Thickness and Cost Comparison of Cement Treated and Granular Base for Flexible Pavement: A Case Study of Pathlaiya-Nijgadh Section of East-West Highway of Nepal

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Abstract

A pavement is considered a multi-layer system that distributes the vehicular load over a large area and transfers it to the foundation. Flexible pavement is mainly deteriorated due to the failure of its layer as well as the subgrade soil. Resisting the vehicular load requires the appropriate thickness of the sub-base and base with optimization of cost. This study aims to find the effect of the cement-treated base on thickness, unit cost, and life cycle cost. Design traffic was estimated for 15 years design period with an annual traffic growth rate of 5% for the Pathlaiya-Nijgadh Section of the East-West Highway of Nepal. The thickness of the granular base and the cement-treated base was 500 mm and 357.43 mm for design traffic of 34.86 million standard axles (msa) and the total pavement thickness for design traffic of 34.86 msa was 590 mm and 457.43 mm respectively. The comparison of cost estimates for the base course revealed that there was a 5.63% reduction in the per km cost of the cement-treated base as compared to the granular base. The cement-treated base seems to be a viable alternative to the base course for road construction as compared to the granular base. The pavement maintenance using a Cement-Treated Base (CTB) was 47.31% more economical than pavement maintenance using a granular base course. The total cost including initial investment and the cost of the maintenance of the pavement construction using CTB was 24.39% lower than that of the granular base.

Keywords: *Cement Treated Base, Pavement Thickness, Design Traffic, Cost Estimate and Pavement Maintenance*

Introduction

Roads are the overwhelming mode of transport for more than 90% of merchandise and travelers in Nepal. Most of the road in Nepal has a problem with rutting and fatigue damage due to either overloading of the vehicle or the construction of pavement from substandard material. Greater Surface Distress Index (SDI) and International Roughness Index (IRI) values show that there may be surface deformation, cracking, and disintegration of the pavement due to high stress and weak base in Nepal. Therefore, it requires a strong base, temperature susceptibility, and strong material against freezing and thawing for the durability of the pavement.

The effect of Cement-Treated Base (CTB) and Cement-Treated Base (CTSB) on the thickness and cost of the pavement concluded that the uses of CTB and CTSB save the material required for the construction of flexible pavement, less construction cost, and high strength than the traditional method (Patil & Karvekar, 2019). Therefore, it became more economical than a granular base in terms of initial construction cost and maintenance cost (Singh, banerjee, & Kumar, 2019), concluding that CTB and CTSB not only save money but also extend the life of the flexible pavement. The thickness of the granular sub-base reduces with increasing California Bearing Ratio (CBR) for a given volume of traffic, however, the thickness of the base course and wearing course is independent of CBR value for the pavement with conventional sub-base and base and Keeping traffic constant, the Dense Bituminous Macadam (DBM) layer, wearing course layer, aggregate interlayer, and cement treated sub-base layers are independent of CBR value. The thickness of the cement-treated base reduces as the CBR value increases (Dewalegama, Sharma, & Sachdeva, 2018). Cement Treated Base (CTB) has a greater modulus than Granular Base (GB), the thickness of CTB is less for the same traffic count than GB. The cost estimate for flexible pavement built with CTB and Granular Sub-base (GSB) shows that the per kilometer cost of construction for a single-lane road with a flexible pavement designed with a CTB base layer was lowered by 52% when compared to a road with GSB as a base layer (Bodhgire, Shinde, & Kakade, 2019). The loads are dispersed over a large area, and the thicknesses of cement-treated flexible pavement layers are less than those required for granular bases carrying the same traffic. The volume of aggregates needed will decrease as the pavement's thickness decreases, which will lower the project's overall cost. The thickness of the most conservative pavement design is approximately 30 percent thicker than the least conservative pavement design (George, 2010). Similarly, the cost-effectiveness analysis based on the use of stabilizing agents showed a reduction in the long-term cost of pavement as compared to untreated bases which was 2.96 times the untreated base for the bottom-up fatigue cracking (Souliman, Bastola, & Zeiada, 2020). It was found that the combined rutting and roughness (IRI- International Roughness Index) of the treated sections averaged about 0.08-inch lower and 1.4 times lower than that of the untreated sections, respectively.

Methodology

Study Zone

The study area of the traffic survey for this study was the Pathlaiya-Nijgadh section (19.992 km) of the East-West Highway of Nepal. The materials selected for this study were suitable for CTB and laboratory tests were conducted in the registered laboratory of Nepal.

Data Collection

Primary Data

Traffic survey and CBR data, which are required for the design of pavement, were collected from the Pathlaiya, junction of the Pathlaiya-Nijgadh section of the East-West Highway. All primary data were collected from the experiments and observations done in the geotechnical laboratory and field study.

Secondary Data

The secondary data were obtained from the DoR norms and specifications, district rates, published research articles, and other design guidelines.

Pavement Design

Wheel load, traffic intensity, and subgrade soil condition were variables considered for the design procedure of flexible pavement for this study. Traffic count surveys were conducted manually at the Pathalaiya Junction and the subgrade CBR test of chainage 347+000 to 366+992 of the Pathalaiya-Nijgad Section was conducted in the laboratory.

Calculation: Traffic in a year of completion was estimated as:

$$A = P(1 + r)^n$$

Where,

A= Traffic in the year of work completion

P= Number of commercial vehicles as per the last count

r= Rate of growth of traffic

n= Number of years between last traffic count and year of completion of construction

Design traffic was considered in terms of a cumulative number of standard axles for pavement design. This was calculated as:

$$N = \frac{365 \text{ x } [(1+r)^n - 1] \text{ x A x D x F}}{\text{r}}$$

Where,

N=Cumulative number of standard axles in the design in terms of million standard axles (msa)

A= Initial Traffic in a year of completion in terms of the number of commercial vehicles per day

D= Lane distribution factor

F= Vehicle damage factor

n=Design life in a year

r= Annual growth rate of commercial vehicle

For pavement design, at first traffic in a year of completion and design traffic were calculated, and the following procedure was carried out.

1. 90th percentile CBR was found from the graph plotted percentage equal to greater than each value versus subgrade CBR.
2. With 5%, CBR below 500 mm compacted subgrade and design CBR was calculated and effective CBR was found.

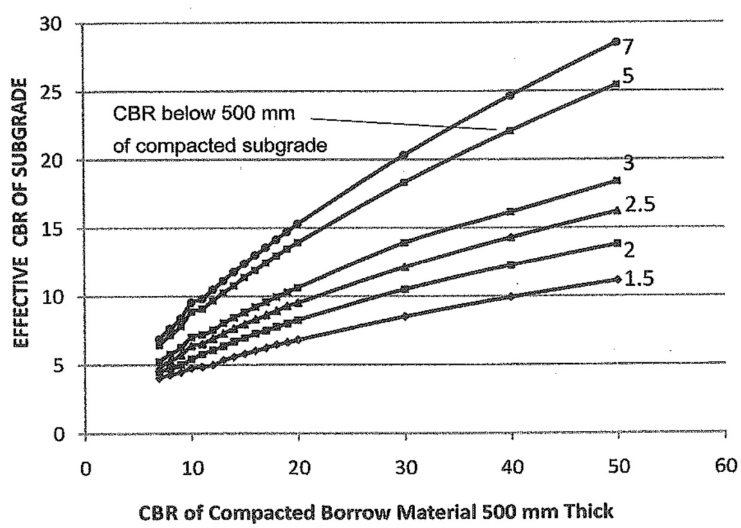

Figure.1: Effective Borrow Material 500 mm Thick (DoR, 2021)

3. With effective CBR, granular base and CTB thickness were found as per the table and graphs of (DoR, 2021).

Cost Analysis

Rate analysis for the construction of base course with granular material and CTB was calculated with the help of norms of DoR for Road and Bridge and district rate of Bara District. The cost estimate was performed from the rate analysis and quantity. Project life cycle cost was calculated from the inflation rate for year 2021/22 (Nepal Rastra Bank, 2022), and the discount rate for the Kamala-Kanchanpur Road section of the East-West Highway (Asian Development Bank, 2018). A comparison of project life cycle costs was performed in present worth (PW) and Equivalent Uniform Annual Cost (EUAC).

Result and Discussion

Pavement Design

The traffic count survey was conducted for 3 days at Pathlaiya junction and Average Daily Traffic was calculated for the different vehicle types. The pavement was designed for the 15 years design period with an annual traffic growth rate of 5%. Origin and Destination (O and D) traffic survey of Pathlaiya junction for 3 days is presented in Table 1. This table gives the traffic flow pattern from the Pathalaiya Junction.

Table 1: Origin and Destination Traffic Survey of Pathalaiya Junction (in PCU)

To	From			
	Hetauda	Nijgadh	Birgunj	Total
Hetauda	0	3851	5413	9264
Nijgadh	4253	0	1957	6210
Birgunj	5710	2018	0	7728
Total	9963	5869	7370	

Table 1: Total Calculation of Traffic Data

Vehicle	Type	Average Number of Vehicle per day	Equivalent Multiplication Factor	Total PCU per day	Number of Vehicle with more than 3 Tonne Weight
Truck	Multi Axle	795	3	2385	795
	Heavy	741	3	2223	741
	Light	461	1.5	691.5	461
Bus	Big	792	3	2376	792
	Mini	137	3	411	137
	Micro	180	1.5	270	180
Car		881	1	881	0
Motorcycle		3187	0.5	1593.5	0
Utility Vehicle		449	1.5	673.5	449
4-Wheel Drive		711	1	711	711
Tractor		133	1.5	199.5	133
3-Wheeler		235	1.5	3525	0
Bicycle		133	0.5	66.5	0
Rickshaw		9	1.5	13.5	0

The summary of design traffic for different vehicle type of Table 2 for the 15 years design period and 5% annual traffic growth rate was presented in Table 3 below.

Table 2: Summary of design traffic for different vehicle types

S.N	Vehicle Type	Design Traffic in msa
1	Heavy Truck (three axles or more)	17.67
2	Heavy two axle	12.03
3	Mini truck/Tractor	2.03
4	Large Bus	1.35
5	Bus	1.77
	Total msa	34.86

Table 3 showed that design traffic for the combined vehicle type, for the design period of 15 years and annual traffic growth rate of 5%, was 34.86 msa.

The CBR values of the subgrade soil vary along a road alignment even on a homogenous section. Therefore, 90th percentile CBR is recommended by (DoR, 2021) for national highways. In this study, CBR values of subgrade soil for different chainage of the Pathlaiya-Nijgadh section were arranged in ascending order and 90th percentile of that data was calculated for design CBR as shown in Fig. 4.7. The design CBR of subgrade was 10.54%.

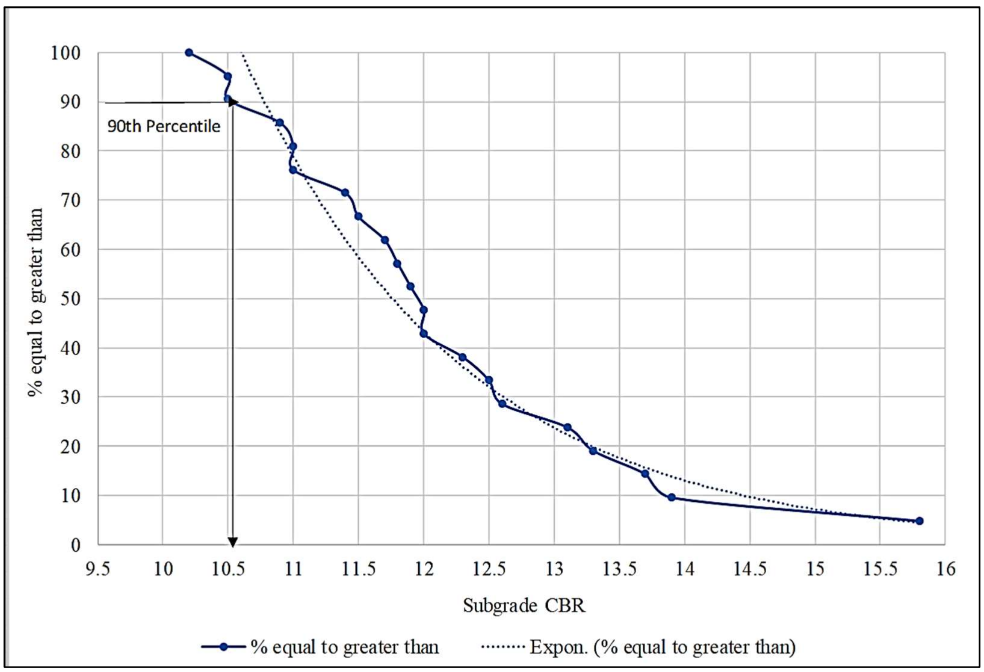

Figure 1: Evaluation of Subgrade CBR for Pavement Design

From data of CBR of below subgrade, there was a minimum 5% CBR below subgrade from DCP test in Pathlaiya-Nijgadh section of East-West highway and the design CBR of subgrade was 10.54%. From the graph provided in guideline to find out the effective CBR, 8% effective CBR of subgrade was calculated as shown in figure 3 below.

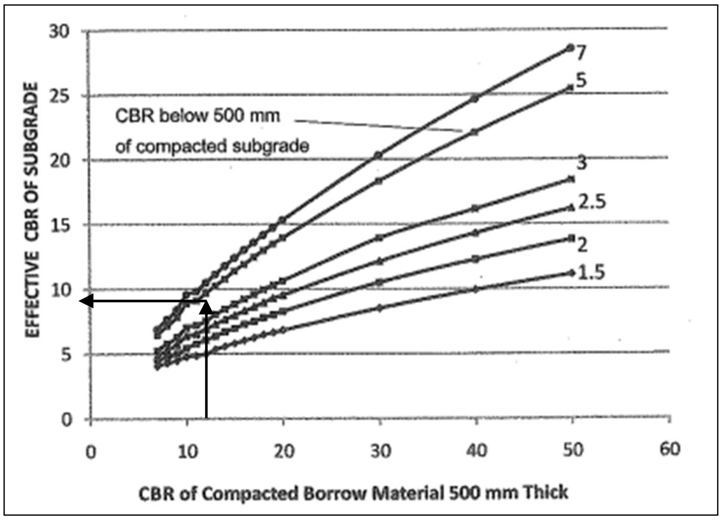

Figure 2: Effective Borrow Material 500 mm Thick

For effective CBR 8% and design traffic of 34.86 msa, pavement thickness up to base course with granular base and CTB were calculated as 500 mm and 357.43 mm respectively using table and graphs from Flexible Pavement Design Guideline-2021. There was a reduction of pavement thickness by 142.57 mm when CTB was used which resisted 34.86 msa traffic load.

Cost Analysis

There was a reduction of cost by 5.63% construction of 1 km pavement using CTB with compared to granular base. The project life cycle cost was determined for the analysis period of 18 years with inflation rate of 5.97% from (Nepal Rastra Bank, 2022) and discount rate 9% (Asian Development Bank, 2018). Maintenance cost was estimated from the DoR norms for recurrent maintenance and periodic maintenance.

Table 3: Cost Comparison of Project Life Cycle Cost in terms of PW

S.N	Description	Pavement Using CTB	Pavement Using GB	Cost Difference	Percentage Beneficial
1	Initial Cost in NRs.	740,453,998.96	863,729,100.00	123,275,101.04	14.27
2	Maintenance Cost (Recurrent and Periodic)	200,730,019.17	380,985,233.43	180,255,214.26	47.31
	Total (NPR.)	941,184,018.14	1,244,714,333.43	303,530,315.30	24.39

Table 4 depicts that the initial cost of pavement construction using CTB was 14.27% lower than using a granular base. The maintenance cost of pavement using CTB was 47.31% lower than using GB. The total cost (initial and maintenance) of pavement using CTB is 24.39% more economical than pavement using the granular base in terms of PW.

Table 4: Cost Comparison of Project Life Cycle Cost in terms of EUAC

S.N	Description	Pavement Using CTB	Pavement Using GB	Cost Difference	Percentage Beneficial
1	Equivalent Uniform Annual Cost (EUAC)	22,925,835.30	43,513,196.22	20,587,360.93	47.31

Table 5 revealed that the cost of pavement using CTB was 47.31% more economic than pavement using a granular base, and this is due to the much lower cost to be expended on pavement using CTB than pavement using a granular base.

Conclusion

The pavement construction was anticipated to be completed in 3 years and design traffic was forecasted for 15 years in the Pathlaiya-Nijgadh Section of the East-West Highway of Nepal. Also, the annual traffic growth rate was 5%. The calculation revealed that design traffic for 15 years was 34.86 msa, design CBR of subgrade from laboratory test was 10.54%, CBR of subgrade below 500 mm was 5% and effective subgrade CBR was 8%. For effective subgrade, CBR 8% and design traffic 34.86 msa, pavement thickness up to base course using the granular base and CTB were 500 mm and 357.43 mm respectively. Total pavement thickness using the granular base and CTB for design traffic 34.86 msa were 590 mm and 457.43 mm respectively. Thickness up to base course using CTB was reduced by 142.57 mm in comparison with granular base. Furthermore, there was a 5.63% reduction in the cost of pavement construction using CTB compared to the granular base for 1km. The project life cycle cost between the construction of pavement by using CTB and granular base was calculated. Pavement maintenance using CTB was 47.31% more economic than pavement maintenance using a granular base. The total cost of (initial and maintenance) pavement construction using CTB was 24.39% lower than that of the granular base. Therefore, the project life cycle cost of CTB was more favourable than that of the granular base.

The scope of the paper is quite pertinent to Nepal. The findings are valid and useful. However, the paper should be improved to make as a good academic paper. The introduction part should be elaborated by focusing on what is known and what is unknown. Therefore, focus on the purpose of this study and outline the study. Accordingly, refine the structure of the following sections as appropriate. The paper can be accepted after these corrections.

Competing Interests Disclaimer

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 absolutely 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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