of test piles should be minimum two and at least one test pile should be added for each additional 500 m^2. A load test should also be carried out on one pile for each 30 m of building length when the piles are working under such objects as tresle bridges, quays and crane trucks.

For all loading tests the Polish regulations state that the distance between test piles should not be less than 3 m. A tested pile can be used in the foundation without any reduction of the design load. In the case of end bearing piles on bedrock or in stony soil, however, the tested pile can only be used when the stresses in the pile and the bedrock do not exceed 50 % of the compressive strength during the test. Tension test piles can be used to resist tensile loads to 80 % of the established failure tension load for piles in sandy soils, and to 50 % for piles in cohesive soils. The reaction piles used during short term load tests which are loaded in the opposite direction from loading in normal work can be used to their full bearing capacity for building loads, if the maximum test load does not exceed 50 % of the statically calculated bearing capacity against pushing or pulling.

3. Testing equipment for load testing of piles

The Polish regulations separate the testing equipment in the loading and measuring installations and state generally that the loading installations should be designed for loads 3 times greater than the expected bearing capacity of the loaded piles. The measuring installation should obtain the displacement with an accuracy of 0.1 mm, and should measure the forces with an error not greater than 2 % within the measurement range. It is recommended that the displacements should be measured both by means of dial indicators with a scale divisions of 0.01 mm and by means of a precise levelling. The accuracy of the measurements should be verified before the tests are started and again after they have been finished. During the test the levelling instrument and the bench-marks must not be influenced by the testing loads.

In the case when reaction is provided by a kentledge the support of the kentledge should not influence the settlements of the tested pile. Therefore the regulations require that the distance from the kentledge support edge to the pile mantle not should be less than 1.6 m. In the case of reactin pile the distance between the mantles of the reaction and tested piles must not be less than 1/10 of the reaction pile length

and not less than 1.5 m. The number of reaction piles should be so great, that they can take a pulling force of at least 200 % of the calculated allowable bearing capacity of the tested pile.

The distance between the measuring beams which support the dial indicators must be at least 3.0 m. The level of the supports should be verified during the load test, for instance by means of precise levelling.

During the erection of loading and measuring installations, the Polish regulations recommend that all elements should be arranged axially and that their attachment stable. The loading installations must be arranged in such a way, that the pile will only get axial loads.

The final recommendation of the Polish regulations regarding the above problems, concerns the site of the load tests. They state that after the testing equipment is arranged, the test site must not be influenced by vibrations from traffic, engines and pile driving in the neighbourhood. If there are no such vibrations it is possible to get dial indicator readings with an accuracy of 0.01 mm.

The Swedish regulations refer to the above problems in a simular way, although more detailed in some cases, when the requirements concern hydraulic jacks, the scale of precise manometers, the use of pressure gauges, the working length of dial indicators and the measuring arrangement of the pile tip movements.

4. Terms for performance of the load test

According to the Swedish regulations a load test should not be started until a given length of time has elapsed after driving. In case of timber piles as friction piles in clay the time specified is 3 weeks and for other friction piles in clay, 12 weeks. For friction piles in sand and end-bearing piles the stipulated time is 1 week. However, in some cases it is observed that the bearing capacity of friction piles in clay increases even after the prescribed times. Therefore it is advisable to test such piles later than the stated time.

The Polish regulations define the above terms for driven and cast- in-situ piles separately. Thus for driven concrete, steel and timber piles in sandy soils, a load test may start directly after the driving and for cohesive soils 1 week after the driving. To eliminate, however, the influence of soil settlements during the reconsolidation after the pile driving, it is recommended that the load test should be started after one week for sandy soils, and after three weeks for cohesive soils. In the case of layered soils, the competent soil is the one in which the pile tip have penetrated at least 2 metres.

According to the Polish regulations the load test of cast-in-situ piles should not be started until the concrete of the pile has reached the compressive or tensile strength needed to transfer the load test. In the case of load tests in an area with a soil replacement or in an area on wich the soil will be surcharged e. g., by means of embankments or buildings

with slab foundations, the regulations recommend that the pile driving not start until the subsequent settlements of the soil are finished. If this is impossible the drag force due to negative skin friction must be subtracted from the allowable pile bearing capacity received from load tests.

5. Preliminary tests of the test piles

Both the Swedish and the Polish regulations require a driving test prior to load testing for driven piles. In the Polish regulations it is required that measurement of pile penetration for each serie of 10 or 20 blows should be taken troughout the driving, while the last three series for each pile must be taken for 10 blows. A driving log must be kept and the measurement of the permanent settlements must be taken under the last blow (or the last series of 5 - 10 blows).

The requirements of the Swedish regulations in this respect are more extensive and concern the performance of a separate driving project of the test pile, the measurement of the pile lengths, perimeter and bending prior to driving of the pile segments.

The Polish regulations require a driving log (Appendix 1) which should include the following notes:

- the day and hour when the driving begins and ends,
- all interruptions,
- the kind and the weight of the hammers used, and in the case of a pneumatic hammer, the driving energy,
- the computation of blow series from the beginning to the end of driving with the height of fall of the hammer showing in every series, the number of blows (by vibratory pile drivers - the series duration in minutes) and the pile settlements, with the settlements during the last three series of 10 blows measured exactly and recorded.

- the adapted auxuliary installations such as the special driving hammer (with its weight, dimensions and cushion indicated), vibrators, drilling fluids, pile shoes. The above data should be supplemented with an exact description of how they were used during the whole driving time.

In the column "Remarks" of the driving log the following should be noted:

- the water depth on the driving site when the piles are driven in water,
- the length of the cut off pile head section and data about any damages to the pile head during the driving,
- the time used to remove any such damages,
- the deviation of the pile from the designed location, and other technical circumstances and observations during the pile driving,
- the levelling data for the pile head after the driving, data about the level of the pile tip and the final pile inclination,
- the data about noted pile damages, the state of the pile head, the damages observed on the pile mantle during driving, etc
- the data about behaviour of the soil surface surrounding the pile,
- the weather conditions during pile driving.

The driving log according to the Swedish regulations includes in principle all that a driving log should include according to the Polish regulations, while the individual questions are written on the driving log form and not in the text of the regulations. Additional requirements of the Swedish driving log concern data about a precast concrete pile, all work done prior to the pile driving, the results of bending and perimeter measurings, settlements of the pile, obstacles in the ground and bouncing of the hammer. Alsc in the Swedish regulations, two alternative recording methods are given and explained in detail, together with the required data for the final report and an example of how results should be presented.

6. Performance of load test

The Polish regulations state that the tested pile should be loaded until either the failure load of the pile is reached or at least twice the intended allowed load. The loading of the test pile should be increased in increments of equal magnitude and corresponding to about 1/10 of the intended allowed load.

Immediately before starting a pile loading test, the pile head should be levelled to any stable points (benchmark) placed beyond the sphere of the soil deformations caused by the load tests.

The settlement readings should be noted in time rates equal to 10 min. When the settlement under a given load lasts more than 1 hour, the time intervals between the readings can be longer than 10 min.

Before adding a new load increment, one should wait for the settlement of the pile to stabilize under the previous load. In cohesive soils the stabilized settlement is reached, when the settlement rate is equal to 0.1 mm per 2 hours. In orther soils the settlement of the pile can be assumed as stabilized, if three successive readings by means of dial indicators with scale divisions of 0.01 mm do not show a total settlement increase of more than 0.02 mm, or six successive readings with a measuring accuracy 0.1 mm do not show a joint increase of more than 0.1 mm.

The regulations permit interruptions during the load test which involve a complete discharge of the test load. The interruptions, however, cannot be longer than one day. After an interruption the test load can immediately be raised to the load at which the interruption took place. The load should then be increased to the projected test load or to a failure load as originally planned.

If the test load reaches the projected bearing capacity of the pile, and again if it reaches the failure load or the projected testing load of the pile, the pile must be unloaded and the rebound and the permanent settlements should be recorded.

The Polish regulations further recommend that tension tests on piles, which should be carried out with load increments equal to 1.0 ton for piles with av projected tension bearing capacity of 20 tons, and 2.0 tons increments for piles with a designed capacity larger than 20 tons. Every load increment must be kept on the pile for 10 min.

The Polish regulations also include recommendations for lateral pile loading tests. They stipulate that the load increments should not exceed 1/10 of the allowable lateral bearing capacity of the pile given in the project, and that every load step should be added and kept constant for 10 min. The tests should be carried out to the point where the horizontal displacement of the pile is 200 % of the displacement

allowed in the project. However the load on the pile must not exceed twice the design load given in the project.

The Swedish regulations state that the loading test should be carried out by means of the CRP-test method, in which the pile head is forced to settle at a constant rate and the force that is required to obtain the settlement rate is recorded. It is, of course, a completely different test method with different requirements compared with the test method recommended by the Polish regulations.

7. Report of pile loading test results

According to the Polish regulations, the report of the pile loading test results should contain:

a) Site plan of the building with the location of all piles and with the test piles marked as well as the location of bore holes, soundings and places where, for example, plate loading tests have been performed.

b) Geotechnical sections containing the location of the test piles and all levelleing data in relation to a stable bench mark.

c) Technical description including particular data concerning the building and the test piles.

d) Cast-in situ pile log (together with the pile certificates) for every concrete and reinforced concrete test pile, which should contain:
   - data about the weather conditions during the pile casting,
   - kind and dimensions of the pile construction equipment used,
   - data about the rebored soil layers and observations made during the boring of the casing pipe (kinds of soil),
   - amount and distribution of concrete used in the casting of the pile,

- data about the level and type of the pile tip and head,

e) Driving log for each pile according to the rules given in section 5,

f) Compilation of data for all preliminary tests containing the level of the pile head before the loading test, the level of any horizontal force which is applied, the initial dial and levelling instrument indications. The last measurement is taken by means of at least two measuring rods fixed to the pile and to a stable point situated away from the tested pile.

g) Pile loading test log for compression or tension of the pile (Appendix II) with a description of the pile loading course including the day and hour when the test begins and ends, the weather and temperature during the test, a confirmation of conformity between the specified testing equipment and the equipment used, a description of the way in which the loads have been applied, a description of the individual events during the tests, for instance damage to the testing equipment, the transposition of the dial indicators, changes in the soil surface, changes of the anchore length, etc.

h) Settlement (lifting) log (Appendix III).

i) Load-settlement (lifting) diagram including the load-settlement (lifting) curve, the load-time curve, and the time-settlement (lifting) curve. The load, time and settlement (liftings) curves are plotted along different axes as shown in Fig. 1.

Suitable scales are: 20 mm = 10 ton for the load-settlement (lifting) curve, 10 mm = 10 ton for the load-time curve,
1 cm = 1 mm for settlements (liftings) and 2 mm = 10 minutes for time.

The individual points on the curves should be the arithmetic mean of readings of all dial indicators compared with the readings from levelling instrument.

The Polish regulations also include adequate standards for reports on the lateral loading test of the pile.

The Swedish regulations require that the following should be annexed to the final loading test report, in addition to the record and descriptions of the driving test and loading test of the loaded piles:
the geotechnical report, the reaction support arrangement, the design of the reaction piles, if used, whith their driving records, and a separate load-settlement diagram.

8. Principles for the interpretation of the pile load test results

Generally the Swedish regulations state, that the interpretation of the test results should be carried out in cooperation with the state authorities and qualified geotechnicians as well as the choice of allowable loads and safety factors.

However it is stated that the failure load (P) can be determined as the load at which the pile head settlement is 2δ (for the first time) where δ is the settlement at the load 0.9 P. This definition has been chosen because of the difficulty in judging the real failure load from a diagram.

The Polish regulation takes the load settlement curve as a basis and depending on the circumstances suggests three possible cases in which the curve should be used (Fig. 2):

a) If the curve from the largets available load during the pile loading test is two times greater than the load which the pile is designed to carry, shows proportionality between the loads and settlements, the allowable load is assumed to be half of the largets load applied.

However, if a change in pile spacing of the foundation is possible, the allowable pile load can be assumed to be equal to 2/3 of the largest load applied. The proportionality is characterised by means of a rectiliniarity of

insignificiant curvature (with a deviation of 10 % from the straight line) of the diagram (Fig. 2a).

b) If the load-settlement curve shows a marked breakdown, the load which has been reached at that point is assumed to be the failure or ultimate load (Fig. 2b).

c) If the load-settlement curve does not show a marked breakdown, then the failure load can be shown graphically, as in Fig. 2c. In such a case, the final section of the curve should be divided by means of a set of equally spaced horizontal straight lines. From the intersection between these straight lines and the load-settlement curve, vertical straight lines should lead to the axis of abscissae which must be inclined to 45° after having crossed the axis. The intersection points of the inclined lines with the nearest vertical lines should give an auxiliary line (dotted line on Fig.2 c) which will show the failure load on the axis of abscissae.

In the cases described in points (b) and (c) above, the allowable load (U) is obtained by dividing the determined failure load P by the safety factor F.

The settlement of the pile s_p, which corresponds to the allowable load determined above must not be greater than the allowable load settlement s_a, defined in the project for the pile loading test. In the opposite case as the competent final allowable load, that load is assumed which corresponds to the allowable pile settlements s_p. The settlement s_p is estimated by means of the load-settlement curve obtained from measurements during the load test.

The Polish regulations also contain the determination of the allowable tension load of the pile, which is assumed as equal to half of the failure load by pulling, determined in the same way as by pushing.

In the case of a lateral pile loading test the allowable bearing capacity is equal to $\frac{1}{F}$ of that force for which the displacement correspond to what was designed before the loading. When the pile head is designed to be fixed in the foundation, but the loading test is performed as for a free pile, the allowable lateral bearing capacity is assumed as equal to twice the value determined in the way given above.

The Polish regulations also state the value of the safety factor F, to be in principle equal to 2. However, in special cases, determined below, it is possible to lower the factor to 1.5 or to medial values.

The safety factor equal to 1,5 can be permitted in the following optimal conditions:

a) if a very marked breakdown exists on the load-settlement diagram (Fig. 2b),

b) if the soil conditions on the whole building site are equal to a regular soil stratification,

c) if the allowable pile settlement was determined by means of very accurate methods taking into consideration: the whole structure rigidity and its settlement sensitivity, the relationsship between the pile and foundation settlement, the allowable ratio for the given structure between settlement differences and distance of the extreme points of the structure, etc,

d) if the foundation loadings are accurately determined, and the information about the kind and quantily of constant and movable loadings is very accurate,

e) if the calculation method of the forces in piles is very reliable (for instance if the pile lay-out is symmetrical and the piles and loads are exclusively vertical).

Assuming that all five circumstances are of equal rank and the above conditions are fullfilled a practical coefficient can be attributed to each of them $f_{min} = \sqrt[5]{1.5} = 1.085$.

The safety factor F = 2 should be accepted for all the above circumstances if the following requirements are valid:

- if the load-settlement curve does not show a breakdown,
- if the soil conditions on the building site are heterogeneous and there are great differences in stratification and characteristics of the soil,
- if the allowable settlement was assumed by means of general estimation without a detailed analysis,
- if the foundation loadings were calculated according to the standards, but there is some uncertainty as to the quantity of constant and movable loadings,
- if the credibility of the calculation of pile loads is small (for instance after the Culmann method).

If the above circumstances are of equal rank a partial coefficient $f_{max} = \sqrt[5]{2} = 1.15$ can be attributed to each.

The total safety factor F should be calculated as the product of five partial coefficients given for the particular circumstances a) to e). For instance: if the conditions in relation to a) c) and e) are optimal and for b) and d) minimal, the value of the safety factor will be equal:

$F = f_{min} \times f_{max} \times f_{min} \times f_{max} \times f_{min} = 1.085 \times 1.15 \times 1.085 \times 1.15 \times 1.085 = 1.7.$

If the pile which was tested and the set of piles represented by that pile are to be loaded in the future by means of dynamic loads, then the allowable pile load determined in the way given above must be multiplied by 0.4 in the case of piles in foundations for drop hammers and by 0.7 in the case of piles in foundations for other engines or railway bridges.

If there is a more than 20 % difference between the allowable pile load determined by means of the loading test and allowable pile load designed in the project, adequate corrections should be introduced to the project in that area, where the tested pile is representative,

a) if the allowable bearing capacity of the pile is too small, the corrections must be introduced in the whole area with the restriction that the corrections should depend, for instance, on application of additional piles, petrification of the soil surrounding the pile or under the pile tip, elongation of the piles installed after the loading test,

b) if the allowable bearing capacity of the installed piles is too high, the corrections must be introduced where it is still possible. The corrections in that case can depend on the shortening of the next piles, greater spacing, etc.

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Recommendation for pile driving test and routine load testing of piles. Royal Swedish Academy of Engineering Sciences, Commission on Pile Research. Stockholm, March 1970.

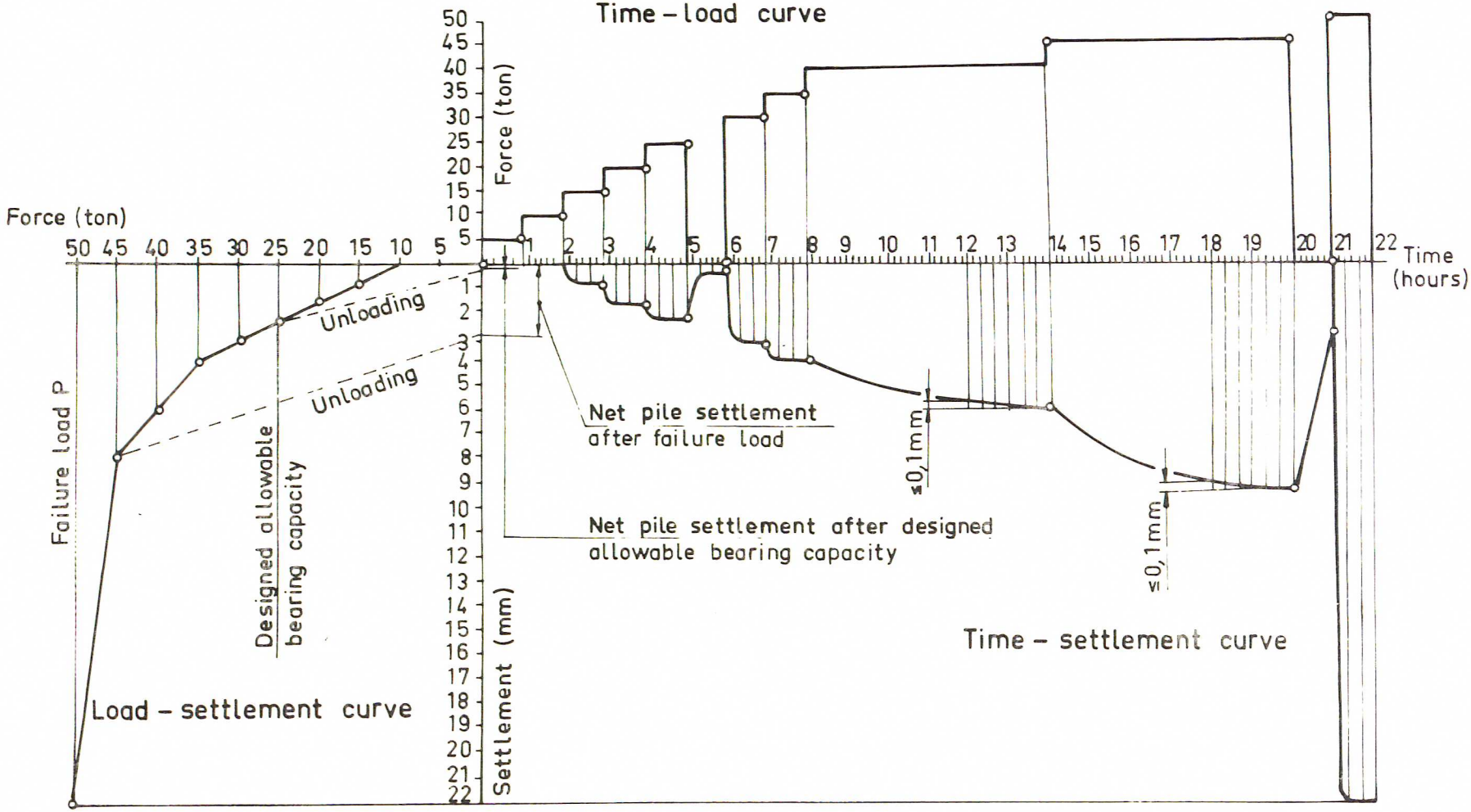

FIG 1. Diagram showing the load-settlement, the load-time and the time-settlement curves from a pile load test.

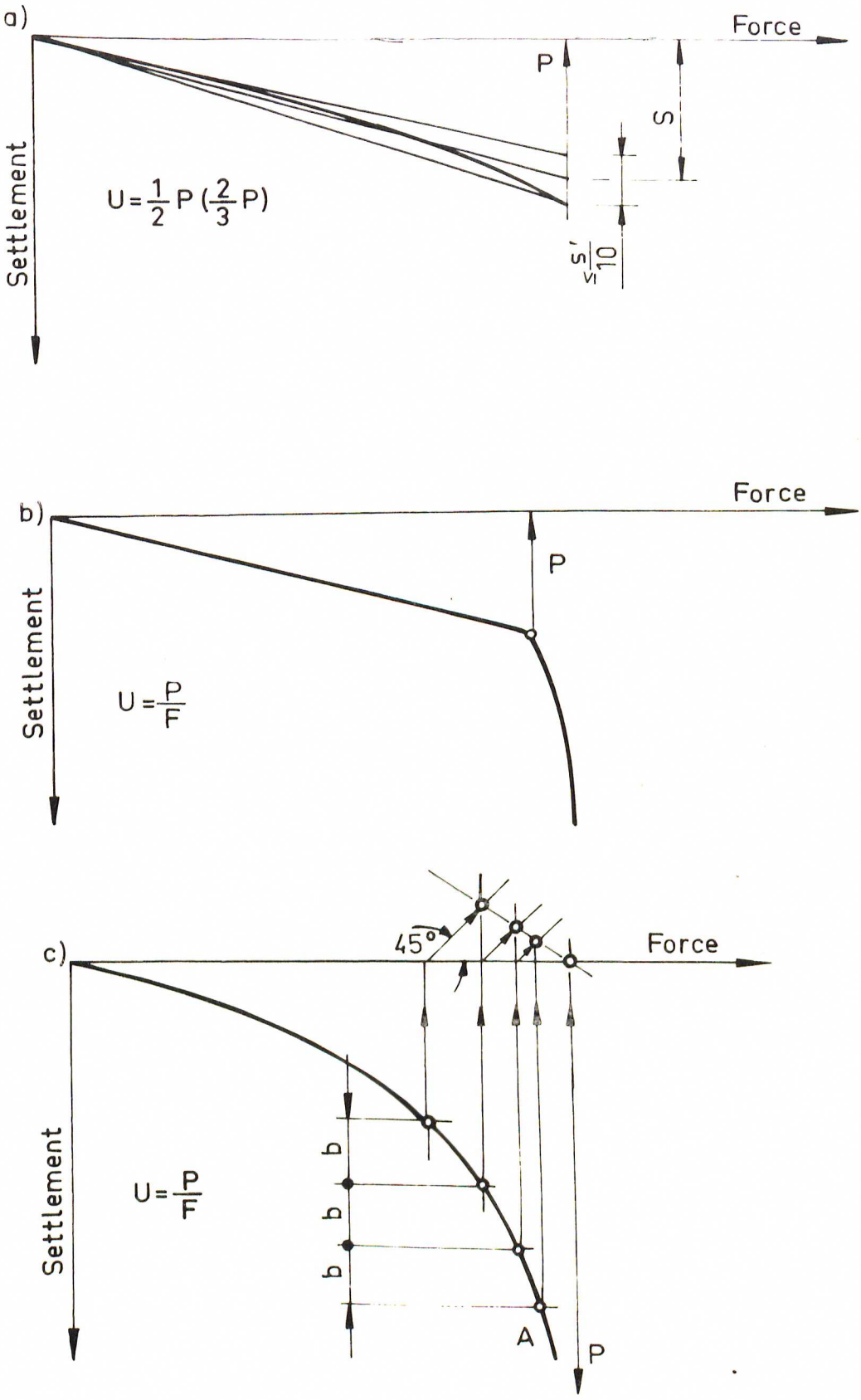

FIG 2. Evaluation of the failure load from different types of load-settlement curves.

DRIVING LOG

Pile No. .....
(pile material: Kind of timber, concrete, steel)

Beginning of driving ..... 19..... h .....

end ..... 19..... h .....

Interruptions .....

.....

Pile length: ..... m Pile inclination: designed .....

measured .....

Pile dimensions: diameter or side lengths ..... cm

Pile settlement under the hammer weight ..... cm

Depth of pile tip on the beginning of blow series	No. of series	The number of blows in series n or the duration of series	Fall height of hammer, cm, or the energy of hammer blow kgm/s	Penetration of pile c′ after the first blow series cm	Penetration of pile under the last blow (or average blow in the last series) $c = \frac{c'}{n}$	Remarks

Pile driver .....

Weight of hammer .....

Kind and energy of hammer .....

Auxiliary installations .....

Signature

PILE LOADING TEST LOG

Pile No.

1. Pile loading test date .....

2. Commission members

   a) ..... b) .....

   c) ..... d) .....

   e) ..... f) .....

3. Name, capacity and building location, description of the kind of structure

   .....

   .....

4. Pile type ..... pile or casing pipe diameter...cm

   total length ..... m, load carrying length ..... m

   inclination ..... cm, pile casting or driving date .....

   Kind of cement ..... cement amount for 1 m^3 ..... kg,

   concrete composition .....

   longitudinal reinforcement: head ..... tip .....

   lateral reinforcement: head ..... tip .....

5. Bearing capacity designed ..... ton, load capacity of the pile structure ..... ton

6. Settlement: allowable ..... mm, calculated ..... mm

7. Description of the testing equipment .....
   (the type of loading)

   .....
   arrangement: hydraulic jack - diameter and cross-section of piston,

   .....
   Kentledge - kind and weight, reaction arrangement

8. Pile weight ..... ton, testing equipment weight ..... ton

9. Pile head level before the pile loading test begins .....

   .....

10. Test results

Loading stage	Load T	Settlement, mm		
		stable	elastic	total
Designed bearing capacity				
Designed bearing capacity x 1.5				
Designed bearing capacity x 2.0 or maximal load				

11. Description of the pile loading test course .....

.....

.....

Appendix

1. Location plan
2. Geotechnical section
3. Pile settlement log
4. Pile driving log or pile cast-in-situ log whith pile card
5. Load settlement diagram

The members of the commission conform that the pile loading test has been carried out correctly and that the neccessary documentation is complete.

Signatures

a) ..... b) .....

c) ..... d) .....

e) ..... f) .....

SETTLEMENT LOG

Pile No.....

Successive number of loading step	At	T	Readings hours	Loading duration	Settlement measurements by means of dial indicators, mm												Settlement measurements by means of levelling instrument mm	Remarks
					dial No. 1			dial No. 2			dial No. 3			dial No. 4					
					Reading	Reading difference	Settlement	Reading	Reading difference	Settlement	Reading	Reading difference	Settlement	Reading	Reading difference	Settlement	Average Settlement		

APPENDIX IV