Chapter 11
Identification of Saudi Arabian Soil Appropriate for Stabilised Earth Construction

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11.1 Introduction

Historically, earth has been used as a construction material in every continent of the world. According to Hadjri et al. (2007), stabilised earth is an alternative construction material that is economically and environmentally beneficial compared to the conventional ones. Practice of earth construction in Saudi Arabia nowadays mainly remains in conserving and restoring architectural heritages (Zami 2017). According to Mortada (2016), adobe and sun-dried mud bricks have been in use for construction purposes since ancient time in Arabian Peninsula (King 1998) and were commonly used in building during pre-Islamic eras in the Saudi Arabia. During the time (AD 622) of Muhammad (the prophet of Islam), mud brick (libin in Arabic) was used constructing his residence and the mosque in Medina too (Mortada 2016; King 1998). According to King (1998), mud is used throughout central Arabia Najd, in both the sand desert areas and in the fertile valleys, much of the interior of Yemen and Oman, which also extends northwards into Iraq and the Syrian Desert. According to King (1998), in the recent past, the presence of earth buildings in the central Arabian towns has a long ancestral relation that is proved by the excavations at Al-Rabadha on the western edge of Najd. The buildings in this excavation were found used sun-dried earth blocks from the centuries preceding Islam through to Abbasid times. Amongst hundreds of rich heritage sites, Addiriyah is one of the most prominent earthen architectural heritage sites of Saudi Arabia (Zami 2014). This important settlement was located on an elevated ground which is 700 m above the sea level at Najd central plateau of the Arabian Peninsula on the banks of Wadi Hanifah. This Wadi Hanifah is considered as the most prominent feature of Addir'iyah and an important geographic and topographic natural formation within the Najd region. Throughout the

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B. V. V. Reddy et al. (eds.), *Earthen Dwellings and Structures*,
Springer Transactions in Civil and Environmental Engineering,
https://doi.org/10.1007/978-981-13-5883-8_11

past centuries, many tribes were attracted by its suitable and favourable settlement conditions, such as natural features, rich fertile clay soil, and water combined with land formation (Ar-Riyadh City Web Site 2014). Therefore, the Addiriyah settlements during the past centuries utilised soil for construction from the bank of Wadi Hanifah. There are settlements of earth construction that are up to date existing in Saudi Arabia other than Addiriyah but source and type of the soil used in buildings of these settlements are unclear in the literature. Furthermore, there are local soils other than clay that are not commonly used as building material, but existing literature appears to be insufficient to prove that these soils are unsuitable for stabilised earth construction. Therefore, this paper investigates on the typologies of locally available soils appropriate for stabilised earth construction. In order to achieve the aim, this paper critically reviews the literatures, observes on CSEB samples and refines the information to establish whether stabilised earth construction is sustainable considering availability of the soil in Saudi Arabian context.

11.2 Availability of Earth in Saudi Arabia for Construction Purposes

According to Al-Amoudi et al. (2010), there are four types of soil (i.e. sand, marl, clay and sabkha) found in Saudi Arabia's eastern province. Marl soil is unique, most suitable compared to sand, clay and sabkha, therefore extensively used in all types of construction sites including road bases, embankments and foundations (Alshammari and Hamid 2016). Netterberg (1982) defined marl as a soil or similar to rock material that contain about 35–65% calcareous material and varying percentage of clay content (Pettijohn 1975; Qahwash 1989). According to Ahmed (1995), calcareous soils (marl) are commonly used in the highway construction and foundations of buildings. A critical review of the literature reveals that calcareous soils (marl) have drawn very little attention from the geotechnical engineers and researchers despite their wide and extensive use in the construction sites all over the world (Ahmed 1995). Current study shows that calcareous soils (marl) are extremely sensitive to the moulding and testing moisture contents; strength and durability of the calcareous soils can be significantly improved by chemical stabilisation using cement despite the fact that the calcareous soil has poor properties (Ahmed 1995).

According to Aiban (1995), calcareous soil is available in the eastern Province of Saudi Arabia in many places, such as Abqaiq, Dhahran, Dammam, Abu Ali, Hofuf, Berri, Fadhli, Jubail, Abu Hadriyah and Safaniyah areas, as shown in Fig. 11.1. Calcareous soils found in eastern Saudi Arabia can vary depending of their colour, plasticity, physical, mineralogical, chemical composition and also engineering properties. Marl colours could be white, dark or light grey, pink, yellow and brown depending on the locations they are quarried from. Moreover, depending on the composition, especially the clay mineral type and content, the plasticity of marl can vary from

Fig. 11.1 Vicinity map of eastern Saudi Arabia showing locations of major marl quarries in eastern Saudi Arabia. *Source* Al-Amoudi et al. (2010)

none to moderate (Aiban et al. 1998). However, the literature review reveals that a number of studies were carried out on the chemical stabilisation of limited types of marl soil sample blocks; it appears that the compressive strength and durability of marl soil sample blocks significantly improve because of chemical stabilisation. But the ongoing research only considers marls used only for the ground preparation or supporting substructure of the building. Current research in Saudi Arabia does not concentrate at all marls considered for constructing superstructures of the building, such as load-bearing wall, column and floor slabs.

In Fig. 11.2, the types of Saudi Arabian soils are roughly classified. According to Beaumont et al. (1976), the Arabian Peninsula is dominated by desert soils, including lithosols and sand. Lithosol is zonal shallow soil, consisting of imperfectly weathered rock fragments. In general, the characteristics of these soils are: poorly developed soil horizons, very low humus content, predominant direction of the water movement in the soil profile upwards in the sabkah areas resulting in the accumulation of salts and

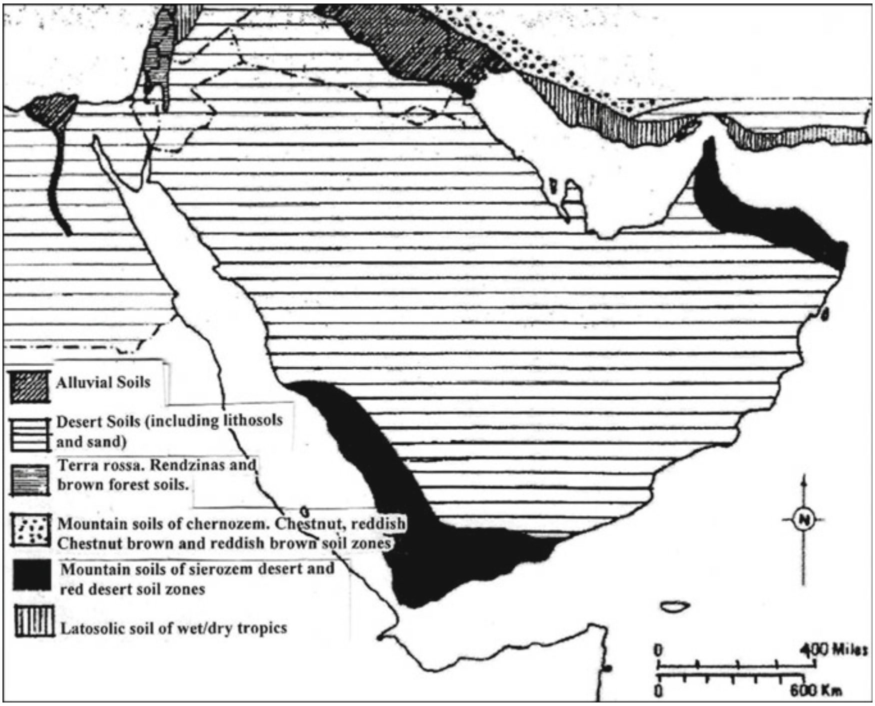

Fig. 11.2 Soil groups of the Middle East. *Source* Beaumont et al. (1976)

other soluble products in the upper layers, rocky stony surface layers of pebbles or moving sand soils (dunes). Other soils found that are not specified in Fig. 11.1 include alluvial soil (soils in river beds and wadis). This soil is sometime fertile or infertile due to high water tables and salt accumulation in the upper soil layers; sometimes, lush vegetation can be found on the higher river banks (Cochrane 1977). Historically, this alluvial soil of Wadi Hanifa was used for the construction purposes in the settlement of Addiriyah. Empirical research on the geotechnical and engineering properties and behaviours of the locally available alluvial soil appears to be very few. Research on modern stabilisation techniques on this type of soil is inadequate; therefore, this needs a long-term research commitment and investments on ways and means to improve the durability and strength of this soil if considered for building construction.

Expansive clay soil is available in different areas of Saudi Arabia and traditionally used for vernacular earth houses. There is a study carried out by Hameed (1991) finding the location of expansive soil in the eastern province of Saudi Arabia and its characteristics. It was found out that expansive soils exist in Al-Qatif and Al-Hofuf areas. Formation and behaviour of these expansive soils are influenced by climate and geology of the area. Clays in both areas are highly plastic, possessing very high swelling potential and rich in smectite, illite, dolomite, palygorskite and kaolinite.

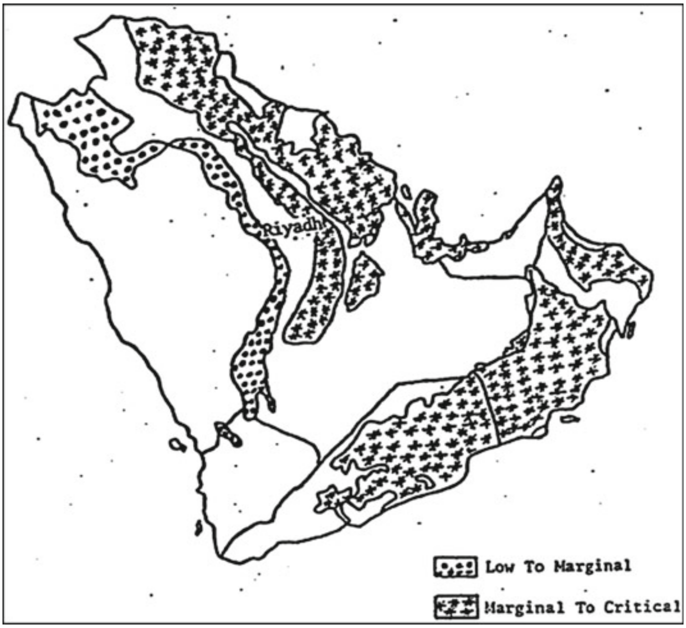

Fig. 11.3 Hazard map for potentially swelling soils of Arabian Peninsula. *Source* Slater (1983)

According to Hameed (1991), the expansive shale zone includes three major development centres, namely Tabuk, Tayma and Al-Ghatt. Expansive soils have also been reported in several other areas, such as Al-Madina and Al-Hofuf (Dhowian et al. 1985) and Al-Qatif area (Abduljauwad and Rafi 1990). Figure 11.3 provides an approximate guide to the suspected distribution and extent of potentially swelling soils (Slater 1983). A study was carried out by Ahmad (1988) whereby engineering properties and behaviour of these expansive clays of Qatif were determined. The results of the investigations showed that Al-Qatif clays are highly expansive and heterogeneous in nature, and 4–8% of commercial lime should be preferred for preconstruction treatment. According to Ahmad (1988), the regions with expansive soil formations in Saudi Arabia are shown in Fig. 11.4.

However, the researches on expansive clays concentrate only for the ground preparation or supporting substructures of the buildings. Current research on expansive clays in Saudi Arabia does not concentrate on constructing superstructures of the building, such as load-bearing wall, column and floor slabs.

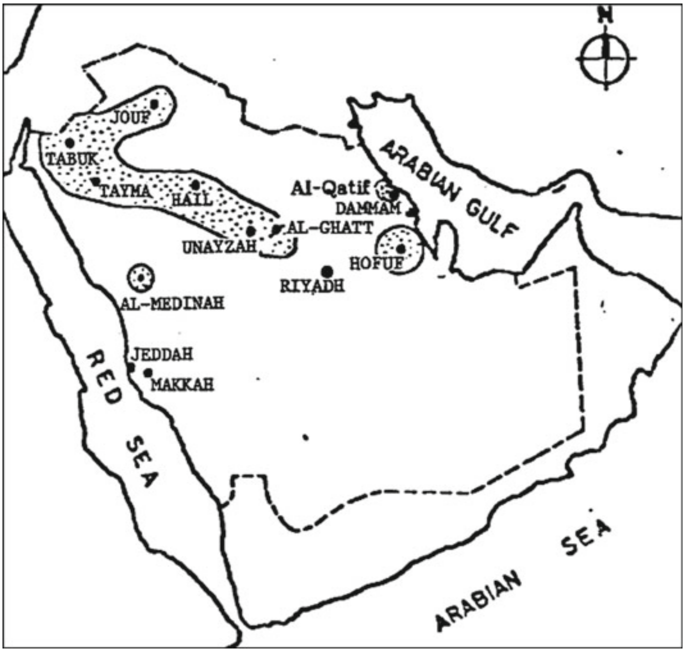

Fig. 11.4 Tentative distribution of expansive formations in Saudi Arabia. *Source* Dhowian et al. (1985)

11.3 Suitability of Marl for Stabilised Earth Construction

Two types of marl samples were collected from the field and brought in the laboratory in order to observe and find out the suitability of marl for stabilised earth construction. These two marls are widely, locally used and commonly known as grey and white

Fig. 11.5 Kharj soil (left), grey marl (middle) and white marl (right). *Source* Author, 2017

marl (Fig. 11.5) amongst construction professionals and researchers. It is important to note that marl is not commonly used as building material in Saudi Arabia but found locally in large quantities. As shown in Fig. 11.6, it is a common scenario of Saudi Arabia to see marl transported into any road or building construction sites in large quantities. A third type of soil called Kharj also was collected from the field for comparison purposes as because Kharj soil is commonly used building material in Saudi Arabia. Kharj soil is red in colour (Fig. 11.5), clayey, locally available, queried from Kharj and commonly transported to all over eastern province of Saudi Arabia to construct houses.

Fig. 11.6 A construction site with white marl in Saudi Arabia. *Source* Author, 2017

Fig. 11.7 Belgian handpress machine. *Source* Author, 2017

Fig. 11.8 Making earth block in Belgian handpress machine. *Source* Author, 2017

Fig. 11.9 Crack-free fresh compressed stabilised earth block (CSEB) before curing. *Source* Author, 2017

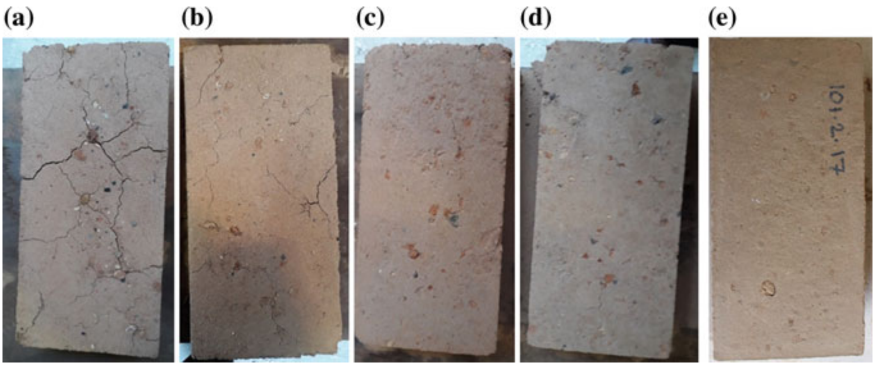

Fig. 11.10 Some of the compressed stabilised earth block samples after curing. *Source* Author, 2017

Table 11.1 Observation remarks on CSEB samples made out of Saudi Arabian soils under fully submerged rainwater

		Types of soil		
		Grey marl	White marl	Kharj soil
Cement as stabiliser	0%	Automatically eroded after curing and completely disintegrated in the submerged rainwater	Automatically eroded after curing and completely disintegrated in the submerged rainwater	Developed a lot of cracks after curing and completely disintegrated in the submerged rainwater
	2.5%	No crack developed but surfaces slightly eroded after curing and partially disintegrated under the rain	No crack developed but surfaces slightly eroded after curing and partially disintegrated under the rain	Developed few cracks, severely eroded after curing and finally disintegrated under the rain
	5%	No crack developed and remained intact after curing and remained integrated under the submerged rainwater	No crack developed and remained intact after curing and remained integrated under the submerged rainwater	No cracks after curing, surfaces eroded slightly and partially disintegrated under the submerged rainwater
	7.5%	No crack developed and remained intact after curing and remained integrated under the submerged rainwater	No crack developed and remained intact after curing and remained integrated under the submerged rainwater	No cracks after curing and remained intact under the submerged rainwater
	10%	No crack developed and remained intact after curing and remained integrated under the rainwater	No crack developed and remained intact after curing and remained integrated under the rainwater	No cracks after curing, intact and remained integrated under the rainwater

(continued)

Table 11.1 (continued)

		Types of soil		
		Grey marl	White marl	Kharj soil
Gypsum as stabiliser	2.5%	No crack developed after curing but completely disintegrated under the submerged rainwater	No crack developed after curing but completely disintegrated under the submerged rainwater	No crack developed after curing but completely disintegrated under the submerged rainwater
	5%	No crack developed after curing but the surfaces eroded significantly; partially disintegrated in the rainwater	No crack developed after curing but the surfaces eroded significantly; partially disintegrated in the submerged rainwater	No crack developed after curing but the surfaces eroded significantly; completely disintegrated in the rainwater
	7.5%	No crack developed after curing but the surfaces eroded significantly; partially disintegrated in the rainwater	No crack developed after curing but the surfaces eroded significantly; partially disintegrated in the rainwater	No crack developed after curing but completely disintegrated in the rainwater
	10%	No crack developed after curing but the surfaces eroded significantly; partially disintegrated in the rainwater	No crack developed after curing but the surfaces eroded significantly; partially disintegrated in the rainwater	No crack developed after curing but partially disintegrated in the rainwater

Source Author, 2017

All three types of soil samples were mixed with two different locally available stabilisers, namely cement and gypsum independently. Mixtures of all types of soil with both stabilisers were independently prepared in five different ratios (0, 2.5, 5, 7.5 and 10%). A Belgian manual earth block making machine (Fig. 11.7) was used to make CSEB out of each soil samples. At total of 27 (9 × 3) sample blocks were produced manually with the help of the Belgian handpress machine as shown in Fig. 11.8 for preliminary observation. All the freshly made compressed stabilised earth blocks (CSEB) looked crack free (Fig. 11.9). Curing of the sample blocks was then done naturally (stored open-air overhead shaded place under moist condition, i.e. covered one week under soaked sacks) for a period of four weeks.

After curing some of the CSEB samples developed cracks (Fig. 11.10a), surface of the blocks eroded, and some automatically disintegrated in rain water. On the other hand, some samples remained intact and integrated (Fig. 11.10c–e) even under the rainy condition. It is important to mention that the average annual rainfall of Dhahran is 3 mm (Mashat and Abdel Basset 2011) and humidity is 55%. However, for the last 10 years annual rainfall and humidity of Dhahran are not consistent; therefore, all the blocks were fully submerged under the water in a container for a period of 24 h and kept outdoor open air until the water was evaporated and the blocks become dry. It took about 7 days to dry out the water from the container and blocks become dry. Table 11.1 presents observation remarks on the CSEB samples under open-air rainy condition.

11.4 Conclusions

This paper has reviewed, investigated and analysed the existing literature on three types of Saudi Arabian soils appropriate for stabilisation and possibilities to use these as building material. It was found out that research on the appropriateness of all types of Saudi Arabian soils for stabilised earth construction appeared to be none, especially the stabilised marl considered as building material. However, preliminary visual observation of the performance of stabilised Saudi Arabian marls appeared to be very promising as building material. This study also concluded that the application of contemporary stabilised marl as a building material for the superstructure of the buildings is rare in Saudi Arabia. Current practice of earth construction in Saudi Arabia mainly follows traditional methods for the purpose of conserving and restoring architectural heritages. Therefore, a lot of research and practical experimentation are needed on stabilised earth construction. However, research on various indigenous earth samples, such as marl, alluvial, expansive clay soils, is on board but only to use it for the ground preparation of road construction and foundations of buildings. Hence, research and experimentations on load-bearing wall, floor slab and finish materials of stabilised earth are very essential. According to the observations made in this research on local soils confirms that the stabilised earth construction in Saudi Arabia will open up new avenues to solve several prevailing problems, such as housing shortage, environmental pollution, lack of cultural identity and loss of architectural heritage. Soil is locally available in all over Saudi Arabia, they are culturally well known, environmentally sustainable and would be an appropriate alternative to the conventional building materials (fired brick and concrete).

Acknowledgements The author wishes to express their deepest gratitude to King Fahd University of Petroleum and Minerals (KFUPM) for the opportunity to accomplish this work. DSR Project Code: IN161032.

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