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SETTLING OF STRUCTURES ON THAWING GROUND

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SETTLING OF STRUCTURES ON THAWING GROUND

Stroitel'naya Promyshlennost' (Construction Industry), 19 (7-8), Stroyizdat Narkomstroya, July-August 1941, pp 27-29

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During construction on permafrost (under the conditions of the possible thawing of the latter), the question concerning the amount of forthcoming settlings has unique significance. An estimation of these settlings can be made on the basis of experiments with hot punches. Let us examine a procedure for testing with punches, recommended by N.A. Tsytovich ([Note]: Collection of Instructions issued by KOVM of Academy of Sciences on studying frozen soils, 1938; Tsytovich and Sumgin, Osnovy Mekhaniki Merzlykh Gruntov (Fundamentals of Frozen Soil Mechanics)).

According to this technique, the soil's thawing is envisaged by means of heating the water poured into a test borehole for a depth of 20-30 cm above a sandy filling (20-30 cm) which covers the borehole bottom after the placement of the punch. Heating the water begins after loading the punch with the planned weight. Thawing continues until stabilization of the settlings. If with the load adopted, abatement of settlings does not occur (in this connection, neither the depth nor the thawing pattern by depth are stipulated), it follows that (as N.A. Tsytovich points out), the load used during the test can not be adopted as the permissible load and in this case, a repetition of the test in other bore pits is recommended. For revealing the minimal amount of load at which settlings not attenuating through time will occur, it is recommended that tests be repeated in various bore pits at varying amount of load. In the book by Tsytovich and Sumgin, it is stated further:

"In combination with other data, the results of tests conducted on frozen soil with a trial load on thawing provides the possibility of choosing the value for permissible compression stress for the thawing soil. This value can be obtained by dividing the minimal critical load (limit load) by the corresponding safety factor, which can be assumed to lie in the range from 1.25 to 2.0, depending on the rigidity of the structure which is being erected."

For the following reasons, such a conclusion can in no way be recognized as adequately justified.

In the first place, the technique recommended by Tsytovich for conducting the tests suffers from a number of defects and does not provide the possibility of properly establishing that "minimal critical (limit) load" which the author has in mind. For instance, we can stress the following aspects:

a) The presence of water in a bore pit necessarily affects the soil's physical properties;

b) We recommend conducting the soil's thawing until complete attenuation of the punch's settlings; moreover, a depth minimum and degree of thawing intensity are not specified. At gradual thawing, the minimum caused in the increase of subsidences through time can set in at any thawing depth and any load but this will still not indicate anything about the value for the bearing capacity and settling tendency of soil during its thawing under a structure.

c) The recommendation to conduct the thawing to the point "when for the same time periods, we find the same increments in settlings" also fails to provide the possibility of making any conclusions since the situation caused by N.A. Tsytovich could be the result of the soil's thawing rates rather than of its properties.

d) We recommend constructing the settling curve as a function of time. However, in case of continuously thawing soil, such a curve does not provide anything for evaluating its bearing capacities, since the pattern of settlings will depend more on the thawing intensity than on the bearing capacities and the amount of the load.

In the second place, it would have been incorrect to solve the question about the permissible load by the application of just one "safety factor" because frozen soils (and the permafrost soils in particular) often occur in a "heaved" state. In our opinion, by "heaved" soils, we should connote the soils in which the skeletal particles have been separated by ice crystals and pockets. At the thawing of the "heaved" soil, its skeletal particles acquire the possibility of merging, and the soil (not even being loaded) but only under the effect of its own weight, decreases in volume, i.e. it settles. If such a soil, already having experienced its "thawing subsidence", is burdened with an external load, it will develop an additional settling, "compression settling", the value of which will depend on the amount of load applied. Having lowered the load on the soil, we will reduce the "compression settling". Such a lowering may not be reflected (or may be reflected quite weakly) on the actual value of "thawing subsidence"; at the same time, the value can often be quite appreciable and can surpass the "compression settling" in the presence of even significant loads. Under such conditions, the assumed "safety factor" does not avoid inadmissible settlings and does not save the structure from intolerable stresses.

We suggest another method of tests, the basic tenets of which can be described as follows. A punch (Fig. 1) is placed in a bore pit at the marker corresponding to the footing of the foundation which is being planned. The punch's heating is accomplished with steam, electricity, etc. To intensify the thawing, on the pit's bottom we place the coil of a steam-conducting pipe and some heat-insulating material. Thawing is achieved under a load somewhat less than that planned (in the event that the latter proves excessive for the soil in question).

It is necessary to monitor the progress of the soil's melting. Thawing depth and settling of punch are determined simultaneously.

When the thawing has been brought to a depth of at least twice the width of the punch, the steam flow is shut off; however, the load on the punch is maintained until stabilization of settlements and thawing depth.

The punch is then subjected to an additional load by steps of 0.25-0.5 kg/cm^2 each; the subsidences are stabilized at each step. The load is brought to the critical point, i.e. after completion of thawing, the experiment is conducted according to the procedure adopted for thawed soils. Unloading is also accomplished by stages of 0.5-1.0 kg/cm^2 each based on the same technique.

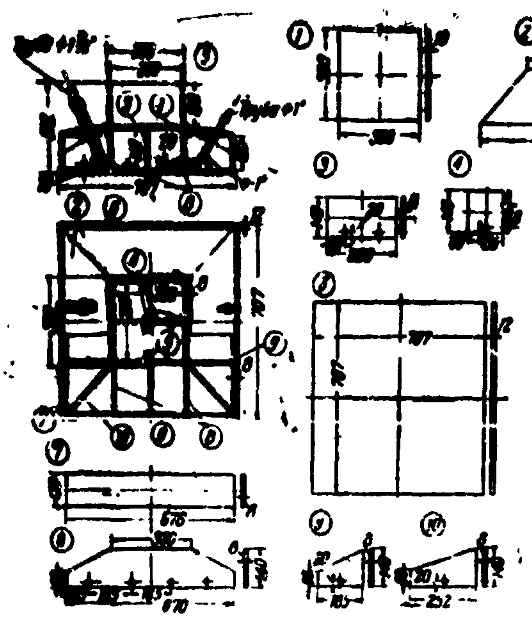

Fig. 1. Punch for Determining the Settlings of Structures: 1 - plate measuring 320 X 320 X 10; 2 - lid; 3 and 4 - internal ribs; 5 and 7- side plate; 6 - plate measuring 707 X 707 X 12; 8 - longitudinal ribs; 9 - external ribs; and 10 - angular rib. Key: a. Pipe 1 1/2" in diameter; and b. Pipe 1" in diameter.

Observations of the frost level are also continued after the cessation of thawing because it is necessary to strive toward the condition that the frost level would not have changed at additional load. To counteract the increase in freezing under the effect of the cold in the lower layers, we can use a slight brief admission of steam.

The entire experiment is continued for about 3 weeks.

Based on the test results, we have drawn a graph reflecting the punch's settlings depending on depth of soil's thawing beneath it (Fig. 2 -- curve OAB) and a curve showing the punch's settlings depending on the amount of additional loads (after thawing) (Fig. 3—curve AБДГ). These two curves provide the possibility not only of judging the degree of settling tendency of the tested frozen soil on thawing under load but also of computing the value of possible future settlings, depending on depth of soil's thawing and on amount of load.

In the technical literature, only one method has been suggested for estimating the settlements of structures on thawing soils, based on data from an experiment involving the heating of punches—this is the "equivalent layer" method in the above-cited report by Tsytovich and Sumgin. In our view, however, it does not appear possible to employ this technique in the form in which it has been discussed.

The equivalent layer method assumes the presence of two conditions: a) constancy of the compressibility factor throughout the entire compression zone and b) the existence of direct proportionality between stresses in the soil and its deformations. However, in the case of frozen soils, neither one nor the other is customary, as clearly follows from a consideration of the property of heaved soils capable of developing settlings even in the absence of a load.

Then the actual pattern of the compression of soil layers within the compression zone's limit occurs (in the case of frozen soil's thawing beneath a structure) under quite different conditions than in the case of thawed soils.

The thawing of frozen ground under a structure proceeds gradually, layer by layer. Each newly thawed layer quickly (we might say instantaneously) becomes compressed by the load from the structure and the soil's own weight. The pressing seemingly occurs without the possibility of lateral expansion for the thawed layer since the first thawed layer (it can be conceived as arbitrarily thin) will be located between the rigid foundation and the underlying unthawed ground, which also can be regarded as incompressible rock. The subsequent thawing layers will exist under similar conditions since from beneath, they will have the same unthawed ground, while above they will have the recently thawed layers but which have already become compressed without a chance for lateral expansion; these recently thawed layers can also be considered incompressible in relation to the newly thawed layer. We should invariably have such a circumstance whenever a layer's thawing proceeds more gradually than its compression, which in most cases will be in effect.

It is quite apparent that such a pattern in the compression of soil beneath the foundations does not correspond in any way to the assumptions lying at the basis of the calculations according to the equivalent layer method. This also compels us to recognize the inapplicability of the technique to the frozen soils thawing under a structure.

On the basis of the data obtained from the experiment with a hot punch, we suggest the following method for estimating the settlings ([Note]: The method of estimating the settlings based on data from laboratory tests with frozen soil samples has been discussed by the author in the articles in Stroitel'naya Promyshlennost', No. 3, 1940 and in Byulleten' Soyuztransproyekt for December, 1939).

In Fig. 2, we have shown curve OAБ for settling of a hot punch; this curve was derived during the testing conducted in 1938 by the author at one of the construction sites. The punch's dimensions were: 70.7 X 70.7 = 5,000 cm^2.

All the additional inferences follow from the assumption of the soil's uniformity by depth of foundation laying; this can be verified by geologic cuttings and by laboratory analysis of the soils' physico-mechanical properties.

As is evident from Fig. 2, on thawing to a 10 cm depth, a punch with an area of 5,000 cm^2 yielded a subsidence of 0.75 cm; this provides a compression value $\Delta H/H = 0.75/10 = 0.075$ (below 10 cm, the unthawed ground consists of incompressible rock).

A foundation similar to our punch but with dimensions of sides n times larger, on thawing for the same depth of 10 cm under the same amount of load, yields the same settlement of 0.75 cm, since the degree of stresses under the foundation in the 10 cm layer under consideration will differ little from the stresses under the punch. With adequate justification, we can assume that the amount of this stress under our foundation will also retain its significance for depths greater than 10 cm, namely to a depth of 10 X n.

For example, if we take a foundation with sides 70.7 X 2 = 141.4 cm, i.e. if we assume n = 2, we can postulate that the stress under consideration will be retained to a depth of 10 X 2 = 20 cm and therefore the settlement of our foundation on thawing to a 20 cm depth can be assumed to equal 0.75 X 2 = 1.5 cm.

In Fig. 2, the graph for the settlements of a foundation measuring 141.4 X X 141.4 has been portrayed in the form of curve OABΓ, while settling at thawing depth of 20 cm has been indicated by segment OAB, twice as large as segment OA, depicting the punch's settling at thawing depth of 10 cm.

At thawing of frozen ground under the experimental punch from 10 to 20 cm, the latter developed the settling indicated by curve OAБ in the form of segment Aa.

The stresses which were acting in this case in the newly thawed layer with a depth of 10–20 cm will be in effect under a foundation measuring 141.4 X 141.4 cm in a lyer 20–40 cm deep. Therefore the segment of the curve for the foundation's settlings corresponding to this layer will be portrayed by segment Bб, parallel to segment Aa_1.

In the same manner, we have drawn curve OДE for a foundation measuring 212.1 X 212.1 cm.

Proceeding further by the same approach, drawing straight segments parallel to the segments of the curve for the experimental punch's settlings, we construct curve OABΓ, yielding the settlings of our foundation for any depth of thawing under the same individual load (in kg/cm^2) which the stamp had in the process of the frozen ground's thawing under it (the stamp).

In the case of rectangular or circular foundations, the calculation should be conducted as for a square foundation which is equivalent in area.

The question will still remain of how to determine a foundation's settlement if the stress under its base exceeds somewhat the stress which existed during the experiment when thawing was under way. Such a question is inevitable since the final load on a foundation is established after the test rather than prior to it.

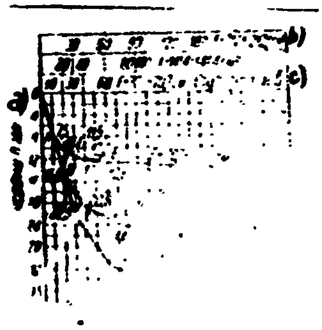

Fig. 2. Curves Depicting the Punch's Settlings Depending on Depth of the Soil's Thawing Under Punch (the chain line depicts the assumed pattern of settlings under punch and foundations beyond the limits of the test data). Key: a. Settlings, mm; b. cm^2 etc.; and c. Depth of thawing.

We have depicted in Fig. 3 the curve OAБBΓ for the dependence of the punch's settling on the load value for the same experiment which has been reviewed above. Segment OA portrays the punch's settlement under an initial load of 2.0 kg/cm^2 at the end of the process of thawing under it and at the moment of stabilization of settlings and thawing depths. Segments AБ, БB and BΓ reflect the punch's settlings at individual load stages after completion of thawing.

In this manner, settling along segment OA includes the "thawing subsidence" and the "compression settling" under pressure $\sigma = 2.0$ kg/cm^2. However, segments AБ, БB and BΓ include only the "compression settling" of the already thawed soil and of the slightly compressed soil (at $\sigma = 2.0$ kg/cm^2).

Based on the graph (Fig. 3), we can assume that the compressibility modulus of soil having thawed under a load of 2 kg/cm^2, for pressures greater than 2 kg/cm^2 (at least from 2-4 kg/cm^2) can be considered constant and therefore at this stage of the experiment and calculations, full use can be made of the procedures employed for thawed soils.

Thawing prior to an additional load can be conducted:

a) in the entire compression zone under the stamp, i.e. of the order of about three widths of the punch; and

b) in a certain part of the compression zone insufficient for applying the equations derived under the assumption of an unlimited compression zone.

For the first case, in computing the foundation's settlements, we can proceed from the Schleicher formula $s = \frac{\omega p \sqrt{F}}{C}$. Here we signify by s the differences in settlings while p the corresponding differences in loads, i.e. for our case, we will utilize this equation in the following form:

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where $(\sigma - 2.0)$ kg/cm^2 the additional load exceeding 2.0 kg/cm^2 at which the soil's thawing was conducted, while Δs the additional settling corresponding to an increase in load from 2.0 kg/cm^2 to σ.

From the equation mentioned, we can derive the value C' for any value of $\sigma > 2$ kg/cm² and hence any value of deformation modulus E; as desired, we can construct a compression curve for pressures greater than 2.0 kg/cm² for our soil after its thawing under a load of 2.0 kg/cm².

Having determined the modulus of elasticity E, we can compute the value of additional "compression settling" for pressure above 2.0 kg/cm² (in the limits of the pressure which had existed during the experiment) for any thawing depth as well.

For this purpose, we will utilize the equation

$$s = pb/2E \ (K + 0.5 \ K_y),$$

suggested by Engineer Pol'shin for the final settlings of a layer with finite depth, supported by an incompressible soil. For our case, this equation can be written in the following form:

$$\Delta s = \frac{(\sigma - 2.0) \ b}{2E} \ (K + 0.5K_y)$$

where σ is given, b equals the half-width of the foundation, K and K_y are taken from the equation suggested for them by Engineer Pol'shin or based on the tables, and depend on the ratio of the rectangular punch's sides a:b (a is the longer side; for a square, a:b 1) and in addition to this, K and K_y depend on value z/b (z -- thawing depth).

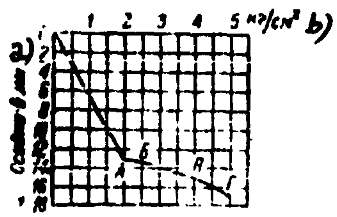

Fig. 3. Curve Indicating a Punch's Settlings Depending on Amount of Additional Loads. Key: a. Settlings, mm; and b. kg/cm².

Adding the calculated value Δs of additional settling to the total settling determined for thawing under an initial pressure (equalling 2.0 kg/cm² in our case also), we obtain the overall settlement of a foundation under the design load.

It now remains for us to consider a case when the soil's thawing under an experimental punch is considerably less than the compression zone and it does not appear feasible to utilize the Schleicher equation. Under these conditions, for determining the E-value we can utilize the test data (based on additional loads after thawing), resorting once again to Pol'shin's formula:

$$\Delta s \quad \frac{(\sigma - 2.0) \ b}{2E} \ (K + 0.5 \ K_y).$$

Here all the values except E are obtained from the experiment with the punch. Having determined E, based on the same formula we can then find the value for the additional settlement of any foundation (i.e. for any b- and z-values); as indicated above, after this we determine its total subsidence.

In this manner, the technique which we have offered for conducting the experiments provides the opportunity of utilizing their results not only for a qualitative evaluation of the soil from the standpoint of its behavior beneath a structure during the thawing process but also for an approximation of the settlements possible at this time for any loads and for any thawing depth with an accuracy which presumably is close to that obtained with thawed soils.

The amount of subsidences is given in dependence on the thawing depth starting with its very initial values: from the builder's standpoint, this is uniquely important and interesting.

For a determination of settlings through time, one must be able to calculate the thawing pattern through time but this is a problem within the scope of heat engineering calculations.