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Discussion

Discussion on "Aiban SA (2006) Compressibility and swelling characteristics of Al-Khobar Palygorskite, eastern Saudi Arabia. Engineering Geology 87(3–4):205–219" ☆

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1. Mineral evolution

The evolution of expansive clay minerals including palygorskite in the sedimentary soils of eastern Saudi Arabian must be understood in light of the prevalent climatic and environmental conditions and the geological origin of the parent materials. This part of the Arabian Peninsula falls within the Hot Dry (B) climate according to the Köppen Climate Classification. The average annual rainfall and evaporation are 50 mm and 1250 mm, respectively. The region does not receive any appreciable precipitation for at least eight months of the year, that is, from April through November. During these months, the average temperature ranges from 15 °C to 45 °C and can reach up to 50 °C, remaining high for several successive days in the summer. Relative humidity ranges from 45% to 85% and remains on the high side during summer. Groundwater salinity is five times that of typical seawater, and the water is characterized by a specific gravity and dynamic viscosity of 1.207 and 1940 μN s/m^2, respectively, compared with 0.999 and 1010 μN s/m^2 for distilled water at 20 °C (Al-Amoudi and Abduljauwad, 1995).

Eastern Saudi Arabia is part of a rectangular depression, representing a buried basement configuration, that rises at a rate of approximately 1 m/km westward and northward from the Persian Gulf. The above mentioned harsh climate and environment, coupled with fluctuating seawaters in the Late Pleistocene, initiated the development of calcareous soils in the depression (Abduljauwad, 1994). During that time, glaciations resulted in a global drop in sea level with the Gulf waters being lowered by 120 m below the current mean (Bell, 1993). The post-glacial transgression steadily increased the sea level and eventually refilled the Gulf basin. This was followed by eustatic sea-level oscillations, which brought about further transgressions during the Holocene. All of these oceanic alterations modified the parent soils of the Permian, Cretaceous, and Tertiary periods by extensive blending with the evolving marine sediments (Azam, 2000). The resulting soils were highly heterogeneous and comprised of

☆ The author has presented in this paper some interesting laboratory test results related to the compressibility and swelling characteristics of two clayey soils in Al-Khobar, eastern Saudi Arabia. Based on his experience with expansive soils from that part of the globe, the discusser would like to furnish the following comments.

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argillaceous shale and calcareous materials such as dolomitic limestone, marl, and chert. As noted by the author, such materials are commonly found in several local soil formations of the Phanerozoic succession: Dammam, Dam, Hadrukh, Rus, and Hofuf.

The author has not elaborated on the geological origin of palygorskite in local soils but has indicated that the age of such sediments ranges from Pleistocene to Cretaceous. The origin of this mineral in local deposits can be one or more of the following: (a) *detrital*, derived from argillaceous rocks by weathering and/or erosion and therefore pre-Pleistocene; (b) *diagenetic*, derived from the particle–fluid interactions in the evolving alkaline environment of the Gulf basin after deposition and hence post-Pleistocene; and (c) *neoformation*, formed by precipitation from solutions that may be pre-Pleistocene or post-Pleistocene. Given the above mentioned geological activity together with the harsh climate and environment of the region, post-depositional diagenesis of argillaceous shale and calcareous materials appears to be the primary mechanism of palygorskite development in indigenous soil formations. Restrained water mobility in a shallow lagoon and an abundance of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} in the pore water catalyzed the physical and chemical weathering processes (Mitchell and Soga, 2005). Alongside palygorskite, other more abundant clay minerals species including smectite (montmorillonite and nontronite), hydrous mica (illite), and kaolonite as well as secondary minerals such as gypsum and anhydrite were also formed. Further, the annual average precipitation of 50 mm (lower than 300 mm) inhibited subsequent transformation of palygorskite to smectite despite the unstable nature of the former mineral (Singer and Norrish, 1974). The present-day expansive clay sediments in eastern Saudi Arabia generally possess mixed mineralogy and contain both clay and non-clay materials (Azam, 2000).

2. Mineral identification

The author has confirmed the inherent heterogeneity of materials in his subsurface investigations of the study site and has even shown crystalline gypsum in Fig. 2. Therefore, it would be extremely difficult to obtain 100% palygorskite samples in the area. However if this was the case, conclusive mineralogical identification of the investigated samples should have been provided. This would have included the use of size separation, chemical pre-treatments, and pre-heating of samples for X-ray diffraction as well as conducting cation exchange capacity and differential thermal analysis on the samples. The last one is particularly applicable to this study as the author has rightly noted the different types of water associated with palygorskite, which exhibits four endothermic peaks due to the loss of each type of water (Mitchell and Soga, 2005).

Whereas the sample preparation technique for X-ray diffraction analysis is not described in the manuscript, it appears from Fig. 4 that bulk mineralogy of randomly oriented samples was determined. It is well documented in the literature that such samples result in an exposure of the different crystal faces thereby revealing several d-spacings. This leads to weak diffraction peaks in specimens containing clay minerals, for which basal spacing intensity is reduced (Moore and Reynolds, 1997). Since detailed clay mineral identification was not conducted during the study, some of the clay mineral species went undetermined. In the absence of size separation, the unidentified clay minerals were most probably covered by palygorskite thereby resulting in 100% palygorskite for both of the investigated samples. The discusser believes that at least one of the samples contained sizeable amounts of smectite and illite clay minerals. This is evident from the X-ray diffraction pattern of the “Gray Material” in Fig. 4 that shows a distinct shoulder between 4° and 8° angle (2θ). This is corroborated by the high liquid limit and plasticity index and the low shrinkage limit of the “Gray Material” compared to that of the “Brown Material”.

3. Microstructural observation

The microstructural observations given in Figs. 5 through 7 do not confirm the presence of palygorskite by being completely devoid of the expected fibrous or lath-like appearance of the mineral. Instead the usual clay sheets are seen in all of the micrographs and the elemental composition (EDX spectra) exhibits the typical clay-forming elements: Si, Na, K, Mg, and Al. Because of variation in scales, comparison of various micrographs is not always straight forward. Further, Fig. 7 is erratic as micrographs b and d do not pertain to the “Gray Material” because these are labeled “Brown Material” in Fig. 5 (micrographs c and d, respectively) or vice versa.

4. Oedometer tests

The author has presented the oedometer test results but some of the conclusions are not based on confirmatory tests and/or rigorous analyses. The comparison between core and remolded samples in the free swell tests (Figs. 8 and 12) is primarily attributed to structural changes due to remolding and yet the morphology of the latter samples is not given in the paper. The effect of sample disturbance could have been determined by applying corrections to the constant volume test data of undisturbed samples (as described in ASTM Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils (D4546–96)) and comparing the corrected data with that of the remolded samples. A comparison between the "Gray Material" in Fig. 8 and the "Brown Material" in Fig. 12 reveals that both of the materials inhibited the three habitual stages of swelling, namely; initial, primary, and secondary. This is because the investigated materials were quite stiff similar to weak rocks as seen in Fig. 2 and supported by the data given in Figs. 9, 10, 11, 13, 14, and 15. Whereas the compression index (Cc) and the swelling index (Cs) have not been determined from the *e*-log *p* curves, the investigated materials behaved quite differently from clays ($0.15 \leq Cc \leq 0.30$) and rebounded almost elastically. Among the two core sample, the higher average swell potential (15.2%) of the "Gray Material" compared to that (8.9%) of the "Brown Material" must be attributed to the possible presence of smectite and illite (Fig. 4) and the low natural moisture content (Table 2) of the former sample. The presence of a greater number of discontinuities in the "Brown Material" also consumed part of the swelling movement thereby resulting in a lower swelling potential.

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