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A CASE STUDY ON EXPANSIVE SOILS AND ROCKS OF AL-KHOD IN NORTHERN OMAN

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ABSTRACT

A case study of damage due to expansive soils and rocks in Northern Oman has been studied. Geological and geotechnical investigation revealed the presence of very stiff to hard silty clay with mudstone. Swell pressures up to 330 kPa, and swell percent values up to 70 were measured. Smectite (montmorillonite) and illite clay minerals were identified as being the main clay minerals present in the soils and rocks. A detailed investigation into the damage to the different building elements has been undertaken to study the mechanism of structural damage, to establish the cause of such damage and to recommend the appropriate measures to be taken for the construction of buildings founded on expansive soils and rocks in Oman.

KEYWORDS

Oman, Expansive soils and rocks, Damage, Geology, Swelling potential, Case study

INTRODUCTION

The Ministry of Defense Married Quarters Village at Al-Khod which is selected as a case study in this paper, was constructed during May 1985 to July 1986 and due to the lack of historical evidence of the presence of the expansive materials, no particular site investigation of the ground was carried out. The village consists of 92 houses of one and two stories as well as communal buildings such as a mosque, a health clinic and a welfare shop. The walls of the building structures are generally constructed with solid concrete blockwork whereas the floor and roof slabs are of reinforced concrete. The structures are supported on reinforced concrete strip shallow foundations. COWIconsult (1988) reported that the first signs of structural cracks in the buildings began to appear immediately after the construction of the building due to flooding of the village area soon after a period of very heavy rainfall. It is very surprising to note that, in these irregular shaped buildings, the widths of the horizontal, vertical and diagonal cracks developed vary from hairline cracks of the order of 0.1 mm to very severe cracks about 75 mm.

The paper presents a brief damage case study of house number 18 based on its damage assessment made in October 1996. The aims of this investigation are to study the mechanism of structural damage to the building, to establish the cause of such damage, and to recommend the appropriate measures to be taken for construction of buildings founded on expansive soils and rocks.

GEOLOGY OF THE SITE

The site is located about 40 km west of Muscat and opposite to the Armed Forces Hospital. A topographical survey of the site shows clearly several areas within the site to be susceptible to flooding. The expansive soils and rocks at Al-Khod were tentatively dated as middle to late Oligocene and Miocene. From Sib map (BRGM, 1986), it appears that the site is underlain by Tertiary deposits. The main lithologies are marls and mudtones which are variable with changes in colour, structure and lithology both laterally and on depth. Al-Rawas (1993) indicated that the occurrence of expansive soils and rocks in Al-Khod is largely within the Tertiary deposits.

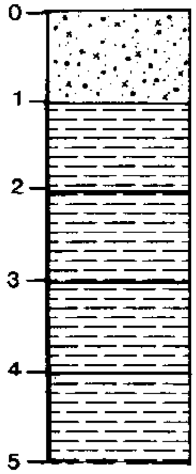
FIELD AND LABORATORY INVESTIGATION

A soil survey was carried out by COWIconsult (1988) to investigate the soil conditions and determine the cause of cracking in the houses. Two deep trial pits were excavated to recover samples for laboratory testing. Two boreholes were carried out by Yahya Costain (1988) near house numbers 19 and 20. The soil profile of the two boreholes is similar, therefore, a typical bore log is shown in Fig. 1.

A soil investigation work carried out by Swissboring (1994) for a site which is located approximately 500 m west of the damaged houses indicated a 6.0 to 13.0 m thick stratum of yellowish brown, very stiff to hard, very silty CLAY with scanty thin layers of gypsum crystals. The clay layer is in turn underlain by a 5.0 to 15.0 m thick layer of yellowish brown to light grey, very stiff to hard, very silty CLAY, interbedded with MUDSTONE and thin layers of gypsum crystals. This layer is underlain by a 3.0 to 6.0 m thick layer of black, very hard, silty CLAY/MUDSTONE.

Twelve samples recovered from the trial pit and borehole near

Depth (m) Symbol Description of Materials



Brownish grey, dense, slightly silty, fine to coarse SAND and GRAVEL with cobbles.

Yellowish brown, very stiff to hard, very silty CLAY with occasional thin layers of gypsum crystals.

Fig. 1 Typical soil profile.

house number 19 were tested. The basic geotechnical data of these samples are shown in Table 1. All the basic geotechnical tests were conducted in accordance with BS 1377 (1975). The majority of the samples (nine samples) are classified according to the Unified Soil Classification System as clay of high plasticity whereas samples MQV1, MQV4 and MQV2 are classified as silt of high plasticity (MH) and as silt of low plasticity (ML), respectively.

MINERALOGY

The mineralogy of the soil samples has been tentatively identified using the chart developed by Holtz and Kovacs (1981). This chart has been superimposed onto the swelling potential chart of Dakshanamurthy and Raman (1973) as shown in Fig. 2.

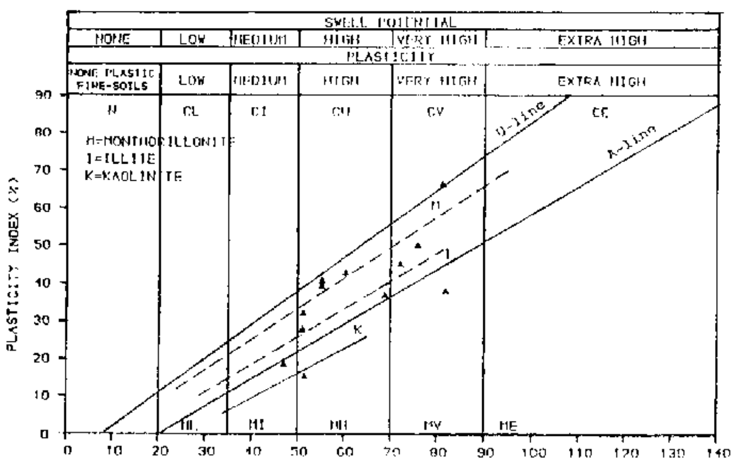


Fig. 2 Swelling potential classification (Dakshanamurthy and Raman, 1973) and mineralogical classification chart (Holtz and Kovacs, 1981).

From the chart, it is seen that samples MQV1, MQV2 and MQV4 were found to be located in the kaolinite zone, and sample MQV3 in the illite zone. On the other hand, samples MQV5, MQV6, MQV7 and MQV9 are located in the zone between illite and montmorillonite, and samples MQV8, MQV10, MQV11 and MQV12 are concentrated in the montmorillonite zone.

SWELLING POTENTIAL

Atterberg limits have been employed in this paper to determine indirectly the swelling potential using the criteria developed by Dakshanamurthy and Raman (1973). From the results shown in Fig. 2, it is seen that with the exception of one or two samples, all samples were found to be located in the ***high*** to ***very high*** ranges of swelling potential.

The free swell of samples MQV1, MQV2, MQV3 and MQV4 was measured directly (Table 1). The samples swelling potential ranges between 45 - 95 % which is significantly high. From the results, it is evident that the swelling potential predicted by Dakshanamurthy and Raman (1973) is consistent with the measured swelling potential values for the soil. Furthermore, Al-Rawas and Woodrow (1992) presented a hazard map showing the distribution of expansive soils in Oman in which the site under study has been classified as a site containing expansive soil of ***high*** swelling potential. Thereby, corroborating the test results very well.

A soil survey carried out by Yahya Costain (1988) showed that the soil was active in swelling with a swell pressure of approximately 100 kPa. However, Swissboring (1994) reported swell pressure values of 112, 225 and 337 kPa for samples recovered from a site which is located approximately 500 m west of the damaged houses. Based on the extent of damage observed and the swell pressure values reported, it is estimated that the swell pressure of the soil beneath house number 18 is in excess of 200 kPa.

DAMAGE STUDY

The detailed investigation into the damages to the different elements of the building has been undertaken through visual inspection of the damaged elements, measurements of the cracks width and the photographs of the elements.

Damage Assessment on Front Face of the building

It was observed that almost all the exterior walls are free from the cracks except a few hairline cracks. It seems that there is negligibly small changes in the moisture content of the soil under the walls in the front face of the structure and the front walls are carrying heaviest loads on them due to the largest rooms and the highest walls as shown in Fig. 3.

Damage Assessment of the Living and Master Bed Room Building Elements

The living room wall facing the backyard has developed the horizontal and diagonal cracks of widths varying from 1 to 5 mm. These cracks are classified as *slight* degree of visible damage according to the BRE (1981) classification. No signs of any distortions are visible in the ground floor and first floor slab of the living and master bed room respectively.

Table 1. Geotechnical properties of samples tested (after COWIconsult, 1988).

Sample	Depth (m)	w (%)	γ_d (kN/m^3)	w_L (%)	w_P (%)	I_P (%)	% < 63μm	USC	FS (%)
MQV1*	0.3-0.6	9.7	-	52	37	15	79	MH	45
MQV2*	0.6-1.0	20.3	16.8	47	29	18	64	ML	45
MQV3*	1.5-1.7	25.2	16.4	69	33	36	86	CH	70
MQV4*	2.5	23.7	17.8	82	44	38	87	MH	95
MQV5	3.0-4.0	20.0	-	76	26	50	84	CH	-
MQV6	5.0-6.0	20.0	-	72	27	45	76	CH	-
MQV7	7.0-8.0	18.0	-	51	21	31	66	CH	-
MQV8	9.0-10.0	20.0	-	81	14	67	87	CH	-
MQV9	11.0-12.0	12.0	-	51	24	27	86	CH	-
MQV10	13.0-14.0	12.0	-	56	16	40	88	CH	-
MQV11	15.0-16.0	10.0	-	60	17	43	86	CH	-
MQV12	17.0-18.0	14.0	-	56	17	39	66	CH	-

w = water content, γ_d = dry unit weight, w_L = liquid limit, w_P = plastic limit, I_P = plasticity index, USC = Unified Soil Classification, FS = free swell, * = trial pit samples.

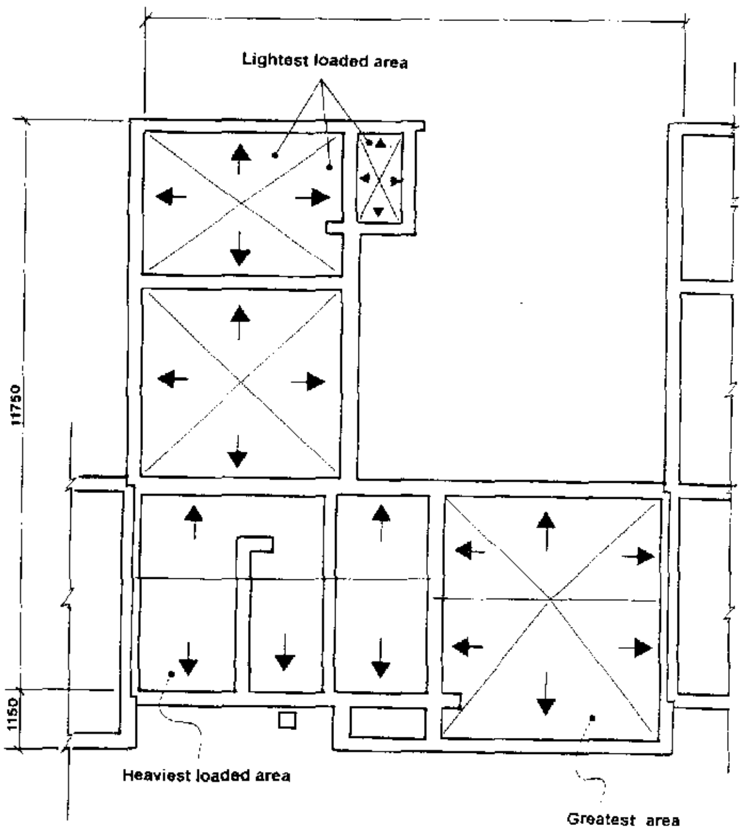


Fig. 3 Plan of house number 18.

It turns out from the damage assessment of these walls that extensive damage has occurred to the walls facing the backyard. This sustained significant damage to the walls has occurred due to the differential foundation heave caused by non-uniform change in soil moisture content. The backyard has been subjected to considerable watering for shrubs and plants throughout the year. Since, the walls were not designed to resist the stresses developed by additional bending moment and shear force due to the interaction between the expansive foundation soil and the structure, consequently the distress has been relieved in the forms of cracks in the walls.

Dining and Bed Room Damage Assessment

Extensive damage has also occurred to the dining room (on the ground floor) walls and of the bed room (on the first floor, above the dining room). The horizontal crack developed near the roof slab of the dining room has width between 5 to 10 mm. It is seen that the east-wall on the first floor is very badly damaged due to the development of the predominantly diagonal cracks of 10 to 25 mm width. Such wall damage falls into moderate to severe degree of damage as per BRE (1981) classification.

Damage Assessment of Kitchen, W.C and Bath Room Building Elements

Very severe cracks have developed to the walls of the kitchen (on the ground floor) and of the W.C and bath room (on the first floor above the kitchen) as shown by Figures 4 to 6. It is very surprising to note from Fig. 4 that the width of the same cracks of the wall located at the first floor vary from 30 to 50 mm. Figure 4 shows that the window frame has loosened and moved slightly away from the wall due to severe cracking around the window opening. Generally, width of most of the cracks lie within a range of 20 to 30 mm.

Figure 5 shows a combination of the horizontal, predominantly diagonal and vertical cracks. Generally, the width of the cracks measured is between 10 to 30 mm. The kitchen walls show the worst damage in comparison with the damages to the majority of the walls of the building. It is most likely that the problem has been aggravated by the defects in the water supply in the kitchen itself. The wall cracks are classified as very severe degree of visible damage in accordance with BRE (1981) classification. Very severe diagonal cracks are observed from the backyard face of the same wall (Fig. 6) varying between 30 to 75 mm.

Distribution of Damage Level

Based on a detailed damage survey of the cracked elements of the building and BRE (1981) classification of visible damage, Table 2 shows the percentage distribution of the cracks with respect to

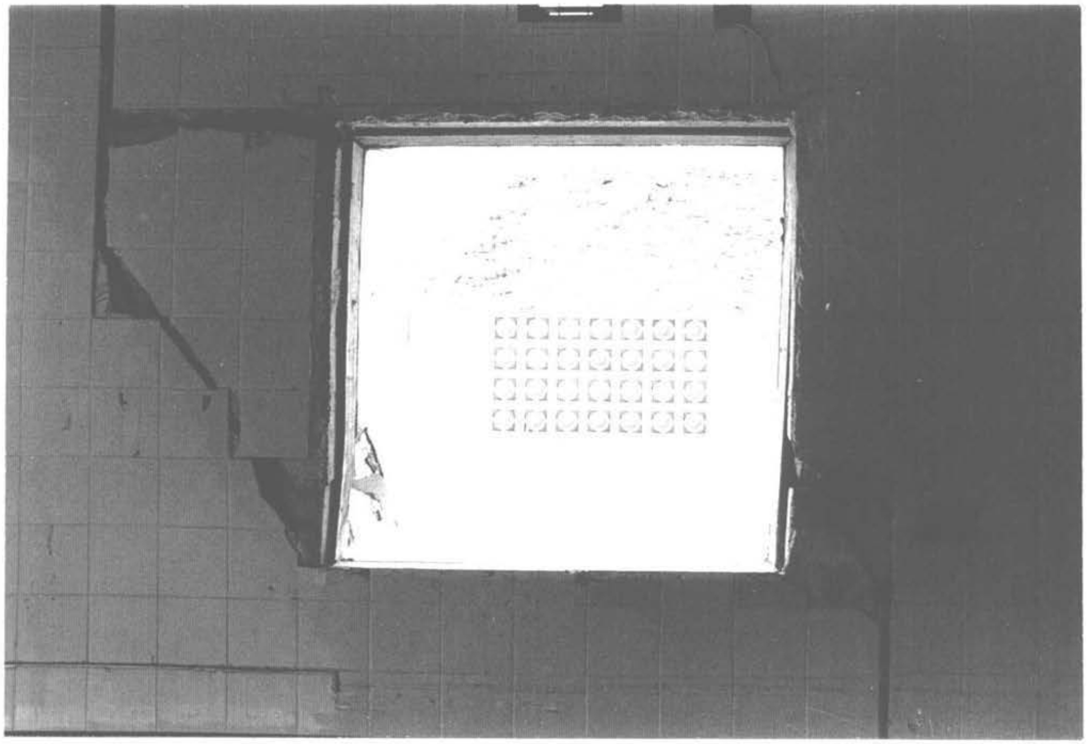


Fig. 4 Very severe cracks in the kitchen wall.

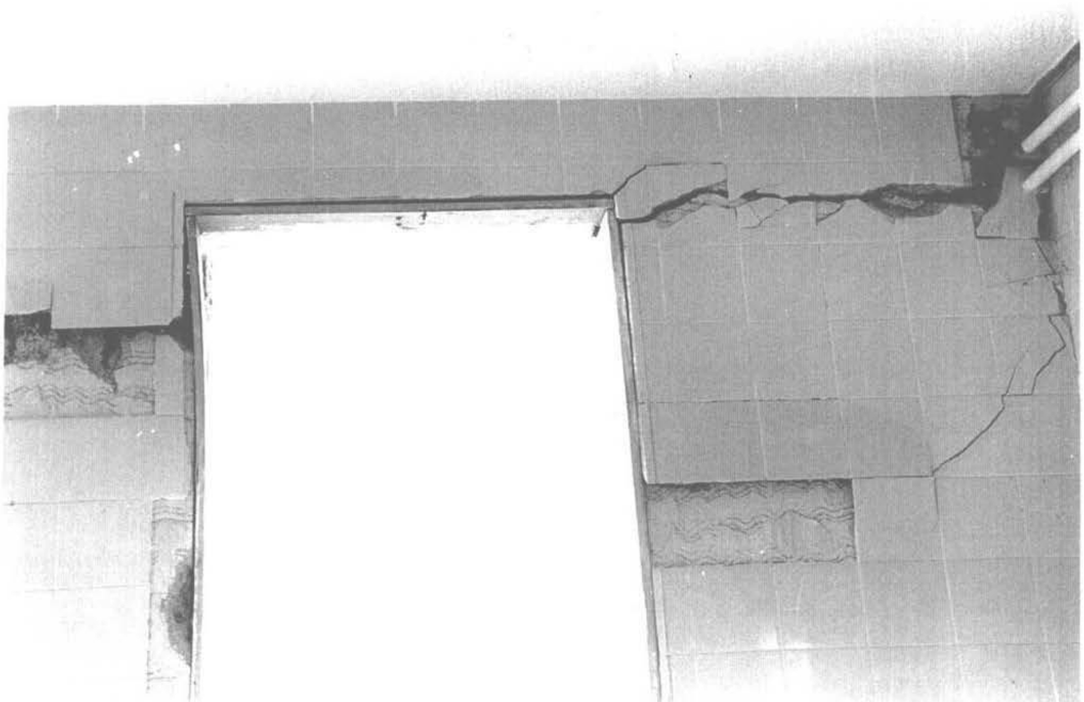


Fig. 5 A close up view of the kitchen wall showing diagonal and horizontal cracks.

Table 2. Distribution of damage level according to BRE (1981) classification.

Damage Level	Very Slight <0.1 mm	Slight <5 mm	Moderate 5-15 mm	Severe 15-25 mm	Very Severe >25 mm
Percentage Distribution	5	30	15	20	30

Fig. 6 Back elevation of house number 18 showing extensive damage to the wall.

different damage level. The paved backyard floor is subjected to significant heave of approximately 20 mm and lesser heave near the building walls.

POSSIBLE REMEDIAL MEASURES

The remedial measures are briefly described in the following paragraphs:

1. Surface drainage must be provided all around the building and the ground surface should be graded.
2. Horizontal moisture barriers should be constructed around the building preferably in the form of concrete and/or asphalt apron to prevent excessive intake of the surface moisture.
3. The interior plumbing including sewer and water supply lines should be checked for leakage periodically.
4. All house gardens should be paved, to prevent the effects of over-irrigation.
5. No shrubs or ground coverplants should be retained or introduced in future within 3 m of house structure gable ends and no trees planted within 5 m of house foundation pads.
6. Prompt investigation of any reported structural damage which if found to be associated with expansive strata must include identification and removal of any water sources.

CONCLUSIONS

The following conclusions may be drawn.

1. Some of the facts which contribute to or aggravate the damage occurring to houses include:
   (i) Failure to recognize the presence of expansive soils and rocks within the site due to the lack of any historical evidence of any construction problems.
   (ii) Failure to carry out soil investigation prior to the construction of the Married Quarters Village.
2. The damage to the houses was due to the ground heave caused by the swelling of soils and rocks in response to the increase in their moisture content.
3. It is very surprising to note in irregular shaped building that the widths of the horizontal, vertical and diagonal cracks developed in the walls vary from hairline cracks of the order of 0.1 mm to very severe cracks about 75 mm.
4. The extent of damage to the houses is a function of a combination of geological, mineralogical, constructional and environmental factors.
5. Based on the observed cracks and BRE (1981) classification of visible damage, it was found that 50% of the cracks are classified as severe to very severe, 15% as moderate and 35% as slight to very slight.

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