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# IMPACT OF VARIATIONS IN GEOTECHNICAL PROPERTIES OF BACKFILL MATERIAL ON THE SERVICEABILITY OF CANTILEVER EARTH RETAINING STRUCTURE: A CASE STUDY

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**Abstract**

Landslides are major natural disasters. It affects the ecosystem and results in economic loss. The Konkan region of Maharashtra, India, also experiences this problem every year. To prevent such disasters Slope stabilisation techniques are used, among which the retaining Structure provision is one of them. Most of the time, permanent RCC earth-retaining structures (ERS) is provided. These structures are constructed for a total serviceability period of 30–60 years but generally, in most of the cases in lateritic soil, they cannot withstand their total serviceable life. To find out the reasons for failure and to increase serviceability, a detailed investigative study of engineering geological and geotechnical properties was conducted to assess the serviceability or structural safety of cantilever earth retaining walls at Dasgaon and Sahilnagar from Mahad Tehsil, Konkan region, Maharashtra, and the preventive Measures resulting from the failure of cantilever ERS are discussed.

**Key words**: Earth retaining structure, lateritic soil, failure, serviceability, structural safety, preventive measures.

## I INTRODUCTION:

In hilly terrain, due to anthropogenic activities and natural activities landslide occurs frequently. It affects the lifestyle of living people, the ecosystem, and the economy of that area. The soil stabilization techniques are introduced to reduce such landslides; the retaining structure provision is one of them. The various types of earth retaining structures such as according to material, according to the serviceability period, according to the mode of failure, according to shape, among which permanent cantilever earth retaining structure is mostly used retaining structure in cut and fill operation and to reduce land instability (Bobade et al. 2012). The geotechnical, structural, and economic consideration is the most important to design the cantilever retaining structure. To design a cantilever retaining structure it is important to know the geology and geotechnical parameters in that area, as it affects the serviceability of that ERS. In this paper, the comparative analysis of pre-input design parameters i.e. the parameters at the time of structural design and post design parameters at the current scenario is compared.

In 2005, the Raigad district experienced heavy rainfall that triggered major landslides in which huge lives and property loss was booked. That triggered a need to suggest the mitigative measures against slope instability (Dhawale et al. 2020). Following this, at Sahilnagar a cantilever retaining structure was constructed in 2013. The designed earth retaining structure for Sahilnagar served for only three rainy seasons and in 2016 the ERS failed after heavy rainfall. Such types of retaining structures are also provided in the nearby area as mitigative measures. To judge the future serviceability of these earth retaining structures the backfill material is subjected to various geotechnical tests to assess the design serviceable life in terms of factor of safety is calculated (Bobade et al. 2021).

Major retaining structures failed with the onset of rains clearly indicating the need to make changes in the input design parameters in the prevailing conditions as well as the full saturated condition of the soil (Tapase et al. 2022). In the case of ERS, the major factors on which the structural design mainly depends are cohesion, soil bearing capacity, internal angle of friction, the soil density, the surcharge angle of backfill, and the height of the retaining wall. Of all the above factors, cohesion, internal angle of friction, dry density, and saturated density of soil are found to depend on the percentage of fine aggregate and natural moisture content in the composition of the backfill material (Bobade and Rajni 2021). An increase in the percentage fineness affects the specific gravity, cohesion, natural moisture content, dry density, and saturated density of soil.

## II STUDY AREA AND GEOLOGY:

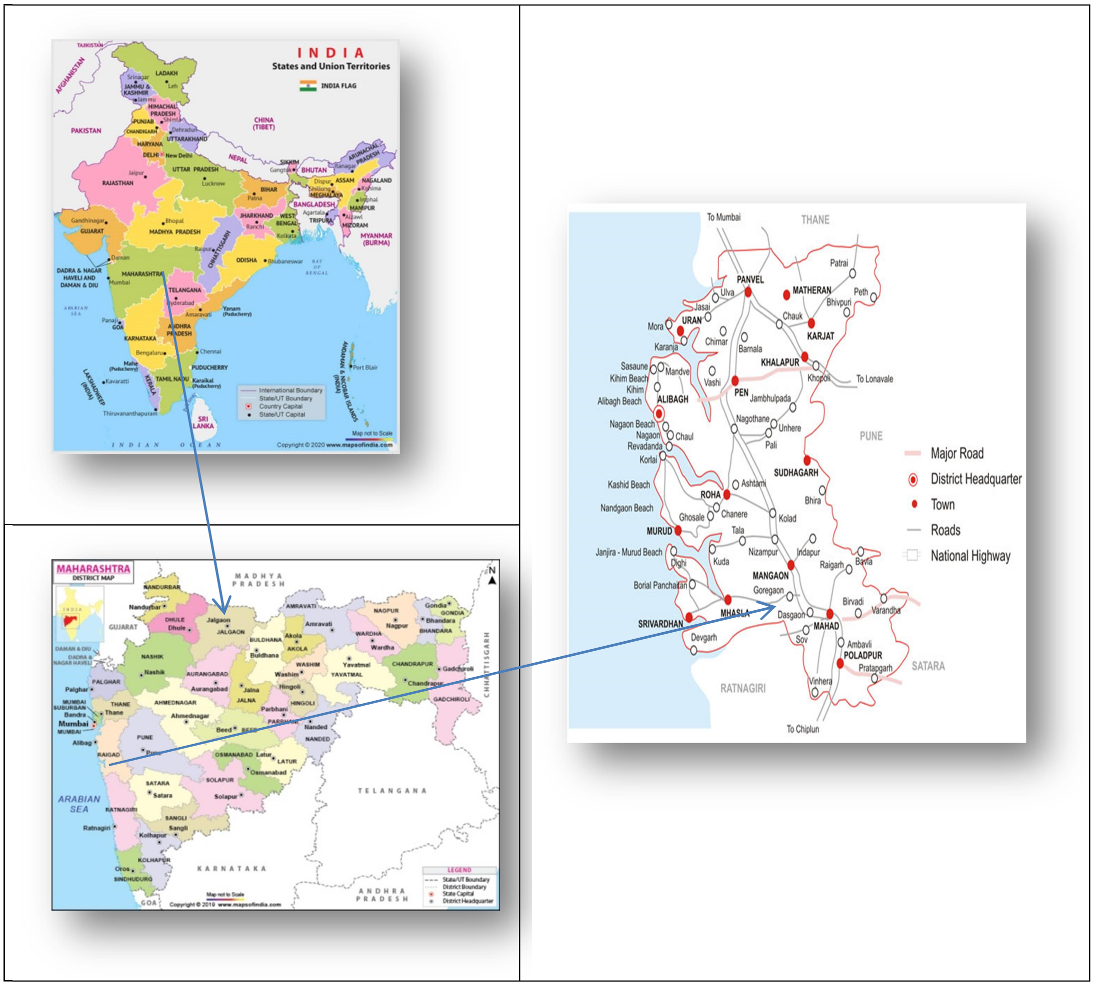


**Figure 1:** Study area

This paper presents a detailed investigation of a major landslide at Dasgaon and Sahilnagar in South –Western Maharashtra i.e. Konkan region and the mitigative measures undertaken. This cantilever ERS is in Raigad District located at Latitude- N 18° 6' 46.08" and Longitude- E 73° 21' 54" at Dasgaon and Latitude- N $18^0$ 4’ 46’’ and Longitude- E $73^0$ 24’ 27’’ at Sahilnagar respectively. The total height of Dasgaon cantilever ERS is 7.5 meters and that of Sahilnagar is 5.5 meters. Deccan Trap Basaltic rock and lateritic rock are mainly found in this region. These rocks develop lithomarge clays and lateritic soil regolith due to the weathering near the surface because of the humid and highly oxidizing climatic conditions. Due to the surface and subsurface flow during heavy precipitation the loose cohesive soil matrix becomes soft and loses strength. The Regolithic mass became heavy, lost support/interlocking, and slumped along the hill slope. This region lies in zone IV as per the map of seismic zones for our country. Hence slope instability can be caused due to minute seismic events that act as a triggering factor. The hilly terrain of Dasgaon and Sahilnagar fall in the coastal strip in the south-western part of Sahyadri. Archaean system, the world’s oldest rock formation is seen here. Due to weathering this rock formation has been converted to the relict hilly terrain with lateritic soil mass resting on the angle of repose of gneisses. There is very heavy rainfall in this hilly terrain in the coastal zone , is seismically active and as per the seismic zonation map comes under zone IV due to which landslides are very commonly observed in this area during the monsoon season.

## III METHODOLOGY:

### A. *Input Design Parameters at the time of Structural Design*

### *(Pre Input Design Parameters)*

Table I shows the input design parameters at the time of structural design for both Dasgaon and Sahilnagar cantilever ERS. The properties of concrete and steel are M 30 and Fe500. The height of the retaining structure for Dasgaon is 7.5 meters and for Sahilnagar it is 5.5 meters.

**TABLE I:** Input Design Parameters at the Time of Structural Design

| Sr. No. | Parameters | Pre values |
|---|---|---|
| **1** | Specific gravity | **2.9** |
| **2** | The dry density of soil ($kN/m^3$) | **18** |
| **3** | The saturated density of soil ($kN/m^3$) | **20** |
| **4** | The cohesion of soil ($kN/m^2$) | **0** |
| **5** | Internal angle of friction (°) | **30** |

### B. **Input Design Parameters at Current Scenario**

### **(Post Input Design Parameters):**

The condition of the backfill material in the prevailing state was analyzed by conducting the following tests on the backfill material. For this three samples were collected from the backfill of Dasgaon and Sahilnagar retaining structures respectively. These tests are important since this design parameter affects the Factor of Safety considered while designing (Garg et al. 2021). The tests conducted were:

1. The determination of natural moisture content of the soil by oven drying method.
2. The determination of the specific gravity of soil.
3. Sieve analysis by mechanical method.
4. Determination of Atterberg Limits.
5. Determination of Maximum dry density and optimum Moisture Content of soil by Standard proctor test.
6. Determination of cohesion and internal angle of friction by the direct shear method.

Tables II and III show the input design parameters at current condition by conducting the laboratory tests on a borrowed soil sample. This input design parameter affects the serviceability in terms of calculation of factor of safety, therefore it is essential to find out this input design parameter.

**TABLE II:** Characteristics Properties of Soil at Current State for Dasgaon

| Sr.No | Parameters | Sample A | Sample B | Sample C |
|---|---|---|---|---|
| 1 | Natural moisture content | 16.95 | 11.39 | 17 |
| 2 | Specific gravity | 2.48 | 2.56 | 2.54 |
| 3 | % of soil passing through 200 No. Sieve | 18.6 | 24.3 | 17.9 |
| 4 | Liquid limit | 48.39 | 41.63 | 43.78 |
| 5 | Plastic limit | 36.43 | 33.26 | 37.56 |
| 6 | Plasticity index | 11.96 | 8.37 | 6.22 |
| 7 | Optimum moisture content | 1.98 | 1.43 | 1.394 |

| | | | | |
|---|---|---|---|---|
| 8 | Maximum dry density | 25.05 | 28.47 | 34 |
| 9 | The dry density of soil | 17.5 | 17.7 | 17.74 |
| 10 | The saturated density of soil | 20.48 | 20.42 | 20.17 |
| 11 | Cohesion of soil | 27 | 21 | 25 |
| 12 | Internal angle of friction | 26.9 | 27 | 26.4 |

**TABLE III:** Characteristics Properties Of Soil At Current State For Sahilnagar

| Sr.No | Parameters | Sample A | Sample B | Sample C |
|---|---|---|---|---|
| 1 | Natural moisture content | 28 | 24 | 29 |
| 2 | Specific gravity | 2.21 | 2.24 | 2.17 |
| 3 | % of soil passing through 200 No. Sieve | 36 | 34 | 33.8 |
| 4 | Liquid limit | 51.8 | 54.47 | 52.03 |
| 5 | Plastic limit | 41.78 | 43.23 | 43.67 |
| 6 | Plasticity index | 10.02 | 11.24 | 8.36 |
| 7 | Optimum moisture content | 1.58 | 1.51 | 1.46 |
| 8 | Maximum dry density | 27.3 | 24.1 | 20.76 |
| 9 | The dry density of soil | 18.390 | 18.301 | 18.792 |
| 10 | The saturated density of soil | 20.86 | 20.91 | 20 |
| 11 | Cohesion of soil | 30 | 26 | 29 |
| 12 | Internal angle of friction | 24 | 21 | 22 |

C. ***Effect of the Percentage of Finer Material on the Shear Strength Parameter of Soil:***

The percentage of finer material in the composition of the soil increases due to the weathering action. This percentage of finer material may affect the shear strength parameter of soil which in turn affects the calculation of factor of safety while designing. Graphs 2, 3, and 3, 4 show the effect of the percentage of finer material on the internal angle of friction and cohesion of backfill material collected from the Dasgaon and Sahilnagar area respectively. This relationship is found out with the direct shear test.

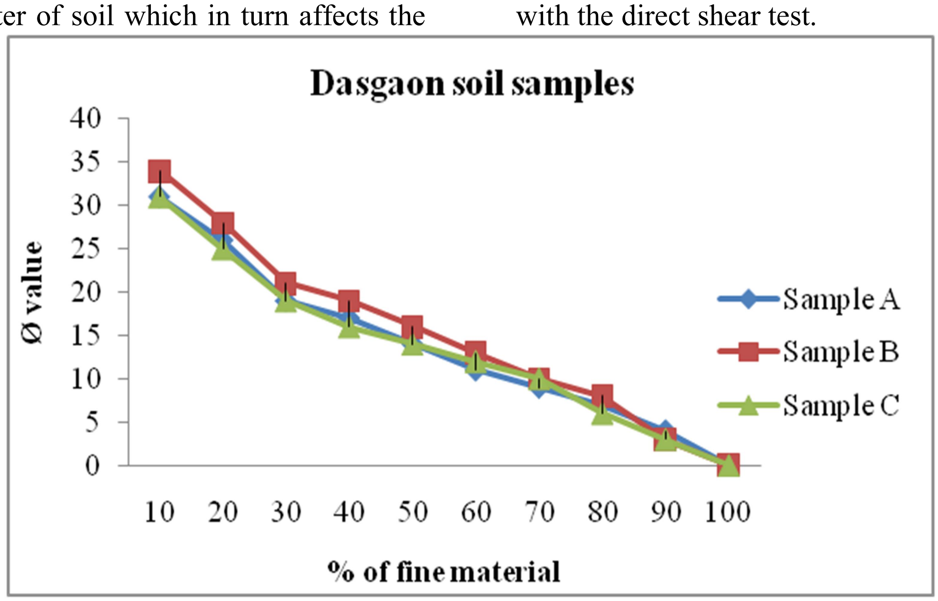


**Figure 2:** Effect of Percentage of Finer Material on an Internal Angle of Friction

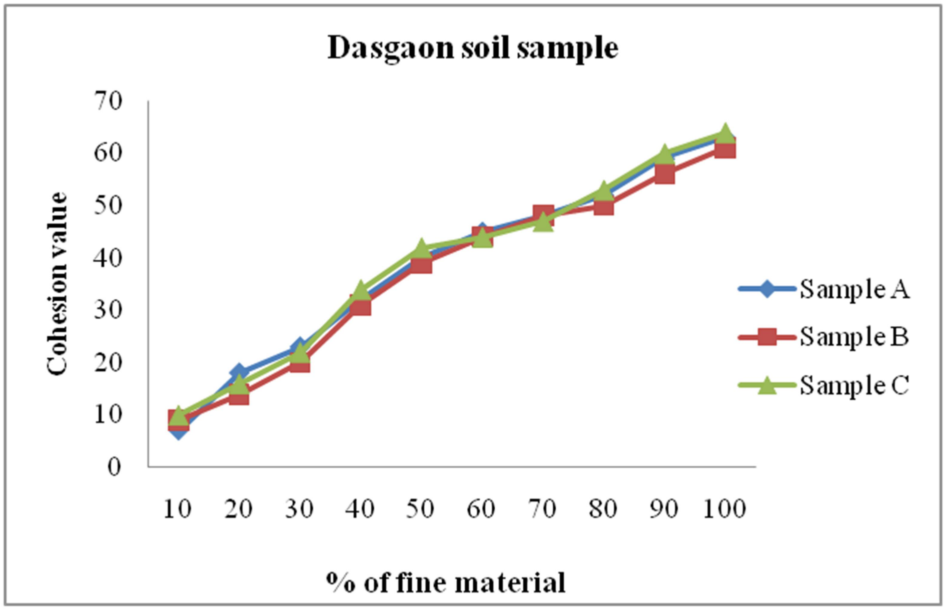


**Figure 3:** Effect of Percentage of Finer Material on Cohesion

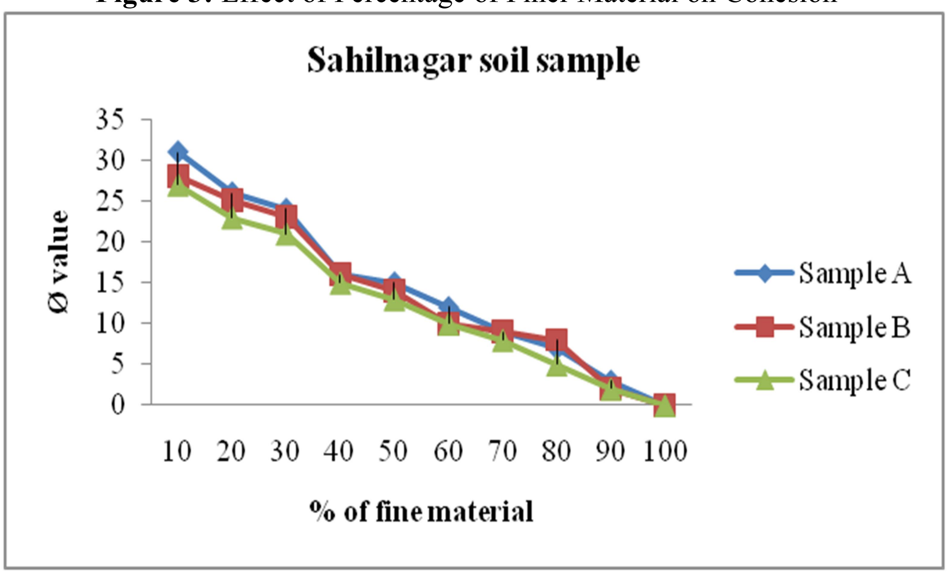


**Figure 4:** Effect of Percentage of Finer Material on an Internal Angle of friction

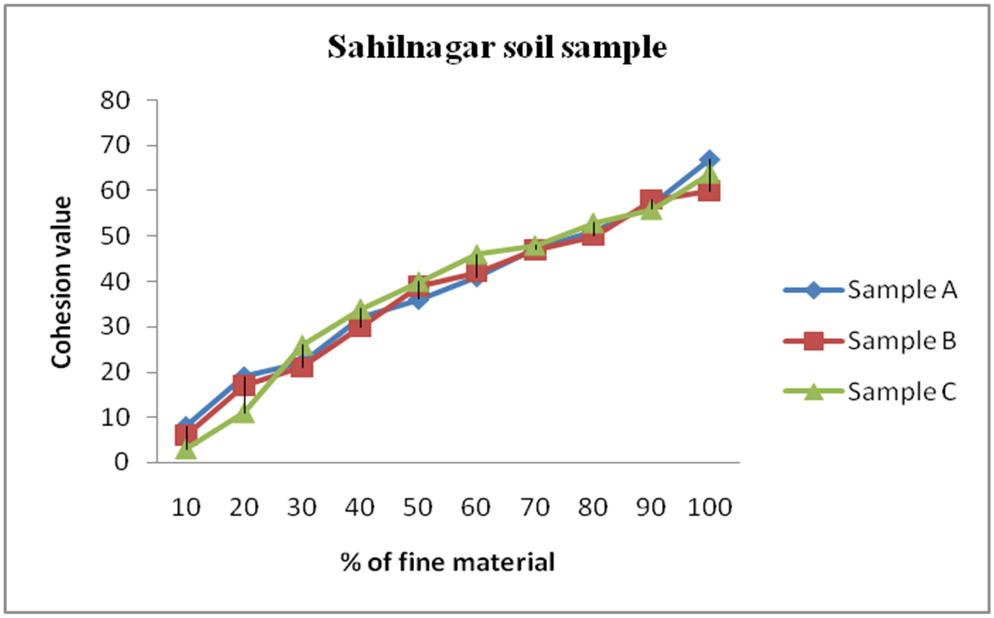


**Figure 5:** Effect of Percentage of Finer Material on Cohesion

From figures 2 to 5, it is observed that as the percentage of the finer material in the soil composition goes on increasing the internal angle of friction goes on decreasing and the cohesion value goes on increasing. This means that in terms of finer material composition, cohesion and the internal angle of friction are inversely proportional.

D. ***Effect of Percentage of Natural Moisture Content on The Shear Strength Parameter of Soil:***

Major retaining structures failed in the rainy season, clearly highlighting the need to compute changes in shear strength parameters at the full saturated condition. The natural moisture content in soil affects the shear strength parameter which may affect the factor of safety. Figures 6, 7, and 8, 9 show the effect of natural moisture content on the internal angle of friction and cohesion of backfill material collected from the Dasgaon and Sahilnagar area respectively. The percentage of finer material is kept as it is described in tables 2 and 3. The direct shear test is used to find out the changing effect of shear strength parameters.

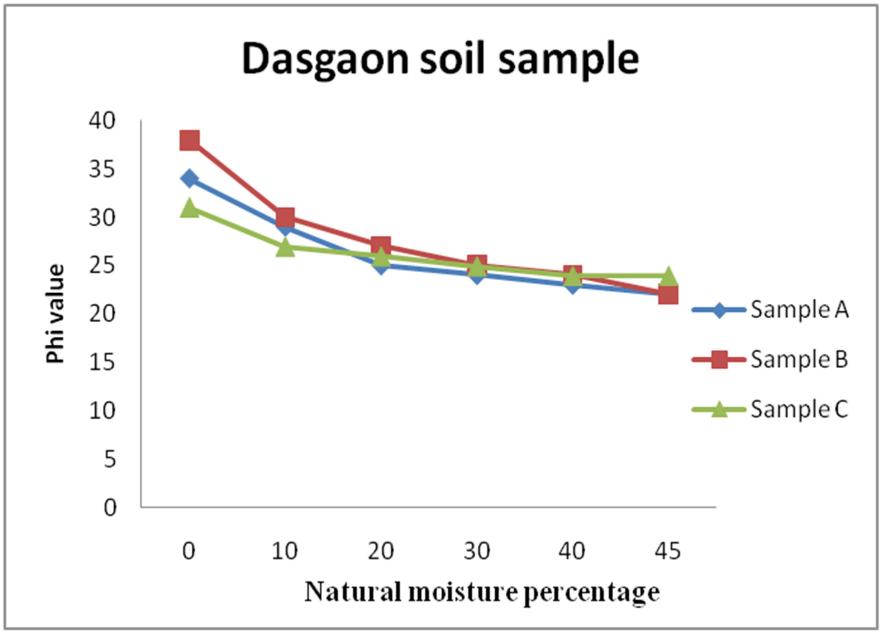


**Figure 6:** Effect of Natural Moisture Content on an Internal Angle of Friction

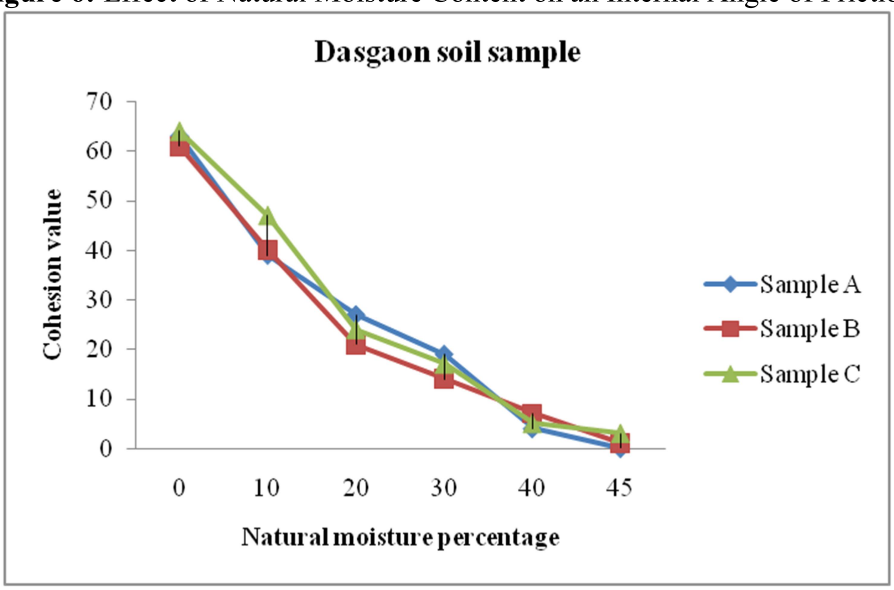


**Figure 7:** Effect of Percentage of Natural Moisture Content on Cohesion

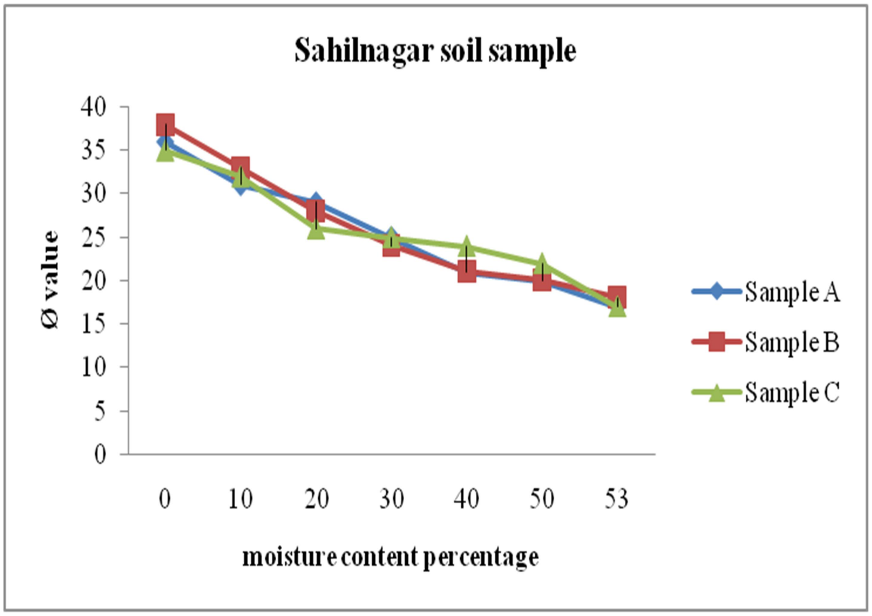


**Figure 8:** Effect of Natural Moisture Content on an Internal Angle of Friction

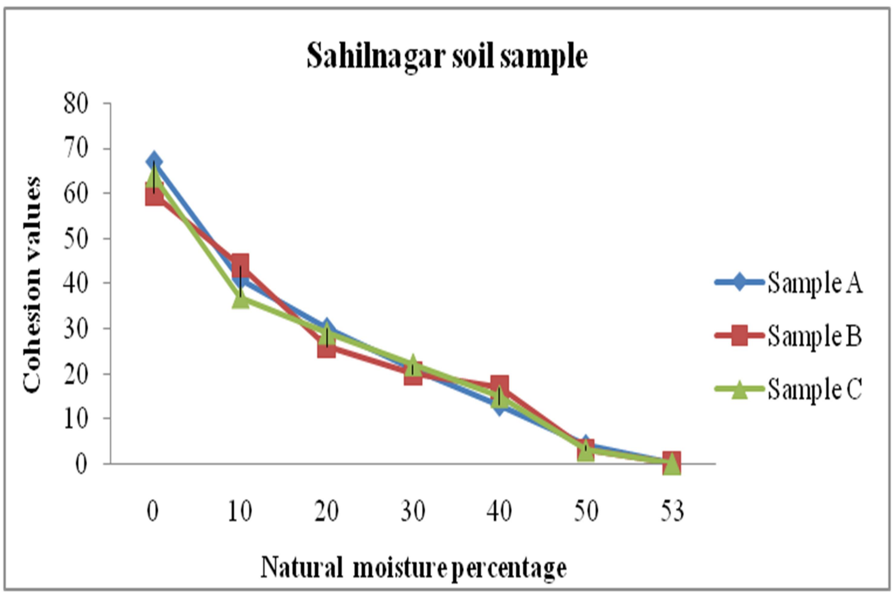


**Figure 9:** Effect of Percentage of Natural Moisture Content on Cohesion

From this Figure 6-9, it is concluded that as the percentage of natural moisture content in the soil composition goes on increasing , both cohesion and the internal angle of friction of soil goes on decreasing.

E. ***Saturated Density at the Liquid Limit Condition of Soil:***

The saturated density is higher than that of dry density of the soil and is the combination of soil mass and water. The saturated density of the soil is higher at the liquid limit of the soil and occurs in the rainy season. Therefore the saturated density is calculated for every collected soil sample at their respective liquid limit. Table No. 4 shows the maximum saturated density of the soil at their respective liquid limit for both areas.

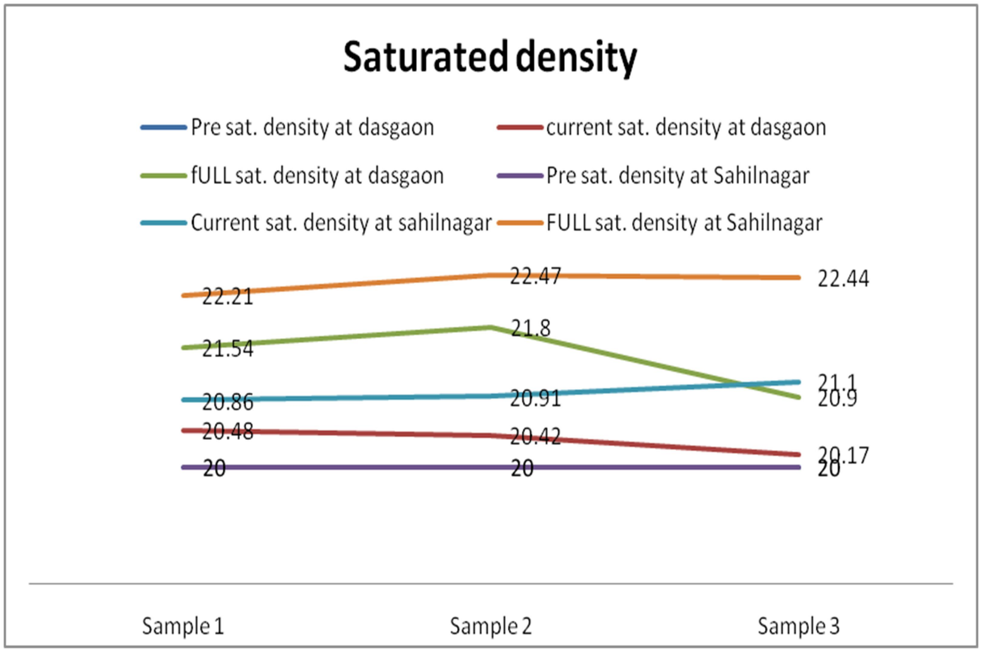


**Figure 10:** Changes in the saturated density of the soil

F. ***Effect of Current Input Design Parameter on the Design Serviceability in Terms of Factor of Safety:***

From the laboratory tests, conducted on the borrowed backfill material, it is clear that with an increase in the water content in the soil, the cohesion of the soil becomes zero and the internal angle of friction decreases. As the percentage of the finer material increases the internal angle of friction decreases and the cohesion of soil goes on increasing. At a fully saturated condition, the cohesion becomes negligible and the minimum internal angle of friction becomes 22° for Dasgaon and 17° Sahilnagar backfill material. The maximum saturated density at the full liquid limit becomes 21.80 KN/M$^3$ for Dasgaon and 22.47 KN/M$^3$ for Sahilnagar backfill material. Height of the retaining structure, the soil bearing capacity and the properties of concrete and steel are not changed. Then the redesigned structure and its change in FOS are noted. The design values are calculated by using Indian standard codes. The input design parameters are the value of cohesion, internal angle of friction, dry and saturated density, and the height of the retaining structure. The various design values and their impact on the Factor of Safety are shown in Table No. IV

**TABLE IV:** Dimensions and Various Loads Applied On The Retaining WalL

| **Design parameters** | **Design values at the time of structural design at Dasgaon** | **Design values at the current condition in saturated condition at Dasgaon** | **Design values at the time of structural design at Sahilnagar** | **Design values at the current condition in saturated condition at Sahilnagar** |
|---|---|---|---|---|
| **Ø value** | 30° | 22° | 30° | 17° |
| **saturated density** | 20 | 21.80 | 20 | 22.44 |
| **Height of R.W. (M)** | 7.5 | 7.5 | 5.5 | 5.5 |
| **The top width of the stem (M)** | 0.5 | 0.5 | 0.5 | 0.5 |
| **The bottom width of the stem (M)** | 1.1 | 1.1 | 0.7 | 0.7 |
| **Toe width (M)** | 1 | 1 | 0.6 | 0.6 |
| **Heel width (M)** | 2.9 | 2.9 | 2.4 | 2.4 |
| **Total width** | 5 | 5 | 3.7 | 3.7 |
| **Height of stem** | 6.5 | 6.5 | 4.75 | 4.75 |
| **Active earth pressure** | 0.333 | 0.455 | 0.333 | 0.548 |
| **Passive earth pressure** | 3 | 2.22 | 3 | 1.83 |
| **Total vertical load (kN)** | 582 | 608.39 | 360.875 | 388.70 |
| **Total vertical moment ($kN/M^2$)** | 1744.47 | 1838.09 | 757.55 | 827.09 |
| **Overturning moment (kN-M)** | 468.75 | 684.63 | 184.67 | 341 |
| **Horizontal earth pressure ($kN/M^2$)** | 187.5 | 273.85 | 100.73 | 186 |
| **Acting at** | 2.5 | 2.5 | 1.83 | 1.834 |

| | | | | |
|---|---|---|---|---|
| **FOS against overturning** | 3.84 | 2.41 | 3.43 | 2.18 |
| **Sliding-Resistive force (kN)** | 424.25 | 328.50 | 216.522 | 209.90 |
| **FOS against sliding** | 2.16 | 1.40 | 2.09 | 1.128 |
| **Minimum pressure at the toe (kN/M$^2$)** | 73.36 | 34.06 | 56.57 | -93.289 |
| **Maximum pressure at the toe (kN/M$^2$)** | 159.43 | 209.28 | 128.49 | 248.76 |

G. ***Analysis of Retaining Structure Using Finite Element Software.***

Analysis of retaining structure is done by using finite element software Stad- Pro. Following four cases of retaining structures are considered for the analysis:

i. Retaining structure design at the time of structural design at Dasgaon.
ii. Retaining structure design at the time of structural design at Sahilnagar.
iii. Retaining structure design at current condition with saturated density at Dasgaon.
iv. Retaining structure design at current condition with saturated density at Sahilnagar.

H. ***Modeling of The Retaining Wall***

Figure 11 shows the modeling of cantilever retaining wall done in Stad- Pro software as per the geometrical details given in table IV. The retaining wall is designed for 7.5 M and 5.5 M respectively for Dasgaon and Sahilnagar. The design values are described in Table no. IV. The loads are calculated by the Indian standard code. These loads are applied to the designed models and the stresses and Overturning moments are calculated and changes are observed.

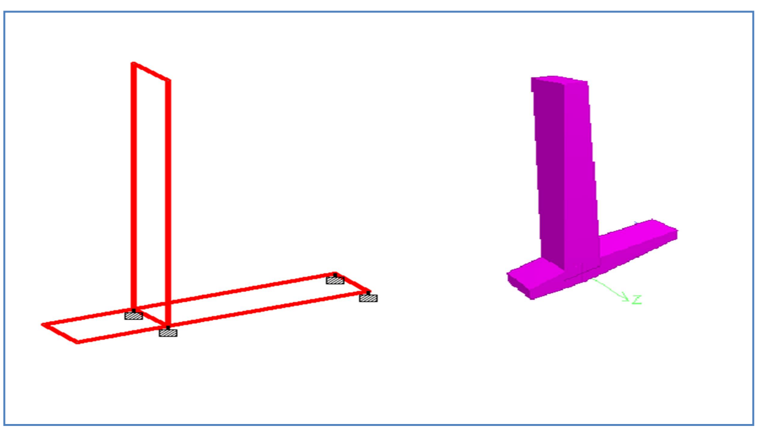

**Figure 11:** Modeling and 3D view of designed models

The following figure12-15 shows the stress calculation in the retaining wall in Stad – Pro software.

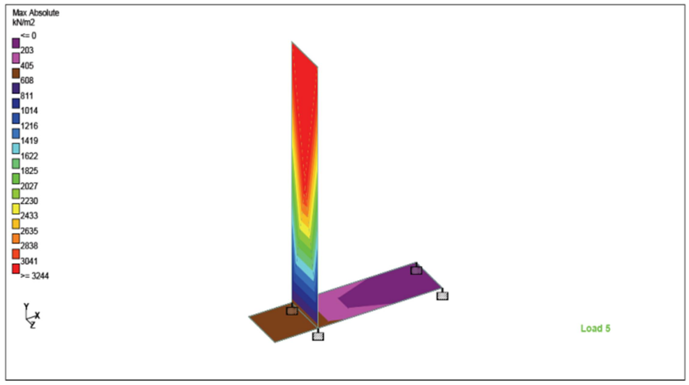


**Figure 12:** Stresses developed in design values at the time of structural design at Dasgaon

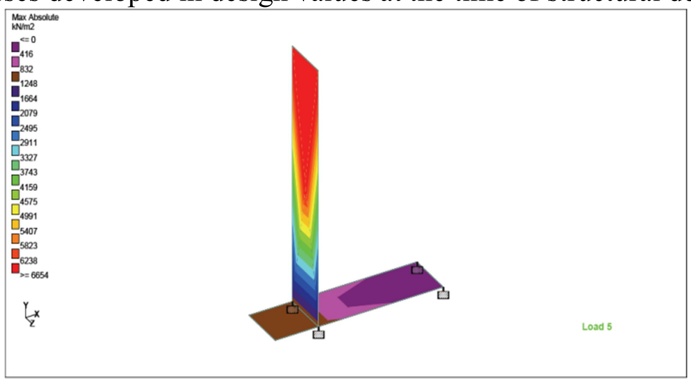


**Figure 13:** Stresses developed in design values at the current condition in saturated condition at Dasgaon

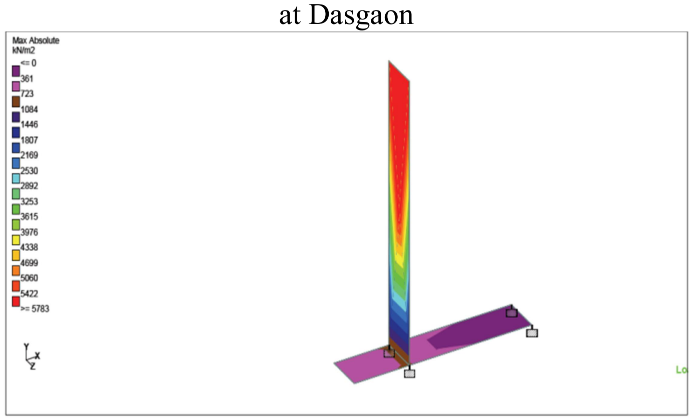


**Figure 14:** Stresses developed in design values at the time of structural design at Sahilnagar

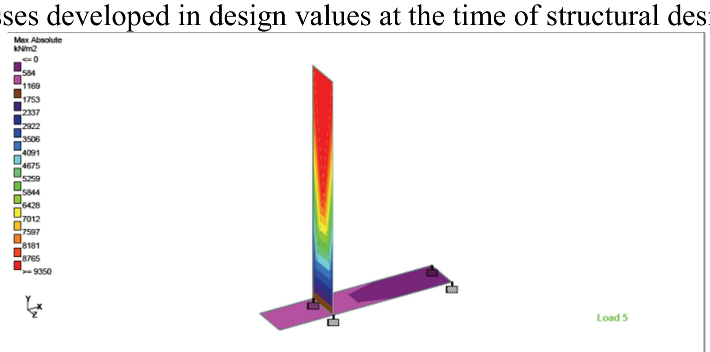


**Figure 15:** Stresses developed in design values at the current condition in saturated condition at Sahilnagar

## IV. RESULTS AND DISCUSSION

The Table No.IV shows the Factor of safety calculated at the saturated condition for Dasgaon and Sahilnagar. This table concludes that as the water content and small particle in the soil increases, the value of Ø decreases and saturated density increases. The value of active and passive earth pressure depends on the Ø value. The decrease in the Ø value may result in an increase in the active earth pressure and decrease in the passive earth pressure.

Due to an increase in the active earth pressure, the total vertical load increases and the overturning moment also increases reducing both the factors of safety.

From figure 16, it is observed that the factor of safety decreases as the water content in the soil is increases. It can be observed figure 17 that the water content in the soil increases which reduces the minimum pressure at the base and increases the maximum pressure at the base.

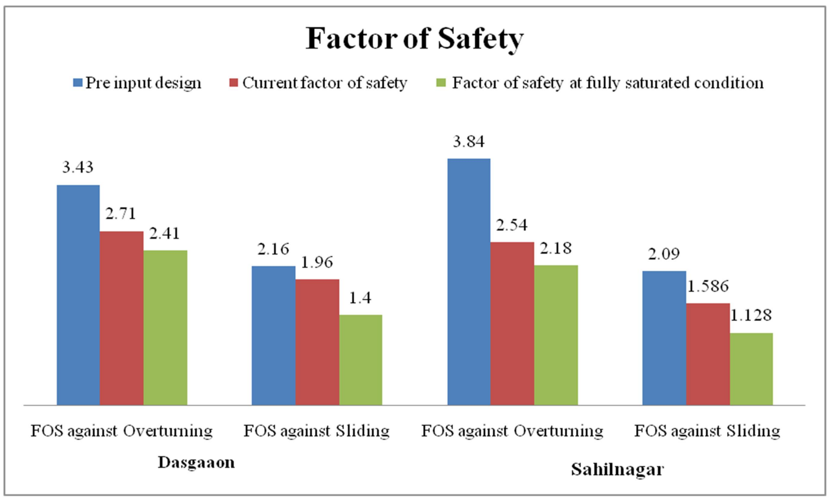


**Figure 16:** Changes in Factor of safety

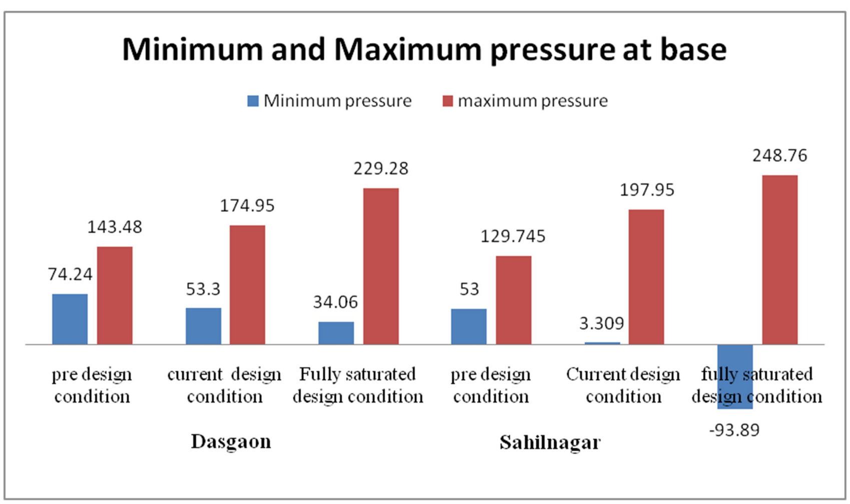


**Figure 17:** Minimum and maximum pressure developed at different condition

Figure 18 shows the variation in total horizontal moments developed in structures in the pre and post-construction conditions. The first and second bar shows the pre and post total horizontal moment developed which is manually calculated. The third and fourth bar shows the pre and post total horizontal moment developed which is calculated by the software.

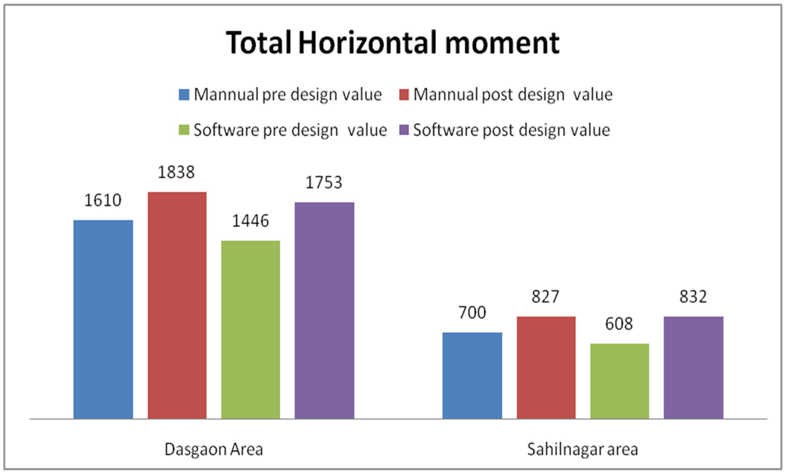


**Figure 18:** Calculation of total horizontal moment

From this data, it is clear that the natural moisture content in soil increases due to natural activities such as rain, etc., and also from human activities such as irrigation, artificial water flow, etc. This may decrease the internal angle of friction of soil and cohesion, resulting in a decrease in the factor of safety considered while designing the structure. Due to weathering action, the percentage of finer material changes also affect the serviceability of the retaining wall.

**TABLE V: Result of Analysis from software**

| **Design parameters** | **Design values at the time of structural design at Dasgaon** | **Design values at a current condition in saturated condition at Dasgaon** | **Design values at the time of structural design at Sahilnagar** | **Design values at a current condition in saturated condition at Sahilnagar** |
|---|---|---|---|---|
| Weight of structure (kN) | 220.808 | 220.808 | 118.493 | 118.493 |
| Maximum Overturning moment ($kN/M^2$) | 489.902 | 639.977 | 141.626 | 341.936 |
| Stresses developed at joint in between stem and base slab ($kN/M^2$) | 1446 | 1753 | 608 | 832 |
| Resultant node Displacement (mm) | 15.983 | 25.964 | 6.455 | 13.363 |

## V. CONCLUSIONS

To deal with natural disasters like landslides the need of the earth retaining structures along the ghat section roads are crucial. The investment and the efforts to construct ERS are very huge. It is observed from the study that the input design parameters considered at the time of designing of ERS changed due the obstructed drainage path. This causes the changes in the moisture content, finer material in the backfill, and the state changes from plastic limit to liquid limit very suddenly. The factor of safety against overturning and sliding is reduces as phi value is reduced and the saturated density increases. Also the minimum pressure at the base reduces and maximum pressure increases as the soil is in contact with water. Sahilnagar retaining structure failed due to changes in backfill properties and the Dasgaon retaining structure is also passing through such changes in the backfill properties. The changes observed in a very short period show the important concern related to the input design parameter considered at the time of design. Due to the variations in input design parameter, considered at the time of design and for the current scenario show that the ERS will never serve for its full-service life unless and until the predicted and calculated input design parameters will lie in predefined range for at least 80% of provided service life.

This proves that due to a change in the considered input design parameters at the current condition the serviceability of the cantilever earth retaining structure is about to decrease against a pre-decided lifespan of 60 years. To avoid such a phenomenon, it is required to protect the backfill material from the entry of flowing water above and below the earth's surface during heavy rainfall. According to laboratory tests and calculations made from the study at Dasgaon and Sahilnagar ERS, it is found that the changes in the water content and percentage of finer material in the composition of soil impacts the structural safety with proportionate changes in respective FOS for which the structure is to be constructed. Therefore it needs to manage these parameters in a safe range to achieve and enjoy the service for a design lifespan of 30-60 years.

To avoid such types of failures following remedial measures are being suggested through this dissertation after the brainstorming on observations and test data.

1. Majority of the times, the changes were observed due to increase in the moisture content in the soil, therefore it is important to moderate the water that comes towards backfill on the soil and below the soil. It is required to protect the backfill material from the entry of flowing water above and below the earth's surface during heavy rainfall.
2. At the time of designing the structure, the designer should consider all soil input design parameters at their respective liquid limit.
3. The input design parameters vary with the variation in the % of finer material in the composition of the soil; therefore it triggers the need to moderate the properties periodically to keep the input design parameters within the safe range.
4. Most retaining structures failed in the rainy season, therefore there is a need to find out the water drainage pattern and block them so water cannot pass through the backfill and the pore water pressure is not exerted much on the retaining wall.

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