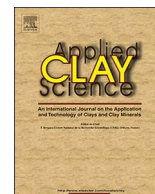




Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: www.elsevier.com/locate/clay

Research paper

Evaluation of a sand bentonite mixture as a shaft/borehole sealing material

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ARTICLE INFO

Keywords:

Compacted sand bentonite mixture
Mechanical and hydrological evaluation
Hydraulic conductivity
Unconfined compressive strength
Shear strength
Waste disposal

ABSTRACT

The mechanical and hydrological characteristics of compacted sand bentonite mixtures with bentonite contents ranging from 5 to 40% were investigated in the laboratory in order to assess their use as a waste isolation material and to select an optimum sand bentonite mixture. Laboratory tests included compaction, compaction permeability, unconfined compression and direct shear tests which led to a recommendation to select a mixture with a bentonite content of 30% for the isolation of underground geological waste disposal repositories. This study complements the previous studies of the authors of this manuscript by determining the mechanical and hydrological properties of sand bentonite mixtures that possess bentonite contents > 30% to determine the geotechnical properties (i.e., unconfined compressive strength, Young's modulus, cohesion and angle of internal friction) and the mechanical behavior of these relatively high levels of bentonite mixtures for the first time in the literature.

1. Introduction

According to the Turkish Electricity Generation and Transmission Company (TEGT, 1999), even if all the energy resources of Turkey were to be used in full capacity, energy shortage in Turkey seems inevitable by the year 2020. For this reason, a nuclear power plant (NPP) will be constructed in Akkuyu in southern Turkey and the nuclear wastes generated by the Akkuyu NPP are planned to be disposed in underground repositories situated in the near vicinity of the Akkuyu NPP and contained reliably in order to prevent contamination of the environment (International Atomic Energy Agency (IAEA, 1990; 1999; 2001; 2003). The potential Akkuyu NPP site is situated on the Mediterranean coast and lies 55 km WSW of Silifke in the Mersin province (Fig. 1). The NPP is planned to be constructed in the Çamalanı bay that is situated approximately 5 km south of Büyükeceli. The Silifke-Anamur highway provides access to the site.

The Turkish Electric Authority (TEK), Earthquake Engineering Research Center of the Middle East Technical University (METU/EERC), General Directorate of Mineral Research and Exploration (MTA), General Directorate of Electrical Survey Administration (EIEI) and State Hydraulic Works (DSİ) have performed geological and geotechnical investigations at the potential Akkuyu NPP site. The 1/1000 scale geological map of the potential Akkuyu NPP site that was prepared by MTA in 1985 encompasses three formations, namely, Akdere formation, Büyükeceli formation and Kirtıladağı formation. The Büyükeceli formation consists of dolomitic wackestone, quartzitic

sandstone, dolomite, wackestone, carbonate mudstone and limestone. The Akkuyu NPP site is situated mainly in the Akdere formation which generally consists of mudrocks, mudstone, shales and alternations of them. The Kirtıladağı formation that conformably lies on the Akdere formation and that is the uppermost formation of the site consists of carbonate mudrocks, sandy wackestone, grainstone, packstone and dolomites (METU EERC, 1984; Demirtaşlı, 1985; EIEI, 1985).

Argillaceous formations, in particular the shale horizons of the Akdere formation, can be considered as host rock formations for the isolation of waste materials. The Akdere formation, particularly the shale and mudstone horizons of the Akdere formation are considered to be desirable for geological repositories in order to reliably contain nuclear waste. The shale horizon of the Akdere formation which is planned to host the nuclear waste generated from the Akkuyu NPP site possesses a mean hydraulic conductivity of about 9.0×10^{-11} m/s (EIEI, 1985; METU EERC, 1984). Argillaceous formations represent very good conditions for hosting repositories for long-lived radioactive waste because of the low solubility of their clay constituents, low hydraulic conductivity, effective filtration capacity for colloids and large molecules, high sorption capacity for dissolved cations and self-sealing ability, provided that they do not contain continuous permeable layers of silt and sand (BENIPA, 2004; Pusch and Svemar, 2004). Hence, any waste material generated from the NPP site could be deposited within this formation. For these reasons, various research studies have been performed in National Underground Research Laboratories (URLs) on argillaceous formations as host rock candidates for the isolation of

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Fig. 1. Location map of the Akkuyu nuclear power plant (NPP) site.



waste materials in France (Meuse/Haute Marne URL at Bure), Switzerland (Mont Terri URL at St. Ursanne), and other countries (Witherspoon and Bodvarsson, 2006).

A conceptual design of an underground nuclear waste disposal repository, often referred to as a deep geological repository (DGR) that could be utilized as a model for the potential Akkuyu Nuclear Waste Disposal Site (NWDS) could entail the following components. The buffer material may consist of a compacted bentonite–sand mixture as stated for example by CTECH (2002). OECD (2000), SKB (2006) and ANDRA (2011) are some of the sources out of many that provide conceptual designs for underground nuclear waste disposal repositories and their components. The criteria will be in accordance with IAEA (2011). Concerning the desirable characteristics of clay rock formations for long-lived radioactive waste, Akkuyu NWDS conceptual design study of DGR could be similar to the deep geological repository for high-level radioactive waste in Opalinus Clay (claystone) at the Mont Terri test site in Switzerland and Callovo-Oxfordian argillites (argillaceous rock) at the Meuse/Haute-Marne test site in France (Witherspoon and Bodvarsson, 2006). It should be noted that the different site-specific geological conditions have led to different design and instrumentation of the URL's. However, the engineered barriers tested and analyzed in the URLs have a similar function and, despite some obvious differences, many of the solutions and techniques are believed to be applicable to disposal repository concepts in a variety of different rock types (Pusch, 2008). Hence, various URLs for studying the possibility of deep geological repository of long-lived radioactive

waste have been successfully operated in different geological environments, such as plutonic rock of the Canadian Shield in Canada (CTECH, 2002) and crystalline rock in Sweden (Aspo Hard Rock Laboratory; Pusch and Svemar, 2004). All penetrations and excavations (i.e., boreholes, shafts) in the vicinity of a underground geological nuclear waste repository are required to be sealed effectively to retard any radionuclide migration to the accessible environment (e.g., U.S. Nuclear Regulatory Commission, 1983, 1985). One of the most essential components of the underground repositories are the materials that are used to isolate the wastes from the environment where the materials are required to have a very low permeability, be compatible with the host rock, be mechanically stable, be resistant to destruction, and be chemically durable (IAEA, 1990, 1999, 2001, 2003; Pusch and Bergström, 1980; Pusch, 1994; Meyer and Howard, 1983; DOE/WIPP, 1995; Akgün, 2000). Sand bentonite mixtures are considered for sealing shafts that are situated in the vicinity of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico (e.g., US DOE/WIPP, 1995; Daemen and Ran, 1996) and as backfill and buffer materials for nuclear waste repositories in Canada, Sweden, Germany, Switzerland and France (e.g., IAEA, 1990; Coulon et al., 1987; Pusch, 1994).

The objective of this study is to perform an experimental program to recommend an optimum sand bentonite mixture to be used for sealing geological repositories that contain nuclear waste. Mechanical and hydrological laboratory testing was performed to determine the Atterberg limits, specific gravity, optimum moisture content, maximum dry unit weight, total unit weight, hydraulic conductivity, unconfined

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