Journal of Rock Mechanics and Geotechnical Engineering 9 (2017) 159–169

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Performance evaluation of cement-stabilized pond ash-rice husk ash-clay mixture as a highway construction material

Deepak Gupta*, Arvind Kumar

Department of Civil Engineering, National Institute of Technology (NIT), Jalandhar, India

A R T I C L E   I N F O

Article history:
Received 25 January 2016
Received in revised form
20 May 2016
Accepted 22 May 2016
Available online 8 December 2016

Keywords:
California bearing ratio (CBR)
Pond ash (PA)
Rice husk ash (RHA)
Optimum moisture content (OMC)
Maximum dry density (MDD)

A B S T R A C T

This paper reports the results of an investigation carried out on clay soil stabilized with pond ash (PA), rice husk ash (RHA) and cement. Modified Proctor compaction tests were performed in order to investigate the compaction behavior of clay, and California bearing ratio (CBR) tests were performed to determine the strength characteristics of clay. For evaluation purpose, the specimens containing different amounts of admixtures were prepared. Clay was replaced with PA and RHA at a dosage of 30%–45% and 5%–20%, respectively. The influence of stabilizer types and dosages on mechanical properties of clay was evaluated. In order to study the surface morphology and crystallization characteristics of the soil samples, scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses were carried out, respectively. The results obtained indicated a decrease in the maximum dry density (MDD) and a simultaneous increase in the optimum moisture content (OMC) with the addition of PA and RHA. Multiple linear regression analysis (MLRA) showed that the predicted values of CBR tests are in good agreement with the experimental values. Developed stabilized soil mixtures showed satisfactory strength and can be used for construction of embankments and stabilization of sub-grade soil. The use of locally available soils, PA, RHA, and cement in the production of stabilized soils for such applications can provide sustainability for the local construction industry.

1. Introduction

With rapid industrialization growth, the industrial activities are producing a large quantity of waste materials. Such wastes are hazardous for health and environment. To minimize the impact of such waste materials, proper management is required. Utilization of the waste materials in different purposes is an effective way of management. The waste materials such as fly ash (FA), pond ash (PA), scrap tire, and rice husk ash (RHA) are generated in bulk and their utilization for general purposes becomes difficult and challenging. Such wastes can be used in large quantities for civil engineering construction. Utilization of such waste materials in the form of admixtures for the improvement of soil characteristics is one of the key ground improvement techniques. This methodology can be used for the improvement of problematic soils like soft clay or swelling soil, which are unable to sustain load from the structure.

A huge quantity of FA and PA as waste products is generated from power plants at global level. In India, about 200 million m^2 of land area is covered up with million tonnes of PA deposits. The production of leachate compounds from the ash ponds leads to the contamination of both the groundwater and surface water bodies as well as soil, because of the presence of toxic elements and heavy metallic substances within them.

The engineering properties of PA can be improved using various techniques among which the incorporation of lime/cement in the PA by mechanical mixing has been found to be the most reliable approach. Kumar et al. (1999) presented the results of laboratory investigation carried on silty sand and PA reinforced with randomly distributed polyester fibers. They showed that incorporation of fibers results in the improvement of various characteristics of soil (e.g. peak compressive strength, California bearing ratio (CBR), ductility, and peak friction angle). Sarkar et al. (2012) reported that the CBR of PA improves with addition of cement. Bera et al. (2007) reported that the increase in compaction leads to an increase in maximum dry density (MDD) and a decrease in optimum moisture content (OMC). Kumar and Gupta (2016) concluded that the cement-stabilized and fiber-reinforced clay mixed with optimum

* Corresponding author.
E-mail address: deepakg757@gmail.com (D. Gupta).

Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2016.05.010

percentage of RHA and PA can be successfully used as fill material for geotechnical applications. Ghosh (2010) studied the suitability of stabilized PA for road base and sub-base construction purposes by performing a series of laboratory tests. The test results revealed that the utilization of Class F PA either individually or in combination with different dosages of lime (i.e. 4%, 6% and 10%) and phosphogypsum (0.5% and 1%) is suitable for construction of sub-base and road base applications. Roy and Chattopadhyay (2008) studied the effectiveness of RHA and PA in the improvement of subgrade quality for the purpose of road construction. It was shown that with the addition of PA or RHA, the compaction characteristics of alluvial soil are influenced significantly. Chand and Subbarao (2007) studied the suitability of lime-stabilized PA for base and sub-base courses of pavement.

Rice husks are the shells produced during de-husking operation of paddy, which varies from 20% (Mehta, 1986) to 23% (Della et al., 2002) by the weight of paddy. The husk is a waste material and is disposed off either by dumping or burning in the boiler for processing paddy. The burning process of rice husk produces ash which is about 20% of its weight (Mehta, 1986). This ash known as RHA contains silica as a major constituent whose quality (percent of amorphous and unburnt carbon) is influenced by the type of burning process (Nair et al., 2006). The RHA is pozzolanic in nature because of its high amorphous silica content (Mehta, 1986). It has been reported that in India, the annual paddy production is about 100 million tonnes which generates more than 4 million tonnes of RHA (Ramakrishna and Kumar, 2008). However, RHA cannot be used individually for the soil stabilization due to lack of cementitious properties in it (Ali et al., 1992). Consequently, it is used along with a binder (e.g. cement, lime, lime sludge, and calcium chloride) for the stabilization of soil (Ali et al., 1992; Muntohar and Hantoro, 2000; Basha et al., 2005; Sharma et al., 2008; Brooks, 2009).

The utilization of RHA and PA for soil stabilization can help in achieving a low-cost construction and also provide an environmental friendly ways of their disposal. Their use would also reduce the consumption of cement, thereby saving the energy and reducing the emissions of greenhouse gases.

It has been shown that PA and RHA have sufficient capability in the improvement of strength behavior of soil. In each case, there is an optimum dosage of PA or RHA to be used beyond which the improvement is insignificant. Therefore, it is expected that for further improvement in strength, combination of different admixtures can be significant. In the current investigation, the soil behavior has been studied in detail using different combinations of PA, RHA and cement in it. This study aims to understand the compaction behavior of soil which is very important for structures (such as pavement and embankment). CBR test is considered for strength behavior.

The geotechnical characteristics of clay mixed with PA, RHA and cement were investigated. Cement was added to soil mix at dosage of 0%–4%, whereas PA and RHA were added to the clay at 30%–45% and 5%–20% by dry weight of sample, respectively. Test specimens were subjected to compaction tests and CBR tests. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) tests were also performed. Specimens were soaked for 3 d after which they were tested for CBR tests.

2. Experimental methods

2.1. Experimental materials

The different materials (i.e. soil, PA, RHA and cement) used in the study have same properties as reported in previous research (Kumar and Gupta, 2016).

2.1.1. Soil

The soil used in this investigation is kaolin clay. According to unified soil classification system (USCS), the soil is classified as clay with low plasticity. The index properties of soil are listed in Table 1.

2.1.2. Pond ash

Light grey colored Class F PA was used in the study. The PA is of nonplastic type possessing a specific gravity of 2.1. The ash may be categorized as Class F type as per ASTM C618-12 (2012). The compositions and properties of PA are listed in Table 2.

2.1.3. Rice husk ash

RHA was collected from local rice mill. The RHA is of non-plastic type possessing a specific gravity of 1.95. Its properties also varied depending on its burning temperature. The physicochemical properties of RHA are listed in Table 3.

2.1.4. Ordinary Portland cement

Ordinary Portland cement (OPC) of Grade-43, having initial and final setting times of 30 min and 600 min, respectively, was used in the study. Physical properties of cement are listed in Table 4.

2.2. Experimental programs

A comprehensive series of laboratory tests was performed on the clayey soil specimens stabilized with different dosages and combinations of the stabilizers, i.e. RHA, PA and cement. The tests performed include Proctor compaction test and CBR test. Table 5 lists a summary of mixed various stabilizer combinations with soil. The percentages used of RHA were 0%, 5%, 10%, 15% and 20% and of PA were 30%, 35%, 40% and 45% of total mass of the mixture with different percentages of cement as 0%, 2% and 4%. Such contents are optimum contents for RHA and PA which are taken from the literature. From the literature, it is found that the optimum content in the case of RHA is 10%–15% (Basha et al., 2005) and in the case of PA, it is 30%–40% (Bera et al., 2007). An amount of soil was mixed with PA, RHA and cement to yield stabilized soil specimens. All the specimens were prepared to the MDD and OMC, and tested after 3 d of soaking.

2.3. Testing procedures

2.3.1. California bearing ratio test

CBR test on stabilized and unstabilized soil specimens was conducted in accordance with ASTM D1883-99 (2000). The procedure adopted for the tests was the same as that used in previous investigation (Kumar and Gupta, 2016).

2.3.2. Analysis of surface morphology and elemental composition

SEM was used to examine the surface morphology of the samples and energy dispersive spectroscopy (EDS) was used to detect the presence and composition of different elements in them. A small portion of samples was kept in an oven at 105 °C for 24 h for drying. The specimen was mounted on a specimen's holder. A thin conducting layer of silver about 200 Å in thickness was coated on

Table 1
Properties of soil.

Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index	OMC (%)	MDD (kN/m^3)
2.7	43	19	24	18.3	18.6