Research Article

Environmental risk mitigation using optimal mix for road embankments of marble dust and WTP sludge with soil

Abstract

Marble Dust (MD) and Water Treatment Plant Sludge (WTPS) are some of the waste materials which are dumped in the nearby area leading to an environmental risk by harmful chemical contamination in the soil and ultimately to the shallow ground water. In order to mitigate this risk, the available MD and WTPS have been used to improve the geotechnical properties of locally available soil which could be used for road embankments. Locally available soil was tested for specific gravity, sieve analysis, heavy compaction and shear parameters. Then equal parts of MD and WTPS were added to the soil at various percentages 5%, 10%, 15%, 20% and 25% of soil to make different mixes. These mixes were tested under heavy compaction to get maximum dry densities (MDD) and optimum water contents (OMC). Direct Shear Test has also been carried out on all the mixes to get the shear strength parameters. The shear strength parameters were plotted with percentage of MD+WTPS. It is found that the cohesion was constantly decreasing with percent of MD+WTPS and comes to almost constant beyond 25%. On the other hand the internal friction angle increases upto 20% and then reduces. Embankments made up of these mixes were modelled in PLAXIS 2D.It is found that the horizontal and vertical displacement of an embankment decreases with increase in percent of MD+WTPS under static loading upto 20% then reduces. The study concluded that by using 20% of MD+WTPS, an optimal mix, in the local soil to be used for road embankment gives three fold problem solution: (a) Environmental Risk Mitigation by using the waste materials MD and WTPS with soil, (b) saving of equal amount of top layer fertile soil which would be excavated along the embankment, and(c) higher shear strength and lesser displacement thus higher stability.

Keywords: optimal mix, road embankment, marble dust, WTP sludge, heavy compaction, direct shear test

Volume 2 Issue 5 - 2017

Sumaiya Khanam,[1] Sadiqa Abbas,[2] Abbas SM[3]
[1]Department of Civil Engineering, University Polytechnic, India
[2]Department of Civil Engineering, Manav Rachna International University, India
[3]Department of Civil and Environmental Engineering, University of Majmaah, Saudi Arabia

Correspondence: Abbas SM, Department of Civil and Environmental Engineering, University of Majmaah Post Box 66, Majmaah, Kingdom of Saudi Arabia, Tel +966-53473-1275, Email abbas_sm@hotmail.com

Received: March 18, 2017 | **Published:** May 08, 2017

Abbreviations: MD, marble dust; WTP, water treatment plant; WTP Sludge, WTP sludge; MDD, maximum dry density; OMC, optimum water content

Introduction

With the rapid economy growth and continuously increased consumption of vast varieties of items, a large amount of waste materials is generated. The vast quantities of wastes viz. marble dust, WTP Sludge, scrap tyres, glass, blast furnace slag, steel slag, plastics, construction and demolition wastes accumulating in stockpiles and landfills throughout the world are causing disposal problems that are both financially and environmentally expensive. Dealing with the growing problem of disposal of these materials is an issue that requires coordination and commitment by all parties involved.[1]

Marble dust is generated as a by-product during cutting of marble. The waste is approximately in the range of 20% of the total marble handled. The amount of marble dust generated in Rajasthan state every year is very substantial being in the range of 5-6million tonnes. The marble cutting industries are dumping the Marble dust in any nearby pit or vacant spaces near their unit, although notified areas have been marked for dumping. This leads to serious environmental problems like dust pollution and occupation of vast areas of land, especially after the slurry dries up. This also contaminates the underground water reservoirs.[2] Potable Water Treatment Plants that employ the conventional processes of coagulation, flocculation and sedimentation produce large quantities of sludge. Often, the volume of generated sludge can be as high as 2% of the total volume of water treated.[3]

Many researchers[4–8] have reported that marble has very high lime (CaO) content up to 55% by weight. Thus, stabilization characteristics of waste limestone dust and waste dolomitic marble dust is mainly due to their high lime (CaO) content. The possibility for the utilization of marble slurry dust for soil stabilisation is investigated[9] and found that 25-30% of the marble slurry dust can be mixed with various soils for the construction of roads and backfill material.

Although it is still in the preliminary stage and yet to be widely studied and reported, the possible use of WTP sludge as geotechnical works material (e.g. waste containment barriers, soil modelling, structural fills), incorporation into construction materials (bituminous mixtures, sub base material for road construction) and as landfill liner have been reported.[10–12] This is particularly based on preliminary characterization test results on the geotechnical and geo-environmental characteristics of WTP sludge which shows some promise as a suitable geotechnical and construction material.[12] reviewed the feasibility of sludge as a filler material in bituminous mixtures for use in general pavement works.

One solution to a portion of the waste disposal problem is to recycle and use these materials in the geotechnical construction such as embankments, roads, backfills etc. The use of waste materials in the geotechnical construction has benefits in not only reducing the amount of waste materials requiring disposal but can provide construction materials with significant savings over new materials. However, full understanding of the engineering behaviour of these materials is essential so that they can be used safely in geotechnical structures.

For the construction of embankments, generally, the top layer of soil is excavated from the nearby area, which is most fertile for vegetation, leaving the area as barren. The present study deals with the mitigation of environmental risk by geotechnical utilization of waste MD and WTPS with locally available soil for embankment construction. The reuse of waste Marble Dust and WTP sludge may also contribute in enhancing the engineering properties of the locally available weak soil for embankment construction.

Methodology

Material used

The raw materials, used for this study are locally available soil, Marble Dust, and WTP Sludge.

a. **Soil:** A large amount of excavated soil was available at Metro construction site nearby to Jamia Millia Islamia, New Delhi, India campus. This area is filled up over the rocky zone. The soil was air dried and pulverized manually to bring homogeneity. This natural soil is light brown in colour.

b. **Marble dust:** The Marble Dust was obtained from Rajasthan State, India. Properties of this Marble Dust has been determined by[13] and presented in Table 1. Minor impurities in the Marble dust include quartz, chert, flint, hematite, limonite, graphic, mica etc. The chemical analysis of the dust shows that it is a mixture of calcium and magnesium carbonates with 90% of the particles below 200microns.

c. **WTP sludge:** The WTP sludge used in the study was collected from the settling basin of the Chandrawal Water Works, New Delhi. The coagulant used in Chandrawal Treatment Plant for treatment of raw water is alum. Therefore, the sludge obtained is gelatinous, bulky and greyish black in colour. The oven dried sample was used by pulverising manually.

Table 1 Chemical composition of marble dust.[13]

Properties	Test value (%)
Calcium Carbonate ($CaCO_3$)	90.06
Magnesia (MgO)	5.85
Silica (SiO_2)	2.32
Alumina (Al_2O_3)	1.36
Iron Oxide (Fe_2O_3)	0.39
Soda	Less than 0.1
Potash	Less than 0.1

Experimental investigations

The collected materials were oven dried at the temperature of 105-110°C and then sieved through 4.75mm sieve. The material passing through 4.75mm sieve was used in experimental work. The sample Mixes were prepared by adding 1:1 mixture (by dry weight) of MD and WTPS to the soil at percentage varying from 5 to 25% of the soil (by dry weight) at an interval of 5%. For each sample Mixes, the predetermined amount of material was mixed with trowel to make particles distribute homogenously. The mixes were numbered for better presentation as depicted in Table 2.

Table 2 Designation of the mixes

Soil+5% MD+WTP Sludge	Mix-1
Soil+10% MD+WTP Sludge	Mix-2
Soil+15% MD+WTP Sludge	Mix-3
Soil+20% MD+WTP Sludge	Mix-4
Soil+25% MD+WTP Sludge	Mix-5

Specific gravity

The specific gravity was determined of soil, marble dust and WTP sludge by density bottle method as per IS: 2720 (Part III/Sec 1)–1980.[14] Five samples of each material were taken to find out specific gravity. Table 3 shows the specific gravity of each material. Specific Gravities of different Mixes have been determined by taking their weighted amount as shown in Table 3.

Table 3 Different properties of soil, MD, WTP sludge and mixes

Sample	Specific gravity	Coefficient of uniformity, C_u	Coefficient of curvature, C_c	MDD (kN/m³)	OMC (%)
Soil	2.66	14.48	0.23	18.97	13.78
MD	2.45	2.59	1.09	-	-
WTP sludge	2.87	5.03	0.73	-	-
Mix-1	2.66	12.78	0.27	19.41	9.56
Mix-2	2.66	11.46	0.32	19.47	9.00
Mix-3	2.66	10.40	0.36	19.00	10.00
Mix-4	2.66	9.55	0.40	18.85	11.00
Mix-5	2.66	8.84	0.44	18.70	11.50

Sieve analysis

The soil, MD and WTPS were tested for Grain Size Distribution. The tests were performed as per IS: 2720 (Part IV)-1985.[15] Three samples of each material were tested for Sieve Analysis and average of them has been presented in Figure 1. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) have been calculated for these materials (Table 3).

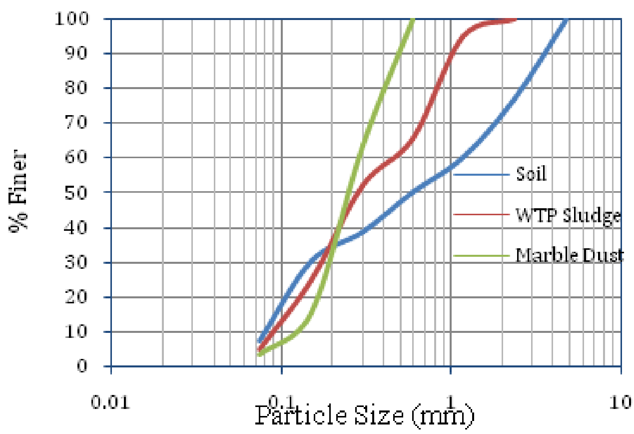

Figure 1 Grain size distribution curves for the soil, MD and WTP sludge.

For different mixes, percentage finer were calculated based on the ratios of different constituents in the mixes (Figure 2). For these mixes, coefficients of uniformity and curvature (C_u, C_c) have also been evaluated and are presented in Table 3.

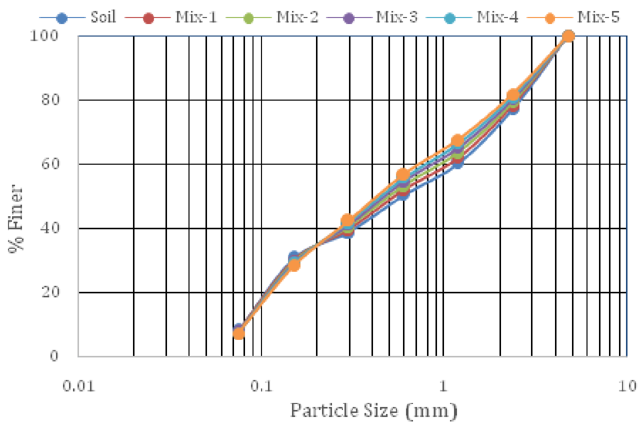

Figure 2 Grain size distribution curves for the mixes.

Modified proctor compaction test (Heavy compaction test)

Heavy vehicles have become very common almost on all the roads to deliver more in shorter number of trips. Therefore, for the construction of roads, heavy compaction should be performed on all the layers of the roads. In this study, heavy compaction test i.e. Modified Proctor Compaction tests have been performed on the soil and the Mixes as per IS: 2720 (Part VIII)-1983.[16] For every sample Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were recorded as presented in Table 3.

Direct shear test

The shear parameters of soil and its different mixes were determined by using Direct Shear Test as per IS: 2720 (Part XIII)-1986.[17] For this test, the samples were prepared at their corresponding MDD and OMC. The specimens were of size 60mm×60mm×25mm and sheared at a rate of 1.25mm/minute. The stress-strain relationship for the soil and all the mixes is depicted in the Figures 3-8. The shear strength parameters i.e. cohesion (c) and angle of internal friction (ø) of the samples were determined and mentioned in Table 4.

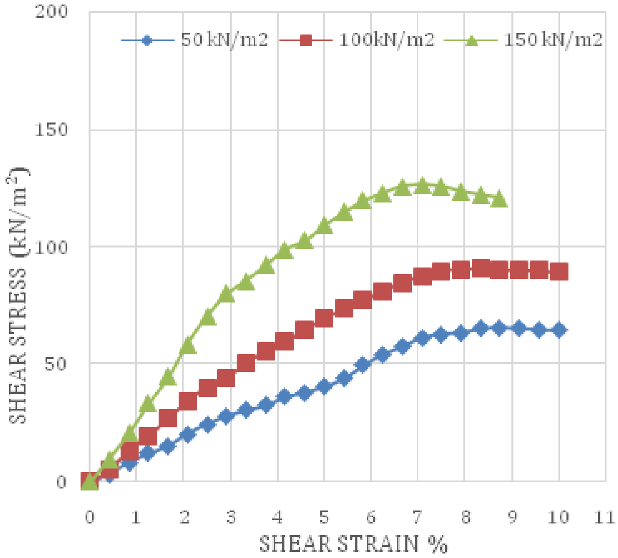

Figure 3 Variation of shear stress with shear strain for soil.

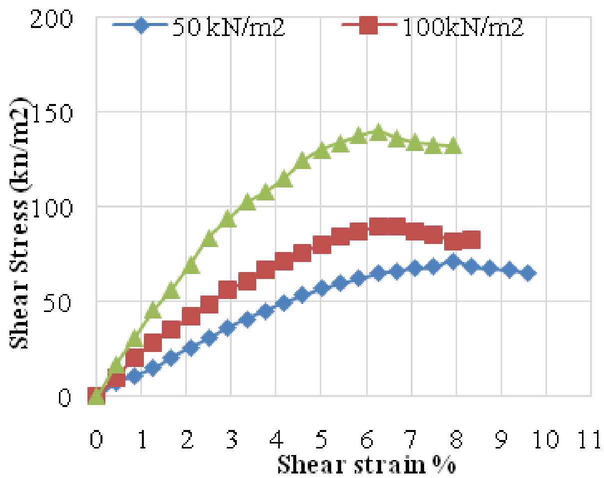

Figure 4 Variation of shear stress with shear strain for soil+5% (MD+WTPS).

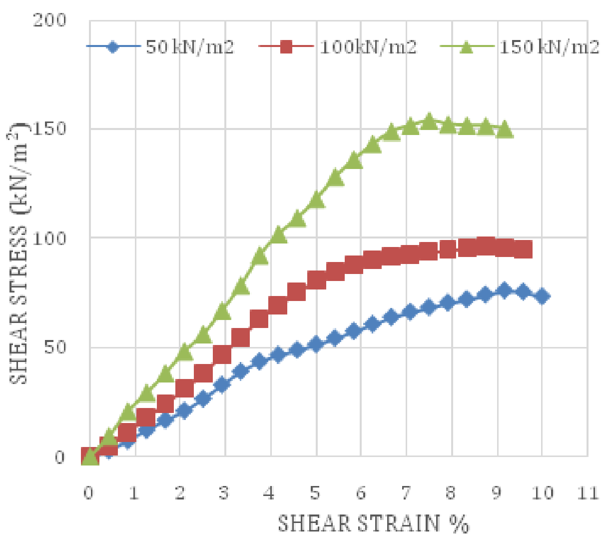

Figure 5 Variation of shear stress with shear strain for soil+10% (MD+WTPS).

Citation: Khanam S, Abbas S, Abbas SM. Environmental risk mitigation using optimal mix for road embankments of marble dust and WTP sludge with soil. *MOJ Civil Eng.* 2017;2(5):151‒156. DOI: 10.15406/mojce.2017.02.00044

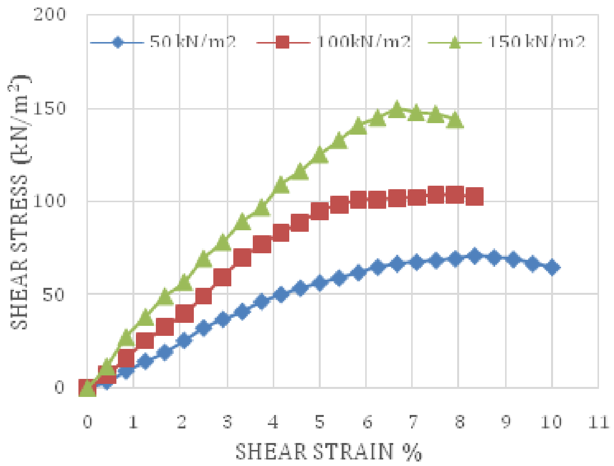

Figure 6 Variation of shear stress with shear strain for soil+15% (MD+WTPS).

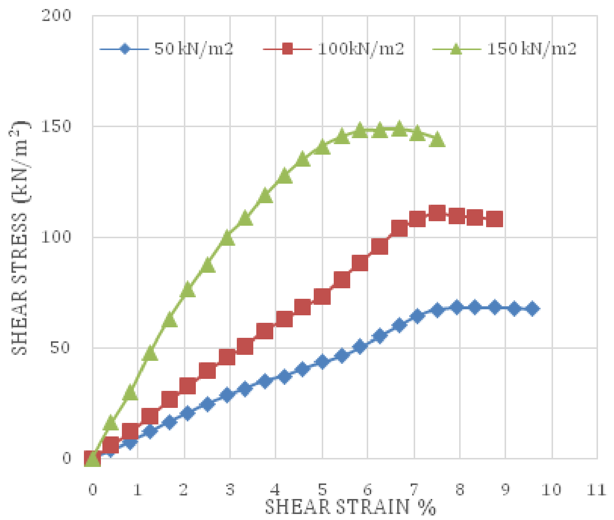

Figure 7 Variation of shear stress with shear strain for soil+20% (MD+WTPS).

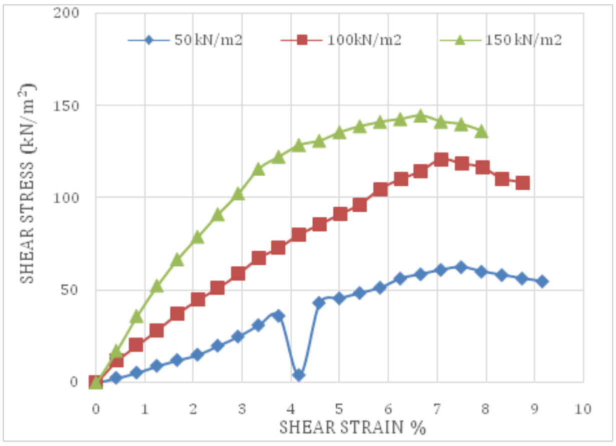

Figure 8 Variation of shear stress with shear strain for soil+25% (MD+WTPS).

Numerial modeling of embankment

A finite element based software PLAXIS 2D was used to calculate the displacements and stresses in different embankments made up of the soil and these mixes. Mohr Coulomb model was selected for the embankment fill materials. The material properties used in the model for different mixes are obtained from the experimental program and listed in Table 4. A road embankment 16m wide and 4m high is analysed by PLAXIS (Figure 9). The sides have a slope of 1:3. The embankment is considered to be made up of different mixes. The sub soil consists of 6.0m thick layer of locally available soil. The numerical model has been analysed with 2D plane strain model considering only half of the section due to its symmetry. A total width of 40m has been used which starts. Typical contour diagrams for horizontal and vertical displacements for embankment with properties of locally available soil obtained from the numerical analysis are presented in the Figure 10 & 11 respectively. The results obtained after analysis shows that maximum settlement occur after full dissipation of pore pressure. The same analysis was carried out for the embankments made up of different mixes and maximum horizontal and vertical displacements were recorded and plotted Figure 12 & 13.

Table 4 Material properties used in finite element analysis

Material properties	Soil	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Unit
Type of behavior	Un-drained	Un-drained	Un-drained	Un-drained	Un-drained	Un-drained	–
$ã_{sat}$	18.6	19.600	19.100	18.100	18.500	19.100	kN/m³
$ã_{sat}$	23	23.188	23.594	23.273	23.111	23.178	kN/m³
k_x	1	0.98	0.94	0.97	0.99	0.98	m/day
k_y	1	0.98	0.94	0.97	0.99	0.98	m/day
E_{ref}	4.00E+04	4.04E+04	4.11E+04	4.05E+04	4.02E+04	4.03E+04	kN/m²
V	0.200	0.190	0.170	0.188	0.195	0.192	–

Table Continued....

Material properties	Soil	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Unit
Type of behavior	**Un-drained**	**Un-drained**	**Un-drained**	**Un-drained**	**Un-drained**	**Un-drained**	**—**
C_{ref}	33.470	31.648	30.200	29.100	28.551	28.300	kN/m²
ö	31.38	34.55	37.00	38.50	38.98	38.50	degree
ø	0.00	0.00	0.00	0.00	0.00	0.00	degree
Material model	Mohr-coulomb	Mohr-coulomb	Mohr-coulomb	Mohr-coulomb	Mohr-coulomb	Mohr-coulomb	—

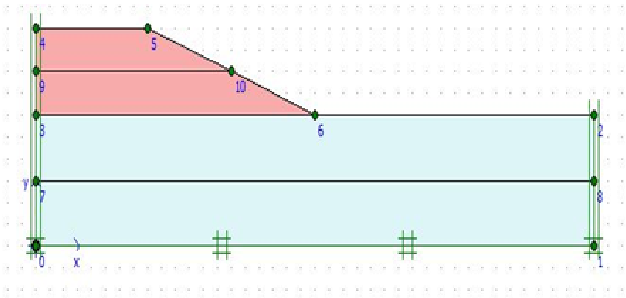

Figure 9 Geometry of embankment model.

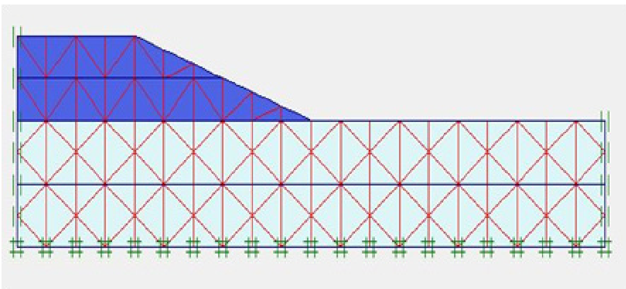

Figure 10 Typical mesh generation.

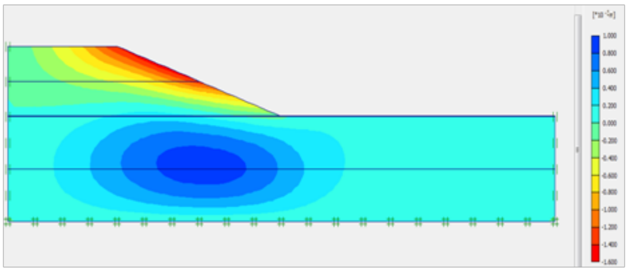

Figure 11 Horizontal displacement at the end of pore pressure dissipation in embankment without MD+WTPS.

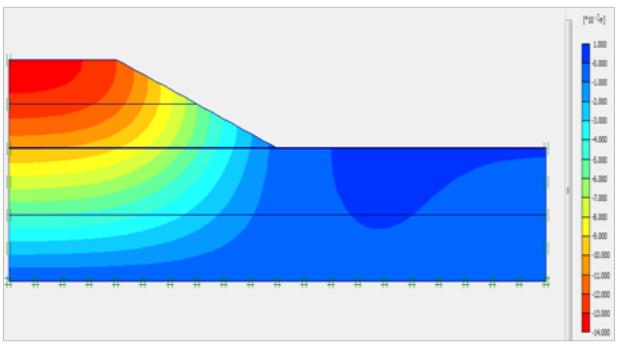

Figure 12 Vertical displacement at the end of pore pressure dissipation in embankment without MD+WTPS.

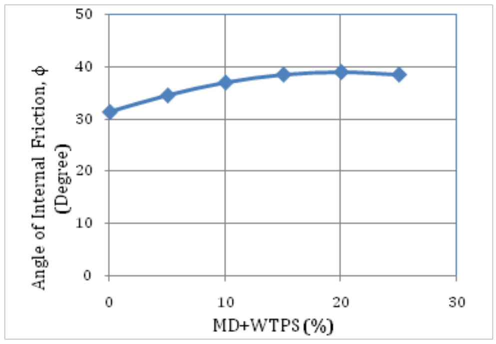

Figure 13 Variation of angle of internal friction with percentage of marble dust+water treatment plant sludge mixed in the soil.

Results and discussion

The shear strength parameters for the soil and for all the mixes have been plotted in Figures 14-16. It is observed that the angle of internal friction increases with percent of MD+WTPS upto 20% then decreases. Whereas, the cohesion decreases and the rate of decrement also decreases thus a constant value at large percentage of MD+WTPS.

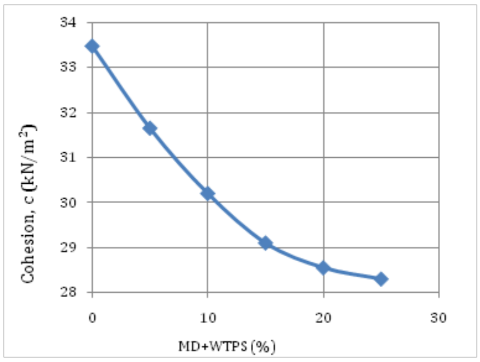

Figure 14 Variation of cohesion with percentage of marble dust+water treatment plant sludge mixed in the soil.

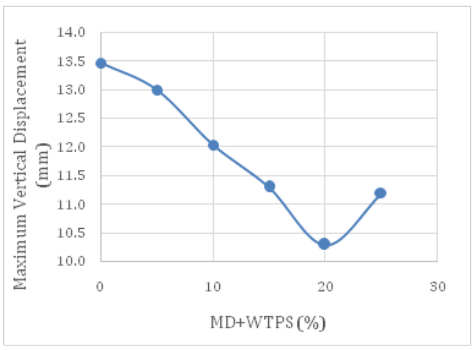

Figure 15 Maximum vertical displacement vs percent MD+WTPS.

Citation: Khanam S, Abbas S, Abbas SM. Environmental risk mitigation using optimal mix for road embankments of marble dust and WTP sludge with soil. *MOJ Civil Eng.* 2017;2(5):151–156. DOI: 10.15406/mojce.2017.02.00044

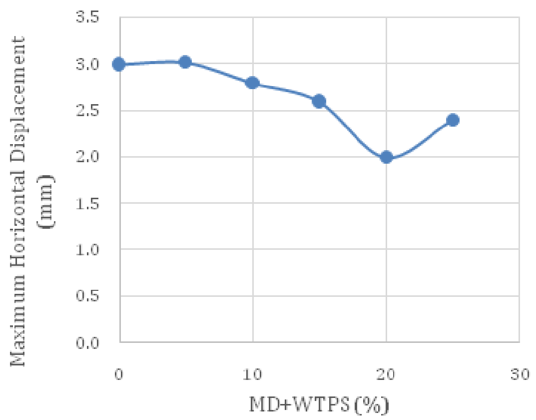

Figure 16 Maximum horizontal displacement vs percent MD+WTPS.

Conclusion

Environmental risk is proposed to be mitigated by using the hazardous waste materials, Marble Dust and WTP sludge, in the soil for the construction of road embankments. The locally available soil tested for shear strength parameters. The soil was also mixed with 5%, 10%, 15%, 20%, and 25% Marble Dust and WTP Sludge in 1:1 ratio and tested under direct shear test. The angle of internal friction was observed to be increasing with percentage of Marble Dust and WTP Sludge upto 20% then decreases.

By numerical modelling of the embankments made up of all these mixes using finite element based software PLAXIS, it is also found that at 20% of Marble Dust and WTP Sludge, the maximum vertical and horizontal displacement are the minimum. Based on these findings, an Optimal Mix for the road embankments has been achieved by mixing 20% Marble Dust and WTP sludge (in equal quantities) of the soil. Therefore, the present study gives three fold problem solution:

a. Environmental risk mitigation by successfully using the hazardous waste materials like marble dust and water treatment plant sludge in the construction of embankment mixed with the locally available soil.

b. By using optimal mix, 20% fertile soil, which is generally excavated along the proposed embankment, will be saved.

c. The optimal mix will give more stability to the embankment.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

References

1. Sumaiya Khanam. *Seismic Stability Analysis of Embankment Made up of Soil Mixed with WTP Sludge and Marble Dust*. New Delhi: Jamia Millia Islamia; 2014.
2. Singh TN, Singh SK, Mishra A, et al. Effect of acidic water on Physico–mechanical behaviour of Rock. *Indian J of Engineering and Materials Sciences*. 1999;6:66–72.
3. Qasim SR, Motely EM, Zhu G. *Water Works Engineering–Planning Design & Operation*. New Delhi: Prentice–Hall; 2006.
4. Çelik MY, Sabah E. Geological and Technical Characterization of Iscehisar (Afyon–Turkey) Marble Deposits and the Impact of Marble Waste to Environmental Pollution. *Journal of Environmental Management*. 2008;87:106–116.
5. Zorluer I, Usta M. *Stabilization of Soils by Waste Marble Dust*. Turkish 4th marble symposium. Afyon, Turkey; 2003. p. 305–311.
6. Oates JAH. *Lime and Limestone*. Germany: Wiley–VCH; 1998.
7. Almeida N, Branco F, Santos JR. Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures. *Building and Environment*. 2007;42:810–819.
8. Tegethoff FW. *Calcium Carbonate: From the Cretaceous Period into the 21st Century*. Switzerland: Birkahauser; 2001.
9. Sabat AK, Behera SN, Dash SK. *Effect of fly ash marble powder on the engineering properties of an expansive soil*. Proc of Indian Geotechnical Conference, Ahmedabad, India; 2005. p. 269–272.
10. Ronald DW, Donald IA. Incorporation of a water softening sludge into pozzolanic paving material. *J Am Wat Works Assoc*. 1977;69(3):175–185.
11. Raghu D, Hsieh H, Neilan T, et al. *Water treatment plant sludge as landfill liner*. Proc of speciality conference on Geotechnical practice for waste disposal. 1987.
12. Carvalho M, Antas A. *Drinking water sludge as a resource*. Proc of IWA specialised conference on management of residues emanating from water and wastewater treatment. Johannesburg, South Africa; 2005.
13. Sarkar Raju, Abbas SM, Shahu JT. Study of geotechnical behavior of pond ash mixed with marble dust. *International Journal of Advanced Technology in Civil Engineering, Interscience Journal*. 2012;1(2):67–71.
14. IS: 2720 (Part III/Sec 1). *Indian Standard on Methods of Test for Soils–Part III: Determination of specific Gravity*. Section–1: Fine Grained Soils. Bureau of Indian Standards Reaffirmed. 1980:2002.
15. IS: 2720 (Part IV). *Indian Standard on Methods of Test for Soils– Part IV: Grain Size Analysis*. Bureau of Indian Standards Reaffirmed. 1985:2006.
16. IS: 2720 (Part VIII). *Indian Standard on Methods of Test for Soils– Part VIII: Determination of Water Content–Dry Density Relation using Heavy Compaction*. Bureau of Indian Standards India, Reaffirmed. 1983:2006.
17. IS: 2720 (Part 13). *Indian Standard on Methods of Test for Soils– Part 13: Direct Shear Test*. Bureau of Indian Standards India, Reaffirmed. 1986:2006.