PREWETTING OF LOESS-SOIL FOUNDATION FOR HYDRAULIC STRUCTURES

HUMIDIFICATION PREALABLE DU LOESS POUR LES FONDATIONS DES CONSTRUCTIONS HYDRAULIQUES

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SYNOPSIS Prewetting of loess-soil by ponding, for hydraulic structures which may have their foundations thoroughly wetted, is highly desirable in special cases in which the natural low density earth material is subjected to important subsidence, under its own weight, when saturated. The above mentioned method was applied for the first time in Roumania, as a foundation solution for radial settling tanks and water reservoirs.
The paper presents geotechnical peculiarities of the building zone and gives a short description of the hydraulic structures which were built. The efficiency of the described procedure is underlined through economical data; informations concerning the satisfactory behaviour of the building are attesting the availability and usefullness of the prewetting method as a mean to avoid supplementary uneven settlements of loess-soil foundation for hydraulic structures.

INTRODUCTION

The presence of loess deposits sensitive to water action, i.e., which are showing large consolidation under certain moisture and load combination, in places where industrial centers are to be built or developed, have raised intricate problems in connection with the choice of the suitable protective measures against supplementary settlements that may occur at the increasing of the soil moisture through water infiltrations that cannot be avoided. The same conditions may appear for buildings sites in loess regions in which water supply pipes and sewers are installed or modified, and in zones of urban development on loessial soils.

Researches started in USSR some 4o years ago and subsequently progressivly improved in a number of countries possessing loess-soils, have led to the acquirement of a very rich documentary material concerning the prospecting processes and identification methods suitable for loessial soils sensitive to water action, as well as the description of protective means against supplementary uneven settlements, appearing during the exploitation stage.

At present, researches are mostly directed towards the improvement of the foundation treatment methods, with a tendency to diversify them and to reduce the volume of necessary work for securing normal behaviour of buildings founded on loess-soils.

In Roumania, after some incidental uneven settlements of structures caused by the local wetting of the sensitive loess foundations, situations that have drawn attention upon the special properties of such soils, the accumulation of data from the researches carried out have led to more accurate technical specifications, periodically modified and adapted to the knowledge level in this field. The roumanian technical specifications for foundations on loess-soil contain recomandations concerning special measures for the reliability of structures errected on soils which can settle by the increase of the natural water content.

The knowledge of the laws governing the appearence and development of supplementary settlement phenomena by "collapse of structure" due to the increase of the soil moisture, and the mastering in sufficient extent, of the elements controlling such deformation processes, has provided us some 18 years ago, with the necessary means to accomplish the straithtening of a high inclined structure, by producing and conducting an uneven settlement through lateral ponding of the foundation, work described by Stanculescu (1952). Geotehnical maps showing the different loess types existent in Roumania have been carried out by Schally and Popescu (1962) and developed by Protopopescu-Pake, Craciun and Popescu (1966). The world wide experience connected with the loess foundation problem acknowledges the prior treatment procedure of such soils, by prewetting through ponding, in the case of hydraulic structures by which water infiltration in the ground, during the exploitation stage, cannot be avoided. Such an exemple, described by Clevenger (1958) is that of the Medicine Creek Dam, Nebraska, whose foundation was thoroughly wetted by ponding before embankment construction, so as to permit a large part of the settlement to take place during the completing of the earth fill. It is to be noted that Denisov

(1946), starting from the great subsidences observed along some irrigation canals, suggested the use of prewetting of such works, considering the method as the one capable to assure against great and uneven settlements in the exploitation stage. With the development of irrigation works in districts with loess in Roumania, subsidence phenomena accompanying water infiltration were thoroughly studied, valuable data being published by Antonescu, Bally and Perlea (1963). Amongst published material connected with this problem, a paper regarding the ponding of two experimental sites of about 9oo sq.m. each, written by Asianin and Krutov (1961), and another regarding schemes of loess subsidence by ponding under the soils weight and under load, signed by Krutov (1962), draw attention upon the main facts concerning the use of the prewetting method by ponding.

The present paper gives a description of a case in which the prewetting method by ponding was successfully used for hydraulic structures belonging to a water purification station of an important Ironwork Plant.

GEOTECHNICAL CHARACTERISTICS OF THE SOIL IN THE EXAMINED ZONE

The zone where the water purification station is situated, corresponds to a tableland cornice, the general slope being of about 2%. The station's site is given on fig.1, together with the plan display of the main structures.

The geotehnical researches have given the following typical stratification;

0 to 24 m.,-macroporous yellow loess, composed out of three distinct layers separated at 7 m., and at 18 m., by two brown loamy horizons. The upper part of the loess formation between the surface and the second loamy horizon has greater porosities - 47 to 51% - and a reduced natural moisture, of lo to 12%. The lower loess layer under the second loamy horizon is somewhat more consolidated having porosities comprised between 44 and 45% and an increased natural moisture of 12 to 16%. It is to be mentioned that the first intercalated loamy horizon, has variable thicknesses on the building zone, between o,7 to 4 m., a local condition which

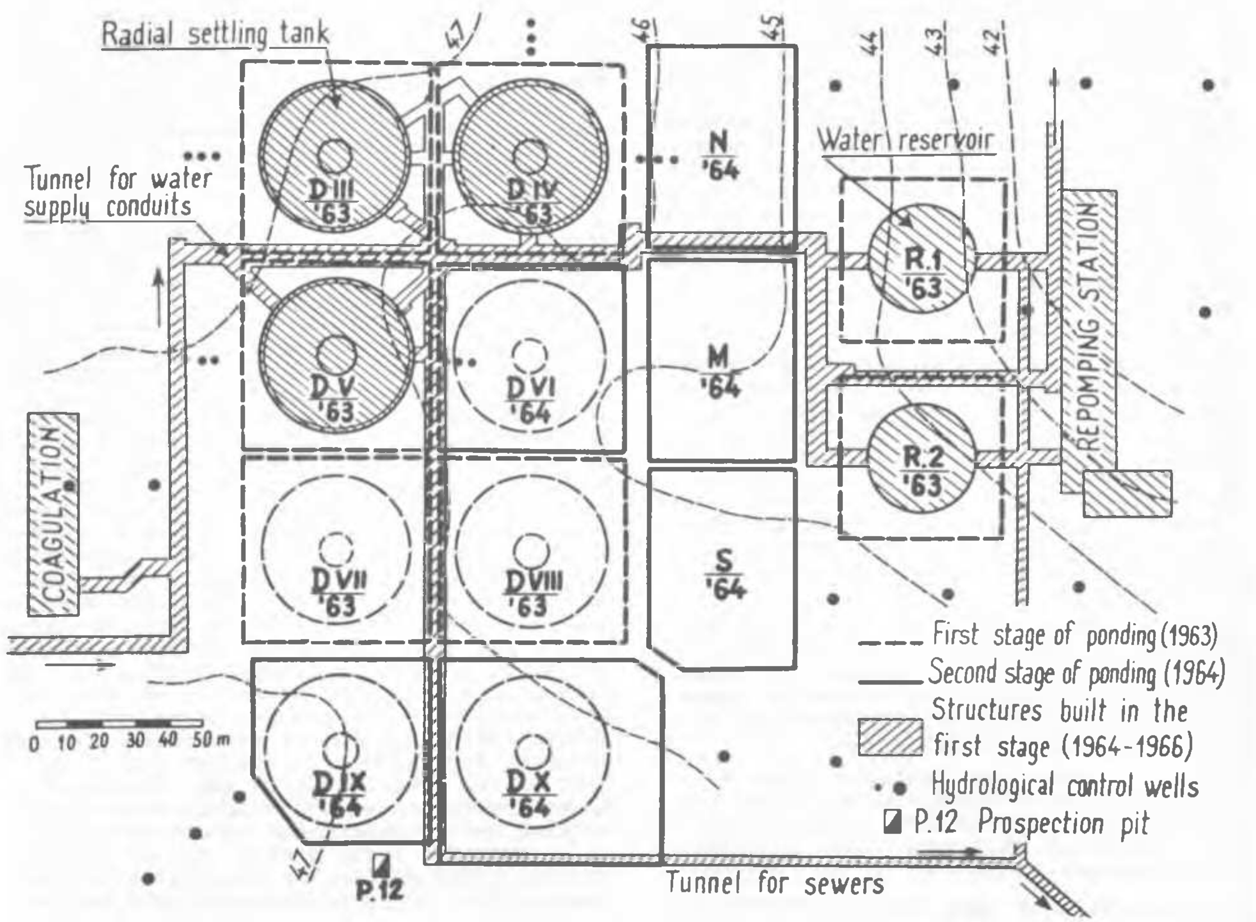

Fig.1 The site sketch of the water purification station.

greatly influenced the behaviour of the foundation by ponding.

24 to 32 m.,-clays and silty clays with sandy intercalation, a prequaternary formation having porosities under 4o% and natural moisture between 14 and 2o%.

The underground water level was met at a depth under the surface of more than 4o m.

In fig.2 are given data referring to two criteria for judging the sensibility of loess to wetting. The first criterion, elaborated by Miheev (1962), is based on the value of the degree of saturation (Sr), and, at the same time, on the value of the ratio :

$$\alpha = \frac{e_o - e_L}{1 + e_o}$$

where,

e_o - is the natural void ratio

e_L - is the void ratio corresponding to the liquid limit.

When Sr o,6 and - o,1, the soil is considered to be susceptible to subsidence by ponding, if the superimposed load is sufficiently great to induce the collapse of the wetted loess structure.

The second criterion, takes into account the supplementary compression strain under a pressure of 3 Kg/sq.cm., at saturation. If the values of the supplementary compressive strains are exceding 2%, the soil is classified as sensitive. Both criteria have shown that the loess formation on the building zone was to be judged as susceptible to settlements under the soil's own weight, when thoroughly wetted.

The exfiltration of the water out the radial settling tanks and water reservoirs, being unavoidable, one could expect the appearence and development of supplementary settlements of a maghitude and nonuniformity that could induce degradation of the main hydraulic structures and of their connections.

CONDITIONS OF CHOICE AND USE OF THE PREWETTING

The water purification station comprises, as main structures, radial settling tanks, having a diameter of 45 m., and water reservoirs of 5.ooo cu.m., capacity, for clear water. All the technological connections, consisting in pipes and sewers are introduced in reinforced concrete tunnels so as to enable an easy control and eventual repairs.

The most sensible structure to uneven settlements and most important from an exploitation point of view, is the radial settling tank, a reinforced concrete structure comprising a central chamber of reaction burried deeply into the soil, a troncconical reinforced concrete raft and cylindrical walls fitted with a perimetral overfall to let the purified water out of the basin, fig.3.

The radial settling tanks and water reservoirs, entirely burried under the ground

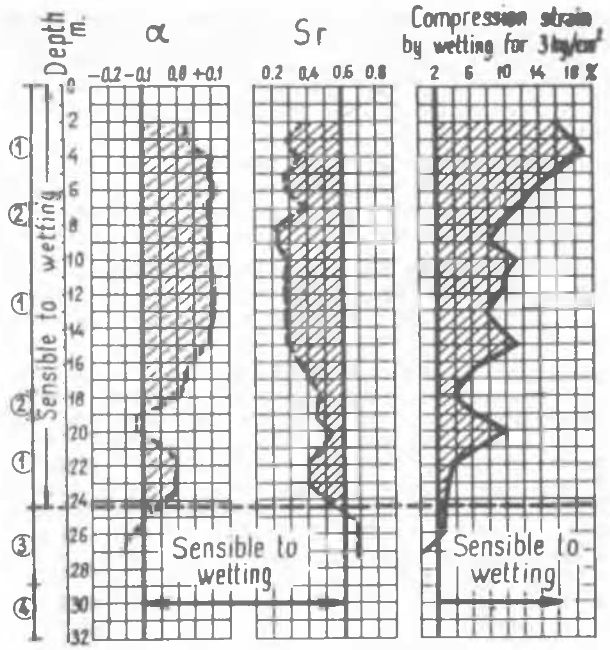

Fig. 2 Criteria for judging the sensibility of loess to wetting.
1 - loess ; 2 - loamy horizon;
3 - clay; 4 - sandy clay.

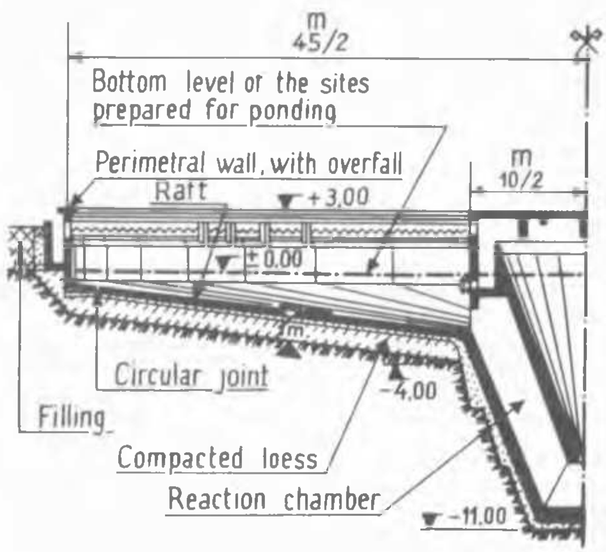

Fig. 3 Vertical cross section through the radial settling tank.

surface, are distributing to the foundation, pressures which are comparable with those given by the excavated earth own's weight.

It is evident that the avoidance of water losses into the soil through exfiltration or owerflow, during the functioning period, or the hindrence of local moistening during the construction period on large excavated areas, could not be practically ensured. Under the mentioned conditions, knowing the existing special soil properties, the problem could be solved only by the following alternatives :

- by means of deep foundations on long piles or columns introduced into the clay strata, under the loess formation ;
- by using the prewetting method through ponding and by building the whole water purification station on previously treated soil.

The great depth of over 24 m., to which one had to introduce the piles or columns, the uncertainity concerning the influence of the soil settlement around the piles caused by the wetting of the loess formation, as well as the high price of the work, constituted arguments to renounce to the first alternative. Therefore, the second solution, of prewetting by ponding, was considered to be suitable for this case and was adopted. It is to be noted that this method was proposed to be used for the first time in Roumania, and in the available literature, there were not detailed descriptions of similar works carried out on such a large scale.

Considered in general, the whole surface belonging to the water purification station had about 6o.ooo sq.m., out of which 45.ooo sq.m., were alloted to the radial settling basins, water reservoirs, water supply and sewer tunnels. For this latter area, the prewetting method by ponding was chosen. Applying this method it was necessary to keep in mind, on the one hand, the especially great surface on which the ponding was to be executed; an important consumption of water was expected. According to the available literature, the necessary quantity of water was evaluated up to lo cu.m./sq.m. On the other hand it was to be kept in mind the necessary time lag for the development of the construction program and the imposed final date for the beginning of the exploitation of the water purification station.

In the given situation, the prewetting method had to be applied by stages so as to assure the fulfiment of all the imposed local conditions. The ponding proceeded on sites having, in general, a square shape of about 25oo to 4ooo sq.m., in surface. Each site was surrounded by compacted earth embankments on which were placed the water supply conduits. For each 3 to 4 sq.m., a vertical sand drain was forseen, the borings being done by percussion without excavation of material. In order to facilitate the water infiltration, and to permit the easy evacuation of the poreentrapped air, during the settlement process, on the bottom of each site prepared for ponding, a layer of ballast was spread. The time-settlement development was followed by a topographical survey, using special surface and depth marks installed on each site subjected to ponding.

The variation of the underground water level was determined through hydrological wells installed on profiles near each wetted site. The necessary water was pumped from a natural surface source situated at about 1,2 Km., distance, making use of a pumping station having a maximum capacity of about 24o cu.m./hour. The ponding of each site has lasted during the first stage in 1963, about 3 months. The closing of the wetting process for each site was conditioned by the progressive diminishing of settlements-time ratio, up to a constant value during a longer period.

During the second stage, in 1964, the ponding of each site has lasted a shorter time, in between 6o to 75 days, due to the accelerating effect on the settlement phenomena obtained by the usage of dry drilled vertical sand drains, executed by the evacuation of the bored material, and to the prewetting and settling of the neighbouring sites. In the two treatment stages of the foundation for the entire water purification station, the following volumes of principal works were executed :

- total surface of the ponded sites .... 43.ooo sq.m.
- earth work and digging .. 48.ooo cu.m.
- ballast spread on the bottom of the sites ..... 1o.ooo cu.m.
- vertical sand drains drilled by percussion having a 5" diameter ...... 6.5oo pieces and a total lenght of ... 85.7oo m.
- vertical dry sand drains drilled by evacuation of the bored material having 8" 5/8 diameter..... 4.ooo pieces and a total lenght of ... 37.5oo m.
- water for maintaining the ponding .... 582.7oo cu.m.
- medium specific volume of infiltrated water ... 13,5 cu.m./sq,m.

The topographical survey, fig.4. comprised during the period 1962 to 1964, over 23oo leveling stations and 5o.ooo observations

Fig. 4 Topographical survey during ponding.

using about 13oo surface and depth marks. Periodical leveling surveys with the aim of controlling the behaviour of the built structures, are carried out continually at present.

Level changes of the underground water were checked by observing 4o control hydrological wells, and, in two years ago, over 5ooo measurements were done.

The actual total cost of the foundation treatment by ponding arises to about 7,5% of the total investment value alloted to the entire range of constructions pertaining to the water purification station.

BEHAVIOUR OF THE PREWETTED SOIL BY PONDING

The measurements and observations carried out during the wetting operations and after, have allowed us to establish some interesting findings relating to the time development of the wetting-settlement process in loess-soil, under its own weight action. These findings refer to :

- the behaviour of the foundation soil during the wetting period and the withdrawal of the infiltrated water ;
- the influence of the massive lateral rewetting on the resumption of the settlements in the previously prewetted sites ;
- the depth strata contribution to the surface deformation ;
- the final shape of the surface relief after the carrying out of the settlements due to ponding.

The behaviour of the foundation soil during the wetting period and later is illustrated for one of the ponded sites, by the graphs presented on fig.5. These graphs bring into evidence a phenomena for which we have not found data in the available publications connected to this problem; after the stoppage of the wetting process, during the withdrawal period of the infiltrated water, the settlements, once stabilized, were reactivated with a relatively important intensity and amplitude. During the massive wetting with about 5o.ooo cu.m., of water, on a site having about 3.4oo sq.m., the settlements have begun in the first ten days, they have increased up to about 5o days from the beginning of the wetting process, after which, in the following 44 days of ponding, the rate of settlements has diminished progressively up to the almost complete stabilization. The final values in respect of the three typical surface marks varied in between 3o to 1o8 cm.

The stoppage of the wetting process and the withdrawal of the infiltrated water have been marked by the reactivation of the settlement process, the supplementary subsidence varying in between 2o to 3o cm., representing 15 to 45% of the final total settlement obtained by ponding.

The settlements reactivation after the wetting stoppage may be explained by the diminishing of the uplift effect, as well as by the consolidation of the silty material thoroughly wetted under the hydrodinamic forces of the infiltration current. The settlements due to the withdrawal of the underground water level do not have the character of a structure collapse generated by the softening of the cementated contact between the particles or the soil aggregates, but it has merely the appearence of a slow-consolidation

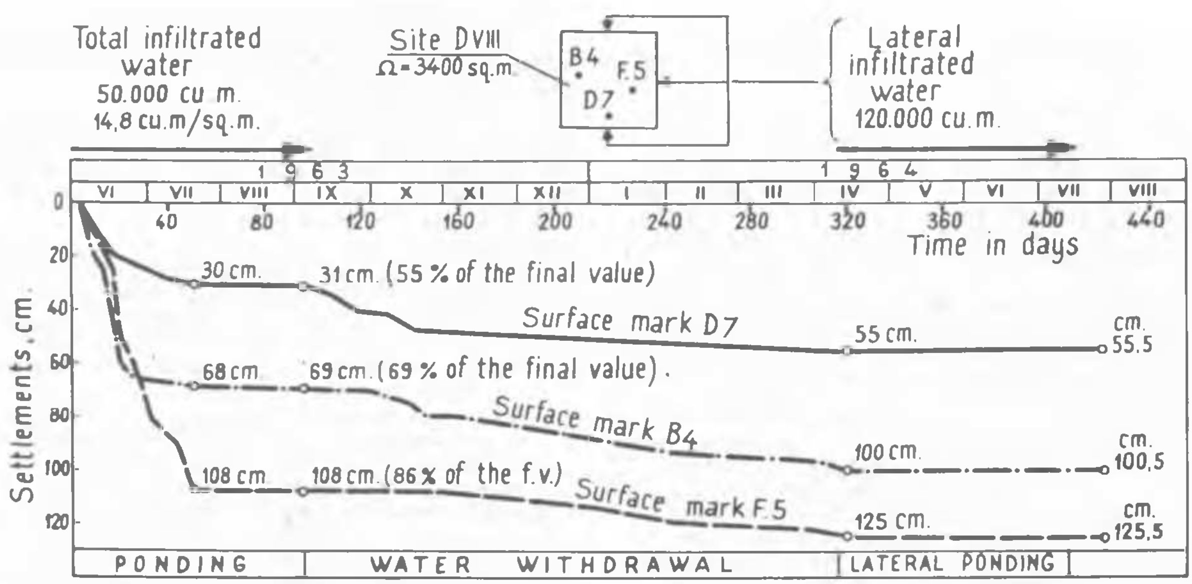

Fig.5 Time-settlements curves of the surface marks in the site D VIII, during the ponding operation and withdrawal of the water.

process, similar to that characteristic for saturated clays.

The settlements during the withdrawal stage have finisghed about 7 months from the stoppage of the wetting in one site, while the same process has taken place, in another site, after 4 months. The lateral rewetting, on three sides, of a previously wetted and settled site, with a total water quantity of about 12o.ooo cu.m., had no longer influenced the subsequent behaviour of the foundation, new settlements not being observed.

The depth strata contribution to the surface settlement, was obtained in respect of three different measurement points, by means of groups of six to eight depth marks in fig.6. It can be observed on the graphs a,b,c, that

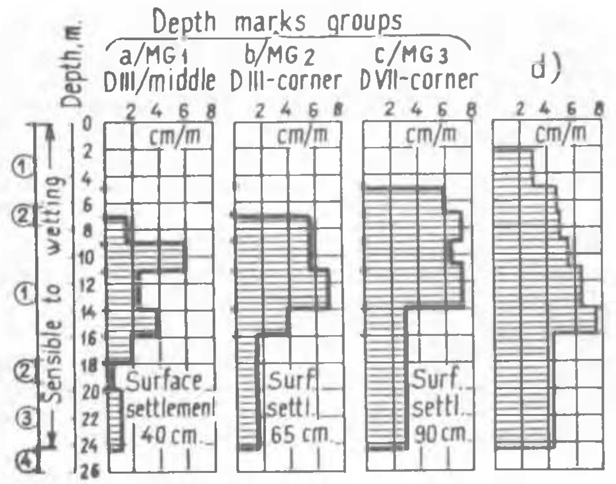

Fig. 6 Contribution of the deep strata deformations to the settlements of the ground surface.

the surface strata up to 5 - 7 m., in depth, do not contribute to the settlement by wetting. They are moving downwards, in block, due to the subjacent strata settlements. The maximum contribution is given by the strata between 5 m., and 15 m., depth. Graph d on fig.6 presents the unit compression strain under the soil's own weight, determined by considering the results of compression tests in the oedometer on natural loess-soil and on saturated samples. In general, greater values for the compression strains have been ascentained in the laboratory tests, as those registered by field determinations, by means of depth marks; besides, an interpretation of the laboratory compressive curves show that also the strata between surface and 5 m., depth, are contributing to the total settlement obtained by ponding under the soil's own weight, fact not confirmed by measurements carried out on the wetted sites.

The final shape of the wetted site surface after the total settlement, appears, as in fig.7. Curves of equal settlements in respect to the initial level of the ground, considered as zero level, are represented. One can see that the settlements have nonuninformly developed with respect to the symetrical axis of each wetted site.

More accentuated settlements are appearing in local niduses, having a depth up to 2 m. In the central part of the building zone, on a winding strip, the settlements were smaler than lo cm., or did not practically appear. There, where these settlements have appeared, the surface deformations were brought into evidence by steps having a height of lo to 2o cm., and cracks along them with openings of the same magnitude, fig.8. The cracks distribution is generally of a concentrical pattern round the niduses of maximum settlements. The cracks zone limit extended from the edge of the wetted site, to about 15 to 2o m., i.e. up to approximatively the value of the total thickness of the sensible loess strata.

The accentuated uneveness of the surface deformation may be explained, on the one hand, by the variety of stratification conditions, characteristical for the platform cornice where the site is situated, and, on the other hand, by the presence of a large variety in the natural cementation, giving different sensivities to the water influence upon the collapse of the soil structure.

BUILDING PROCESS AND BEHAVIOUR OF THE HYDRAULIC STRUCTURES

Beginning with the autumn of 1963, the excavation works have procedeed in accordance with the project, as soon as the withdrawal of the water permitted. The excavations were executed successively to the radial settling tanks D IV, D III and D V. In order to obtain a supplementary impermeabilization under the raft and to create a more compact support for the reinforced concrete slab, a general compacted layer of loess, having 1 m., thickness, was forseen.

The raft was carried out in the first stage by sectors, the empty construction joints being kept to be filled later as the settlement progress were to become less intensive and more uniform, fig.9.

The topographical survey on four marks of the settling tanks was started immediatly after the pouring of the equalizer concrete strata which supported the raft. After the pouring of the central chamber of reaction, four level marks were installed on this part, more deeply founded.

A first test of the behaviour of the raft under construction, has taken place during the period March-June 1964, whem a massive lateral wetting was carried out on the sites during the second stage of ponding. About 3o.ooo cu.m., of water, were introduced in site D VI. No supplementary settlements on the level marks under survey were registered.

In the third trimester of 1965 the overfall walls of the radial settling tanks were executed. Subsequently, in 1966, the filling

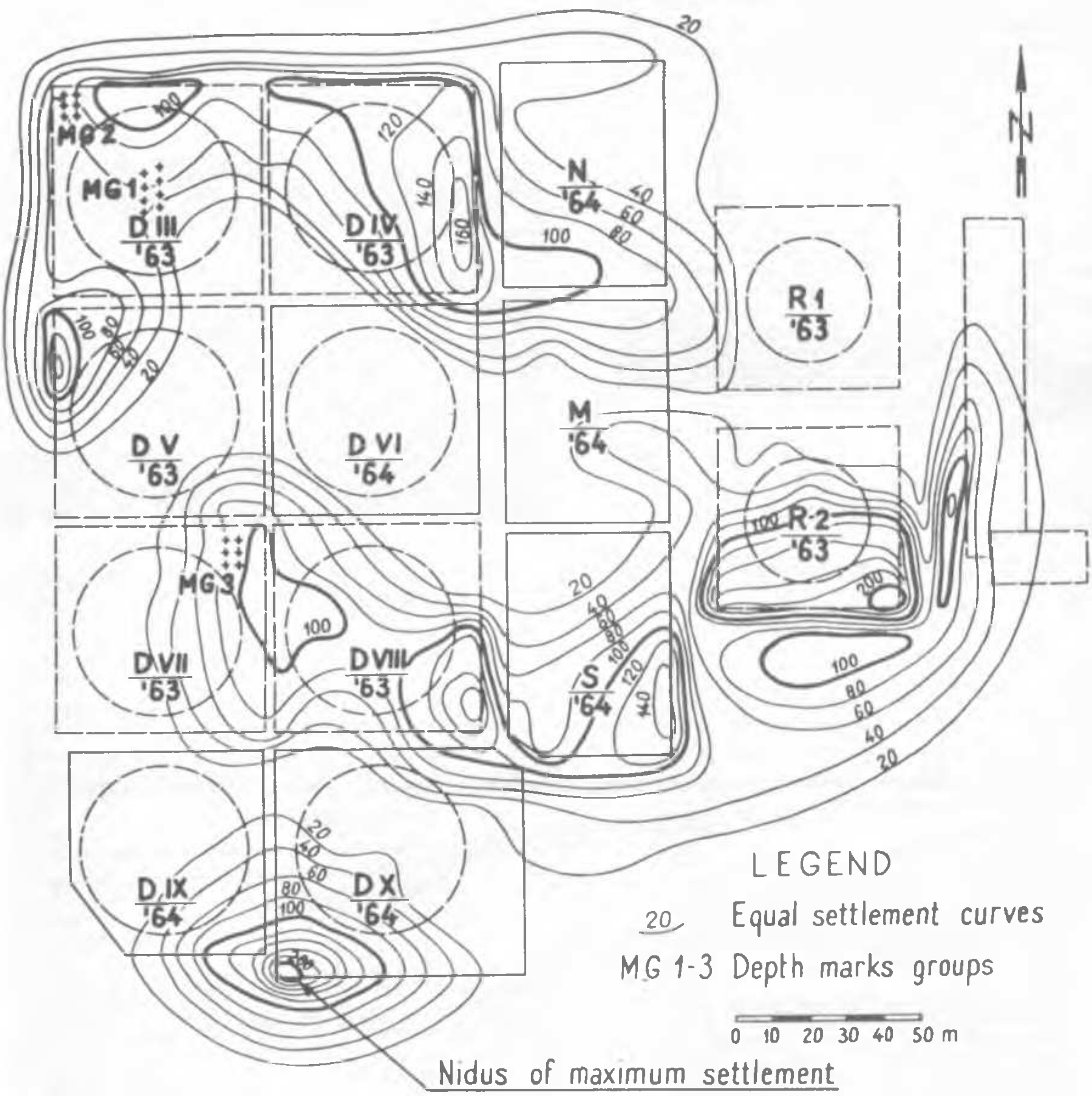

Fig. 7 Final shape of the settled area after prewetting.

round the settling tanks were carried out. The height of those fillings were of about 2 m. At the beginning of September 1966 three settling tanks were put into function.

The graphs in fig.lo present the behaviour of three settling tanks during the period of construction, starting from January 1964 up to November 1968. One can observe, essentially, on graph a, that the average settlements during a period of nearly five years, have values comprised between maximum 25 cm, (D IV) and minimum 4,5 cm. (D.V).

On graph b from fig.lo is presented the variation of the maximum difference of settlements on the settling tanks contour. The interesting values occured beginning with the moment of the lateral overfall wall construction.

One must keep in mind that a metallic overfall fixed on the external wall of the settling tank is adjustable, and can be lifted or lowered in the limits of 2o cm., the maximum of settlement differences which were appreciated to occur.

Under the above said conditions the settling tanks were exploited during over two years in good conditions, fig.11.

Fig. 8 Cracks near a ponded site.

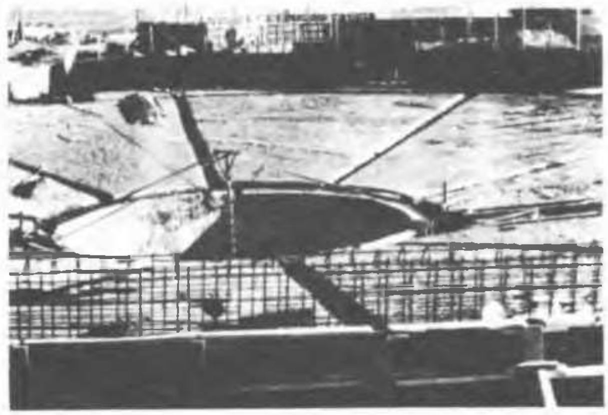

Fig. 9 The raft built with open joints in the first construction period.

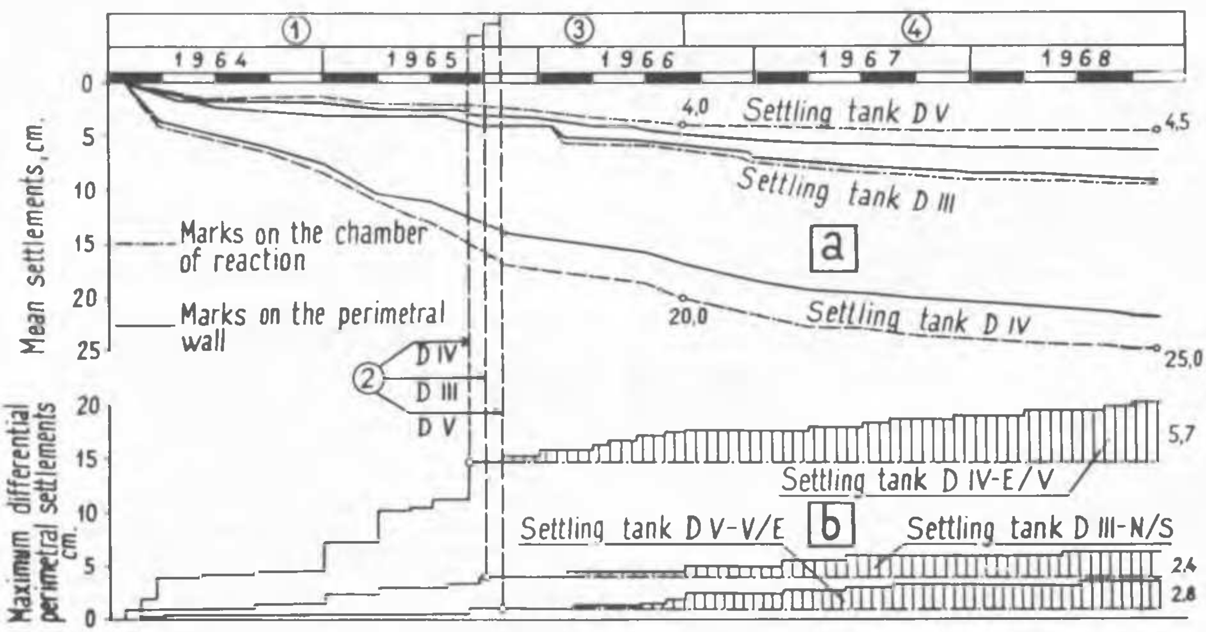

Fig. lo Mean settlements and maximum differential perimetral settlements of the settling tanks.
1 - settling tank in construction phase; 2 - accomplishment of the overfall wall; 3 - accomplishment of the earth filling round the settling tanks; 4 - exploitation period.

Fig. 11 Accomplished settling tanks in exploitation.

CONCLUSIONS

By the surveying the behaviour of the executed structures on prewetted loess for a period of about 64 months, some usefull conclusions were drawn, as follows :

1. Settlements under the wetted soils's own weight have had important values, reaching localy 2 m. They developed in an uneven manner over the ponded surface with niduses placed independently of the wetted site symetry axis.

2. The soil deformation did not appear within the extent of the superior strata up to 5 to 7 m., depth, corresponding to a presure due to the soil's own weight under o,8 to 1 Kg/sq.cm.

3. The settlements of the wetted soil start quickly, after 7 - lo days, stabilize themselves during the ponding period, after 3o to 5o days, and, what is of a special importance, they reactivate after the stoppage of the water infiltration by the withdrawal of the water table.

4. On a prewetted and definitely settled zone, a new infiltration has no practical effect.

5. Without special measures the wetting-settlement cycle on a given site, needs minimum an anual campaign, after which one can begin the construction process. The shortening of the wetting-settlements cycle can be obtained by separating the soil volume subjected to ponding from the neighbouring strata, by a continous perimetral excavation having a depth equal to the sensible strata thickness, filled with sand or noncompacted earth.

6. For hydraulic structures similar to the described ones, founded on loess-soil strata of great thickness, the prewetting by ponding can be used with good technical and economical results.

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