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A new technology of marble slurry waste utilisation in roads

A K Misra*, Renu Mathur, Y V Rao, A P Singh and Pankaj Goel
Central Road Research Institute (CRRI), New Delhi 110 025, India

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Marble slurry dust (MSD, a waste of marble industry, finds bulk utilization potential in roads. This study indicates that besides embankment construction with this waste, 20-30% of soil can be replaced by MSD for sub-grade preparation. Technology has been validated by taking full scale trials in the field.

Keywords: Embankment, Marble slurry dust (MSD), Roads

Introduction

Around 4000 marble mines and 1100 marble processing units, spread over 16 districts of Rajasthan[1], generate huge quantity of marble dust (5-6 million tonnes/y) in the form of slurry during processing and slabing of marble stones. Indiscriminate disposal of marble slurry dust (MSD), mostly on road sides, is causing problems of drainage, flow regime, air pollution and damage of agriculture land. Extensive research work has been carried out at CRRI, New Delhi, for bulk utilization of this waste in road pavement layers, embankments and in concrete works[2-4].

This study presents work carried out at CRRI on pavement design, methodology adopted for construction, performance evaluation, economy achieved etc. for utilization of MSD in roads.

Experimental

Materials and Laboratory Studies

From Rajsamand District, Rajasthan (India), soil sample was collected from construction site at Sirola to Kuncholi Road and MSD from site at Moonlight Marbles. MSD and soil samples were prepared for various tests for their characterization. Soil-MSD mixes were also prepared using various proportions of MSD. Dry soil samples were prepared as per IS: 2720, Part 1[5].

Grain size analysis[6] of soil specimen was carried out for different sieve size as follows: 40 mm, 100%; 20 mm, 95.5%; 10 mm, 93.3%; 4.75 mm, 90.90%; 2.36 mm, 85.9%; 1.18 mm, 78.8%; 600 µm, 70.8%; 425 µm, 66.0%; 300 µm, 54.3%; 150 µm, 37.3%; and 75 µm, 27.6%. Grain size analysis of MSD gave complete passing through 75µm sieve.

Liquid limit test[7] and plastic limit test[7] were performed on soils, MSD and on soil-MSD mixes (Table 1). Based of grain-size analysis and plasticity index, soil and MSD were classified as per unified soil classification system. Proctor test[8], California Bearing ratio (CBR) test[9] and unconfined compressive strength (UCS) test[10] were performed on soils, MSD and soil-MSD mixes. As CBR values corresponding to a penetration of 5 mm exceeded that for 2.5 mm, test was repeated and reported results of bearing ratio correspond to 5 mm penetration (Table 1). Direct shear test[11] on soil, MSD and soil-20% MSD mixes was done to determine cohesion (c) and angle of internal friction (f), respectively, values are as follows: soil, 0.03 kg/cm^2, 40°; MSD, 0.2 kg/cm^2, 32°; and soil-20% MSD, 0.13 kg/cm^2, 38°.

Design of Road Pavement

A pavement is designed to support wheel loads. Topmost layer is surfacing, to provide a smooth, tough, dust free, reasonably water proof and strong layer. Base, which comes immediately next below, is medium, through which stresses imposed are distributed evenly. Additional help in distributing loads is provided by sub-base layer. Sub-grade is compacted natural earth immediately below pavement layers. Top of sub-grade is also known as formation level.

*Author for correspondence
E-mail: akmishra.crri@nic.in

Table 1—Engineering properties of soil, MSD and soil - MSD mixes

Engineering properties	Soil	Soil+ 10% MSD	Soil+ 20%MSD	Soil + 25%MSD	Soil + 30%MSD	MSD
Liquid limit ,%	29	28.4	27. 5	26.5	25.6	25
Plastic limit ,%	22.5	21.8	20.8	19.7	18.6	17.8
Plasticity Index, %	6.5	6.6	6.7	6.8	7.0	7.2
Maximum dry density, g/cc	1.9	1.95	1.93	1.92	1.914	1.82
Optimum moisturecontent, %	11.0	11.6	11.9	12.1	12.1	12.5
CBR ratio, %	12.5	16.5	17.7	15.4	10.2	4.0
Saturated moisture content for CBR test	13.3	11.5	11.2	11.1	15.6	18.7
Unconfined compressive strength, kg/cm^2	1.3	1.4	1.4	1.5	1.75	-

An adequately constructed embankment is provided for successful performance of a road pavement. Generally, soils having high shearing & bearing strength, density (Min., 1.65 g/cc) and that do not exhibit large volume change are preferred. Design of road pavement depends on CBR value of sub-grade. CBR of *in-situ* soil was 12.5% and that of soil – MSD mix was 17.7%. Laboratory studies suggest that MSD (20%) mixed with soil (on dry weight basis) gives optimum results (Fig. 1).

For low volume traffic, design life and design CBR of sub-grade soil etc, pavement thickness have been worked out[12]. Low cohesion (c = 0.20), high angle of internal friction (ϕ =32) and density (1.82 g/cc) of MSD have potential in embankment preparation. Since site provided for construction of demonstration road stretch had no low line area, an embankment in cutting/ confined condition (1m x 4m x 150m) was constructed with 100% MSD to study settlement behaviour of MSD under prevailing load and environment conditions.

Data used for pavement design of single lane carriage way is as follows: initial traffic (A), 50 CVD; vehicle damage factor (F), 1.5; traffic growth rate (r), 7.5%; design life (n), 10 y; CBR of soil, 12.5%; CBR of soil + 20% MSD mix, 17.7%; design CBR for soil & soil-MSD mix 8.3 & 11.8% (assumed 2/3 of laboratory CBR). As per design calculations, lane distribution factor (D) is 1. Cumulative number (N) of standard axles to be catered for in design life is calculated as

$$N = 365 (1+r)^{n} - 1 /r \times ADF$$
$$= 365 (1+.075)^{10} - 1 / .075 \times 50 \times 1 \times 1.5$$
$$= 0.3873 \text{ msa}$$

As per IRC 37 – 2001, for 7-10 CBR and 1 msa traffic, thickness of pavement correspond to 375 mm. Therefore, base thickness will be 225 mm and GSB 150 mm.

Construction of Test and Control Sections

As a first step of construction, clearing of shrubs, stumps, roots, undergrowth, rubbish and other objectionable material from already marked area was done.

Mixing of MSD and Soil

Measured amounts of MSD and soil (1:5) to be mixed were piled up in open field. Soil and MSD were mixed using JCB till a homogenous mix was obtained. It was ensured that mix gives the same maximum dry density (MDD) as determined in laboratory.

Construction of Sub-grade and Embankment

Local soil or soil-MSD mix used for construction of conventional and test sections respectively was spread over prepared surface. For proper compaction, sub-grade was compacted in uniform layers (25 cm loose thickness) and at optimum moisture content (OMC). Next layer was allowed only after attaining required compaction of first layer. During construction, thickness of loose and compacted layers were checked. To check *in-situ* density (97%), sand replacement method was adopted[13]. In case moisture was above OMC, layer was allowed to dry in sunlight and in case it was below OMC, water was added to attain OMC level[14]. In embankment (1m x 4m x150m), 100% MSD was compacted at OMC in layers till it attained 95% MDD. Compaction and quality check was similar as done in sub-grade preparation.

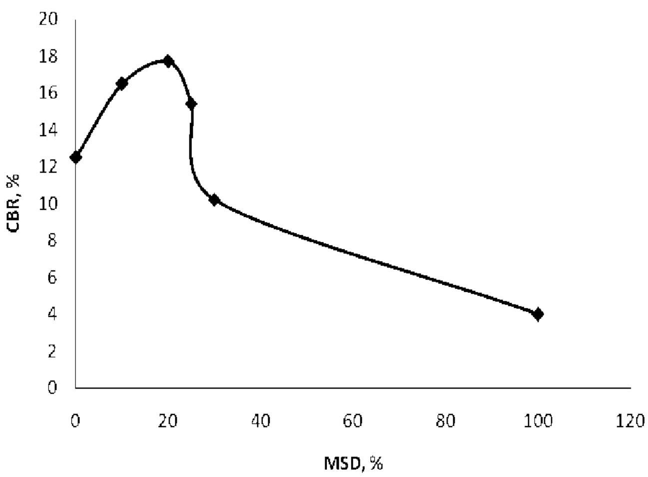

Fig. 1—Effect of MSD on CBR of soil

Construction of Granular sub-base (GSB), Water Bound Macadam (WBM) and Premix Carpet (PMC)

GSB (150 mm), WBM and PMC were laid over prepared sub grade as per standard procedures[15]. Base-course (WBM) was constructed in three layers (75 mm each). A first and second layer was of G-II and third was of G-III as per Table No. 400-7. Screening and binding materials were also as per Table No. 400-8 & 400-9 respectively. Spreading and consolidation of sub base and premix surfacing (20 mm) with seal coat laid over base-course (WBM) were in accordance with MORSTH guidelines.

Results

Pavement Performance Evaluation

Pavement Distress Measurement

Common types of distresses encountered on pavements and considered for measurement are cracking (alligator cracking, map/block cracking, longitudinal and transverse cracking, edge cracking etc.), potholes, raveling, shoving, bleeding, depression/settlement, edge breaking, patch work. For measurements and recording data on different forms of distress, sections were divided into subsections (5 m each), with clearly marking start and end points. Subsections were further divided into three equal longitudinal left, center and right strips. Different distresses were marked, carefully measured separately in regular shapes and recorded subsection and strip wise on standard proforma. In case of single longitudinal and transverse cracks, affected area is taken as the product of actual length of crack and 0.3 m width strip. Cracking is further defined with 3 severity levels (narrow, medium and wide).

Riding Quality Measurements

Riding quality, road user comfort and vehicle operation costs are directly influenced by roughness of pavement surface. Roughness was measured with DIPSTICK (auto read road profiler). Left and right wheel paths were identified at a distance of 0.9 m from each edge and dipstick measurements were taken on both wheel paths to get roughness in terms of IRI (international roughness index) and same was converted into BI (bump integrator) terms using World Bank equation[16], $BI = 630\ (IRI)^{1.12}$.

Deflection Measurements

Structural conditions of test sections were evaluated by response in terms of deflection under a standard rear axle load (8170 kg) of a loaded truck (tyre pressure, 5.6 kg/cm^2). Deflection measurements[17] were taken on 6 points in a 45 m long section, in a staggered manner. These points were located at 0.9 m from respective edges on sections of single carriage-way. All necessary corrections for temperature and moisture were applied to get corrected characteristic rebound deflection.

Sub-grade Moisture

Moisture content in sub-grade level varies significantly throughout the year due to soil type and its level of compaction, pavement materials and their compaction level, surface condition, rainfall temperatures, depth of water table and height of embankment, surface and subsurface drainage etc. To find out moisture content, a pit of suitable size was dug on shoulder adjoining pavement section in transition length portion, up to sub-grade level. Two samples of soil at 50 mm below sub-grade top were taken out and immediately sealed in labeled sample tins/plastic containers to avoid evaporation. Subsequently, moisture content was determined as per IS: 2720 (part-II) and recorded. These values were used for applying seasonal corrections to rebound deflection data.

Data Analysis on Distress, Roughness and Deflection Progression

Data was collected from all five sections (150 m each, starting from Sirola cross section) as follows: 1st section , control section ; 2nd section , test section having 20% MSD in sub-grade -01; 3rd section, test section having 20% MSD in sub-grade and over embankment constructed of 100% MSD-02; 4th section, test section having 20% MSD in sub-grade-03; 5th section , control

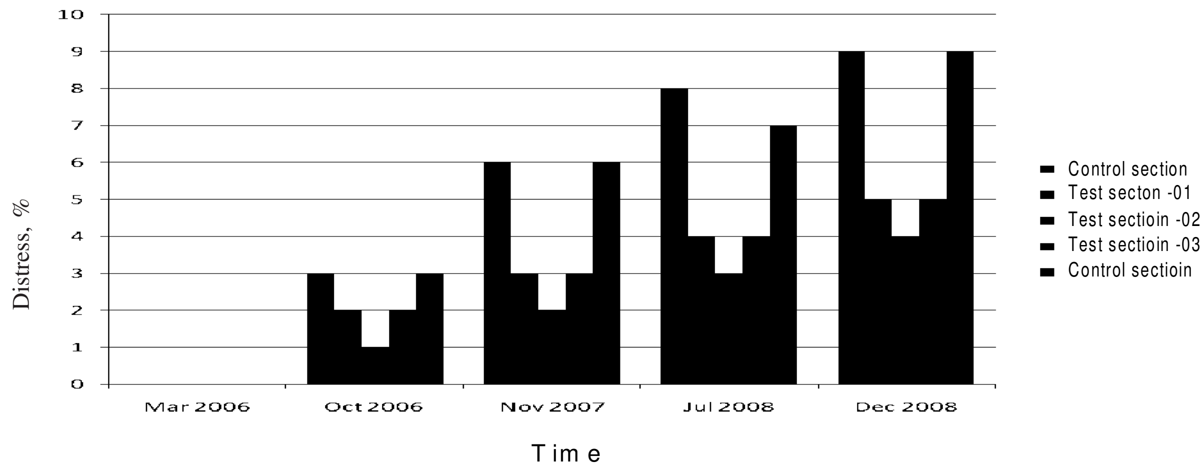

Fig. 2—Distress values on test sections at Kucholi village road

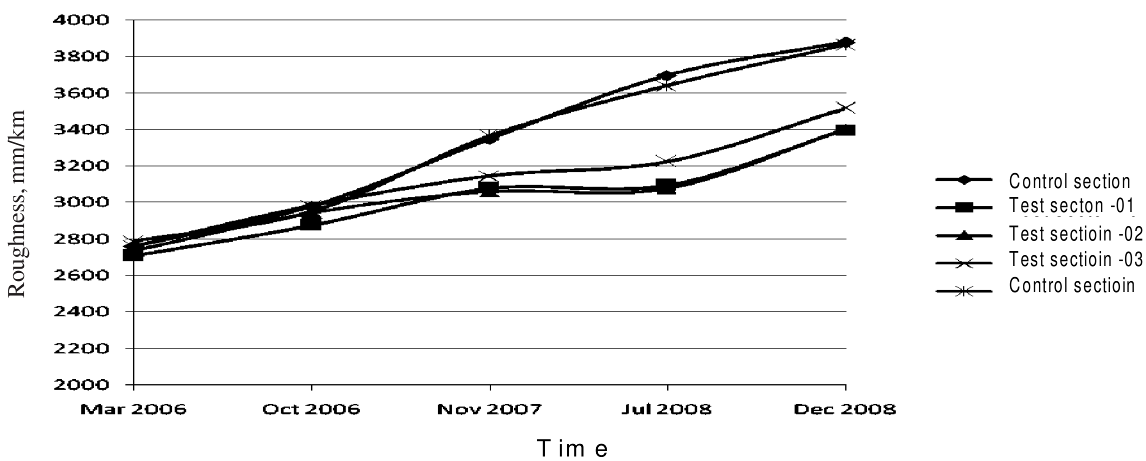

Fig. 3—Roughness progression values on Kucholi village link road

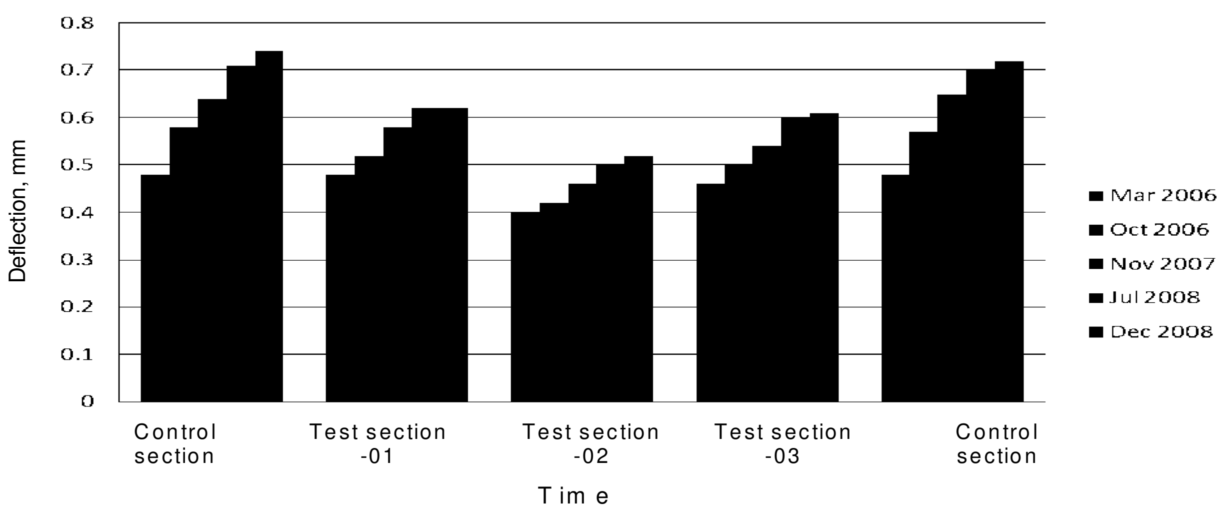

Fig. 4—Progression of deflection values on Kucholi village link road

section. Over study period, distress progression was found as follows: test sections, 3-5%; and control sections, 7-9% (Fig. 2).

Roughness progression in test sections (1-3) is less (687-757 mm/km) as compared to control sections (1074-1120 mm/km). In case of test section no. 02, which is constructed over MSD embankment, roughness is minimum (Fig. 3). Structural strength decreased in control (0.22 mm, 54%) and test sections (0.12 mm, 30%), indicating a residual life of 46% and 70% in control and test sections respectively (Fig. 4). This suggests that control sections will require renewal in 1-2 years while tests sections can be under service without any treatment for another 4-5 years.

Cost Benefit Analysis for Single Lane Pavemant (3.75 m carriageway, 1.0 km long)

Soil requirement for sub-grade preparation (600 mm height) = 5000 m^3
MSD requirement (20% by wt of soil)
= 1000 m^3/ 1900 tonne

Saving in sub-grade soil using MSD
= 1000 m^3
Cost of this soil
= 1.0 Lakh

Extra cost for mixing of MSD & soil + lead & lift (10 km), mixing with JCB
JCB charges/ day [mixing capacity (300 - 400 m^3/d) @ Rs. 2/- / m^3] = Rs 600/-
Mixing cost = Rs 10,000/-; transportation (lead & lift) = Rs 15,000/-
Total = Rs 25,000/-
Net saving = Rs 75,000/-

Discussion

Grain size analysis revealed that soil collected from site is coarse grained. Plasticity tests revealed that soil is sand associated with silt of low compressibility (SM). MSD is very fine and passes completely through 75 μm sieve. Dust sample used in construction work belong to CL-ML group (mixture of clay and silt of low compressibility). Effect of mixing MSD (up to 40%) with soil resulted in minor changes in plasticity of soil .Change in plastic behavior of soil is related to plasticity of added dust. Load bearing capacity (CBR test) of soil improved with addition of MSD (up to 20%). Dust made soil slightly cohesive and resulted in better compaction of pavement layers. UCS of soils with MSD also improved. MSD has low cohesion and high coefficient of internal friction.

Construction site provided for demonstration road stretch was passing through agriculture land having irrigation drains on both sides. Normal rainfall of the area is 550 mm. During 2006, 2007 & 2008, rainfall recorded was 774, 591 and 345 mm. Despite, high rainfall and submerged conditions, test sections showed no signs of distress over study period. Under performance evaluation, test sections constructed using MSD were found having more strength and stability as compared to the control sections.Distress progression is slow in case of test sections as compared to conventional sections. From cost benefit analysis, use of MSD in sub-grade preparation for a double lane road would save Rs 1,50,00/-per km. In multi lane roads and for high embankments, savings would increase many folds.

Conclusions

MSD can be gainfully utilised in bulk quantities in construction of road pavement layers and in embankments. Use of MSD results in saving of soil and savings on difference in cost of natural material soil, besides protection of environment.

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