Jarofix Waste Material in Embankment Construction

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***Abstract*: Due to the large-scale road infrastructural development in India, conventional soil is depleting very fast while different industries are producing a huge amount of waste materials as by-products. Utilization of such waste materials leads to sustainable road construction. Jarofix is one of the waste materials generated during the extraction of zinc from its ore. At present, the accumulated jarofix is about 35 lakh tons, while the annual production is about 6 lakh tons in India. Detailed R & D study was carried out to study the feasibility of jarofix in the construction of embankment. Jarofix sample was collected from Chittorgarh, Rajasthan and its geotechnical characteristics were investigated. Design and slope stability analysis of jarofix embankment of varying heights and slopes was carried out to decide its practical applicability in the field construction. The factor of safety was determined by numerical analysis under different water conditions, viz. partially saturation, steady flow, sudden draw down with, and without seismic factor. Results of variation of factor of safety with height, saturation, and slope are presented. Multiple linear regression analysis was carried out to evaluate the effect of different design parameters on the factor of safety of the embankment. A typical settlement analysis of jarofix embankment is also presented in this study. It is concluded that jarofix waste material has a good potential for construction of embankment.**

***Keywords*: Jarofix, Waste Material, Embankment, Construction**

Introduction

India is a major zinc producer country in the world. Indian zinc industry consists of primarily two private industries, namely Hindustan Zinc Limited (HZL), Rajasthan and Binani Zinc Ltd., Ernakulam, Kerala. Hindustan Zinc has a market share of 60% of total zinc production. Hindustan Zinc Ltd. operates zinc smelters at Chanderiya (Rajasthan) by hydro-process has annual capacity of 3 lakh ton; Debari (Rajasthan) has a hydro-process with an annual capacity of 1 lakh ton; the Binani zinc smelter limited operates by hydro-process and has annual capacity of 0.3 lakh ton at Ernakulum (Kerala). This industry has approximately 4.3% share in the total zinc smelter capacity in the Asia Pacific region.

Zinc ores are extracted from zinc mines. The lumpy (rocky) ores are crushed and grounded into particles of size smaller than 0.1 mm. By flotation process, zinc concentrate ores are prepared which has zinc content of 40–60%. During the extraction of zinc from its ore by hydro-process, jarosite waste material is produced as a by-product. It is mixed with 2% lime and 10% cement, to make a stable material which is called jarofix. At present, the accumulated jarofix is about 35 million tons, while the annual production is about 6 million tons in India (Sinha et al. 2012). The typical jarofix mound at Chittorgarh, Rajasthan. It is occupying about 100 acres of costly land near the plant. Different researchers advocated that this material has potential for road construction (Pappu et al. 2006; Sinha et al. 2012; Arora et al. 2013).

In the present study, jarofix was collected from Hindustan zinc limited, Chittorgarh and local soil from nearby area. Geotechnical characterization of both materials was carried out in the laboratory. Based on geotechnical characteristics, stability analysis of jarofix and jarofix-soil embankments of varying height (1–10 m) and slopes (19°–45° or 1V:3H to 1V:1H) was carried out to decide its practical applicability in the field construction. The factor of safety was determined by numerical analysis under different water conditions, viz. partially saturation, steady flow, sudden draw down with and without seismic factor. The effect of different water conditions on stability of jarofix embankment has been discussed. Variation of factor of safety with height, saturation, and slope is presented. Multiple linear regression analysis was carried out to evaluate the effect of different parameters, viz. height, slope and jarofix content on the factor of safety of the embankment.

Literature Review

Chen and Dutrizac (2000) stabilized jarosite material with Portland cement for safe disposal. Seyer et al. (2001) studied the mineralogical behavior of jarosite mixed with lime/Portland cement which resulted in stabilized mix.

Demers and Haile (2003) advocated that cured/aged jarofix is easy to excavate, compact and is chemically stable. It makes an excellent fill material.

Vsevolod et al. (2005) stabilized the jarosite waste material with small percentage of cement/lime and concluded that the stabilized mix has potential for use in base and sub-bases of road, airfields and dams, manufacturing of tiles and bricks, etc.

Reddy et al. (2011) studied the geotechnical characteristics of jarosite waste and concluded that it is suitable for the utilization as a landfill material. In India at present, jarofix has no application and is dumped haphazardly on the costly land available near the plant.

Pappu et al. (2004, 2006) studied the utilisation potential of jarosite waste to utilise as a building material. It was concluded that jarosite as an additive with fine grained materials like clay and can reduce its shrinkage potential and improves the quality of building materials.

Anil K. Sinha et al (2018): Cement-stabilised jarofix material can effectively reduce the thickness of subbase and base layers of a flexible pavement approximately by 20%, and lead to economical and sustainable road construction. The stiffness and failure stress of the jarofix-soil embankment were found to be higher than those of the jarofix embankment alone.

Objectives

Followings are the objectives and scopes of work.

1. Physical, chemical and geotechnical characterization of jarofix and soil.
2. Geotechnical characterization of mechanically and chemically stabilised jarofix.
3. Slope stability analysis of jarofix and jarofix-soil mixes embankment.
4. Laboratory jarofix embankment model study with and without reinforcement.
5. Construction and evaluation of field jarofix embankment.
6. Performance monitoring study of jarofix and jarofix-soil mixes embankment.

Methodology

Jarofix material was collected from Hindustan Zinc Limited, Chanderia, and Rajasthan. Physical, chemical and geotechnical characteristics were evaluated as per Indian standard procedures. To study the improvement in the strength characteristic, mechanical and chemical stabilization of jarofix were studied by using additives as soil and cement respectively. Mechanical stabilization technique was adopted by blending with locally available soil in the proportion 1:3. The feasibility of chemical stabilization was also studied by blending cement in the proportion 1:3. Slope stability analysis of the jarofix embankment with varying slopes and height was analysed under traffic/surcharge loading with different saturation and seismic conditions.

Strength and deformation behaviour of jarofix and jarofix-soil mixes (1:1) were studied in the laboratory by small scale laboratory embankment physical model.

The behaviour was also investigated by introducing geogrid reinforcement into the model at varying depth and number of layers.

An experimental test track was constructed at Chittaurgarh, Rajasthan and the strength- deformation behaviour was studied during actual construction. Different field tests that were carried out include; field dry density test, dynamic cone penetration test to evaluate CBR and plate load test to evaluate the stress – deformation behaviour of jarofix/jarofix-soil mixes. To investigate the possibility of underground water pollution, Toxicity characteristics leaching procedure test was carried out of leachate samples collected under the jarofix embankment and analysed for heavy metals. Comparison of cost of construction was also estimated using jarofix and soil as embankment materials for a typical cross section.

Performance of jarofix embankment was monitored by collecting different data viz. deflection, roughness and settlement values over a period of 2 years. The rebound deflection data were recorded by using Benkelman beam equipment. The surface roughness observations were recorded by using dipstick. The surface level of pillars installed at different chainages was monitored to estimate the settlement of embankment. Apart from these observations, the total surface settlement was observed by taking auto level observations in a grid pattern on the top of road surface.

Table 1 - Physical, Chemical and Leachate Characteristics of Jarofix

Physical Properties

Specific	2.4
Gravity pH	9.08%
Loss on Ignition	7.94%
Moisture Content	37

Chemical Composition (%)

CaO	8.02
SiO_2	8.09
Al_2O_3	5.29
Fe_2O_3	36.75
SO_3	31.25
MgO	0.3
Na_2O	3.06
Insoluble Residue	3.91

Leachate Concentrations of Various Inorganic Parameters (mg/kg) *

	Chloride	Fluoride	Sulphate	Phosphate	Nitrate
Jarofix	318	4	38065	73.9	127
Regulatory Limit (HWM, 2008)	5000	5000	50000	20000	20000

Leachate Concentrations of Various Heavy Metals (mg/kg) *

	Zn	Pb	Cd	Ni	Co	Mn	Fe	Cr	Cu
Jarofix	2614	247	38.14	1.9	0.03	417	3.4	ND	50
Permissible Limit (HWM, 2008)	20000	5000	50	5000	5000	NS	NS	5000	5000

NEERI Report (2010), ND – Not Detected, NS – Not Specified, HWM- Hazardous Waste Material Rule 2008

Test Performed
1. Grain size analysis
2. Atterberg limit test
3. Free swelling index test
4. Specific gravity test (G)
5. Proctor compaction test
6. California Bearing Ratio (CBR) Test
7. Unconfined compressive strength test
8. Direct shear test
9. Consolidation test

Conclusion
Slope stability analysis of jarofix embankment was carried out with different heights ranging from 1 to 10 m under different water saturation and seismic conditions. The safe height and slope of the embankment was evaluated by numerical analysis. The effect of slope, height and water saturation on factor of safety has been determined.

Results of stability analysis of jarofix embankment with varying thickness of cement stabilised jarofix cover was also studied. Conclusions from the experimental investigations are as following:
1. Jarofix embankment in general is stable up to the height of 2 m for all considered slope, water saturation condition and seismic factor. Factor of safety decreases with increase in the height of embankment for a particular slope and seismic condition. Considering the target factor of safety of 1.25, jarofix and their mixes are stable upto the height of 5 m for slope of 1V:3H under all the considered conditions.
2. Factor of safety marginally increases with increase in content of jarofix in jarofix-soil mixes under specific saturation and seismic condition. It drastically reduces from partially saturation condition to sudden draw down condition. Factor of safety decreases with increase in the slope of embankment under different saturation and seismic conditions. The rate of decrease of factor of safety is more for increase of slope from 3H: 1V to 2H: 1V than from 2H: 1V to 1H: 1V. It is also concluded that jarofix and jarofix-soil embankment of different heights with slope 1H: 1V are in general, unstable under different saturation and seismic conditions.
3. Factor of safety of unprotected slope increased from 0.89 to 1.47 for 3m thick cement stabilized jarofix cover. It is concluded that cement stabilization of slopes is very useful especially during construction of high embankments with a steep slope. This type of cross section may be used where space (less) and height (more) are major constraint for the construction of embankment.
4. Multiple linear regression analysis indicated that factor of safety values of jarofix-soil embankment under different saturation conditions depend on height, slope and jarofix content. FOS value is more affected by the height of the embankment in the case of sudden draw down condition while slope of the embankment is dominant factor in the case of partially saturated and steady seepage flow conditions. However, jarofix content is the least affecting factor.

Scope of Further Research
Further studies required to be carried out on some of the following areas.
1. Characterisation of jarofix from different plants in the country may be investigated to know the extent of variation of engineering properties of jarofix. Chemical composition of jarofix may be varied with different ores and process of production.
2. Strength and deformation behaviour of jarofix model embankment under different saturation condisions viz. sudden draw down and steady seepage flow, needs to be studied in the laboratory.
3. Full scale model study will give more reliable stress-strain behaviour of this material. Experimental study shall also be validated with numerical analysis. The results shall be compared with centrifuge model test.

4. The effect of more reinforcement layers (N > 2) on failure stress on the jarofix model embankment should be studied. This needs to be optimised with number of reinforced layers and vertical spacings.
5. The effect of stress level and density in both laboratory and prototype model needs to be studied on failure stress - strain behaviour.

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