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Sand-Biosolids Mixture Characterization and Potential

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Abstract – Biosolid-sludge of sewage treatment plants was mixed with clean coarse sands to reduce soil permeability and assess the potential of utilizing such mix for several geotechnical applications. One of the applications was to develop a soil mix with low permeability for use in roadway embankments subjected to torrents from sudden heavy rain in desert areas. The main purpose was to address a sustainable and eco-friendly mix to be used as an additional protection to the current boulder lining for such embankments. In this study, biosolid sludge was mixed with medium dense sand using percentages equal to 0%, 5%, 10%, and 20% by weight of sand. The sludge was broken on sieve number 4" then a Proctor test was performed to determine the optimum moisture content to be used with all these mixes. Several other laboratory tests were conducted such as direct shear, unconfined compression and California bearing ratio to determine changes in the mechanical properties of the mixes. This in addition to the free swelling test to assess the tendency of volume expansion of these sand-biosolid mixes, as well as the constant head permeability test.

***Keywords*:** Biosolids, Sludge, Soil, Mix, Characterization, Permeability, Embankment.

1. Background

Biosolid result from sewage treatment plants is defined as sewage sludge that underwent treatment to reduce pathogens, odour and to inactivate heavy metals. The term was created in 1991 to differentiate between treated sewage sludge and raw sludge [1]. The undrained shear strength with water content relation was investigated for sludge by [2], whereas a linear relation between the logarithm of water content and the logarithm of remoulded undrained shear strength was developed. Geotechnical characterization conducted by [3] concluded that biosolids are classified as (OH) organic material with high plasticity with particle density substantially less than natural inorganic soil. [4] investigated a full mechanical characterization and optimum moisture content for biosolids for compaction purposes. [5] investigated the usage of biosolids as a fill material in road embankments, where their findings concluded that biosolids must be stabilized with an additive or blended with high-quality material to enhance the strength properties. Several research investigated adding various materials to biosolid to alter its behaviour, such as [6] who investigated stabilizer cement, [7] stabilised the biosolids with crushed bricks, [8] used fly ash, and [9] used cement-lime mixture. Other research discussed the long-term settlement link with biodegradation presented by [10] marking biosolids safe for long term usage. [11] conducted a study related to the aging process of biosolids and concluded that the angle of friction for biosolids increase and cohesion decreases with respect to time due to the decay of organic matter. Adding biosolids from sewer treatment plants to sand soil add more stability to sludge, meanwhile decrease sand permeability. Accordingly, this mix was used in roadway embankments, especially those subject to rare but sudden heavy rain in dry desert areas, as using that mix with low permeability can resist torrents with minimum added cost to typical soil. The overall factor of safety for slope stability increased with time [11]. Another approach for using biosolids is to improve side slopes of constructed embankments and reduce cracks developed due to erosion [12].

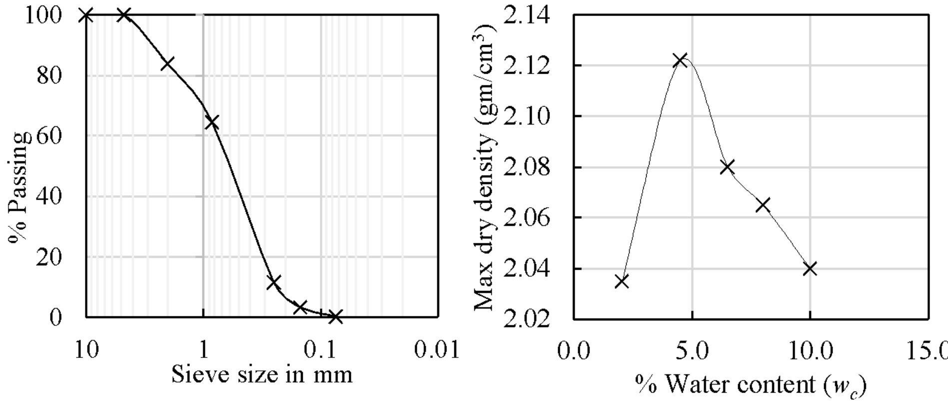
2. Experimental Procedures

Sand sample was collected from a desert area near Nile University at Giza governorate, Egypt. The collected sample was classified as SP (poorly graded sand) according to the unified soil classification system (USCS) Figure 1A represents the sieve results for the collected sample, while Figure 1B represents the compaction curve using modified proctor method.

The optimum moister content (OMC) was found to be 4.5% as presented in Figure 1B, and this ratio was used as default water content for all the sand-biosolid mixes used later in this study.

Sand-Biosolid, biosolid sample was obtained from “Bulaq El-Dakrur” wastewater treatment plant at Giza governorate, Egypt. The sample was odourless with black-brown colour with low density solid lumps, whereas large size lumps were mechanically broken down to pass sieve 4” (4.75 mm). The Sand-biosolid mix was prepared with three mixing percentages 0, 5, 10, 20% by weight. Sand and Biosolid are weighted dry and mixed thoroughly before adding water equivalent to the OMC of 4.5%. As presented later, other laboratory tests were carried out on the mixes to measure changes in geotechnical and hydrological properties with the change of biosolid content in sand.

Sieve No.	% pass
4	100
10	84
20	64
60	11
100	3
200	0
pan	0

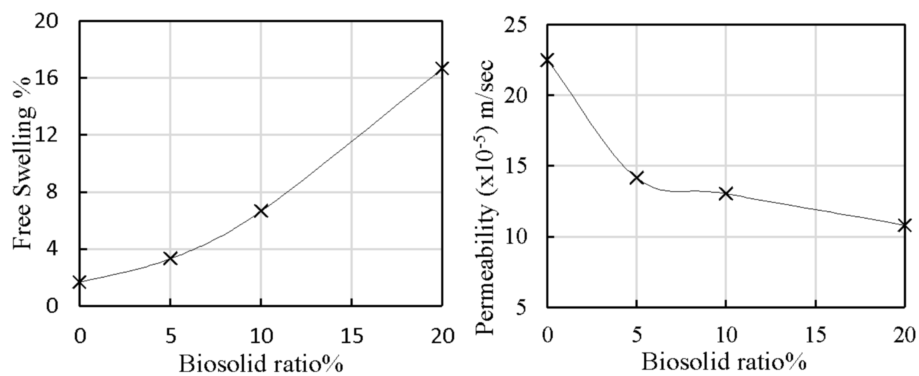


w_c	γ_d
2.0	2.04
4.5	2.12
6.5	2.08
8.0	2.07
10.0	2.04

Figure 1: (A) Sieve analysis for the sand sample, and (B) Modified Proctor test results and OMC.

Due to very high swelling potential of biosolid [4], free swelling test was first conducted on the four mixes. Figure 2A illustrates the change in free swelling tendency of each mix, and it was found that increasing the percentage of biosolids increased the free swelling to about 16.67%. To evaluate the hydraulic conductivity (or coefficient of permeability) of the mixes, the constant head test was conducted, where Figure 2B indicates a substantial decrease from $22.5x10^{-5}$ to $10.8x10^{-5}$ m/sec in the coefficient of permeability of the mixes by increase the percentage of the biosolid from 0 to 20%. This means that the permeability of the sand-biosolids mix decreased by about 52%.

Biosolid (%)	Free Swelling (%)
0	1.67
5	3.33
10	6.67
20	16.67



Biosolid (%)	Permeability (m/sec)
0	0.000225
5	0.00014167
10	0.00013056
20	0.00010833

Figure 2: (A) Free swilling test results, and (B) Permeability coefficient for sand-biosolid mixes.

To measure the potential of using sand-biosolid mixes for roadway embankment, the California Bearing Ratio (CBR) and direct shear tests were conducted. Figure 3A illustrates the change in the CBR values by using different biosolid ratios. A significant increase of 10% was achieved in the CBR at 20% biosolid. This means that biosolids have acted as fine materials inside the sand soil and filled the voids between particles and enhanced the penetration and density of the mix. On the other hand, direct shear test determined the effect of using biosolids on the shear strength parameters of sand, Figure 3B shows minor changes in cohesion values and angel of internal friction by using different biosolids ratios, whereas Table 1 presents the exact values.

Table 1: Shear strength parameters of different sand-biosolid mixes.

Biosolids content	Cohesion	Internal friction angle
0%	5.91 kPa	33.16º
5%	5.53 kPa	32.09º
10%	7.45 kPa	38.91º
20%	9.3 kPa	25.38º

Biosolid (%)	CBR
0	2.4
5	8
10	10
20	11.6

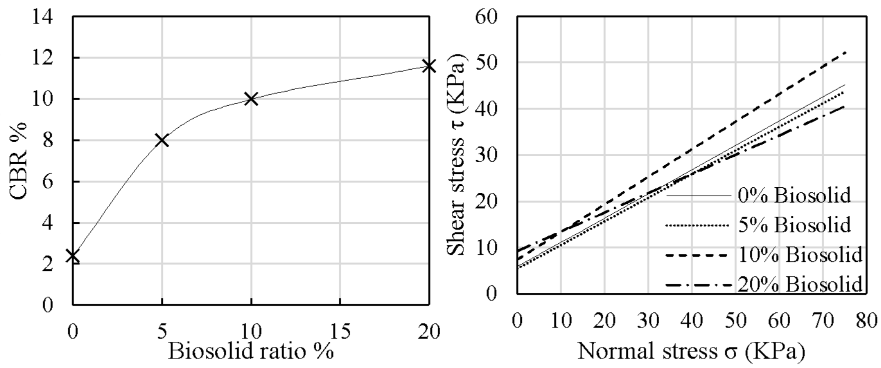


Figure 3: (A) CBR results for sand-biosolid mixes, and (B) Direct shear test results

Potential for roadway embankment fill. Roadways constructed in arid areas, elevated form natural ground levels, are subjected to the threat of torrents following sudden heavy rain called flash floods [13] [14]. The usual protection for these road embankments is done using stone pitching or sloped plain concrete slab-grade elements. During the presence of high hydraulic gradients, caused by retaining large quantities of water behind one side of the roadway embankment, water seeps through cracks in pitching or expansion joints between plain concrete elements. This seepage causes internal erosion [15]. Subsequently this internal erosion causes instability in the soil matrix [16]. Fines transmitted form one region of soil to another cause progressive soil erosion [17] furthering the risk of collapse and/or excessive settlement of the embankment.

The initial content of fines represents a key role in the stability of the soil mass. The sudden removal of fines due to internal erosion leads to large deformation and instability in the soil embankments. It is worth noting that soils with more fines content exceeding 20% exhibited weaker behaviour when uneroded compared to soils with less than 20% fines [18]. This means that a limited content of fines in cohesionless soils can yield more internal stability espeically for gap graded granural soils such as natrual desert sand soils.

Figure 4 presents an envision for the use of a sand-biosolid zone as a core inside a typical sand fill for a roadway embankment. The decreased permeability of the mix would prolong the sudden transformation of fines from the soil underneath the roadway outwards, leading to a reduction in the exit hydraulic gradient and enhancement in the safety factor of the side slopes. Also, the decreased permeability would slowdown the progressive internal erosion of the soil.

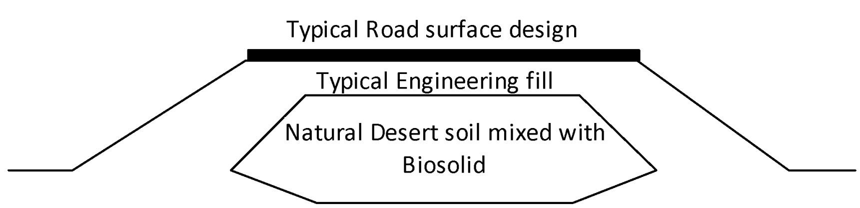


Figure 4: The proposed configuration for an embankment with sand-biosolid core.

3. Discussion and Conclusion

Biosolids proved to an efficient and eco-friendly additive for the improvement of cohesionless soils used in geotechnical applications related to reduced permeability. Desert sand soils was selected herein, mixed with various percentages of biosolid sludge coming from water treatment plants. Mechanical properties of these mixes were measured via a series of laboratory tests, and it was found that adding biosolids to the soil did not significantly affect the shear strength properties and swelling tendency. However, a noticeable reduction in the coefficient of permeability by about 52% and increase in the CBR by 10% was clear after adding biosolids with percentage equal to 20% by weight. In case of using sand-biosolid mix inside a soil mass subject to water flow, the reduced permeability can decrease the velocity of flow inside that mass. This also reduces the displacement of fines in the soil matrix, leading to a lower risk of piping. When the hydraulic gradient is prolonged and not mitigated in time, the fines transported within the soil mass should transfer to regions that require larger exit hydraulic gradient. Accordingly, inclusion of sand-biosolid core in roadway embankments subject to flash floods in arid areas can be proposed, one that needs further investigation to measure the actual benefits and limitations.

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References

[1] Q. Lu, Z. L. He and P. J. Stoffella, “Land Application of Biosolids in the USA: A Review,” *Applied and Environmental Soil Science,* vol. 2012, pp. 1-11, 2012.

[2] B. C. O'Kelly, “Undrained shear strength–water content relationship for sewage sludge,” *Proceedings of the Institution of Civil Engineers - Geotechnical Engineering,* vol. 166, no. 6, pp. 576-588, 2013.

[3] V. Suthagaran, A. Arulrajah and M. W. Bo, “Geotechnical laboratory testing of biosolids,” *International Journal of Geotechnical Engineering,* vol. 4, no. 3, pp. 407-415, 2010.

[4] B. C. O'Kelly, N. K. Oettle and J. A. Ramos, “Geotechnical properties of compacted biosolids for monofill design, As-Samra, Jordan,” *Environmental geotechnics,* pp. 1-31, 2018.

[5] A. Arulrajah, M. M. Disfani, V. Suthagaran and M. W. Bo, “Laboratory Evaluation of the Geotechnical Characteristics of Wastewater Biosolids in Road Embankments,” *Journal of Materials in Civil Engineering,* vol. 25, no. 11, pp. 1682-1691, 2013.

[6] V. Suthagaran, A. Arulrajah, J. Lamborn and J. L. Wilson, “Geotechnical testing to determine the suitability of biosolids for embankment fill,” *Biosolids Speciality Conference IV, Adelaide, South Australia, Australia, 11-12 June 2008,* 2008.

[7] D. Wanigaratne and L. Udamulla, “Mechanically and chemically stabilized bio-solids as embankment fill material,” *,* 2013.

[8] M. M. Disfani, A. Arulrajah, F. Maghoolpilehrood, M. W. Bo and G. A. Narsilio, “Geotechnical characteristics of stabilised aged biosolids,” *Environmental geotechnics,* vol. 2, no. 5, pp. 269-279, 2015.

[9] F. Maghoolpilehrood, M. M. Disfani and A. Arulrajah, “Geotechnical characteristics of aged biosolids stabilized with cement and lime,” *Australian Geomechanics Journal,* vol. 48, no. 3, p. 113, 2013.

[10] M. M. Disfani, A. Arulrajah, V. Suthagaran and M. W. Bo, “Long-term settlement prediction for wastewater biosolids in road embankments,” *Resources Conservation and Recycling,* vol. 77, no. 77, pp. 69-77, 2013.

[11] K. Pinapati, “Variation Of Geotechnical Strength Properties With Age Of Landfills Accepting Biosolids,” *,* 2006.

[12] A. J. Puppala, R. Williammee, N. Intharasombat and S. Qasim, “Research Pays Off: Treatment of Soils with Compost to Mitigate Pavement Cracking: Texas Tests and Applies Stabilization Method,” *TR News,* no. 252, 2007.

[13] W. M. M. Elssadek, M. G. Ibrahim and W. E. Mahmod, “Flash Flood Risk Estimation of Wadi Qena Watershed, Egypt Using GIS Based Morphometric Analysis,” *Applied Environmental Research,* vol. 40, no. 1, pp. 36-45, 2018.

[14] M. M. Taha, S. M. Elbarbary, D. M. Naguib and I. El-Shamy, “Flash flood hazard zonation based on basin morphometry using remote sensing and GIS techniques: A case study of Wadi Qena basin, Eastern Desert, Egypt,” *Remote Sensing Applications: Society and Environment,* vol. 8, pp. 157-167, 2017.

[15] I. Johnston, W. Murphy and J. Holden, “A review of floodwater impacts on the stability of transportation embankments,” *Earth-Science Reviews,* vol. 215, p. 103553, 2021.

[16] D. S. Chang and L. M. Zhang, “Extended internal stability criteria for soils under seepage,” *Soils and Foundations,* vol. 53, no. 4, pp. 569-583, 2013.

[17] A. Mehdizadeh, M. M. Disfani, R. Evans and A. Arulrajah, “Progressive Internal Erosion in a Gap-Graded Internally Unstable Soil: Mechanical and Geometrical Effects,” *International Journal of Geomechanics,* vol. 18, no. 3, p. 4017160, 2018.

[18] M. Ouyang and A. Takahashi, “Influence of initial fines content on fabric of soils subjected to internal erosion,” *Canadian Geotechnical Journal,* vol. 53, no. 2, pp. 299-313, 2016.