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Establishing a Relationship of CBR and Base Course Thickness with Base Course Material Properties of different aggregate samples of Nepal

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Abstract

The quality of the construction materials used in pavement layers must be assessed before construction. Some of the important properties governing the suitability and quality of a construction material include California Bearing Ratio (CBR), Los Angeles Abrasion (LAA), Aggregate Impact Value (AIV), and Plasticity Index (PI) value of the material. The base course material must ensure the criteria outlined in the Standard Specifications for Road and Bridge Works published by the Department of Roads. In Nepal, there have not been sufficient studies to establish a relationship between CBR and base course thickness with other physical properties of base course material. Hence, a relationship between LAA, AIV, and PI value of the base material to the CBR value and pavement thickness has been formulated in this study, which can be advantageous in a road construction project to reduce time, acting as an alternative check to design base thickness.

Keywords: CBR, thickness of base course, LAA, AIV, PI, regression analysis

1. Introduction

The California Bearing Ratio (CBR) test is one of the most widely used methods for assessing the strength of subgrade soil, sub-base, and base course materials in pavement thickness design. This test measures soil strength through penetration resistance and is used alongside empirical curves to determine the thickness of pavement layers. Therefore, the CBR method is considered empirical rather than theoretical in pavement design. To carry out a CBR test, a representative soil sample must be taken from the site, and a remolded specimen should be prepared using the Standard Proctor Compaction method at the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

Determining the soaked CBR value requires around four days, making the test time-consuming, costly, and labor-intensive. Consequently, only a limited number of CBR tests can be conducted per kilometer of the proposed roadway. Due to this limitation, the test results may not adequately reflect the variations in CBR values along the road, which can hinder rational, economical, and safe design decisions. This issue can be addressed by increasing the number of soil samples, but this would raise project costs and extend the schedule. To overcome these challenges, researchers have explored statistical correlations between the CBR value and other easily measurable soil properties such as Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Maximum Dry Density (MDD), Los Angeles Abrasion (LAA) value, and Optimum Moisture Content (OMC), since these tests are simpler and faster (Shirur and Hiremath, 2014). Similarly, to avoid sample disturbance and to enable quicker verification of results, indirect methods of estimating the CBR value are increasingly seen as necessary. In recent years, predictive models for estimating CBR values have gained significant attention.(Kumar et al., 2019)

In Nepal, the quality of locally sourced base course materials must comply with the requirements outlined in the Standard Specifications for Road and Bridge Works published by the Department of Roads. Since the CBR test demands a large quantity of material and requires compaction to the MDD, the process is both time-

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consuming and costly. As a result, there is a need for a simpler, quicker method to estimate the soaked CBR by correlating it with more easily determined properties (Rakaraddi & Gomarsi, 2015).

The CBR method is found to be a reliable method to establish the correlation between the LAA value and the base course thickness, which was established using the CBR values of different sources of aggregates in Nepal (Uprety and Tamarakar, 2017). Similarly, this study attempts to develop a framework for the prediction of CBR value and base course thickness from the physical properties of base course materials by establishing a correlation between them, utilizing samples from different sources of base course materials in Nepal.

2. Literature Review

Multiple researchers have formulated equations using different properties of materials. (Zumrawi, 2012) found a strong correlation between CBR values and the index properties of cohesive soils. Soil samples from three clayey sites were tested, revealing a direct linear relationship between CBR values, the state factor (Fi), and the plasticity index. (Alawi and Rajab, 2013) used multiple linear regression to predict the CBR of sub-base layers in Makkah, Saudi Arabia, based on simple tests like sieve analysis, LAA, MDD, and OMC. They found that density, OMC, and LAA were the most influential factors, with a strong correlation ($R^2 = 0.94$) to CBR values. (Shirur and Hiremath, 2014) analyzed soil samples with liquid limits between 20 and 70 from various locations to investigate the relationship between CBR and soil properties. Using multiple linear regression, they established a strong empirical model predicting CBR from MDD and OMC. The study also found a linear relationship between the PI and CBR. Rakaraddi and Gomarsi (2015) developed simple and multiple linear regression models to correlate soaked CBR values with soil properties using samples from the Bagalkot district. Their analysis found the liquid limit to be the most influential predictor, followed by OMC, MDD, and PI. Multiple regression provided stronger correlations than simple regression. (SandhyaRani and Nagaraj, 2017) developed correlations between CBR values and soil index properties specific to the Yadadri region using 18 soil samples. Simple regression analyzed the relationship between CBR and liquid limit, while multiple regression included LL, PL, MDD, OMC, PI and percentage passing sieve no. 200. The predicted CBR values closely matched lab results, validating the proposed models. (Bassey et al., 2017) examined the relationship between CBR and soil index properties using samples from Ibiono, Oron, and Onna in Akwa Ibom State. Laboratory tests determined soaked CBR, LL, PL, PI, MDD, and OMC. Non-linear and multiple linear regression analyses, performed with Minitab 13 and Excel 2013, revealed that PI and OMC (Ibiono), OMC and MDD (Onna), and LL, PI, and OMC (Oron) are effective predictors of CBR values.

Iqbal et al. (2018) established correlations between the CBR values and index properties of Jamshoro soil using single and multiple linear regression models. Multiple Linear Regression Analysis (MLRA) yielded stronger correlations, with R^2 reaching 0.984. Soaked CBR was reliably predicted using LL, PI, and % finer, while unsoaked CBR correlated well with LL, PI, and MDD. Gudeta and Patel (2018) developed predictive models using 59 soil samples from various regions of Pakistan, covering both fine and coarse-grained soils. Separate models were created: for fine-grained soils, based on liquid limit and plasticity index; and for coarse-grained soils, based on coefficient of uniformity (Cu) and maximum dry density. Model validity was confirmed using an additional 25 test samples. (Kumar et al., 2019) analyzed grain size distribution and plasticity characteristics to model CBR behavior. Prediction models developed using these parameters yielded R^2 values between 0.42 and 0.49. The study concluded that incorporating more relevant soil properties enhances the accuracy of CBR predictions. (Pal and Pal, 2019) developed a model relating soaked CBR to grain size distribution and plasticity index using extensive test data from fine-grained soils across West Bengal. (Torgano et al., 2020) used non-linear and multiple linear regression analyses on soil samples from Boditi town to correlate CBR with soil properties. They found that CBR decreases with higher PI and increases with higher LL. Soaked CBR is mainly influenced by LL and PI, with % finer having a minor effect, while unsoaked CBR depends largely on LL, PI, and MDD.

In the Nepalese context, (Khatri et al., 2019) investigated single and multiple linear regression models to correlate CBR with soil index properties using 36 samples from the Thankot-Chitlang road. The developed model predicts CBR ($R^2 = 0.8$) based on gravel, sand, clay content, LL, PL, PI, fines percentage, MDD, and OMC. Its accuracy was confirmed through validation with independent test data. (Uprety and Tamarakar, 2017) collected base and subbase samples from various quarries to study the relationship between base course thickness and the base materials' LAA value. Using CBR values from the same sources, they established the correlation based on the CBR method. The Traffic Classification E (450–1500 CPVD), equivalent to 4–9 million standard axles (msa), was selected to calculate thickness while using the CBR method. A maximum difference of 10.5 cm was observed between base course thicknesses calculated using the DOR design guidelines and the IRC-recommended CBR method for flexible pavements. Although the CBR method is not widely practiced, it remains the only feasible approach to link LAA values with base course thickness by incorporating the CBR of base and subbase materials (Uprety and Tamarakar, 2017).

3. Objectives and Contribution

The primary objective of this research was to determine the relationship between CBR value and thickness of base course with different physical properties of base course materials in the construction of flexible pavement. This research will provide a basis for concerned stakeholders to assess in quality control of pavement material by determining the CBR of the sample material from its physical properties prior to conducting any lab tests. Similarly, the relationship obtained between the thickness of the base course and the physical properties of the base course material can be used for an alternative check on design thickness with the use of locally available material. Methodologically, this study aligns with the previous work presented in (Uprety and Tamarakar, 2017) which focused solely on LAA and thickness, but this study expands to include other base material properties such as AIV and PI. Following a similar approach, this study uses the CBR method to calculate base thickness with base and subbase materials from different sources. The soaked CBR values are determined, and Traffic Classification E (450–1500 CPVD) is applied, aligning with the prior study's parameters. The study uses Simple Linear Regression Analysis and Multiple Linear Regression Analysis to establish relationships between different properties, similar to several studies that have been conducted previously.

4. Methodology

This research uses a lab experimental approach, which focused on obtaining the primary data from laboratory tests of the collected base course materials from 20 different sources, 9 from Gandaki, 8 from Bagmati, and 3 from Sudurpashchim Province of Nepal, and was analyzed and interpreted.

The samples collected from the different sources were checked to meet the conformity of the standard as per the Standard Specifications for Road and Bridge Works. The number of test samples and tests required for physical properties is based on the test frequency suggested by SSRBW. Similarly, the CBR was determined according to Indian Standard IS: 2720 (Part 16)-1987. Laboratory tests were performed on the samples following the manual of standard test, 2015, published by DOR to obtain different physical properties of the base course material. The different lab tests performed are as follows:

- Los Angeles Abrasion (LAA)
- Aggregate Impact Value (AIV)
- Modified Compaction Test
- Atterberg's Limits (LL, PL, PI)
- CBR Test for base and sub-base material

4.1 Calculation of Base Course Thickness from CBR Method

The data from the lab tests - CBR value of base course and subbase material - was used to determine the base course thickness using the CBR method of pavement design with IRC modification. The CBR test is a penetration test meant for the evaluation of subgrade soil, subbase, and base courses. The design of flexible pavement can be done using the CBR method, which uses empirical curves to determine the thickness of pavement and its component layers. In this method, a chart contains several curves (A, B, C, D, E, F, and G) which represent the different levels of traffic intensities. Using the CBR value of each pavement layer, for a

given traffic intensity, an appropriate curve is selected to get the total pavement thickness. The thickness of each layer is then calculated by subtracting the thickness calculated from the relative CBR values.

IRC recommendation for CBR method of design suggests that the wearing course, such as surface dressing or open graded premixed carpet up to 2.5 cm thickness, should not be counted towards the total thickness of pavement, as they do not increase the structural capacity of the pavement (IRC: 37-1970).

4.2 Model Formulation

The relationship between CBR and properties of base course materials was established using regression analysis. The established relation was validated using Mean Absolute Percentage Error (MAPE). Similarly, the relation between the base course thickness and the same properties of the base material was established and validated. The data analysis was done using simple and multiple regression analysis using SPSS. The relationship model was formulated using samples from 15 sources, and the validation of the model was done using samples from 5 other sources.

4.2.1 Simple Linear Regression Analysis

A graph was plotted between CBR and the other properties of the base material, and a suitable trend line was drawn through those points to obtain the value of the coefficient of determination (R2). The coefficient of determination measures how well the future outcomes are likely to be predicted by our model. The dependent and independent variables required for each case have been presented in Table 1 below.

4.2.2 Multiple Linear Regression Analysis

A multiple linear regression analysis attempts to develop a correlation between more than two variables. One is the response, and the others are explanatory variables. For the first part, CBR of the base course is taken as the dependent variable, and other base course material properties are taken as the independent variables. Similarly, for the next part, the base course thickness is taken as the dependent variable, and other base properties are taken as the independent variables. We can predict the CBR value and base thickness from the generated regression equation at any instant, provided the values of the independent variables. The dependent and independent variables required for each case have been presented in Table 1 below.

Table 1. Dependent and Independent Variables for Simple/Multiple Linear Regression

Dependent Variables (y)	Independent Variables (x)
Case I: CBR of Base	LAA, AIV, and PI
Case II: Thickness of Base	LAA, AIV, and PI

4.3 Coefficient of Determination (R-Squared Value)

The R-squared value is a statistical measure of fit that shows the amount described by an independent variable or variables in a regression model for a dependent variable. The R-squared value, also known as the Coefficient of Determination, is a number ranging from 0 to 1 that indicates how closely the trend lines' estimated values represent the true data. R-squared defines to which extent variance of one variable explains the variance of another variable.

4.4 Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error (MAPE) is commonly used as a loss function for regression problems and in model evaluation, because of its very intuitive interpretation in terms of relative error. The mean absolute percentage error, also known as mean absolute percentage deviation, is a measure of the prediction accuracy of a forecasting method in statistics. It usually expresses the accuracy as a ratio, as shown in the formula in Equation 1.

$$M = \frac{1}{n} * \sum_{t=1}^{n} E\mathrm{i} \qquad \text{(Equation 1)}$$

where,

M: Mean Absolute Percentage Error

n: Number of times the summation iteration happens

Ei: Error defined in Equation 2

$$E_i = \frac{|At - Ft|}{At} * 100\% \qquad \text{(Equation 2)}$$

At: Actual value

Ft: Forecast value

(Lewis, 1982) suggests the threshold values for MAPE as a statistical check, as shown in Table 2 below.

Table 2. MAPE Value Threshold

MAPE Value	Interpretation / Prediction Accuracy
<10	Highly Accurate
10-20	Good Forecasting
20-50	Reasonable Forecasting

5. Results and Discussion

The collected samples were tested in the laboratory to obtain the CBR, LAA, AIV, and PI values for the base material and were found to be suitable for use in the base course as required by the SSRBW. The CBR of the subbase was also obtained from laboratory tests of subbase material from the same source. Using the CBR method on the calculated CBR value of subbase material, the base thickness (Tb) above the top of the subbase layer with respect to the selected curve (traffic class E) was calculated. Based on the IRC recommendation, taking the surface layer as surface dressing of 2.5 cm, the thickness of the surface dressing has not been counted towards the total thickness of the pavement. The lab results obtained are presented in Table 3.

Table 3. Summary of all laboratory test results and base thickness

Source Code	CBR of Base (%)	CBR of Subbase (%)	Base Thickness (cm)	LAA (%)	AIV (%)	PI (%)
1	105	91	7.5	22.00	12.52	0.3
				24.98	16.08	1.01
2	82	48	10.15	37.55	25.31	5.73
				36.12	26.07	6.00
3	96	80	7.5	27.98	18.98	3.51
				26.34	17.57	3.29
4	81	38	10.5	33.22	25.67	4.24
				34.14	24.32	4.01
5	84	52	9.25	37.22	23.01	5.56
				39.57	24.12	5.92
6	83	50	9.25	37.12	21.89	5.85
				38.88	22.78	6.00
7	81	36	10.25	38.00	22.96	5.29
				39.11	23.39	6.00
8	92	65	8.15	28.92	22.27	4.56
				30.46	22.39	3.24
9	84	51	9.5	34.96	25.78	5.48
				33.32	24.16	5.92
10	88	63	8.5	32.60	24.18	4.92
				32.08	23.74	3.89
11	80	31	13	34.96	25.72	5.98
				30.00	24.87	5.51
12	95	91	7.5	28.10	16.57	2.86
				27.99	17.40	4.26
13	83	48	10.15	35.67	24.96	5.76
				33.87	24.31	6.00

14	85	80	7.5	35.29	22.73	5.07
				34.12	22.87	6.00
15	84	38	10.5	34.08	22.04	4.08
				34.75	20.16	4.12

5.1 Model Formulation (CBR and Base Course Material Properties)

Using SPSS, the relationship between CBR and the physical properties of the base course material was established. Simple Linear Regression Analysis was initially performed between the dependent variable (CBR) and the independent variables (LAA, AIV, and PI), followed by the use of Multiple Linear Regression Analysis between the variables. The graphical representation of the results is shown in Figure 1, and the developed regression equations are shown in Table 4.

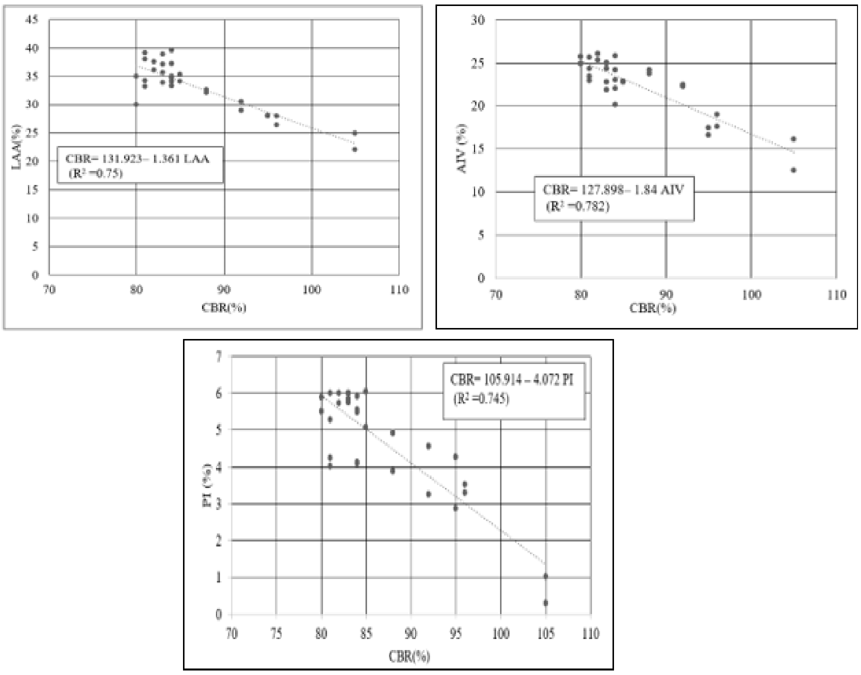

Figure 1. Results of SLRA between CBR and LAA, AIV, and PI

Table 4. Developed Regression Equations between CBR and LAA, AIV, and PI

Model No.	Relation of CBR with	Regression Equation	R2 value	F	Sig (p)
1	LAA	CBR = 131.923 – 1.361 LAA	0.75	83.81	0.00
2	AIV	CBR = 127.898 – 1.84 AIV	0.782	100.37	0.000
3	PI	CBR = 105.914 – 4.072 PI	0.745	81.66	0.000
4	LAA, AIV, and PI	CBR = 131.625 – 0.59 LAA – 0.963 AIV – 0.804 PI	0.881	64.19	0.000

From the above regression analysis result, the R2 value implies that the variation of the dependent variable (CBR) is explained by the variation of the independent variables (LAA, AIV, and PI). The p-value of 0.000 (<0.005) shows that the relation is significant. The coefficient is negative, which shows there is an inverse relation between the CBR value and different aggregate properties. The result obtained in this study shows similarity to previous studies, where (Zumrawi, 2012) also found a direct linear relation between CBR and PI. Similarly, (Alawi and Rajab, 2013) also developed a prediction model for CBR with LAA of aggregate. A recent study by (Shah and Tamrakar, 2024) found a negative correlation between CBR and PI with R2 value of 0.85. Kalaunee (2020) developed a relationship between LAA and AIV of base material, suggesting that AIV can also be a parameter used to predict CBR, which can be seen in the result as CBR was found to be related to LAA, AIV, and PI.

5.2 Model Formulation (Base Course Thickness and Base Course Material Properties)

Using the same approach, the relationships between the base thickness and the physical properties of the base course material were established using SLRA and MLRA. The graphical representation of the results is shown in Figure 2, and the developed regression equations are shown in Table 5.

Table 5. Developed Regression Equations between Base Thickness and LAA, AIV, and PI

Model No.	Relation of Base Thickness with	Regression Equation	R2 value	F	Sig (p)
1	LAA	Thickness of base (cm) = -1.302 + 0.308 LAA	0.48	26.08	0.000
2	AIV	Thickness of base (cm) = -2.465 + 0.509 AIV	0.75	85.32	0.000
3	PI	Thickness of base (cm) = 4.203 + 1.003 PI	0.56	36.73	0.000
4	LAA, AIV, and PI	Thickness of base (cm) = -2.223 + 0.02 LAA + 0.441 AIV + 0.136 PI	0.76	27.33	0.001

From the linear regression to predict the Thickness of the base (cm) from LAA, AIV, and PI values, the R-squared value was found to be 0.76, implying that 76% of the variation of the dependent variable (Thickness of base (cm)) is explained by the variation of independent variables LAA, AIV, and PI. (Uprety and Tamarakar, 2017) determined relationship between the thickness of the base course and the LAA of the base material. When LAA was only considered, the Thickness of the base course (cm) = 2.25 + 0.27* LAA (%) was suggested by (Uprety and Tamarakar, 2017). In this study, the simple linear regression between thickness and LAA gives the equation as Thickness of base course (cm) = -1.3 + 0.308* LAA (%). A similar trend was found to be obtained from this study.

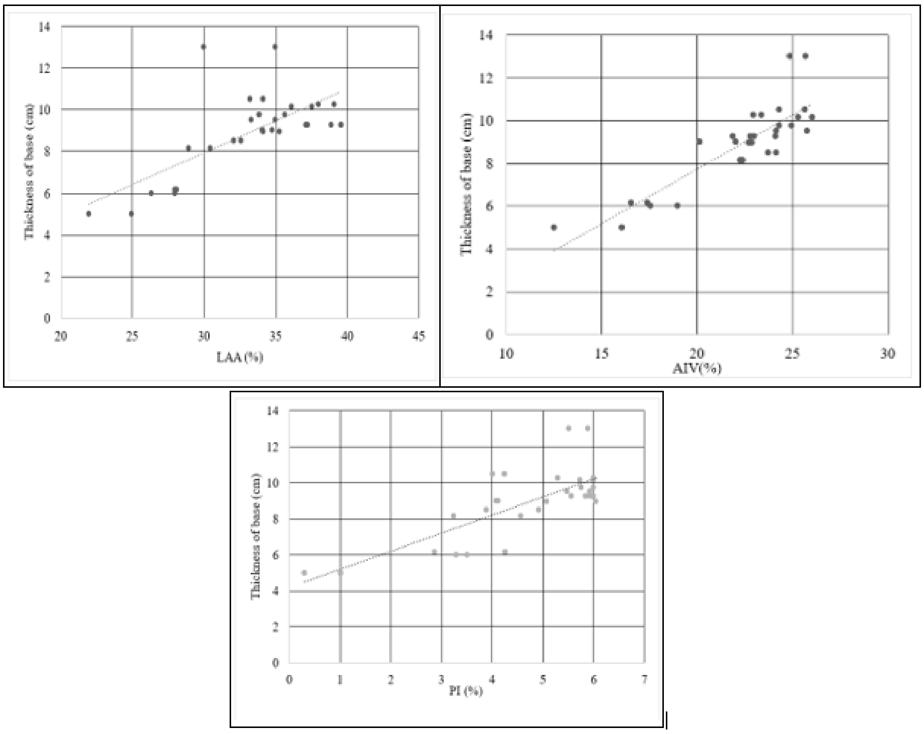

Figure 2. Results of SLRA between Base Thickness and LAA, AIV, and PI

5.3 Validation of the Model

The developed models were validated using samples collected from 5 other sources. The MAPE values of each sample were calculated and averaged. Based on the MAPE results and the threshold values, it can be concluded that both simple linear and multiple linear regression models between the variables provide a useful predictor. The test results from those sources used for validation are presented in Table 6, and the average MAPE values calculated for the models are shown in Table 7.

Table 6. Summary of all laboratory test results and base thickness for the validation samples

Source Code	CBR of Base (%)	Base Thickness (cm)	LAA (%)	AIV (%)	PI (%)
16	85	9	35.11	24.52	4.24
			37.22	25.05	4.33
17	93	7.5	29.64	19.45	5.3
			28.48	22.55	4.89
18	80	10.75	39.11	22.4	4.84
			38.44	23.87	4.00
19	97	7.5	27.14	16.58	2.59
			27.28	16.96	2.84
20	82	9.85	33.34	24.29	5.92
			34.52	23.71	4.86

Table 7. Validation of the SLRA and MLRA Models

Model No.	Relation of CBR with	Regression Equation	Average MAPE
1	LAA	CBR = 131.923 – 1.361 LAA	2.27
2	AIV	CBR = 127.898 – 1.84 AIV	3.27
3	PI	CBR = 105.914 – 4.072 PI	5.45
4	LAA, AIV, and PI	CBR = 131.625 – 0.59 LAA – 0.963 AIV – 0.804 PI	2.41
Model No.	Relation of Base Thickness with	Regression Equation	Average MAPE
1	LAA	Thickness of base (cm) = -1.302 + 0.308 LAA	8.59
2	AIV	Thickness of base (cm) = -2.465 + 0.509 AIV	8.75
3	PI	Thickness of base (cm) = 4.203 + 1.003 PI	14.98
4	LAA, AIV, and PI	Thickness of base (cm) = -2.223 + 0.02 LAA + 0.441 AIV + 0.136 PI	8.56

From the data of actual and predicted values, the Mean Absolute Percent Error (MAPE) was calculated. The comparison of errors from previous studies was done, and it appears that present models show less error for CBR prediction and a very similar result for base course thickness prediction than previous where (Gudeta & Patel, 2018) calculated percentage errors of 8%, 9% and 7% for CBR prediction models from different parameters.

6. Conclusion and Recommendation

- The relationship between the CBR of base and LAA, AIV, and PI was developed using simple linear regression analysis. The simple linear regression models developed give a good fit regression model.
- The multiple linear regression analysis between CBR and the base material properties gave the following relationship:
- CBR = 131.625 – 0.59 LAA – 0.963 AIV – 0.804 PI (R2 = 0.881)
- Similarly, the relationship between the base course thickness and LAA, AIV, and PI was developed using simple linear regression analysis. The simple linear regression models developed give a good fit regression model.
- The predicted thickness of the base course is very close to the values obtained using the CBR method. Hence, the proposed relationship is acceptable.
- The multiple linear regression analysis between the base course thickness and the base material properties gave the following relationship:
- Thickness of base (cm) = -2.223 + 0.02 LAA + 0.441 AIV + 0.136 PI (R2 = 0.76)

- The developed models were validated using 5 sample sources, checked using MAPE. The calculated MAPE values were within the threshold values, which suggests that the above equations can be used to predict CBR and base course thickness using physical properties of the base materials (LAA, AIV, and PI).

It is expected that the use of these models will significantly reduce the time and effort in road construction projects. These models will be useful for flexible pavement construction agencies like the Department of Roads (DOR), Department of Local Infrastructure (DOLI), Infrastructure Development Office (IDO), municipalities, and construction engineers to economize cost and time for material testing in construction, and provide a check to design thickness for preliminary project analysis and budgeting.

Recommendation for further studies

- This study was done from 20 sources of the base sample, and it is recommended to include more sources all over Nepal and validate the relation in the real field also.
- The thickness calculation of the base course was done using the CBR method of analysis, and for Traffic Class E, it is recommended to compare the relation for other traffic intensities also.
- It is recommended to perform other physical and mechanical tests, such as Modulus of Elasticity and Poisson's ratio, and use recent methods of pavement design.
- It is recommended to the Department of Roads to carry out further research to relate thickness with other properties of pavement aggregates.

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