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GEOTECHNICAL AND STRUCTURAL MODULATION FOR STRENGTH AND ADSORPTION ENHANCEMENT OF URBAN SEWAGE SLUDGE

Sewage sludge (SS) is the semi-solid slurry obtained as a byproduct in wastewater treatment plant. It is rich in nutrients and harmful compounds such as metals, nano particles, antibiotics, pharmaceutical products, pathogenic bacteria and viruses. Presence of such life-threatening and environmental polluting substance demands efficient management of SS. In the past, different techniques have been explored for the management of SS, such as pyrolysis-gasification, combustion, landfill, incineration and wet oxidation. These techniques are efficient; however, it is not viable for a developing nation like India due to resource constraints. Also, the composition of SS produced in India is dynamic, which further result in additional problems. Unlike developed nations, we do not have a proper lined system, which makes the quality and quantity of SS highly unpredictable. The lack of lined drain arrangement leads to a significant amount of sediment content in wastewater, generating vast amounts of SS. Present thesis work put an effort on developing a green sustainable engineered way to address the management issue of harmful SS towards a cleaner environment. For the study, SS was gathered from the primary settling tank of Jaspur sewage treatment plant, Ahmedabad (India)

on June 2018. SS was consisted of 68% silt and 27% clay. Liquid limit (LL) and plastic limit (PL) was 52% and 24%. Based on the obtained geotechnical parameters SS was classified as CH (Highly compressible) type. Upon testing for the critical geotechnical property such as differential free swell index (DFSI), it was observed that SS exhibited expansive behaviour. Change in volume and swell pressure was obtained as 47% and 57 kPa. Volume change behaviour was due to the presence of the expansive mineral montmorillonite. Swell shrink behaviour of SS added another engineering challenge, to use it effectively. To check the applicability of expansive SS for civil geotechnical purpose, SS was treated with lime (CaO). For the study five different SS samples were constituted using 0, 2, 4, 6, and 8% of lime by weight of the SS and cured for 7, 14, and 28 d. Stability of the lime-modified SS was evaluated through the determination of geotechnical, microstructural, and mineralogical properties. A significant improvement in unconfined compressive strength (UCS) from 207 to 1102 kPa was achieved after 28 d of curing SS with 6% lime. Improvement in UCS was due to formation of cementing compounds as a result of pozzolanic reaction.

Marked reductions in swell pressure of 47, 51, 54, and 58% was obtained with 2, 4, 6, and 8% lime treatment. Also, plasticity index decreased with surge in lime percentage for different curing periods, indicating SS has become much more workable and less expansive. Scanning electron microscopy (SEM), X-ray diffraction (XRD), Thermogravimetric analysis (TGA), and Fourier transform infrared spectroscopy (FTIR) after lime treatment confirmed generation of new compounds, responsible for the improved engineering properties of SS. It was concluded that lime treatment can be an efficient alternative to stabilize SS for potential use as a construction material, for subbase of flexible pavement as per IRC (Indian Road Congress) 37-2012 guidelines. Applicability of SS for civil engineering purpose was further extended by utilizing it as a source material for bricks. One of the motive behind the study, apart from addressing the disposal and management of SS, was to conserve the natural arable soil. In India, the pure

alluvial soil is generally utilized as a source material of brick, which affects the crop yield; and exploitation of natural alluvial soil and sands causes immense environmental degradation. In the present work, SS was amended with fly ash (FA) as an admixture, FA was obtained from Gandhinagar thermal power plant (India). Upon geotechnical testing, it was found that FA contains 17%, 82%, 1% of sand, silt and clay fraction type particles and classified as MI (silt of intermediate compressibility) type. LL and PL was reported as 44 and 0%. For the study, FA composition was varied from 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% in the SS+FA mixture. The study was conducted to understand the dimensional and firing temperature effect on the mechanical properties of synthesized bricks. For exploring the dimensional effect, two extreme size of brick D1 (2x2x2 cm^3) and D2 (7x7x7 cm^3) was considered and compared with each other. The study found that for all FA combinations, the D1 sample demonstrated higher strength than D2. The increase in load-carrying capacity of smaller sample might be because of the formation of triangle wedges, which was not observed in the case of D2 sample. In order to understand the effect of firing temperature on the mechanical properties of bricks, three different firing temperature i.e., 900, 1000 and 1100°C was selected for the present study.

Study revealed that the maximum strength was demonstrated by the 1100°C fired brick sample, which was due to densification effect achieved by vitrification. It was concluded that the strength exhibited by 1000°C and 1100°C fulfills the requirement for civil engineering construction work as per IS standards (IS 13757:1997 Reaffirmed 2007). Whereas for 900°C, the strength obtained was below the codal provision. Towards the end, research work investigated the potential of utilizing SS as a source material for synthesizing magnetized geopolymer nano adsorbent for removing Arsenic (As) from the aqueous solution. As SS is rich in alumina and silica due to presence of 27% clay fractions, it was proposed to carry out the synthesis of magnetized geopolymer by utilizing SS. The batch experiment was conducted at different initial concentration of As(V) i.e. 10, 20, 30, 40, 50, 70

and 100 ppb for a contact time 15, 30, 45, 60, 75, 90, 120 and 180 min. It was observed that maximum sorption capacity of magnetized geopolymer towards As(V) (51.6 ± 3.97 μg g^{-1}) was obtained at near neutral pH (~6.0). Increasing the initial As(V) concentrations from 10 to 100 μg L^{-1}, the sorption efficiency also surged from 4.37 to 27.0 μg g^{-1}. Adsorption of As(V) onto magnetized geopolymer followed pseudo–second–order ($R^2 \geq 0.95$) and Freundlich ($R^2 \geq 0.98$) kinetic and isotherm models, respectively. Competition studies supported field–scale applicability of the present waste material (SS) converted into a porous, low-cost magnetic geopolymer for removing metalloid As.

Overall, the major highlights of the present thesis work can be summarized as:

I. 6% lime treatment improved strength, swelling and plasticity characteristics of SS. Also, the treated SS was suitable for subbase pavement construction.
II. Dimensional effect and firing temperature had a significant influence on compressive strength of bricks. It was found that the 1100°C fired bricks confirms to Indian standards provision for construction purpose.
III. SS can be utilized for synthesizing geopolymer. Maximum sorption by magnetized geopolymer occurred at near neutral pH (~6). Adsorption of As(V) followed Freundlich ($R^2 \geq 0.98$) isotherm and Pseudo–second–order ($R^2 \geq 0.95$) model.

The present study was carried on SS collected from one treatment plant; it is suggested to conduct studies on samples from different locations. As the composition of SS will vary depending upon the catchment area, season, and monitoring period. The research work demonstrates various framework for successfully utilizing SS to address its management issues. Also, the multidisciplinary utilization of SS demonstrated in the present study as a potential resource will enable researchers to dive deeper and perform comparisons with the present state of art.