CHAPTER 3 LABORATORY EXPERIMENTS AND PREPARATION OF DATASETS

3.1 GENERAL

The current chapter focused on collecting test samples and preparing datasets through laboratory test methodology to fulfill the aforementioned objectives. The testing procedure for individual experiments is discussed in detail. For each set of objectives, almost similar methodology was adopted.

3.2 COLLECTION OF TEST SAMPLES

In the present investigation, in-situ soil samples were collected from an ongoing National Highway Authority of India (NHAI) construction project work site. The project is focused on the "Development of four laning of Varanasi Gorakhpur section of National Highway (NH)-29 from km 84+160 to km 149+540 (Package-3) in the state of Uttar Pradesh (UP)" under National Highway Development Project (NHDP) on Engineering Procurement and Construction (EPC) mode. The project was designed and constructed by Jaiprakash Associates Limited (Jaypee Group).

Numerous soil samples were taken from different chainage along the length of the road for quality assessment/control purposes. From these chainage point, 1011 soil samples were collected, which were brought to the laboratory for the experimental investigations. Out of these, 287 samples were tested in the institute laboratory while 724 samples were tested in the field laboratory. Tests in the field laboratory were conducted under our presence. Table 3.1 shows a sample of the dataset from various laboratory testing.

Table 3.1. A list of sample dataset.

Sl. No.	Sample chainage	Gravel (%)	Sand (%)	FC (%)	LL (%)	PL (%)	PI (%)	MDD (g/cm^3)	OMC (%)	CBR (%)	Soil Group	Source of testing
1	88+500 (LHS)	1.06	14.14	84.81	29.25	21.20	8.05	1.906	11.03	8.20	CL	IL
2	88+500 (LHS)	1.05	14.04	84.91	29.00	21.25	7.75	1.910	10.80	8.60	CL	FL
3	88+500 (LHS)	0.80	14.68	84.53	27.85	20.27	7.59	1.907	10.83	9.10	CL	IL
4	88+500 (LHS)	0.92	16.65	82.44	28.90	20.83	8.08	1.871	12.33	9.30	CL	IL
5	99+380 (LHS)	4.21	9.28	86.52	29.95	21.21	8.75	1.838	11.85	7.50	CL	FL
-	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	-	-	-	
1007	148+250 (RHS)	0.29	12.79	86.92	29.20	23.23	5.97	1.815	11.75	9.85	CL-ML	FL
1008	148+250 (RHS)	0.48	29.51	70.01	27.90	20.05	7.85	1.840	10.25	9.90	CL	IL
1009	148+250 (RHS)	0.90	17.98	81.13	28.75	21.03	7.73	1.885	11.65	9.90	CL	IL
1010	148+250 (RHS)	0.04	25.23	74.74	30.60	23.00	7.60	1.876	11.89	9.90	CL	FL
1011	148+250 (RHS)	0.36	13.12	86.53	28.15	21.10	7.05	1.887	10.28	9.90	CL	FL

Where, IL and FL represents the Institute Laboratory and Field Laboratory, respectively.

3.3 LABORATORY EXPERIMENTS

The current study adopted basic laboratory soil tests to fulfill all the objectives.

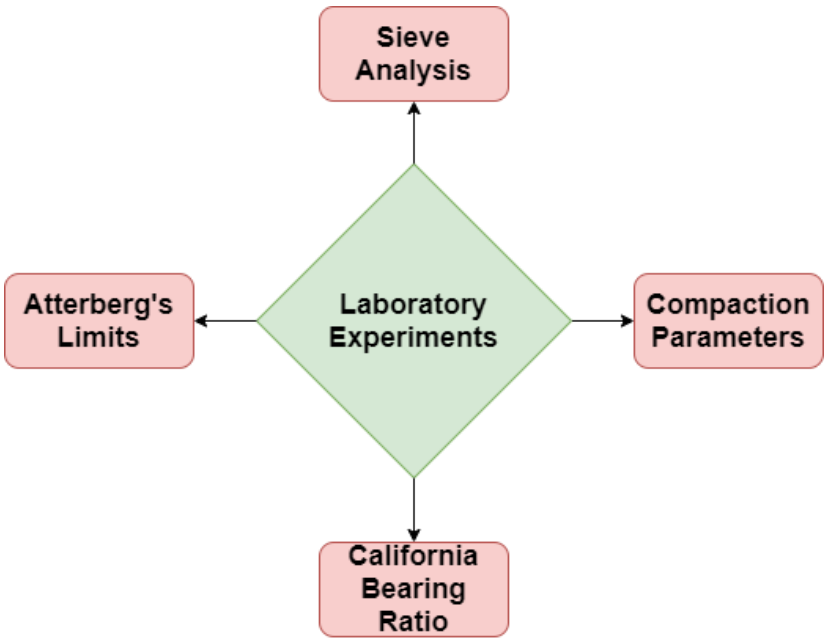

Figure 3.1 Test methods conducted in the laboratory.

3.3.1 Atterberg's Limits test

The Atterberg's limits, also known as consistency limits, of a fine-grained soil are the physical state in which it exists. It is used to denote the degree of firmness of soil. Consistency of soil is indicated in terms of soft, firm or hard. In 1911, Swedish agriculture engineer Atterberg (1911) mentioned that fine-grained soil could exist in four states, namely, liquid, plastic, semi-solid or solid states. The water contents at which the soil changes from one state to the other are known as Atterberg's limits. The test method was conducted in accordance with IS 2720 (Part 5) (1985).

3.3.1.1 Liquid limit

The water content at which the soil changes from the liquid state to the plastic state is known as the liquid limit (LL). The soil doesn't resist against shearing and can flow like liquids at this stage. As the water content is reduced, the soil becomes stiffer and develops resistance to shear deformation. In other words, the liquid limit is also defined as the minimum water content at which the soil changes from the liquid state to the plastic state. The Casagrande apparatus (shown in Figure 3.2) is used to conduct the test in the laboratory.

Figure 3.2 Casagrande apparatus for liquid limit.

About 150g soil sample passing through a 0.425 mm IS sieve was taken and placed on a glass plate. In order to make a uniform paste for testing required amount of

water is added to the sample. Few amounts of paste were then transferred to the cup of a liquid limit device and were leveled to an approximate size of 12 mm using a spatula. The groove was then made in soil by using the trenching tool. The cup was placed onto the shaft, and the whole apparatus was set on a felt pad and crank was then rotated at the rate of about two revolutions per second until the two surfaces separated by the groove touched each other at the bottom of the cup along an uninterrupted length of 12 mm. The number of impacts required is recorded. Finally, 8-10 g of the paste was taken from the groove area and transferred into a cup to determine the water content by oven drying. The test was performed with five different water contents. By plotting the no. of blows along the horizontal axis on a logarithmic scale and the water content along the vertical axis on an arithmetic scale, the relevant points were connected and this line will give the liquid limit at its intersection with the vertical of the 25 number of blows. The average of three individual tests was considered the actual liquid limit and the maximum variation in between three individual trials was within ±3%. The entire process was repeated for each soil sample.

3.3.1.2 Plastic limit

The plastic limit of soil is defined as the moisture content at which soil begins to crumble when rolled into a thread of 3 mm. The plastic limit test took about 20-30 g of oven-dried soil sample passing through a 0.425 mm sieve. The required amount of water was added and a number of small balls were made from the prepared sample. Using a palm, these balls were rolled on a glass surface till a uniform thread of 3 mm diameters was obtained, as shown in Figure 3.3. These crumbled pieces were taken into a cup to determine the moisture content. The average of three individual tests was considered the actual plastic limit and the maximum variation in between three individual trials was within ±5%.

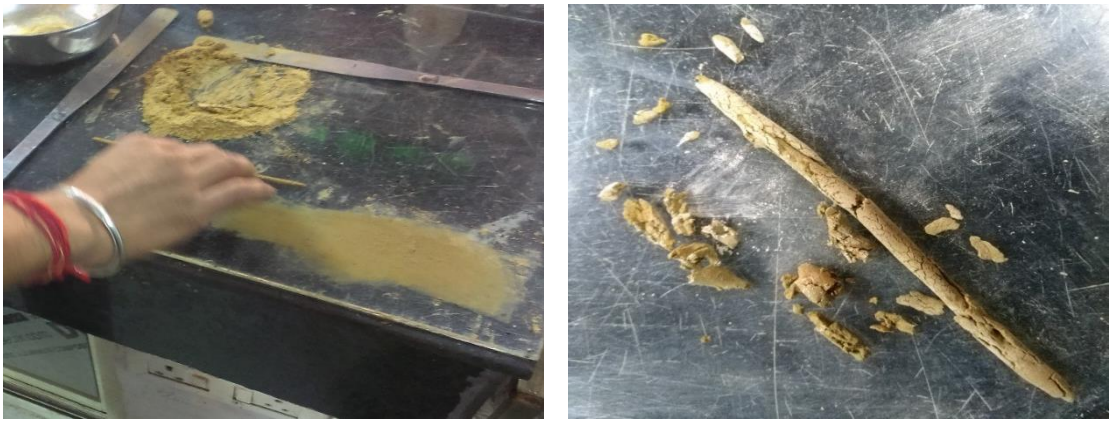

Figure 3.3 Plastic limit of soil mixtures.

3.3.1.3 Plasticity index

The plasticity index is the difference in the liquid limit and plastic limit of the soil mixture. In general, the plasticity index is calculated through equation (3.1).

$$Plasticity\ index\ (PI) = (LL - PL) \tag{3.1}$$

3.3.2 Sieve analysis test

Sieve analysis is a quantitative measurement of the amount of various sizes of particles present in the soil. Generally, in the soil sample, gravel, sand, silt and clay fractions are recognized as containing particles of decreasing magnitude. Sieve analysis, also known as particle size distribution (PSD), is conducted through IS 2720 (Part 4) (1985). The set of sieves used for the analysis in the present study was 4.75 mm, 2.0 mm, 0.425 mm, and 0.075 mm, which were arranged in ascending order from down, as shown in Figure 3.4.

Figure 3.4 Mechanical sieve shaker for particle size gradation analysis.

Figure 3.5 Wet sieve analysis through 0.075 mm sieve.

The proportions of the 200 g oven-dried (105^{o}C-110^{o}C) soil sample were taken in a steel tray. The material was poured into the top sieve of the arranged panel. The stacked sieves and the material were then put into a mechanical sieve shaker (see Figure 3.4) for a minimum time of 10min. The soil fractions retained on each sieve were collected and the mass of each fraction was recorded. Material retained on the 0.075 mm sieve was washed through demineralized water, as shown in Figure 3.5. Consequently, the amount of fine content comprised of silt and clay proportions was estimated. The cumulative mass of soil fraction retained on each sieve was calculated. Based on the total amount of soil taken during testing, the percentage of fraction retained on each sieve was estimated.

3.3.3 Proctor compaction test

Compaction of soil is used to improve the engineering properties of soil. The compaction test can be performed in the laboratory as well as in the field. The laboratory Proctor compaction test is classified into standard and modified compaction. The current study adopted the modified Proctor compaction test conducted as per IS 2720 (Part 8) (1994). The test is performed on the disturbed samples of soil particles passing through a

19mm IS sieve. A 5 kg air-dried soil sample was taken into a pan. Initially, some amount of water was added to the soil sample and mixed thoroughly. The mould of 1000 cm^3 capacity with attached baseplate was taken and the prepared material was filled into 5layers of equal thickness, with each being given 25 blows through the 4.9 kg rammer, which is dropped from a height of 45 cm measured from the soil layer. In the present investigation, the compaction test in the laboratory was performed manually. Therefore, special care was taken that blows shall be distributed uniformly over the surface of each layer (see Figure 3.6 (a)). Once the soil was compacted in the mould, it was transferred to the pan and the collar was removed from the top of the mould. The extra soil was removed and levelled off carefully through the straightedge as shown in Figure 3.6 (b). The mould filled with the soil was weighed nearest to 1 g. Some amount of soil from the top, mid and bottom of the mould was taken into a cup to estimate the moisture content of the sample then the soil was eradicated from the mould. Again same amount (3 kg) of fresh soil of the same gradation was prepared by adding some increasing amount of water, more than the previously added. Similar to the above procedural method the mould was prepared and moisture content was obtained. The process continued until the curve obtained for moisture content versus the dry density was of an inverted 'V' shape. A minimum of five points were achieved for each mix combination. An average of three individual tests was considered the actual maximum dry density (MDD) and optimum moisture content (OMC) of the respective soil sample. It was perceived from the experience of manually casting of numerous soil samples that soil in the mould gets starts bulging on the wet side of OMC while compacting through a rammer.

Figure 3.6 Modified Proctor compaction of soil samples.

3.3.4 California bearing ratio test

The California Bearing Ratio (CBR) test can be carried out both in the laboratory and in-situ. The samples can either be prepared in three different ways (a) the test can be performed on a remolded sample in the laboratory, (ii) on an undisturbed sample carefully extracted from the field and trimmed to fit the standard mould in the laboratory closely and finally (iii) an in-situ sample which is entirely tested in the field.

3.3.4.1 Laboratory CBR testing

The laboratory CBR test is conducted according to IS 2720 (Part 16) (1987). The test specimen in the laboratory is prepared either by using the field density and moisture content or MDD and OMC obtained through IS 2720 (Part 8) (1994) or any other density at which the bearing ratio is desired to calculate. The test specimen can be prepared either using the static compaction or by using the dynamic compaction; IRC-37 (2018) recommends to adopt the static compaction to prepare the laboratory CBR test specimen.

This is because the static compaction can maintain the uniformity of used MDD even after casting the CBR specimen, which might not be facilitated in the case of dynamic compaction. However, dynamic compaction may also be preferred if no setup is available for static compaction. In this study, both i.e. institute laboratory and field laboratory CBR samples were prepared using static compaction procedure.

A cylindrical mould with an inside diameter of 150 mm and height of 175 mm, along with a detachable extension collar of 50 mm height and a detachable perforated base plate of 10mm thickness, was taken for the preparation of the test specimen. The quantity of dry soil for the CBR specimen was estimated through equation (3.2) as per IRC-37 (2012). The required amount of dry soil was uniformly mixed (as shown in Figure 3.7) and respective moisture content was used to prepare the material.

$$Weight\ of\ wet\ soil = Volume\ of\ the\ mould\ \times d \times \frac{(100+m)}{100} \qquad (3.2)$$

Where

d = dry density achieved through Proctor compaction test (g/cm^3)

m = OMC achieved through Proctor compaction test (%)

Figure 3.7 Preparation of materials for CBR specimen.

The selected mould, along with the base plate, was placed on a plane surface and a spacer disc of 148 mm diameter and 47.7 mm height was inserted into the mould. A filter paper of the same diameter was placed on top of the spacer disc. Now, the prepared soil was filled to the edge of the mould and tamping was done using a steel rod. A collar was attached to the mould and the remaining soil was poured into the mould. The filter paper was placed on the top of the soil, followed by a displacer disc above the filter paper. The prepared specimen was placed on the base of the compression machine (see Figure 3.8).

Figure 3.8 Static compaction of the specimen through a compression machine.

Figure 3.9 Laboratory prepared remolded CBR specimen.

The specimen was loaded uniformly until the spacer disc was inserted in the mould and then released. In some of the soil types certain amount of rebound occurs, therefore, an extra disc was placed over the previous disc and load was applied until the first disc was inserted slightly below the top of the mould so that the soil could achieve the actual volume. The specimen, along with all the accessories (spacer disc, collar, etc.),

was taken out from the compression machine, all accessories were removed and the prepared remolded specimen was obtained, as shown in Figure 3.9.

Figure 3.10 CBR test specimen in soaking condition and swell measurement.

To simulate the worst field moisture condition, the CBR specimen was kept in a water tank for a minimum time period of four days. Before soaking, the remolded specimen was loaded with an annular weight to produce a surcharge equal to the weight of base material and pavement expected in actual construction. A surcharge weight of 2.5 kg having 147 mm diameter with a central hole of 53 mm diameter is considered equivalent to 6.5cm construction (Chauhan, 2010). In this study, 5 kg was used to place over the soil specimen. The specimen with assembly and weight were immersed in a water tank and swell readings were taken within a specific time interval. Figure 3.10 shows a complete setup of the soaked CBR specimen.

At the end of the soaking period, the change in the dial gauge was recorded. The tripod was removed and mould was taken out from the water tank. The free water collected in the mould was removed and the specimen was downward to drain the water. Special care was taken not to disturb the specimen during water removal.

The mould containing the specimen was placed on the lower plate of the CBR testing machine. The specimen was loaded with a surcharge weight equal to that used during the soaking period. A plunger of a specified dimension connected with a proving ring was placed over the specimen through the surcharge weight hole. A complete

penetration measuring setup of the CBR test is shown in Figure 3.11. The load and deformation gauge was initially set to zero. The load was applied to the soil through the plunger at a rate of 1.25mm/minute. The load reading was recorded at penetration of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm. Once the measurement of all the penetrations was done, then the clamp of the loading frame was released and the plunger was removed from the specimen. About 80-100 g of soil sample was collected in a cup to estimate the moisture content.

Figure 3.11 A complete test setup of CBR loading frame.

The above-recorded penetration data was used for the measurement of CBR value. Generally, the CBR value at 2.5mm penetration is more than that at 5.0mm penetration. Measurement of CBR value was performed using Table 3.2 and equation (3.3). Whenever the CBR value was obtained maximum at 5.0mm penetration than the 2.5mm penetration, the test was repeated. If again was obtained maximum at 5.0mm penetration, then it was selected as a design CBR value. An average of three individual tests was considered as the actual CBR value. Standard load at 2.5mm or 5mm penetration can be measured using Table 3.2.

$$CBR\ (\%) = \frac{Load\ measured\ at\ 2.5mm\ or\ 5mm\ penetration}{Standard\ load\ at\ 2.5mm\ or\ 5mm\ penetration} \times 100 \qquad (3.3)$$

Table 3.2. Standard load at various depths of penetration.

Penetration depth (mm)	Standard load (kgf)
2.5	1370
5.0	2055
7.5	2630
10	3180
12.5	3600