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Performance Evaluation of Zinc Tailing Waste Material for Embankment Construction: Experimental and Numerical Investigation

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Abstract

The rapid development of road networks needs huge construction materials. Mining and industrial wastes can be used as sustainable road construction materials and will be alternatives to fulfill the huge demand in road construction. Zinc tailing is one such mining waste and has the potential for road construction. This material was collected from Zawar mines (Rajasthan), and characterization was carried out for embankment/subgrade applications. A physical model test was conducted in the laboratory to examine the stress-settlement behavior. To improve the modulus value of tailing, it was reinforced with geogrid in two different laying patterns, viz. layer/loop and stress-settlement behavior was studied. Different parameters were studied: reinforcement depth, layer of reinforcement, number of loops, and depth of loop of reinforcement. The experimental result was validated with the numerical finite element method (SoilWorks). Tailing comprises fine-grained silt-size particles (61%) with no swelling behavior and non-plastic nature. It has values of MDD and OMC as 1.86 g/cm3 and 11%, respectively. It has a higher value of CBR (12%) and internal friction angle (34.6o) with cohesionless nature. The variation of settlement with stress is linear for reinforced and unreinforced tailing fill. As the depth of reinforcement increases, settlement increases in both layer and loop reinforcement. The settlement trajectory obtained from a numerical method closely resembles that of a laboratory physical model, particularly when the applied stress is up to 600 kPa. The modulus of elasticity of tailing was significantly improved with the introduction of geogrid reinforcement either in layer or loop.

1. Introduction

The development of road infrastructure stands as a cornerstone in the progress of a nation [1-3]. Over the past decade, India has seen a remarkable expansion of its road network, extending its reach to every corner of the country. The construction of different classes of roads, such as national highways, district roads, and village roads, necessitates materials of varying quality. Material requirements are substantial and heavily reliant on the availability of raw natural resources. It has been observed that road with low traffic volume requires less robust construction material, which can often be met with locally available waste materials [4-5]. These materials encompass fine-grained particles of the original ores and chemicals used in the extraction of valuable metals. In India, several industries generate substantial amounts of industrial waste, including zinc tailing, steel slag, jarosite, jarofix, red mud, zinc slag, coal ash, lead slag, and copper slag. The evaluation of the suitability of such materials is a critical undertaking for researchers and practitioners. Utilizing mine waste as construction material must meet several criteria. First and foremost, they must demonstrate their safety in terms of both engineering and environmental aspects. Various

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types of waste materials have been proposed and employed in diverse construction applications, including road construction [6- 13]. For instance, Kehagia [14] emphasized the usefulness of bauxite tailing waste for road embankment construction. Similarly, Mahmood and Mulligan [15] characterized different copper tailings that may be used to build the sub-base for pavements. In a similar vein, Fang et al. [16] promoted the utilization of copper tailing material in the manufacturing of sand-lime brick. Collins and Miller [17] have noted the potential for repurposing discarded material from mining and mineral processing industries in building and construction. Similarly, Ahmed and Lovell [18] have explored the use of discarded materials derived from mining industries for road construction purposes. Kanalli et al. [19] examined the potential of utilizing mine waste as a stabilizing agent for black cotton soil. Mining waste was investigated for potential uses, and it was discovered that it might be used as a construction material [20-22]. The efficient use of mine residue for road construction can significantly benefit the environment by reducing waste volume and providing a sustainable source of building material [23]. A study conducted by Russell [24] highlights the significance of applying critical state soil mechanics and finite element analysis to gain insights into how embankments behave under various conditions. Zhuang and Li [25] highlight the advantages of FEM in assessing lateral displacements caused by embankments and conclude that FEM software enables a thorough investigation of this phenomenon. The Study conducted by Sreekantan et al. [26] affirms that FEM modeling facilitates a detailed assessment of embankment behavior.

According to a 2019 report [27] from Hindustan Zinc Ltd., Zawar Mines in Rajasthan, India, annually produces approximately 3 million tons of zinc tailing. Zinc ore undergoes various stages of processing to yield different products. Initially, it is extracted in the shape of lumps of varying dimensions.These lumps are then crushed to a size smaller than 150mm through a process called primary crushing. Subsequently, secondary and tertiary crushers further crush it to less than 10 mm in size. These stages of beneficiation result in two distinct products at zinc mines. The first product is known as zinc concentrate, containing approximately 55% zinc metal, and it is sent to zinc smelters for further purification [28]. The second product is commonly referred to as 'Tailing,' which is essentially waste material. The tailing, now a slurry after being diluted with water (50%-65%), flows into a disposal pond [29] (Figure1). Currently, this waste tailing material is being employed in the backfilling of underground mines, and the leftover tailing is dumped into a tailing dam near the beneficiation plant, which occupies valuable land [30] About 66% of the zinc tailings are used to fill in the mines, while the rest portion being held in tailing dams [31, 32]. In the present study, an effort has been made to evaluate the suitableness of zinc tailing as an embankment and subgrade material for road construction. To improve the modulus of elasticity of tailing, geogrid reinforcement was introduced in layers or loops. The experimental result was validated with numerical analysis and presented in the paper.

Figure 1. Pictorial view of the tailing dam at Hindustan Zinc Ltd., Zawar, Rajasthan.

2. Material and Method

2.1. Geotechnical characterization of zinc tailing

The geotechnical characteristics of the collected zinc tailing waste sample have been studied. Grain size analysis was carried out by sieve analysis and sedimentation analysis by hydrometer [33]. Figure 2 illustrates the grain size distribution curve of the tailing sample. The majority of the particles are fine grained silt size, and their composition consists of 31% sand, 61% silt, and 8% clay-sized particles. The particle has an average diameter (d_{50}) of around 0.06 mm. The coefficient of uniformity and coefficient of curvature have been observed to be 40 and 3.5, respectively. On the zinc tailing, testing for both the liquid limit (LL) and plastic limit (PL) was performed [34]. The liquid limit has been measured to be 25%. For the plasticity limit test, a 3 mm thread size was tried to prepare but could not be prepared. This showed that tailing is non-plastic in nature. As per Indian standard classification [35], zinc tailing has been categorized as ML, which stands for inorganic silt with low compressibility based on LL, PL and grain size.

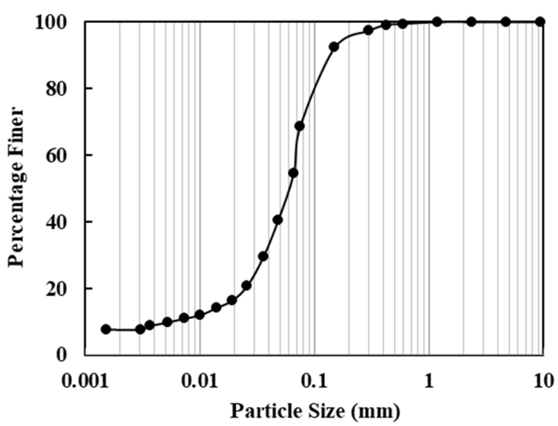

Figure 2. Grain size distribution curve.

It was observed from the free swelling index test [36] that the material has non-swelling characteristics (FSI = 0). The moisture content of the tailing material is investigated [37] and observed to be 12%, which shows that the collected sample was in a moist state. The specific gravity of the sample has been evaluated and found to be 2.71 [38]. The higher value of specific gravity shows that tailing contains some heavy mineral composition viz. zinc, iron, alumina etc. To examine the suitability of zinc tailing refuse in road construction, different tests such as Proctor compaction test, California bearing ratio test (CBR), permeability test, and direct shear test have been conducted. Figure 3 shows the results obtained from the modified Proctor compression test along with zero air void line. The optimal moisture content of tailing was found to be 11%, while maximum dry density (MDD) was observed to be 1.86 g/cm^3. The CBR test has been performed as per Indian standards [39]. Samples of the CBR test were prepared by compressing it at 97% of maximum dry density with optimum moisture content. The prepared sample was soaked in potable water for 4 days. The average soaked CBR was determined to be 12%. This CBR value of tailing is comparable to that of conventional silty soil, which has about CBR values of 8-12%. The variable head permeability testing has been performed [40]. Unconfined compressive strength (UCS) test was carried out as per Indian standard [41]. The sample of size 50 mm x 100 mm has been prepared and sheared at a rate of 1.25 mm/min [42]. The average UCS and strain at failure were obtained as 660 kPa and 1.74%, respectively. This indicates that tailing has a low compressive strength in unconfined conditions. The stress-strain curve is linear up to the failure stress, indicating the elastic behavior of the material till peak stress. The modulus of elasticity (E) was evaluated as 38000 kPa. The coefficient of permeability (k) has been observed to be 7 x 10^{-7} m/sec. The measured permeability value of the tailing material suggests that it possesses favorable drainage characteristics and may be suitable for use as an embankment fill or subgrade material. Other researchers have also reported similar characteristics regarding the feasibility of zinc tailing for embankment construction [43, 44]. The compression index, which was observed to be 0.03 from the consolidation test, indicated that the material is not readily compressed. The loss of ignition test has also been performed to evaluate the amount of organic volatile matter in a sample which can include moisture, carbonaceous material, and other volatile components. The loss on ignition of the tailings was assessed by subjecting them to heating at 950°C as per the IS [45] respectively. The average value of loss on ignition was calculated as 1.8%. This indicates that tailing material had only trace levels of volatile organic compounds and carbonate minerals. The direct shear test has been performed to evaluate the strength parameters of the zinc tailing waste material [46]. A mould of size 6 cm x 6 cm x 2.5 cm was used to prepare the sample. The tailing sample was compressed at 97% maximum dry density and optimum moisture content.

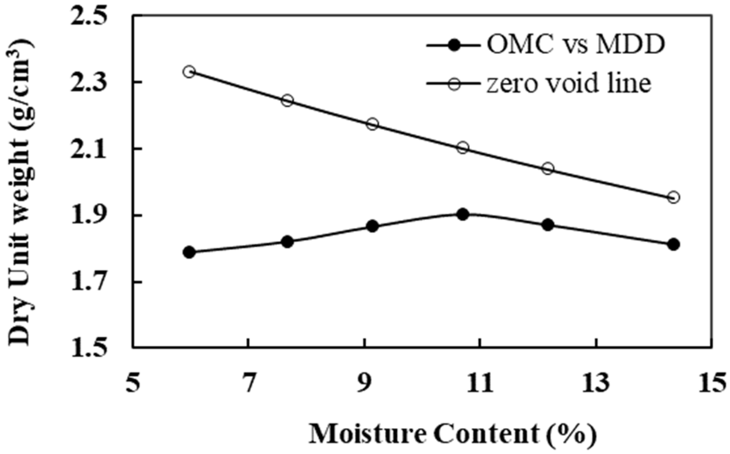

Figure 3. Relationship between dry density and moisture content.

The mould size was taken considering the largest particle size of tailing (< 1 mm). The sample was saturated for 24 hours, and drained test was carried out at a slow rate (0.025 mm/minute), which allowed the water to dissipate during the test. Figure 4 shows the variation of shear stress with normal stress. The angle of internal friction of the sample has been found to be 34.6^o, and there was no value of cohesion. The high angle of internal friction of the tailing shows that it can be used for embankment fill applications. Table 1 shows the summary of the geotechnical properties of tailing.

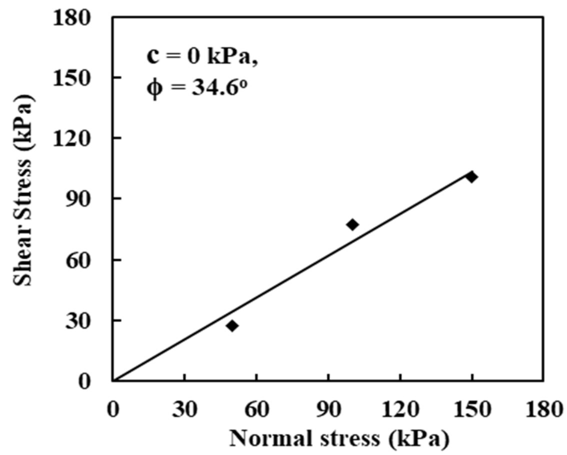

Figure 4. Variation of shear stress with normal stress.

Table 1. Summary of geotechnical properties of zinc tailing

Properties	Value
Coefficient of Uniformity	40
Coefficient of curvature	3.50
Specific gravity	2.71
Maximum dry density, g/cm^3	1.86
Optimum moisture content, %	11
Liquid Limit, %	25
Plastic Limit, %	Non plastic
Classification of soil	ML
CBR, %	12
Compression index	0.03
Cohesion, kPa	0
internal friction, degree	34.6
Permeability, m/s	**1.73 10^{-7}**

2.2. Characterization of geogrid reinforcement

Biaxial geogrid was procured from the authorized agency, New Delhi. Different tests on geogrid were carried out, namely tensile strength, rib length, thickness, aperture size and wide width. The tensile strength of the geogrid was studied at the Geotechnical Engineering Laboratory, Indian Institute of Technology Delhi. The longitudinal rib was measured as 4.60 mm in girth, while the transverse rib was measured as 3.86 mm. The tensile strength test of a single rib has been conducted in accordance with ASTM D6637 [47]. Using the constant rate of extension testing device, a single, typical geogrid rib sample was clamped and put under a tensile force. The amount of tensile force needed to cause the specimen to fail (rupture) was noted. The final single rib tensile strength (kN) was then calculated by averaging the results of six separate tests. The rate of testing was applied as 25 mm/min. The maximum load and stress were recorded as 1.1 kN and 122 N/mm^2, respectively. The Average thickness of geogrid was obtained as 3 mm. The average junction thickness was measured as 3.86 mm by using a screw gauge. The selected geogrid had an average aperture size of 31 x 31 mm in both directions, as measured with the digital caliper. The wide-width test has also been performed as per ASTM D 4595 [48]. Figure 5 (a-d) shows the step-by-step procedure for sample preparation and testing of geogrid in the laboratory for wide-width tests. Figure 6 shows the variation of force with respect to displacement from the wide-width strip test. Force increased as displacement increased and reached 9000 N, corresponding to 35 mm displacement.

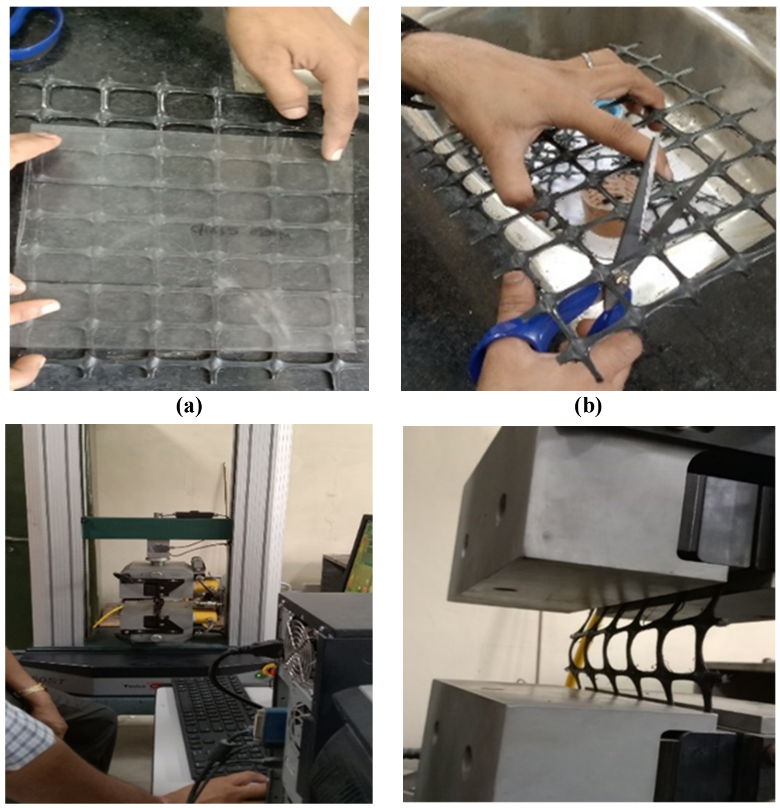
(a) (b) (c) (d)

Figure 5. Geogrid testing: a) Measuring of geogrid for desired dimension, b) Cutting of geogrid as per desired dimension, c) Test setup and d) Geogrid after testing.

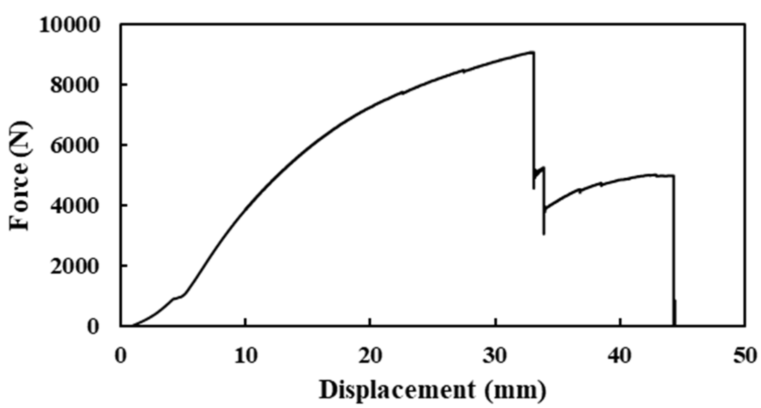

Figure 6. Variation of force with displacement.

After that, the force decreased suddenly and reached 3000 N at the same displacement of 35 mm. Again a slight increase in force was observed and again decreased to zero at 44 mm displacement. This indicates that the failure of geogrid is ductile in nature.

3. Strength and Deformation Behavior of Zinc Tailing

To examine the strength and deformation behaviour of zinc tailing, a laboratory physical model tank was fabricated, and tailing was filled up in the tank. To improve the strength, geogrid reinforcement was introduced in different layers, tests were carried out, and stress-settlement behaviour was studied.

3.1. Experimental Set-Up

The model testing tank of dimensions 1000 mm x 1000 mm x 750 mm was used in the present study. The dimension of the tank was suitably selected to diminish the boundary effects. Figure 7 shows the experiment test setup for the laboratory physical model. The load was applied through a 166 mm square and 18 mm thick steel plate model footing [44]. To prevent the model tank from yielding laterally during tailing compaction in the tank and while applying stress at the model footing, steel angle sections were welded at the top, bottom, and centre of the tank. All four tank walls were composed of 20 mm thick acrylic panels, and the interior walls were smoothed to minimize friction.

3.2. Sample preparation

3.2.1. Tailing without reinforcement

Before laying the tailing material in the model tank, some preparations were done like smoothing the vertical wall of the tank with the help of grease so that there is no friction resistance. The optimal moisture percentage for mixing tailing with water was determined to be (OMC = 11 ± 1%). This tank was to be filled up to 60 cm. The process of tamping becomes simplified by gradually adding layers, allowing for the density to be monitored and verified using a core cutter (Figure 8). By maintaining the desired density over the entire height, the compaction thickness of each layer was set at 20 cm. Aiming for a density of 95% of MDD for preparation of tailing specimens, based on the compaction energy of heavy Proctor tests, 2700 kJ/m^3, free fall of the fabricated hammer, and count of hits/strikes were set according to the number of attempts. The multiple trials denoted ± 1% variation in the required density. A number of attempts/trials of study consistently denoted that in order to achieve a compacted layer of desired density measuring 20 cm, it is necessary to distribute an uncompacted layer measuring 25-26 cm within the tank. This process was conducted using heavy Proctor energy. This density was maintained throughout the study. Following the compaction process, the upper layer of the compacted tailing was subsequently leveled. The levelled tailing waste was permitted to rest for 24 hours in order to attain moisture equilibrium. Additionally, the upper surface of the material was consistently shielded with damp jute bags to prevent any loss of moisture. The line diagram is shown in Figure 9.

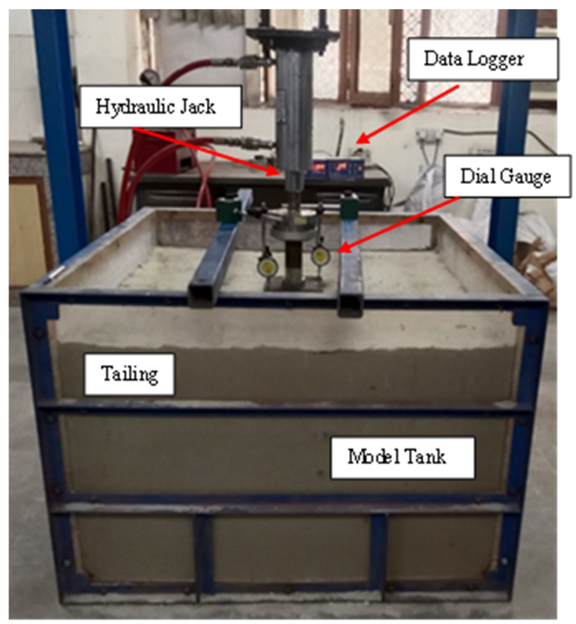

Figure 7. Experimental set up for physical model test

Figure8. Density check by core cutter

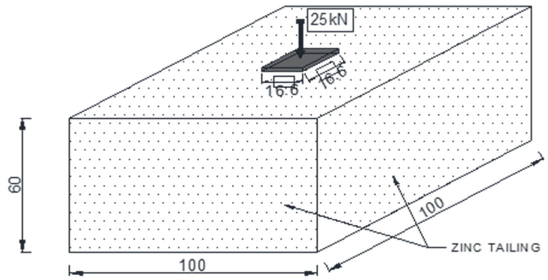

Figure9. Line diagram of tailing filled model tank

3.2.2. Tailing with reinforcement in layers

Tailing was reinforced with single and double layers of geogrid at different depths. The compaction for reinforced tailing follows the same process as discussed in the previous section, where each layer is compacted to a thickness of 20 cm. This compaction process was continued until the desired height of the first layer of reinforcement was reached. In order to fit in the tank, the required size of geogrid reinforcement was spread over the compacted tailing surface (Figure 10). This was kept as 8 cm (Figure 11) from the top of the model fill or 52 cm from the bottom of the tank. Tailing waste was then filled and compacted at OMC above the reinforcement. This filling and compaction process was continued until the desired height of the tank was reached (60 cm).

Figure10. tailing and reinforcement in the model tank

Similarly, a single layer of reinforcement was placed at 12 cm and 30 cm from the top of the model tank. For double-layer reinforcements, a similar process was followed, and reinforcement was applied at 20 cm and 40 cm from the bottom of the tank. The line diagram for single and double-layer reinforcement is shown in Figure 11.

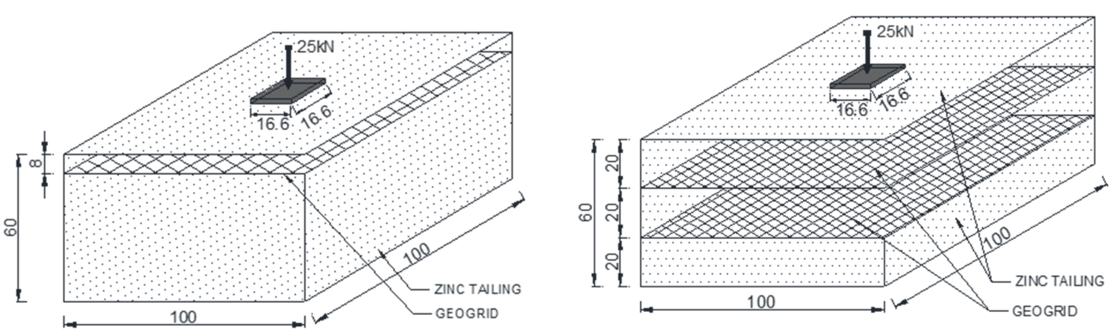

Figure11. Line diagram of tailing filled model tank with reinforcement (a) single (b) double layers

3.2.3. Tailing with reinforcement in loops

Tailing was reinforced with single and double loops of geogrid at different depths. The process of reinforcing tailing involves the ongoing filling and compaction of tailing material in layers that are 28 cm from the bottom of the tank until reaching the height of the very first loop of reinforcement. The line diagram of the single reinforced loop is shown in Figure 12. After 28 cm of compacted tailing fill, reinforcement was laid, as shown in Figure 13. Then, tailing was filled and compacted for 5 mm thickness. Then, reinforcement was made rounded or loop and then tailing was filled and compacted. Then, the remaining model tank was filled up and compacted at 95% degree of compaction with a total thickness of 60 cm. Similarly, for the double-layer reinforcement system, two loops of reinforcement were placed at 16 cm and 38 cm from the bottom of the tank. The loop of geogrid prevented the lateral movement of tailing under vertical stresses by sandwiching the tailing layer between the geogrid layers. Special attention was given during looping to ensure that the compaction is proper, and that the geogrid is not damaged during the compaction process.

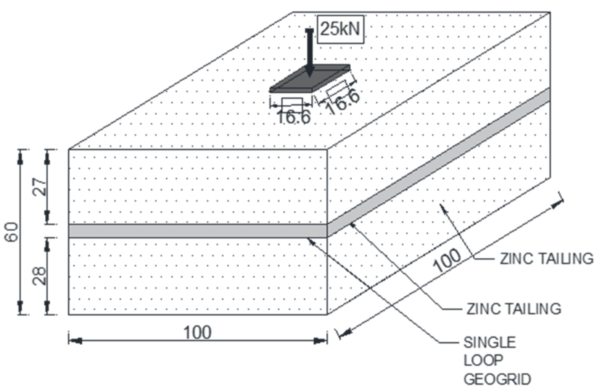

Figure12. Line diagram of single loop reinforcement


Figure13. Filling of tailing over spread loop reinforcement in model tank

3.3. Method of Testing

After 24 hrs, a double-acting hydraulic jack was used to apply force through a 166 mm square plate. With the aid of a loading frame, the load was transferred to the plate. The load cell was attached to the data logger in order to measure the load. Dial gauges (02) placed diagonally at the plate's corners allowed us to monitor its average settlement. At a constant rate ranging from 0.5kN to 31.5kN, the load was imparted to the tailing surface. Each load increment was followed until the settlement ceased at 0.02 mm/min. For each loading, stress corresponding to the settlement was recorded. Considering the capacity of the loading frame, a maximum of 800 kPa stress was applied. This is the limitation of the experiment.

3.4. Interpretation of result of laboratory model test

The failure stresses for both unreinforced and reinforced tailing material were determined for different depths of reinforcement and loops. In the case of reinforced fill, different parameters were considered for the determination of failure stress, namely reinforcement depth, number of layers of reinforcement (N), number of loops, and depth of loop of reinforcement.

3.4.1. Load-settlement behavior

Stress variation in relation to plate settlement for unreinforced tailing fill and single layer reinforced at different depths (D = 0, 30, 12, 8 cm) is shown in Figure 14, while the variation of stress with respect to the settlement of plate for unreinforced and number of reinforced tailing fill (N = 0, 1, 2) is shown in Figure 15. Similarly, variation of stress with respect to the settlement of plate for unreinforced and number of reinforced loops tailing fill (L = 0, 1, 2) is shown in Figure 16.

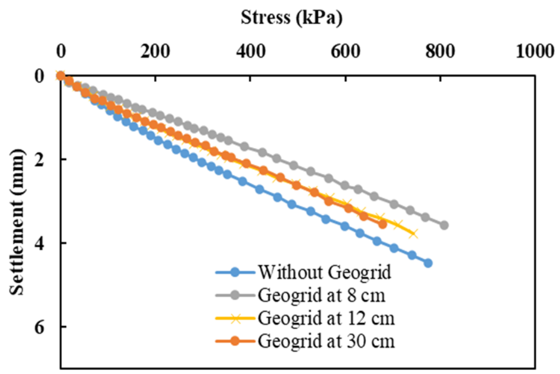

Figure 14. Variation of settlement with stress

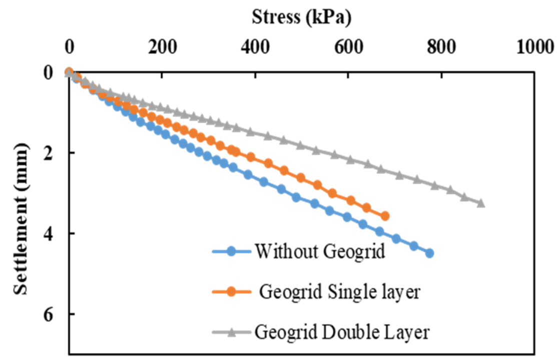

Figure 15. Variation of settlement with stress

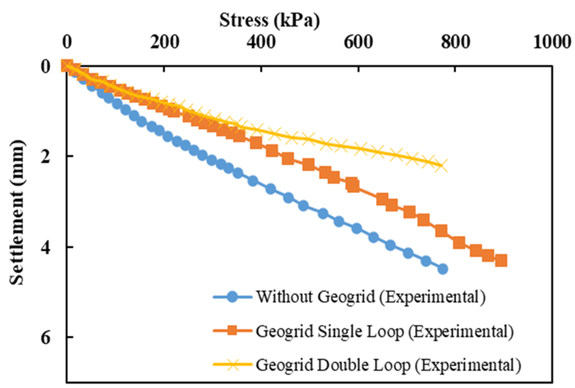

Figure16. Variation of settlement with stress

In both reinforced and unreinforced tailing fills, the relationship between settlement and stress variation was linear. The settlement significantly reduces with the embedding of reinforcement. This indicates that load-bearing capacity improves with the reinforcement of soil using geogrid.

3.4.2. Effect of depth of reinforcement/loop

As the depth of reinforcement increases, settlement increases in both cases, either layer reinforcement or loop reinforcement. The minimum settlement was obtained for the depth of reinforcement at 8 cm in the case of one-layer reinforcement. It was noticed that the geogrid placed at a depth of 8 cm was more effective than the geogrid placed at 12 cm and 30 cm, respectively. This is due to the fact that the geogrid placed at 8 cm provides a higher reinforcing effect since it is the nearest as compared to others, which is in the influence zone of the loaded plate kept at the surface. The reinforcement effect of the geogrids decreases with increasing the distance from the influence zone of the loaded plate. The results show the reinforcement response of geogrids in improving the bearing capacity of the waste material. The values of settlement (Δ) of the plate (plate width, b =166 mm) in the model's test corresponding to the applied traffic stress (577 kPa or 8.17 ton) were observed to be 2.75 mm and 3.75 mm for geogrid reinforced fill at 8 cm depth and without geogrid, respectively. Accordingly, the moduli of elasticity (E_{mod}) were obtained by using the following expression.

$$E_{mod} = 1.18\ (pb/\Delta) = 1.18\times577\times16.6/3.75 = 3.01\text{ MPa (without geogrid)} \quad (1)$$

$$E_{mod} = 1.18\ (pb/\Delta) = 1.18\times577\times16.6/2.75 = 4.11\text{ MPa (geogrid at 8 cm depth)} \quad (2)$$

This indicates that there is about a 27% reduction in settlement, when reinforcement is used in the single layer at 8cm depth as compared to the case without geogrid. In this case, a 36% increment in the modulus of elasticity is also observed in comparison to the case without geogrid. It was also observed that stiffness or modulus or settlement is insensitive if reinforcement varies from 12 cm to 30 cm depth in a single layer. The application of reinforcement improves the modulus of tailing, and as a result thickness of the pavement will be reduced. However, the modulus value obtained from equation 1 (3.01 MPa) is significantly low in comparison to the value obtained from the UCS test (38 MPa). This may be due to the differences in the loading condition as in the case of the former, modulus was calculated at 577 kPa, while in the case of the latter, loading was applied up to failure.

3.4.3. Number of reinforcement and its effect/loop

As the number of geogrid layers increases, settlement decreases in both cases of layer reinforcement or loop reinforcement. The minimum settlement was obtained for two layers of reinforcement or two loops of reinforcement. This indicates that bearing capacity increases with increasing the number of geogrid layers or loops. It was noticed that settlement decreases as the total number of reinforcements increases in the tailing compacted fill. The average settlement of tailings was measured as 3.75mm without the use of geogrid and 2.05m with two layers of geogrid. These measurements were taken under a traffic loading of 8.17 t and a tyre contact pressure of 577 kPa. The moduli of elasticity were determined and discussed below.

$$E_{mod} = 1.18\ (pb/\Delta) = 1.18\times577\times16.6/2.05 = 5.51\text{ MPa (two layers of geogrid)} \quad (3)$$

This indicates that there is about a 46% reduction in the settlement, which increases the modulus of elasticity by about 83% if two layers of geogrid reinforcement are used in comparison to without geogrid. It was also observed that stiffness/settlement/modulus are significantly improved from single-layer reinforcement to double-layer reinforcement. This may be due to the full mobilization of stress in between tailing and geogrid.

4. Validation of Experimental Model Result by Numerical Model Analysis

The analysis of the numerical model was conducted using SoilWorks software. The results of the load test in the present study have been validated using finite element software. The validation will be useful in developing the numerical, which will be useful to perform a wide range of parametric analyses in further studies. Table 2 shows the material properties of the zinc tailing waste material and the biaxial geogrid.

The model was discretized into fine mesh using uniformly sized 0.02 m quadrilateral elements. The horizontal displacement of the side plate was prevented by providing appropriate boundary conditions. The loading was applied by stepwise equivalent point load via a plate under plain strain conditions. The mechanical responses of the tailing waste material were simulated by the Mohr-Coulomb model. A non-linear static analysis was conducted, taking into account factors such as geometry, materials, loading and boundary conditions. The effect of applied vertical stress extended to a measurement of 2B (0.33) from the upper surface of the tailing waste.

Table 2. Material Property used in numerical modelling.

Zinc Tailing		Geogrid Reinforcement	
Property	**Value**	**Property**	**Value**
Constitutive Model	Mohr-Coulomb	Modulus of Elasticity (E)	0.39 kN/mm^2
Modulus of Elasticity (E)	38000 kN/m^2	Poisson's ratio	0.25
Poisson's ratio	0.30	Unit Weight	0.0046 kN/m^2
Unit Weight	1.86 g/cm^3 ≈ 18.6 kN/m^3	Temperature Coeff.	5.5 x 10^{-6}
Saturated Unit weight	20 kN/m^2	Thickness, mm	3.86
Cohesion (C)	0.5 kN/m^2	Aperture size, mm	31×31
Internal Friction Angle (ϕ)	34.6^o ≈ 35^o		
Earth Pressure Coeff (K_o)	0.44		
Temperature Coeff.	1 x10^{-6}		

In the case of an applied stress of 600 kPa, the stress-settlement curve extracted from the numerical model is comparable to that obtained from experimental modelling (Figures 17-19). At a stress of 577 kPa (8.17 T), the numerical and physical models of unreinforced tailing showed settlements of 2.00 mm and 3.75 mm, respectively. Figure 18 shows the comparison of experimental and numerical results with the application of single and double layers of geogrids. Figure 19 shows the comparison with single and double-loop placement of geogrids in the prepared bed. It was observed that the placement of geogrid in loop material is more effective in improving the performance. The placement of geogrid material in a loop pattern requires a higher amount of geogrid and consequently increases the cost. In the field, a judicial decision is to be taken by the authorities on the placement of different patterns of the geogrid (layer or loop wise) depending upon the requirement at the site.

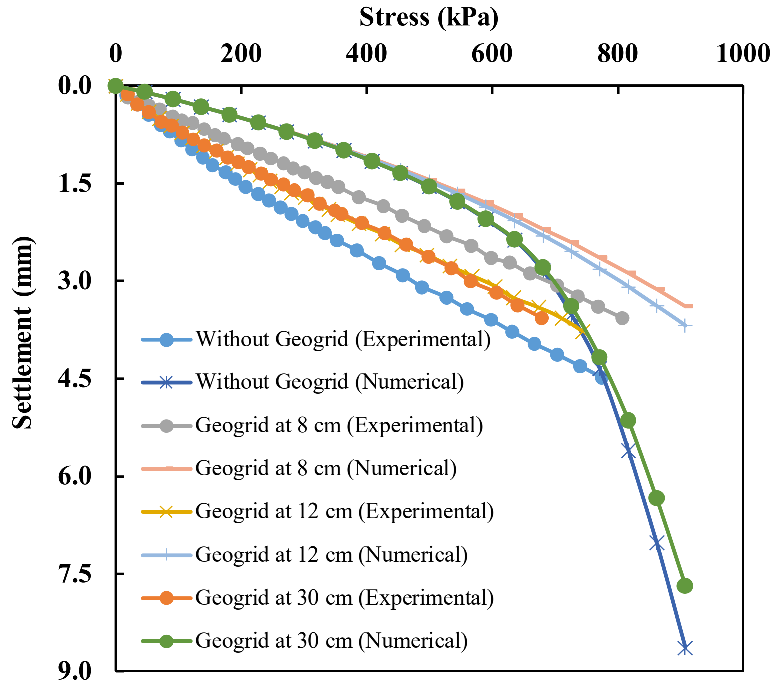

Figure 17. Comparision of numerical and experimental results with and without geogrid.

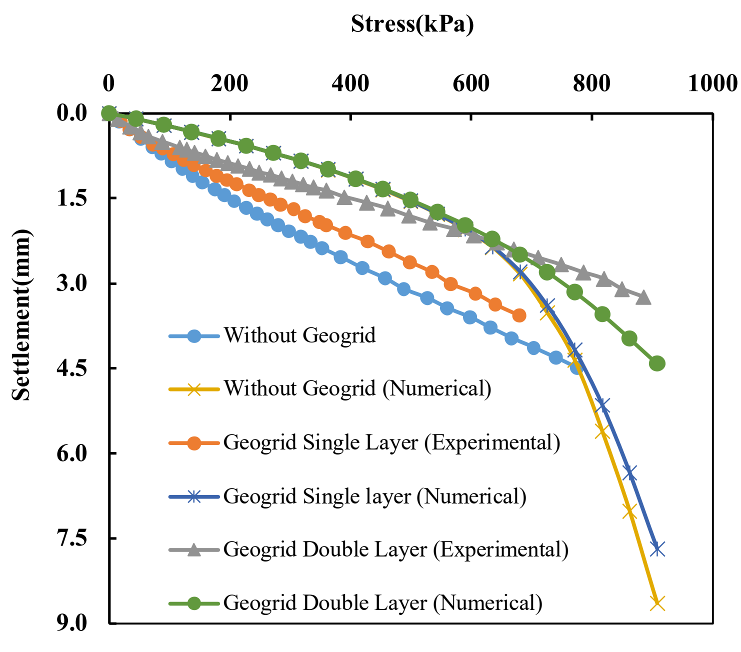

Figure 18. Comparision of numerical and experimental results with or without layers of geogrid

5. Conclusions

Tailing was collected from Zawar mines, Rajasthan, and a study was carried out for the application in embankment and subgrade construction. Following are the brief conclusions.

i. The moisture content of the tailing material is close to its OMC. Hence, there is no need for extra water for compaction at the site. Specific gravity is a little bit higher than the similar particle size of silty soil due to mineral composition. It is composed of fine-grained silt particles (61%) with no swelling behavior and non-plastic nature. It has values of MDD and OMC as 1.86 g/cm^3 and 11%, respectively, which make it suitable for embankment and subgrade construction. It has a high CBR value (12%). The internal friction angle is about 34.6° and cohesion is zero in saturated conditions. High friction value makes it suitable for embankment construction, but precautions should be taken regarding erosion of slope.

ii. The maximum tensile stress of geogrid was recorded as 122 N/mm^2. The average geogrid thickness was found to be 3 mm, and the average geogrid aperture size was found to be 31 mm x 31 mm in both directions.

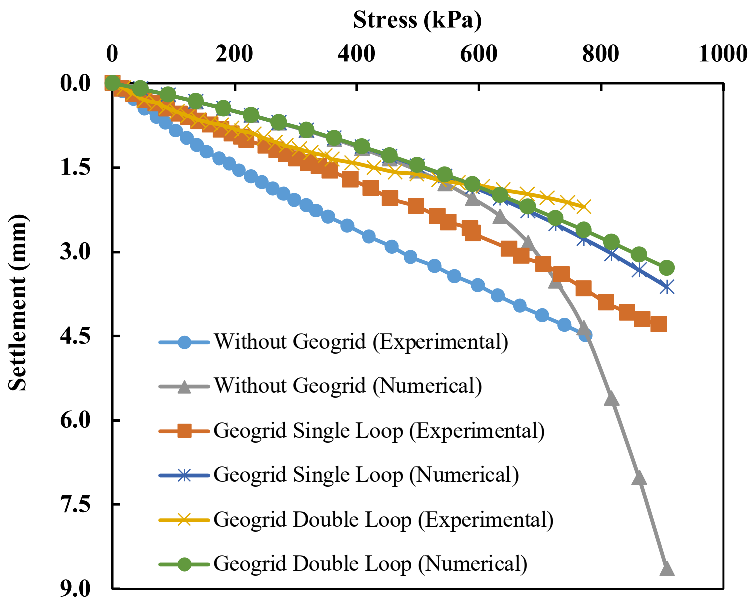

Figure 19. Comparision of numerical and experimental results with or without loop layers of geogrid

iii. The variation of settlement with stress is linear for reinforced and unreinforced tailing fill. As the depth of reinforcement increases, settlement increases in both cases, either layer reinforcement or loop reinforcement. The minimum settlement was obtained when a single-layer reinforcement was provided at a depth of 8 cm. The minimum settlement was obtained for double layers of reinforcement or double-loop of reinforcement. The settlement trajectory obtained from a numerical method closely resembles that of laboratory physical modelling, particularly when the applied stress is up to 600 kPa.

iv. The modulus of elasticity of tailing was significantly improved with the introduction of geogrid reinforcement in both cases, either layer reinforcement or loop reinforcement. This will increase the modulus of resilience or stiffness of tailing as a subgrade material, which will lead to a reduction in the total pavement thickness. However, the limited number of load tests only gives an idea about the suitability of zinc mine tailing for embankment/subgrade construction. A detailed investigation is desired to develop design guidelines for its application on a large scale.

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ارزیابی عملکرد ضایعات باطله روی برای ساخت خاکریز: بررسی تجربی و عددی

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چکیده:

توسعه سریع شبکه‌های جاده‌ای به مصالح ساختمانی عظیم نیاز دارد. پسماندهای معدنی و صنعتی می‌توانند به عنوان مصالح راهسازی پایدار مورد استفاده قرار گیرند و جایگزینی برای برآوردن تقاضای عظیم در ساخت و ساز جاده خواهند بود. باطله روی یکی از این ضایعات معدنی است و پتانسیل راهسازی را دارد. این مواد از معادن زوار (راجستان) جمع‌آوری شد و مشخص‌سازی برای کاربردهای خاکریزی/زیرگرم انجام شد. آزمایش مدل فیزیکی در آزمایشگاه برای بررسی رفتار تسویه استرس انجام شد. برای بهبود مقدار مدول باطله، آن را با ژئوگرید در دو الگوی تخمگذار مختلف تقویت کردند، یعنی. رفتار لایه/حلقه و تنش-ته‌نشینی مورد مطالعه قرار گرفت. پارامترهای مختلف مورد مطالعه قرار گرفتند: عمق آرماتور، لایه آرماتور، تعداد حلقه‌ها و عمق حلقه تقویت‌کننده. نتایج تجربی با روش اجزای محدود عددی (SoilWorks) تایید شد. باطله شامل ذرات ریز دانه به اندازه سیلت (۶۱٪) بدون رفتار تورم و ماهیت غیر پلاستیکی است. مقادیر MDD و OMC به ترتیب ۱.۸۶ گرم بر سانتی متر مکعب و ۱۱ درصد است. دارای مقدار CBR (۱۲٪) و زاویه اصطکاک داخلی (۳۴.۶°) با طبیعت بدون چسبندگی است. تغییر نشست با تنش برای پر کردن باطله تقویت شده و غیر مسلح خطی است. با افزایش عمق آرماتور، نشست هم در تقویت لایه و هم در تقویت حلقه افزایش می‌یابد. مسیر نشست به‌دست‌آمده از یک روش عددی بسیار شبیه به یک مدل فیزیکی آزمایشگاهی است، به‌ویژه زمانی که تنش اعمال شده تا ۶۰۰ کیلو پاسکال باشد. مدول الاستیسیته باطله به طور قابل توجهی با معرفی تقویت کننده ژئوگرید در لایه یا حلقه بهبود یافت.

کلمات کلیدی: باطله روی، مواد زائد، ژئوگرید، خاکریز، آنالیز عددی.