A comparative study of slope stability analysis of Manganese slag stabilized soil to an ordinary soil

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Abstract. Slopes are required in the construction of Highways, Railways, Earthen dams, canal banks, levees and at many other locations. The construction of embankment over the ground is not possible in a vertical way. The Soil can be piled up with slope only. The cost of earthwork is minimum if the slopes are steepest but the Steeper slopes are not safe as per stability conditions because it may fail in shear. The only force acting on the piled earth is gravity force. This gravitational force produces shear in the soil and causes slippage. The failure lead to loss of property and life. There is a lesser chance of slippage of soil if we provide more bottom width compared to its top width. But it requires more area and more earth to fill. So, it is uneconomical.

In the present study, the soil was collected from the highway extension project, from the geotechnical investigation it was identified that the soil shear strength was quite low. To improve shear characteristics and to decrease the dry density of soil, it is to be stabilized with a lightweight material, possessing good frictional characteristics. A waste by-product was identified from the industry of nearest village called Manganese (Mn) slag. The soil was stabilized with various percentages of Mn slag, from the geotechnical characterization, an optimum % of slag is selected as 10 %. An embankment slope is assumed for further slope stability analysis. The analysis is carried out on two slopes, one is made with ordinary soil and the other is soil stabilized with optimum Mn slag %. Both stabilized soil embankment and ordinary soil embankment are analysed by using the Method of slices and the final results were compared.

Keywords: Red soil, Manganese slag, Embankments, shear characteristics, Slope stability analysis;

1. Introduction
An earth slope is an unsupported, inclined surface of a soil mass. The cost of earthwork would be minimum if the slopes are made steepest. However, very steep slopes may not be stable. A compromise has to be made between economy and safety, and the slopes provided are neither too steep nor too flat. In other words, the steepest slopes which are stable and safe should be provided. In this regard, to provide safe slopes, the soil shear characteristics has to be improved. The addition of frictional material will increase the angle of internal friction of stabilized material.

In this study the analysis of embankment slopes is carried out for two types of soils, one is with unstabilized soil which is directly collected from the site and the other is soil stabilized with a waste by-product called Manganese (Mn) slag. In these two cases, the Factor of safety is calculated by analysis method ‘Method of slices. The factor of safety is the ratio of Resisting moment (M_R) to Overturning
moment (M₀). These two moments are depending on shear parameters of the material – Cohesion (c) and Angle of internal Friction (ϕ). By increasing the angle of internal friction of soil, the resisting moment has to be increased and also by decreasing specific gravity of stabilized material the Overturning moment will be decreased. Therefore, if the soil is stabilized with a frictional material which is light in weight, the factor of safety could be increased. So that the chances of failure of the slope are minimized.

In this regard, a Waste material is identified in a nearby village called Mn slag, which is a by-product of Iron ore melting, observed at “FERRO ALLOYS CORPORATION” in Garividi village near Vizianagaram.

For the analysis, the soil used was collected at the site area of highway extension project of Vizianagaram. The single lane of NH 43 is extending as a two-lane road. The project includes several embankments at various heights.

Many researchers studied the effect of the addition of slag material to different soils, and many studies are described various methods of slope stability analysis. Ibrahim M Asi et. al. (2017) studied the effect of the addition of steel slag in the stabilization of expansive clay. In their conclusions, they stated that the addition slag will decrease plasticity and in increase dry density and frictional characteristics of clayey soils.

1.1 Objectives of the present study
The objectives of the present study are:
- To increase the stability of slopes economically.
- To make use of Industry waste material which is hugely available.
- To reduce the cost of construction by decreasing the bottom width and by increase side slopes.

2. Materials
2.1 Red soil
The soil was collected from highway extension project of NH 43 at a depth 0.5 m from G.L. The soil itself using as an embankment material. The soil was primarily identified as Red soil, possessing both cohesion and friction and particle size is a nearly sand-sized particle. Further Geotechnical investigation is carried out.

2.2 Manganese slag
Slag is the glass-like by-product left over after a desired metal has been separated from its raw ore. Slag is usually a mixture of metal oxides and silicon dioxide. The main product of the smelting process is a carbon-saturated ferroalloy consisting of 76 to 80% manganese, 12 to 15% of iron, 7.5% of carbon, and 1.2% of silicon. 70 to 80% of the manganese is recovered in the melt, and a slag consisting of 30 to 42% manganese is also achieved.

From the primary observation, the particle size of slag is medium sand and it is completely cohesionless material possessing high frictional characteristics. The material is also light in weight. Further geotechnical classification is done by tests.

3. Methodology
3.1 Material Investigation
The soil which was collected at the site was further investigated by using various Geotechnical tests such as Specific gravity test, Consistency limits, Dry sieve analysis, IS compaction test, Direct shear test. The same Geotechnical characterization was also done to the other material Mn slag from the tests. Now, the soil was mixed with different % of Mn slag such as 5, 10 and 15. The material proportion is mixed based on dry mix proportion. The same Geotechnical characterization is done at three % of Mn slag.

3.2 Analysis procedure
The slope stability analysis of an embankment slope is done by using the Method of Analysis. As many methods are available for the analysis of slopes, Method of slices was selected for its accuracy of analysis of finite slopes.
4. Results and Discussions

4.1 Geotechnical characterization of Materials

The Red soil and Manganese slag materials are examined by conducting various Geotechnical tests to know specific gravity, Atterberg limits, shear parameters and compaction characteristics. Table 1 presents the Geotechnical properties of Red soil and Mn slag individually.

| Property                          | Red soil | Manganese slag |
|----------------------------------|----------|----------------|
| Specific gravity                 | 2.47     | 1.89           |
| Gradation characteristics        |          |                |
| i. Gravel (> 4.75 mm)            | 9 %      | 0              |
| ii. Sand (4.75 mm – 0.075 mm)    | 77 %     | 100 %          |
| iii. Fines (< 0.075 mm)          | 14 %     | 0              |
| Consistency limits               |          |                |
| i. Liquid limit                  | 24 %     | NP             |
| ii. Plastic limit                | 17 %     | NP             |
| iii. Plasticity index            | 7 %      | -              |
| IS classification               | SP       | SP             |
| Compaction characteristics       |          |                |
| i. Optimum moisture content      | 12 %     | 6.5 %          |
| ii. Maximum Dry density          | 2.68 g/cc| 1.55 g/cc      |
| Shear characteristics            |          |                |
| i. Cohesion                      | 18 kN/m² | 0              |
| ii. The angle of internal friction (φ) | 28° | 42° |

4.2 Geotechnical characterization of soil stabilized with Mn slag

In this study, the Red soil was stabilized with various percentages of Mn slag like 5%, 10% and 15%. The material was added to the soil by its dry weight and the Geotechnical characterization was done by different tests. The optimum % of slag is decided based on the values obtained from various tests.

From the laboratory test results, it is observed that the stabilized Red soil shows valid results when it is stabilized with 10 % of Mn slag. After that at 15 % of Mn slag, the soil specific gravity and dry density were rapidly decreasing. Therefore, the optimum % was selected as 10 %. Figure 1 presents the variation of Geotechnical properties of stabilized material with the addition of Mn slag of various percentages.

**Figure 1.** Variation of Geotechnical properties of stabilized material with the addition of Mn slag
Table 2 presents the Geotechnical characterizations of Red soil stabilized with Mn slag of different percentages.

**Table 2. Geotechnical characterizations of Red soil stabilized with Mn slag**

| Property                        | Soil + 0% Mn slag | Soil + 5% Mn slag | Soil + 10% Mn slag | Soil + 15% Mn slag |
|---------------------------------|-------------------|-------------------|--------------------|--------------------|
| Specific gravity                | 2.47              | 2.21              | 2.1                | 1.8                |
| Gradation characteristics       |                   |                   |                    |                    |
| Gravel (> 4.75 mm)              | 9 %               | 9 %               | 8 %                | 8 %                |
| Sand (4.75 mm – 0.075 mm)       | 77 %              | 81 %              | 83 %               | 85 %               |
| Fines (< 0.075 mm)              | 14 %              | 10 %              | 9 %                | 7 %                |
| Consistency limits              |                   |                   |                    |                    |
| Liquid limit                    | 24 %              | 18 %              | NP                 | NP                 |
| Plastic limit                   | 17 %              | 12 %              | NP                 | NP                 |
| Plasticity index                | 7 %               | 6 %               | NP                 | NP                 |
| IS classification               | SP                | SP                | SP                 | SP                 |
| Compaction characteristics      |                   |                   |                    |                    |
| Optimum moisture content        | 12.5 %            | 11.6 %            | 10.4 %             | 8.2 %              |
| Maximum Dry Density (g/cc)      | 2.25              | 2.1               | 1.95               | 1.5                |
| Shear characteristics           |                   |                   |                    |                    |
| Cohesion (kN/m²)                | 18                | 16                | 14.5               | 10                 |
| The angle of internal friction  | 28°               | 31°               | 38°                | 45°                |

4.3 Analysis procedure

To meet the requirements of practical issues, a slope with known height and angle were assumed for the analysis. By using the analysis method, called Method of slices, the slope was analysed and value of factor of safety and a most critical circle was determined.

Now, if the slope is constructed with stabilized soil material, the analysis was carried out for the same assumed slope that how the factor of safety was varied.

**Analysis problem:**

An embankment is to be constructed to a height of 4 m and the side slopes of 1:1 incline 45°. The properties of the soil are unit weight = 22.5 kN/m³, cohesion = 18 kN/m³, angle of internal friction is 28°. A minimum factor of safety 2.5 required.

The solution is obtained by assuming different radii of a critical circle using the method of slices and a critical circle is one whose factor of safety is minimum.

Slope of embankment = 45°

For embankment slope 45°, α = 28°, β = 37°

**Trial -1**

Analysis by Swedish circle method (Graph 1)

Considering the slip circle radius, r = 6 m

Length of the arc slip surface wedge, L = 9.529 m

Step: 1 Calculation of each slice area by counting the number of squares under the embankment

Step: 2 Weight of each slice is measured by multiplying volume (unit length) by the unit weight of soil

Step: 3 Tangent and Normal are drawn for each slice and angle intended between the tangent and normal was determined

Step: 4 Tangential and Normal Components of Force are determined from the following formulae

Tangential force (T) = W sin α'

Normal force (N) = W cos α'
Graph 1: Analysis of failure wedge for slip circle with radius = 6 m (ordinary soil)

The tabulated details are presented in Table 3 for Trail 1.

Table 3. Trail 1 details of Swedish circle method of ordinary soil

| Slice no. | Area of each slice (A) m² | Weight of each slice (W) kN | Angle intended between the tangent and Normal components (α’) in ° | Tangential force (T) = W sin α’ | Normal force (N) = W cos α’ |
|-----------|---------------------------|-----------------------------|---------------------------------------------------------------|--------------------------------|---------------------------|
| 1         | 0.56                      | 12.6                        | -10                                                           | -2.18                          | 12.4                      |
| 2         | 1.7                       | 38.25                       | -6                                                            | -3.99                          | 38.04                     |
| 3         | 2.68                      | 60.3                        | 10                                                            | 10.47                          | 59.38                     |
| 4         | 3.45                      | 77.625                      | 20                                                            | 26.55                          | 72.94                     |
| 5         | 3.59                      | 80.775                      | 26                                                            | 35.40                          | 72.6                      |
| 6         | 2.93                      | 65.925                      | 3                                                             | 40.58                          | 51.94                     |
| 7         | 1.92                      | 43.2                        | 50                                                            | 33.09                          | 27.76                     |
| 8         | 0.34                      | 7.65                        | 64                                                            | 6.83                           | 3.35                      |

\[ \sum T = 146.75 \]
\[ \sum N = 338.41 \]

Area of each slice is calculated from the graph.
Weight of each slice = Area of each slice x Unit weight of soil.

α’ is an angle between weight acting vertically downwards and normal component of weight resolved. Now,

\[ \text{Factor of Safety} = \frac{\text{Resisting Moment}}{\text{Overturning Moment}} = \frac{CL + \sum N \tan \phi}{\sum T} = \frac{(18 \times 9.529) + (338.41 \times \tan 28)}{146.75} = 2.39 \]
In a similar way the analysis is carried out for different radius of a critical circle and the most critical circle with a minimum factor of safety is found out. The key details of all trails are shown in the following table 4.

**Table 4.** The factor of safety for the slip circle with different radii of ordinary soil

| Trail no. | The radius of slip circle (r) m | Length of arc (L) m | The angle at the centre of the arc (°) | Factor of safety |
|-----------|---------------------------------|-------------------|---------------------------------------|------------------|
| 1         | 6                               | 9.52              | 91                                    | 2.39             |
| 2         | 5.8                             | 10.22             | 101                                   | 2.5              |
| 3         | 5.75                            | 11.34             | 113                                   | 2.69             |
| 4         | 6.5                             | 8.28              | 73                                    | 1.9              |
| 5         | 6.6                             | 7.83              | 68                                    | 2.08             |
| 6         | 5.9                             | 10.19             | 99                                    | 2.2              |
| 7         | 6.2                             | 8.87              | 82                                    | 2.29             |
| 8         | 6.7                             | 9.328             | 79                                    | 2.37             |

The minimum factor of safety of most critical circle for ordinary soil embankment is 1.9. But the required factor of safety is 2.5. So, the embankment will fail in that most critical surface which results in loss of property and life. So, the soil is stabilized with optimum % of Manganese slag which is 10%.

Analysis of the stabilized soil embankment by Swedish circle method is carried out for the same design problem with changed geotechnical engineering properties.

**Analysis problem**

An embankment is to be constructed to a height of 4 m and the side slopes of 1:1 incline 45°. The properties of the soil are unit weight = 19.5 kN/m³, cohesion = 14.5 kN/m³, angle of internal friction is 38°. A minimum factor of safety 2.5 required.

**For stabilized soil**

The solution is obtained by assuming different radii of a critical circle using the method of slices and a critical circle is one whose factor of safety is minimum. Table 5 presents the details of Swedish circle method of stabilized soil (Trail 1).

Slope of embankment = 45°

For embankment slope 45° α = 28°, β = 37°

**Trial – 1**

Considering the slip circle radius, r = 6 m and Length of the arc slip surface wedge, L= 9.529 m

**Table 5.** Trail 1 details of Swedish circle method of stabilized soil

| Slice no. | Area of each slice (A) m² | Weight of each slice (W) kN | Angle intended between a tangent and Normal component (α’) in ° | Tangential force (T) = W sin α’ | Normal force in N W cos α’ |
|-----------|---------------------------|----------------------------|-------------------------------------------------------------|-------------------------------|---------------------------|
| 1         | 0.56                      | 10.92                      | -10                                                         | -1.89                         | 10.75                     |
| 2         | 1.7                       | 33.15                      | -6                                                          | -3.46                         | 32.96                     |
| 3         | 2.68                      | 52.26                      | 10                                                          | 9.07                          | 51.46                     |
| 4         | 3.45                      | 67.275                     | 20                                                          | 23                            | 63.21                     |
| 5         | 3.59                      | 70                         | 26                                                          | 30.688                        | 62.91                     |
| 6         | 2.93                      | 57.135                     | 38                                                          | 35.17                         | 45.02                     |
| 7         | 1.92                      | 37.44                      | 50                                                          | 28.68                         | 24.06                     |
| 8         | 0.34                      | 6.63                       | 64                                                          | 5.96                          | 2.9                       |

\[ \sum T = 127.618 \]
\[ \sum N = 293.27 \]
Now,

\[
\text{Factor of safety} = \frac{\text{Resisting Moment}}{\text{Overturning Moment}} = \frac{C L + \sum N \tan \phi}{\sum T} = \frac{(14.5 \times 9.529) + (293.27 \times \tan 38)}{127.618} = 2.88
\]

In a similar way the analysis is carried out for different radius of a critical circle and the most critical circle with a minimum factor of safety is found out. The key details of all trails were shown in table 6.

**Table 6.** Table showing factor of safety for slip circle with different radii of stabilized soil

| Trail no. | The radius of slip circle (r) in m | Length of arc (L) in m | The angle at the centre of the arc (°) | Factor of safety |
|-----------|-----------------------------------|------------------------|--------------------------------------|------------------|
| 1         | 6                                 | 9.52                   | 91                                   | 2.88             |
| 2         | 5.8                               | 10.22                  | 101                                  | 2.67             |
| 3         | 5.75                              | 11.34                  | 113                                  | 2.6              |
| 4         | 6.5                               | 8.28                   | 73                                   | 2.58             |
| 5         | 6.6                               | 7.83                   | 68                                   | 2.66             |
| 6         | 5.9                               | 10.19                  | 99                                   | 2.7              |
| 7         | 6.2                               | 8.87                   | 82                                   | 2.77             |
| 8         | 6.7                               | 9.328                  | 79                                   | 2.9              |

By analysis, the minimum factor of safety of un-stabilized soil is 1.9 at 6.5m radius slip circle which is less than the required factor of safety i.e., 2.5. So, there is a chance of failure at the most critical slip surface. Therefore, the soil is stabilized with the manganese slag material which is freely and abundantly available.

From the analysis of stabilized soil slope analysis, the minimum factor of safety is improved from 1.9 to 2.58. Hence the embankment is safe and the height and slope of the embankment are increased with the same bottom width.

5. **Conclusions**

Various Geotechnical tests such as specific gravity, compaction, and direct shear tests were conducted for the soil which is taken from the bank of the lake which is just highway extension project of NH 43. From the study, the following observations were made and conclusions were drawn.

1. The soil having less plasticity so that the material can be used as an embankment material. But the shear properties were quite low.
2. To improve shear properties of soil and to decrease the unit weight of soil the soil stabilized with a waste by-product called Mn slag, which is hugely available at the Ferro Alloys Ltd, Garividi, Vizianagaram.
3. The soil was stabilized with 5, 10 and 15 percentage of Mn slag by its dry weight. The geotechnical characterization of stabilized soil at different percentages was found out.
4. From the values, the optimum % of Mn slag was selected as 10 %. With the addition of 10% Mn slag, the soil shear properties were greatly improved and the density was also decreased. And the soil becomes also non-plastic with the addition of 10% slag.
5. A design problem was taken for the analysis concerning field criteria. The slope was analysed and the minimum factor of safety obtained was 1.9. at this minimum factor of safety, the slope has chances to fail.
6. Now, the analysis is carried out for the same designed slope with stabilized soil i.e., higher shear properties and lower density. Now, the minimum factor of safety obtained is 2.7, which safe as we assumed a minimum factor of safety as 2.5.
7. With this improved factor of safety, the slope is safe against the field conditions and we can also increase the top width of the embankment by increasing steepness of the slope.

8. Finally, if the soil was stabilized with Mn slag, it will be safer and more economical for future developments also.

References

[1] Faisal I Shalabi, Ibrahim M Asi, Hisham Y Qasrawi 2017 Effect of by-product steel slag on the engineering properties of clay soils *Journal of King Saud University – Engineering Sciences* 29 (4) p 394-9

[2] Hamed Niroumand, Khairul Anuar Kassim, Amin Ghafoorpour, Ramli Nazir 2012 The role of geosynthetics in slope stability *Electronic Journal of Geotechnical Engineering* 17 (HR) p 2739-48

[3] Santosh Dhakar, Jain S K 2016 Stabilization of soil: A Review *International Journal of science and research (IJSR)* 5 (6) p 545–9

[4] Brain O, Oyegblie Benjain, Oyegblie A 2017 Applications of Geo Synthetic membranes in Soil stabilization and Coastal defence structures *International Journal of Sustainable built environment* 6 (2) p 636-62

[5] Amin Pourkhosravani, Behzad Kalantari 2011 A review of current methods for slope stability evaluation *Electronic Journal of Geotechnical Engineering* 16 p 1245–55

[6] Sakellariou M G, Ferentiou M D 2005 A study of slope stability prediction using Neural network *Springer, Geotechnical and Geological Engineering* 23 p 419–45