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Determination of an Empirical Model between California Bearing Ratio and Aggregate Crushing Value of Base Course Materials of Selected Sources in Madhesh Province

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Abstract
The research study focuses on evaluating the physical properties of base course aggregates from various river sources in Madhesh Province and their suitability for road construction, based on the "SSRBW 2016 (2nd Amendment 2022)" by the Department of Roads (DoR). Sixty-six aggregate samples from twenty-two rivers were tested in accordance with IS codes and DoR testing manuals. The study aimed to assess strength and durability, particularly analyzing the relationship between Aggregate Crushing Value (ACV), and California Bearing Ratio (CBR) Value. Results showed that 21 out of 22 sources met the required specifications. Seventy-five percent of suitable samples were used for regression analysis to develop an empirical relationship between CBR and ACV, while the remaining percent were used for model validation. A strong correlation ($R^2 = 0.8444$) was found, indicating that ACV can be a reliable substitute for CBR testing, simplifying and expediting aggregate evaluation for pavement design.

Keywords*—Aggregate crushing value, base course, California bearing ratio value test.*

1. BACKGROUND

Nepal, as a landlocked developing country, prioritizes the development of a well-connected, sustainable, and environmentally friendly road network to drive socioeconomic progress. A reliable road system lowers transportation costs and improves access to essential services such as healthcare, education, tourism, agriculture, and commerce ultimately aiding in poverty reduction.

Road pavements, essential for vehicular movement are built in layers including subgrade, sub-base, and base course and wearing course. The choice between flexible, rigid, or composite pavements depends on factors like durability and cost. The base course is particularly important in providing structural support, commonly made from granular materials. Aggregates are a key component in road construction, and their suitability depends on properties like strength and hardness. To ensure quality and consistency, the Department of Roads (DoR) in Nepal follows the Standard Specifications for Road and Bridge Works

(SSRBW 2016). Engineering tests like Aggregate Crushing Value (ACV) and California Bearing Ratio (CBR) are crucial in evaluating material performance.

Maintaining construction quality requires careful sourcing of materials, strict adherence to standards, and the use of proper testing methods. Research into the physical properties of locally available aggregates helps guide planning and ensures roads are durable, safe, and efficient. And the development of relationship between them help for reducing cost and time.

1.1 Research Objectives

The general objective of the study is the determination of California bearing ratio value using aggregate crushing value of base course from different aggregate sources in Madhesh Province.

2. LITERATURE REVIEW

The study conducted field and laboratory investigations to explore the correlation between two rock parameters in Sri Lanka. The research revealed that the Los Angeles Abrasion (LAA) value is between 1.64 and 1.38 times the aggregate impact value (AIV) when plotted on a normal scale. A regression analysis established the relationship between LAA value and AIV as follows: LAA Value = 1.1749 * AIV + 1.5636. [4]

The suitability of rocks from quarries in the Central Development Region by conducting various laboratory tests, including the Flakiness Index Test, Los Angeles Abrasion Value Test, Aggregate Crushing Value Test, Aggregate Impact Value Test, and Water Absorption Test on bulk samples from different quarries. These tests were carried out in accordance with the relevant codes and compared against the Standard Specifications for Road and Bridge Works. Based on the results, the construction materials from various sources were evaluated for their suitability in different pavement layers of roads. [7]

The study investigate the Los Angeles Abrasion Value (LAAV) test, commonly used to assess the abrasion characteristics of granular materials in road construction. Despite its effectiveness, the LAAV test has drawbacks such as being time-consuming, noisy, dusty, and requiring significant space. The study explored a modified compaction method as an alternative, which simulates dynamic loading conditions experienced by unbound granular materials in base and sub-base layers. Testing on nineteen aggregate samples revealed a strong correlation between LAAV and compaction abrasion values (CAVs). The findings suggest that the modified compaction method could be a practical alternative for evaluating abrasion resistance. [1]

In a study conducted rock samples from various regions in Nepal were analyzed to investigate the relationship between the Los Angeles abrasion value (LAA) and the thickness of the base course. This study involved comparing the technical properties of aggregates, specifically the LAA values, with the California bearing ratio (CBR) values, to determine the

correlation between the LAA values and the base course thickness. The research involved collecting twenty samples from base and sub-base courses from different quarries across Nepal. These samples were then tested for their LAA and CBR values. The findings were presented through a regression analysis, which resulted in the following equation: Thickness of base course = 2.25 + 0.27 x LAA. [13]
The study about suitability of the aggregates obtained from river source of Rupandehi and Nawalparasi District, Nepal. Different laboratory tests i.e. flakiness index test, CBR test, PI test, Los Angeles Abrasion value test, aggregate impact value test and water absorption tests on the bulk samples taken from the different river sources are carried out according to the relevant IS code standards and are compared with the standard specifications for road and bridge works. Four local rivers source aggregates, Tinau River of Rupandehi and Turiya, Binayee and Khajura Riverbed materials were comply with the standard specification for Road and Bridge works, 2001and hence, suitable for use as the road construction materials. [2]

The study about suitability of the aggregates obtained from riverbed of Gandaki province, different laboratory tests i.e. flakiness index test, Los Angeles Abrasion value test, aggregate impact value test and water absorption tests on the bulk samples taken from the different river sources are carried out according to the relevant AASHTO/ASTM/IS code standards and are compared with the standard specifications for road and bridge works. According to the tests performed the construction materials from the different sources are decided whether they can be used or not for the construction of base coarse of the roads and relationship between AIV and LAAV was LAAV=1.247*AIV+ 6.61. [5]

The study conducted a comparative study assessing the physical properties of riverbed aggregates (RBA), crushed aggregates, and their combinations for road sub-base, aligning with department of roads' guidelines. Laboratory tests included various aggregate compositions ranging from 100% Crushed to 100% RBA, evaluating properties like gradation, Atterberg's Limits, compaction, water absorption, specific gravity, CBR, LAA, AIV, ACV, FI, and EI. Results showed all properties met specified limits. RBAs outperformed crushed aggregates in LAA and AIV, while crushed aggregates excelled in ACV, CBR, FI, and EI. Considering physical, strength, and cost aspects, RBAs demonstrated advantages over crushed aggregates. [10]

The study about the base material. To assess their performance, tests evaluating resistance to degradation are vital but time-consuming. Thus, establishing empirical links between degradation and strength parameters becomes valuable. The article aimed to compile existing literature on relationships between parameters such as aggregate impact value (AIV), aggregate crushing value (ACV), ten percent fines value (TFV), Los Angeles Abrasion value (LAAV), and micro-Deval coefficient (MDE), and rock strength indicators like uniaxial compressive strength (UCS) and point load strength index (IS50). It sought to offer best-fit formulas for different rock types while acknowledging the challenges and limitations in these relationships. [8]

3. METHODOLOGY

Appropriate approach were developed in order to meet the goals outlined in the first chapter. The process includes data collected from laboratory test, literature reviews, study area selection, extraction, analysis, and interpretation.

3.1 Study Area

Madhesh Province has eight districts with Koshi, Bagmati, Bishnumati, Paoda, Balan, Khutti, Chure, Kamala, Charnath, Jaladha, Aauri, Rato, Janga, Baake, Phuljor, Puljhor, Lakhandei, Paurai, Chhadi, Dhansar, Lal Bakaiya, Pashah, dudhaura, Sikari, and Sukhaura River are the aggregate sources of Madhesh Province.

3.2 Sampling Method

To assess the quality and characteristics of riverbed aggregates, samples were gathered from different locations across Madhesh Province. The sampling focused on areas known for their frequent use of aggregate sources, where extraction and utilization are most common. These sampling areas were selected based on their relevance to pavement construction activities and their geological diversity, ensuring a representative sample of the province's aggregate resources. The sampling procedure involved collecting materials from different locations within the riverbeds, ensuring a comprehensive assessment of the aggregates. All samples were carefully documented and transported for further analysis, following standard protocols to maintain the integrity of the materials as per SSRBW 2016.

3.3 Sample Collection

To assess riverbed aggregate characteristics in Madhesh Province, 66 samples were collected from 22 rivers, with three samples per river as per SSRBW 2016 guidelines, ensuring representation of natural variability. Locations were identified through local surveys, focusing on widely used sources near highway bridges, particularly within 50 meters upstream and downstream where extraction tenders are issued. Sampling sites were selected for their relevance to local aggregate use. Standard protocols were followed to maintain sample integrity. Each sample was properly labeled and transported to the lab for testing, aiding in developing a comprehensive model of aggregate distribution and quality in the region.

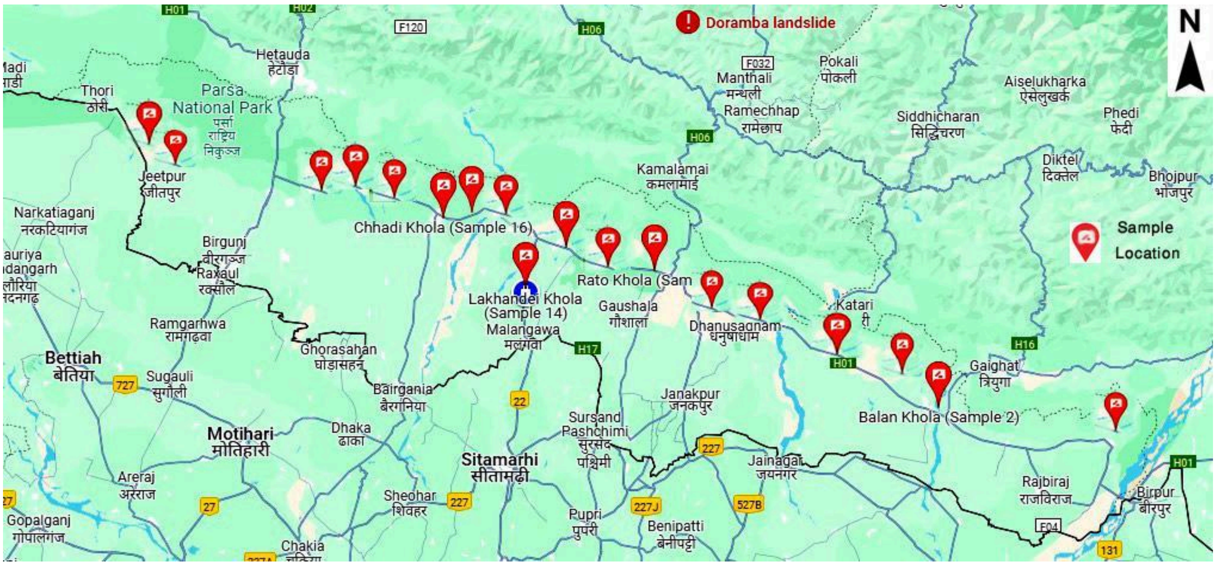

Figure 3.1 Map of Sample Collection Location of Madesh Province

3.4 Data Collection

Primary data were collected by laboratory tests and secondary data were collected from standard specifications and report published by DoR, Nepal (2016). All the test are done in laboratory of Advanced College of Engineering and Management.

3.4.1 Primary Data Collection

Physical properties of aggregate are gradation, water absorption, specific gravity, Elongation index, Flakiness index, California bearing ratio value test, Los Angeles Abrasion value test, aggregate impact value test and aggregate crushing value test were determined through laboratory test. Laboratory test were performed to determine suitability of aggregates for pavement construction on study area. The following physical properties for base course material were tested as per Specifications and related codes of conduct.

- Aggregates crushing value (ACV) test - IS: 2386 (Part IV)
- California bearing ratio (CBR) test – IS: 2720 (Part -16)

3.4.2 Secondary Data Collection

The secondary data was collected from SSRBW 2016 and codes of Indian standards. The specification was provide standard tests involved in representing the quality of materials for different layers of pavement. Physical requirements of base course materials for secondary data sources from SSRBW 2016.

3.5 Data Analysis

Samples were collected from study area and Laboratory tests for each physical property was conducted in accordance with the manual of standard tests, DoR (2015) and IS codes. Data analysis were done as per the objectives which are described in chapter one.

3.5.1 Analysis and Established Relationship between CBR Value and ACV

Regression analysis was conducted using the test results from 75% suitable samples to establish a relationship between the California bearing ratio value and the aggregates crushing values, based on output data from laboratory analysis.

3.5.2 Validation of Modal

The results and relationship were validated to ensure the data analysis with 25% suitable samples were used for modal validation. Data are validated in two ways. 75% suitable samples are used for model development and 25% suitable samples were used to validate the regression model. Also, model is validated with theoretical and trend basis of previous studies. [5]

4. Results and discussion

4.1 California Bearing Ratio Value Test Results

Before conducting California bearing ratio value test there should be needed optimum moisture content, so optimum moisture content and maximum dry density value are obtained by conducting standard proctor tests and table 4.1 shows the optimum moisture content and maximum dry density value test results with California bearing ratio value test results.

Table 4.1 Comparison of CBR value test result with Standard Specification

SN	District	Sources	CBR (%)		
			Specifications	Tests Results	Remarks
1	Saptari	Paoda River	Minimum 80%	77.43	Not Complied
2		Balan River		82.73	Complied
3	Siraha	Khutti River		82.60	Complied
4		Chure River		81.93	Complied
5		Kamala River		82.07	Complied
6	Dhanusha	Charnath River		82.46	Complied
7		Jaladha River		82.86	Complied
8		Aauri River		84.19	Complied
9	Mahottari	Rato River		82.07	Complied
10		Janga River		82.33	Complied
11		Baake River		82.07	Complied
12	Sarlahi	Phuljor River		82.86	Complied

13	Sarlahi	Puljhor River	Minimum 80%	82.20	Complied
14		Lakhandei River		82.46	Complied
15	Rautahat	Paurai River		83.13	Complied
16		Chhadi River		82.07	Complied
17		Dhansar River		82.33	Complied
18	Bara	Lal Bakaiya River		82.60	Complied
19		Pashah River		80.74	Complied
20		Dudhaura River		82.33	Complied
21	Parsha	Sikari River		81.14	Complied
22		Sukhaura River		82.33	Complied

Table 4.1 presents the California Bearing Ratio (CBR) test results for aggregates from various river sources in Madhesh Province. The CBR test evaluates the strength and load-bearing capacity of aggregates, with a minimum acceptable value of 80% for road construction suitability. Among the 22 river sources tested, 21 met the required standard, indicating adequate strength for use in road projects. The highest CBR value was 84.19% from Aauri River in Dhanusha District, while the lowest was 77.43% from Paoda River in Saptari District, which did not meet the specification, suggesting limited suitability for structural applications.

4.2 Aggregate Crushing Value Test Results

Table 4.2 Comparison of ACV Test Result with Standard Specification

SN	District	Sources	ACV (%)		
			Specifications	Tests Results	Remarks
1	Saptari	Paoda River	Maximum 30 %	21.31	Complied
2		Balan River		20.25	Complied
3	Siraha	Khutti River		19.29	Complied
4		Chure River		20.73	Complied
5		Kamala River		21.37	Complied
6	Dhanusha	Charnath River		17.63	Complied
7		Jaladha River		19.69	Complied

8	Dhanusha	Aauri River	Maximum 30 %	16.39	Complied
9	Mahottari	Rato River		16.98	Complied
10		Janga River		18.16	Complied
11		Baake River		14.26	Complied
12	Sarlahi	Phuljor River		17.72	Complied
13		Puljhor River		17.77	Complied
14		Lakhandei River		16.07	Complied
15	Rautahat	Paurai River		23.35	Complied
16		Chhadi River		17.52	Complied
17		Dhansar River		16.79	Complied
18	Bara	Lal Bakaiya River		17.31	Complied
19		Pashah River		14.21	Complied
20		dudhaura River		17.90	Complied
21	Parsha	Sikari River		15.18	Complied
22		Sukhaura River		18.75	Complied

Table 4.2 provides a comparison of the ACV test results for aggregate samples from various river sources across different districts in Madesh Province against the standard specification. The ACV is a measure of the strength of aggregate material, indicating its resistance to crushing under gradually applied compressive load. Singh (2016) has done similar types of Aggregate Crushing Value (ACV) tests for various combination of RBA and Crushed sub-base materials and compare with the relationship between ACV and RBA content focused on Indrawati River, Sindhupalchowk.

The maximum permissible ACV is 30%. Aggregates with a value above 30% may be too weak to provide adequate load-bearing capacity in base course construction applications. All 22 river sources have aggregate samples that comply with the maximum limit of 30% for the ACV, indicating that all tested aggregates have sufficient crushing resistance to be considered suitable for construction.

4.3 Relationship between CBR Value and ACV

4.3.1 Regression Analysis

Second order polynomial Regression Analysis between CBR & ACV

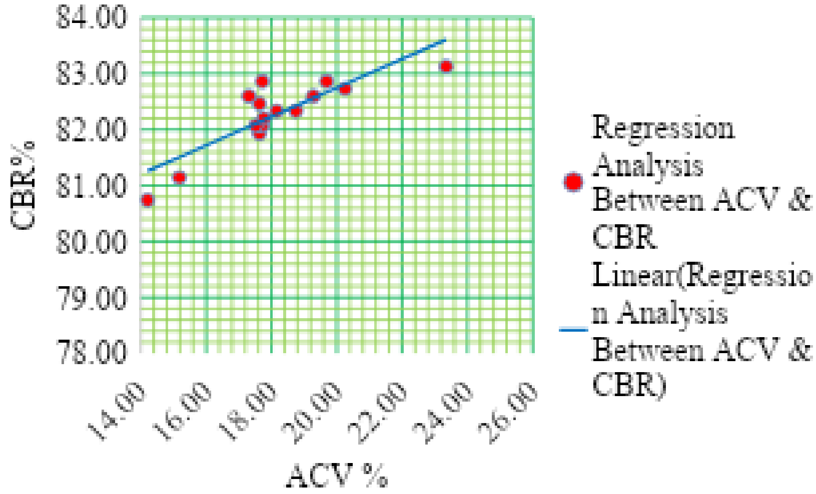

Figure 4.1 second order polynomial Regression Analysis between CBR & ACV

CBR = -0.0315*ACV^2+1.4328*ACV+66.758 ………………. (Equation 4.1) and

R^2 = 0.8444.

Validation for second order polynomial Regression Analysis between CBR and ACV

Table 4.3 Validation of Regression Analysis between CBR and ACV

S. N	District	Sources	ACV %	Actual CBR %	Predicted CBR %	Difference %
1	Siraha	Kamala River	16.75	82.07	81.92	0.15
2	Dhanusha	Aauri Khola	20.43	84.19	82.88	1.31
3	Mahottari	Baake Khola	14.26	82.07	80.78	1.29
4	Sarlahi	Lakhandei Khola	16.07	82.46	81.65	0.81
5	Rautahat	Dhansar Khola	16.79	82.33	81.93	0.40
6	Bara	Dudhaura Khola	15.70	82.33	81.49	0.84

The best model was obtained as equation 4.1 with R^2 value of 0.8444 and maximum value of difference (1.31) between actual vs. predicted CBR then other trials. The polynomial regression analysis between CBR and ACV, relationship was found as: CBR = -0.0315*ACV^2+1.4328*ACV+66.758.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objective of this study was to determine the physical properties of selected base course aggregates samples in order to establish the relationship of CBR with Aggregate Crushing value i.e. ACV. Thus, laboratory tests on 66 samples of 22 location of 22 rivers were done to determine ACV and CBR. Further, it can be concluded as:

- The relationship between CBR Value and ACV was developed by polynomial regression analysis as $CBR = -0.0315*ACV^2 + 1.4328*ACV + 66.758$ with $R^2 = 0.8444$.
- Relationship are validated using six suitable samples and predicted values are close to actual values of test results.

5.2 Recommendations

- Out of 22 River source sample, 21 River sources except Paoda River sample are recommended to use for base course construction in Madhesh Province.
- Using obtained relationship, CBR can be predicted. Therefore, it is recommended to perform ACV to predict CBR to get close to actual values and to reduce time & cost for laboratory tests.

5.3.1 **Recommendations for Further Studies**

- This research study was only done on selected sources located in Madhesh Province and is recommended to perform all over Nepal.
- It is recommended to conduct further research using additional sources beyond those selected sources for this study, which were based in Madhesh Province.

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