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Strength of Cement Treated Base Courses in the Flexible Pavement Design for Pathlaiya-Nijgadh Section of East-West Highway of Nepal

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Abstract

Rutting and fatigue are the most common pavement distresses that are caused due to overloading, subgrade strength, and poor construction quality. The strength of the pavement layer can be improved by the construction of cement-treated layers. This study suggested that the cement-treated base is the effective modification technique for a granular base course by evaluating the unconfined compressive strength, and modulus of rupture. The unconfined compressive strength revealed that a cement-treated base is an effective treatment for the improvement of strength. Similarly, flexural strength indicated that a cement-treated base is an effective method to reduce the fatigue damage of the base course, and 5% cement content is sufficient to resist crack formation on the base course. 5.34% cement content in CTB developed a stiff mix with a stronger ability towards applied load dispersion that can resists deformation. In the meantime, unconfined compressive strength, modulus of rupture, and modulus of elasticity obtained at 5.34% cement content on a cement-treated base satisfied the minimum requirement as set by the Department of Roads, Government of Nepal.

Keywords: Cement Treated Base, Cement Content, Flexural Strength, Unconfined Compressive Strength.

1. Introduction:

Pavement design and construction is the most important element of the entire highway construction. The whole performance of the road transportation sector is dependent on traffic load and pavement structural strength as well as its surface condition. The major function of a pavement structure is to transmit applied traffic loads to the roadbed and system to mitigate and adapt the positive response to chronic and acute stress. Resilience pavement construction should have the mechanism to restore, maintain, and even improve their essential functions. The essential function of the pavement structure is to distribute the transmitted stresses from the wheel load from the layer to the soil base which helps to resist the pavement deflection (Timsina, 2018). Flexible pavement, such as hot mix asphalt (HMA), open graded friction course, or rubberized asphalt, is laid over a rigid section [1]. A concrete base layer typically provides structural capacity, while an asphalt surface layer serves as a wearing surface course. Wheel loads, traffic intensity, climate, geography, and sub-grade soil conditions are just a few of the variables that are being considered for the flexible pavement design process.

The pavement has problems of deformation, cracking, and disintegration due to stress from heavy vehicles and water intrusion. The failure of granular bases may occur due to the loss of interlocking between aggregate, which cannot transfer the wheel load to the ground underneath properly which fails pavement [2]. The use of cement with the granular base may increase the binding properties of aggregates and the strength of the base course though it is difficult to estimate the optimum quantity of cement content to be added in the granular base to gain the required strength [3]. Therefore, it is required to establish a reliable relationship between cement content versus UCS and modulus of rupture (M_{RUP}).

A cement-treated base (CTB) is assumed to be a strong, frost-resistant base for concrete or black-top pavement construction, and can be a mix of natural soil, gravel, or synthetic aggregates with specified amounts of cement and water. The treated layer usually serves as a good working platform for later construction, as well as providing enough structural support for the pavement structure. While utilizing soil cement, it is important to consider the mix design, design of thickness, and construction techniques. The mix design specifies the proper percentage of cement (and water) in the mixture to ensure that the soil-cement base has to fulfill the strength and durability requirements. The flexible pavement design guidelines of Nepal emphasize that the CTB material shall have a minimum UCS of 4.5 to 7 MPa in 7/28 days, 5000 MPa modulus of elasticity, and 20% of the 28-day UCS value (MPa) for flexural strength [4]. The previous result indicates that the strength and firmness characteristics are significantly improved by using cement [5]. Pavements with CTB will be substantially stronger and more rigid than those with a granular base that has not been stabilized. The thickness of CTBs may be less than that of granular bases carrying the same traffic. Moreover, it can disperse loads over a larger area, lowering subgrade strains and serving as the load-carrying element of flexible pavement. The design thickness of CTB for 34.86 million standard axles (msa) has been estimated as 357.43 mm while the design thickness of the granular base course has been 500 mm [6]. Similarly, CTB's stiffness may decrease the deflection, base rutting, and other asphalt strains induced in the pavement [2]. Therefore, it is essential to investigate the performance of the soil cement stabilized pavement and its design.

2. Methodology:

2.1. Study Zone:

The materials selected for this study were suitable for CTB. The laboratory tests were conducted in a laboratory inside Kathmandu Valley. The study area for this study was the Pathlaiya-Nijgadh section (19.992 km) of the East-West Highway of Nepal.

2.2. Data Collection:

Primary Data: The data has been taken from the primary data collected from the laboratory investigation and field survey. For laboratory investigation, data from the Sieve analysis, Los Angeles Abrasion, Aggregate Impact Value, Aggregate Crushing Value, Unconfined Compressive Strength, Modulus of Rupture, and Modulus of Elasticity have been used for the research analysis.

Secondary Data: The secondary data were obtained from the norms and specifications of the Department of Roads, Government of Nepal, published research articles, and other design guidelines. The comparison has been made based on laboratory results with the standard value listed in the guidelines [4].

2.3. Base Material Selection:

(a) Aggregate:

For use in a base course, the material was sufficiently well-graded to ensure a well-closed surface finish and have a grading within the range of Standard Specification for Road and Bridge Works (SSRBW), [7] of Nepal. The physical requirement of the base material is according to Standard Specification for Road and Bridge Works (SSRBW), [7] of Nepal which has been presented in Table 1.

Table 1: Physical Requirement of the Base Material

Name of Test	Test Methods	Test Result	Specifications (SSRBW)
Los Angeles Abrasion Test (LAA)	IS:2386 Part IV	30.13%	Max 40%
Aggregate Impact Test (AIV)	IS:2386 Part IV	24.53%	Max 30%
Aggregate Crushing Value Test (ACV)	IS:2386 Part IV	27.35%	Max 40%
Plasticity Index (PI)	IS:2720 Part V	NP	Max 6%
Flakiness Index	IS:2386 Part I	23.68%	Max 35%

(b) Cement:

For the preparation of the mixture, 43 grade Ordinary Portland Cement was used. The initial setting time, final setting time and strength test were conducted according to IS and the results are shown in Table 2.

2.4. Unconfined Compressive Strength (*UCS*):

A reliable testing machine having sufficient capacity and capable of applying loads was used for compressive strength testing. To conduct the test, a previously calibrated compression testing machine was used. The compression strength test was performed in the laboratory. To perform the test, the prepared samples as confirmed to ASTM D1632-96 were used for testing. The cylindrical cubes were tested for their crushing strength at 7 days and 28 days. The compressive strength of concrete cubes with different variations of cement content was determined.

Table 2: Cement Test

Name of Test	Test Methods	Result	Specifications (SSRBW)
Initial Setting Time (min)	IS: 4031 Part V	210	45 (Minimum)
Maximum Final Setting Time (min)	IS: 4031 Part V	345	600 (Maximum)
Compressive Strength (MPa)	IS: 4031 Part VI		
3 days		27.24	16
7 days		39.31	22
28 days		51.78	33

Preparation of Sample for *UCS* Test:

Specimens with a total mix of base material and cement were prepared confirming to the ASTM D1632-96 for specimen preparation. CTB specimen was prepared with different cement content ranging from 0% to 6% with a uniform increment of 1% by weight of CRM base material. At first, the base material was graded within the limit specified by the Standard Specification for Road and Bridge Works (SSRBW) of Nepal from sieve analysis. In the second stage, this well-graded base material was pulverized with different cement content and compacted in the mould. 6 number of specimens were prepared for each proportion of cement content for 7 days and 28 days to validate the unconfined compression test result for the sample of minimum UCS requirement of 4.5 to 7 N/mm^2 for 7 and 28 days respectively [4]. The size of the cylindrical mould was 15 cm in diameter and 30 cm in height which has been tested to find the unconfined compressive strength of the concrete using Eq. (1) proposed by [8].

$$UCS = \frac{P}{A} \tag{1}$$

where,

UCS = Unconfined Compressive Strength in N/mm^2

P = Maximum Load Applied in N

A = Cross-Sectional Area in mm

2.5. Modulus of Rupture:

The flexural strength of CTB is determined using center point testing method which is important to estimate the slab thickness. The pavement should be thick enough to withstand flexural stresses and fatigue damage caused by wheel loads. The cracks developed due to volume changes in CTB should be minimized with the proper design. The shrinkage cracks appear at the surface of the pavement during the early life of CTB-based pavement construction. Similarly, fatigue cracks are initiated at the bottom of the CTB when fatigue consumption exceeds a certain magnitude [9]. The comparison of the thickness of the granular base and the cement-treated base for this section of road has been estimated based on design traffic of 34.86 msa for 15-year life period [6].

Preparation of Sample for Modulus of Rupture Test:

Specimens with a total mix of base material and cement were prepared to confirm the IS:516-1959 for specimen preparation. CTB specimen was prepared with different cement content ranging from 0% to 6% with a uniform increment of 1% by weight of CRM base material. At first, the base material was graded within the limit specified by SSRBW of Nepal from sieve analysis, and this well-graded base material was pulverized with different cement content and compacted in the mould. The number of specimens was prepared for each proportion of cement content for 28 days to determine the maximum flexural strength requirement of 1.4 N/mm^2 for 28 days [4]. The size of the beam for the flexural strength test was 10 cm x 10 cm x 50 cm which can be calculated by using Eq. (2) proposed by [10]

Modulus of Rupture (Flexural Strength)

$$M_{RUP} = \frac{P \times L}{b \times d^2} \quad (2)$$

where,

M_{RUP} = Modulus of Rupture in N/mm^2

P = Maximum Load Applied in N

L = Length of Sample in mm

b = Breadth of Sample in mm

d = Height of Sample in mm

2.6. Modulus of Elasticity:

The modulus of elasticity is also known as the rigidity of the CTB. It is an empirical indication of the CTB mix. It's a metric indicating a material's resistance to shear and permanent deformation. It was calculated by using Eq. (3) proposed by DoR (2021).

$$E_{CTB} = 1000 \times UCS \quad (3)$$

3. Result and Discussion:

Granular bases, which can fail when an interlock is lost, cannot compete with CTB slab-like characteristics and beam strength. This occurs when traffic loads force wet subgrade soils up into the base. CTB is practically impervious due to its hard, rigid nature. It is resistant to cyclic freezing, rain, and spring-time damage. Even when subjected to traffic, a cement-treated base gains strength with age. This reserve strength contributes to CTB's outstanding performance in sustainable infrastructure development. The unconfined compressive strength, flexural strength (modulus of rupture), and modulus of elasticity tests were used to evaluate the performance of CTB. The result of the unconfined compressive strength, flexural strength, modulus of elasticity, and optimum cement content in CTB has been presented in the following sections:

3.1. Unconfined Compressive Strength:

Unconfined Compressive Strength (UCS) test results for the 7 days and 28 days is shown in Table 3 and Fig. 1 which depicts cement content versus UCS. The upward trend of the values of UCS indicates that the strength increases with the increment of cement content. UCS 4.62 N/mm^2 for 7 days and 7.39 N/mm^2 for 28 days had achieved 6% cement content which satisfied the Flexible Pavement Design Guideline i.e., 4.5 N/mm^2 for 7 days and 7 N/mm^2 for 28 days.

The variation of *UCS* value against various percentages of cement content of 7 days and 28 days is shown in Fig. 1. It demonstrates a reciprocal relationship in which increasing the cement content improves the strength of the 7-day and 28-day mixtures.

Table 3: *UCS* Values for different Cement Content for 7 days and 28 days

Cement Content (%)	UCS (N/mm^2) 7 days	UCS (N/mm^2) 28 days
0	0.00	0.00
1	0.61	0.84
2	1.33	1.89
3	1.97	3.68
4	2.57	5.04
5	3.61	6.75
6	4.62	7.98

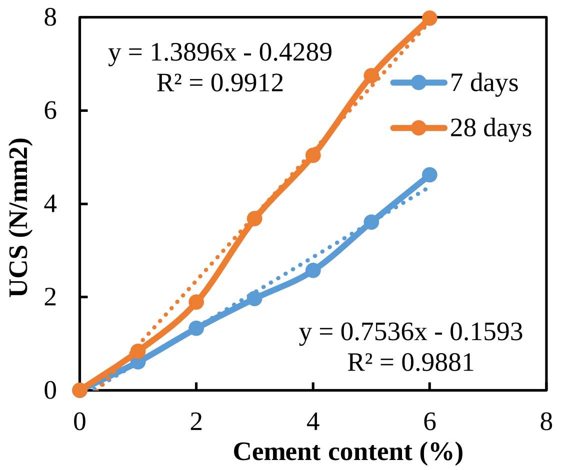

Figure 1: Variation of *UCS* with different cement content of 7 days and 28 days

A similar study conducted by [3] concluded that an increase in the strength of the mixture is due to the hydration products of the cement which fill in the pores of the matrix, increasing the rigidity of the structure by generating a large number of strong bonds in the soil.

Since the nature of this study is also similar to the above-mentioned study, the higher value of *UCS* achieved in this study may be due to the hydration products of the cement which therefore might have increased the rigidity of the mixture.

3.2. Flexural Strength (Modulus of Rupture):

For fatigue damage analysis of the cement-treated base, the modulus of rupture (M_{RUP}) or flexural strength of the CTB material is required. Greater M_{RUP} indicates a higher possibility of fatigue damage i.e. crack initiation to crack growth. The maximum value modulus of rupture obtained at 6% cement content was 1.52 N/mm^2 which satisfied the minimum requirement of 1.4 N/mm^2.The variation of M_{RUP} values with cement content in different percentages is presented in Table 4.

Table 4: M_{RUP} for different cement content %

Cement Content (%)	M_{RUP} (N/mm^2)
0	0.00
1	0.06
2	0.59
3	0.80
4	1.03
5	1.31
6	1.52

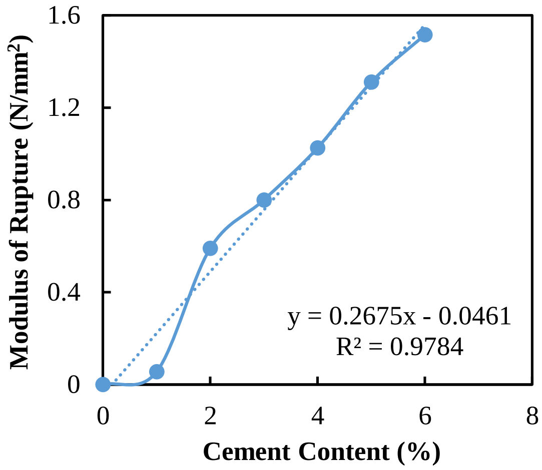

Figure 2: Variation of Modulus of Rupture with different % of cement content

Figure 2 shows the variation of the modulus of rupture with different percentages of cement content. The upward trend of the curve clearly indicates that the M_{RUP} increases with an increase in the cement content. Top-down cracking (TDC) is a dominant type of distress when we provide layers of fully bonded thick pavement with a cement-treated base (CTB). The use of a crack relief layer can enhance the effect of top-down cracking in the CTB-based pavement. The result shows that there is a higher possibility of fatigue damage for the cement content of more than 5%. Since the M_{RUP} at 5% is 1.31 N/mm^2 and the maximum design value of cementitious stabilized aggregate for M_{RUP} is 1.40 N/mm^2. Therefore, it is recommended that, 5% cement content is suitable for the CTB in terms of flexural strength.

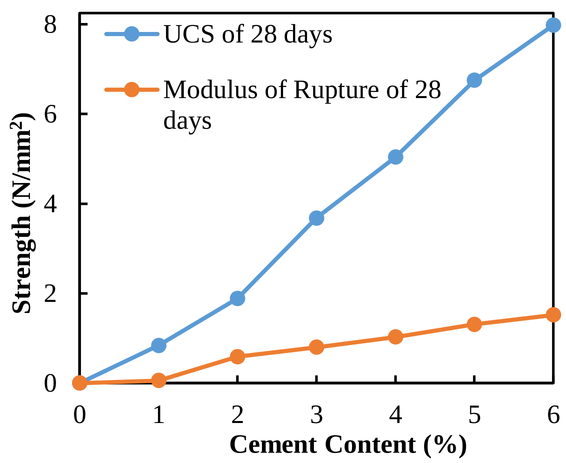

Figure 3: Variation of *UCS* and M_{RUP} with different cement content for 28 days

The variation of *UCS* and M_{RUP} values against the various percentage of cement content over 28 days is shown in Fig. 3. It shows that both *UCS* and M_{RUP} value increases with the increase in cement content.

The similar study conducted by [11] has concluded that the increase in Modulus of Rupture with the increase in cement content and [3] also concluded that the increase in *UCS* with the increase in cement content.

Therefore, the above-established relationship between *UCS*, Modulus of Rupture and cement content has a strong relationship to determine the design value of this parameter.

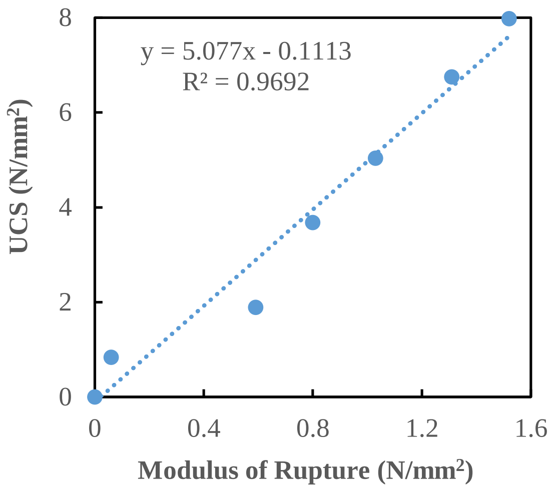

Figure 4: Relationship between *UCS* and M_{RUP}

The relationship between *UCS* and M_{RUP} is demonstrate in Fig. 4. There is a clear trend of increasing modulus of rupture with an increase in unconfined compressive strength.

A similar study conducted by [12] has concluded the relationship between *UCS* and M_{RUP} could be used to estimate the Pavement Mechanistic-Empirical design input corresponding to design compressive strength.

Therefore, the above-established relationship between *UCS* and M_{RUP} could be very useful to estimate the Pavement Mechanistic-Empirical design input corresponding to design compressive strength for the different percentages of cement content.

3.3. Modulus of Elasticity:

Because of the difficulties associated with testing and interpreting test results, methods for determining an appropriate elastic modulus of CTB material are complicated. Due to these difficulties, it was suggested that instead of testing, a relationship between the material's strength and modulus of elasticity be used for design purposes.

Table 5: Modulus of Elasticity for different cement content

Cement Content %	Modulus of Elasticity (E_{CTB}) MPa
0	0.00
1	840.35
2	1890.16
3	3680.12
4	5040.24
5	6750.60
6	7980.25

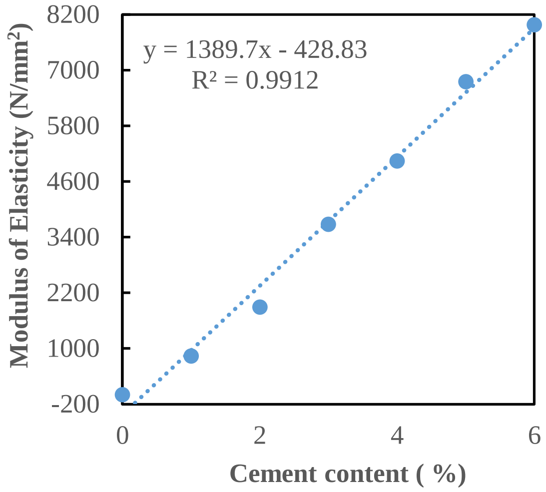

Figure 5: Variation of Modulus of Elasticity with different cement content

The elastic modulus of CTB was estimated from the *UCS* of the materials. Modulus of elasticity (E_{CTB}) is a measure of the strength of base material and depends on the quality of the material. A stiffness mix with a high modulus of elasticity value has a stronger ability to disperse the applied load and is more resistant to deformation. The modulus of elasticity obtained at 6% cement content was found maximum value of 7980.25 MPa. Figure 5 and Table 5 shows the E_{CTB} for various cement content levels.

3.4. The Relationship Between Variables:

Multiple regression is a statistical approach for analyzing the relationship between a group of dependent variables and an independent set of variables. In this study, based on experimental data, a linear model was developed to identify the influence of cement content on the *UCS* and M_{RUP}. The following Table 6 shows the linear relationship of the variables using MS Excel software, which is a compressive system for analyzing data.

Table 6: Summary of relationship between variables

Relationship between	R^2	Model
Cement content (%) - UCS - M_{RUP} of 28 days	0.9941	C(Predicted) = 0.494×UCS + 1.144 × MRUP + 0.281

where, C = cement content in %

This relationship was established from the regression model because M_{RUP} has a limiting value, if this value exceeds the maximum value, then the surface will have a fatigue cracking. Therefore, to find the Optimum Cement Content (*OCC*) for satisfying the *UCS*, M_{RUP} and *E*, from the above relation OCC was predicted, where the design value of *UCS* and M_{RUP} were taken as 7 N/mm^2 and 1.4 N/mm^2 respectively as per design standards.

$$OCC_{\text{(Predicted)}} = 0.494 \times 7 + 1.144 \times 1.4 + 0.281 = 5.34\ \%$$

Strength parameters of cement treated base using optimum cement content are presented in the Table 7.

Table 7: Strength parameters at optimum cement content for CTB

Cement Content	Strength Parameters (N/mm^2)		
	Unconfined Compressive Strength	Modulus of Rupture	Modulus of Elasticity
5.34 %	7.17	1.37	7168.68

From the above table it is seen that the optimum cement content (OCC) which has a value of 5.34% seems to satisfy the criteria of 28 days of unconfined compressive strength (7 N/mm^2) modulus of rupture (1.4 N/mm^2) and modulus of elasticity (5000 MPa) provided in the [4].

4. Conclusion:

This study investigated the effect of cement content on the strength of cement-treated base using *UCS* and flexural strength test. The modulus of elasticity was also calculated through empirical relationship. The layer's strength improves as the cement content rises. But using too much cement may cause shrinkage cracks. To reduce the excessive cement content, flexural strength test was done to satisfy the design modulus of rupture to mitigate the cracks and rutting.

The finding of this study recommends using 6% cement in the pavement base layer for *UCS* of CTB to meet design value. The results of the *UCS* tests revealed that CTB is an alternative to the granular base to improve its strength and possibly reduce water vulnerability. Also, the results of the flexural strength test indicated that CTB is effective measure to reduce the fatigue damage of the base course. This study also recommends that the 5% cement content has a sufficient design value to resist crack formation on the base course. However, when all three parameters are looked at in combined manner, the optimum cement content satisfying all the strength parameters of CTB was 5.34%. Optimum cement content was predicted from the relationship between *UCS*, M_{RUP} and cement content through the multiple regression analysis. The findings of this study demonstrate that the cement content and age of the test specimens have a significant impact on the *UCS* of CTB. The study also showed that there is a reciprocal relationship between cement content and the flexural strength of CTB.

Conflicts of Interest:

The authors have declared that no competing interests exist. The data used for this research are commonly and predominantly used data in our area of research and country. There is no conflict of interest between the authors and other stakeholders because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by any authorities rather it was funded by the personal efforts of the authors.

Data Availability Statement:

The data that support the findings of this study are available to the main author, upon reasonable request.

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