Improved method for the observation of settlement

Terzaghi, K.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20331564
Technical Translation (National Research Council of Canada); no. NRC-TT-323, 1952

NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation TT-323

Title: Improved method for the observation of settlement. (Verbessertes Verfahren zur Setzungsbeobachtung.)

By: K. von Terzaghi, Technische Hochschule, Vienna.

Reference: Die Bautechnik 11: 579-582, 1933.

Translated by: D. J. Wright

Improved Method for the Observation of Settlement

Number and type of elevation markers

In the case of structures which are more or less rigid (bridge piers, silos of moderate height) it is sufficient to have one elevation marker at each corner. In high buildings and industrial structures which are constructed around a framework of girders, on the other hand, one must have an elevation marker for every 20 to 30 m^2 of area, for only in this way does one get a clear concept of the magnitude and distribution of the variations in settlement.

Experience has shown that elevation markers which consist of round iron bolts are either damaged or completely ruined during the course of construction. Structures inspected by many authors after construction was complete showed that of twenty original elevation indicators, only a few, if any, remained. In order to eliminate this danger, the author uses elevation markers which, by virtue of their shape, draw the attention of workers entrusted with the dismantling and cleaning, have no projecting parts, and are protected against wilful damage by means of a cap which can only be unscrewed with a key.

They are made of galvanized iron piping 14 to 16 cm. long (Fig. 1), the outer end of which is provided with a brass socket. The opening of the socket is furnished with a screw cap which can only be removed with the aid of a key. In order to undertake the levelling, one replaces the screw cap with a turned bolt (Fig. 2) which, in turn, is again replaced by the screw cap when the levelling has been completed.

In order to install the elevation markers in a horizontal position, a longer bolt is screwed into the socket (Fig. 3) and the position of the bolt is checked with the aid of a bubble tube level. While the elevation marker is being cemented in with quick-setting cement the pipe socket is firmly held in the horizontal position by means of a wedge.

Position levelling

In levelling elevation markers, one must count on an error of at least 1mm. When levelling in excavations, the errors are often even greater and the method is time-consuming. In order to reduce the margin of error and to simplify the measuring, the author uses the device shown in Fig. 4a to 4c. It consists of two stand pipes 1 and 2 (Fig 4a) connected by means of a flexible tube and suspended, by means of hangers, on the bolts serving as elevation markers. The system is filled with water. The upper ends of the glass tubes are provided with soldered brass caps. When the stand pipe is suspended, the distance between the upper side of the bolt and the polished top of the brass cap is constant at Z_o for each pipe (Fig. 4a). The vertical distance Z_1 or Z_2 between this upper edge and the free level is measured with the aid of the micrometer screw (Figs. 4b and 4c), graduated in.01 mm., and the pointed rule attached to the screw. In order to be able to use the device described, the elevation markers must be dealt with in groups at approximately the same elevation. At the boundary between each two groups, two markers are fitted one over the other to one and the same rigid structural member (e.g. a cellar wall); these markers make it possible to proceed from one group to another.

The main fixed point

There are two possible ways of establishing the main fixed point: either it is a point in the side wall of an adjacent older structure which has completely settled and is at least 50 m. distant from the structure being inspected or the main fixed point is located at the bottom of one of the test bore holes (a ground depth gauge) provided that the bore holes have reached a layer which can be no further compressed.

In the first case, it is very often possible to locate the main fixed point in such a way that the measurement from the structure to the main fixed point can also be made with the tubular level, although an intermediate fixed point may sometimes be necessary. Under all circumstances, it is necessary that there be one elevation marker on the outside of the new structure above street level and a second in the same wall section on the inside of the building about 1 m. above the cellar floor. If the difference in elevation between these two points amounts to some meters, subsequent measurements should be taken at least twice during construction because the layers of mortar may undergo considerable compression as the load which they carry is increased. The measuring is done by means of a slide gauge provided with a vernier (reading 1/10 mm.). The initial levelling of the inside markers should be taken even before the cellar floor is finished.

In the event that the elevation fixed point is located inside the building in a bore hole, one follows the same procedure as that used in making the ground depth gauge already described (1). The fixed point is formed by a pointer attached to the upper end of the rod of the gauge. It is inserted slightly below the cellar floor in a supporting pipe, the upper end of which is covered. In order to measure, with the aid of the tubular level, the difference in elevation between the fixed point and the elevation markers in the ground floor of the building one proceeds according to Fig. 5. The cover is removed and at the fixed point is placed a levelling staff with a metal base, the upper end of which carries a peg. The difference in elevation between the staff peg and the adjacent marker is determined with the aid of the tubular level.

In the case of very long bridges, it is recommended that a permanent pipe line be laid between both sides of the bridge road; this pipe line is furnished with a stand pipe in the axis of each bridge pier, in accordance with Figs. 4b and 4c. When a bridge is constructed in this way, the inspector need only take readings with the aid of a micrometer screw. In taking tubular level measurements of a similar type on the Reichsbruecke at Vienna, the author's assistants were able to establish the fact that vibration due to traffic has no effect on the degree of accuracy of the micrometer readings.

The application of the method outlined to observations of the movement of retaining walls was discussed by the author at the convention on the building of dams across valleys held at Stockholm in 1933.

The results of observations

The results of observations are to be given numerically both according to local distribution and also according to the time at which they were made.

The local distribution is shown most clearly by curves for the same amount of settlement. Since the place at which the greatest degree of settlement occurs occasionally changes in the course of time, it is generally necessary to draw up settlement plans for two or three different stages of the settlement action. In plotting the course of the settlement in relation to time, it is recommended that the increase in relation to time of the ground pressures or the pile loadings be recorded above the horizontal (time) axis and the increase in the settlement of representative points of the structure be recorded below this axis. One should also append the following: a simplified ground plan, a characteristic cross section, data on load per unit of surface area of the main part of the structure, position of bore holes and a brief description of the results of drilling.

Example of settlement observation made by the method described above.

A new structure is about 37 m. long and 12 m. wide. The bottom of the cellar is about 1 m. below ground level in the left half of the building and about 2.4 m. below ground level in the right half. The building is a five-storey brick structure with reinforced concrete flanged girders and reinforced concrete inserted ceilings and is divided into two equal sections by an expansion joint. (Fig. 7 dot-and-dash line). In order to establish the nature of the ground, four drill holes and four trial shafts were made. The results of the exploratory work are given in the relief profile (Fig. 6). Because of the inadequate bearing capacity of the artificial embankment, it was decided that the foundation in the embankment should be laid on tapering piles in the Stern - Zeissl system, which had been rammed into the gravel to a depth of 1 to 1.5 m. The piles were loaded with 25 tons apiece and the load test made on one of them (Fig. 7a, pile P) showed a sinking of about 0.1 cm. under a load of 25 tons.

Since the left end of the structure was built on naturally deposited solid gravel and the upper part, on the other hand, on an embankment about 5 to 6 m. high, the piles under the left section of the building are from 1 to 1.5 m. long as opposed to those under the right side which are 6 to 7 m. long. For this reason, the following data are worth knowing:

What is the relationship between the sinking of the pile foundation and that of the single pile under load, and what effect does the difference in foundation of the two parts of the structure have on the settlement? The answer to this question may be found in curves for the same position at two stages of construction, which are given in Figs. 7a and 7b. The elevation markers are indicated by the letters H_1 to H_{18} and the drill holes and shafts by small circles and triangles, respectively. Fig. 8 gives the curve for the increase in the load on the piles in relation to time, and the relevant settlement of representative points in the structure. From the settlement diagrams, one can establish the following facts: the difference in the depth of the foundation does not effect the settlement diagram, for the differences in the settlement are substantially greater in the sections having the same foundation than the differences between the average settlement of the sections having different foundations. The time curve for the settlement varies somewhat for different sections of the structure. Consequently the settlement diagrams for the two stages of construction shown in Fig. 7 differ considerably in spite of uniform application of the load. Particularly noteworthy is the delay in settlement of point H_3 (Fig. 8). Similar changes in the course of the curve for the same position in relation to time were found by the author in settlement diagrams made several decades after the structure was completed. This displacement of the centre of gravity of the settlement action in relation to time is probably caused by variations in the degree of permeability which, in turn, results in a varying speed in the time curve of the consolidation process.

In the first stage of construction (Fig. 7a) the greatest settlement took place at the point at which the concrete mixer and the hoist were located (H_{17}) and might perhaps be attributed to vibration. Later on, the "deep spot" moved toward the point H_3 with the delayed settlement. It is quite informative to compare the result of the trial loading of pile P and the sinking which the same pile, under the same load, underwent as one of a group of piles (Fig. 9). The bend in the lower settlement curve seems to indicate that the pile, after sinking about 8 mm., transferred part of its supplementary load to a more efficient neighbouring pile. The Figure shows that the settlement of a structure, even one with stationary pile foundations, can be considerably more extensive than one would expect. In any case, a part of the difference is due to the fact that the trial loading (upper curve) lasted only two days while the load due to construction was applied over a period of three months.

Because of the structure's slight degree of movement, it would hardly have been possible to obtain a similarly clear picture of the details of the settlement action of the ground floor by taking the level. Measurement of the settlement of 20 to 30 elevation markers requires no more than a day.

Settlement actions of the order of magnitude of those shown in Fig. 7 would have to be regarded as unavoidable in the case of high buildings, and as a rule they are considerably greater. The variations in settlement are, in our experience, normal and have no apparent effect on the construction. The upper limits of settlement variations which high buildings of various types of construction can endure without suffering any damage is still not known and can only be estimated empirically on the basis of observations such as these. Likewise, for example, to practice medicine sucessfully, one must study not only those who are sick but also those who are healthy.

Observations based on ground depth gauges.

In the event that one wants to take into account not only the amount but also the location of settlement movements, depth gauges are inserted at various depths below the foundations. Observations can be made with the aid of Zeiss time clocks, the pointers of which rest on the upper end of the rod. As an example of the value of the information gained from these depth gauges, we might mention the following: a practically rigid structure with a horizontal projection of about 40 x 40 m. rests on a layer of rather soft clay mixed with sand deposits which is about 7 m. deep, and which in turn rests on a strong layer of homogeneous stiff clay. The structure, by virtue of its own weight, exerts a pressure of about 1 kg/cm^2. Under this load, no noticeable sinking occurred. Many months after the building was finished, the load on the building ground had increased as shown in Fig. 10. Since we had inserted several elevation markers and, at a depth of 8m. below the foundation, i.e. below the top of the layer of stiff clay, a ground depth gauge several months before the supplementary load was applied, we were able to measure the effect of the increase in load. The observations gave the result shown graphically in Fig. 10. As the load increased, the structure at first remained steady for a few months. Then a settlement into the soft underground layer which was about 7 m. thick took place and, at the end of several more months, the stiff clay which was at a depth of more than 8 m. also began to move. About half the total settlement occured in the stiff clay. The phase difference between the loading and the settlement has often been observed by the author in the case of foundations on clay. It is worthy of note in the present case that the apparently stiff clay which is regarded as a good structural base is far from providing a firm foundation. The example shows that when planning the underpinning of a building in doubtful cases one must supplement the readings of simple elevation markers by readings on the ground depth gauges in order to find out in this way the true location of the movements. Otherwise there is danger of building the structure on a base layer which is also moving. The author also knows of several cases where the location of the movement was many meters below the level of the masonry members built during the course of the underpinning. In such cases the effect of the underpinning is completely lost.

Economical significance of settlement observations.

Since the observations mentioned above involve a certain slight expenditure, the question arises: to whom are the results useful? The answer is: to the builders, the contractors, the inspectors and the community.

The owner of a building, who has the results of pertinent and adequate settlement observations at his disposal has, in the event of any subsequent damage to the neighbouring area due to construction, irrefutable basis to substantiate his claims. Merely by revealing the measuring of his elevation markers he is in a position to prove whether or not construction has caused a further settlement of his property. Also if he wants to increase the weight of his building by adding another storey, or wants to increase the real weight or to replace the structure by a new and heavier one, the effect of the proposed change can be estimated on the basis of the observations on the settlement of the old structure. The knowledge of the behaviour of the subsoil under the influence of load increases the value of the structure in the event that it is to be sold.

If, when the subsoil consists of clay, cracks appear several years after the structure is built, the extent of future damage to the building can only be estimated when the movements of the structure have been noted during and after construction at definite intervals of time. Before the first crack appears, it is very often less costly and more effective to take underpinning precautions than at an advanced stage of settlement. The author was able to show repeatedly that for want of knowledge as to the previous history of the movements, the underpinning of a building was undertaken at a time when the settlement which could be expected was only a small fraction of that which had already taken place. Over and above that, the knowledge of the previous movement makes it easier to discover its cause and thus to solve the problem of underpinning.

The advantage to be gained by the builders from observations of settlement are so clear that the technical inspectors should be expected to undertake such observations in the interests of their employers.

After several year's experience in settlement observations, the contractor and the trained engineer attain useful knowledge which will enable them to estimate the amount by which a new structure is liable to settle. The empirical considerations are of particular value in cases where, for example, one part of a new structure is to be built on thick sand and the other on stiff clay. If the engineer only knows from experience that in neither a complete foundation on sand nor one on clay has structural damage occured, there is always the possibility in the case of a new structure that differences in settlement amounting to several centimeters will occur in the intermediate region.

The observation of the completed structure is particularly important to building contractors who use "special piles". The statement that foundations built according to special methods will not sink has been believed by no one for several years and the man with greater experience has an advantage over his competitors. Increasing insight into the amount, the extent and the general progress of the phenomena of settlement, rather than assurances of numerical data, will be required.

Finally, the community itself will gain from observations of the phenomena of settlement. Every year, in every country, a lot of capital is wasted because of insufficient or very expensive underpinning. The official regulations, which are intended to guard against such waste and guarantee the firmness of foundations, are inadequate in comparison to those relating to the construction of high buildings and bridges. One of the most important properties of many foundations, namely, that the increase in changes due to settlement takes place over a period of four decades at an almost uniform rate of progress, was only discovered in the last few years! The same is true of settlement which takes place in the first few months or years after the load is applied. In order to make research on soil mechanics of use to the construction industry and provide the basis for improvement in regulations concerning excavation, it is necessary at least in urban areas and in the construction of highways in the provinces, to have a clear picture of the extent and the course in relation to time of settlement. Theory alone does not permit us to close the wide gaps in our knowledge to any satisfactory degree.

The above information shows that parties engaged in construction work can make valuable and widespread use of the results of careful settlement observations. The greatest value is to the builders. Yet it is these very builders who, because of their lack of scientific knowledge, are least willing to bear the cost of such observations. For an average high building with a floor space of 400 m^2, the cost, freely calculated, is somewhat as follows:

20 fixed points, delivery & insertion	40 RM
4 measurements before completion of the building and 6 measurements until equilibrium is achieved, including 10 day's work on the part of a technical assistant @ 10 RM	100 RM
Compilation of the results, 6 days @10	60 RM
Total	200 RM.

The cost therefore amounts to, at most, 50 pf. per m^2 of the area. The results of the observations assure the builders of a valuable document in the event of future lawsuits over damage to his property on the part of neighbours and in the event of proposed structural changes. The community obtains data of incalculable value for the setting up of regulations concerning the foundations of high buildings in the urban area. Consequently it would be justifiable for the community to levy a small tax of about 50 pf./m^2 of area on every new building in conjunction with the building permit and, with the proceeds, to employ some assistants for the exclusive purpose of making settlement observations.

Reference

1. Terzaghi, "The bearing capacity of pile foundations", Bautechn. 1930, no. 31 and 34.

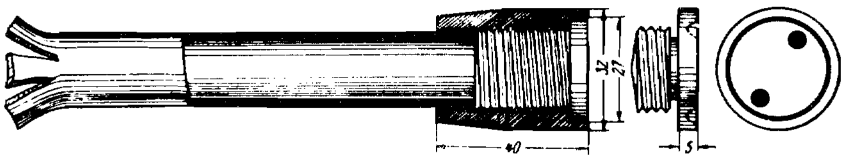


Fig. 1

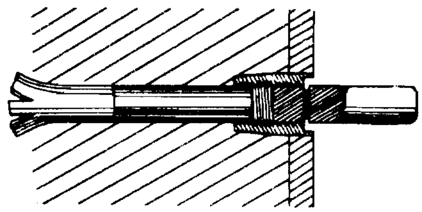


Fig. 2

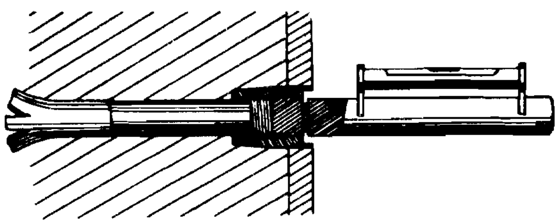
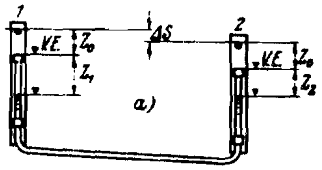


Fig. 3

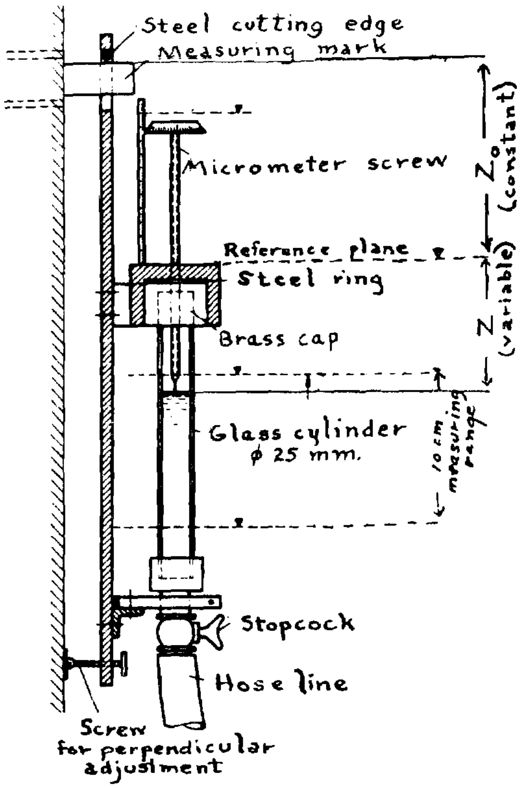


Z_0 constant

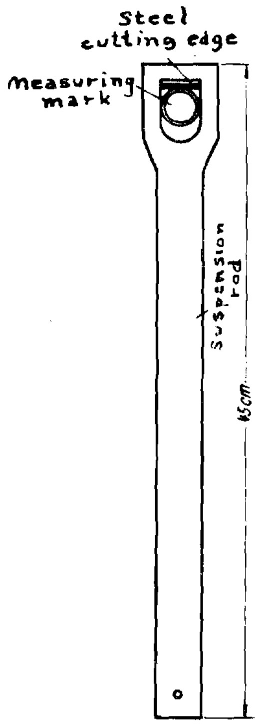
Z_1, Z_2 measured

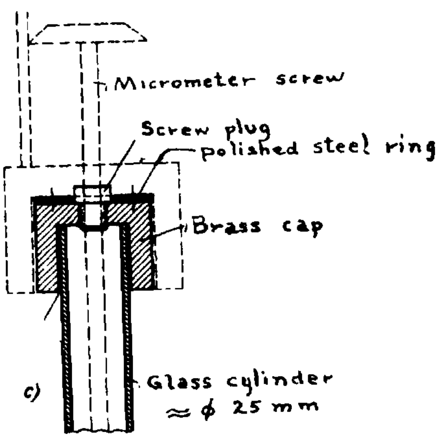
$\Delta S = Z_1 - Z_2$

(difference in height
between points 1 and 2)



b)





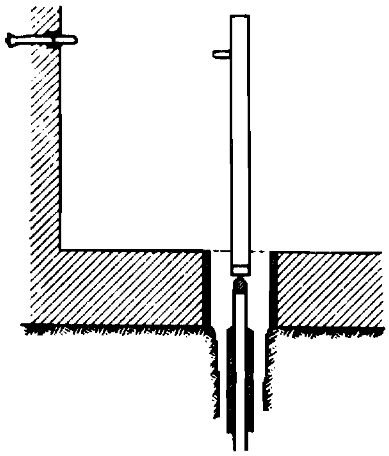


Fig. 5

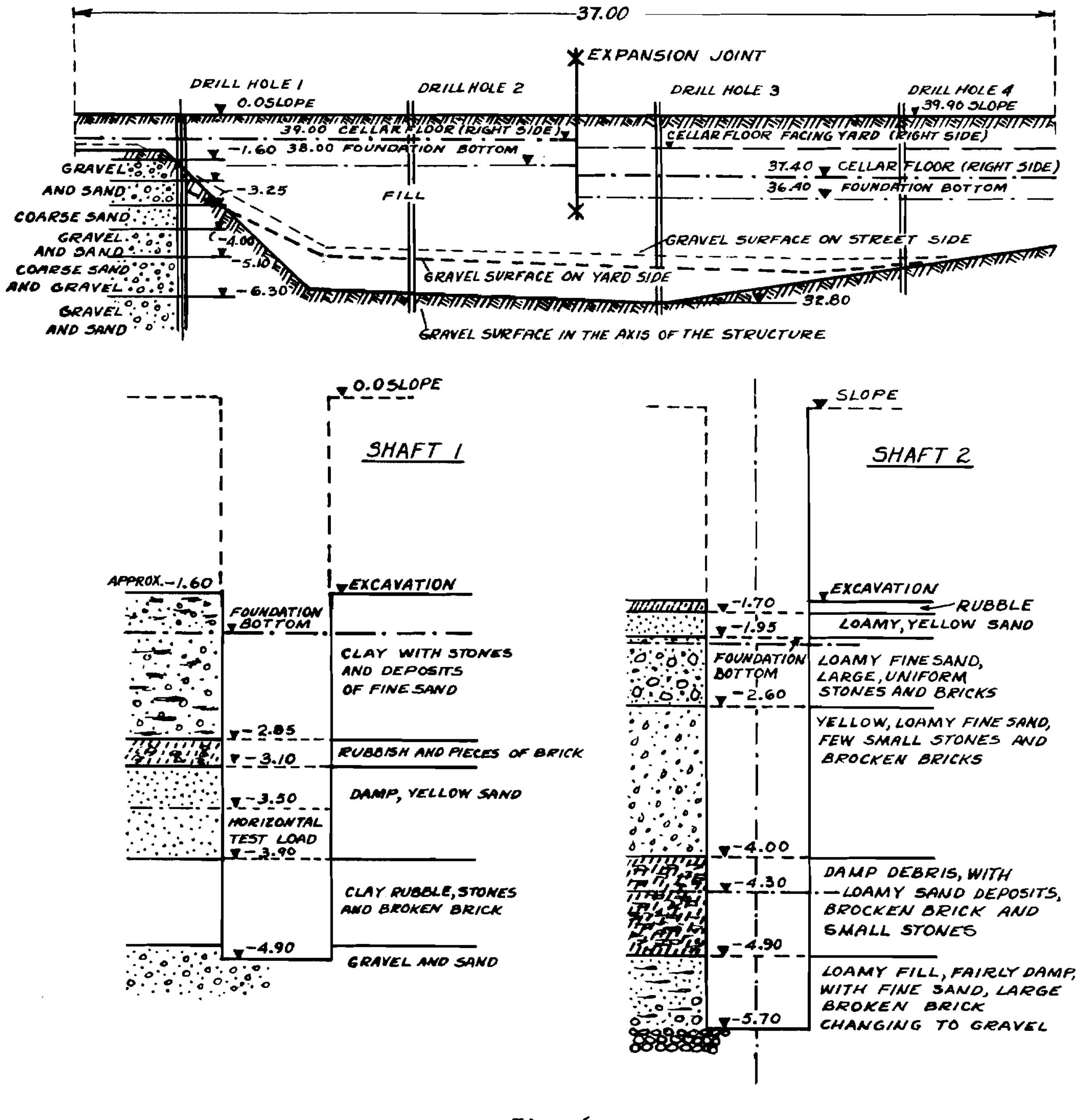

37.00
EXPANSION JOINT
DRILL HOLE 1
0.0 SLOPE
DRILL HOLE 2
DRILL HOLE 3
DRILL HOLE 4
39.90 SLOPE
39.00 CELLAR FLOOR (RIGHT SIDE)
CELLAR FLOOR FACING YARD (RIGHT SIDE)
-1.60 38.00 FOUNDATION BOTTOM
37.40 CELLAR FLOOR (RIGHT SIDE)
36.40 FOUNDATION BOTTOM
GRAVEL AND SAND
COARSE SAND
GRAVEL AND SAND
COARSE SAND AND GRAVEL
GRAVEL AND SAND
-3.25
-4.00
-5.10
-6.30
FILL
GRAVEL SURFACE ON STREET SIDE
GRAVEL SURFACE ON YARD SIDE
32.80
GRAVEL SURFACE IN THE AXIS OF THE STRUCTURE
0.0 SLOPE
SHAFT 1
APPROX. -1.60
EXCAVATION
FOUNDATION BOTTOM
CLAY WITH STONES AND DEPOSITS OF FINE SAND
-2.85
RUBBISH AND PIECES OF BRICK
-3.10
-3.50
DAMP, YELLOW SAND
HORIZONTAL TEST LOAD
-3.90
CLAY RUBBLE, STONES AND BROKEN BRICK
-4.90
GRAVEL AND SAND
SLOPE
SHAFT 2
EXCAVATION
-1.70
RUBBLE
-1.95
LOAMY, YELLOW SAND
FOUNDATION BOTTOM
LOAMY FINE SAND, LARGE, UNIFORM STONES AND BRICKS
-2.60
YELLOW, LOAMY FINE SAND, FEW SMALL STONES AND BROCKEN BRICKS
-4.00
DAMP DEBRIS, WITH LOAMY SAND DEPOSITS, BROCKEN BRICK AND SMALL STONES
-4.30
-4.90
LOAMY FILL, FAIRLY DAMP, WITH FINE SAND, LARGE BROKEN BRICK CHANGING TO GRAVEL
-5.70

Fig. 6

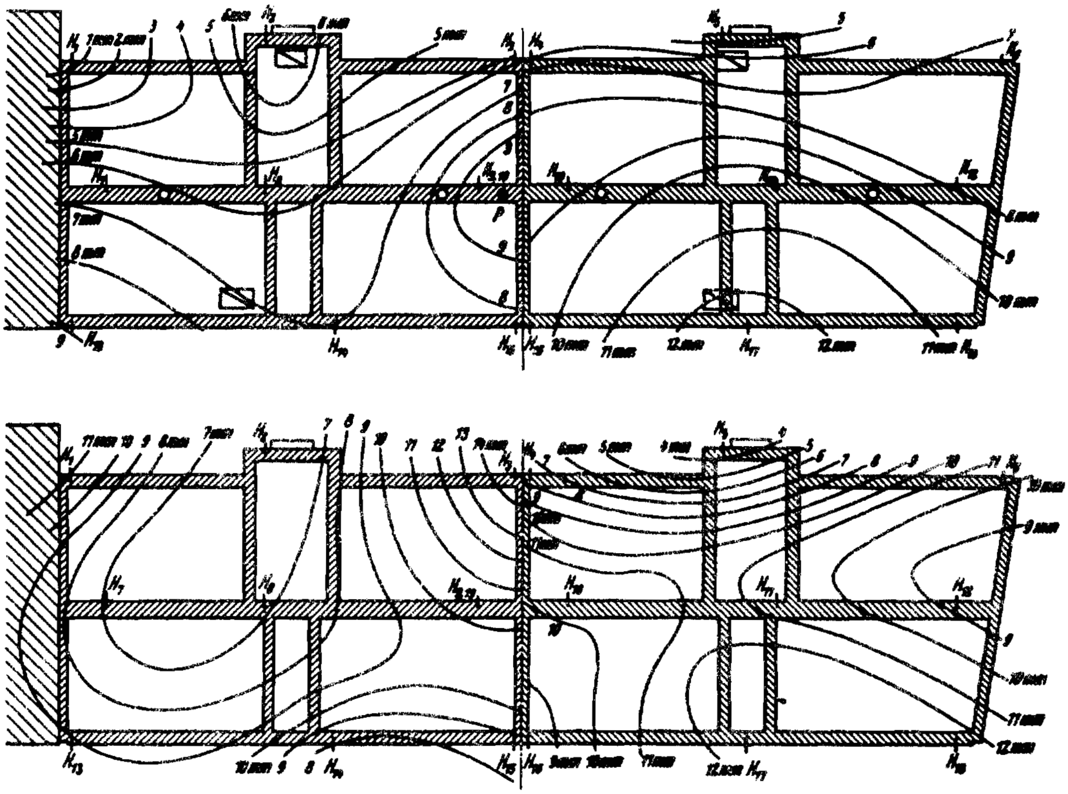


Fig. 7a and b.

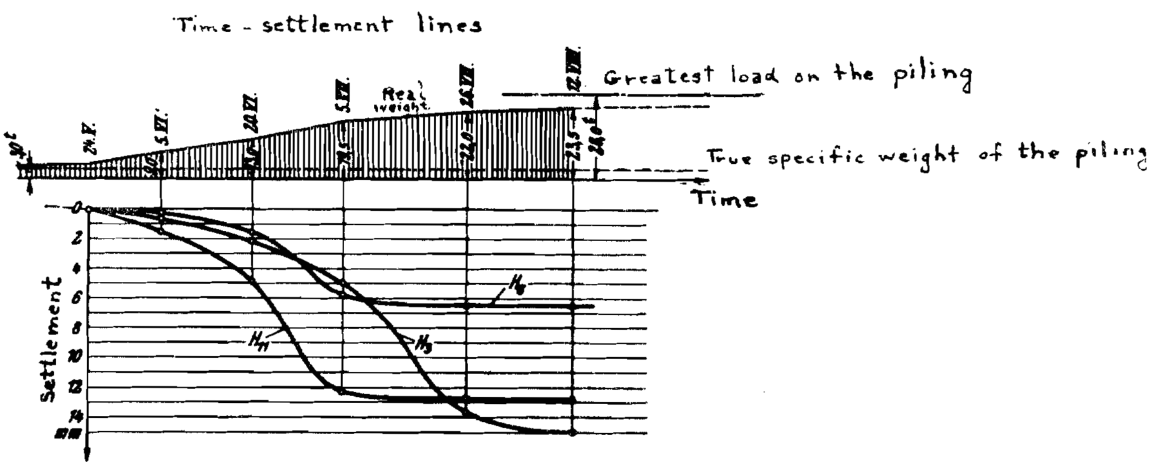


Fig. 8.

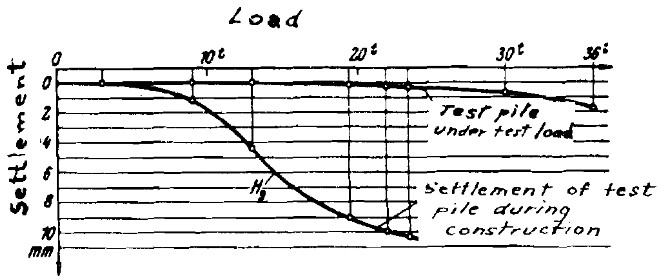

Load
0
10t
20t
30t
36t
Settlement
0
2
4
6
8
10
mm
Test pile under test load
Settlement of test pile during construction

Fig. 9.

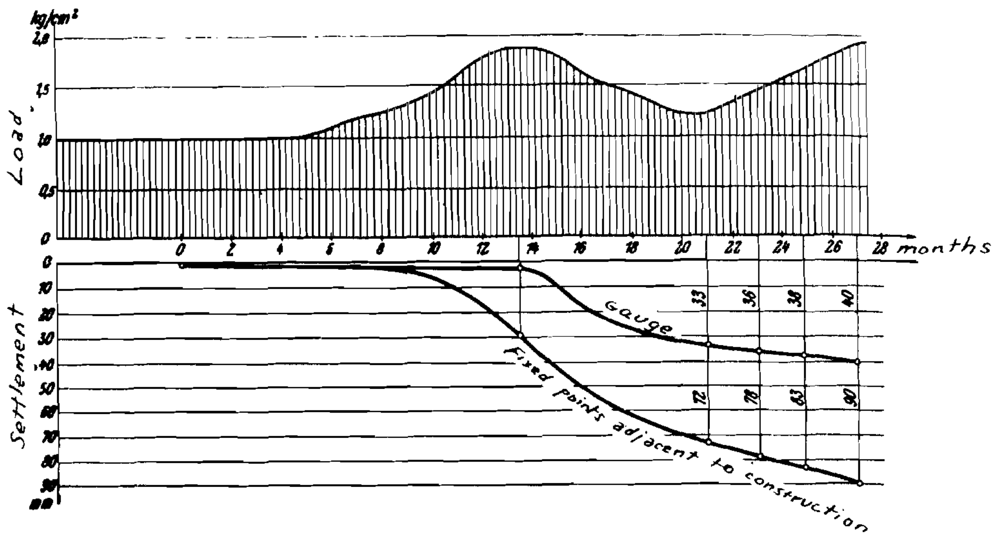

kg/cm²
2,0
1,5
1,0
0,5
0
Load
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
months
Settlement
0
10
20
30
40
50
60
70
80
90
mm
Gauge
33
36
38
40
72
78
83
90
Fixed points adjacent to construction

Fig. 10.