IMPROVEMENT OF ROAD SUBGRADE USING WASTE TYRES

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Abstract

The increasing number of waste tyres globally is imposing huge threats on the environment, deeming a necessary proper disposal. One way of disposing these waste tyres is by using it in subgrade as stabilizers. In this paper, research has been carried out on the improvement of road subgrade using waste tyres by conducting laboratory experiments to economically increase the strength of subgrade. Sieve analysis, Atterberg Limits test and free swell test were performed on the soil for classification and suitability purposes. Different percentages of waste tyre crumbs ranging from 2% - 8% were mixed with soil on which California Bearing Ratio test and Modified Proctor Tests were performed to determine the soils strength and their respective optimum moisture contents. Results revealed that inclusion of 6% waste tyres by soil weight was the optimum percentage. Design of pavement for natural and tyre-reinforced subgrade soil revealed a reduction in pavement thickness by 92 mm for tyres-reinforced subgrade. Cost analysis of pavement constructed over weak subgrade by conventional method and reinforcement with tyres showed a saving of 8.39% when tyres were used, thereby inculcating economic benefit. The use of waste tyres in sub-base layer and its environmental impacts are recommended to be explored.

Key Words: *subgrade, waste tyre crumbs, optimum moisture content, California bearing ratio, pavement*

1. INTRODUCTION

According to Mashiri, et.al (2015), the annual waste tyre production is estimated to be about 1.5 billion globally and is predicted to increase with every passing year. In case of Bhutan, though there are no statistical reports on the yearly production of waste tyres being generated, the accumulated number of vehicles as of March 31st 2020 was 108,573 (RSTA, 2020). Accordingly, if each vehicle changes two tyres every year then the waste tyres being generated yearly would be 217,146 which is an alarming number for a small country like Bhutan.

Waste tyres possess characteristics which makes them difficult to dispose. Current waste tyre disposal methods adopted across the globe includes incineration, dumping in landfills and stockpiling. While landfilling, because the tyres are non-biodegradable and have large volumes with 75% void spaces, they take up valuable spaces and remains in the landfill for a long time. According to Williams (2017), open dumping of waste tyres are susceptible to combustion and becoming the perfect ground for breeding mosquitoes and other vermin.

Teja and Siddhartha (2015) reports that waste tyres can be utilized with technical development to stabilize soils in the construction of flexible pavements to not only improve their engineering properties but also to provide an environment-friendly alternative of reducing the waste tyres being generated. For the construction of a durable and economical pavement, subgrade material possessing good engineering properties is required to increase its service life span and to reduce the required thickness of the pavement as reported by Sameera, et.al, (2018). The pavement laid upon poor subgrade is not economical but when there is a necessity of constructing it over a weak subgrade then several countermeasures can be taken to improve its strength such as removal and replacement of subgrade soil, stabilization with a cementitious or asphaltic binder and additional base layer which all incurs a huge sum.

In this study, waste tyres are incorporated as reinforcing material with the natural subgrade soil to increase its strength. Strength improvement is achieved by increasing its CBR value with the addition of waste tyres. Different percentages of waste tyres are mixed with subgrade soil and CBR test is performed to determine their corresponding

CBR values. CBR test determines the penetrative resistance of the material and is the most important parameter while designing roads (Khanna & Justo, 1971). The optimum percentage of waste tyre added to the subgrade soil is found and pavement is designed as per Department of Roads.

2. METHODOLOGY

The flowchart below depicts various procedures carried out in the present study.

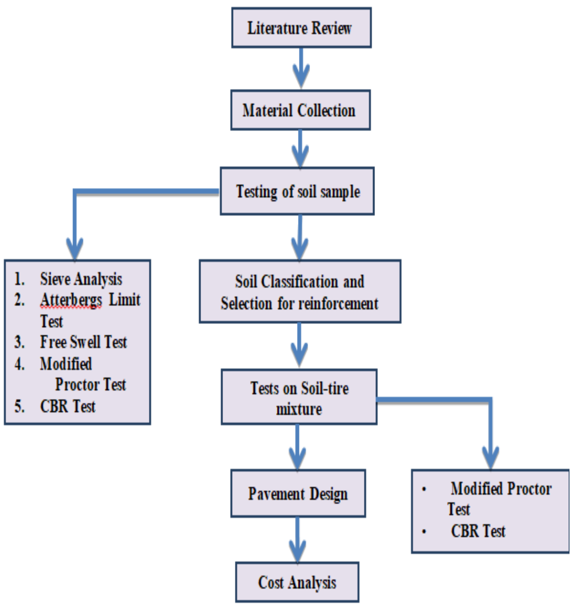

Fig. 1 Methodology flowchart

2.1 Literature Review

Ravichandran, et.al, (2016) researched on two soil samples A_1 and A_2 collected from a depth of 0.7 m, classified as high compressibility clay (CH) to improve its CBR value and permeability with the addition of waste tyres. Crumb tyres of sizes 425-600 microns were added to the soil at a varying percentage of 5, 10, 15 and 20 by soil weight. Results showed both OMC and MDD decreased with increase in the rubber quantity, which was because of the crumb rubber having a lower specific gravity. The overall CBR of the soil improved with the optimum percentage of crumb tyres at 10% for both the samples.

Teja and Siddharatha (2015) conducted a study on soils reinforced with waste tyres of cylindrical shape having diameter 15mm-20mm, length 20mm-25mm and found decrease in OMC at 7.5% of waste tyres mixed with soil. Also MDD decreased with increase in the percentage of tyres in soil. Increase in CBR up to 1.6% led to the reduction of the total pavement thickness, hence cutting down on cost of the project.

Reddy (2013) performed tests on tyre chips of size 10 mm to 20 mm. Tyre chips of different proportions of 4%, 5%, 7% and 10% by weight were added to soil. Heavy compaction test and CBR test were conducted to test the strength of soil with addition of rubber tyres. Using tyres in construction of embankment was found to improve subgrade soil since soaked CBR value at 5% tyres chips added to soil was more than 10%.

2.2 Material Collection

Waste crumb tyres, ranging in shape from fibrous filaments to fine powder, were collected from the locality (Jaigaon) generated during tyre re-soling. The waste tyres collected were sieved through IS sieve 4.75 mm which were then used to reinforce the soil sample for testing purposes.

Fig.2 Waste Tyre crumbs collected from workshop.

As stated by Warr (2015), soils exhibit a distinct color to hint at the dominant processes occurring within and also to reflect its physical and chemical properties. Hence, the soil samples collected along the Phuntsholing – Kamji site area for the research were selected mainly in accordance with the different soil colors depicted at sites.

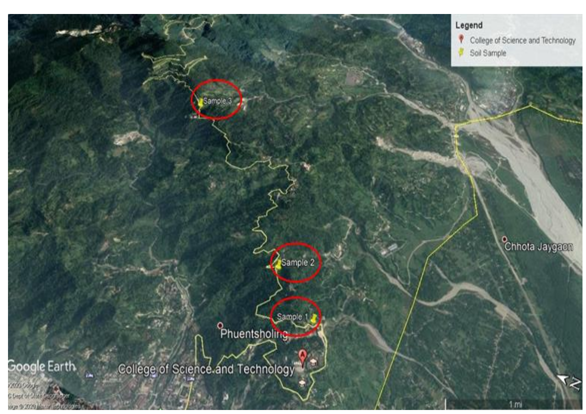

Fig.3 Map showing the location of soil sample collection sites.

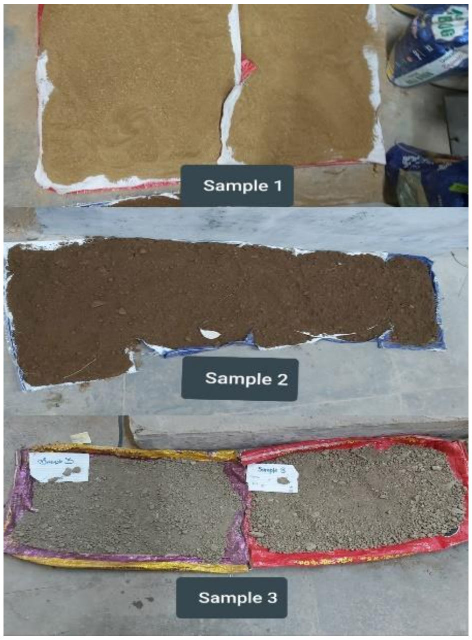

Fig.4 Collected soil samples.

2.3 Tests conducted

Sieve analysis, Atterberg's limit, Free Swell test, Heavy/Modified Proctor and CBR tests were conducted on the samples.

2.4 Design and cost analysis of Pavement

The pavement was designed as per Department of Roads (2005). Cost analysis was carried out using BSR (2020) for both reinforced and unreinforced soil.

3 RESULTS AND DISCUSSION

The results of tests conducted on unreinforced soil were obtained as shown in Table 1 below.

Table 1 Test results of natural unreinforced soil

Sl No.	Properties	Sample I	Sample II	Sample III
1	Grain size analysis	C_u=7.25 C_c=1.94	C_u= 10 C_c=0.55	C_u=16 C_c=0.5
2	Liquid Limit (%)	42.5	26.53	41.95
3	Plastic Limit (%)	18.65	17.26	22.14
4	Shrinkage Limit (%)	19.97	6.89	12.61
5	Plasticity Index	23.85	9.27	19.81
6	OMC (%)	10.81	11.11	12.5
7	Free Swell Index (%)	20	10	10
8	MDD(g/cc)	1.58	1.43	1.39
9	CBR (%)	6.13	24.7	16

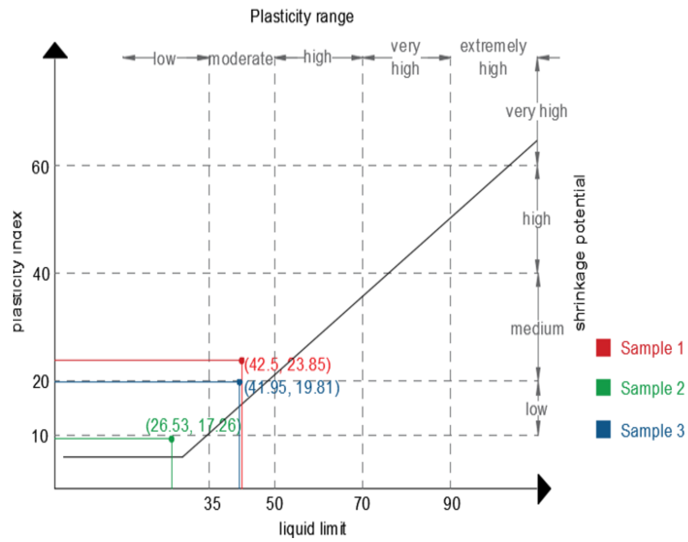

Fig.5 Shrinkage Potential Graph

All the three soil samples have LL<50%, PI<25%, FSI<50% and OMC between 9-13% which indicates good subgrade characteristics and hence are suitable for use in subgrade.

However soil sample 1 was found to have the lowest soaked CBR among the three samples of 6.13% and hence was selected for reinforcement with waste tyres. Tyres were added to the soil at 2, 4, 6 and 8 percent by weight of the soil.

Soil sample 1 is well-graded sand (SW), as per Indian Standard Soil Classification System (ISSCS). This soil sample has a LL of 42.5%% and PL of 18.65% whose difference gives the Plasticity Index (PI) of 23.85%.

Figure 4 above classifying the soil in terms of plasticity index and shrinkage potential, shows that soil sample 1 possesses moderate plasticity and medium shrinkage potential. The Free Swell Index of soil was found to be 20% which indicates low degree of expansion as per table 8 from IS 1498 – 1970.

The soil has an OMC of 10.81% and MDD of 1.58g/c.

Fig.6 Soil-tyre crumb mix

3.1 Test results for reinforced soil

The table 2 below depicts the results of tests conducted on the sample with different percentages of crumb tyres.

Table 2 Test results for reinforced soil

Sl No.	Properties	2%	4%	6%	8%
1	OMC (%)	9.5	7.15	7.14	7.0
2	MDD(g/cc)	1.52	1.58	1.58	1.58
3	CBR (%)	7.11	8.3	9.48	8.17
4	% Increase	15.99	35.4	54.65	33.28

It was observed that as the percentage of waste tyres added to the soil increased, OMC of soil decreased which could be because the tyre content does not absorb water. However, the MDD increases hence showing an increase in the soil's strength. After the inclusion of 2% waste tyres, CBR value of the soil was found to increase from 6.13% to 7.11%. The CBR value improved with the addition of waste tyres till 6% where the soil had a maximum CBR value of 9.48%, after which soil showed decrease in CBR value.

The load-penetration graph of tyres reinforced soils obtained are shown in Figure 5.

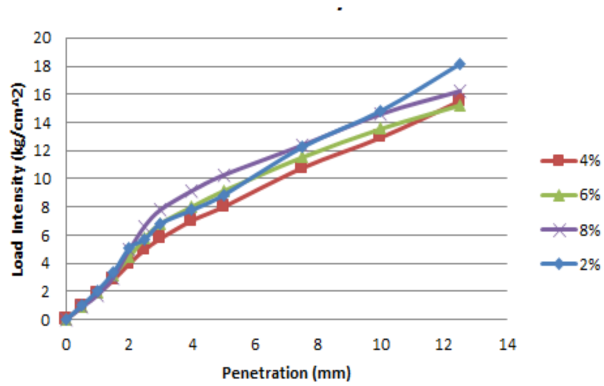

Fig.7 CBR values with waste tyre reinforcement

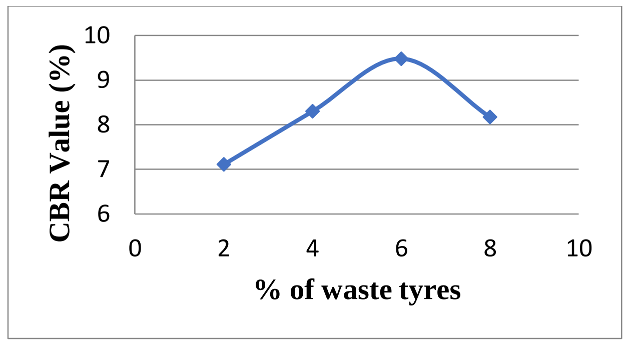

Fig.8 Effect of waste tyre crumbs on CBR values of soil sample

Figure 7 above illustrates the parabolic relationship between waste tyres and soaked CBR value of the soil. CBR increases with the increase in waste tyres added till its maximum value i.e. 6%, for the given sample, and then decreases thereafter.

4 PAVEMENT DESIGN

The road under consideration in this study falls under Asian Highway no. 48 and its design standard is considered equivalent to that of the Primary National Highway (PNH).

To achieve comparative analysis of pavement thickness with and without tyre reinforcements, cumulative number of standard axles formula was adopted from IRC 37:2001.

Assuming the initial traffic to be 200 CVPD, average annual growth rate of 7.5%, VDF of 1.5, DF of 0.75 and design life of 15 years, the cumulative number of standard axles was found to be 3.2 msa.

The pavement was then designed for 3.2 msa traffic, taking the CBR value of both unreinforced and reinforced soil.

4.1 Unreinforced Subgrade Soil

Total Pavement thickness = 496 mm

The pavement composition is as follows:

1. Bituminous Surfacing = 50 mm DBM + 25 mm PMC
2. Base = 250 mm
3. Sub-base = 171 mm

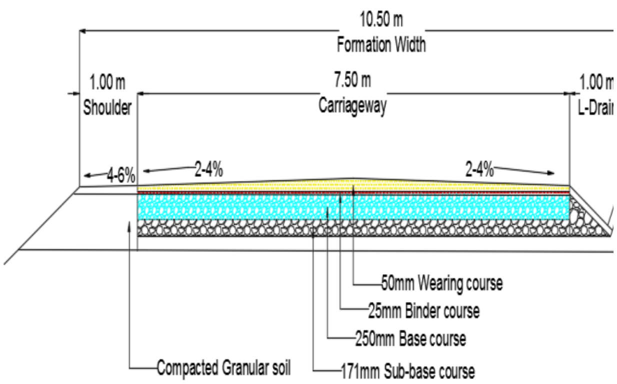

Fig.9 Section of pavement on unreinforced subgrade soil

4.2 Tyre-Reinforced Subgrade Soil

Total pavement thickness = 404mm

The pavement composition is as follows:

1. Bituminous Surfacing = 50 mm DBM + 25 mm PMC
2. Base = 200 mm
3. Sub-base = 129 mm

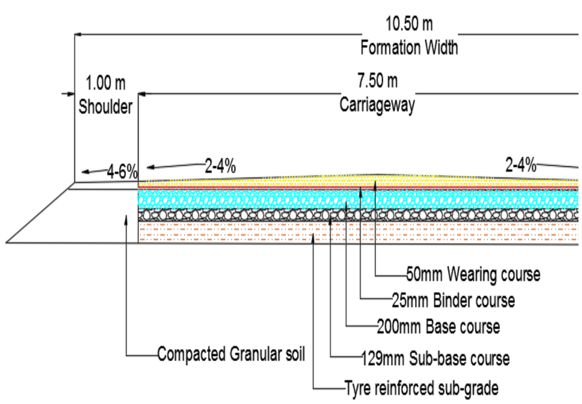

Fig.10 Section of pavement on tyre-reinforced subgrade soil

It was observed that on reinforcing the subgrade soil with tyres, pavement thickness reduces by 92 mm.

5 COST ANALYSIS

The cost of pavement was estimated for 1 km length using Bhutan Schedule of Rates 2020. Table 3 below portrays the cost analysis conducted.

Table 3 Cost Analysis for Unreinforced and Tyre-reinforced soil

Soil	Unreinforced Soil	Tyre-Reinforced Soil
Total Thickness (mm)	496	404
Total Cost (Nu.)	13,065,922.8	11,969,183.93
Decrease in Cost (Nu.)	1,096,739	
Percent Decrease (%)	8.39	

Estimated cost of the pavement for unreinforced soil having a total thickness of 496mm was Nu.13,065,922.8. On reinforcing the soil at the optimum percentage of 6% waste tyres, the total pavement thickness reduced to 404mm and its estimated cost was Nu. 11,969,183.93. The inclusion of waste tyres in the subgrade soil reduced the estimated cost of pavement by 8.39%.

6 CONCLUSION

Tyre incorporated soil was found to show improvement in subgrade strength. The CBR value increased with the increase in waste tyres till it attained maximum increment at 6% waste tyres, proving it to be the optimum mix percentage for the given soil sample. From CBR tests conducted, soil sample 1 had a CBR value of 6.13% which increased to 9.48% at the optimum percentage increasing the strength of soil by 54.65%.

Flexible pavement design as per DoR revealed the total thickness of the pavement for natural soil to be 496 mm and 404 mm for tyre-reinforced soil. The overall cost of pavement estimated per km length of road was Nu.13,065,922.8 for natural soil and Nu.11,969,183.93 for tyre-reinforced soil, indicating a saving of 8.39% hence indicating economy.

7 RECOMMENDATIONS

i. The present research researched on the feasibility of incorporating waste tyres in well graded sand. Feasibility of incorporating waste tyres in other types of soil may be explored in the future.

ii. Inclusion of waste tyres as soil stabilizer in subgrade layer of the flexible pavement was carried out. The usage of waste tyres in another flexible pavement layer such as that of sub-base is recommended.

iii. The study on environmental impact of waste tyres in subgrade layer can also be explored.

8 LIMITATIONS

The present study initially aimed to conduct a comparative study on how the three soil samples collected for the study behaved when waste tyres were incorporated. However, due to the unforeseen circumstances such as the pandemic and insufficiency of time required, only one soil sample could be incorporated with waste tyres to study its feasibility in subgrade.

The equipment provided in the lab was not in its best condition which often caused difficulties while conducting the tests.

9 ACKNOWLEDGEMENTS

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