Full Length Research Paper

Evaluation of geotechnical properties and structural strength enhancing road pavement failure along Sylhet-Sunamganj highway, Bangladesh

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The study looks at the impact of poor soil properties and improper design on highway pavement failure on critical locations along Sylhet-Sunamganj road, Bangladesh. The entire study was conducted in the month of June to July, 2011 which was usually rainy season in Bangladesh. Pavement structural condition was evaluated by Dynamic Cone Penetrometer (DCP) test and sub-grade soil properties were obtained by laboratory soil tests. The California bearing ratio (CBR) values and thickness of the pavement layers were found as 66, 66 and 47% and 90, 90, and 110 mm for surface, base and sub-base layers respectively. According to Roads and Highway Department, the respective values needed were 100, 140 and 180 mm respectively with CBR values of 90, 55 and 16% respectively. It was clear from such comparison that requisite depth of construction were not maintained in various sections which might assist the pavement to its distressed condition. Sub-grade soil properties were evaluated as sandy soil of category A-3 (According to American Association of State Highway and Transport Officials) having moisture content range from 11.11 to 14.94%, specific gravity ranges from 2.21 to 2.49, optimum moisture content range from 9 to 16% were not appropriate for pavement construction. Clayey soil sample that was found from SUST gate arena having moisture content of 16.51%, specific gravity of 2.3, liquid limit of 40.80%, plastic limit of 17.85%, plasticity index of 22.95% and dry density of 2060 kgm^{-3} was totally unsuitable for such an important pavement construction. Specially, maintaining of liquid limit < 40 and plasticity index < 15 of soil is a must for such important pavement construction.

Key words: Dynamic cone penetrometer test, California bearing ratio, penetration rate, sub-base, sub-grade soil.

INTRODUCTION

A pavement section may be generally defined as the structural material placed above a sub-grade layer (Woods and Adcox, 2006). Structure of a specific pavement represents three separate layers of surface, base and sub-base whereas, the characteristics of the soil bed over which the entire pavement system rests on represents pavements geotechnical properties (Mcghee, 2010). It is crucial to develop a sub-grade with a California Bearing Ratio (CBR) value of at least 10

(Novikov and Miskovsky, 2010). Research has shown that if a sub-grade has a CBR value less than 10, the sub-base material will deflect under traffic loadings in the same manner as the sub-grade and cause pavement deterioration (Islam, 2011). The stability and durability of pavement depends on the traffic load or intensity and the strength of pavement layers (Kiehl and Briegleb, 2011). If the pavement is not perfectly designed considering present traffic condition, the pavement failure is a must. Moreover if it is designed without considering incremental traffic in the near future, the pavement life will be successively reduced. Moreover, as a flexible pavement surface reflects the entire behavior of the sub grade

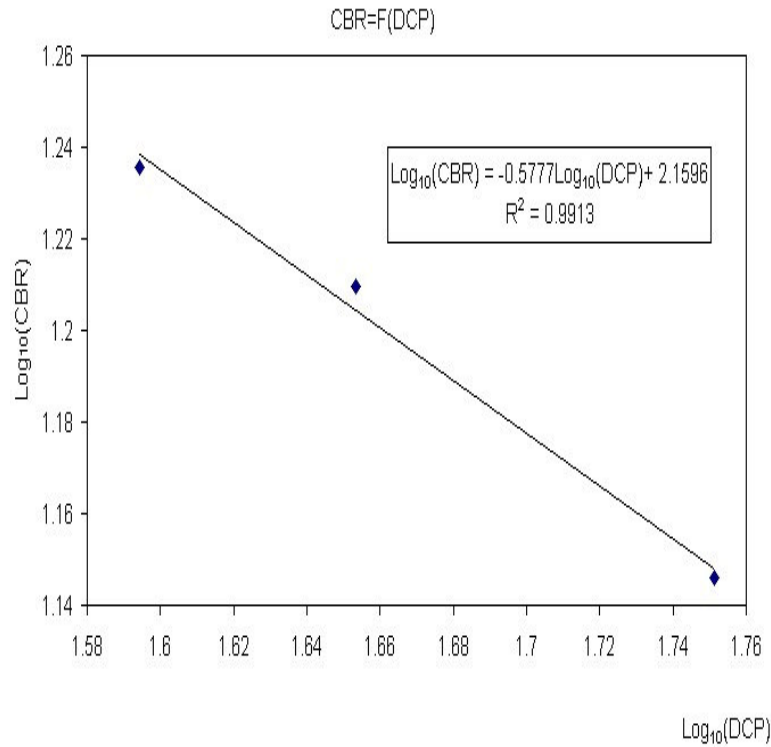*Corresponding author. E-mail: hasancee@yahoo.com.

Figure 1. DCP-CBR relationship.

layer, it thereby, emphasizes more attention on making the soil sub-grade of superior soil properties. In previous research, it was discovered that roads failed due to the following reasons:

1. Inadequacies in pavement structural design (Ogundipe and Olumide, 2012).
2. Poor sub-grade soil properties (Talukder, 2009).
3. Insufficient pavement drainage (Miller and Bellinger, 2003).
4. Effect of seasonal fluctuations of temperature over base course aggregates (Sarsam, 2010).
5. Poor visco-elastic properties of asphalt binder (Nahid, 2011).

As pavement failure characterized with all types of distresses like cracks, ruts, potholes, raveling etc never happens only due to one reason, thereby this research tries to examine the structural condition with geotechnical properties of the materials at failed section of the road. Obtained results are also compared with the RHD design guidelines of that specific pavement.

METHODOLOGY

The DCP is an instrument designed for the rapid *in-situ* measurement of the structural properties of the existing road pavements constructed with unbound materials (Russell et al., 2004). It was also used for determining the *in-situ* CBR value of

compacted soil sub-grade beneath the existing road pavement (Figure 1). The DCP consists of a cone fixed to the bottom of a tall vertical rod. The output of the DCP test is a penetration rate (PR), expressed in mm (inches) per blow which is related to the strength of the material, as measured by the CBR as follows:

$\log_{10}(CBR) = -0.5777 \log_{10}(DCP) + 2.1596$ where, $R^2 = 0.9913$ and CBR = F (DCP)

The field data is reduced in terms of penetration versus corresponding number of blows. The number of blows then plotted horizontally along the x-axis and the penetration reading plotted vertically along the y-axis (Figure 2). Depending on the pavement structure and environmental condition, the plot is divided into "best fit" straight lines. The corresponding thicknesses of pavement layers were then obtained using the curves for respective traffic volume (Woods and Adcox, 2006).

DCP VALUE OF THE STUDY AREA

The DCP test was conducted at three locations arbitrarily named 5th, 6th and 7th kilometers (Figure 2). The penetration values of 10 blows interval were measured to evaluate the DCP value at different longitudinal distances of Sylhet-Sunamganj highway. In order to evaluate the DCP Values at different layers of the road section and the slope or best fitted curve of the different layers were determined based on maximum regression coefficient. DCP test was performed at the most deteriorated portion of the Sylhet-Sunamganj highway at 5th, 6th and 7th kilometer chainage from Sylhet in order to evaluate the actual strength of pavement which might got the responsibility of pavement deterioration (Figure 3). All the following Figures 4, 5 and 6 have shown the DCP test results at different longitudinal sections.
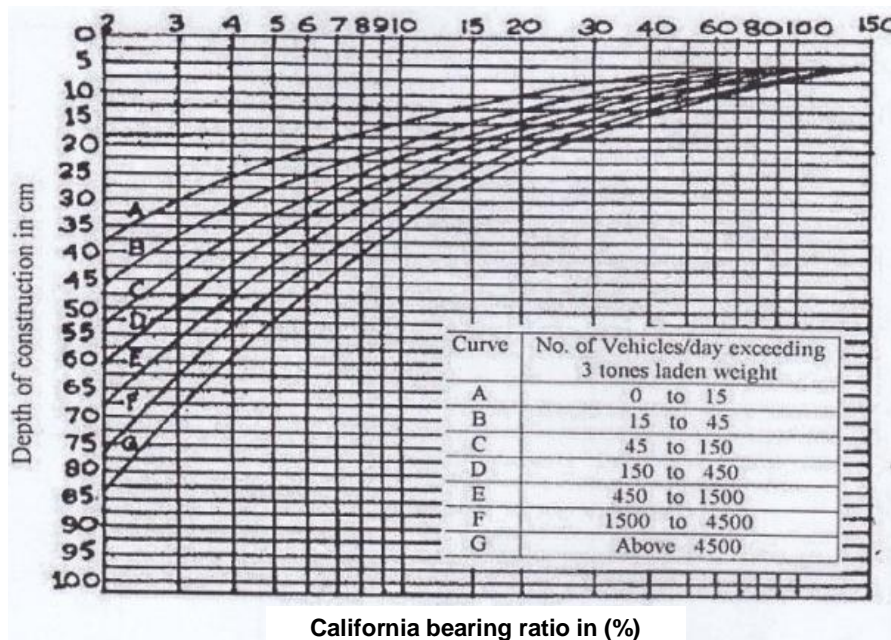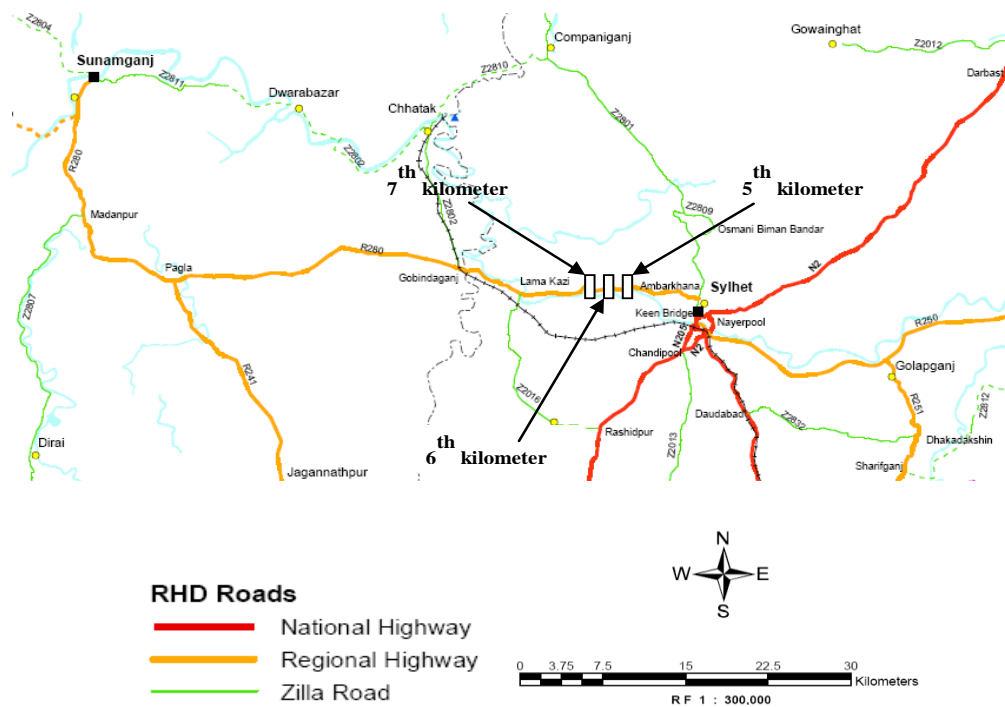
Figure 2. CBR-depth relationship.

Figure 3. Map and road network of the study area (www.rhd.gov.bd).

In Figure 4, the x-axis represents the cumulative numbers of blows and y-axis represents the cumulative penetration in mm. Cumulative numbers of blows were taken up to 150 blows. Cumulative penetration was measured by scale per 10 blow intervals. The first, second and third layer indicates surface, base and sub-base layer respectively. DCP was measured on the basis of maximum regression coefficient. It was seen that regression coefficient for first five data was found to be 0.985 and the DCP value from the slope of the curve was found to be 1.39 and the thickness was 78 mm for this layer. In Figure 4, it was seen that the regression coefficient was increasing as we penetrate deeper and deeper.

The regression coefficient was first lower and then became higher and higher again. Again, DCP was first lower and it became
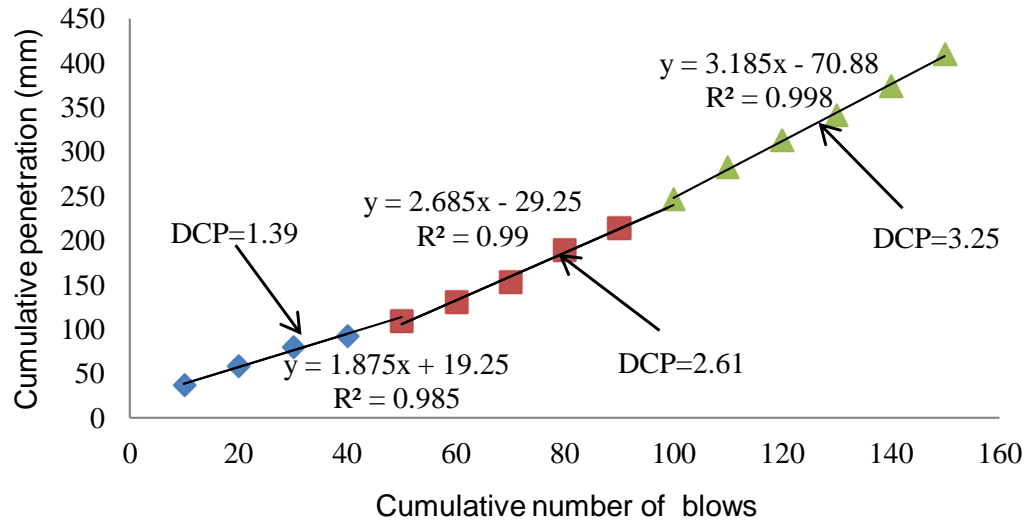
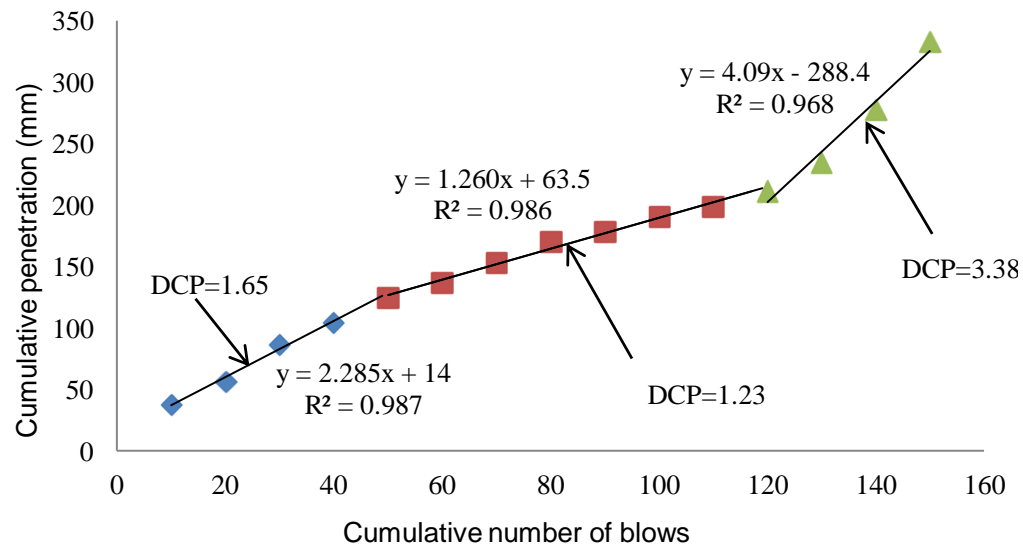**Figure 4.** DCP test result at 5th kilometer.

Figure 5. DCP test result at 6th kilometer.

higher and higher again. The explanation of this regression coefficient was related with the deviation of data. High scatter data means lower regression. So, data for first layer was more scattered than the second and third layer respectively. This represents a certain deviation that occurred in the case of the surface layer. As we know, the surface layer is harder than the base layer as well as base layer was softer than the sub-base layer but in the case of Figure 4, the sub-base layer penetration at 150 blows was 409 mm which was quite extraordinary. Such an extensive penetration represents the sub-base layer condition was really bad at that specific section.

The DCP values of Figures 5 and 6 were quite promising for the three separate layers. The DCP was first higher, and then lower and again higher where regression coefficient was first higher, then lower and again higher for surface, base and sub-base respectively.

The strength of specific pavement layers were depended upon the density of the material and the gradation of the particle sizes.

Each and every layer has its own constituents to perform their respective roles during operation. The sub-grade layer over which the entire pavement system rests on, also need to be compacted enough in accordance to load that seems to be applied.

SOIL PROPERTIES EVALUATION

The sub grade soil (disturbed samples) for several tests was collected at three locations along the highway. Some of the samples were sealed in polythene bags to preserve the *in-situ* condition of the soil. The samples were labeled A to C: 1) Sample A: Surma Gate (in front of British-American Tobacco office), 2) Sample B: Shahjalal University of Science and Technology entrance gate and, 3) Sample C: Tuker Bazar (in front of Bazar mosque). In order to find out basic characteristics of the soil type, soil samples were subjected to the following tests:
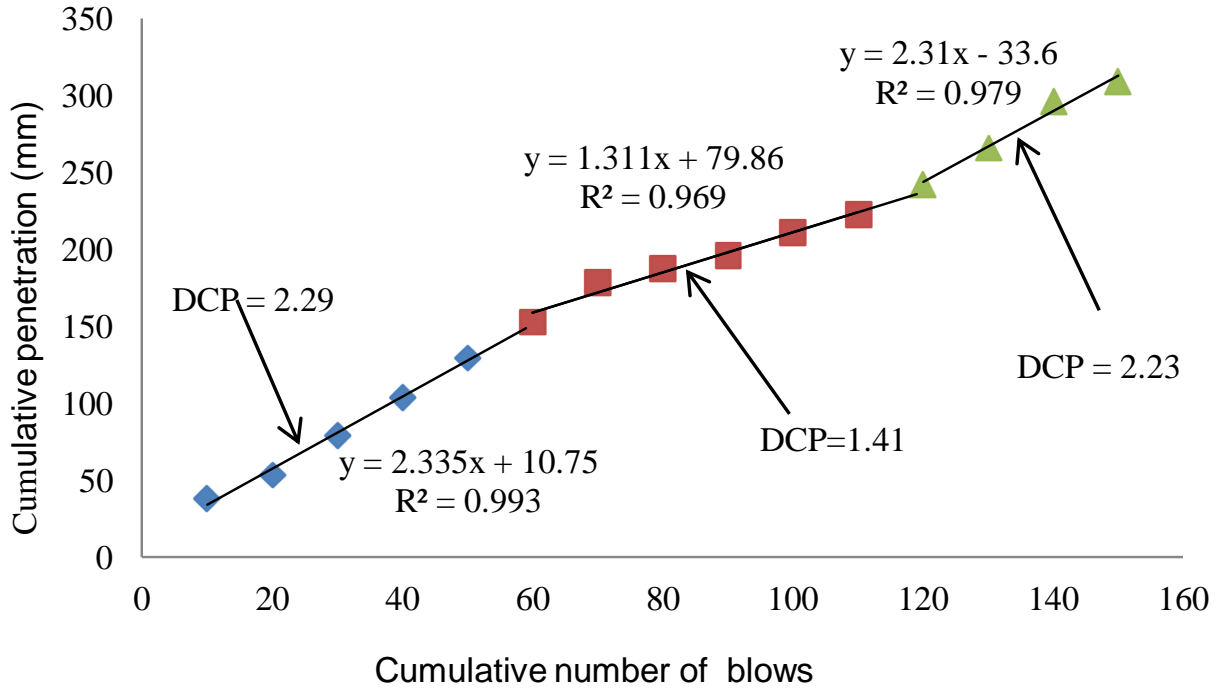
Figure 6. DCP test result at 7th kilometer.
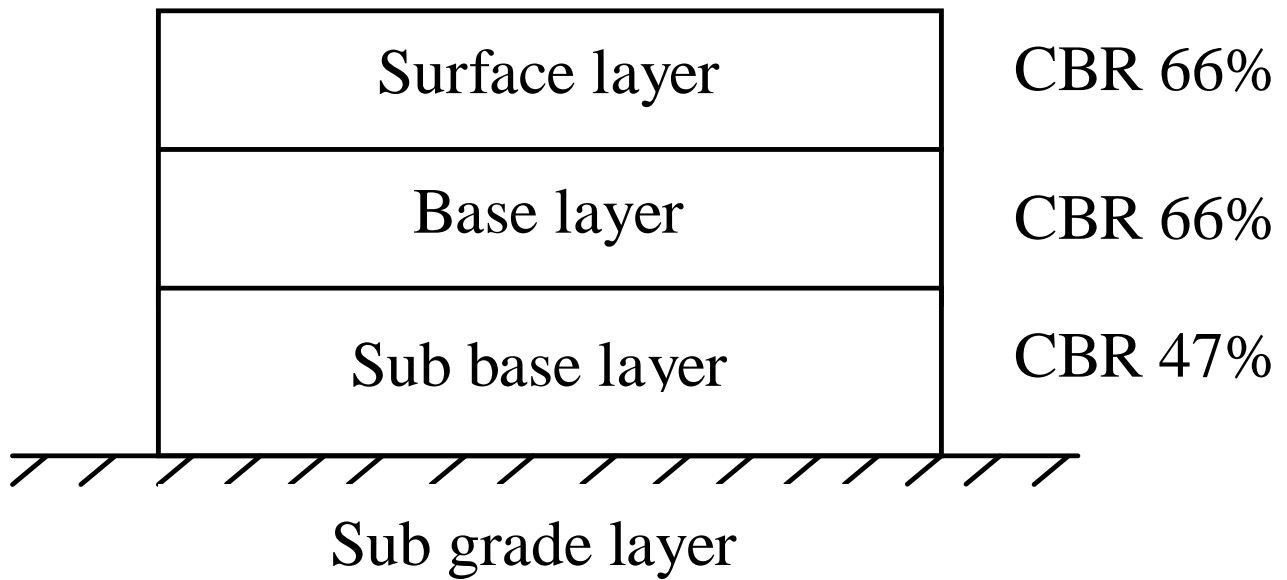
Figure 7. Pavement system with respective CBR values.

1. Mechanical sieve analysis.
2. Specific gravity.
3. Moisture content.
4. Compaction test.
5. Atterberg's limit.

The tests named mechanical sieve analysis, specific gravity, moisture content, compaction test was done in accordance with BS1377 (1990). Since sandy soil was the main type of soil found,

Atterberg limit test was not applicable in this case (Figure 7).

RESULTS AND DISCUSSION

The DCP values of 6th and 7th kilometer were quite promising rather than the 5th kilometer where excessive

Table 1. DCP test result of 5th kilometer.

No. of layer	Thickness of layer(mm)	DCP (mm/blow)	CBR (%)
First (surface)	78	1.39	78
Second (base)	105	2.61	50
Third (sub base)	116	3.25	44

Table 2. DCP test result of 6th kilometer.

No. of layer	Thickness of layer (mm)	DCP (mm/blow)	CBR (%)
First (surface)	88	1.65	68
Second (base)	82	1.23	74
Third (sub base)	120	3.38	42

Table 3. DCP test result of 7th kilometer.

No. of layer	Thickness of layer (mm)	DCP (mm/blow)	CBR (%)
First (surface)	100	2.29	52
Second (base)	79	1.41	75
Third (sub base)	97	2.23	55

Table 4. Average DCP test result.

No. of layer	Thickness of layer (mm)	CBR (%)
First (surface)	90	66
Second (base)	90	66
Third (sub base)	110	47

Table 5. Comparison of results between RHD design guideline and study findings.

No. of layers	Recommended thickness (mm) According to RHD	Recommended CBR (%) According to RHD	Existing thickness (mm) According to DCP	Existing CBR (%) According to DCP
First (surface)	100	90	90	66
Second (base)	140	55	90	66
Third (sub base)	180	16	110	47

penetration was found at the sub-base layer, which might indicate that the sub-base layer condition at 5th kilometer section was not good. Tables 1 to 5, showed the DCP values and their corresponding CBR values. In Table 4, all results were found by averaging the above data. Table 5 shows and proves the inadequate design of the pavement where requisite depth and CBR values were not maintained during construction. Table 6 shows the summary of all the soil test results. The values represent the average of the three replicates of each sample tested.

Mechanical sieve analysis

American Association of State Highway and Transportation Official (AASHTO) classification of soils shows that samples A, B and C falls within A-3 indicating they are fine sand.

Moisture content

As shown in Table 6, the moisture content ranges from

Table 6. Soil sample test result.

Test	Sample A	Sample B	Sample C
Natural moisture content (%)	11.1	14.94	14.28
Specific gravity	2.49	2.21	2.21
Liquid limit (LL) (%)	NP	NP	NP
Plastic limit (PL) (%)	NP	NP	NP
Plasticity index (PI) (%)	NP	NP	NP
Linear shrinkage (%)	NP	NP	NP
Bulk dry density (kgm^{-3})	2000	1938	1909
Maximum dry density (kgm^{-3})	1800	1690	1670
Optimum moisture content (%)	16.5	9	12

Table 7. Characteristics found for clayey soil at SUST gate.

Tests	Sieve analysis	Moisture content	Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Dry density (kgm^{-3})
Result	Type-clayey	16.51	2.3	40.80	17.85	22.95	2060

11.11 to 14.94%. These were considered adequate.

Specific gravity

The values of specific gravity of three samples are shown in Table 6. They are considered appropriate for sub-grade, sub-base and base course materials.

Compaction characteristics

As shown in Table 6, maximum dry density (MDD) and optimum moisture content (OMC) of the samples range from 1670 to 1800 kgm^{-3} and 9 to 16.5%. These values are not perfect specifically for sandy soils as evaluated while at 100% of the MDD and OMC are attained during field compaction ranges from 6 to 10%.

Atterberg limit

In case of sandy soil, Atterberg limits are not present. But whenever the soil is near, SUST gate were excavated for re-construction of the road which was the most deteriorated portion of the entire road and the soil type was found as clayey with the following properties given in Table 7. Table 6 represents the quality of the soil which may never be considered to fulfill the requirements for a well graded sub-grade layer which is a must for a pavement of good performance.

Conclusion

From the study, it was discovered that such current

deteriorated condition of such a vital road happened due to inappropriate design of the pavement or poor geotechnical properties of sub-base and sub-grade soil or other reasons like improper drainage and improper maintenance treatments etc. It was clear from this study that, appropriate thickness of different layers was not given considering the importance of that road.

Thicknesses of surface, base and sub-base were 90, 90 and 110 mm with relative CBR values of 66, 66 and 47% was measured by the DCP test. According to Roads and Highway Department, the respective values needed were 100, 140 and 180 mm with CBR values of 90, 55 and 16% respectively. It was clear from such comparison that requisite depth of construction were not maintained in various sections which might assist the pavement to its distressed condition. The impact of soil properties behind such a pavement failure was tried found out through various tests like mechanical sieve analysis, moisture content determination, specific gravity determination and compaction test etc. The soil characteristics like moisture content ranged from 11.11 to 14.94%, specific gravity range from 2.21 to 2.49, maximum dry density range from 1670 to 1800 kgm^{-3} and optimum moisture content ranging from 9 to 16.5% were really not appropriate for pavement construction. Clayey soil sample that was found from SUST gate arena having moisture content 16.51%, specific gravity 2.3, liquid limit 40.80%, plastic limit 17.85%, plasticity index 22.95% and dry density 2060 kgm^{-3} was totally unsuitable for such an important pavement construction, where, maintaining of LL< 40 and PI < 15 is a must. Moreover, road side soil was sandy type, whereas sub-grade soil at SUST gate pavement section was clayey type. Such an inconsistency between road side soil and sub-grade soil might get an impact on sub-surface drainage system and might enhance the

failure of the road. Since the study was conducted in rainy season, clogging of water in pavement layers might decrease corresponding CBR values of respective layers. Therefore, it is important that materials that conform to specification are needed to be used in the construction of the road pavement. In some cases, appropriate correction measures could be adopted to make the materials suitable. Also, the pavement life can be extended by providing adequate drainage facilities.

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