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EXPERIMENTAL STUDY ON USAGE OF TYRE SCRAPS AS A STABILIZING MATERIAL FOR SUBGRADE OF FLEXIBLE PAVEMENT

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Abstract - This study throws light on the suitability of waste materials like Marble Dust, Marble Chips and Tyre Scraps as soil stabilizer for use in pavement. The role of marble dust, marble chips, and tyre scraps in improving the characteristics of expansive subgrade material is analyzed. The amount of cost savings for a pavement when it is stabilized separately with marble dust, marble chips and tyre scraps is also studied. Initially, the physical properties of clay and marble dust have been studied by conducting wet sieve analysis, Liquid Limit and Plastic Limit tests. Then, for the purpose of determining the strength of virgin and stabilized materials, California Bearing Ratio (CBR) tests have been conducted. The results of the experimental research show that marble dust, marble chips and tyre scraps can effectively be used as soil stabilizer for subgrade as the CBR value is increased. A considerable amount of cost savings is also possible when the expansive clay soil is stabilized with marble dust, marble chips and tyre scraps.

Keywords – Pavement, Stabilizer, subgrade, expansive

1. Introduction

Expansive soils can cause extensive damage to structures if not adequately treated. Extensive laboratory / field trials carried out by various researchers have shown promising results for application of such expansive soil after stabilization with additives / stabilizers.

The use of stabilization to improve the properties of a material is becoming more widespread due to the increased strength and load spreading ability that these materials can offer. Stabilization technology is extremely relevant for heavily trafficked pavements where its benefits are beginning to be appreciated.

Ultimately the main reason for using stabilization usually is cost savings. The cost savings associated with stabilization can take many forms including reduced construction costs, reduced maintenance costs throughout the life of the pavement or an extension of the normal pavement life.

Pavement design is based on the premise that minimum specified structural quality will be achieved for each layer of material in the pavement system. Each layer must resist shearing, avoid excessive deflections that cause fatigue cracking within the layer or in overlying layers, and prevent excessive permanent deformation through densification. As the quality of a soil layer is improved, the ability of that layer to distribute the load over a greater area is generally enhanced so that a reduction in the required thickness of the soil and surface layers may be permitted.The structure of the pavement is shown in fig 1.

As per IRC: 37- 2001 (1) the subgrade must have a minimum CBR value of 2%. When any material present as a subgrade material does not conform to this specification, capping layer of any suitable material whose California Bearing Ratio (CBR) value not less than 10% must be provided between the subgrade and the sub base. If expansive soil is present as a subgrade material, buffer layer of thickness ranging from 0.6m to 1.0m need to be provided between the subgrade and the sub base in addition to the arrived thickness of the pavement.

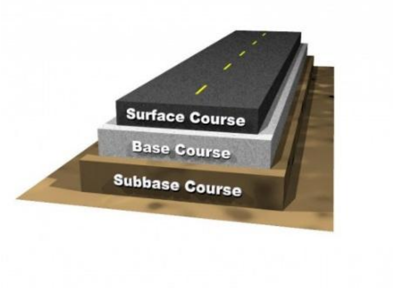

Fig 1 Pavement structure

The purpose of providing a sub base layer is to have a thicker pavement at lower cost. The sub base material should have a minimum CBR of 20% for cumulative traffic upto 2 msa and 30% for traffic exceeding 2 msa.

A base course is defined as a layer of granular material which lies immediately below the wearing surface of the pavement. The base course must have a minimum CBR value of 80%. The recommended minimum thickness of granular base is 225mm for traffic upto 2 msa and 250mm for traffic exceeding 2 msa.

The top layer of the flexible pavement is bituminous surfacing. The main purpose of providing surface is to provide smooth riding surface, to prevent ingress of water and to prevent damage to base and sub base due to detrimental action of wheel load. The most commonly used wearing courses are surface dressing, open graded premix carpet, mix seal surfacing, semi dense bituminous concrete and bituminous concrete.

Around 4000 marble mines and 1100 marble processing units spread over various regions in India generate huge quantity of Marble Dust (MD) and Marble Chips (MC) during processing and slabing of marble stones. Indiscriminate disposal of marble dust on road sides is causing problems of poor drainage, air pollution and damage of agricultural land. In order to minimize these illnesses, the waste marble dust and marble chips can effectively be used as a stabilizing agent for clay and red soils.

Fig 2 Marble dust and Marble chips

Tyre Scraps (TS) perhaps rank among the most extensively researched and implemented recycled materials in recent years. Approximately 200,000 tons of tyre scraps are collected each year, out of which 1,50,000 tones are recycled and reused. The remaining 50,000 tons remain as waste which can be potentially used for roadway applications in the field of stabilizing the subgrade and sub base.

Fig 3 Tyre Scraps

On the whole, the CBR value of subgrade will be increased when marble dust, marble chips, and tyre scraps are used as stabilizing agent for pavement materials.

2. Literature Review

Stephen (1995) (13) has described that flexible pavement design deals primarily with structural aspects (i.e., the selection of appropriate materials, characterization of strength or load-carrying properties, layer thickness determination. He has developed analytical models, transfer functions, traffic loading simulation models, material characterization methodologies and life cycle cost analysis to predict the state of stress in pavement layers when different types of soil stabilizers are used for sub grade strengthening.

To understand the optical properties of mineral dust Lyn et al (2002) (6) has computed optical properties for a variety of particle shapes and sizes up to equivalent-volume size parameter $X = 27\pi r/A = 8$, and they have performed laboratory measurements on a variety of mineral powders in the same size regime and somewhat larger.

Enzymes as soil stabilizers have been used by Mihai et al (1990) (8) to improve the strength of sub grades due to low cost and relatively wide applicability compared to standard stabilizers. Two types of soils (soil I and II) and two enzyme products (A and B) were taken for the study. The specimens were subjected to resilient modulus testing and shear strength testing. The stiffness of soil I was increased in average by 69% and by 77% for soil II. The type of soil affected significantly the effectiveness of the treatments.

Guidelines and standards have been developed by Asmidar et al (2008) (2) to assist practitioners in designing pavements after subgrade stabilization. The laboratory tests carried out on two most common types of residual soils, namely the granite residual soils and sedimentary residual soils showed that soils mixed with 8% cement appeared to exhibit a marked increase in strength to meet the requirement as sub-base material. With more cement added, there was further increase in the strength of the stabilized soils. In some cases, the strength gain with 12% cement was sufficient to meet the requirement as base material. Soil with more coarse material exhibited higher Unconfined Compressive Strength (UCS) value.

Alaa et al (2006) (1) have reported that the use of recycled materials to stabilize marginal soils offers a viable alternative from economical, technical, and environmental standpoints. Recycled materials provide an attractive alternative to traditional Engineering construction materials such as asphalt, concrete, natural aggregate and others. In addition to a lower cost in comparison to traditional materials, their use has the potential to alleviate landfill problems as well as avert costs typically associated with their disposal.

Mehmet et al (2008) (7) have described the usability of the pumice as a stabilization material in the sub base considering volumetric unit weight. Initially, the physical properties of lightweight aggregate material have been analyzed. For the research, few experiments have been carried out such as stability to freeze, solidity, strength, Atterberg limits and CBR. A rise of 93% of CBR value was observed after the stabilization process.

Robert (2009) (11) has suggested that the strength of expansive soil can be increased when it is stabilied using rice husk ash (RHA) and fly ash, which are waste materials. Stress strain behavior of unconfined compressive strength showed that failure stress and strains increased by 106% and 50% respectively when the fly ash content was increased from 0 to 25%. When the RHA content was increased from 0 to 12%, Unconfined Compressive Stress increased by 97% while CBR improved by 47%. Therefore, an RHA content of 12% and a fly ash content of 25% are recommended for strengthening the expansive sub grade soil. A fly ash content of 15% is recommended for forming a swell reduction layer because of its satisfactory performance in the laboratory tests.

Onur (2009) (10) has made a study in which waste limestone dust and waste dolomite marble dust, by-products of marble industry, were used for stabilization of expansive soils. Waste limestone dust and waste dolomite marble dust were added to the expansive soil with predetermined percentage of stabilizer varying from 0 to 30 percent. Grain size distribution, consistency limits, chemical and mineralogical composition, swelling percentage, and rate of swell were determined for the samples. Swelling percentage decreased with increase in stabilizer percentage.

Hurley and Thornburn (1972) (4) have summarized pertinent information on stabilizer properties, reaction mechanisms, injection methods of soil solidification, properties of stabilizer soil mixtures, and use of sodium silicates as dust proofers and water proofers and as secondary additives with other stabilizers. Sodium silicates with or without the addition of precipitants are of little value in dust proofing or waterproofing fine-grained soils. On the other hand, laboratory tests seem to indicate that sodium silicate used as an additive can improve the strength and durability of soils stabilized with Portland cement, lime, or lime-fly ash.

Dallas and Syam (2009) (3) have studied the process of soil stabilization with the traditional calcium-based stabilizers, Portland cement, lime, and fly ash. The report describes and compares the basic reactions that occur between these stabilizers and soil and the mechanisms that result in stabilization. The report presents a protocol for each stabilizer through which the selection of the stabilizer is validated based on the tests conducted on mixes. The mixture design process defines an acceptable amount of stabilizer for the soil in question based on consistency testing, strength testing, and in some cases (resilient) modulus testing. Within each additive validation and mixture design protocol, an assessment of the potential for deleterious soil additive reactions was made.

Samson et al (2009) (12) have made an attempt to study the Engineering properties of cement stabilized seashore soils in pudukkottai and Thanjavur districts. The Engineering properties like specific gravity, optimum moisture content, maximum dry density, liquid limit, plastic limit and grain size analysis of the collected samples were determined by suitable laboratory tests. The decrease in plasticity index with the addition of 2 – 6% cement, decrease in maximum dry density, and increase in optimum moisture content with the addition of cement have also been reported.

Katebi (2009) (5) has described the stabilization of calcareous soil with lime which can be used as a road base or sub base material. The soil stabilized with 6% lime can be utilized as a sub base material as its soaked CBR value of 35% and UCS of 450 kPa complies with the evaluation criteria (CBR = 32% and UCS = 430 kPa) for the sub base layer.

Misra et al (2009) (9) have investigated that Marble Dust Slurry (MSD), a waste of marble industry finds bulk utilization potential in roads. Besides embankment construction with this waste, 20 – 30% of soil can be replaced by MSD for subgrade preparation. From cost benefit analysis, they have revealed that use of MSD in subgrade preparation for a double lane road would save Rs. 1,50,000 per km.

3. Materials and methods

3.1 Material collection

Expansive clay has been collected from various areas like Ganapathy area in Coimbatore city. Marble Dust and Marble Chips have been collected from marble cutting units like Sharma Marbles and Kamadhenu Marbles in Thadagam road in Coimbatore city. Tyre Scraps has been collected from Star Tyre Retrading Company in Erode.

3.2 Testing of materials

The physical properties of clay, and marble dust have been studied by conducting wet sieve analysis, dry sieve analysis, Liquid Limit (LL) and Plastic Limit (PL) tests.

Optimum proportion of marble dust to be mixed with clay (subgrade) has been arrived at so as to have a mix with a Plasticity Index (PI) of 6% or less. Optimum moisture content has been found out by carrying out Standard Proctor Compaction Test (SPCT).

The change in strength of clay after being mixed with marble dust, and tyre scraps has been determined by conducting California Bearing Ratio (CBR) test. Based on the test results, flexible pavement has been designed with and without buffer layer and the percentage of cost savings of stabilized pavement with respect to unstabilized pavement is arrived.

3.2.1 Wet sieve analysis

50 g in each of clay and marble dust, quarry dust and red soil is taken separately and wet sieved through 75 micron sieve and percentage of fines is found out.

3.2.2 Liquid limit test

This test is done as per IS: 2720 (Part 5) – 1970.

Fig 4 Casagrande's liquid limit apparatus

The empirical formula meant for calculation of liquid limit in the one – point method is given by,

Liquid limit = WN / (1.3215 – 0.23 log N)

Where,

WN = % of water added

N = number of blows

3.2.3 Plastic Limit test

This test is done as per IS: 2720 (Part 5) – 1970. The water content at which the soil can be rolled into a thread of approximately 3mm in diameter without crumbling is known as the plastic limit.

3.2.4 Standard Proctor Compaction Test

The objective of Standard Proctor Compaction Test is to determine the Optimum Moisture Content (OMC) so that it could be used for compacting the pavement material in the CBR mould. This value ensures maximum dry density and hence minimum void ratio and maximum strength. A plot of dry density vs. moisture content is plotted and optimum moisture content is determined.

3.2.5 California Bearing Ratio test

The California Bearing Ratio test is a penetration test meant for the evaluation of sub grade strength of roads and pavements. The results obtained based on these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

Fig 5 CBR apparatus

Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm. A plot of load vs. penetration of the plunger is plotted and CBR value is calculated.

CBR 2.5 = (Load 2.5 / 1370) * 100 %

CBR 5.0 = (Load5.0 / 2055) * 100 %

The CBR values are usually calculated for penetration of 2.5 mm and 5 mm. Generally the CBR value at 2.5 mm will be greater than at 5 mm and in such a case the former shall be taken as the design CBR. If CBR for 5 mm exceeds that of 2.5 mm, the test should be repeated. If similar results follow, the CBR corresponding to 5 mm penetration should be taken design CBR.

4. Test results

The results of the classification tests conducted on various materials are given in table 1:

Table 1 Classification test results

Material	Grain size distribution			LL (%)	PL (%)	PI (%)	IS classification
	Gravel (%)	Sand (%)	Fines (%)				
Clay	0	16	84	51	22	29	CH
MD	0	22	78	Non – plastic		0	ML

The results of liquid limit tests performed on various proportions of clay and marble dust are given in table 2.

Table 2 Liquid limit tests on clay & marble dust

Proportion of clay with MD	Liquid limit (%)
70:30	50
60:40	40
50:50	35
40:60	30

Table 2 shows that a mix of clay and MD in the proportion of 40:60 yields a liquid limit of 30%.

The graph showing the results of SPCT is given in fig 6.

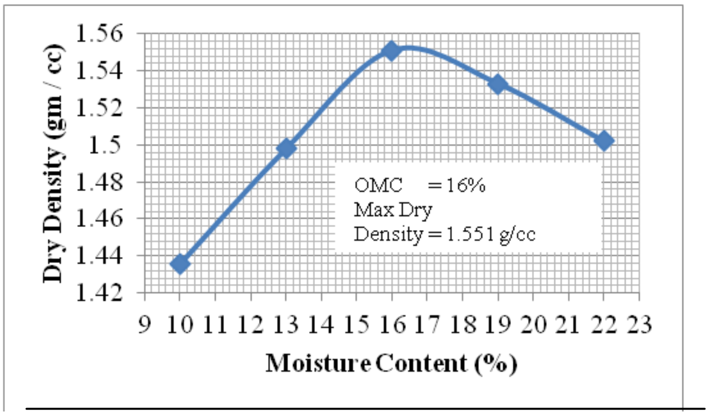

Fig 6 SPCT on clay & MD (40:60)

The graphs showing the results of the CBR test of virgin clay and marble dust stabilized clay are given in fig 7 and fig 8.

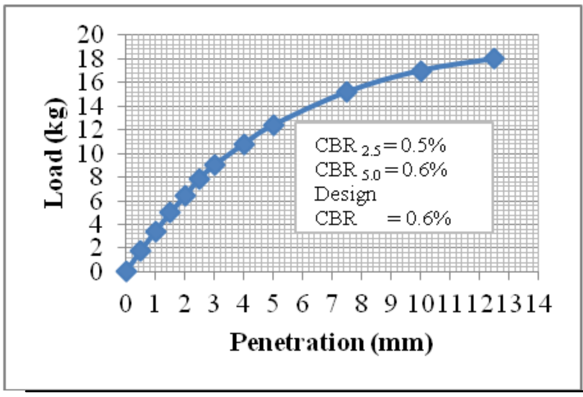

Fig 7 CBR test on clay

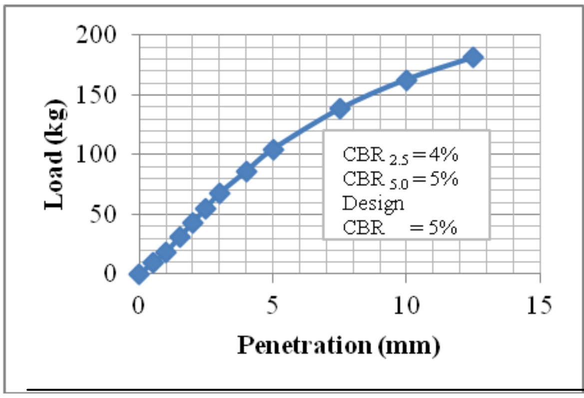

Fig 8 CBR test on clay & MD (40:60)

Comparing fig 7 and 8, it is evident that the CBR value of clay is increased from 0.6% to 5% when stabilized with marble dust.

For stabilizing the subgrade (clay), marble dust has been added in the proportion of 40:60. In addition, scrap tyres are also added in trial proportion for the purpose of increasing the CBR.

The graphs showing the results of SPCT is given in fig 9. It is evident that 20% is the optimum proportion of tyre scraps to be added to clay for effective subgrade stabilization.

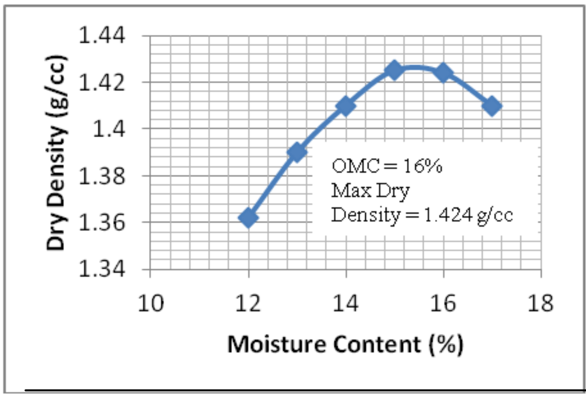

Fig 9 SPCT on clay, MD, TS (32:48:20)

The California Bearing Ratio Test for the above proportion is given in fig 10.

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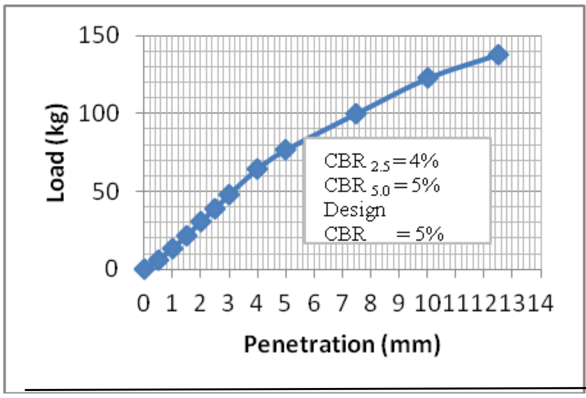

Fig 10 CBR test on clay, MD, TS (32:48:20)

Comparing fig 7 and 10, it is evident that the CBR value of clay is increased from 0.6% to 5% when stabilized with marble dust and tyre scraps.

5. Design of Flexible Pavement

5.5.1 Pavement design with buffer layer

As per clause 4.2.1.5 of IRC: 37-2001, the sub grade must have a minimum CBR value of 2%. When the CBR is less than 2%, then capping layer of 150mm thick need to be provided between the sub grade and the sub base layer. When highly expansive soil is present as a sub grade material, buffer layer having thickness ranging from 0.6m to 1.0m need to be provided.

The very high value of liquid limit (i.e) 51% indicated that the clay is expansive. Hence buffer layer has to be provided to increase the performance of the pavement.

The first step in pavement design is to estimate the cumulative number of standard axles to be catered for the design which is calculated as follows:

N = {365 [(1+r)n – 1] * A * D * F} / r

Where,

N = Cumulative number of standard axles to be catered for the design in terms of msa

A = Initial traffic in the year of completion of construction in terms of number of commercial vehicles per day (cv/day)

D = Lane distribution factor

F = Vehicle damage factor

n = Design life in years

r = Annual growth rate of commercial vehicles

The initial traffic in the year of completion of construction can be calculated as,

A = P (1+r)x

Where,

P = Number of commercial vehicles as per last count

x = Number of years between last count and year of completion of construction

The relevant data assumed are,

As per clause 3.3.2.2 of IRC37:2001, an average annual growth rate of 7.5% is adopted.

(i.e.) r = 0.075

As per clause 3.3.5.1 of IRC37:2001, for single lane carriageway, the lane distribution factor is 100%.

(i.e.) D = 1

The number of commercial vehicles is assumed to be 120 cv/day.

As per clause 3.3.4.4 of IRC37:2001, for the assumed value of 120 cv/day and for the terrain type of rolling plain, the vehicle damage factor is taken as 2.5.

As per clause 3.3.3.2 of IRC37:2001, the design life is taken as 15 years.

(i.e.) n = 15 years

The number of years between last count and year of completion of construction is assumed as 2 years.

Therefore, A = 120 (1+0.075)2 = 139

N can be calculated as,

N = {365 [(1+0.075)15 – 1] * 139 * 0.6 * 2.5]} / 0.075 = 2 msa

From plate 1 of IRC37:2001,

For the minimum CBR value of 2%, the total pavement thickness is 715mm. The recommended pavement structure is given in fig 11.

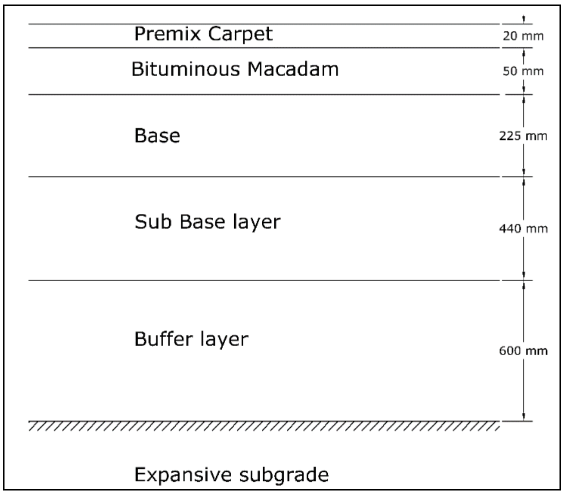

Fig 11 Pavement design with buffer layer

5.5.2 Pavement design without buffer layer

From the CBR test results of the clay, marble dust and tyre scraps mix, the CBR value obtained is 5%. For the CBR value of 5%, the total pavement thickness is 490mm. the pavement structure is given in fig 12.

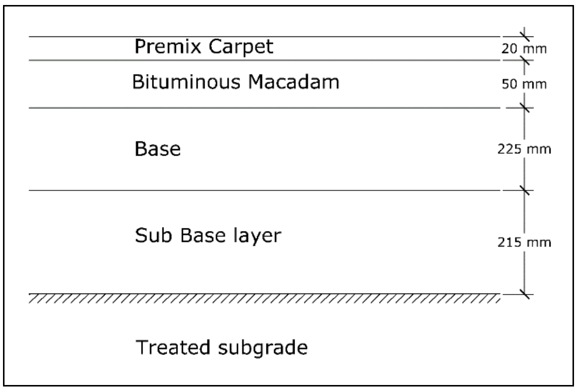

Fig 12 Pavement design without buffer layer (subgrade stabilized with tyre scraps)

6. Cost Estimation

The quantity of various materials and cost of pavement per unit area for pavement structure with buffer layer are given in tables 3 and 4 respectively.

Table 3 With buffer layer – calculation of quantities

Items of works	No	Length (m)	Width (m)	Depth (m)	Quantity
Compaction of subgrade	1	1	1	0.5	0.5m^3
Buffer layer	1	1	1	0.6	0.6m^3
Sub base	1	1	1	0.440	0.440m^3
Base	1	1	1	0.225	0.225m^3
BM	1	1	1	0.050	0.050m^3
Premix carpet (PC)	1	1	1	-	1m^2

Table 4 With buffer layer – abstract of cost

Items of works	Qty	Unit	Rate		Per	Amount	
			Rs	Ps		Rs	Ps
Compaction of subgrade	0.5	m^3	120	00	m^3	60	00
Buffer layer	0.6	m^3	300	00	m^3	180	00
Sub base	0.440	m^3	600	00	m^3	264	00
Base	0.225	m^3	1100	00	m^3	247	50
BM	0.050	m^3	6000	00	m^3	300	00
PC	1	m^2	30	00	m^2	30	00
Total Cost / m^2 area = Rs 1081.50							

The quantity of various materials and cost of pavement per unit area for pavement structure without buffer layer, when the subgrade is stabilized with tyre scraps are given in tables 5 and 6 respectively.

Table 5 Without buffer layer – calculation of quantities

Items of works	No	Length (m)	Width (m)	Depth (m)	Quantity
Compaction of subgrade	1	1	1	0.5	0.5 m^3
Sub base	1	1	1	0.215	0.215 m^3
Base	1	1	1	0.225	0.225 m^3
BM	1	1	1	0.050	0.050 m^3
PC	1	1	1	-	1 m^2

Table 6 Without buffer layer – abstract of cost

Items of works	Qty	Unit	Rate		Per	Amount	
			Rs	Ps		Rs	Ps
Compaction of subgrade	0.5	m^3	120	00	m^3	60	00
Sub base	0.175	m^3	600	00	m^3	105	00
Base	0.225	m^3	1100	00	m^3	247	50
BM	0.050	m^3	6000	00	m^3	300	00
PC	1	m^2	30	00	m^2	30	00
Total Cost / m^2 area = Rs 781.50							

Comparison of table 4 and 6 shows a cost reduction of 27.7% when the expansive subgrade is treated with tyre scraps.

7. Summary and Conclusions

From the experiments, test results and discussion, the following conclusions have been made:

The stabilization process of clay Marble Dust (MD) and Marble Chips (MC) is very effective.
The CBR value of clay when stabilized with MD is increased from 0.6% to 5%.
The CBR value of clay when stabilized with tyre scraps is increased from 0.6% to 5% for use as a subgrade.
Addition of MD to expansive subgrade not only reduces expansive nature of subgrade but also increases its CBR value.
Reduction of expansive nature of subgrade eliminates buffer layer and increases the CBR value and hence reduces the overall thickness of pavement.
Elimination of buffer layer and reduction of overall thickness of pavement offsets the cost and mixing cost of Marble Dust and Tyre Scraps with clay so much that a reduction in overall cost of 27.7% is effected respectively.

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