2nd International Civil Engineering Conference (ICEC 2020)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

Characterizating and Establishing Treatment Requirements for a New Railway Subgrade along Lagos-Ibadan Route, Nigeria

*** Abdulrasheed, A, A.; Amadi, A. A.; Adejumo, T. W. and Alhassan, M.**
Department of Civil Engineering, Federal University of Technology, Minna
* Corresponding author: alhassanabdulrasheed4@gmail.com

ABSTRACT
Subgrade is a critical component of railway systems as it provides a stable platform for the track substructure. This paper describes an effort to characterize and evaluate subgrade treatment needs for a new railway from KM75+500 to KM116+500 along Lagos-Ibadan rail line. Samples were collected from KM75+500 KM90+500, KM105+500 and KM116+500 at depths of 0.6m, 2.5m and 4.0m and taken to laboratory for tests such as particle size analysis, Atterberg limits, standard Proctor. The results showed that the selected locations were made up of two different layers of subgrade soil. The top subgrade bed characterized as A-2-6 subgroup in AASHTO classification system comprises of 78% of sand and 17% of fine particles and is considered as average soil according to International Union of Railways specifications. The lower layer consisting of 51% sand and 49% fines is classified as A-6, with high liquid limit of 41% and plastic index of 19% at KM116+500, and is regarded as poor soil according to railway specifications that requires stabilization. Consequently, an additional stabilized subgrade layer prepared by mixing 70% clayey sand soil with 30% graded gravel needs to be provided above this layer. More so, soil reinforcement such as non-woven geotextile layer should be provided at KM116+500 having A-6 class of soil before placing the prepared subgrade.

Keywords: classification, Railway, Subgrade, Treatment, stabilization.

1. INTRODUCTION

Recently, due to large scale development of Railway through laying of new tracks, upgrading of old railway to accommodate high speed trains and construction of double or more tracks, huge amount of alternate materials have become necessary in Nigeria for successful completion of the railway modernization. It is also important to make sure that the quality of such construction reaches the standard necessary for the safe, comfortable and cost effective passage of trains at designed conditions. Further, for such huge construction volumes, availability of good quality materials in cost effective manner is a challenging problem. The term subgrade is sometimes used to denote the elevation grade line of the track ready to receive subballast during construction (Dingqing *et al.* 2015). Subgrade is a critical component of railway systems as it provides a stable platform for the track superstructure. A progressive shear failure, excessive swelling and shrinking and subgrade attrition must be avoided (Selig and Waters 1994).

Subgrade is the foundation on which everything above depends for support, and is often the most variable as well as the weakest of track components. For Embankment, subgrade may be of borrowed soil whereas in cuttings, it can be the naturally occurring soil of sufficient strength..

Function of subgrade can be achieved by restraining settlements of the natural soil and of the embankment filling, as well as providing stable mechanical characteristics under design train loads and velocity in a time-independent manner. Use of local available cheap materials with acceptable engineering properties to make them suitable functionally and cost effective may be a welcome solution (Mundrey 1993).

If the subgrade is granular, then track stability is usually assured and drainage becomes the main concern, although the subgrade may not be sensitive to moisture variations. If the subgrade is fine grained, then questions of stability can arise requiring some classification of the subgrade and drainage becomes even more of a concern, especially for moisture-sensitive clays. In essence, the modern builder has the option to "fix" the poor ground conditions and to make them suitable for the project's needs (Munfakh and Wyllie 2000).

Subgrade treatment has one or more of the following primary functions:

i. Increase shear strength and bearing resistance
ii. Increase density
iii. Decrease permeability
iv. Control deformations (settlement, heave, distortions)
v. Increase drainage
vi. Accelerate consolidation
vii. Decrease imposed loads provide lateral stability.

According to International Union of Railways (Table 1) the behaviour of the subgrade may macroscopically be described by and classified as follows: S0: ''Unsuitable'' Soils that need removal or stabilization. S1: ''poor soil'' Soils containing fines > 50 % – These soils may be accepted ''as is'', however, drainage must be provided. Soil improvement may be needed. S2: ''Average'' Soils containing fines from 12% to 50%. S3: ''Good'' Soils containing fines < 12% (Profillidis 2006).

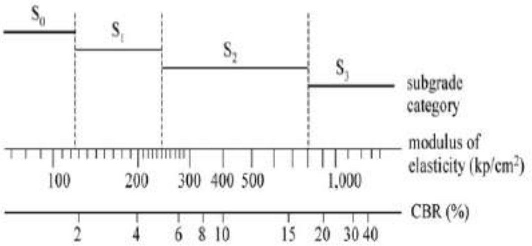

Figure 1: Values of CBR, which correspond to the various subgrade categories (Profillidis, 2006)

If the subgrade soil used is classified as S1 or S2, it is recommended to place an additional layer composed of a better quality soil material. This layer is often termed prepared subgrade layer (as shown in Figure 2). The prepared subgrade layer should be more compact than the soil of the base. Accordingly, most railways require the prepared subgrade layer to have a compaction coefficient of 100% by the normal Proctor test, while this value is routinely 95% for base layers (in the case of embankments). Use of the prepared subgrade layer leads to substantial improvement in the subgrade behavior only if the following two requirements are met, (A) The soil of the base of the subgrade has a low water content, otherwise grains of the base may enter the prepared subgrade layer, thus deteriorating the transverse slope, (B) The prepared subgrade layer should be homogeneous and free of local concentrations of fine-grained material. (Joyanta and Chattopadhyay, 2015).

Subgrade soil characterization should include determination of soil type, grain size distribution, physical state, and mechanistic properties of strength and stiffness. The primary governing issue for subgrade is the soil type. This is followed by determination of the physical state of the soil including the density and moisture content. Finally, specific questions about the physical properties and engineering characteristics should be investigated. Coarse-grained subgrade (sands and gravels) with little clay or silt tends to be least problematic. With adequate drainage and reasonable surface compaction, most sand and gravel subgrade tends to perform well. However, coarse-grained subgrade is not trouble free and is subject to unique failure mechanisms including liquefaction and cyclic mobility. The grain size distribution, unit weight, water table elevation, and moisture content tend to be the main indicators of potential problems with liquefaction or cyclic mobility, although specific evaluation of engineering properties may be needed for design or remediation. (Dingqing et al. 2015).

Table 1; Specifications for Railway Formation (UIC)

Prepared Subgrade	SQ2/SQ3 Soils CBR > = 8 generally, but not < 7 in isolated cases (of soil compacted soil at 98% of MDD*) Plasticity Index < = 12 Field Compaction :Min. 98% of MDD* Minimum E_{V2} = 60 MPa	100 cm
Embankment Fill Top layer (subgrade)	SQ2/SQ3 Soils CBR > = 5 generally, but not < 4 in isolated cases, compacted at 97% of MDD* Minimum E_{V2} = 30 MPa Field Compaction : Min. 97% of MDD*	100 cm (or less as per actual height of Embankment fill)
Lower Fill	SQ1/SQ2/SQ3 Soils CBR > = 3 generally, but not < 2 in isolated cases, compacted at 97% of MDD*	As per Embankment height
Ground Soil/Sub-soil Strata	Minimum Undrained Cohesion of soil, c_u = 25 KPa or Minimum EV2 = 20 MPa or N >=5 Ground Improvement is required, if any of the above parameters are not complied with.	-

* MDD mentioned in above table for determination of CBR is the MDD achieved in Lab &for field compaction is the MDD achieved in field compaction trials.

Subgrade treatment is described as an alteration or modification to one or more of the Subgrade properties using various common methods. Subgrade can be stabilized either chemically using chemical additives, mechanically by compaction, biologically by bacteria. The level of stabilization depends greatly on the type of structure to be built and engineering properties of the soil. According to Thomas *et al.* (2002), engineers and contractors attempted many ways to treat the damages associated with soft soils but it was all based on trial-and-error. Most of the methods used were mechanically stabilizing the soil and a physiochemical treatment was necessary to permanently alter the properties of soft soils. Otoko and Blessing (2014) used cement and lime to improve the strength and the compaction behavior of marine clay. The maximum dry density increased as the amount of cement or lime increased with a corresponding reduction in the optimum moisture content, when the soil was compacted. Also, Soltani-Jigheh and Jafari (2012) found that inclusion of gravel to the clay influenced both the optimum moisture content and the maximum dry density, an increase in gravel content increases the maximum dry density and reduces the optimum moisture content.

This paper is intent to characterize and establish treatment requirements of a section of the new railway subgrade along Lagos-Ibadan route, Nigeria.

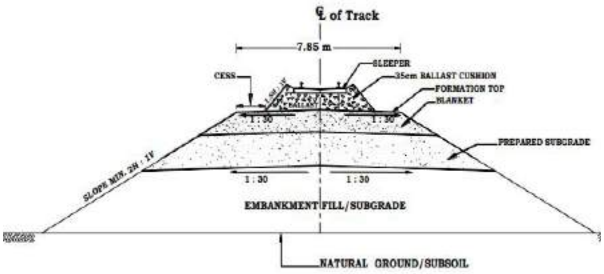

Figure 2: Overview of new railway subgrade (TB10001-2005).

1.1 Case Study Location

This study was carried out from chainage KM75+500 to KM116+500 along Lagos-Ibadan railway (Figure 3). The topography of the area below the embankment is dominated by denuded plains and residual hills and the terrain is slightly undulating. The ground elevation is between 52 to 145m above sea level. The vegetation is developed with shrub and grass mainly. The stratigraphic lithology and engineering geologic characteristic are Silty clay of brownish yellow, hard plastic, Gneiss which is fully weathered brownish yellow and Gneiss heavily weathered brownish yellow but Surface water is not developed

Plate 1; Typial view new railway in Nigeria

2. METHODOLOGY

1.1 Field sampling and laboratory test preparation

Samples were collected by method of disturbed sampling procedure in conformity with BS 1377 (1992) at depth ranging 2.5m to 4.0m. The sampling sites were taken at chainages KM75+500 KM90+500, KM105+500 and KM116+500. These samples were collected at their moist condition using plastic bags. The plastic bags were tied to reduce loss of moisture. In-situ moisture contents were determined immediately. The samples were brought to the laboratory for testing using oven temperatures of 105°C for every test. Each sample was dried in oven until continuous weighing gives constant weight. The soil samples taken from twelve test pits at various depths were analyzed to determine the particle size analysis, Atterberg limits, specific gravity and unit weight of soil,. Then these properties were used in the classification of soil samples. The various tests were carried out according to ASTM D-1883(2010) as well as BS 1377 (1992) standard test procedures.

3. RESULTS AND DISCUSSION

3.1 Soil moisture content

This test is used to verify the natural moisture condition of the subgrade section in the study area. The moisture content test was performed on total of eight soil samples at KM75+500, KM90+500, KM105+500 and KM116+500 at depths ranging from 2.5m to 4.0m. The average natural moisture content of the selected section is shown in Figure 3. It is observed that natural moisture content at KM75+500 increased from 21% 2.5m depth to 35% at 4.0m depth. Other selected chainages have similar moisture content profile. This means that the subgrade in this section have low to high moisture content with respect to depth in all the selected locations.

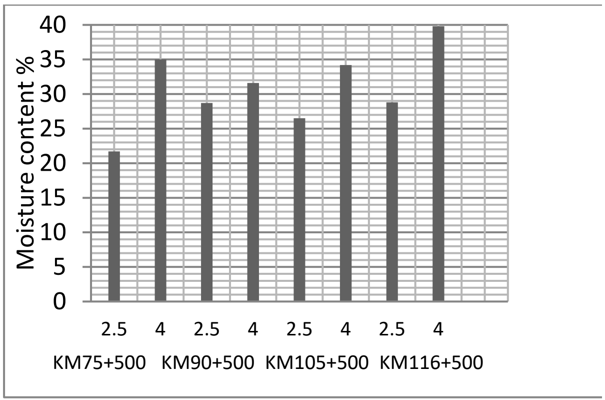

Figure 3: Natural moisture content of the subgrade at varied depths for each location

3.2 Particle size analysis

The sieve analysises conducted for the four selected subgrades along the study area are presented in Figure 4.

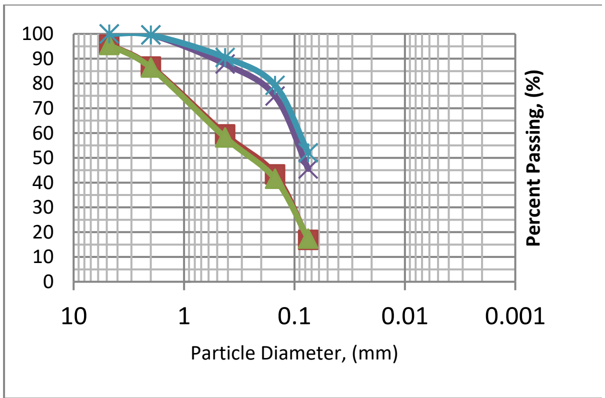

Figure 4: Particle size analysis of the subgrade at chosen locations 2.5m depth

3.3 Specific gravity of soil

The specific gravity of soil in the selected subgrade section of embankment has been determined using a specified temperature of distilled water. The specific gravity of soils in the study area at selected sections ranges from 2.63 to 2.65 as shown in Table 2. These specific gravities agreed with the report of Tuncer and Lohnes, who noted that the specific gravity of clayed and silty soils varied from 2.60-2.90. Also Reidenouer reported that materials of specific gravity below 2.65 usually deteriorate at engineering sites, mainly on moisture influx due to weakness and durability. Therefore, the selected subgrade section may deteriote with time if not treated or improved

Table 2: The average specific gravity at chosen locations

Subgrade profile	Labels	Depth of sample taken (m)	Average specific gravity
KM75+500	K4012	0.6-2.5	2.65
	K4013	2.5-4.0	2.63
Km90+500	K4022	0.6-2.5	2.65
	k4023	2.5-4.0	2.63
Km105+500	K4032	0.6-2.5	2.65
	k4033	2.5-4.0	2.63
Km116+500	K4042	0.6-2.5	2.62
	K4043	2.5-4.0	2.64

3.4 Bulk and dry densities of soil samples

The standard proctor test was conducted on sample to determine both the bulk and dry densities of the samples. This test was performed for soil samples that have been taken at different depth intervals in the study area. The results of the tests have been presented in Figure 5a and 5b. The bulk density of the subgrade section as shown in Figure 5b with respect to depth, this ranged between 1.78-2.15 g/cm^3. These bulk density values of the selected subgrade fall within the range of swelling clays as suggested by Seedman and Hong et al (2012), they observed that osmotic swelling occurs in clay with bulk density less than 2.45 g/cm^3. This could cause instability of the subgrade due to high water absorption, thereby increasing the natural moisture content of the subgrade. In Figure 5a, compaction curves of the samples shows that the optimum moisture content ranged between 14 and 17%, while the maximum dry density ranged from 1.79 and 1.86g/cm^3 as shown in table 3. Arora (2008) noted that clay with high plasticity have very low dry density and high optimum moisture content, this is consistent with the view that high optimum moisture content and low maximum dry density is suggestive of poor subgrade materials.

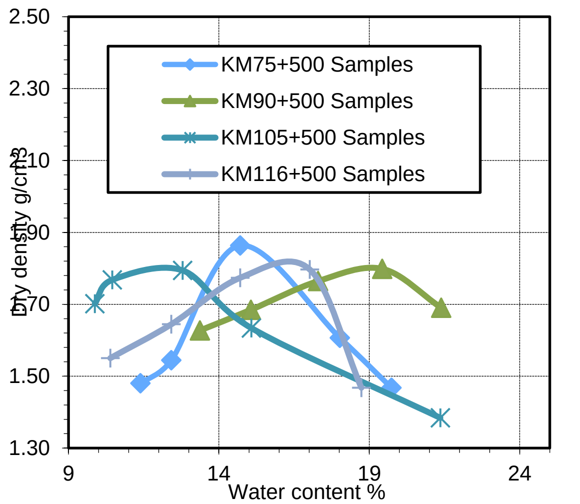

Figure 5a: Compaction curves of the subgrade from each chainages at 2.5m depth

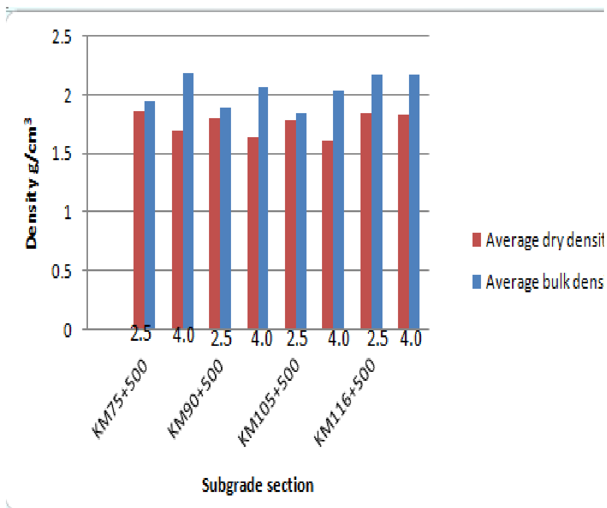

Figure 5b: The average bulk density and dry density at chosen locations

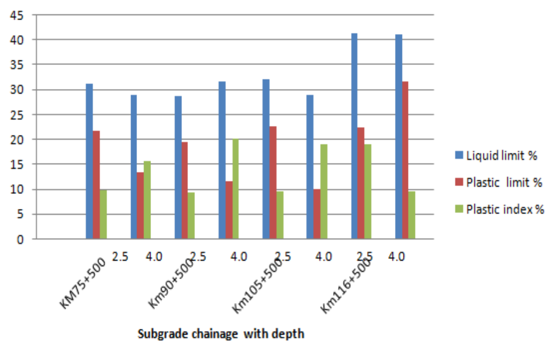

Figure 6: Atterberg's limit of the subgrade soils at depth 4.0m for chosen locations

Table 3: MDD and OMC of the subgrade from each chainages at 2.5m depth

Chanaiges	Maximum dry density MDD g/cm³	Optimum moisture content OMC %
KM75+500	1.86	14.70
KM90+500	1.79	19.42
KM105+500	1.79	12.79
KM116+500	1.79	17.02

3.5 Atterberg's limits

The structural strength of the soils is established through Atterberg's limits. Liquid limit tests were carried out to determine the moisture content of the soils required to cause it to lose its cohesion and flow as a liquid. On the other hand, plastic limit tests were carried out to determine the moisture content required before the soils split or crumble. The plasticity index was calculated from liquid and plastic limits to give the range over which the soils in the study area remain plastic before deformation. The results are presented in a comparison bar chart for liquid limit, plastic limit, and plasticity index, given in Figure 6.

The selected subgrade materials have average value of liquid limit LL and plastic limit PI of 30.5 to 41% and 10 to 19.8% respectively. The average values of PI and LL of the studied subgrade materials might suggest of low to relatively high expansion potential of the subgrade, thereby making the railway subgrade vulnerable to failure if not treated or improved.

The properties of the four selected chainages are highlighted in Table 4. Particle size analysis which is presented in Figure 4 shows that the subgrade soils from the four locations at 4.0m depth have fine fractions that ranged from 40-50%, 0-3% coarse and 50-60% of sand which is classified as clayed soil while at 2.5m depth the subgrade consist of 15-20% fines, 4-6% coarse particles and 70-80% sand which is classified as clayed sand. The sample with the highest clay content of the four soils is KM116+500 samples which has 52% fines content. The International Union of Railways (UIC) categorizes this soil grade as a poor soil for subgrade construction. As a result, such soils cannot be used for prepared subgrade until they are treated or improved.

From Figure 6, it is observed that at KM116+500 soils specimens have high liquid limits of 41.3% and 41.2% at 2.5 and 4.0 m depths respectively. According to Specifications for Railway Formation (Table 1) plastic index PI should be less than 12%. Soils with plastic index PI higher than 20% are classified as having very high potential for volume change (Holtz and Gibbs 1956).Therefore, subgrade soils at this location need special treatment or improvement in order to meet the UIC criteria.

Similarly, the KM75+500, KM90+500 and KM105+500 subgrade soils have moderate liquid limits which varied from 28.8 to 33.3% and average plastic index PI range of 15% to 19%. This is still more than 12% plastic index requirement for a construction of railway formation. Therefore, subgrade soils at these locations need treatment or improvement in order to meet the UIC criteria.

Table 4: Summary of the soil characteristic in the selected areas

	KM75+500		Km90+500		KM105+500		Km116+50
Soil samples & properties	0.6-2.5	2.5-4.0	0.6-2.5	2.5-4.0	0.6-2.5	2.5-4.0	0.6-2.5
Moisture content %	14.5	17.3	15.7	17.5	15.9	18.5	15.0
Dry unit weight kN/m³	18.6	17.0	18.0	16.4	18.3	16.1	19.5
Specific gravity Gs	1.95	2.19	1.88	2.15	1.85	2.11	2.62
Liquid limit %	33.30	28.90	28.80	31.60	32.20	29.00	41.3
Plastic limit %	21.90	13.40	19.50	11.50	22.70	10.00	22.3
Plastic index %	9.80	15.50	9.30	20.10	9.50	19.00	19.0
Percentage gravel %	4.49	0.00	6.49	0.00	5.35	0.00	4.70
Percentage sand %	78.13	51.10	77.13	53.96	79.46	59.70	70.3
Percentage fines	17.38	48.90	16.38	46.04	15.19	40.30	19.2
AASHTO soil Classification	A-2-6 Clayey sand	A-6 Clay soil	A-2-6 Clayey sand	A-6 Clay soil	A-2-6 Clayey sand	A-6 Clay soil	A-2-6 Clayey sand
UIC classification	S1	S0	S1	S0	S1	S0	S1

4. CONCLUSION

Soil investigation was conducted on four locations namely KM116+500, KM90+500, KM105+500 and KM75+500 along Lagos-Ibadan railway modernization. Samples were collected from the four locations each at depths ranging 2.5m to 4.0m. The basic properties of the soil samples were measured following procedures outlined in ASTM D-1883 (2010) and BS 1377 (1992). The index properties of the subgrade at 2.5m and 4.0m depths in each location is characterize as clayed sand and clay soil respectively, which is categorized as poor subgrade soils according to railway specification. The plastic index PI of the subgrade soils in four locations at depth 2.5m and 4.0m varied from 10% to 19.8%, which exceed specification of railway formation (plastic index PI less than 12%). Therefore these subgrade layers/formations require treatment before they can be used as prepared subgrade in construction of railway formation.

5. RECOMMENDATIONS

Considering the poor nature of the subgrade materials (within 2.5 – 4.0m depth) at the selected chainages, this research therefore recommends mechanical stabilization which entails mixing 25-30% graded gravel with 75% clayed sand and compacting it to achieve its maximum density and placing it as an additional layer to serve as prepared subgrade along the study area.

Special treatment should be provided at KM116+500 due to high liquid limit of the subgrade, which is caused by presence of expansive clay. It is further recommended that soil reinforcement in the form of non-woven geotextile layer (geomembrane) be placed on top of the subgrade before the mechanically stabilized prepared subgrade. This would prevent upward migration of the fines from the subgrade causing contamination of prepared subgrade and also to prevent penetration of coarse particles of prepared subgrade into soft grained particles of sub-grade.

REFERENCES

Arora, K. R (2008). Soil mechanics and foundation engineering (geotechnical engineering), 8th edn. Lomus offset Press, Delhi. p 953

ASTM D1557 (2012). Standard test methods for laboratory compaction characteristics of soil using modified effort (2,700kNm/m^3). West Conshohocken PA: ASTM international.

ASTM D4318 (2010). Standard test methods for liquid limit, plastic limit, and plasticity index of soils. West Conshohocken, PA: ASTM International.

Charles, J.A. (2002). Ground Improvement: the Interaction of Engineering Science and Experience-based Technology. *Géotechnique*, 52(7): pp. 527-532

Cheng, Y.M. and Lau, C. K. (2014). Slope stability analysis and stabilization, 2nd edn. Taylor & Francis Group, New York, pp 17–97

China Railway Corp. (2010). Code for designing heavy haul railway. Beijing, China: China Railway Publishing House,

Dingqing, L.; James, H.; Ted, S. and Steven, C. (2015), Substructure from: Railway Geotechnics CRC Press Boca Raton, Florida. Accessed on: 06 Oct 2020

Holtz, W. G. and Gibbs H. J. (1956) "Engineering Properties of Expansive Soils," Transactions of ASCE, Vol. 121, pp. 641-679

Hong, J. C.; Jong K.M.and Li S. J. (2012). A study of decreasing behavior of strength and elastic parameters due to water infiltration in rock cores. J korea Geotech Soc 28(1):204-211

Joyanta, M. and Chattopadhyay, B.C. (2015), Construction of Blanket and Subgrade for Railway with Sand- Moorum- Natural Fiber Mixed Composites international journal of innovation in engineering and technology vol 5 (2) pp. 35-46

Karl, T.; Peck, R.B. and Gholamreza, M. (1995). Soil mechanics in engineering practice (third edition). New York: John Wiley & Sons, Inc.

Munfakh, G.A. and Wyllie, D.C. (2000). Ground Improvement Engineering—Issues and Selection. *GeoEng 2000*, 19-24 Nov. 2000, Melbourne, Australia, Vol. 1: Invited Papers, Technomic, Lancaster, PA, pp. 333-359.

Mundrey, J.S. (1993), " Railway Track Engineering", Tata McGraw Hill Publishing Company Ltd., New Delhi, pp 187-192

Otoko, G. R. and Blessing, O. C. (2014). Cement and lime stabilization of a Nigerian deltaic marine clay (chikoko). European Inter. J. Sci. Tech. 3(4), 53–60.

Profillidis, V. and Kouparoussos, A. (2006). 'Mechanical Behavior of the Railway Subgrade" KEDE, Scient. Bulletin of the Ministry of Public Works of Greece, Vol. 3-4, Athens.

Rendenouer, D.R (1970). characteristics of sediments and their dispersal systems along the shelf and slope of an active forearc margin eastern Hokkaido, northern Japan. Sedimentary Geol 201(3-4):341-364

Seedman, R. (1986). The behavior of clay shales in water. Canadian Geotech. J 23(1):18-22

Selig, E.T. and Waters J.M. (1994). Track Geotechnology and sub- structure management. New York: Thomas Telford Services Ltd

Soltani-Jigheh, H. and Jafari K. (2012). Volume Change And Shear Behavior Of Compacted Clay sand/Gravel Mixtures International Journal of Engineering & Applied Sciences (IJEAS) Vol.4, Issue 3;152-166

TB10001, (2005). Code for design on subgrade of railway. Beijing, China: China Railway Publishing House

Thomas, M.; Petry, P. E.; Little, D. N. and Asce, F. (2002). Review of stabilization of clays and expansive soils in pavements and lightly loaded structures history, practice, and future. J. Mater. In Civ. Eng. 14(6), 447–460

Tuncer, O.D, Lohnes C. G. (1977). Specific gravity of soils. J Geol. 75:432-534