SECTION VI

FOUNDATION PRESSURE AND SETTLEMENTS OF BUILDINGS ON FOOTINGS AND RAFTS

GENERAL REPORT

A. CAQUOT (France)

We recall that this section includes four sub-sections:

a) measurement of settlements and comparison with theory,
b) measurement of stress distribution in the contact face.
c) influence of ground water.
d) special problems in foundation engineering.

Sub-sections a) and d) have inspired the largest number of communications, 24 for sub-section a) and 15 for sub-section d), whereas only one communication for b) and three for c) have been submitted.

Sub-section a): MEASUREMENT OF SETTLEMENTS AND COMPARISON WITH THEORY.

A large number of communications reveal a fair measure of agreement between computed and observed settlements.

Such is the case, particularly, for settlements of the following works:

- Railway Bridge across the Maas, near Venlo. Analysed by Mr. de Nie (Holland).
- Viaduct of the Arnhem-Zutphen railway. Described by the same author.
- Waterloo Bridge, London,. Analysed by L. F. Cooling (G.B.)
- Buildings in São Paolo. By Sen. Milton Vargas (Brazil)
- Buildings in the Texas Gulf Coast area. By Messrs. Raymond F. Dawson and W.E. Simpson (U.S.A.)
- Pier of a Bridge on the Rhone. By MM. Mayer, Levi and L'Heriteau (France)

Very classical methods were used for the measurement of the physical characteristics of the soil and for the calculation of consolidation. Several authors dwell on the precautions that should be taken when transporting samples. Mr. de Nie (Holland), in particular, gives an account of the settlement of a bridge abutment whre the previous calculations differ from observed settlement to a very considerable extent: he attributs this to the fact the samples taken has been disturbed during transit.

For the calculation of consolidation settlement, where it is given in detail, the authors accept, for existing stresses the distribution existing in a homogeneous and isotropic mass, that deforms in accordance to Hooke's law, when loaded by forces that act normally to its plane surface.

Mr. Ralph E. Fadum discusses, in a very interesting paper, the validity of all assumptions pertaining to stress analyses for settlement computation purposes.

All the hypotheses recalled in the above mentioned papers, and also that according to which the structure producing the load is assumed to be relatively flexible in comparison with the soil providing its support, are made so that mathematical solutions that have been developed from the theory of elasticity, may be applied to the problem of stress analysis.

Mr. Fadum concluded that from these simplifications it follows that:

1) the observed settlements vary in magnitude from a value equal to that computed to a value equal to approximately one half of that computed for corresponding points,
2) the location at which the observed settlement is approximately equal to the computed settlement is at the point where the minimum settlement was observed to have occurred, while the location at which the observed settlement is equal to approximately one half of the computed settlement is at the point where the maximum settlement was observed to have occurred.

He also noted that the settlements computed from Westergaard's solution, using an assumed value of Poisson's ratio equal to zero, showed in general a somewhat better, though not a significantly better, agreement with the corresponding observed settlements than did the settlements as computed from Boussinesq's solution.

Implicitly or explicitly, it is with these imperfections of stress analysis in mind, that three authors have developed settlement prevision with the help of observed settlement data.

This is the case for:

- Messrs. Geers and van Mierlo (Holland) who give an estimation of future settlements of the dikes of the North East Polder (Holland), based on observation of past settlements.
- Messrs. Van Mierlo and den Breeje (Holland) in their study of the Spangen Polder near Rotterdam, who use a compromise between Terzaghi's classical theory of consolidation and Koppejan's theory.
- Sen. A.J. Costa Nunes (Brazil), for a metallic reservoir foundation built on a reinforced concrete slab. In this very interesting article the author deduces, from observations of settlements. the characteristic coefficients of elastic stresses, the elasticity coefficient of the foundation concrete, then inversely, he deduces the settlements in terms of the further loads that it will have to bear.

Four authors have more especially studied the case of settlements produced by structures with a somewhat variable live load. They are:

- Mr. L.F. Cooling who has observed the settlement of four grain silos. He finds a difference between the theoretical movement under a grain load and the measured movement. According to him, this result tends to confirm the suggestion put forward by Dr. Terzaghi that, particularly for buildings supported on a raft foundation at a depth of more than about 8 ft. below the ground surface, there exists a great resistance against lateral yield of the stratum which substantially reduces the elastic settlement.

- Mr. R.V. Allin (Persia) presents a stuay of loading tests in Persia and concludes that the main lesson to be learnt from these bearing tests is that in water laden soils of a soft, silty nature, it is extremely important to restrict the speed at which the load is brought to bear during construction.
- Messrs. O.K. Peck and R.B. Peck(U.S.A.) who also explain an anomaly in the settlement curve of a large water reservoir by the excessive loading speed.
- Mr. K. Fischer (Austria) who observes, for a bridge, an S shaped settlement curve which he puts down to the linear increase of the load during the erection of the building. This curve tends towards a limit value whreof the magnitude corresponds approximately to the mean value of the estimate.

Most of the authors find an upward movement of the foundation when it is unloaded.

Divers authors have attempted to give approximate formulae for a ready evaluation of settlements.

- Messrs. O.K. Peck and R.B. Peck, already mentioned above, see a relationship between compressibility and the liquid limit.
- M.E. de Beer (Belgium) deduces the coefficient of compressibility of in situ sands from the results of sounding tests.
- Mr. Curt Kollbrunner (Switzerland) who explains a simplified theory of consolidation due to Steinbrenner, which, according to the author, gives results of a satisfying degree of accuracy.
- M. Bendel (Switzerland) considers Hooke's law as a particular case of the so called general law of Bendel.
- Mr. Proctor (U.S.A.) approximately predicts the settlement of natural or compacted soils by applying certain percentages of soil consolidation.
- Mr. Arne Jeppesen's (Denmark) study on foundation problems of the piers of the 60m.high Little Belt Bridge, is interesting because it gives prominenece to the seasonal variations of settlement and tilting of its piles under the influence of the sun which displaces the point of application of the resultant of the forces.
- And finally, two other communications have a very particular aspect. That of M. von Moos (Switzerland) who explains the conditions of the big landslide at Zug in 1887, and that of Messrs. O.K. Peck and R.K. Peck on the settlement of the foundations of a structure; built for the servicing of steam locomotives, which was irreparably damaged by flooding due to washing.

SUB-SECTION b: MEASUREMENTS OF STRESS DISTRIBUTION IN THE CONTACT FACE.

The only communication received on this subject comes from M.E. de Beer (Belgium). It is entitled :
Tests for the determination of the distribution of soil reactions underneath beams resting on soil.

The author has measured, by a strain indicator, the stresses developed in the fibre of a loaded beam exerting pressure on the Rhine sand fill of a rigid container. He measures the coefficient of compressibility of this sand and comes to the conclusion that, of all the methods of computation, the method of the parabolic (2nd. degree) distribution of the stress under the beam gives results which best approach the tests results and he thinks that this is true whatever may be the rigidity of the beams.

SUB-SECTION c : INFLUENCE OF GROUND WATER.

In his communication "Influence of ground water level oscillation on subsidence of structures", M.Josef Jaky (Hungary) once more encounters the phenomenon of critical density.
He believes that the settling is connected with the difference between compactness and critical compactness by a parabolic law.

M. Bendel (Switzerland) has studied the influence of the variations in the surface of a lake on the rising and falling of the banks. He finds that the curves of equal variation run parallel to the shore and that the amplitude of the variations decrease with distance. He also gives a certain number of formulas which he considers as connecting (in terms of hydraulic gradient) the variations of soil level when the water level varies.

SUB-SECTION d) : SPECIAL PROBLEMS IN FOUNDATION ENGINEERING.

Only one communication, within the framework of this sub-section d), is of a general character. It is that of Messrs. Cooling and Ward (G.B.), entitled: Some examples of foundation movements due to causes other than structural loads.

In Great Britain, during the last five years, a very large number of examples of building damage due to foundation movement has been encountered in which the effect of the weight of the building on the ground is negligible. Broadly speaking, the damage arises from movement of the ground below the level of the foundations due to either climatic changes or the action of heat from industrial buildings.

The movements may be grouped as follows:-

(1) Natural Drying
Drying shrinkage of clays under structures founded at a shallow depth due to:-
(a) Seasonal changes in evaporation and reinfall.
(b) Transpiration of tress and shrubs.

(2) Artificial Drying
Drying shrinkage of clays under industrial buildings (brick kilns, boiler houses etc.) due to penetration of heat.

(3) Artificial Frost Heave
Frost heave under cold storage buildings due to penetration of frost.

The first subject: Natural Drying, has incidentally, been developed elsewhere under the heading of the foundations of houses, by Messrs. J.E. Jennings and Henkel (South Africa) and by Mr.J.W. Hunter (G.B.), Site Exploration for Foundations at Portsmouth, Mr. Adalbert Pogany, Deformation of brick works due to the sinking of foundations, and Messrs. Neumann and Polensky (Palestine). A problem of foundations on loamy soil in subtropical countries;.

The authors agree that the moisture variations of the upper layers cause changes in the volume of the clay. A general observation in respect of most of the cracked buildings is that they appear to crack by the apparent downward movement of the corners of the structure. In fact the absolute movements may, in general, be upwards owing to a dome shaped rise of the clay. The authors also agree that in order to avoid differential settlements, contacts between parts of the building, excluding of course footings, has to be avoided. Mm. Neumann and Polensky moreover, advocate a second method in the case where a layer with a constant volume is found not to be too deep: the whole clayey earth in the building area may be excavated to the depth of the footings and filled again with other material which is not subject to volume change if the water content changes.

Mr. J.W. Hunter shows clearly that the solution to adopt depends on the volume of the building and likewise, Messrs. Jennings and Henkel deplore that it should be a common practice to design elaborate reinforced footings without taking into consideration the elastic properties of the composite construction. M. Pogâny's paper is more especially concerned with the deformations which may occur in brick works, under these conditions.

The third subject given by Messrs. Cooling and Ward, frost influence, has been extensively developed in the communications of Mr. R.M. Hardy (Canada), Foundation conditions in the Edmonton area, Mr. R.A. Hemstock, Engineering in perma frost in Canada's Mackenzie Valley; and Mr. Harry Carlson (U.S.A.), Stability of foundations on permanently frozen ground. Mr. Harry Carlson's studies are concerned with military installations built in Alaska. He arrives at the same general conclusions as the other two authors: "The use of piling and an air air space under heated structures appears at this time to be the most effective method of insuring the stability of such structures constructed on permanently frozen ground which loses bearing capacity upon thawing.

The Secretariat of the Congress (still in sub-section d) has received two communications on mining subsidence. The first, from Mr. K.W. Mautner (G.B.) is a general study of divers factors:

I Nature of the over-lying strata,
II Depth of the worked seam or seams,
III Thickness and slope (dip),
IV Method of working of the seams,
V Stowage of filling in the worked areas (dead wall), which influence the magnitude and manner of the subsidence.

The conclusions of this important work are recommended to the members of the Congress. The other communication comes from Mr. Felix Zalewski (Poland) who deals with a special case; that of a new electric power plant in Silesia that is to be built over mines and shews the necessity, if one is to get a true picture of the soil, of using the rotary boring method breaches due to the subsidence of the soil can be seen on the bored out sample.

Finally, a few other communications have been received under sub-section d :

- The strength of the foundations of pylons, by Société Intercommunale Belge d'Electricité.

From tests carried out, it would appear if one agrees with the author "That the theories, which are generally admitted in the mechanism of pulverulent soil do not correspond to reality". One would like to know the reasons for this conclusion to compare the test results with the previsions of the correct calculation based on the exact measurements of the different characteristics.

- A communication on some soil rupture and settlement problems in the construction of a lock at Dupel, by M.I. Marivoet (Belgium), in which the authors check stability and settlement conditions, and,
- A communication on problems in heavy waterfront construction, by Coxe and Stokes (U.S.A.)
  Both of interest from the point of view of the technique of Port Engineering.
- A description of foundations types for great buildings in São Paolo, by Sores, Rios and Silva (Brazil).
- Foundations for masts of Stevedore training ship; which is a very special subject.

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SUB-SECTION VI a

MEASUREMENTS OF SETTLEMENTS AND COMPARISON WITH THEORY

VI a 23

DISCUSSION

N. CARILLO (Mexico)

I am reporting on a late paper that was not included in the general report. It refers to the sinking of Mexico City. It is not the merit of the investigation presented in the paper, where a correlation of theory, soil testing and field observations is made by the speaker, that I want to emphasize; but rather, the remarkable settlement of the City of Mexico, where soil mechanics is a matter of primary importance. Certain districts have sunk over 13 feet in this century, five of these feet having occurred in the last 9 years. Some areas are now sinking at the rate of one millimeter a day, or more than an inch a month. Of course, the reason for this generalized and accelerated settlement is independent of the buildings loads; a park and our three century old cathedral are included in the rapidly settling areas. I will not describe now our City's bentonitic subsoil; Mr. J.A. Cuevas, a Mexican engineer, already presented a general description in the Proceedings of the First International Conference, in 1936. But I will choose at random some laboratory and field data, which we are collecting under the auspices of the Mexican Commission for the Promotion of Scientific Research. Void ratios greater than 12, compressibilities larger than 3 cm^2/kg and natural water contents of more than 500% are common in undisturbed samples.

Such large void ratios result in very small submerged unit weights of the soil, which artesian seepage practically balanced at the beginning of the Century. Important strata of our upper subsoil were thus actually weightless. Many buildings rest on piles 50 meters long, which carry the loads to the first important hard stratum found in the soft clay. These buildings are apparently rising because of the progressive consolidation of the upper clay bed.This induces negative skin friction in the piles, which thus carry excessive and irregular loads, producing tilting and cracking of the buildings. (I want to call your attention to the interesting paper by Mr. Manuel Gonzalez of Mexico, in these Proceedings). Also, because of the obvious irregularity of the settlements of the City, there is bending and cracking of the soil crust, with consequent catastrophic dangers for buildings, monuments, sewers and water supply lines.

The paper I am reporting shows that consolidation of the subsoil due to the progressive lowering of water pressure in the aquifers, which over 2000 sub-artesian wells are now exploiting, accounts for the order of magnitude of the sinking of Mexico City. Control of underground water pumping seems to be the only remedy.

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SUB-SECTION VI d

SPECIAL PROBLEMS IN FOUNDATION ENGINEERING

VI d 16

DISCUSSION

J.D. LEWIN (U.S.A.)

I would like to compliment Mr. Harry Carlson on his excellent paper VId 6 and the basic concepts of presentation the problem of foundations on permafrost.

I am sorry, however, that he was limited in space and did not show some illustrations which would bring into the focus the peculiarity of permafrost conditions.

There are several points I would like to touch:

First the question of heat transfer.This is of particular importance where the groundwater exists below the frozen surface under the building (fig. 1) (USED drawing).

Second, is the penetration of heat into permafrost layer below the footing of foundation. Fig. 2 (from Vasilief) illustrates what did happen to a powerhouse foundation built on piles about 10 m. long.

The third question, which has been hardly mentioned by the author, although well illu-

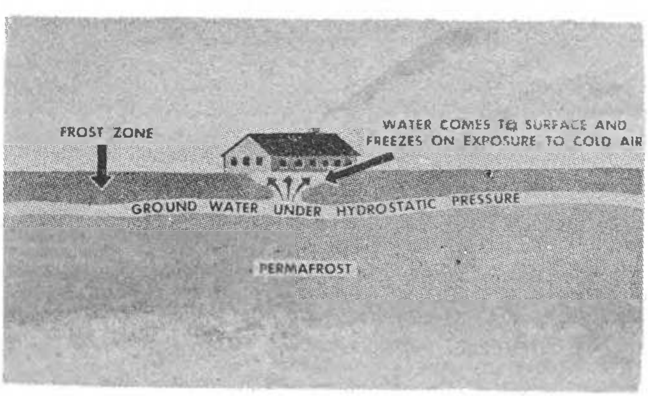

FIG. 1

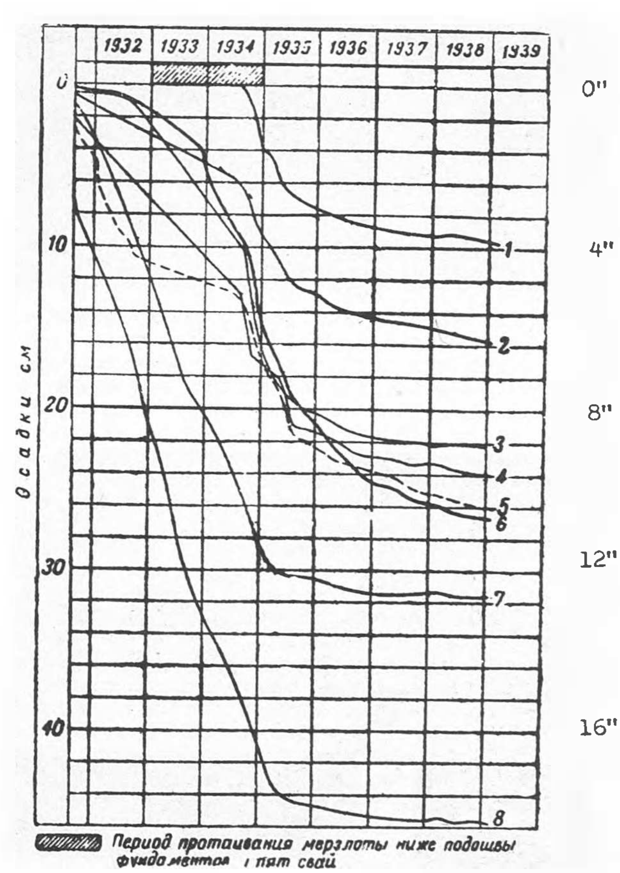

FIG. 2

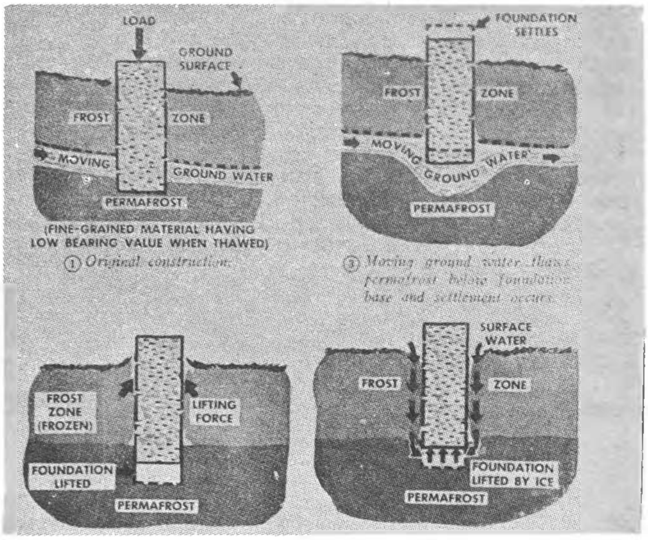

FIG. 3

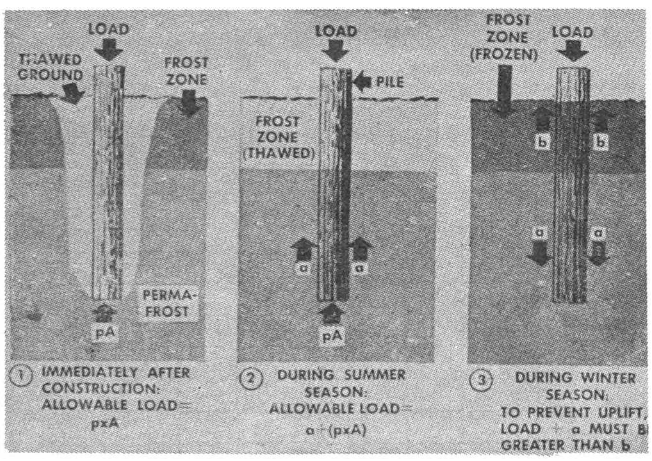

FIG. 4

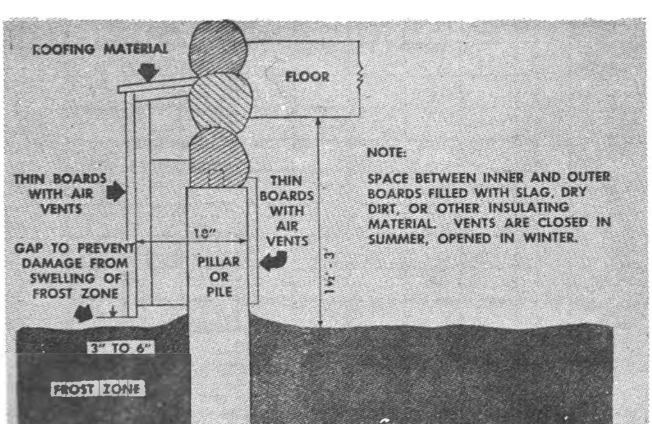

FIG. 5

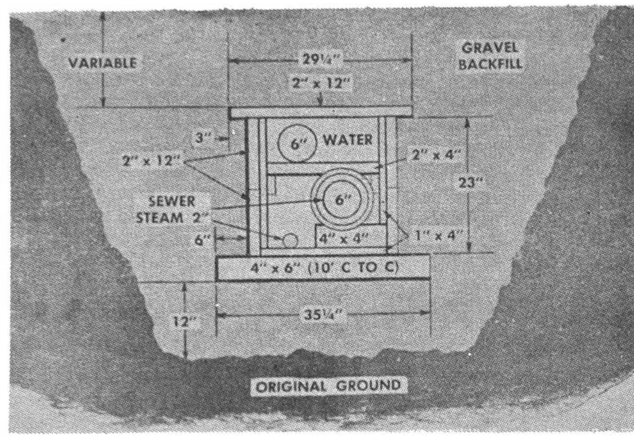

FIG. 6

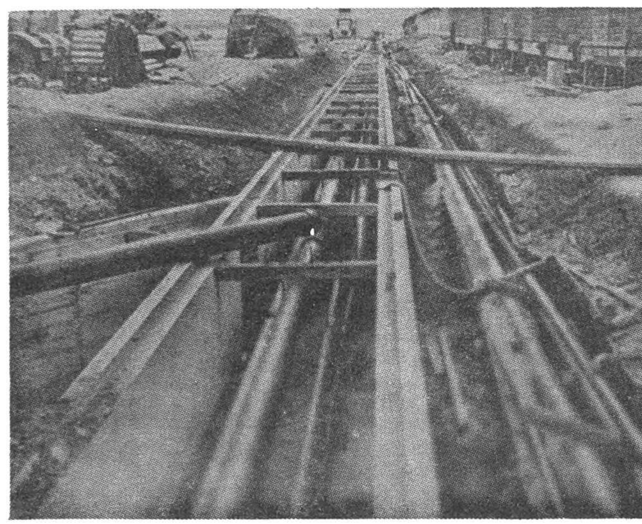

FIG. 7

FIG. 8

strated by the U.S. Engineers, fig. 3 is the interplay between the groundwater and the foundation.

Fourth question, (fig. 4) is that of piles. I think that the Army illustration based on Zytoviches drawing, shows very well the different forces acting on piles during the various seasons.

Fifth question (fig. 5) is that of aeration. All russian publications go into great detail of computations of ample aeration below the building floor. This army drawing is adaptation of three russian proposals.

Sixth question is that of conveying public utilities in permafrost area. Fig. 6 (an USED picture).

It must be realised that large areas of Canada, Alaska & Siberia cannot be properly developed until economic means are found to supply communities with water, sewers and other public utilities.

Attempts by the army to place such utilities in the permafrost ground have been in some cases disastrous. (Fig. 6 and 7) (USED).

Another method is to place utilities over the ground (fig. 8) (USED) which is considered as an uneconomical solution. I would like to leave the question open and would appreciate any suggestion in this direction.

Seventh and the last question is that of bridge abutments. I would like to call your attention to a frametype abutment developed by Prof. Vasilief, USSR, which permits a flex-

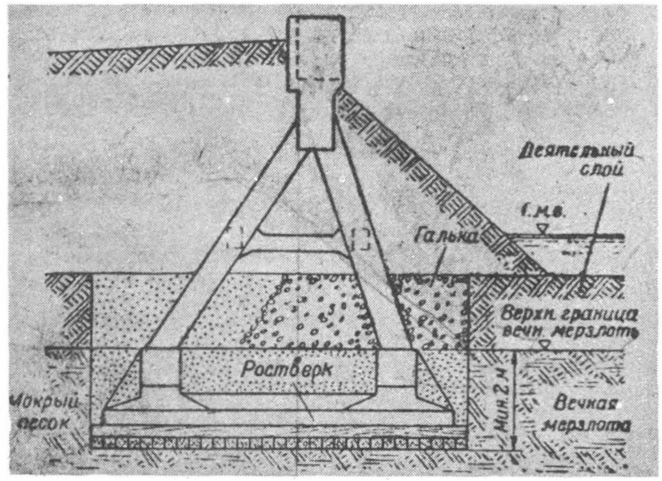

FIG. 9

ible structure, which conducts but little heat into the permafrost, and thus affords maintenance of ground in permanently frozen state (fig. 9). It also permits precasting of structural sections and their assembly into a structure even during severe climatic conditions.

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VI d 17

DISCUSSION

W.H. WARD (England)

Professor Caquot has very kindly taken the paper by my colleague Mr. Cooling and myself as a basis for discussion on special problems in foundation engineering.

I just want to take one part of the paper and go into one or two points in relation to the other papers presented by authors from several other countries, on the subject of swelling and shrinking of clays causing movements of small dwelling houses. It is impossible to get a general impression of the movements of these houses in the various climates without taking into account a large number of factors of climatic origin. Therefore we cannot expect that in every area on this earth the houses will go down at the corners or go up in the middle.

I just want to give one or two points, which I hope will help people to onderstand how the houses behave in different ways in different climates. In our rather humid country it is perhaps rather surprising that shrinkage movements give rise to the most important problems in the foundations of small houses. In England we have these heavy plastic clays and they are full of cracks and generally speaking in winter the water rises in the cracks and so the clay becomes fully saturated and even in the height of the nummer it is also more or less saturated. Where the surface is grass covered and I must emphasize this point, the surface moves up and down roughly two or three inches each year and at the same time the groundwater level moves up and down in a similar fashion. But in a more tropical climate the soil may be unsaturated to a considerable depth and the ground-water can be a long way down. Therefore, when you get rains concentrated over a short period, there will be different conditions. The rain is going to saturate the upper crust, which is going to swell up and therefore I suspect that the swelling movement is more important in tropical climates than the shrinking movements in England. The time of construction of the house in relation to the seasons is also important. If you build the house in, the height of the dry season, then when the ground water rises, the clay underneath the house has the opportunity of swelling. If the groundwater does not rise, as in some tropical countries, the subsequent rainfall of the house will cause swelling movements around the external walls.

Now there is another point which might help to explain some of the differences between cold and hot climates. In a hot climate the ground outside will be on the average warmer than the clay beneath the house. So there will be migration of water to the ceol surface underneath the building and you will get swelling at this point.

In addition there are many other factors which bring about differences in the movements of buildings founded on shrinkable soils in the different climates.

It would be extremely useful to all of us in the various countries to make systematic field observations of the movements of the buildings and of the ground at different depths. Moreover records should be kept of rainfall, run of wind, humidity, temperature, sunshine hours, distribution of vegetation, position and orientation of buildings, topography and groundwater level.

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CLOSING DISCUSSION

Prof. K. TERZAGHI (U.S.A.)

The contributions to sections VI and VII and Mr. Caquot's brilliant general report have shown that our knowledge of the performance of loaded raft and pile foundations has considerably increased during the last decade. Yet, two important phenomena are still beyond the scope of rational approach. These phenomena are the secondary time effects and the effect of driving piles into undisturbed clay on the compressibility of the clay.

The secondary time effect appears to be chiefly due to the high viscosity of the adsorbed layers of water which separate the soil particles from each other. On account of the viscous resistance against intergranular slippage the settlement due to consolidation is followed by another type of settlement which is not in accordance with the theory of consolidation.

All the existing theories of the secondary time effect are based on the assumption that the strata of clay acted upon by the weight of the superimposed structures are laterally confined. On this assumption the curves representing the relation between time and secondary settlement should be similar to those obtained by laboratory tests on confined clay specimens. In practice the loaded clay layers may be in any state intermediate between almost complete lateral confinement and no confinement at all. Therefore it is not surprising that the trend of the secondary settlement of full-sized structure is by no means always in accordance with theory.

If a loaded layer is incompletely confined or not confined at all, a considerable --if not the major--part of the secondary settlement is due to creep, involving a slow flow of the loaded clay in radial directions out of the loaded area. During the last few years I had an unusual opportunity to observe this type of movement. The load covered a strip of ground with a width of about 250 ft. It was located above a slightly precompressed clay stratum with a thickness of about 70 ft. As soon as the unit load became roughly equal to one half of the unconfined compressive strength of the clay, the clay located on both sides of the loaded strip started to flow in horizontal directions away from the loaded area. At a constant load the rate of outward movement was also constant.

Lateral spread of a loaded clay stratum is inevitably associated with a settlement of the surface of the loaded portion of the stratum. The rate of this settlement, like that of the spread, is constant at constant load whereas the rate of secondary settlement of confined layers of clay decreases conspicuously with time. The rate of the secondary settlement of several of the structures which I have had under observation remained practically constant over periods of several decades whereas that of the secondary settlement of others decreased rapidly. The existing theories account only for secondary settlement of the second type. Hence our methods for predicting secondary settlement cannot yet be trusted.

The second still unexplored phenomenon consists in the effect of driving piles into undisturbed clay on the compressibility of the clay located between the piles. A few years ago observations were made concerning the effect of pile driving on soft, glacial clay in Detroit, Michigan. The observers arrived at the conclusion that the compressibility of the clay located between the piles remained practically unaltered. Since the clay is already consolidated under the influence of its own weight, piles driven into such a clay carry no load other than the weight of the superimposed structure. By contrast, in Mexico City, it was noticed that the surface of the clay located between the piles settled gradually by several inches. Since the subsiding clay adheres to the surface of the piles, the pile is acted upon by "negative skin friction" which drags the pile down and forces its point deeper into the supporting stratum. The load on the point of such piles is equal to the sum of the load imposed upon the pile by the weight of the structure and another load which is almost equal to the full skin friction. The effect of pile driving on the compressibility of clays intermediate between the Detroit and the Mexico clay is not yet known. Hence at the present state of our knowledge the load on the points of piles which are driven through clay cannot yet reliably be estimated.

Experience indicates that neither the creep of undisturbed clay nor the disturbance of the clay structure by pile driving can adequately be reproduced in the laboratory. Hence reliable information concerning these two important phenomena can be obtained only by correlating the results of observations on full-sized structures with those of identification tests on samples of the clay located beneath the structures. At the present time the available case histories barely suffice to inform us on the existing possibilities. The observational data required for bridging the gap between laboratory test and field performance are not yet available.

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