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STUDIES ON HEXAGONAL WIRE MESH-REINFORCED CRUSHED STONE DUST

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Abstract

Crushed Stone Dust (CSD), which is a waste product from an aggregate crusher, could be used as a pavement layer. To improve the tensile strength of CSD, it is worthwhile reinforcing it. In the present study an attempt has been made to reinforce a loosely and densely compacted CSD layer with Hexagonal Wire Mesh (HWM) placed in various positions. The results indicate that the California Bearing Ratio (CBR) value is improved by the placement of HWM in CSD. Field Rutting studies were also conducted on test tracks made of unreinforced and reinforced CSD layers. The rut depths were significantly reduced due to the inclusion of the reinforcement in the CSD layer.

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Key words

- Crushed stone dust,
- Hexagonal wire mesh,
- CBR test, Rutting.

1 INTRODUCTION

Crushed Stone Dust (CSD) is a waste product which is produced in huge quantities from crushing plants.The reuse of waste materials is a wise choice and is also one step towards accomplishing sustainable development. Common materials for pavement construction are well-graded sand, gravel and crushed stone aggregates. CSD can be used as an alternative to natural river sand, which is used as coarse pavement material. CSD can avoid detrimental effects on the environment caused bythe excessive mining of river sand as explained by Sanjay et al., 2016. The utilization of CSD is possible through geotechnical applications such as embankments, back-fill material, and sub-base material [Soosan et al., 2005; Sridharan and Soosan, 2005; Sridharan et al., 2006]. Studies have been conducted on the effect of CSD on the geotechnical properties of soil used in highway construction; they concluded that the California Bearing Ratio (CBR) value steadily increased with an increase in the percentage of CSD. The improvement in the CBR value can be attributed to a significant improvement in the angle of the shearing resistance. The higher CBR values of soil-CSD mixes enhance their potential for use as a subbase for flexible pavements. The results showed that the CSD proved to be a promising substitute for sand and can be used to improve the engineering properties of soils.

A CSD layer can be used as a unpaved road layer, and its efficacy can be improved by introducing a reinforcement within the layer. Geosynthetics have been used as a reinforcement in earth structures such as mechanically stabilized earth walls, column-supported embankments, soil slopes, and paved/unpaved roads. Geosynthetics are commonly used in the mechanical stabilisation of unpaved roads with low volumes of traffic. The practical use of geosynthetics above a weak subgrade or within a base course has demonstrated the benefit of reducing rut depths and prolonging pavement life [Calvarano et al., 2016]. Several experimental research works were carried out for strengthening unpaved roads by the inclusion of reinforcement layers. Al-Qadi et al., 2016 carried out full-scale accelerated pavement testing to measure pavement responses, monitor pavement performances, and quantify the benefits of a geogrid in flexible pavements. A geogrid was found to be very effective in reducing shear deformation of granular material, especially in the direction of traffic and on thin pavements. The study also concluded that for thick base layers, a single geogrid layer installed in the upper one-third of a layer would improve the pavement's performance. Goud and Umashankar, 2017 conducted large-scale model experiments and observed that the inclusion of planar reinforcements in the form of a geogrid or steel wire mesh within the aggregate layer resulted in a load improvement factor ranging from 1.1 to 1.9. Field rutting studies were conducted by Madhavi Latha, 2013 in order to assess the performance of geosynthetic-reinforced unpaved roads.

The present study focuses on the inclusion of Hexagonal Wire Mesh (HWM) as a reinforcement in a CSD layer. HWM system units are formed from a single sheet of hexagonal, PVC-U coated, galvanized, double-twist and woven steel mesh. The present study aims at studying the laboratory CBR values (both in unsoaked and soaked conditions) and field rut studies on HWM-reinforced CSD in order to assess its suitability as a pavement layer.

2 MATERIALS USED

2.1 Crushed Stone Dust (CSD)

The crushed stone dust (CSD) used in the experiment was brought from a crusher unit situated in the village of Paritala about 25 kilometers away from Vijayawada, India. A dry sieve analysis test [ASTM D6913M] was conducted on the crushed stone dust in the geotechnical laboratory. The grain size distribution of the CSD is shown in Fig. 1. The CSD used in the present study is classified as Well-Graded Sand (SW) according to the Unified Soil Classification System [ASTM D2487]. The values of the maximum and minimum dry density of the CSD were evaluated in accordance with the guidelines of [ASTM D4254]. The test results are summarized and presented in Table 1.

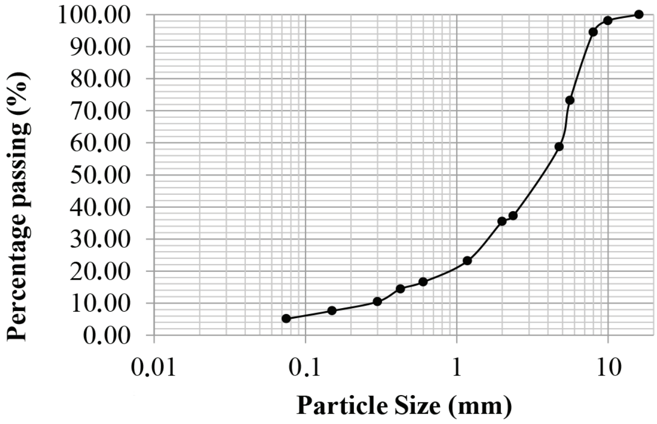

Fig. 1 *Grain Size Distribution Curve of Crushed Stone Dust*

Tab. 1 *Properties of Crushed Stone Dust*

Property	Value
Specific Gravity	2.66
Gravel %	41.28
Coarse Sand %	23.26
Medium Sand %	21.04
Fine Sand %	9.33
Fines %	5.09
Coefficient of Uniformity, Cu	20.83
Coefficient of Curvature, Cc	2.13
Classification of Soil	SW
Maximum Dry Density (g/cc)	1.962
Minimum Dry Density (g/cc)	1.600

Fig. 2 *Hexagonal Wire Mesh Roll*

1.2 Hexagonal Wire Mesh

The hexagonal wire mesh (HWM) was procured from a local market and is available in the form of rolls as shown in Fig. 2. The properties of the HWM were evaluated in a laboratory and are presented in Table 2.

Tab. 2 *Properties of Hexagonal Wire Mesh*

Property	Value
Nominal Thickness (mm) [ASTM D5199]	0.35 (Single rib)
	1.15 (Double twist)
Size of aperture opening along length (mm)	14.2
Percentage of open area	84.56
Mass per unit area (gsm) [ASTM D5261]	500
Specific gravity (g/cc) [ASTM D792]	1.14
Tensile strength in longitudinal direction at 2% Strain (kN/m) [ASTM D6241]	4.2
Elongation indirection ofmachine (%)	16.8

3 TESTS CONDUCTED

3.1 Laboratory CBR Tests

Laboratory CBR tests [IS:2720 (Part 16), 1992] were conducted on a CSD layer that was compacted loosely and densely (with and without HWM) in unsoaked and soaked conditions. The relative den-

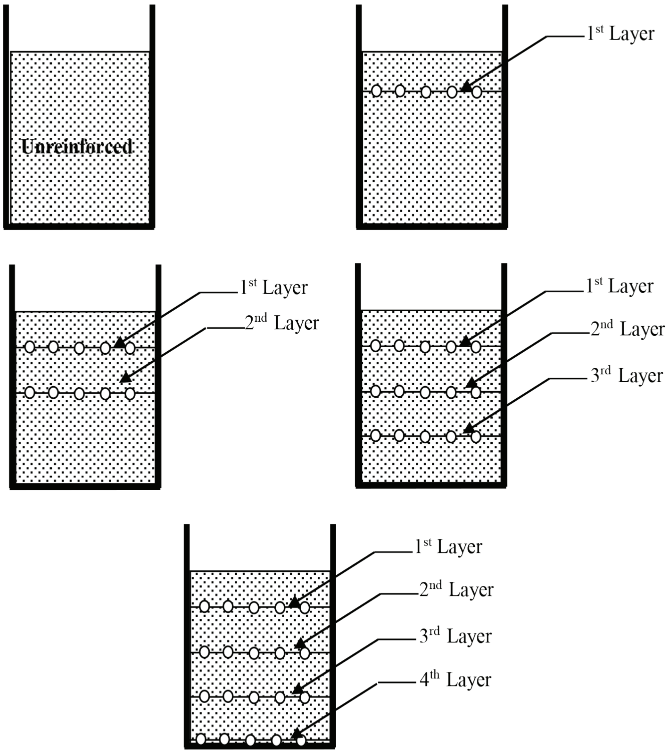

Fig. 3 *Position of the reinforced layer(s) in the crushed stone dust layer*

sity (RD) maintained was 30% for a loosely compacted CSD layer and 80% for a densely compacted CSD layer. In practice, densely compacted layers are used to build unpaved road structures. In the present study, tests were also conducted in order to know the effect of the reinforcement on loosely compacted unpaved roads. The CBR value was determined at specified penetration levels of 2.5 mm and 5.0 mm. The various positions of the reinforcement layer(s) are shown in Fig. 3. Usually, the zone of influence of the load is 1.5 to 2 times the size of the footing. The diameter (D) of plunger of the CBR apparatus used in the present study was 50 mm in diameter. Hence, the load effect is upto a depth of 75 to 100 mm from the surface of the CSD layer. The reinforcement layers were positioned in such a way that they are within and outside the influence of the load. The position of the reinforcement layers were 0.6D, 1.2D, 1.8D, and 2.4D from the top of the CSD layer.

3.2 Field Rutting Studies on the test track made with an unreinforced and HWM-reinforced CSD Layer

Field rutting studies were conducted on an unpaved road, which consisted of a CSD layer laid over a prepared subgrade. Tests were conducted on unreinforced (as shown in Fig. 4) and HWM-reinforced CSD layers (as shown in Fig. 5). The reinforcement was placed at 30 mm (=H/4) from the top. A scooter weighing 110 kg was driven by a person weighing 60 kg along the centreline of the finished road bed. The speed of the vehicle was maintained at 18 to 20 km/hr, and the vehicle passed in one direction only. The test sections were subjected to a moving vehicle load simulated by the passage of the scooter (as shown in Fig. 6) along the central section of the road. The rut depths were measured along the centre of the test track with an increasing number of cycles, and the results were analysed to compare the relative efficiency of the reinforcement layer in reducing the formation of ruts in the unpaved roads.

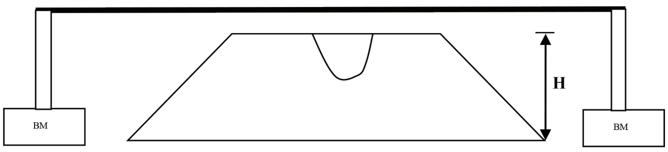

Fig. 4 *Experimental set-up for measuring the rut depth of the unreinforced CSD layer*

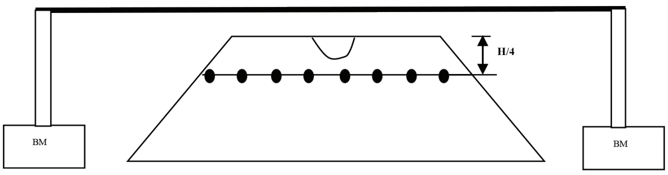

Fig. 5 *Experimental set-up for measuring the rut depth of the HWM-reinforced CSD layer*

Fig. 6 *Passage of a scooter along the central section of the unpaved road*

4 RESULTS AND DISCUSSION

4.1 CBR test results of theloosely (RD=30%) compacted CSD layer reinforced with HWM

The unsoaked and soaked CBR tests were conducted on a loosely compacted CSD layer that had a relative density of 30%. Further CBR tests were conducted on a loosely compacted CSD layer reinforced with HWM layers in various positions. A typical load versus-the penetration curve obtained from the unsoaked CBR test conducted on the unreinforced, loosely compacted CSD layer is depicted in Fig. 7. Figs. 8 and 9 show the variations of the unsoaked and soaked CBR values with the introduction of the HWM reinforcement in the loose CSD layer.

From Fig. 8, it can be observed that a higher unsoaked CBR value can be noted when the reinforcement layers are placed at 0.6D and

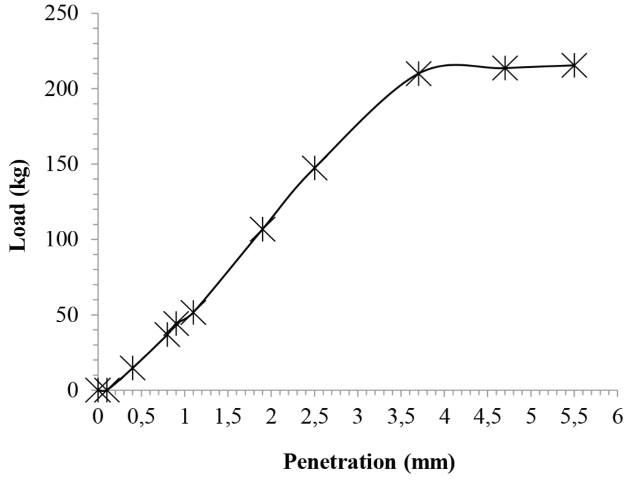

Fig. 7 *Typical Load-Penetration Plot*

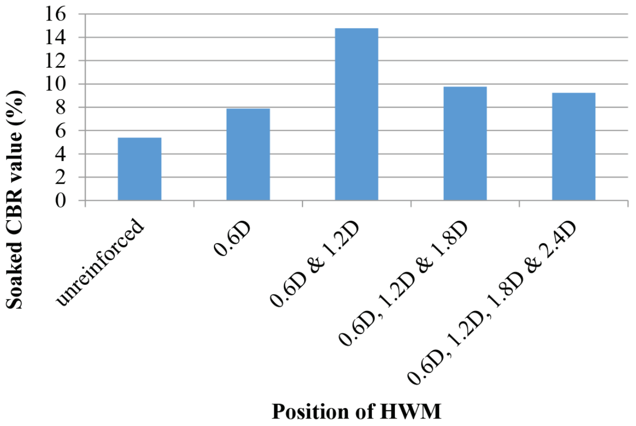

Fig. 9 *Soaked CBR values of a loosely compacted CSD layer reinforced with HWM*

1.2D from the top. 'D' is the diameter of the plunger of the CBR apparatus used in the present study. The unsoaked CBR values are nearly the same for the rest of the reinforcement placements. The increase in the unsoaked CBR value of the HWM-reinforced CSD is about 3 times that of the unreinforced CSD. The improvement in the CBR value is due to the interlocking of the CSD particles in the reinforcement layers.

From Fig. 9, it can be observed that three times the value of the unreinforced soaked CBR value can be noted when the reinforcement layers are placed at 0.6D and 1.2D from the top. The soaked CBR values are nearly the same for the rest of the reinforcement positions. The effect of the HMW reinforcement is greater when the reinforcement is placed at 0.6D. From this study it is clear that with the introduction of the HWM reinforcement, the soaked CBR value of the CSD layer can be improved. The improvement in the CBR value is due to the sediment of the fines at the bottom leaving the coarsened particles at the top, which leads to more confinement. Hence, it is advisable to place the reinforcement within the influence of a pressure bulb.

4.2 CBR Test results of the densely (RD=80%) compacted CSD layer reinforced with HWM

Unsoaked and Soaked CBR tests were conducted on densely compacted unreinforced and reinforced CSD layers which had a relative density of 80%. Figs. 10 and 11 show the variations of the unsoaked and soaked CBR values with the introduction of the HWM reinforcement in the densely compacted CSD layer. From Fig. 10, it can be seen that there is a significant increase in the value of the unsoaked CBR when the reinforcement layers are placed at 0.6D and 1.2D from the top. The increase in the unsoaked CBR value of the HWM-reinforced CSD is about 3.5 times as compared with the unreinforced CSD.

From Fig. 11, it can beseen that a higher soaked CBR value can be observed when the reinforcement layer is placed 0.6D from the

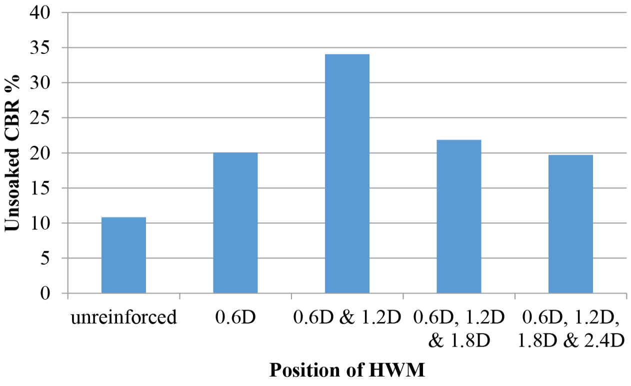

Fig. 8 *Unsoaked CBR values of a loosely compacted CSD layer reinforced with HWM*

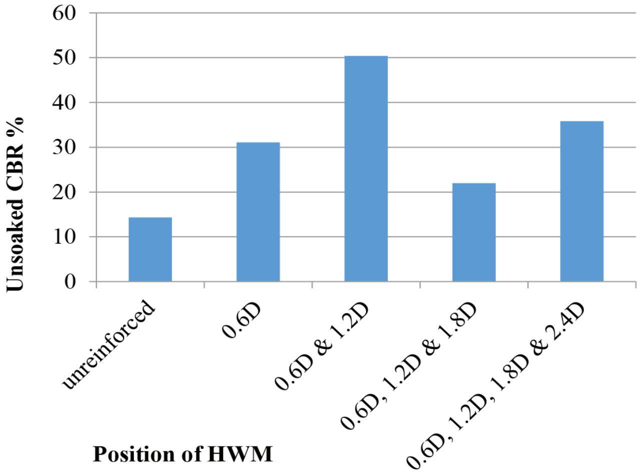

Fig. 10 *Unsoaked CBR values of a densely compacted CSD layer reinforced with HWM*

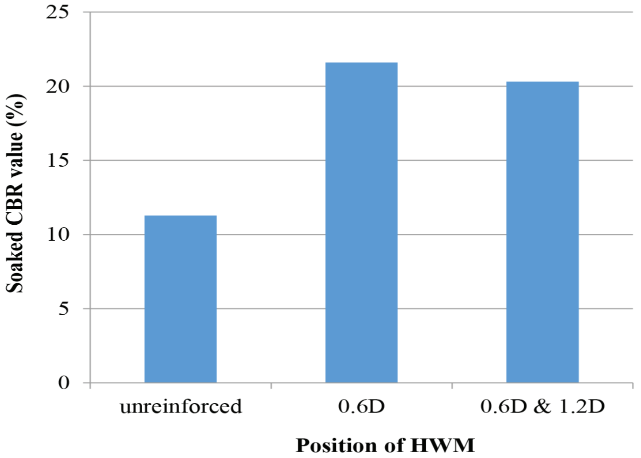

Fig. 11 *Soaked CBR values of a densely compacted CSD layer reinforced with HWM*

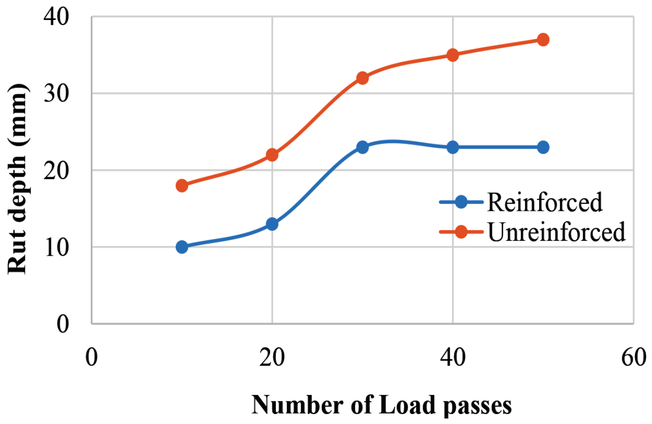

Fig. 12 *Rut depth vs. number of load passes*

top. The soaked CBR values are nearly the same for the rest of the reinforcement positions. The increase in the soaked CBR value of the HWM-reinforced CSD is about 2 times greater compared with the unreinforced CSD. The soaked CBR value for a densely compacted CSD layer reinforced with a single layer of HWM is 21.36%. It is very clear that the provision of even a single layer providesenough soaked CBR value due to the densification of the CSD layer. A densely compacted CSD layer reinforced with a single layer of a HWM reinforcement placed 0.6D from the top can be used as a sub-base, particularly for low volume rural roads.

4.3 Results of the field rutting studies on the test track made with the unreinforced and HWM-reinforced CSD layers

A rut is a depression or groove worn into a road or path by the travel of wheels. The results of the field rutting tests conducted on the unreinforced and HWM-reinforced CSD layer aredepicted in Fig. 12. From Fig. 12, it can be clearly seen that the rut depth for the HWM-reinforced CSD layer is relatively less when compared with the unreinforced CSD layer. The rutting is insignificant for the reinforced CSD layer when the number of loads are more than 30. The reduced rutting is mainly due to the interlocking of the CSD particles within the apertures of the reinforcement. IRC: SP- 20 recommends that the maximum rutting that can be accepted in rural roads may be taken as 50 mm.

5 CONCLUSIONS

The following conclusions can be drawn from the present study:

1. The unsoaked CBR values are higher than the soaked CBR values for the unreinforced and reinforced CSD layers.The soaked CBR values for theHWM reinforcement layers placed 0.6D and1.2D from the top in a loosely compacted (relative density of 30%) CSD layer are about three times higher than the unreinforced one.
2. The soaked CBR values for a reinforcement layer placed 0.6D from the top in a densely compacted (relative density of 80%) CSD layer is about two times higher than an unreinforced one.
3. The higher soaked CBR value of 21.26% resulted for the densely compacted CSD layer reinforced with HWM placed 0.6D from the top. This could be due to densification, which can enhance the interlocking of CSD particles in an HWM reinforcement.
4. A densely compacted CSD layer reinforced with a single layer of an HWM reinforcement placed 0.6D from the top can be used as a sub-base, especially for low volume rural roads.
5. It can be observed that when the number of load passes exceeds 30, the rutting depth is almost same and within permissible limit for the HWM reinforcement is placed at the upper one-fourth of the CSD layer. The HWM-reinforced CSD layer can be used as a cost effective structural pavement layer.

REFERENCES

Al-Qadi, I.L., Dessouky, S.H., Kwon, J. and Tutumluer, E. (2012) *Geogrid-Reinforced Low-Volume Flexible Pavements: Pavement Response and Geogrid Optimal Location*, J. Transp. Eng., 138(9), pp.1083-1090.

ASTM D2487 (2010) *Standard practice for classification of soils for engineering purposes (Unified Soil Classification System)*, American Society for Testing of Materials; PA, USA.

ASTM D4254 (2006) *Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density*, minimum index density, American Society for Testing of Materials, PA, USA.

ASTM D5199 (2012) *Standard Test Method for Measuring the Nominal Thickness of Geosynthetics, American Society for Testing of Materials*, PA, USA.

ASTM D5261 (2009) *Standard Test Method for Measuring Mass per Unit Area of Geotextiles*, American Society for Testing of Materials, PA.

ASTM D6913M (2017) *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*, American Society for Testing of Materials, PA, USA.

ASTM D792 (2008) *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*, American Society for Testing of Materials, PA, USA.

ASTM D6241 (2014) *"Standard Test Method for Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe"*, American Society for Testing of Materials, PA, USA.

Calvarano, L.S., Palamara, R., Leonardi, G. and Moraci, N. (2016) *Unpaved road reinforced with geosynthetics*, Periodical Engineering, Elsevier Ltd., Vol. 158, pp. 296-301.

Goud, G.N. and Umashankar, B. (2017) *Planar Reinforcements for Flexible Pavement, International conference on Geotechniques for Infrastructure PROJECTS*, 27-28 Feb 2017, Thiruvananthapuram.

IS:2720 (1992) (Part 16) *California Bearing Ratio Test, Bureau of Indian Standards*, New Delhi, India.

IRC: SP-20 (2002) *Rural Roads Manual*, Indian Roads Congress, New Delhi, India.

Madhavi Latha, G. (2013) *Performance Evaluation of Geosynthetic Reinforced Unpaved Roads*, Centre for infrastructure, Sustainable Transport and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore, India.

Sanjay, M., Sindhi, P.R., Vinay, C., Ravindra , N. and Vinay, A. (2016) *Crushed rock sand:An economical and ecological alternative to natural sand to optimize concrete mix*, Perspectives in Science, Elsevier B.V., 8, pp. 345—347.

Soosan, T., Sridharan, A., Jose, B., and Abraham, B. (2005) *Utilization of Quarry Dust to Improve the Geotechnical Properties of Soils in Highway Construction*, Geotechnical Testing Journal, ASTM, Vol. 28(4), pp. 391-400.

Sridharan, A. and Soosan, T.G. (2005) *Utilization of crusher dust to improve the geotechnical properties of soil in highway construction*, Canadian Geotechnical Journal, 28, pp. 391-400.

Sridharan, A., Soosan, T.G., Babu T.J. and Abraham, B.M. (2006) *Shear strength studies on soil-quarry dust mixtures*, Geotechnical & Geological Engineering, Vol. 24(5), pp. 1163–1179.