ASSESSMENT OF SOIL COMPACTION-A PROJECT STUDY

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ABSTRACT

Soil compaction is one of the most important aspects of any earthwork construction. Compaction improves the engineering properties of the fills. Nearly all compaction specifications are based on achieving a certain value of dry unit weight (γ_d). During construction, the geotechnical engineers measure the unit weight of compacted soil in the field to verify the contractor's compliance with the requirement. This paper is a project study of road construction project "Road Zia Colony to Mirpur Cantonment". Soil samples were collected from five different locations. In situ dry density was obtained by Sand Cone Test from each location. The laboratory tests (Standard Proctor Test) were carried out to find out the dry density for each sample. The maximum dry density in relation to moisture content was obtained. Relative compaction (C_R) of soil at each location was then calculated to the soil compaction of the said road project.

KEY WORDS— Compaction, porosity, density, Unit Weight

1.0 INTRODUCTION

The behavior of every foundation, roads, airfields etc depends primarily on the engineering characteristics of the underlying deposits of soil or rock. The proper compaction of the soil is intended to ensure that the compacted soil will reliably and safely withstand loads of various kinds. Soil compaction on construction sites occurs either deliberately when foundations and sub grades are prepared or as an unintended result of vehicular traffic (Randrup and Dralle 1997). Soil compaction decreases porosity (e.g. Harris 1971). To determine whether a soil is compacted or not, and thus whether a treatment is necessary for the alleviation of soil compaction, the degree of compaction needs to be quantified.

It has been said that the top three factors in real estate are "location, location and location". It can also be said that the top three factors in road pavement construction are "compaction, compaction, and compaction". Compaction is the process by which the volume of air in a pavement mixture is reduced by using external forces to reorient the constituent aggregate particles into a more closely spaced arrangement. This reduction of air volume in a mixture produces a corresponding increase in unit weight or density (Roberts et al. 1996). Numerous researchers have stated that compaction is the greatest determining factor in dense graded pavement performance (Scherocman and Martenson, 1984; Scherocman, 1984; Geller, 1984; Brown, 1984; Bell et. al., 1984; Hughes, 1984; Hughes, 1989). Among the major causes for failure of roads in the tropics is inadequate compaction during construction. There is, therefore, the need to strictly control the compaction of the pavement layers if the design life of the road is to be attained; thereby eliminating large maintenance costs.

The road, "Zia Colony to Mirpur Cantonment" was an under construction road project on almost filled land. At the time of our study, different parts of the road were being filled up by the imported soils and compaction was going on. A project study was done to the compaction of soils. The study was undertaken to determine the in-situ compaction state of the ongoing Mirpur Cantonment to Zia Colony Road Project and compare with the compaction state obtained from the laboratory test results.

2.0 LITERATURE REVIEW

2.1 GENERAL

Soil compaction occurs when soil particles are pressed together, reducing pore spaces between them (**Figure 2.1**). Soil compaction increases soil strength-the ability of soil to resist the failure.

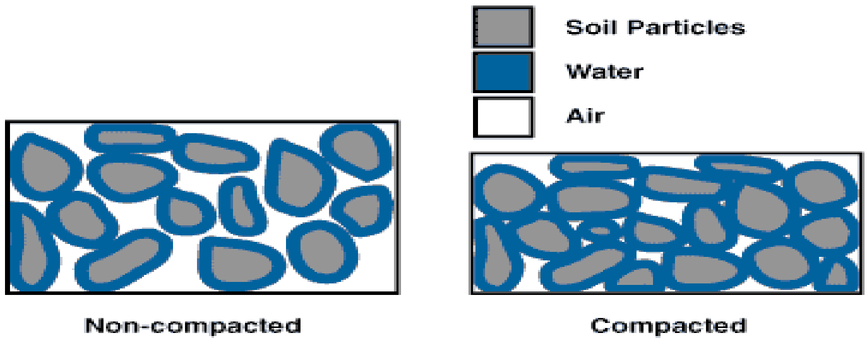


Figure 2.1: Effects of compaction on pore space

Soil compaction changes pores pace, particle size, particle distribution and soil strength. One way to quantify the change is by measuring the bulk density. As the pore space is decreased within a soil, the bulk density is increased (Compaction Handbook, 2008) (**Figure 2.2**).

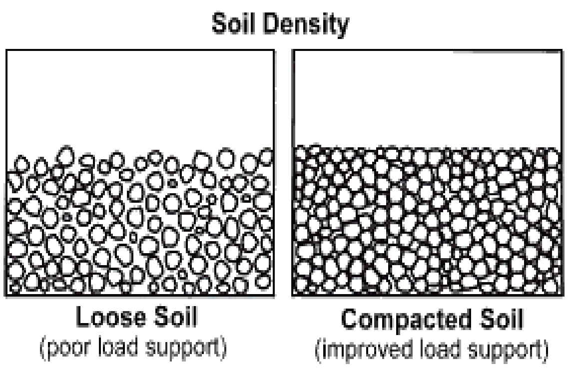


Figure 2.2: Soil density (googles pages)

If compaction is performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types earthwork projects and other construction projects utilize mechanical compaction techniques.

2.2 PURPOSE OF COMPACTION

Sir Clement Attlee, Prime Minister of England in the 1950's once remarked about Winston Churchill that "nothing grows under a heavy roller". Soils become compacted by the simple application of pressure from foot traffic, vehicles and even rain drops. The greater this pressure, the greater the soil compaction. The purpose of compaction is to improve the qualities of the soil used either as a sub-grade materials for roads or in the fills of any project. There are five principle reasons to compact soil:

a. Increases load-bearing capacity.
b. Prevents soil settlement and frost damage.
c. Provides stability.
d. Reduces water seepage, swelling and contraction.
e. Reduces settling of soil.

2.3 MEASUREMENT OF COMPACTION

The degree of compaction of soil is measured by its unit weight or dry density, (γ_{dry}) and optimum moisture content (W_c). Dry density is the weight of soil solids per unit volume of the soil in bulk. Knowing the wet unit weight and the moisture content (W_c), the dry unit weight can be determined from:

$$\gamma_{dry} = \frac{\gamma_{wet}}{1 + \frac{w_c(\%)}{100}}$$

The vulnerability of soils to compaction varies with soil texture (% of sand, silt, and clay), moisture content, and the amount of pressure applied.

2.4 MECHANISM OF SOIL COMPACTION

The process of soil compaction is simply expelling the air from the voids or reducing air voids. By reducing the air voids, more soil can be added to the block. When moisture is added to the block, water content, w_c, is increases, the soil particles will slip more on each other causing more reduction in the total volume, which will result in adding more soil and hence, the dry density (γ_{dry})) will increase accordingly (**Figure 2.3**).

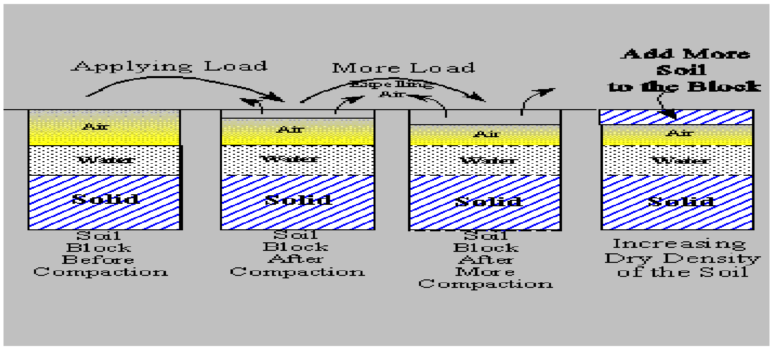


Figure 2.3: Mechanism of soil compaction

2.5 TYPES OF COMPACTION

There are four types of compaction effort on soil or asphalt:

a. Vibration
b. Impact
c. Kneading
d. Pressure

These different types of effort are found in the two principle types of compaction force: static and vibratory. Static force is simply the deadweight of the machine, applying downward force on the soil surface, compressing the soil particles. Static compaction is confined to upper soil layers and is limited to any appreciable depth. Kneading and pressure are two examples of static compaction.

Vibratory force uses a mechanism, usually engine-driven, to create a downward force in addition to the machine's static weight. The compactors deliver a rapid sequence of blows (impacts) to the surface, thereby affecting the top layers as well as deeper layers. Vibration moves through the material, setting particles in motion and moving them closer together for the highest density possible. **Figure 2.4** shows the result of improper compaction.

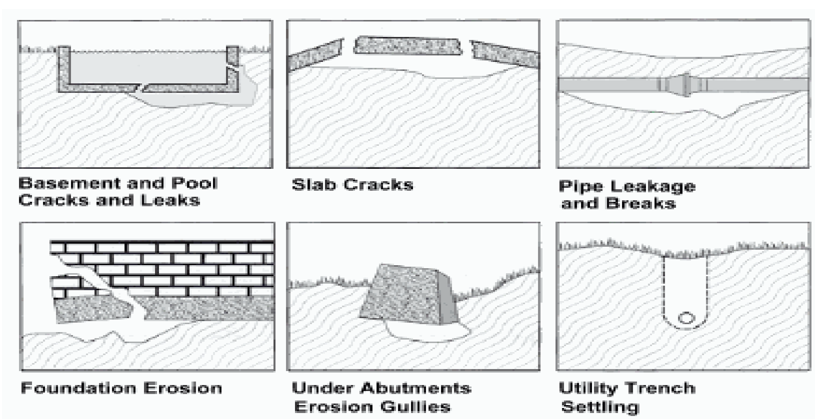


Figure 2.4: Results of poor compaction

3.0 METHODOLOGY

3.1 GENERAL

Methodology incorporates the planning and organization of entire project work **(Figure 3.1)**.

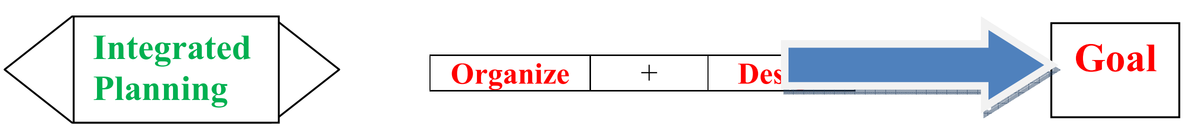


Figure 3.1: Methodology

This Project study is systematically planned under the broad heads illustrated by the following flow chart **(Figure 3.2)**. Data has been collected from the field as well as from the laboratory tests in order to analyze and obtain required result. Obtained result helped us to asses the best possible compaction state.

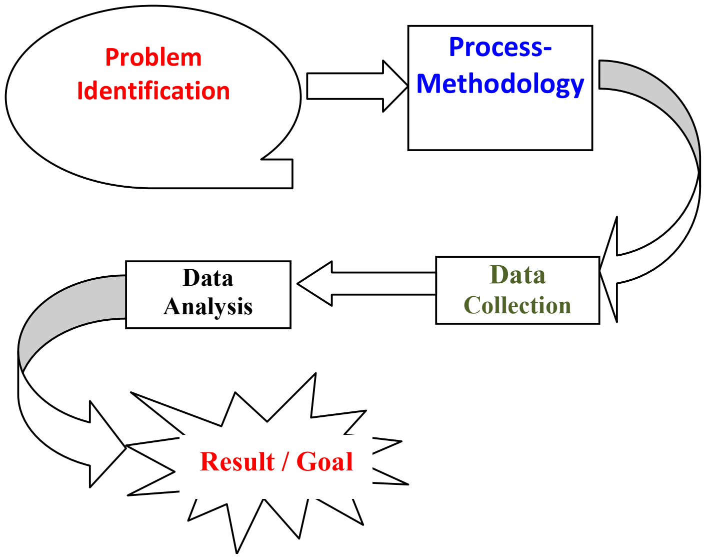


Figure 3.2: Project planning

3.2 DESCRIPTION OF THE SITE

Zia Colony to Mirpur Cantonment road project site is situated on the eastern side of Mirpur Section–12. The site is an open and flat terrain with some enclosed water bodies throughout its length. Originally it was almost a low laying land and presently transformed in to an almost flat and level surface filled by transported soils. Road project works is shown in **Figures 3.3.** Data regarding the project site are furnished below:

a. Total length : 6.30 km
b. Width :18.3 km(including footpath and divider)
c. No of RCC bridge :01 of 42 m length at 2.425 km point
d. No of pipe /Box culvert : 04 nos

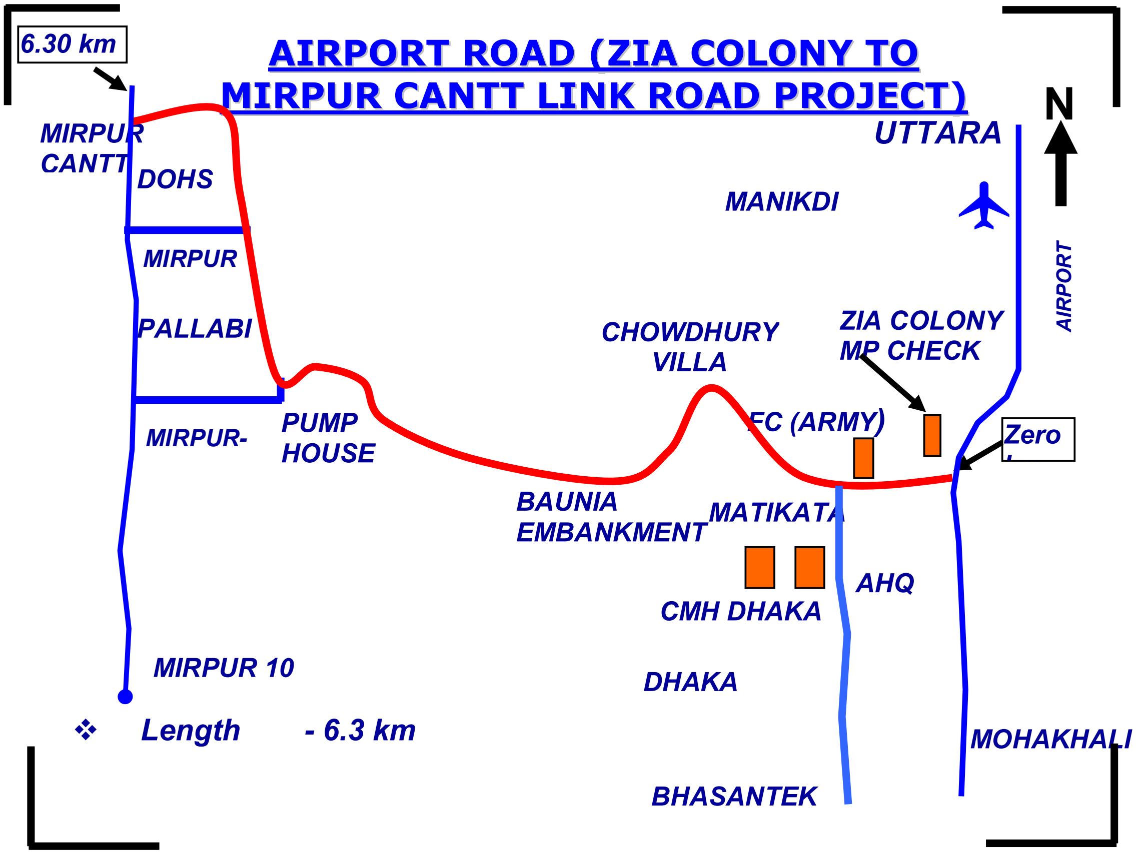


Figure 3.3: Road Zia Colony to Mirpur Cantonment

4.0 Field And Laboratory Investigation

4.1 Field Investigation-Sand Cone Test

One of the most common field density tests methods is the 'Sand Cone Test' (ASTM D1556) and this method is applied in the study (**Figure 4.1**).

Figure 4.1: Typical arrangement of sand cone test apparatus (geotech.org)

4.2 Laboratory Investigation-Standard Proctor Test

This method consists of compacting the soil in the laboratory to obtain maximum dry unit weight (γ_{dry}), then requiring the compactor to achieve at least some specified percentage of this value in the field by the 'Standard Proctor Test' (**Figure 4.2**)

Figure 4.2: Standard proctor test apparatus (geotech.org)

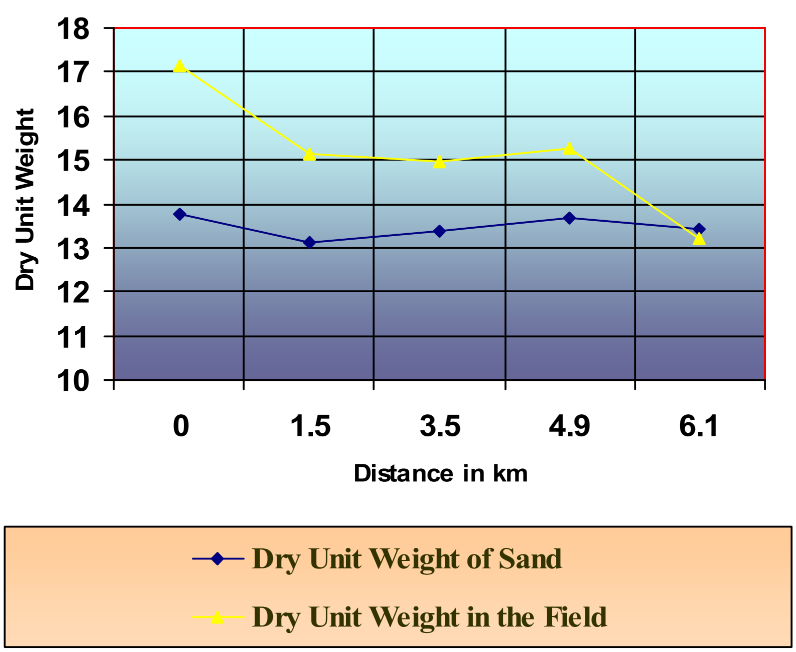
4.3 Data Collection

4.3.1 From the Field Test

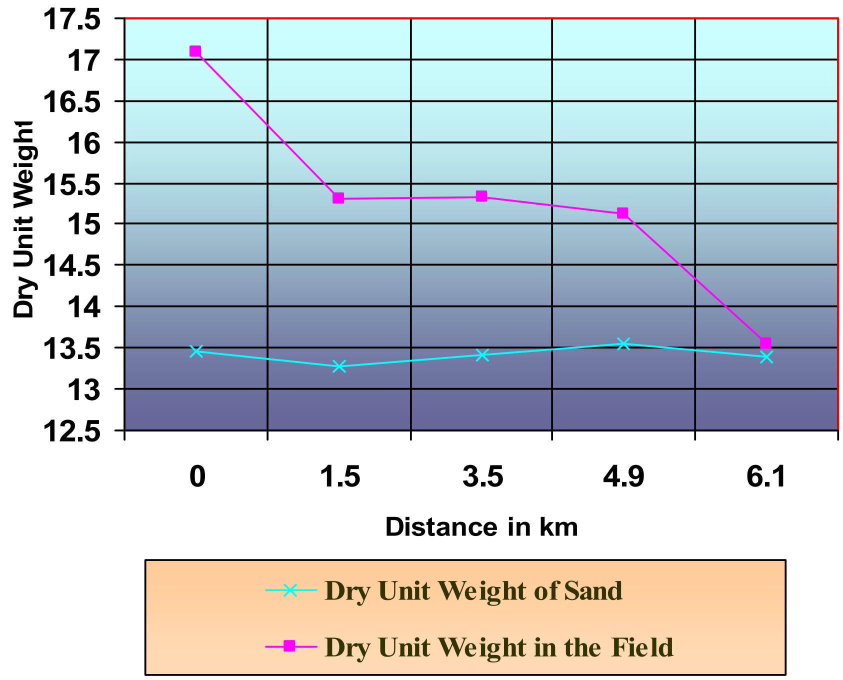
By Sand Cone Method, Dry unit weight in the field (γ_d) was determined. Total ten no of tests were carried out in five different locations along the road project. Location wise "Dry Unit Weight γ_{sand}" and "Dry unit weight in the field (γ_d)" are tabulated below (**Table 4.1** and **Graph 4.1** & **4.2**).

Test No	Location	Dry Unit Weight (γ sand)	Dry unit weight in the field (γ_d)	Test No	Location	Dry Unit Weight (γ sand)	Dry unit weight in the field (γ_d)
01	00 km	13.45 KN/ m ³	17.09 KN/ m ³	02	00 km	13.76 KN/ m ³	17.13 KN/ m ³
03	1.5 km	13.27 KN/ m ³	15.30 KN/ m ³	04	1.5 km	13.14 KN/ m ³	15.14 KN/ m ³
05	3.5 km	13.42 KN/ m ³	15.34 KN/ m ³	06	3.5 km	13.39 KN/ m ³	14.96 KN/ m ³
07	4.9 km	13.55 KN/ m ³	15.12 KN/ m ³	08	4.9 km	13.67 KN/ m ³	15.27 KN/ m ³
09	6.1 km	13.39 KN/ m ³	13.56 KN/ m ³	10	6.1 km	13.41 KN/ m ³	13.21 KN/ m ³

Table-4.1: Dry unit weight of soil obtained in the field



Graph 4.1: Comparisons of field data (side of road way)



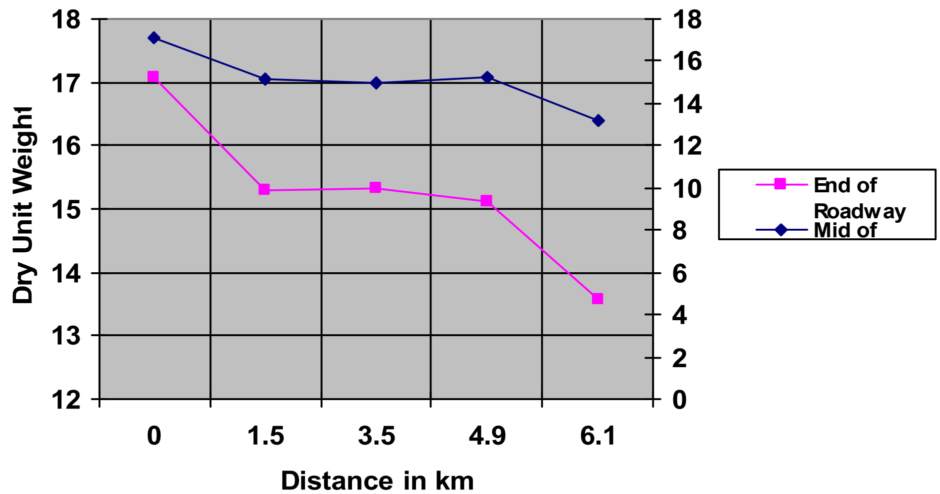
Graph 4.2: Comparisons of field data (centre of road way)

4.3.2 FROM LABORATORY TEST

After determining the dry unit weight in the field, samples from the corresponding locations were brought and analyzed in the laboratory by Standard Proctor Test. For this test, each of the samples is analyzed by adding different amount of moisture content. The obtained dry unit weights were then plotted on the graph and from the graph maximum dry unit weights were obtained. Dry unit weights obtained are shown in (**Table 4.2** and **Graph 4.3**).

Sample No	Location (km)	Dry Unit Weight (KN/M^3)	
		End of Road Way	Mid of Roadway
1	00	17.09	
2	00		17.13
3	1.5	15.3	
4	1.5		15.14
5	3.5	15.34	
6	3.5		14.96
7	4.9	15.12	
8	4.9		15.27
9	6.1	13.56	
10	6.1		13.21

Table 4.2: Variation of dry unit weight (γ_d) obtained from Standard Proctor Test



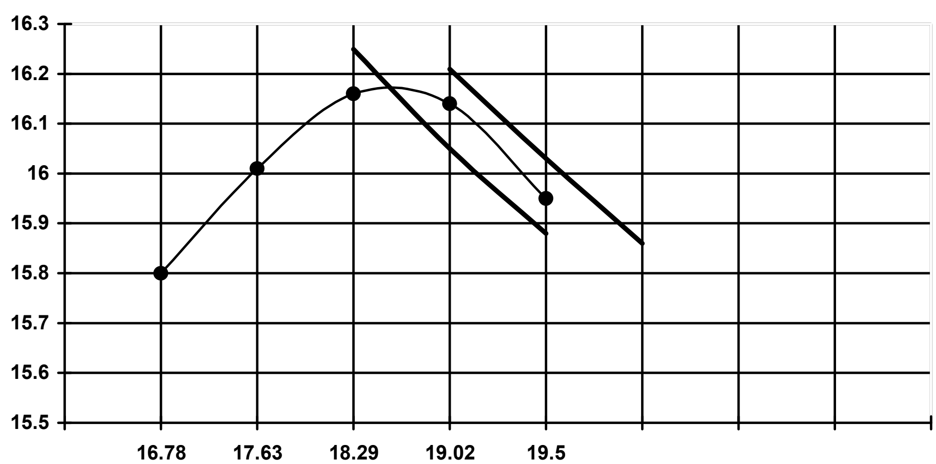
Graph 4.3: Variation of dry unit weight (γ_d) obtained from Standard Proctor Test

For each of the sample, dry density was calculated against maximum moisture content. **Table 4.3 and graph 4.4** shows the dry density of soil sample no, 06

Specific Gravity: 2.77 Sample No: 06
Date: 12.08.2008 Location : 3.5 km

Ser No	Can No	Wt. of Can in gm	Wt. of Can + wet soil in gm	Wt. of Can + dry soil in gm	Wt. of dry soil in gm	Wt. of moisture in gm	M.C in %	Avg MC in %	Wt. of mold in gm	Wt. of mold + compacted soil in gm	Wt. of compacted soil in gm	Wt density kN/ m	Dry density kN/ m
1	8	35	74	68	33	6	18.18	16.78	4312	6140	1828	18.88	15.80
2	9	39	84	78	39	6	15.38						
3	5	34	75	68	34	7	19.59	17.63	4312	6134	1822	18.81	16.01
4	7	31	73	67	36	6	16.67						
5	6	32	74	66	34	8	23.53	18.29	4312	6155	1843	19.03	16.16
6	10	41	87	79	38	8	21.05						
7	24	31	74	67	36	7	19.44	19.02	4312	6162	1850	19.10	16.14
8	23	27	78	70	43	8	18.60						
9	18	31	74	67	36	7	19.44	19.50	4312	6160	1856	19.17	15.95
10	15	31	75	68	37	7	18.92						

Table 4.3: Moisture content and dry density achieved from the compaction test.

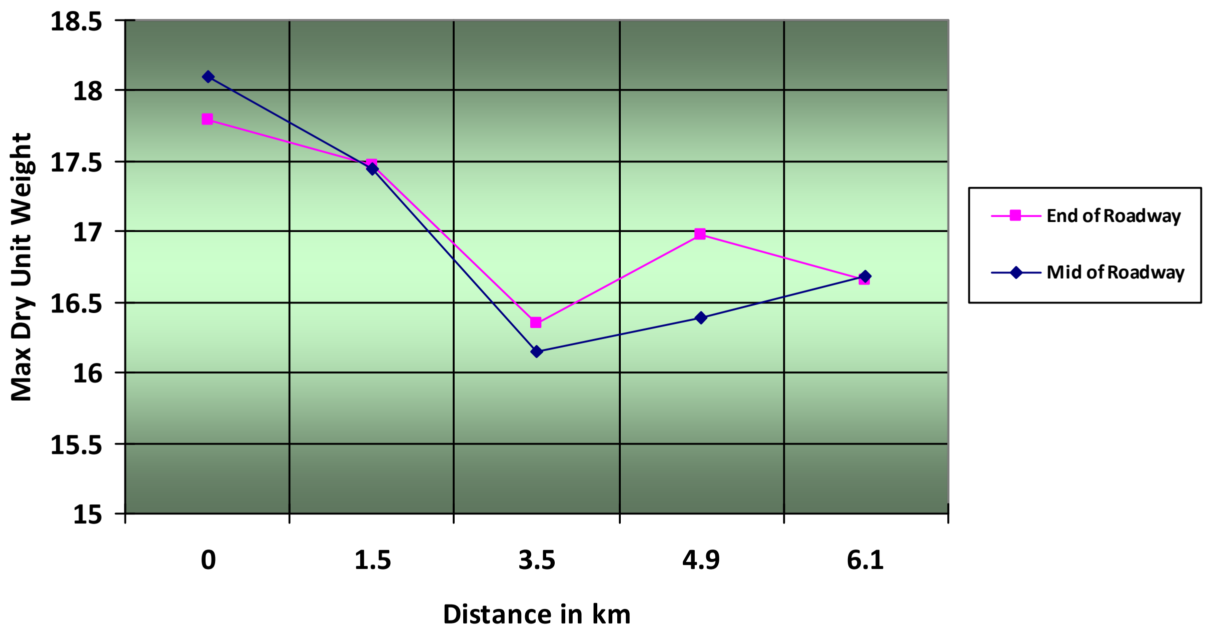


Graph 4.4: Dry unit weight vs moisture content.

Max dry unit weights obtained for all the soil samples are shown in **Table 4.4** and **Graph 4.5**.

Sample No	Location (km)	Max Dry Unit Weight (KN/M^3)	
		End of Road Way	Mid of Roadway
1	00	17.79	
2	00		18.1
3	1.5	17.47	
4	1.5		17.45
5	3.5	16.35	
6	3.5		16.15
7	4.9	16.98	
8	4.9		16.39
9	6.1	16.65	
10	6.1		16.68

Table 4.4: Max dry unit weight ($\gamma_{d\ max}$) achieved from the Graph



Graph 4.5: Variation of maximum dry unit weight (γ_d max)

4.5 RELATIVE COMPACTION

Relative compaction is the percentage ratio of the field dry density of soil to the maximum dry density as determined by standard compaction method. Once the maximum dry unit weight has been established for the soil being used in the compacted fill, we can express the degree of compaction achieved in the field by using the relative compaction, C_R.

$$C_R = \frac{\gamma_d}{\gamma_{d(max)}} X\ 100\%$$

Where:

γ_d = dry unit weight achieved in the field

$\gamma_{d(max)}$ = maximum dry unit weight (from proctor compaction test)

Most earthwork specifications are written in terms of the relative compaction, and require the contractor to achieve at least a certain value of C_R. The minimum acceptable value of C_R listed in a project specification is a compromise between cost and quality. If a low value is specified, then the contractor can easily achieve the required compaction and presumably, will perform the work for a low price. Unfortunately, the quality will be low. Conversely, a high specified value is more difficult to achieve and will cost more, but will produce a high-quality fill. **Table 4.5** presents typical requirements.

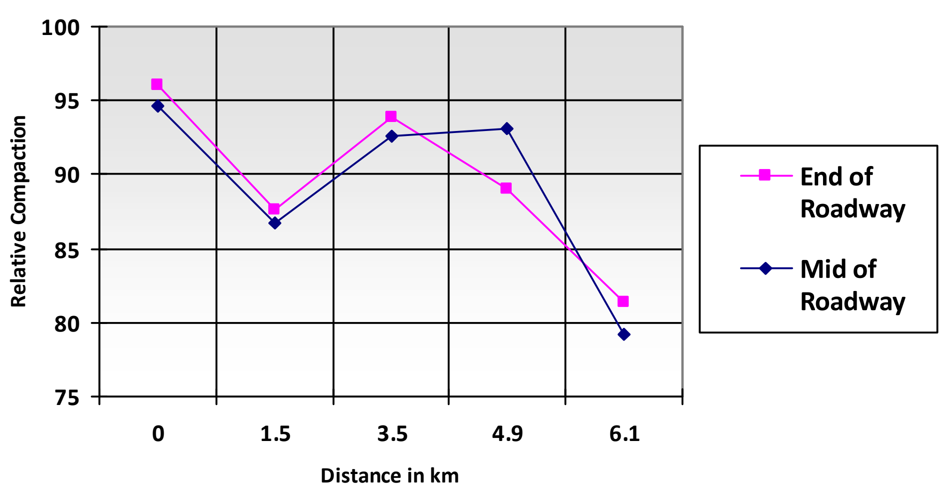
Type of Project	Minimum Required Relative Compaction
Fills to support building or roadways	90%
Upper 150 mm of sub grade below roadways	95%
Aggregate base material below roadways	95%
Earth dams	100%

Table 4.5: Typical compaction requirements

Considering the above compaction requirements, in our specified project area, the required compaction standard should be 95%. But due to various limitations, relative compaction (C_R)as 90% for this road project has been considered. The various data are given and plotted in the **Table 4.6** and **Graph 4.6** below:

Sample No	Location (km)	Relative Compaction(C_R) in %	
		End of Road Way	Mid of Roadway
1	00	96.07	
2	00		94.64
3	1.5	87.58	
4	1.5		86.76
5	3.5	93.82	
6	3.5		92.63
7	4.9	89.05	
8	4.9		93.17
9	6.1	81.44	
10	6.1		79.20

Table 4.6: Values of relative compaction (C_R) in %

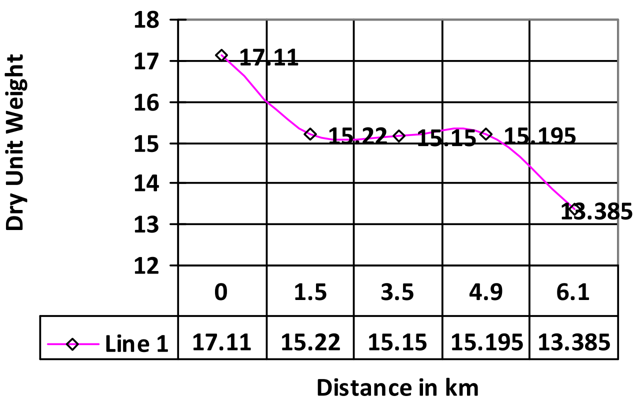


Graph 4.6: Variation of relative compaction (C_R) in %

5.0 TEST RESULTS

5.1 ANALYSIS OF RESULTS OBTAINED BY SAND CONE APPARATUS

In the field, sand cone test was carried out for obtaining field dry unit weight. The various data are shown below (**Graph 5.1**):

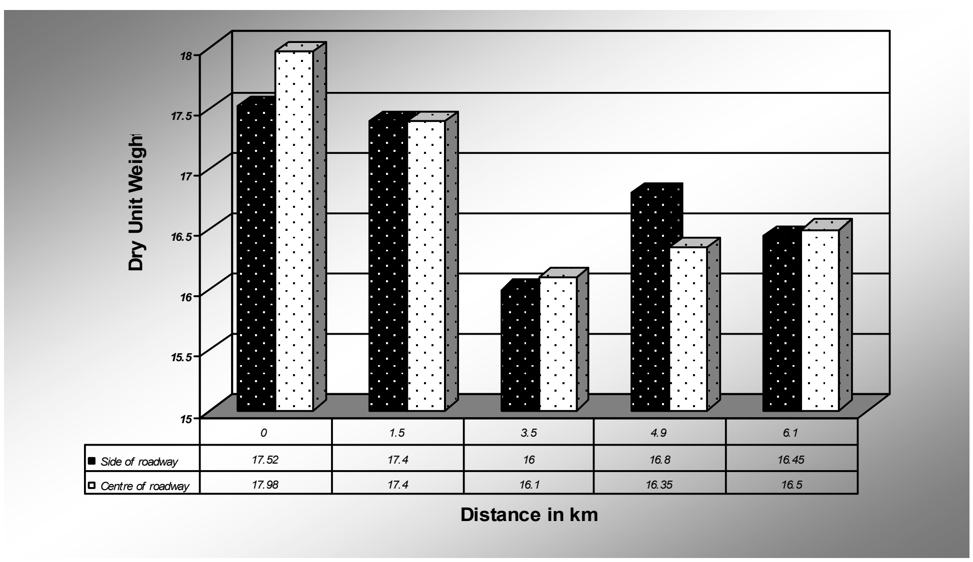


Graph 5.1:Dry unit weight obtained in the field by Sand Cone Test

From **Graph 5.1,** it can be observed that at the starting of the road, the obtained dry density is the maximum. Increasing in the road length shows gradual decrease of dry density. If we visualize with the project works it also shows the similar pattern. The road was well constructed up to 2.5 km. There is a gradual increase of dry density from 3.5km to 5 .00 km point.

5.2 ANALYSIS OF RESULTS OBTAINED BY STANDARD PROCTOR TEST

Various dry unit weights obtained are shown in graphical form in the following **Graph 5.2**.



Graph 5.2: Variation of dry unit weight obtained by Standard Proctor Test

From **Graph 5.2**, it can be observed that the dry density is the maximum at the starting of the road project. Gradual increase of road length shows significant decrease of dry density from 0 km up to 3.5 km. Dry density is the minimum at 3.5 km, after that it is increasing with the gradual increase of road length. It clearly indicates that compaction standard is maximum at beginning of the road and minimum at centre of the road length. In other places, the parameters vary from average to high.

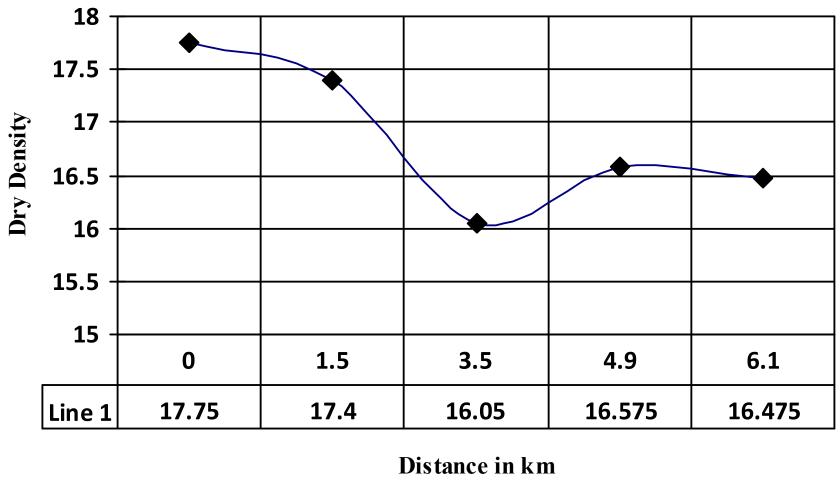
5.3. THE ANALYSES OF OVERALL DATA.

5.3.1 OVERALL DRY UNIT WEIGHTS

The overall dry unit weights are shown in the following **Table 5.1** and **Graph 5.3**.

Ser No	Location	Overall Dry Unit Weight
1	00 km	17.75 KN/ m ³
2	1.50 km	17.4 KN/ m ³
3	3.50 km	16.05 KN/ m ³
4	4.90 km	16.575 KN/ m ³
5	6.10 km	16.475 KN/ m ³

Table 5.1: Overall dry unit weight obtained by Standard Proctor



Graph 5.3: Variation of average dry unit weight obtained by Standard Proctor Test

5.3.2 OVERALL RELATIVE COMPACTION.

The values of relative compaction are shown in **Table 5.2**

Ser No	Sample No	Location (km)	Date of Test	Dry unit weight achieved in the field γd	Max dry unit weight (γd max)	Relative Compaction CR (in %)	Remarks
1	1	0	29.7.2008	17.09	17.79	96.07	CR>90%
2	2	0	29.7.2008	17.13	18.1	94.64	CR>90%
3	3	1.5	6.8.2008	15.3	17.47	87.58	CR <90%
4	4	1.5	6.8.2009	15.14	17.45	86.76	CR <90%
5	5	3.5	12.8.2008	15.34	16.35	93.82	CR>90%
6	6	3.5	12.8.2009	14.96	16.15	92.63	CR>90%
7	7	4.9	16.8.2008	15.12	16.98	89.05	CR <90%
8	8	4.9	16.8.2009	15.27	16.39	93.17	CR>90%
9	9	6.1	27.8.2008	13.56	16.65	81.44	CR <90%
10	10	6.1	27.8.2009	13.21	16.68	79.20	CR <90%

Table 5.2: Overall value of relative compaction.

5.3.3 COMMENTS ON THE OVERALL DATA

From the obtained data plotted in **Graph 5.1** and **Graph 5.2** it is easily apparent that the compaction parameters are the maximum up to 1.5 km point. From 1.5 km point, the parameters start decreasing gradually and reach to minimum at 3.5 km point. After that the parameters again increases and shows a consistent compaction from 4.9 km point up to the end of the road project. It can be easily visualized that from starting of the road up to 1.5 km point, the compaction level is compatible with standard compaction parameters. From 1.5 km point up to 3.4 km point, compaction level is decreasing gradually with the increase of the road length. From the **Graph 4.6** and **Table 5.2**, it is clearly obvious that relative compaction is at standard compaction level (near about 93%) at 1.6 km point and ultimately reduces to 90% at 3.4 km point. From 3.4 km point up to 3.7 km point, the value of relative compaction is below 90% which indicates poor compaction standard and needs more compaction to reach up to 95% in that road length. After 3.7 km point, again, the value of relative compaction starts increasing up to the end of the road. But more compaction is required to achieve standard compaction parameters. It is observed that greater compaction exists along the middle of the roadway than the sides. This remark coincides with the actual situation. Due to greater no of rolling and movement of various construction/public vehicles and plants through out the road project, compaction is more at centre of the road.

6.0 CONCLUSIONS

The ability to investigate and evaluate the dry density of any road project leads one to determine the state of the relative compaction which ultimately specifies compaction standards. The project study has only dealt with the evaluation of the compaction standards of the under construction road project, which has immense potentiality to judge the condition of the road. Basing on field tests and laboratory test results, the relative compaction tests were calculated. For relative compaction of more than 95%, the road will be usable for heavy vehicle, for 90~95 % road is for all other vehicle movement. For relative compaction of less than 90%, soils may be further compacted.

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