TWO CASE STUDIES ON THE DETERMINATION OF HYDROCOMPRESSION SETTLEMENTS IN RUSSIA

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SYNOPSIS

In collapse susceptible soils, the structure which can resist considerable amount of pressure in the unsaturated state can go under severe settlements with the increase in water content. Zones that exhibit reduction in bulk volume of subsoils due to wetting are encountered in two large scale housing projects in Russia. Collapse potential of foundation soil is estimated with studies made with available subsoil data based on extensive geotechnical investigations. Hydrocompression and elastic settlements are investigated for both of the projects and the foundation design is evaluated in terms of tolerable differential and total settlements.

1. INTRODUCTION

Zones that exhibit reduction in bulk volume of subsoils due to wetting are encountered in two large scale housing projects in Russia. Both housing developments are constructed for the former Soviet Union military personnel drawn back from Germany. These developments are required to be constructed in a very short period of time with all social facilities. Therefore, a quick decision making mechanism between office and site works has been set to avoid interruption of the construction works.

The first case study namely, Wolgograd Military Housing Project is constructed by a joint venture of ARGE WALTER-TEKSER (AWT), German and Turkish contractors. The second project referred to as Morosowsk Military Housing Development is constructed by TEKSER Cons. Co.. The Engineer for both of the projects is German consortium of consulting companies, CWU. İstanbul based Turkish geotechnical consulting company, ZETAŞ Earth Technology Corporation is asked to evaluate the available subsoil data, especially in terms of foundation settlements. In both projects, zones that are vulnerable to hydrocompression settlement are encountered. The resulting total and differential settlements are expected to be critical for the buildings for certain portions of the sites. Collapse potential of foundation soil is estimated with studies made with available subsoil data based on extensive geotechnical investigations.

2. GENERAL DESCRIPTION

2.1. Hydrocompression Settlements

The main problem of the projects in case of foundation design is the settlement under foundation loading and hydrocompression settlements. The loose deposits of various sized particles (usually silt) are observed to collapse when exposed to water, especially under high normal stresses. Hydrocompression settlements result from the denser rearrangement of particles after the breakdown of the soil structure with the inclusion of water inside the voids. The hydrocompression settlements below mat foundations are expected to result in differential settlements that may exceed tolerable limits. Therefore critical evaluation of such settlements under each unit is carried out and the final recommendations for the foundation design is developed. The relevant Russian specifications SNIP is adopted for this purpose.

2.2. Soil Investigations and Subsoil Conditions

The characteristics of the hydrocompressible layers existing in both projects show resemblance in general.

Nine different subsoil layers are identified as example in the Wolgograd project. Table 1 provides the listing of the layers with general descriptions and comments on settlement upon wetting. It is seen that IGE1, IGE3 and IGE4 type soils are stated to exhibit settlement upon wetting (i.e. hydrocompression).

Table 1. Hydrocompressive Properties of Subsoil Layers Present in Wolgograd (ZETAŞ, 1993a)

Soil Layer	General Description	Settlement Upon Wetting
IGE1 and 1a	Fine-coarse grained erratic soil, partly includes clay	Exhibits large settlements when water content increases
IGE2	Clay	Exhibits swelling when water content increases. No settlement problem
IGE3	Clayey soil-erratic	Exhibits settlement when water content increases
IGE4	Sandy soil	May exhibit settlement when water content increases
IGE5 and 5a	Medium dense sand	No settlement problem
IGE6	Stiff-hard clay	No settlement problem
IGE7	-	No settlement problem

Various laboratory and in-situ tests are conducted to identify the soil structure and behavior. Considerable number of borings and CPT testings are distributed through the construction areas to get a representative ground characterization. The soil properties including specific gravity, water content, modulus of elasticity are estimated from the results of laboratory tests run parallel with the borings.

The test called double oedometer test or hyrocompression test (Jennings and Knight, 1956) utilizing the oedometer test is used to provide quantitative and qualitative information on the collapse potential of the subsoil. This method can be used to evaluate the response of the soil to both wetting and loading at different stress levels. The laboratory technique consists of running two consolidometer tests on identical samples. One sample is tested at its natural water content while the other is tested under soaked conditions. Double oedometer tests are conducted by local Russian Institutes and the strain due to wetting under various stress levels is obtained from the test comparing the compressions of the in-situ and soaked samples. The hydrocompression strains (ε_{sl}) for various vertical stresses for typical profiles of both sites are given in Figure 1 below. The calculation of hydrocompression settlements using these parameters is explained and discussed in the following section.

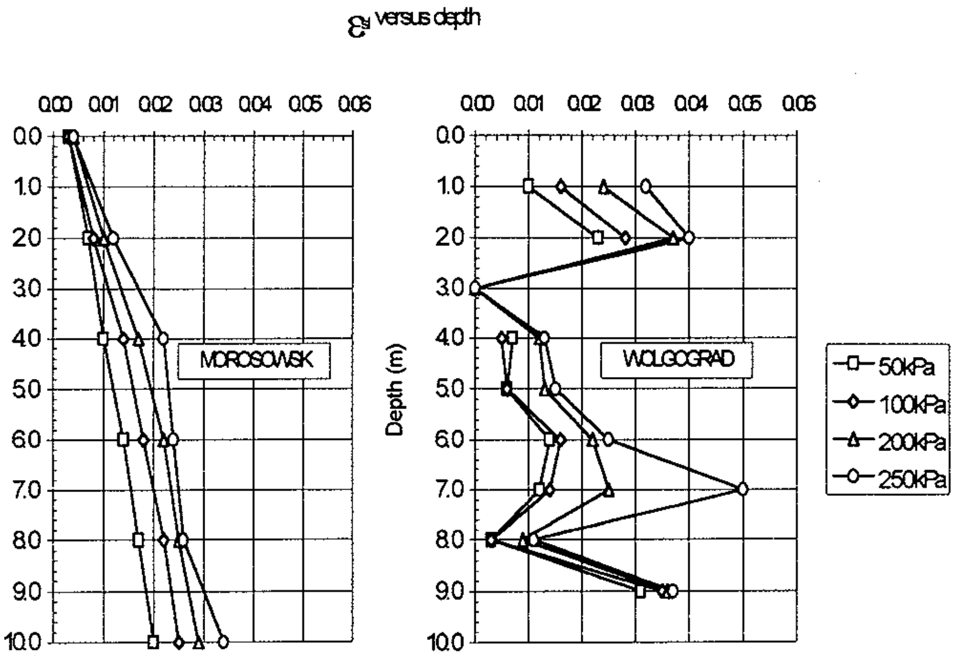


Figure 1. Typical Examples of Variation of Hydrocompression Strain with Depth

2.3. Superstructural Information

The high housing buildings are constructed by shear walls as vertical members and carrying flat-slabs making a rigid structure based on 450 cm thick mat foundations. The social buildings are constructed as conventional beam-column frame structure rested onto mat foundations. The tolerable total settlement for such structure is limited by 10 cm in former USSR standards. The differential settlement criteria, ratio of settlement to the length of the shorter mat dimension is set as s/l = 0.005 in the same standards. More detailed discussion on this is given in the preceding sections.

3. SETTLEMENT CALCULATIONS

3.1. Settlement Calculation Methodology

The soil profile beneath the foundation is divided into sufficient number of different zones each corresponding to a representative sample that was tested with double oedometer test as described. The unloading stress (P_e) upon mat excavation and stress increase (P_f) under complete structural load are determined at 0.50 m depth intervals starting from foundation base by elastic methods. The final vertical pressure (P_r) at various depths is calculated by adding the initial in-situ overburden pressure (P_o) to the difference between P_f and P_e. The hydrocompression of each zone is then calculated as the product of the layer thickness (h) and the strain due to wetting (εsl) corresponding to the final pressure (P_f).

$$S_{sl} = \Sigma(\varepsilon sl \cdot h \cdot k)$$

The elastic settlement which is of concern in terms of total settlements is calculated with the similar subdivision of the soil profile. The net stress increase due to excavation and structural loading is calculated using conventional stress distribution procedures (Westergaard, 1938) as done for the hydrocompression case. The elastic settlement for each sublayer is calculated simply using the elastic modulus (E) and the net stress increase (σ) for the relevant zone.

$$S_e = B \cdot \Sigma(\sigma h/E)$$

In these relations B and k are taken as 0.80 and 1.00 respectively. The coefficients are taken from the relevant USSR standards.

3.2. Settlement Criteria

The estimated total settlement is composed of elastic settlement and hydrocompression settlement. The total and differential settlements are separately investigated. Only hydrocompression settlements are considered to contribute to differential settlements. Since hydrocompression settlements occur upon wetting, outer part of the building is more susceptible to such settlements. Therefore the foundation mat settles more at the perimeter and less, if any at the middle part. In fact, such a settlement pattern, i.e. concave down is known to be more critical (Burland and Wroth, 1974).

The allowable total settlement according to USSR code is 10.0 cm for framed buildings. This value seems high, since 2"= 5 cm total settlement is allowed for mat foundations in general practice. Proposed differential settlement values in the literature are summarized Table 2. USSR building code allows for 0.005 slope due to differential settlements for structures where auxiliary strain does not arise during nonuniform settlement of foundations (Polshin and Tokar, 1957). When compared with other criteria it appears that the selected criteria for total and differential settlements allows for some cracking but not major within the structure.

Table 2. Maximum Differential Settlements for Buildings

Reference	*Criteria*	*Allowable Settlement (cm)**
USSR building code	s/l=1/200	3.35
Bjerrum (1963), for first cracking of panels	s/l=1/300	2.23
Bjerrum (1963), for considerable cracking	s/l=1/150	4.47
Terzaghi & Peck, (1967), no cracking	3/4 inch	1.91
Skempton & MacDonald, (1956), cracking is possible	s/l=1/300	2.23

s : hydrocompression settlement

l : length of differential settlement, half mat width

(*) Allowable settlement is determined for foundation width of 13.4 m

3.3. Calculated Settlements/Case Results

3.3.1. Morosowsk

The typical base pressure for the building groups is in the range of 73.0-77.4 kPa. The settlement analysis are performed for 77.4 kPa stress increase due to structural load (P_f) at mat base. Mat foundation with 40 cm thickness is chosen with mat base depth of 2.0 m taking structural loads and expected settlements into consideration. The unloading stress (P_e) upon mat excavation is estimated to be 33.3 kPa at the foundation base.

The modulus of compressibility for the subsoil is estimated to be 30 MPa which is an average value with little scatter. The soil profile is divided into 2.0 m subdivisions for elastic settlement calculations.

Double oedometer tests are performed under various stresses to obtain the hydrocompression strain of soil under corresponding pressures. The relevant εsl value corresponding to the present stress resulting from overburden pressure and structural load is taken from the data and utilized in hydrocompression settlement calculations. A typical example of elastic and hydrocompression settlement distribution with depth is presented in Figure 2. The elastic and hydrocompression settlements are treated separately and the distribution of cumulative settlement versus depth is sketched for each case.

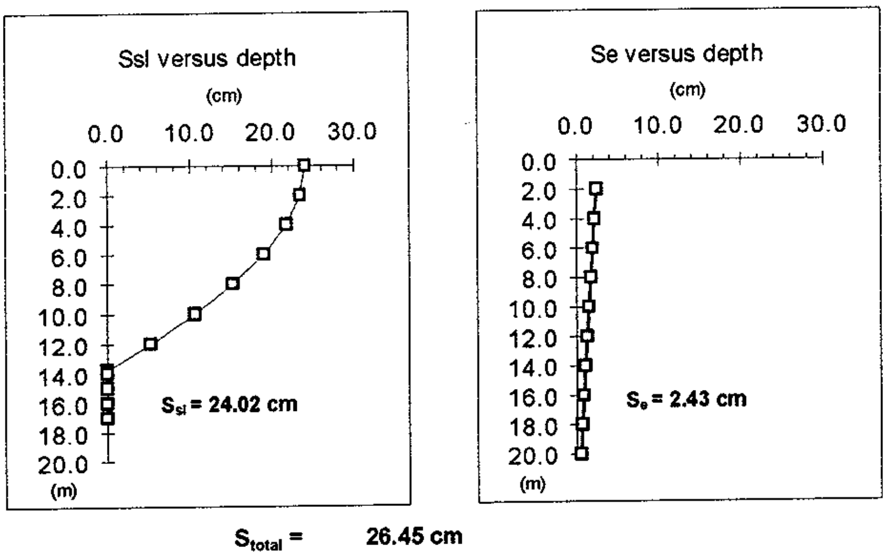
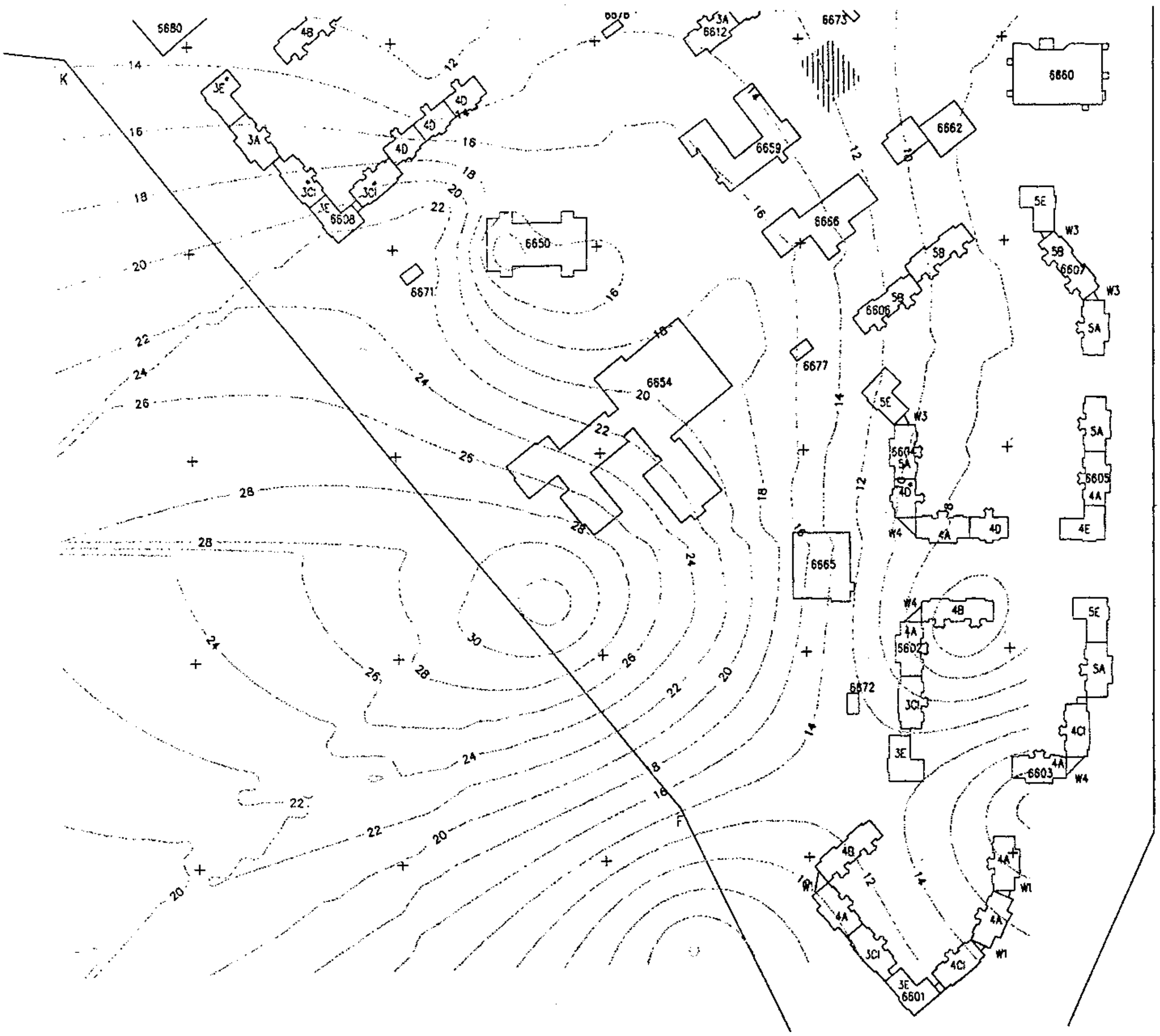


Figure 2. An Example of Settlement Distribution with Depth - Morosowsk (ZETAŞ, 1993b)

It is seen that more than 90% of total settlement results from hydrocomression settlement. The hydrocompression settlement diminishes after 14.0 m depth for the given profile. The calculated hydrocompression settlements at the site for 77.4 kPa stress increase are illustrated as settlement contour maps and presented in Figure 3. This figure indicates that hydrocompression settlements up to 32 cm take place and the settlement criteria defined in 3.2 is exceeded most of the construction area. Therefore in such zones driven piles are implemented as proper foundation types.



—11— Hydrocompression Settlement (cm)

Figure 3. Hydrocompression Settlement Contours for 77.4kPa Stress Increase - Morosowsk (ZETAŞ, 1993b)

3.3.2. Wolgograd

The similar stress distribution is used for both cases due to the similarity of structural loads. The modulus of elasticity values given approximately for every 1.0 m depth interval obtained from subsoil investigations are used for settlement calculations. The modulus for various layers is in the range of 3-15 MPa which is a measure of highly compressible subsoil. Therefore the elastic settlements contribute to nearly half of the total settlement.

The elastic and hydrocompression settlement for a typical soil profile for the loading conditions of the previous case is shown in Figure 4. It is seen that 9.23 cm hydrocompression settlement contributes to 16.21 cm of total settlement. The contribution of elastic settlement is considerable in this case in opposed to the site of Morosowsk. Therefore smaller subdivisions are made and the corresponding modulus for each layer is used in detail instead of an average modulus as in the Morosowsk case.

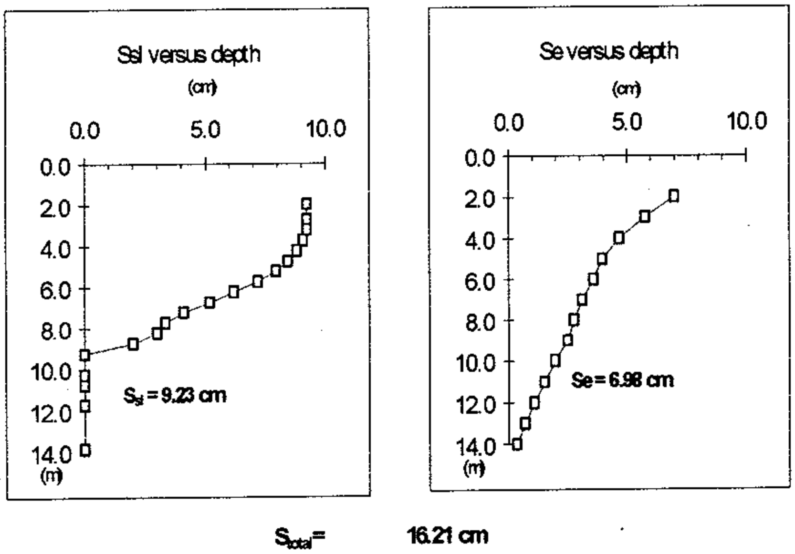


Figure 4. An Example of Settlement Distribution with Depth - Wolgograd (ZETAŞ, 1993a)

The mat width for the considered case is 13.40 m. As a result, considering the half foundation width with 0.005 slope the maximum allowable hydrocompression settlement is 3.35 cm. The maximum allowable total settlement which is the sum of elastic and hydrocompression settlements is taken as 10.0 cm as stated in the USSR building code.

The settlement for various points are calculated using this procedure and a settlement contour of the site in terms of differential and total settlements are obtained. This site characterization is used to evaluate the proper foundation types to be implemented at different parts of the site and and hydrocompression settlement contours for the site are given in Figure 5.

4. CONCLUSION

In collapse susceptible soils the structure which can resist considerable amount of pressure in the unsaturated state can go under severe settlements with the increase in water content. Therefore a foundation designed safely for the bearing capacity of the initial state can fail with the resulting settlements with the exposure of the water into the soil. Various methods are available for the determination of hydrocompression settlements. Double oedometer tests are performed

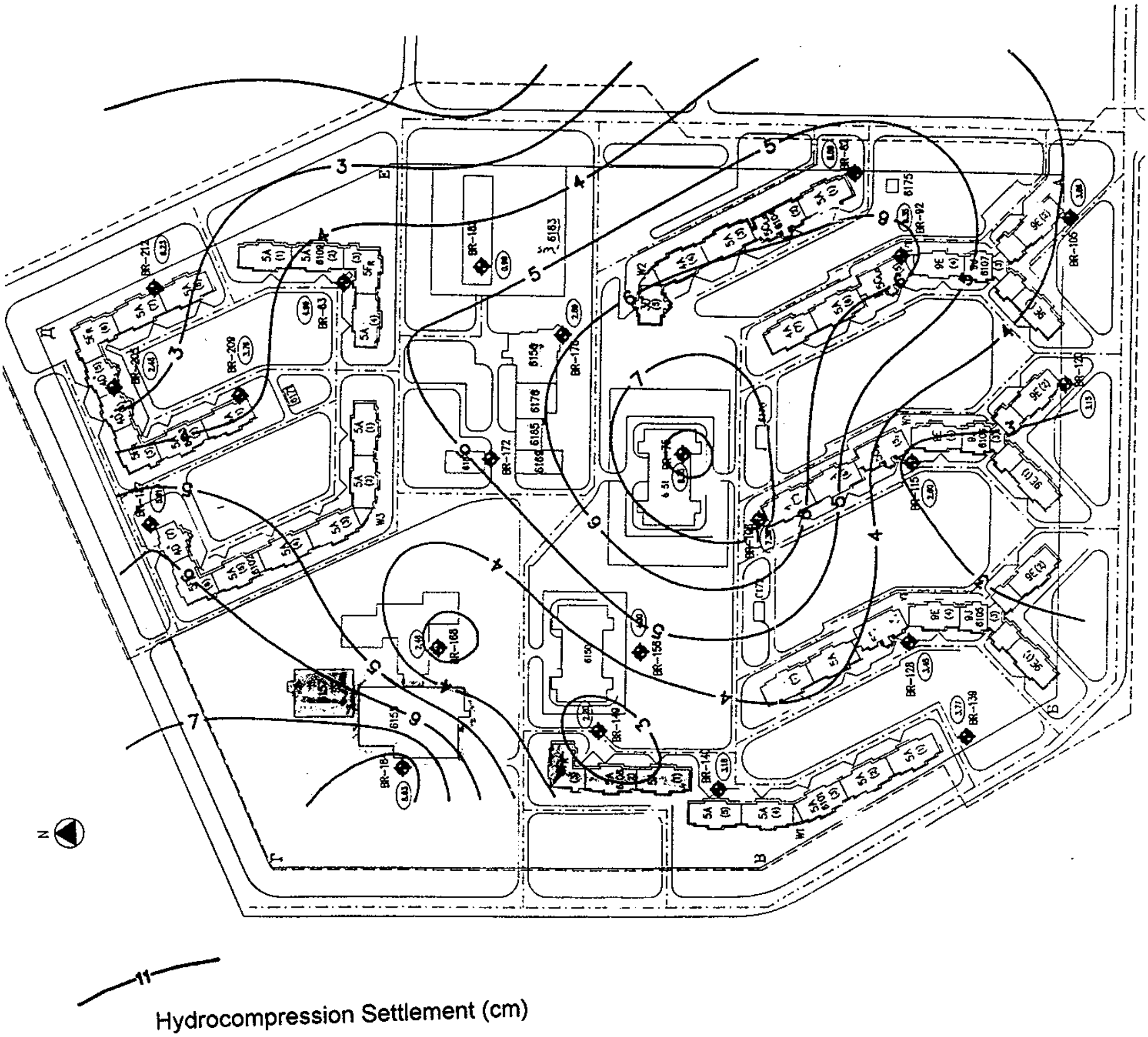


Figure 5. Hydrocompression Settlement Contours for 77.4kPa Stress Increase - Wolgograd (ZETAŞ, 1993a)

to determine the hydrocompressive behavior of the subsoil and calculate the corresponding settlement.

Two case studies involving hydrocompression settlements are presented for two major housing development projects in Russia, Morosowsk and Wolgograd. The elastic and hydrocompression settlements for both of the cases are calculated and the resulting differential and total settlements are determined to be critical for some portions of the construction areas. The calculated hydrocompression settlements for such zones lead to the selection of piled foundations instead of mat foundations considered at the original design stage.

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