Collapsible Soil Foundation of Canals in Central Brazil

Sols Collapsibles dans les Fondations de Canaux au Centre du Brésil

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SYNOPSIS

The occurence of collapsible soils in the foundation of big canals of an irrigation project, in the central region of Brazil, has motivated the realization of studies, including laboratory tests, field tests and the ponding of an experimental stretch of the main canal. The fact that the canals had been designed to be built with compacted fill and concrete lining brought up worries relatively to the settlements that could occur. Based on the laboratory results, the quantification of the phenomenon and the estimation of the settlements of the canal was tried. The ponding test of the experimental stretch enables the review of those estimates and the acquirement of data concerning the velocity of settlement occurence. Based on the results of field and laboratory tests, the criteria for the final design of the canals were established.

I. INTRODUCTION

During the geological and geotechnical studies carried out on an irrigation project in the central region of Brazil, collapsible soils were discovered in extensive areas. This problem was considered especially important because of the fact that the main canals, projected for a capacity of $80m^3/s$, had been designed to be built up with earth fill and concrete lining. The possibility of the occurence of settlements that would be detrimental to the canals, motivated the realization of several studies including ponding of an experimental stretch, with 300m extension, of the main canal.

II. THE IRRIGATION PROJECT AND THE PHYSICAL ENVIRONMENT

The irrigation project of the Jaiba Agroindustrial District was designed for the irrigation of 100.000ha in the São Francisco Valley, in the north of the Minas Gerais State, using the water pumped from the river.

The main canal (CP-1) conducts water ($80m^3/s$) from the first pumping station (EB-1) along the second fluvial terrace, presenting stretches where the transversal section is constituted of cuts in the original terrain and others were it is built up completely with earth fill.

The foundation soils of the first two main canals (with lengths of 7 and 20Km, respectively) were indentified as collapsible after the results of laboratory tests carried out on undisturbed samples.

The Jaiba region has a semiarid climate and relatively low pluviosity (annual average of about 800mm) with the rains concentrated mostly during a period of three months.

The natural vegetation is constituted predominantly of "cerrados" (savanas), occurring isolated zones of sparse forest.

Alluvial soils predominate in the lower terraces and colluvial soils in the higher zones. In the studied region, under the decimetric layer of superficial clayey sand with organic material, occur layers of fine to medium sands with some silty clays, aproximately 10m thick, and a layer of practically pure fine to medium sand. Under these layers occur the saprolite of limestone and then comes the weathered and sound rock.

The phenomenon of collapse was detected only in the superficial layers of clayey and silty sands that present very low natural degrees of saturation. The initial evidence was a rupture that occured in a secondary canal with concrete lining, which was in experimental operation.

III. LABORATORY TEST

The experimental studies were started with the laboratory tests. Inicially, three undisturbed samples were obtained from two sites along the main canal. Those samples were tested in the oedometer and subjected to soaking at different pressures. During these tests, the specific settlement, due to collapse of the soil, reached 3,5%.

After this first tests for the recognition of the phenomenon, six more undisturbed samples were brought to the laboratory (aprox. 1000 Km away) for additional testing. These samples were taken from two pits located in a region that had not yet been reached by any construction activities. The tests were carried out in two series which consisted basically, of:

i) complete oedometric tests, carried on "twin" specimens from the same sample, one of them being soaked since the beginning and the other one mantained at natural moisture content during the whole test;

ii) oedometric tests carried out on specimens which were loaded until a predetermined pressure and then soaked under this same pressure.

The first procedure which is similar to that used by Jennings (1957), did not presented very useful quantitative results, because of the great heterogeneity of the specimens, even of those coming from the same sample. So, due to very different initial void ratios, these tests didn't present much consistency.

The second procedure which was also used by Holtz and Hilf (1961) and Vargas (1973), showed to be much easier for analysis, resulting in more consistent data, in spite of the great variability of the test results.

From the results of the laboratory tests, it could be concluded that the most important factor affecting those results was the depth from which the sample had been collected. So, samples from small depths (1,0 to 2,0m) reached high values of specific settlements due to collapse (until 8,8%), while those from intermediate depths (3,0 and 4,0m) presented maximum values to the order of 2% and the only sample collected at a greater depth (6,0m) showed specific settlements smaller than 0,7%. This conclusion becomes evident by looking at the graph of fig. 1.

Another factor that is evidently important for the conditioning of the collapse settlement is the pressure at which the sample is soaked. As can be seen in fig. 1 there is a certain tendency that higher pressures at soaking conducts to greater values of settlements, but this tendency doesn't clearly appear because of the erraticity of the test results.

In fig. 1 it was tried to establish an envelope for the specific settlements in function of the depth, that is drawn in dashed line.

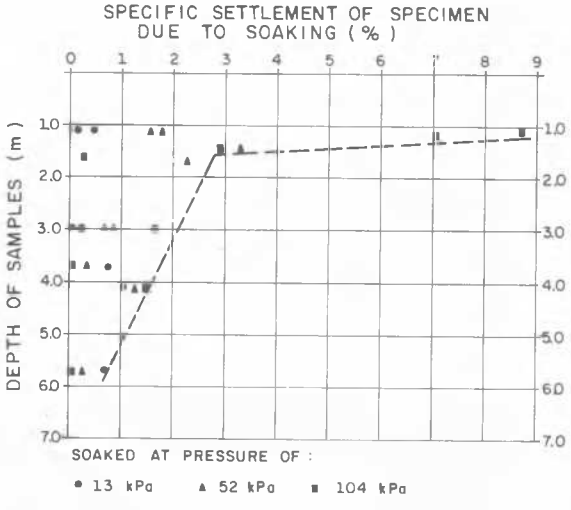

Fig. 1 - RESULTS OF OEDOMETRIC COLLAPSIBILITY TESTS

Scanning microscope analysis on undisturbed specimens was also carried out which revealed a typical microstructure of sandy collapsible soils: the sand grains usually have no direct contacts between themselves, but are bound by the smaller particles of clay and silt. When saturated, these bonds are broken and the microstructure disarranges, producing the collapse deformations. Fig. 2 shows a scanning electron micrograph of an undisturbed sample, on which the described microstructure becomes evident.

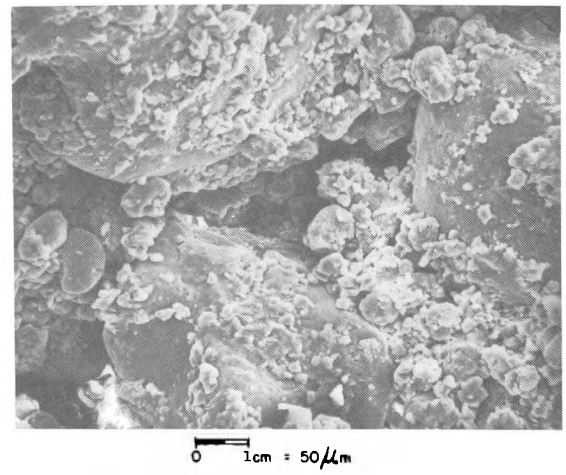

Fig. 2 - SCANNING ELECTRON MICROGRAPH OF UNDISTURBED COLLAPSIBLE SOIL SAMPLE.

IV. "IN-SITU" PONDING TESTS

To determine the performance of the canal - fills in real size when subjected to the phenomenon of collapse of the foundation soils, two "in-situ" tests were carried out.

The first of these tests, involved a prototype of compacted earth fill, built in a shallow trench in which a water level was mantained during a period of about one month.

The other test was carried out on an experimental stretch of the main canal, 300m in length, that was submitted to ponding for almost two months, meanwhile measurements were being made from the installed instrumentation.

During the first test of the prototype fill, settlements were measured in various sections of this fill and in the surrounding area, inside and outside the inundated trench. It could be verified that settlements occured only in the region where the fill had been built, which settled in an almost monolithic way, reaching 33mm after the 21 days during which time the water was mantained in the trench. It is interesting to note that in the surrounding areas, where no surcharge had been imposed to the terrain, no settlements occured during the test period, in spite of the fact, that the saturation degree of the subsoil increased considerably. These degrees of saturation grew from initial values in the order of 60% to final ones from 70% to 90% , not reaching the same high values verified in the laboratory - tests. The results of this test and the previsions made for the performance of the canal at that occasion were presented by Wolle et al (1978).

The ponding of the experimental stretch intended to obtain data concerning the even

tual application of this procedure to all the concrete lined canals as a systematic treatment to improve the foundation soils. The use of ponding as a systematic stabilization process for collapsible soils in canal construction has been described by Gibbs and Bara (1967).

The instrumentation used in the experimental stretch, intended to evaluate the settlement occurence during the time of the experiment, which was measured at various sections of the canal, and also to accompany the variation of the groundwater table. The instrumented section was selected in such a way as to obtain the largest variations of conditions in respect to the height of the fill. Therefore, the fill height varied from 1,0m, in the section of station 206 to 5,0m in the section of station 199. In fig. 3, the transversal section of station 194 is presented, showing the location of the installed instrumentation and a simplified profile of the subsoil. The instrumentation was installed immediately after the end of the earthworks and the measurements were carried out the following five months.

Only after this period was the ponding initiated. Between the end of the earthworks and the beginning of the ponding, no settlements were recorded through the instrumentation measurements and the ground water table remained stable.

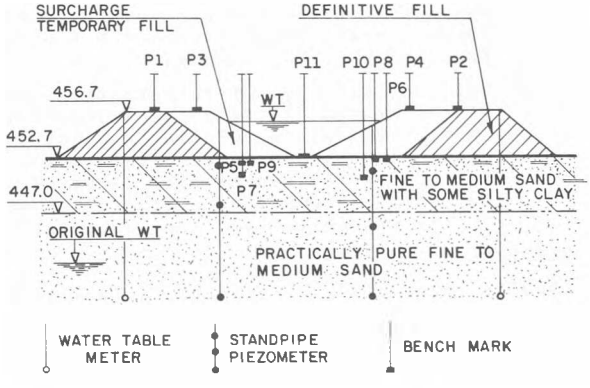

Fig.3 - TRANSVERSAL SECTION OF EXPERIMENTAL CANAL STRETCH (SECTION OF STATION 194)

The ponding of the experimental stretch was performed, mantaining for a period of 50 consecutive days, the water at the normal operation level of the canal. During this period, the instrumentation was measured systematically. In fig. 4 the settlement-time curves, determined at the benchmarks of the section of station 194 are presented. At the bottom of this figure, the water level in the canal and the variation of the ground water table is drawn. From the analysis of this graph it becomes evident that after six weeks from the beginning of the ponding, the ground water table stabilized, while the settlements showed a tendency to stabilize at the end of the test. The largest settlement recorded was 7.2cm and it was verified that no compressions occured in the body of the fill, all settlements resulting from collapse deformations in the foundation - soil. It was also verified that settlements measured at deep benchmarks were smaller, as can be seen in fig. 5. From the analysis of the graph of this figure it is possible to establish settlement-depth envelope, similar to that drawn in fig. 1, for the results of laboratory tests.

During the ponding, the largest settlements were measured in the section of station 194 were the earth fill was 4.0m high. In the section 199, in spite of height of the fill (5.0m), the settlements were much smaller because of the soil replacement that had become necessary, motivated by work conditions. The excavation of the natural soil till a depth of 1.5m and its replacement with compacted fill reduced the settlements to negligible values. Also in the section of station 206, the measured settlements were very small, due to the reduced increase of the applied earth pressures originated from the fill, that in this section had a height not greater than 1.0m. In the other sections with intermediate conditions, intermediate settlements were measured.

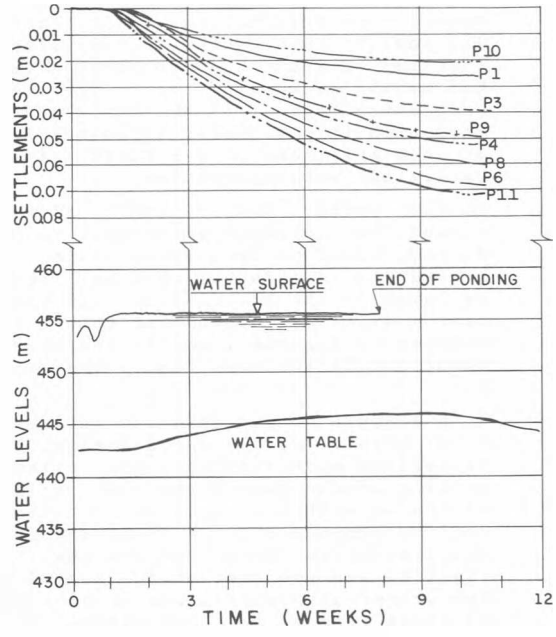

Fig.4 - SETTLEMENTS AND WATER TABLE VARIATION DURING CANAL STRETCH PONDING (SECTION OF STATION 194)

V. SETTLEMENT PREDICTIONS AND DESIGN SOLUTIONS

Based on the laboratory test results, predictions of settlements were established for the full size object, the main canal. This prediction collided with the fundamental problem of the erraticity of the test results, and especially, with the impossibility of determining the influence pattern on the collapse settlement, of the acting stress level. Therefore, the study was performed based on mean values and using also the "settlement envelope" of fig. 1.

Considering the test results presented in fig. 1 as representative for the various horizons of the subsoil and integrating the deformations throughout the collapsible layer,

the calculated values of settlement resulted in 15.8cm.

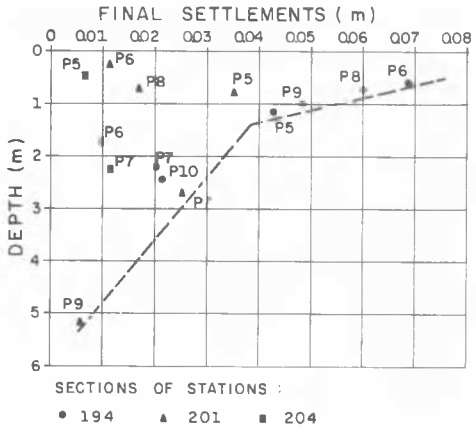

Fig. 5 - SETTLEMENTS MEASURED DURING PONDING AT THE DEPTH BENCHMARKS

The settlements measured during the ponding test of the experimental canal stretch are all smaller than the predicted value. This fact can be attributed to several factors, but mainly because of the difference of saturation reached in the field and laboratory conditions. Other influencing factors are the stiffness of the earth fill and geological heterogeneities.

On this matter, Dudley (1970) already mentioned that collapse settlement values predicted, based on laboratory tests, should be reduced to a factor that he indicated as being to the order of 2.0. In the present case it was convenient to use the envelopes of figures 1 and 5; therefore the reduction factor resulted to the order of 2.2.

With respect to the solution for the practical problem of the canal design, two alternatives were proposed: the systematic ponding of the canals and the replacement of the superficial layer of collapsible soil by compacted earth fill. Because of the limited amounted time for the construction and the cost of the pumped water, the second alternative was chosen. Because of these reasons and considering the results of the instrumentation as measured in the section of station 199 of the experimental stretch, the adopted design solution was not to proceed with the ponding of the canal but to replace the superficial soil layers of the foundation, until a minimum depth of 1.0m, with compacted fill.

VI. CONCLUSIONS

The occurence of collapsible soils in the foundations of the canals of the Jaiba Irrigation Project motivated the realization of studies, including laboratory tests, - field tests and the ponding of an experimental stretch of the main canal (CP-1).

The principal conclusions of the study are:

1. Oedometric tests carried out on "twin" samples, one at natural moisture and the other soaked from the beginning of the test, presented little usefull quantitative information, because of the heterogeneity of the specimens, even of those cut from the same sample, that showed great variability of the initial void ratio and compression index.

2. Oedometric tests carried out with the specimens at natural moisture content at the beginning of the test and subjected to soaking at predetermined pressure stages enabled a clear identification of the collapse phenomenon. It was also possible to establish a certain correlation between collapse and the depth where the samples had been taken.

3. Although the variation of collapse with the depth of the sample could be established, it wasn't possible to determine a correlation of this phenomenon to the - stress level. It became evident, nevertheless, that the presence of a surcharge is necessary, in this soil, for the occurence of collapse settlements.

4. During the ponding test of the experimental canal stretch, it could be verified that pattern of variation of the settlements, in function of depth, was very similar to that observed in the laboratory tests.

5. An estimate of collapse settlements based on laboratory data resulted in larger values than those observed during the ponding of the canal stretch. The reduction factor to transform calculated values to observed ones is aproximately 2.2. in the present case, close to the 2.0 factor refered to by other authors.

6. For the solution of the practical problem of the design of the Jaiba irrigation canals, the adopted solution was not to proceed with the ponding of the canal, but to replace the superficial layer of natural soil by compacted earth fill, because of the economical and time aspects.

REFERENCES

-DUDLEY, J.H. (1970)-Review of Collapsing Soils, Journal SMFE Div., ASCE, SM3, May 1970. p.p. 925-947.

-GIBBS,H.J. and BARA,J.P. (1967)-Stability Problems of Collapsing Soils, Journal SMFE Div., ASCE, SM4, July 1967, p.p. 577-594.

-HOLTZ, W.G. and HILF, J.W. (1961)-Settlement of Soil Foundations Due to Saturation, Proc. 5th Int. Conf. SMFE, Paris, 1961. v.1. p.p.673-679.

-JENNINGS, J.E. and KNIGHT,K.(1957)-The Additional Settlement of Foundations Due to a Collapse of Structure of Sandy Subsoil on Wetting, Proc. 4th Int. Conf. SMFE, London, 1957, v.1, p.p. 316-319.

-VARGAS, M. (1973)-Structurally Unstable Soils in Southern Brazil, Proc. 8th Int. Conf. SMFE, Moscow, 1973, V. 2.2. p.p. 239-246.

-WOLLE,C.M., BENVENUTO.C., POLLA,C.M. (1978)- Estudo Preliminar da Colapsividade dos Solos no Projeto Jaiba (MG); Proc. 2nd Brazil. Cong of Eng. Geology, São Paulo, 1978, V.I. p.p.179-193.

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