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HEAVE PROBLEM IN SPREAD FOOTING IN JORDANIAN EXPANSIVE SOIL

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ABSTRACT

Spread footing foundation system is widely used here in Jordan. Cheap cost compare with other foundation type and accumulative practice makes them preferable in the construction industry. Overdesign of such footing and the lack of effective heave prediction lead to an unexpected outcome. Several residences building in Irbid province were suffered from severe crack. Subsequently, owners of these houses are enforced to leave their homes. In this paper a case study of a damaged one-storey reinforced concrete structure presented. The investigation shown that, the spread footings in the damaged part of the structure are over design, while the grade beam used to connect these footing is under design**.**

INTRODUCTION

In this paper a case history of a severely damaged resident one-story reinforced concrete structure constructed over the expansive clay of Irbid City, Jordan. Plan of the building's foundation is shown in Fig. 1, from which it can be seen that a spread foot system with a strap beam were used. The building was constructed in summer 1995 after the adopted of Jordanian code (1983) which has a mandate to have a detailed soil exploration and measured to deal with highly swell/ shrink soil. The building is constructed from reinforced concrete beams and columns with interior walls composed of hollow concrete blocks and exterior walls composed of plain concrete decorated with limestone panels. The building founded on a strap footing, single footing connected together by grade beam, bearing directly on expansive soil. The expansive soil in this site extends to 5 m below the ground surface. Originally the footing design to bear a three storey whilst a single storey was built. The contact pressure, therefore, very low and as shown later on this paper it nearly less than the swelling pressure of the soil beneath the footing.

As it will be described later in this paper, the contact pressure for this case study is less than the swelling pressures that could be developed by typical changes in soil moisture content. As such, the building is likely to heave during clay wetting, as well as to settle during clay drying. The footings are 1.5 x 1.5 m and 40 cm in thickness and located at a depth of about 1.5 m below the ground surface. The connected grade beam was 30 cm x 40 cm. Cross section of the grade beam is shown in Fig. 2.

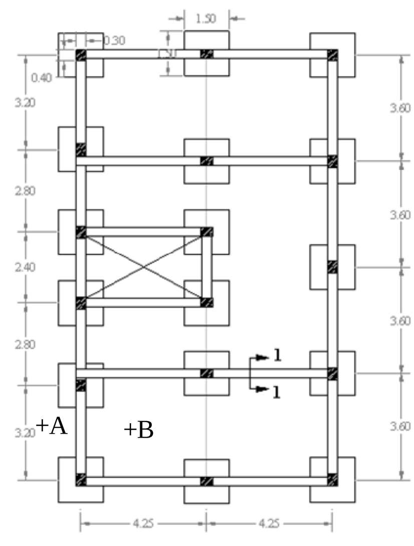

Fig: 1 Foundations' Plan

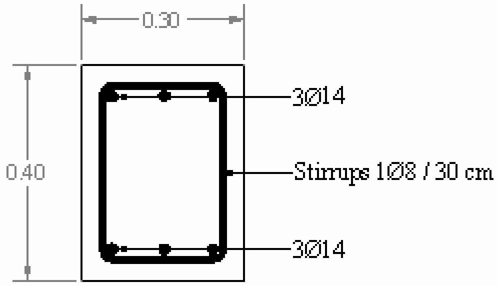

Fig. 2. Cross section of the ground beam.

The owner first noticed hairline cracks in the building walls one year after the construction. The width of these cracks increased with time, and 7 years after construction the cracks in the external walls became noticeable. In 2003, the owner enforced to evacuate partially the house since the repair cost as estimated by civil engineer exceeds the original cost of the structure. Figure 3 shows the north and west face of the damaged portion of the structure. Only the northern face suffers from severe cracking while nothing noticeable on the west face. Figure 4 shows a closed view of the northern face. From this figure a diagonal and vertical cracks are shown from the top edge of the wall until the grade beam. Figure 5 shows a measured crack opening.

Fig: 3 Damaged Building: evacuated damaged portion

PROPERTIES AND DESCRIPTION OF SOIL PROFILE

Soil profile in the Irbid District in Jordan consists of a clay layer of varying thickness from 1.5 to more than 6 m underlined by weathered materials, regolith, followed by basaltic bedrock. Irbid clays are light to dark brown in color. Grain size distribution of Irbid soil indicates that it contains 5%, 30%, and 65% of sand, silts and clay fraction respectively [Masoud, 1998; Tuncer et al. 1990; Basma et al 1995; Nuseir and Alawneh, 2002].

Fig: 4 Damaged Building: diagonal and vertical cracks

Previous investigation of Irbid soil's plasticity characteristics indicated that the liquid limit ranges from 65 to 90%, plastic limit between 15 and 40% and shrinkage limit varies from 10% to 20% [Masoud 1988]. Therefore, Irbid soil is classified according to the Unified Soil Classification System (USCS) as CH-MH. Based on these soil indices, the soil in this area are generally classified from high to very highly expansive soil according to United States Army Engineers Waterways Experimental Station method [Holtz, 1969] and United States Bureau of Reclamation [Slater, 1983]. The ground water table in the city is very deep. Furthermore, Jordan weather is semiarid with a wet season from November to May and the rest of the year is a hot dry season. Total annual precipitation in the region, including sporadic snow, varied from 300 to 850 mm with an average of 550 mm. Soil moisture content increase in the wet season and potentially decreased in the long summer season. Water content varied from 40 % near the surface and stabilized to 32% at depth of 2.5 m. Moreover in summer it varies from 22% in the surface and stabilized at depth of 2.5 m to 32%. Dry unit weight of the soil was found to be in the range of 13 to 17kN/m^3.

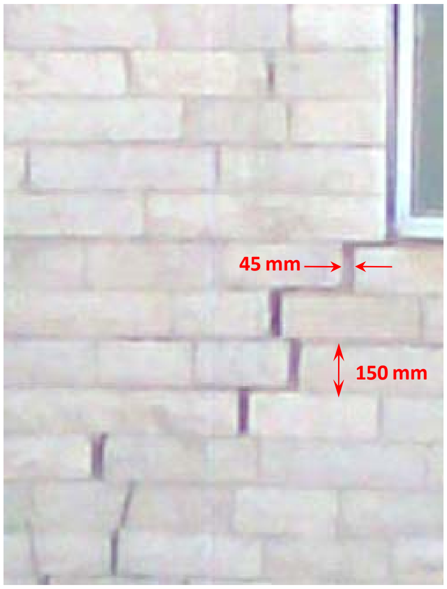

Fig. 5. Damaged Building: size of the cracks opening

LABORATORY SWELLING BEHAVIOR

Laboratory test were conducted to evaluate the swelling parameters required to predict heave using oedometer test. The test procedures were similar to those of the American Society for Testing and Materials (ASTM) under the designation no. 4546-85. The soil samples were tested in free swell and swell pressure test. In free swell the soil specimen were prepared at its natural water content and dry unit weight by compacting it into a consolidation ring of 76 mm in diameter in 20 mm in height. The compacted soil sample was placed in a consolidation cell between air-dry porous stones and subjected to a vertical confining pressure of 6.9kPa. The soil samples then inundated with distilled water and allowed to complete primary swell. On other identical sample were also prepared to test swell pressure. The second prepared specimen was confined under 6.9kPa and soaked with distilled water, but the sample prevented to swell by gradual increasing the confining stress. The test results reported at dry unit weight of $16kN/m^3$ and water content range assembled the seasonal variation of water content. Figure 6 and Fig. 7 shows the results of odometer swelling tests on remolded samples taken from the soil at the foundation level.

It's clearly shown that the lower the initial moisture content, the higher will be the swelling pressure and the amount of swell. For initial moisture contents below 24% the swelling pressure and the amount of swell increase significantly. The maximum value of 1650kPa is certainly well being above the average contact pressure of footing system selected. Moreover, the amount of swell percentage corresponding to in-situ moisture content varies between 4% at moisture content of 38% to 17% at moisture content of 24%.

Basma et al. (1995) investigate the effect plasticity cyclic swelling on this clayey soil. Two shrinkage schemes were adopted, partial and full shrinkage. The reported results showed that cyclic swelling and shrinkage has a marked influence on the expansive behavior of clays. A decrease in the swelling ability of the clays, corresponding to a reduced water absorption capability, was observed when the soils were alternately wetted and partially shrunk. On the other hand, an

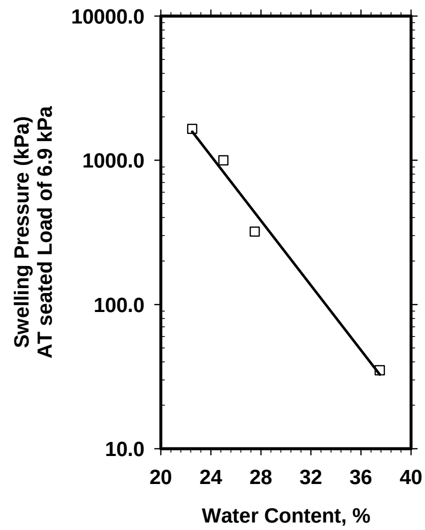

Fig: 6: Swelling pressure varies with field seasonal moisture content

increase in the swelling potential was noted when the soils were fully shrunk. In either case, equilibrium can be attained after several cycles. Similar trend were also reported by other investigators for different expansive soil [Chen, 1965, Osipov et al. 1987, Dif and Bluemel, 1991, and Day, 1994]

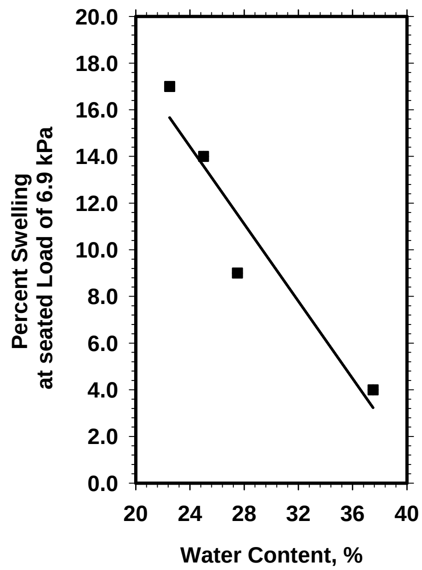

Fig 7: percent Swell varies with seasonal field moisture content

HEAVE PREDICTION

Heave prediction and measurement methods in expansive soils were proposed by many researchers [Seed et al. 1962, Johnson and Snethen, 1978, Mitchell, 1980, and Vu and Fredlund, 2004, Wray, 2005, amongst others]. Some of them are empirical in nature and rely in indices properties. The others are based on laboratory experimentation to measure swell parameters. These methods include pressure method proposed by [Johnson and Snethen, 1978] and suction methods by [Lytton, 1977]. In the former method the heave is evaluated as:

$$\Delta H = \frac{C_s H}{1 + e_0} \log \frac{P_s}{\sigma'_{vf}} \tag{1}$$

Where ΔH represents the potential heave, H is thickness of the swelling layer, C_s the swell index, e_0 the initial void ratio, P_s the swell pressure and σ'_{vf} the final effective overburden pressure. The swell index was 0.04, and the specific gravity of the soil sample was 2.80. The predicted heave as a variation of water content in point A and B, located in Fig. 1, is shown in Fig. 8. It is clearly shown from Fig. 8 the detrimental affect of water content variation in the amount of heave. However, the observed settlement in the point A was -200 mm and the observed heave in point B was +250 mm. This is mainly due to repeated cycles of wetting and drying. The inner part of the building mostly will be in partially shrinking scheme, therefore the maximum amount of swelling, heave, will occur in the first couple of years after construction. In other hand, the edge of the building will tend to behave in completed drying shrinkage, therefore the difference of swelling and shrinkage will be high.

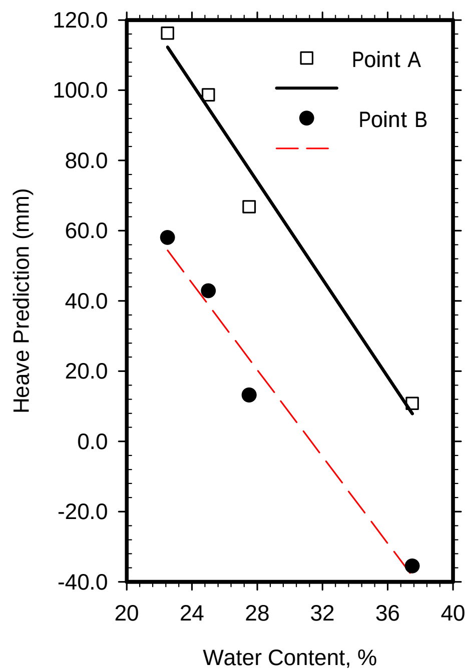

Fig: 8 Predicted heave.

CAUSES OF DAMAGE

The expansive soil in the sites as states before is subject to long dry periods and periodic heavy rains of short duration. The dry periods tend to desiccate the soil, as is clearly appear through the deep surface crack present in the back yard of the building, thereafter, in the rainy season cause large amounts of swelling in the top soil layer. In the dry season the water vapor immigrates from water table and entrapped underneath building. If it condenses it leads the soil to swell whilst the soil in the perimeter of the building shrinks due to the presence of large olive and pine trees. The swelling of inner soil zone and the shrink of soil in the perimeter of the building leads to a differential settlement which causes the cracks as shown in Fig. 4 and Fig. 5.

LESSONS LEARNED

The case study emphasized the importance of maintaining a reasonably uniform state of subsoil moisture around the buildings. Although the footing designer used a continuous grade footing beam to increase the footing stiffness to encounter differential heave and settlement, the stiffness of the used grade beam was under deigned. Following [Chen 1975] and [ACI Code, 1995], the author calculated the minimum dimension of the grade beam connected the footing in the damaged zone should be (0.30 m x 0.85 m). Therefore, it is the writers' belief that the distortion would have been significantly reduced, if an adequate grade beam design had been adopted.

CONCLUSION

In this paper a case study of a damaged one-storey reinforced concrete structure presented. The variation of moisture content in the foundation soil due to drying and wetting, leads to a cycle of shrinking and swelling. Differential heave between the soil underneath the building and its parameter leads to a severe cracks in the structure northern face. The Owner enforced to evacuate the damaged portion of the structure since the cost of repair is higher than the reconstruction cost of this portion. Moreover, calculated footing area in the damaged part shown that, the footing itself is over design, whilst the grade beam used to connect the footing is under design.

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