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Civil Engineering Journal

Vol. 3, No. 8, August, 2017

Effect of Compaction Energy on Engineering Properties of Expansive Soil

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Received 1 August 2017; Accepted 1 September 2017

Abstract

Swelling of expansive clays is one of the great hazards, a foundation engineer encounters. Each year expansive soils cause severe damage to residences, buildings, highways, pipelines, and other civil engineering structures. Strength and deformation parameters of soils are normally related to soil type and moisture. However, surprisingly limited focus has been directed to the compaction energy applied to the soil. Study presented herein is proposed to examine the effect of varying compaction energy of the engineering properties i.e. compaction characteristics, unconfined compressive strength, California bearing ratio and swell percentage of soil. When compaction energy increased from 237 KJ/m^3 to 1197 KJ/m^3, MDD increased from 1.61 g/cm^3 to 1.75 g/cm^3, OMC reduced from 31.55 percent to 21.63 percent, UCS increased from 110.8 to 230.6 KPa, and CBR increased from mere 1 percent to 10.2 percent. Results indicate substantial improvement in these properties. So, compacting soil at higher compaction energy levels can provide an effective approach for stabilization of expansive soils up to a particular limit. But if the soil is compacted more than this limit, an increase in swell potential of soil is noticed due to the reduction in permeability of soil.

Keywords: Expansive Soils; Compaction Energy; Compaction Characteristics; Unconfined Compressive Strength; Swell Potential; Soaked California Bearing Ratio.

1. Introduction

Field compaction of fine grained soils mostly involves adoption of numerous procedures and equipment with substantially varying compaction energy. Therefore, laboratory compaction tests are carried out at varying compaction energy levels e.g. standard proctor test and modified compaction test. While higher compaction generally gives improvement in engineering properties of soil, it can further result in undesirable swelling of expansive soils as well when these soils come in contact with moisture under non favorable conditions. Swelling and shrinkage of expansive soils is one of the major threats a foundation engineer faces Seed et al., 1962 [1]. Hence, to investigate the alteration of engineering properties of soil in relationship to compaction energy assumes exceptional interest. Severe damages occur to the structures built on these soils. Strength and deformation properties of soil are typically related to the soil type and moisture present in the soil. But a surprisingly limited consideration is paid to the effect of compaction energy applied to the soil. Compaction energy is one of the most significant parameters effecting the engineering properties of soil.

Study presented herein is designed to examine the effect of varying compaction energy on the engineering properties i.e. compaction characteristics (optimum moisture content OMC, maximum dry density MDD), unconfined compressive strength (UCS), California bearing ratio (CBR) and swell percentage of soil.

2. Literature Review

Attom, M. F, 1997 [2] investigated the effect of varying compaction energy on shear strength, permeability and swelling pressure of compacted cohesive soil. They discovered that with an increase in compaction energy, there is a rise

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in shear strength on dry side of optimum water content, while there was a slight or no effect on the unconfined compressive strength when the water content of the soil is above the optimum. Additionally, increasing the compaction energy at the dry side of the optimum will decrease the permeability and increase the swelling pressure of the compacted soil.

Sridharan, A., and Y. Gurtug, 2004 [3] reviewed the compaction behavior of fine grained soils. They noted that both, swelling pressure and swell potential, are considerably influenced by variation in compaction energy. Higher the plasticity index of soil, larger will be the swell potential of soil. They confirmed that increase in compaction energy improves some engineering properties of soil significantly, but it also reveals an undesirable increase in swell potential of soil. Higher swelling has adverse effect on the structures built on these soils. Drew, I., & White, D. J, 2005 [4] investigated the effect of compaction energy on engineering properties of soil i.e. OMC, MDD, UCS and stiffness, etc. They worked out that the variation in compaction energy causes a significant change in behavior of soil. Nwaiwu et al., 2012 [5] studied the influence of compactive efforts on properties of quarry dust-black cotton soil mixtures using graphical method, two-way analyses of variance and multiple regression analysis. Amarnath, M. S, 2012 [6] used locally available loamy soil for studying the laboratory strength and performance characteristics of soil compacted at four compaction energy levels i.e. standard Proctor compaction energy, modified Proctor compaction energy levels and the other two energy levels are selected in between these two energy levels. CBR, UCS, Tri-axial tests were carried out at all four compaction energy levels. The increase in dry density found to be 14.3 for soil compacted at modified compaction energy compared to samples compacted at standard compaction energy. The increase in CBR and UCS found to be 2.8 and 3.3 times for specimens compacted at modified Proctor compaction energy compared to standard Proctor energy level. Similarly, the increase in elastic modulus is 3.3 times. Jolly and Vinod, 2012 [7] studied the effect of compaction energy on compaction characteristics of soil. They observed a noteworthy development in MDD and a decrease in OMC of soil with the increase in compaction energy. Vinod et al., 2015 [8] studied the effect of compaction energy on the compaction characteristics and California bearing ratio (CBR) value of soils. They reported that there an increase in MDD and decrease in OMC of soil when compaction energy was increased. CBR of soil was also improved with the increase in compaction energy. Sabat and Mohrana, 2015 [9] investigated the effect of compaction energy on locally available expansive soil. When compaction energy increased from 592 KJ/m^3 to 2700 KJ/m^3, MDD increased from 19.26 KN/m^3 to 22.46 KN/m^3, OMC decreased to 13.66% from 16.43%, UCS increased to 777 KN/m^2 from 245 KN/m^2 and soaked CBR increased to 6.1% from 1.72%. On the basis of these results, they concluded that increasing compaction energy has a positive impact on most of engineering properties of soil but higher compaction energy also results in an undesired increase in swell potential of soil. Present study is intended to examine the effect of varying compaction energy on engineering properties of expansive soils

3. Materials and Methodology

3.1. Materials

To investigate the effect of compaction energy, it was crucial to choose a soil which can produce notable fluctuations in its properties with variation in compactive effort and moisture. Expansive soils display a substantial divergence in their properties with minor variations in moisture and compaction. So, the primary reason for selection of bentonite clay was its significant response to the varying conditions of moisture and compaction energy. Expansive soil was procured from a local supplier. It was high swelling bentonite clay with the following properties provide by manufacturer Table 1.

Table 1. Properties of Bentobest (Ahmed Saeed & Company)

SiO2	50–60%
Al2O3	15–20%
Fe2O3	2–4%
MgO	4 – 6 %
CaO	0.5–1%
Na2O	0.9–1.9%.
K2O	0.2–0.5%
TiO2	0.2–0.5%
Others	0.5–1%
Moisture	5–10%
Swelling	Above 12 times
Suspension	Above 12 times
Water absorption	5 times
Fineness	3 to 5% only remaining on sieve 200

3.2. Methodology

The experimental program was carried out in the following sequence. First of all, properties of natural soil i.e. Atterberg's limits and grain size distribution were determined. ASTM D 422 -63 was used for sieve analysis, ASTM D 7928-16 was used for hydrometer analysis and Atterberg's limits test was carried out in accordance with ASTM D 4318.

Then compaction tests were carried out using varying compaction energy. A brief summary of compaction energy levels is given in Table 2. OMC and MDD of soil is determined for each compaction energy level.

Table 2. Various compaction energy levels

Compaction Energy Level		Weight of hammer (N)	No of Blow/layer	No of Layers	Drop height (m)	Volume of mold (cm^3)	Compaction Energy (KJ/m^3)
1	Standard Proctor	24.5	10	3	0.305	944	237
2	Modified Proctor	44.5	10	3	0.457	2123	287
3	Standard Proctor	24.5	10	5	0.305	944	395
4	Modified Proctor	44.5	10	5	0.457	2123	479
5	Standard Proctor	24.5	25	3	0.305	944	594
6	Modified Proctor	44.5	25	3	0.457	2123	718
7	Standard Proctor	24.5	25	5	0.305	944	990
8	Modified Proctor	44.5	25	5	0.457	2123	1197

In next step, ASTM D 2166 was followed for determination of UCS of soil. Samples were prepared using the OMC and MDD as determined in previous step for each compaction energy level and testing was carried out as per standard procedure.

Similarly, CBR of each soil sample was determined using ASTM D 1883-99. Samples were prepared using OMC and MDD of each sample and tested after soaking for 96 hours.

Free swell pressure test was used to determine swelling pressure for each soil sample. Preparation of samples was carried out using the moisture and density as determined in compaction tests for each soil sample.

All the tests were carried out as per guidelines provided by ASTM. SI units were used throughout the research.

4. Results and Discussions

First of all, classification of soil was carried out. Sieve analysis test was carried out using wash method. More than 98 percent soil passed sieve # 200. Hydrometer analysis test showed that the soil contained 41 percent silt and 57% clay particles. Liquid limit of soil was determined to be 126.2 percent and plastic limit as 43 percent. Plasticity index of soil was 83.5 percent. It is classified as CH as per USCS system and A-6-7 as per AASHTO classification system.

Once, the classification of soil was done, next step was to perform compaction tests at various compactive efforts and OMC and MDD of soil for each compaction energy was determined. Table 2. shows the parameters varied for each compaction test and resulting compaction energy. Nearly all soils exhibit a similar relationship between moisture content and dry density when subjected to a given compactive effort

Figure 1. and Figure 2. represents the variation of MDD and OMC with varying compaction energy, respectively. When compaction energy increased from 237 KJ/m^3 to 1197 KJ/m^3, MDD increased from 1.61 g/cm^3 to 1.75 g/cm^3. This increase in density of soil shows that a denser material is obtained with closer packing of soil particles. While OMC reduced from 31.55 percent to 21.63 percent. This reduction is due to the decrease in void spaces available in soil mass. As the soil particles are packed more closely, so the voids available for accumulation of water are less.

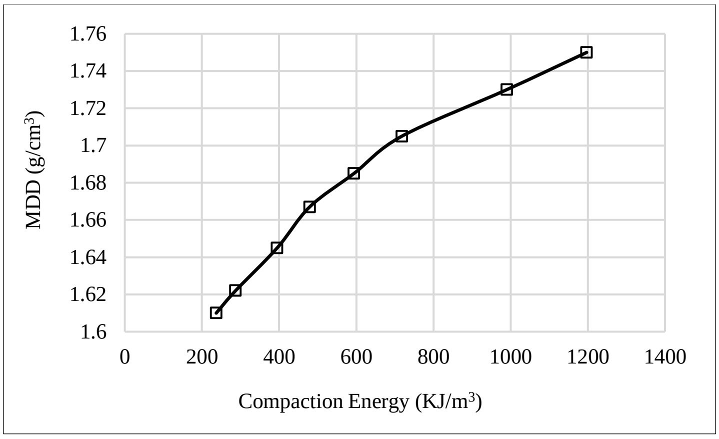

Figure 1. Compaction energy vs MDD

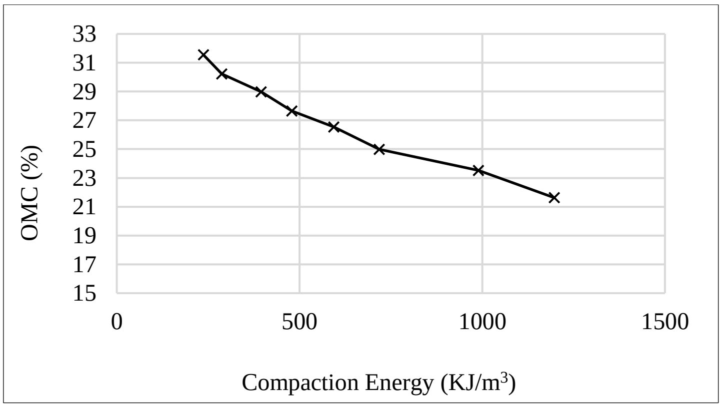

Figure 2. Compaction energy vs OMC

Moisture density relationship for each test sample is shown in Figure 3. The moisture-density relationship indicates the workability of the soil over a range of water contents for the compactive effort used. The relationship is valid for laboratory and field compaction. With increase in compaction energy, OMC of soil reduces and soil is compacted at dry side of optimum. When soil is compacted at dry side of optimum, attractive forces among the particles are high and soil structure is flocculated.

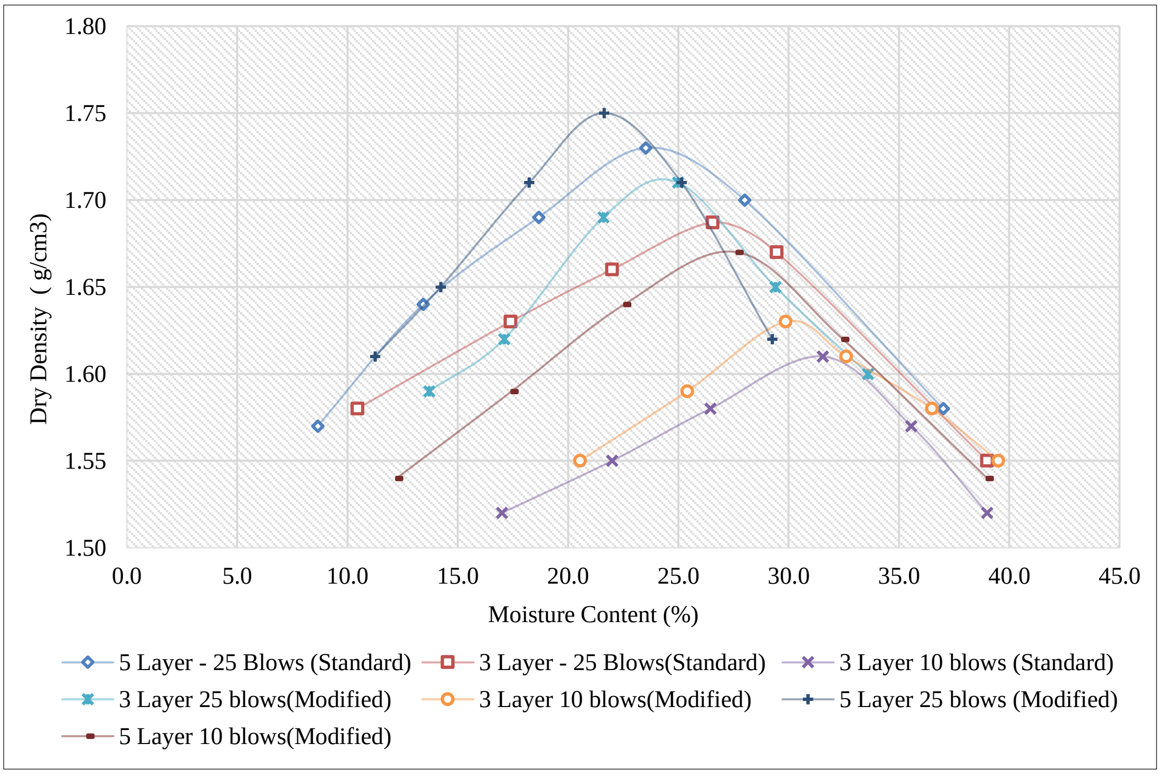

Figure 3. Moisture density relationship at various compaction energy levels

Figure 4. shows the stress strain behavior of each test sample when UCS tests were performed. Figure 5. shows a gradual increase in UCS of soil. When compaction energy increased from 237 KJ/m^3 to 1197 KJ/m^3, UCS increased from 110.8 to 230.6 KPa. Moisture content and packing density of soil are key parameters which contribute towards compressive strength of soil. Since OMC reduces and MDD increases with an increase in compaction energy, there is a significant improvement in UCS of soil. Flocculated soil structure on dry side of optimum offers greater resistance to compression than dispersed structure. So, compressive strength of soil improves with the increase in compaction energy.

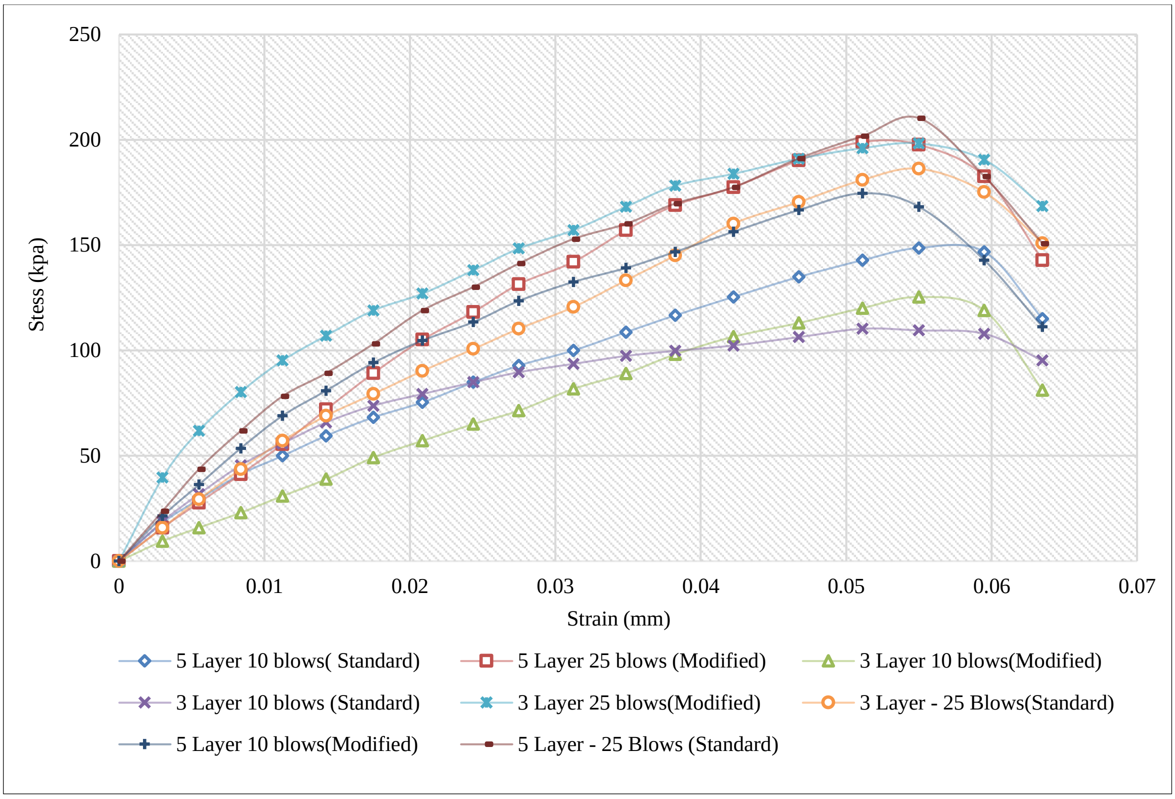

Figure 4. Stress Strain Relationship at various compaction energy levels

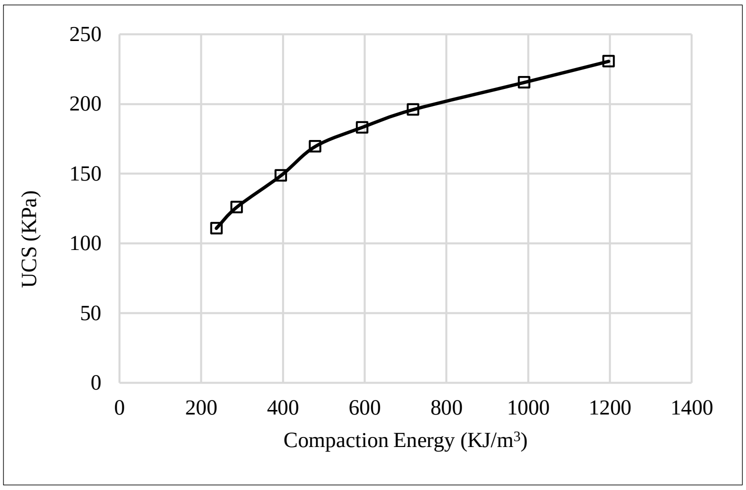

Figure 5. Compaction energy vs UCS

CBR is another soil property which depends upon the soil structure and inter-particle forces. The variation of CBR with increasing compaction energy is shown in Figure 6. When compaction energy increased from 237 KJ/m^3 to 1197 KJ/m^3, CBR increased from mere 1 percent to 10.2 percent. Results indicate a significant improvement in CBR of soil. The reason for increase in CBR is similar to that for UCS of soil. Higher compaction energy reduces OMC which results in flocculated soil structure with stronger inter-particle bonding and greater value of CBR is obtained.

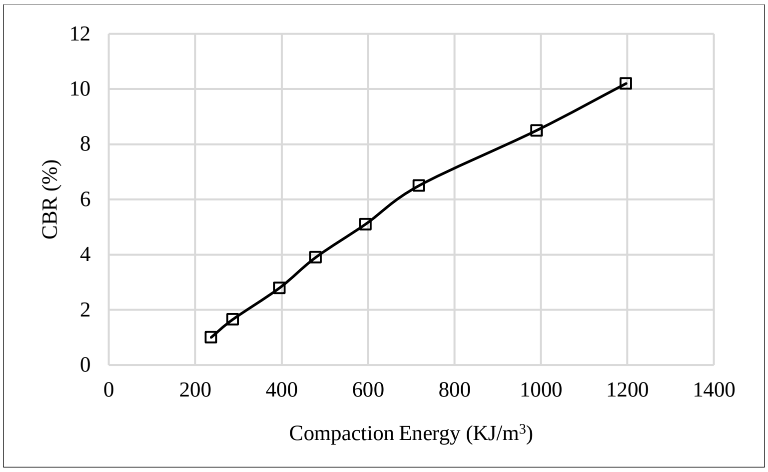

Figure 6. Compaction energy vs CBR

Figure 7. shows the variation of swell percentage with increasing compaction energy. An increase in swell potential is observed with increasing compaction energy. When compaction energy increased from 237 KJ/m^3 to 1197 KJ/m^3, swell percentage increased from 0.3 percent to 6 percent. This phenomenon can be associated to the fact that compacting soils at dry side of optimum reduces permeability of soil resulting in an increase in swell potential of soil.

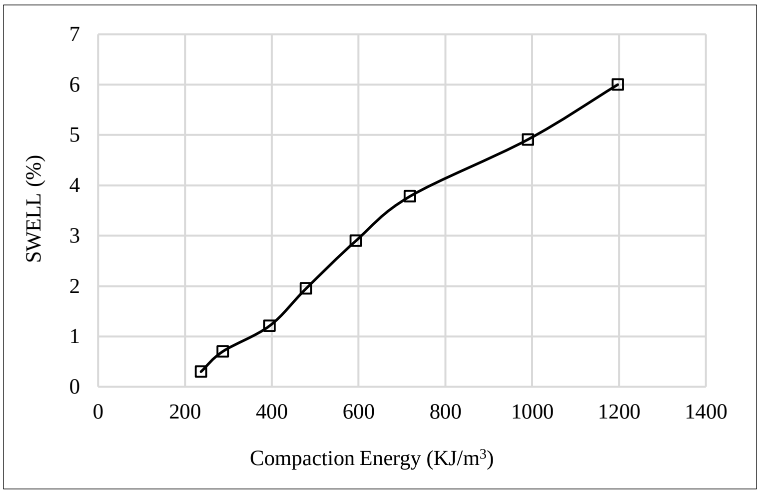

Figure 7. Compaction energy vs swell

5. Conclusion and Recommendations

Compaction energy or compactive effort plays an important role in the engineering properties of soil. Purpose of this study was to evaluate the effect of variation of compaction energy on the engineering properties of soil. Based on the test results, following conclusions are drawn:

- Soil used in the test is High Plastic Clay CH.
- There is a gradual increase in maximum dry density of soil as compactive effort is increased. This increase is a result of more congested packing of soil particles. Optimum moisture content of soil reduces as the compaction energy increases. This reduction is due to the decrease in void spaces available in soil mass. As the soil particles are packed more closely, so the voids available for accumulation of water are less.
- Unconfined compressive strength (UCS) of soil increases with the increase in compaction energy. Moisture content and packing density of soil play an important role in determination of compressive strength of soil. Since moisture reduces and density increase with increase in compaction energy, so, ultimately an increase in unconfined compressive strength of soil is observed.
- California bearing ratio (CBR) is a key parameter for the determination of behavior and performance of road subgrade. This study shows a significant improvement in California bearing ratio of soil as the compaction energy increases.
- Swell potential of soil increases with increase in compaction energy. Compaction of soil on dry side of optimum reduces permeability of soil, resulting in an increase in swell potential.

- Life span and performance of a structure largely depend upon the compressive strength and California bearing ratio (in case of road subgrade) of soil. The above results show a significant improvement in these crucial properties of soil. So, it can be concluded that the variation in compaction energy can be useful for the improvement of poor quality soils.

Following recommendations are made for improvement of current study and for future research

- Soil used in present study was high plastic clay. Research should also be done for granular soils.
- A cost analysis must be performed to determine the cost effectiveness of site improvement by increasing compaction energy and by replacing on site material with some borrow material of better quality.
- Some other engineering properties which depend on moisture and density of soil i.e. shear strength should also be studied to determine the effect of variation in compaction energy on these properties.
- One-point CBR tests were performed in this research. It is recommended to use 3 point CBR as well and variation (it there is any) in general trend should be determined.

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