Slope Stability in Rainfall Induced Landslided Area In Tirumala Hills By- Geotechnical Investigation

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Abstract. Landslides are the sudden events which results in loss of both human and environmental life. It mainly happens due to the rainfall occurred in soil instable areas. If the rainwater passes into the pores of soil in slope areas then the soil transforms as slurry or muddy and the runoff takes place along with soil. So landslide will occurs accordingly in hill down areas. The soil samples will be collected at five successive selected locations where the slide occurred. The slope stability of the soil in landslide area can be tested and Factor of safety will be calculated. If the factor of safety will be less than 1, then the soil will be susceptible for instability. If the FOS will be greater than 1, then the soil will be stable under saturated conditions. Generally landslides are common in Tirumala hills. This paper explains about the nature of soil and properties of land erupted soil in Tirumala ghat road.

1. Introduction

   Natural disasters will always make troubles because they are so often unpredictable. Frequently these types of events are occurred by mass wasting, deforestation, mining, slope failures, mudflows, road and railway works, drainage works. These types of errors lead to dangerous disasters. Mainly, man-made disasters can be controlled easily by taking several precautions or measures. The main aim is to save the lives and properties affected by natural disasters especially in hilly areas. Landslides can be controlled by growing vegetation, construction of barriers, reducing deforestation, etc., Generally, The mudflows will takes place during rainy season in slope areas. The mass wasting will also occurs during rains.

   Sometimes the wasting of soil leads to rock falls also. On steep hillsides, debris flow begins as shallow landslides that liquefy and accelerate. Sometimes, landslides lead to earthquakes, volcanos. There are several causes for landslides, both natural and human-induced. Landslides are capable of damaging highways and trains, burying fields and crops, falling houses and causing numerous deaths. Because of soil slope deficiencies, the devastation of buildings and trees will occur. Shear power, particle size distribution, density, permeability, moisture content, plasticity and angle of repose are the properties influencing the stability of a slope. Slope stability can be strengthened by stabilising the soil, supplying piles or retaining walls with lateral reinforcements, grouting or asphalt injecting into special positions. The safety factor Atlast can assist in the study of soil slope stability.

2. Methodology

   • Selecting the study area
• Collection of Soil Samples
• Geo-technical Investigation
• Grain size distribution (Sieve Analysis)
• Moisture Content
• Unit Weight
• Specific Gravity
• Direct Shear test
• Calculation of factor of safety in different conditions.

3. Study area

The samples were collected in these geographical coordinates in Tirumala Hills.

- 13°38'49.9 N 79°23'37.3 E
- 13°39'29.5"N 79°25'13.6"E
- 13°39'43.0"N 79°21'01.1"E
- 13°38'58.9"N 79°20'31.0"E
- 13°38'53.0"N 79°20'58.9"E

4. Tests And Results

4.1. Sieve Analysis

A Sieve Analysis is a tool or technique used to determine the distribution of particle size of a granular substance to move through a set of sieves of increasingly smaller mesh size weighing the volume of material stopped as a fraction of the entire mass of each sieve.

My Results Post Testing:
Sample 1:

| S.No | Sieve Size (mm) | Soil retained (gr) | % Retained | Cumulative retained % | % Finer |
|------|----------------|--------------------|------------|-----------------------|---------|
| 1    | 4.75           | 402                | 40.2       | 40.2                  | 59.8    |
| 2    | 2.36           | 188                | 18.8       | 59.0                  | 41.0    |
| 3    | 1.18           | 170                | 17.0       | 76.0                  | 24.0    |
| 4    | 0.600μ         | 139                | 13.9       | 89.9                  | 10.1    |
| 5    | 0.300μ         | 65                 | 6.5        | 96.4                  | 3.6     |
| 6    | 0.150μ         | 32                 | 3.2        | 99.6                  | 0.4     |
| 7    | 0.075μ         | 3                  | 0.3        | 99.9                  | 0.1     |
| 8    | Pan            | 0.1                | 0.1        | 100                   | 0       |
### Sample 2:

| S.No | Sieve Size (mm) | Soil retained (gr) | % Retained | Cumulative retained % | % Finer |
|------|-----------------|--------------------|------------|-----------------------|---------|
| 1    | 4.75            | 238                | 23.8       | 23.8                  | 76.2    |
| 2    | 2.36            | 96                 | 9.6        | 33.4                  | 66.6    |
| 3    | 1.18            | 355                | 35.5       | 68.9                  | 31.1    |
| 4    | 600μm           | 228                | 22.8       | 91.7                  | 8.3     |
| 5    | 300μm           | 79                 | 7.9        | 99.6                  | 0.4     |
| 6    | 150μm           | 0                  | 0.3        | 99.9                  | 0.1     |
| 7    | 75μm            | 0                  | 0.1        | 100                   | 0       |
| 8    | Pan             | 0                  | 0          | 100                   | 0       |

### Sample 3:

| S.No | Sieve Size (mm) | Soil retained (gr) | % Retained | Cumulative retained % | % Finer |
|------|-----------------|--------------------|------------|-----------------------|---------|
| 1    | 4.75            | 137                | 13.7       | 13.7                  | 86.3    |
### Sample 4:

| S.No | Sieve Size (mm) | Soil retained (gr) | % Retained | Cumulative retained % | % Finer |
|------|-----------------|--------------------|------------|-----------------------|---------|
| 1    | 4.75            | 212                | 21.2       | 21.2                  | 78.8    |
| 2    | 2.36            | 158                | 15.8       | 37.0                  | 63.0    |
| 3    | 1.18            | 351                | 135.1      | 72.1                  | 27.9    |
| 4    | 600μm           | 130                | 13.3       | 85.4                  | 14.6    |
| 5    | 300μm           | 133                | 13.3       | 98.7                  | 1.3     |
| 6    | 150μm           | 09                 | 0.9        | 99.6                  | 0.4     |
| 7    | 75μm            | 02                 | 0.2        | 99.8                  | 0.2     |
| 8    | Pan             | 02                 | 0.2        | 100                   | 0       |

![Graph of grain size distribution](graph.png)
Sample 5:

| S.No | Sieve Size (mm) | Soil retained (gr) | % Retained | Cumulative retained % | % Finer |
|------|----------------|-------------------|------------|-----------------------|---------|
| 1    | 4.75           | 149               | 14.9       | 14.9                  | 85.1    |
| 2    | 2.36           | 219               | 21.9       | 36.8                  | 63.2    |
| 3    | 1.18           | 178               | 17.8       | 54.6                  | 45.4    |
| 4    | 600µ           | 184               | 18.4       | 73.0                  | 27.0    |
| 5    | 300µ           | 225               | 22.5       | 95.5                  | 4.5     |
| 6    | 150µ           | 38                | 3.8        | 99.3                  | 0.7     |
| 7    | 75µ            | 05                | 0.5        | 99.8                  | 0.2     |
| 8    | Pan            | 02                | 0.2        | 100                   | 0       |

5. Moisture Content

In most industrial and testing facilities, moisture content measurement is a vital component of material consistency and is basically a function of quality management. Spectroscopic, chemical, conductivity, and thermo gravimetric analysis are the main approaches. The weight of the soil sample after the sample has been oven dried. Take the weight of the sample of oven dried dirt. The moisture content is measured using the phrase below.

\[ w = \frac{W_d}{W_m} \times 100 \]

Here are the results acquired from my testing:

SAMPLE NO. 1

Tray weight = 15gr → Eq. 1
Tray weight + Wet Soil weight = 65gr → Eq.2
Tray weight + Dry Soil weight = 64gr → Eq.3

Dry Soil Weight, Md = (Tray weight + Dry soil) – (Tray weight) = Eq.3 – Eq.1 = 64 – 15
Mass of Water, $M_w = (\text{Tray weight + Wet soil} - \text{Tray weight})$

$= \text{Eq.2} - \text{Eq.1}$

$= 65 - 64$

$= 1\text{gr}$

Water Content $w = (M_w/M_d) \times 100$

$= (1/49) \times 100$

$w = 2.040\%$

SAMPLE NO. 2

Tray weight = 15gr → Eq.1
Tray weight + Wet Soil weight = 65gr → Eq.2
Tray weight + Dry Soil weight = 59gr → Eq.3

Dry Soil Weight, $M_d = (\text{Tray weight + Dry soil} - \text{Tray weight})$

$= \text{Eq.3} - \text{Eq.1}$

$= 59 - 15$

$= 44\text{gr}$

Mass of Water, $M_w = (\text{Tray weight + Wet soil} - \text{Tray weight})$

$= \text{Eq.2} - \text{Eq.1}$

$= 65 - 59$

$= 6\text{gr}$

Water Content $w = (M_w/M_d) \times 100$

$= (6/44) \times 100$

$w = 13.63\%$

SAMPLE NO. 3

Tray weight = 15gr → Eq.1
Tray weight + Wet Soil weight = 65gr → Eq.2
Tray weight + Dry Soil weight = 63gr → Eq.3

Dry Soil Weight, $M_d = (\text{Tray weight + Dry soil} - \text{Tray weight})$

$= \text{Eq.3} - \text{Eq.1}$

$= 63 - 15$

$= 48\text{gr}$

Mass of Water, $M_w = (\text{Tray weight + Wet soil} - \text{Tray weight})$

$= \text{Eq.2} - \text{Eq.1}$

$= 65 - 63$

$= 2\text{gr}$

Water Content $w = (M_w/M_d) \times 100$

$= (2/48) \times 100$

$w = 4.167\%$

SAMPLE NO. 4

Tray weight = 15gr → Eq.1
Tray weight + Wet Soil weight = 65gr → Eq.2
Tray weight + Dry Soil weight = 63gr → Eq.3
Dry Soil Weight, $M_d = (\text{Tray weight} + \text{Dry soil}) - (\text{Tray weight})$

$= \text{Eq.3} - \text{Eq.1}$

$= 63 - 15$

$= 48$ gr

Mass of Water, $M_w = (\text{Tray weight} + \text{Wet soil}) - (\text{Tray weight})$

$= \text{Eq.2} - \text{Eq.1}$

$= 65 - 63$

$= 2$ gr

Water Content $w = \frac{(M_w)}{(M_d)} \times 100$

$= \frac{(2/48)}{100}$

$W = 4.167 \%$

**SAMPLE NO. 5**

Tray weight = 15 gr $\rightarrow$ Eq.1

Tray weight + Wet Soil weight = 65 gr $\rightarrow$ Eq.2

Tray weight + Dry Soil weight = 60 gr $\rightarrow$ Eq.3

Dry Soil Weight, $M_d = (\text{Tray weight} + \text{Dry soil}) - (\text{Tray weight})$

$= \text{Eq.3} - \text{Eq.1}$

$= 60 - 15$

$= 45$ gr

Mass of Water, $M_w = (\text{Tray weight} + \text{Wet soil}) - (\text{Tray weight})$

$= \text{Eq.2} - \text{Eq.1}$

$= 65 - 60$

$= 5$ gr

Water Content $w = \frac{(M_w)}{(M_d)} \times 100$

$= \frac{(5/45)}{100}$

$w = 11.11 \%$

**6. Specific Gravity Test**

That’s the ratio between both the density of a matter and the density of a technical information given. The specific gravity of liquids is almost always measured against water at its densest. It will sink a substance with a relative density greater than 1. In industrial sector, specific gravity is frequently seen as a simple way to obtain information on the concentration of solutions of different materials, such as brines, sugar solutions and acids.

My Results From The Testings:

**SAMPLE NO. 1**

$W_1 =$ Empty Pycnometer Weight

$= 720$ gr

$W_2 =$ Pycnometer Weight + Weight of Soil

$= 720$ gr + 500 gr

$= 1220$ gr

$W_3 =$ Pycnometer Weight + Weight of Soil + Weight of Water $W_2 - W_1$

$= 1852$ gr

$W_4 =$ Pycnometer Weight + Weight of Water
Specific Gravity, \( G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \)

\[ = \frac{1220 - 720}{(1220 - 720) - (1852 - 1560)} \]

\[ = \frac{500}{(500) - (292)} \]

\( = \frac{500}{208} \)

\( G = 2.403 \text{gr} \)

SAMPLE NO.2
W1 = Empty Pycnometer Weight
= 720gr
W2 = Pycnometer Weight + Weight of Soil
= 720gr + 500gr
= 1220gr
W3 = Pycnometer Weight + Weight of Soil + Weight of Water W2 − W1
= 1826gr
W4 = Pycnometer Weight + Weight of Water
= 1560gr

Specific Gravity, \( G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \)

\[ = \frac{1220 - 720}{(1220 - 720) - (1826 - 1560)} \]

\[ = \frac{500}{(500) - (266)} \]

\( = G = 2.136 \text{gr} \)

SAMPLE NO.3
W1 = Empty Weight of Pycnometer
= 720gr
W2 = Weight of Pycnometer + Weight of Soil
= 720gr + 500gr
= 1220gr
W3 = Weight of Pycnometer + Weight of Soil + Weight of Water W2 − W1
= 1875gr
W4 = Weight of Pycnometer + Weight of Water
= 1560gr

Specific Gravity, \( G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \)

\[ = \frac{1220 - 720}{(1220 - 720) - (1875 - 1560)} \]

\[ = \frac{500}{(500) - (315)} \]

\( = 500/185 \)
G = 2.702gr

SAMPLE NO.4
W1 = Empty Pycnometer Weight
    = 720gr
W2 = Pycnometer Weight + Weight of Soil
    = 720gr + 500gr
    = 1220gr
W3 = Pycnometer Weight + Weight of Soil + Weight of Water
    W2 – W1 = 1855gr
W4 = Pycnometer Weight + Weight of Water
    = 1560gr

Specific Gravity, \( G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \)
= \frac{1220 - 720}{(1220 - 720) - (1855 - 1560)}
= \frac{500}{(500) - (295)}
= 500/205
G = 2.439gr

SAMPLE NO.5
W1 = Empty Pycnometer Weight
    = 720gr
W2 = Pycnometer Weight + Weight of Soil
    = 720gr + 500gr
    = 1220gr
W3 = Pycnometer Weight + Weight of Soil + Weight of Water
    W2 – W1 = 1872gr
W4 = Pycnometer Weight + Weight of Water
    = 1560gr

Specific Gravity, \( G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)} \)
= \frac{1220 - 720}{(1220 - 720) - (1872 - 1560)}
= \frac{500}{(500) - (312)}
= 500/188
G = 2.659gr

7. Direct Shear Test

A direct shear test is a field and laboratory test used only by engineering applications to calculate the shear ultimate strength of soil or rock content, or low shear strength discontinuity of soil or rock. This test is known for the ease of design and facilities used and the potential to evaluate under different conditions of saturation, drainage and consolidation.

Results from the Testing:
Sample 1:

| Normal stress (kg/m²) | Direct shear (kg/m²) |
|-----------------------|----------------------|
| 0                     |                      |
| 2500                  |                      |
| 5000                  | 0.416                |
| 7500                  |                      |
| 10000                 | 0.569                |
| 12500                 |                      |
| 15000                 | 0.694                |

Sample 2:

| Normal stress (kg/m²) | Direct shear (kg/m²) |
|-----------------------|----------------------|
| 0                     |                      |
| 2500                  |                      |
| 5000                  | 0.118                |
| 7500                  |                      |
| 10000                 | 0.301                |
| 12500                 |                      |
| 15000                 | 0.625                |
### Sample 3:

| Normal stress (kg/m²) | Direct shear (kg/m²) |
|----------------------|----------------------|
| 0                    | 0                    |
| 2500                 | 0.0972               |
| 5000                 |                      |
| 7500                 | 0.3                  |
| 10000                |                      |
| 12500                | 0.555                |
| 15000                |                      |

### Sample 4:

| Normal stress (kg/m²) | Direct shear (kg/m²) |
|----------------------|----------------------|
| 0                    |                      |
| 2500                 | 0.416                |
| 5000                 |                      |
| 7500                 | 0.501                |
| 10000                |                      |
| 12500                | 0.771                |
| 15000                |                      |
Sample 5:

| Normal stress (kg/m²) | Direct shear (kg/m²) |
|-----------------------|----------------------|
| 0                     | 0                    |
| 2500                  | 0.527                |
| 5000                  | 0.75                 |
| 7500                  | 0.854                |
| 10000                 |                      |
| 12500                 |                      |
| 15000                 |                      |

8. Unit Weight Of Soil

The unit weight of the soil, divided by total volume, is the total weight of the soil. Total soil weight also includes water weight. The amount of water as well as the volume of air together with the volume of the soil include the total volume occupied. Multiply the former by 9,811 in order to transform the density (expressed in terms of g/cm³) into unit weight (kN/m³). This is so because 1g/cm³=981X10⁻⁶KN1X10⁻⁶m³=9.81KNm³
Hence,

\[ \gamma = 9.81 \times \rho \]

According to literature reviews, the unit weight of soil in Tirumala hills is equal to 18.

9. Factory of Safety

The following equation proposed by Vanacker (2003) is used to calculate the factor of safety.

\[
F_s = \frac{C + Cr + (\gamma - \gamma_w)z \cos^2 \alpha \tan \phi}{\gamma z \cos \alpha \sin \alpha}
\]

Where:
- \( F_s \) — Factor of safety
- \( z \) — soil thickness
- \( \alpha \) — local slope angle
- \( \phi \) — Effective angle of internal friction

\( m \) — soil saturation

\[ c \] — Cohesion of soil

\[ cr \] — Root Cohesion

\[ \gamma \] — Unit weight of soil

\[ \gamma_w \] — Unit weight of water

m-soil saturation

Sample 1:

\[
F_s = \frac{c + cr + (\gamma - \gamma_w \times m)z \cos^2 \alpha \tan \phi}{\gamma z \cos \alpha \sin \alpha}
\]

\[
= \frac{0.3 + 20 + [18 - 10 + 0.02] \times 1 \times \cos^2 15 \tan 32}{18 \times 1 \cos 15 \sin 15}
\]

\[
= \frac{0.3 + 20 + 18 \times 1 \times [0.931 + 0.624]}{18 \times 1 \times 0.965 \times 0.258}
\]

\[
= \frac{11.8668}{4.481}
\]

\[ F_s = 2.64 \]

Sample 2:

\[
F_s = \frac{c + cr + (\gamma - \gamma_w \times m)z \cos^2 \alpha \tan \phi}{\gamma z \cos \alpha \sin \alpha}
\]

\[
= \frac{0.05 + 20 + [18 - 10 + 0.13] \times 1 \times \cos^2 15 \tan 33}{19.95 + 1.04 \times (0.931)(0.6494)}
\]

\[
= \frac{4.481}{4.481}
\]

\[ F_s = 12.682 \]

\[ F_s = 2.83 \]

Sample 3:

\[
F_s = \frac{c + cr + (\gamma - \gamma_w \times m)z \cos^2 \alpha \tan \phi}{\gamma z \cos \alpha \sin \alpha}
\]
\[
\begin{align*}
F_s &= \frac{0.1 + 20 + [18 - 10 + 0.4] \cos^2 15 \tan 30}{18 + 1 \cos 15^\circ \sin 15} \\
&= \frac{20.1 + (0.32)(0.931)(0.577)}{4.481} \\
&= 10.9675 \\
&\approx 4.481 \\
\end{align*}
\]

\[F_s = 2.44\]

Sample 4:
\[
F_s = \frac{c + c_r + [Y - Y_w + m] \cos \alpha \tan \phi}{\gamma z \cos \alpha \sin \alpha}
\]
\[
\begin{align*}
&= \frac{0.4 + 20 + [18 - 10 + 0.04] \cos^2 15 \tan 21}{4.481} \\
&= \frac{20.4 + 0.32(0.931) \times (0.554)}{4.481} \\
&= \frac{20.72 + 0.5157}{4.481} \\
&\approx \frac{10.686}{4.481} \\
\end{align*}
\]

\[F_s = 2.58\]

Sample 5:
\[
F_s = \frac{c + c_r + [Y - Y_w + m] \cos \alpha \tan \phi}{\gamma z \cos \alpha \sin \alpha}
\]
\[
\begin{align*}
&= \frac{0.39 + 20 + [18 - 10 \times 0.11] \cos^2 15 \tan 35}{4.481} \\
&= \frac{20.39 + 0.88(0.931) \times (0.700)}{4.481} \\
&= \frac{21.27 + 0.6517}{4.481} \\
\end{align*}
\]

\[F_s = 3.09\]

10. Discussion and future scope

- Landslides will be controlled by constructing barriers, retaining walls, growing vegetation over the surface etc., generally landslides happen due to both natural and man-made ways.
- Naturally occurred landslides cannot be stopped and can be controlled by barriers and vegetation growth.
- Man-made landslides can be stopped and controlled by afforestation, forest fires control etc.
- So, The natural disasters can be controlled in natural ways by growing of vegetation.

11. Conclusion

Landslides are inevitable. Eventually, the factor of safety for all the samples are greater than 2. So, all the samples proves that the landslides will not happen in Tirumala hills (According to the area where samples collected).

- 13°38'49.9 N 79°23'37.3 E – NEGATIVE
12. References

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