International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 07 | July 2024 www.irjet.net p-ISSN: 2395-0072

A Review on Resistance Factor Design and Resistance Factor Calibration of the Internal Limit States of Soil Nail Wall

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ABSTRACT

A method used for soil stability, when landslides are a major problem, is building a wall with dirt and nails. A slope can also be strengthened and stabilised by using it. To strengthen the natural ground, the process known as "soil nailing" includes grouting metal bars, sections, or steel reinforcement (such as nails) into the drill holes. It is a top to down method of building. In order to stabilise slopes, excavations, etc., it is utilised. To construct retaining walls in cut applications (top-down design), soil nailing has become increasingly popular in the United States. Current state of the resistance factor and soil nail design. By utilising the Federal Highway Administration's (PHWA) most recent nail load and occupancy model, a generic approach for calibrating resistance factors for It is briefly presented the pull-out load and resistance factor design (LRFD) and the tensile failure internal limit conditions of soil nail walls. Resistance factor designs for the permanent soil wedge and the anchor's pullout limit site are calibrated against a large design space. For computing resistance factors, Simple models for artificial neural networks (ANNs) have been created. The paper also discusses concerns regarding the impact of outliers in datasets and potential dependencies between variables that may have a significant impact on the calibration results.

Keywords: limits of internal stability, tensile yielding capacity, Setting the resistance factor's calibration, and the load factor Index of target reliability, Reinforced Soil Walls, Steel Reinforcement, and Soil Nails.

1.INTRODUCTION

Since the late 1960s, engineers and construction professionals in a number of nations, including the US, Europe, and Japan, have used the special efforts and benefits of soil nailing. Geotechnical engineering techniques such as foundation reinforcement of soil have a wide range of uses for stabilising excavations and slopes. Advanced composite material reinforced soil is made of dirt and reinforcement. The compressive and tensile strengths of this substance are comparable to those of reinforced cement concrete. Nature contains the fundamental concepts of soil reinforcement. In 1969, Vidal was the first to employ a cutting-edge method of soil fortification. According to Vidal's idea, the soil and the horizontal parts that provide frictional reinforcement. In 1986, retaining walls were built in France utilising this idea. Nowadays, developing nations frequently adopt slope reinforcement techniques. There has been significant theoretical development in the field of reinforced soils. In a railroad widening project in France, close to Versailles, an 18-meter-high sandbank was stabilised for the first time. **(Rabejac and Toudic, 1974)** There has been significant theoretical development in the field of reinforced soils. France and other European countries have a higher prevalence of soil nailing. The earthen wedge wall was initially utilised in Germany in 1975.

Over the past 25 years, reinforced soil (RS) walls have been used in India and are being used more frequently in the construction of bridges and roads. Modern materials and technology are required for these applications. Theoretical advancements, design methodologies, and experience acquired in lab settings, full-scale tests, and field applications in the behavior of RS Walls in India and overseas have enabled practising engineers to use their knowledge more broadly. Projects involving roads and bridges use this technique. The release of these recommendations (hence referred to as the "Guidelines") covering design and construction techniques is long overdue, In order to benefit both new and existing users, it is essential to offer consistency in the design and philosophy used by different system manufacturers. It is believed that this must be guaranteed. Minimum standards and criteria for material acceptance must be met in order to ensure address the long-standing demand for In the realm of roadway and bridge engineering, homogeneity in partial load factors and partial material safety factors is important, as well as to achieve a design life of 100 years. **(INDIAN ROAD CONGRESS 2014)**

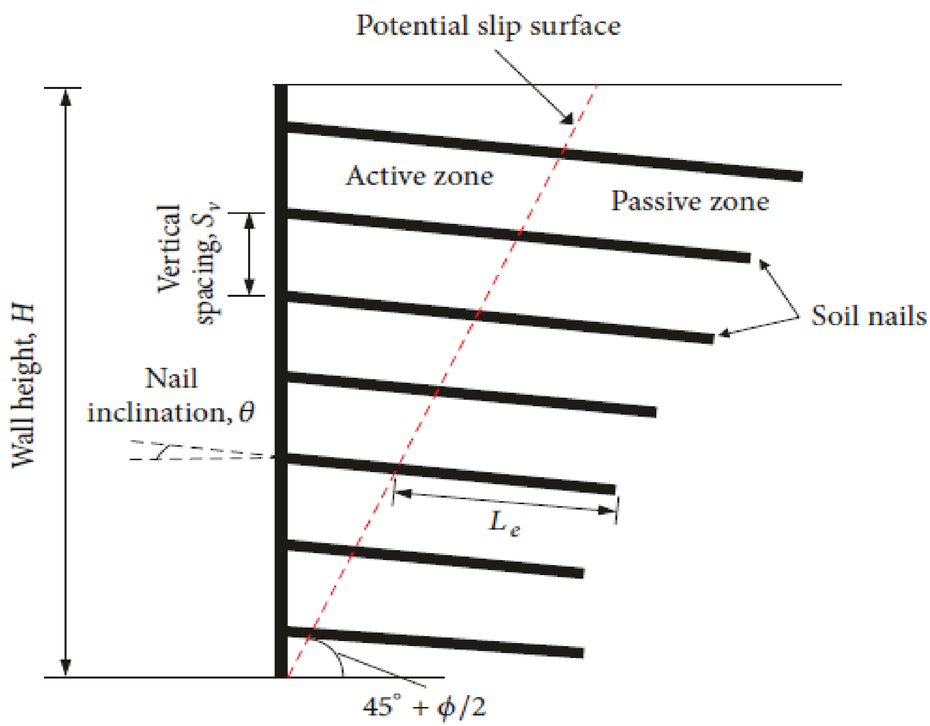

Fig1: Geometry of a typical soil nail wall. **(Huifen Liu,[1] et al. 2017)**

Design and implement of systems of systems for retaining soil and fill that direct to open areas. These rules apply to all bridges, flyovers, railway crossings, and high-fill retaining walls for road embankments. Benefits of resistant soil include increased power for carrying loads with lower compressibility in load. The recommendations do not cover the technical aspects of such applications. These recommendations do not include the support for carrying from open spans using RS walls. These requirements do not apply to reinforced soil constructions with slope angles less than 70 degree from the horizontal.

The procedure scope includes, but is not restricted to:

(1) The soil used in its construction, the reinforcements type and qualities.
(2) Types of facing, fill and reinforcement.
(3) Material evalution.
(4) Design techniques.
(5) Extensive fabrication procedures to meet requirements RS wall behavior and attributes. **(INDIAN ROAD CONGRESS 2014)**

1.1 Concept of soil nailing

According to the idea behind soil nailing, slopes and excavations are stabilised from top to bottom. Soil-nail interaction leads to the generation of tensile tension in soil nails, which gives soil nails their reinforcing effect against ground deformation. The creation of axial force, which is essentially a tension force, is where the majority of resistances originate. In the past, bending and shear have been thought to contribute little to resistance.

A slope or excavation becomes more stable as a result of soil nailing.

a) Increasing both the shear resistance and the usual force influencing the shear plane. In the abrasive soil, the plane skidded.

b) In both cohesive and frictional soils, lowering the pushing force along the slip plane.Reinforcement is laid horizontally or parallel to a gradually slope in soil nailing. The direction of tensile stress to generate the maximum amount of tensile force. **(Arindam Dey 2015).**

1.2 Types of soil nailing

The following are some of the different kinds of soil nailing:

a) A grouted soil nail is introduced into the hole using either pressure or gravity after nails are initially positioned in the centre of the drill hole.

b) Driven nail **-** These nails are driven immediately following each stage of excavation.

c) Jet Grouted Nails: These composite inclusions are composed of dirt that has been grouted around a steel bar in the middle. High frequency nails are then put after vibro-percussion drive with high pressure grout.

d) Nails that are launched into the ground this technique involves rapidly firing nails into the earth. utilising the launcher for compressed air. This approach is quick, adaptable, and cost-effective. About 320 km/h is the setting speed for the nails. **2015 (Arindam Dey).**

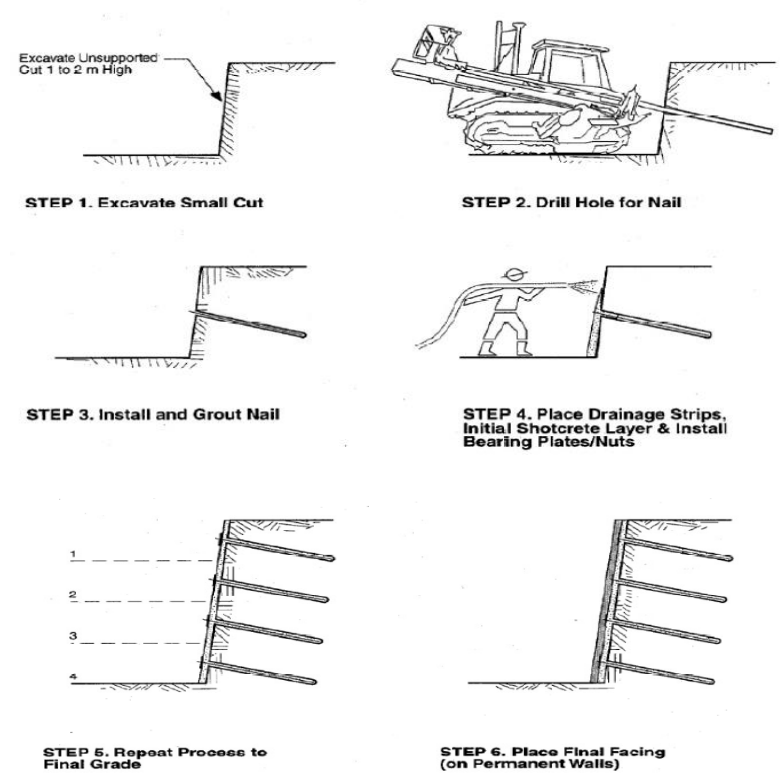

Fig2: Order of construction for soil nailing **(Byrne et al., 1998)**

1.3Main component or element of Soil Nail Wall

(a) Connectivity Elements

(b) Reinforce Bars

(c) Grout

(d) Centralizers

(e) Corrosion security

(f) Drainage structure

(g) Barrage face **(Carlos A .Lazarte et al. 2015)**

The following is a diagram of every major component of a soil nail wall.

Fig3a: Solid tendon in a photograph that has a steel plate, a washer, and nut studs that are not headed for attachment to the final facing. Thanks to DYWIDAG-System International for the image. **(Carlos A.Lazarte, 2015)**

Fig3b: Photo: Solid bars with threads with permission of Con-Tech Systems, Ltd. **(Carlos A.Lazarte, 2015)**

Fig3c: A typical grouting facility. Picture provided by Barry Siel, FHWA. **(Carlos A.Lazarte, 2015)**

Fig3d: Picture: The solid bar is fastened with standard PVC centralizers. (The centralizer spacing shown is solely for demonstration purposes; larger spacing is actually employed.) Thanks to Williams Form Engineering Corp. for the photo. **(Carlos A.Lazarte, 2015)**

Fig3d: Standard steel centralizers were fitted to the HBSNs in the image. Image provided by Schnabel Engineering. **(Carlos A.Lazarte, 2015)**

Fig3e: Photo: partial encapsulation by corrugated bark (right) and solid tendons with a grey or purple epoxy covering (left). Thanks to DYWIDAG-Systems International for the images. **(Carlos A.Lazarte, 2015)**

Fig3f: Solid tendon that has been photo-threaded with a steel plate, a washer, and a nut. studs that are not headed for attachment to the final facing. Thanks to DYWIDAG-System International for the image.. **(Carlos A.Lazarte, 2015)**

Fig3g: On-site shotcrete test panel curing is shown in the image. Thanks to Schnabel Engineering for the photo.. **(Carlos A.Lazarte, 2015)**

Fig 3: Main component of soil nail wall

1.4 Ground Condition

1.4.1 Suited soil

a) Remaining dirt and worn rocks

b) Stiff cohesive soils that are resistant to creep distortion, such as clay silt and other soil types.

c) Sand and gravel that is dense and has some adhesive qualities.

d) The elevation of a piece of land above the ground water table.

1.4.2 Non -Suited

a) Because they don't have enough time to stand up before nailing installation, they should use loose, fine-grained sand.

b) Soils with high moisture content or damp pockets because they compromise stability.

c) Excessive loads must be borne by soils because of their frost sensitivity and expansive characteristics.

d) Rocks that are severely fractured and have voids or open joints because to grouting issues.

2. MECHANISM OF SOIL NAILING:

To support excavation in soil or soft, worn rock, powerful, inert components called soil wedges are drilled and grouted:

- Stresses generated from soil or weathered rock mass deformation contribute primarily to the stability of earth-resistant structures.
- Use shear stress (also known as bond stress) along the grout-ground interface to transfer tensile loads to the surrounding ground.
- Create resistances that can be anticipated using recognized design processes.
- To guarantee adequate, long-term functionality of the system, corrosion prevention must be long-lasting and provable.
- Interact structurally with the excavator's front load testing is done using the recommended procedures.
- As per established protocols, routine manufacturing is submitted to QC/QA.**(Carlos A. Lazarte 2015, Sabatini, P.J., Pass, D.G. 1999, Sabatini, P.J., Bachus 2002, Sabatini, P.J., Tanyu 2005).**

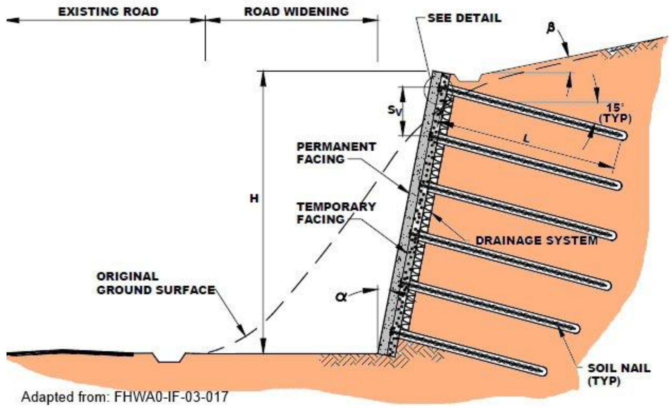

Fig4: Typical soil nail wall arrangement(https://www.deepexcavation.com/en/products/snail-plus-soil-nailing-software/design-of-soil-nail-walls-information ,2022)

A dirt nail wall's general construction system entails the following:

a) Diving for the initial nails

b) Installing initial

c) If necessary, add wire mesh or other reinforcement to the first layer of shotcrete that is put over the soil.

d) A soil nail head plate's smoke.

e) Shotcrete construction in a second stage.

f) To reach the next earth wedge's level, descend, add some shotcrete and another wedge, etc.

g) Using steps c) through f) repeatedly up until the last level of excavation is reach.

h) Build more permanent facings if necessary.

In construction, drainage filters and pipelines are frequently installed.

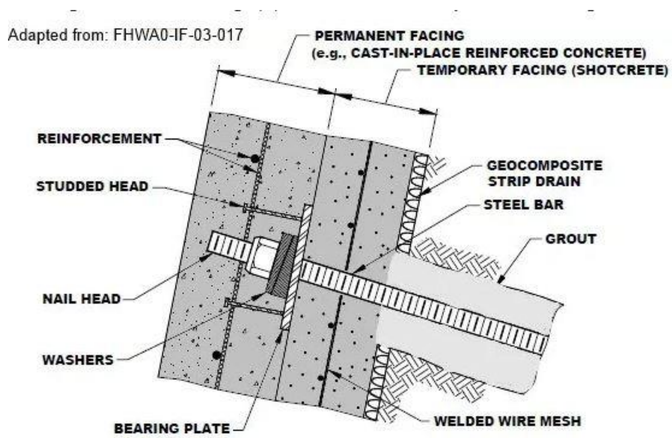

Fig5: Typical soil-nail wall cross section

(From U.S. Practice)(https://www.deepexcavation.com/en/products/snail-plus-soil-nailing-software/design-of-soil-nail-walls-information ,2022)

3. DESIGN PHILOSOPHY

- The structure in this paper enables manual users to:
- Check structural capacity using AASHTO load factor values "LRFD Bridge Design Specification" (2014) in typical LRFD equation style.
- Design soil nail walls using a specially created limit-equilibrium, conventional acceptable stress design (ASD) based computer programme to verify the supposed many in soil nail wall mechanism.
- Consist of resistance factors that are associated to the weight factor in AASHTO (2014) to produce designs that are as conservative as or somewhat more so than designs created using ASD based safety factors (FS) as described into earlier edition of this guide.

Include associated permissible boundary states and corresponding resistance components for further earth-retaining structures, compatible with, but not identical to those defined in AASHTO (2014), and that are rounded to the closest 0.05. **(Carlos A .Lazarte et al. 2015)**Include resistance characteristics that are relevant to the bare minimum frequency needed for verification testing.

a) Similar to artificial design ,LRFD focus on "limit state design", where soundness or crash situation is taken into account.

b) Factored load factored toughness, often known as.

c) Load factors are under control and increase loads, whilst resistance factors decrease toughness.

d) Load and load factor, resistance and resistance factors.**(J.S. Arora 2022)**

4. METHODOLOGY

4.1 The ASD Method (Allowable Stress Design)

Engineering design uncertainty has typically been acceptable stress design (ASD) factors of safety (FS). The allowed "stresses" (or, more generally, resistance) of structural components are determined using the ASD approach by dividing the components ultimate strength by FS. The general design requirement for the ASD technique is:-

$$\sum Q_i \leq R_{all} = R_n / FS$$

Where:-

$\sum Q_i$ is the outcome of every joint load operating on a certain structural component under a particular failure scenario.

R_{all} is the maximum stress that can be placed on that structural element.

R_n is the maximum or ultimate strength of a structural component.

FS is the applied safety factor to that maximum resistance.

4.2 The LRFD Method (Load & Resistance Factor Design)

In the AASHTO LRFD Bridge integrated LRFD approach

Four categories of limit states are defined in design specifications:

i) States of strength limlits
ii) States of extreme events

iii) States of service limits
iv) States fatigue limits

Strength bound state are those that pertain to the strength (usually known as nominal resistance in the LRFD standard, as define later) and stability of structural elements over the design life of the construction. Generally speaking a design equation can be written as follows for each strength limit state.

$$\phi R_n \geq \sum_{i=1}^{N} \gamma_i \eta_i Q_i$$

Where:-

Rn is nominal struggle of a specific structural element to the assumed strength limit condition

Ø is a Rn –related non dimensional resistance factor

Qi is the i-th weight type involved in this bound situation

γi is a Qi- related non-dimensional load factor

ηi is factor for weight adjustment

N is the variety of load type must be taken into account at the limit state.

The tendons' yield strength, the earth's shear strength, the addition resistance of the soil nails, and numerous facing resistances are examples of nominal resistances. The reader should be aware that the terms power (usually used in ASD platforms) and nominal resistance (often used in LRFD platforms) are equal in order to maintain consistency. The average nominal resistivity of the soil and other naturally occurring materials used in LRFD platforms. The measurement of clay resistance is done in the ground or in a lab. **(AASTHO 2014, Carlos A. Lazarte et al. 2015)**

5. SEQUENCE OF CONSTRUCTION

The key steps for building an earthen wedge wall are as follows: **(FHWA-NHI-14-007-2015)**

1) Digger
2) Nail-hole drilling
3) Setting up nails and grouting
4) Setting up a strip drain
5) The creation of new levels
6) Construction of final facing. **(Prashant C.Ramteke[1,2*] et al. 2022, FHWA. 2015)**

6. CALIBRATION FACTORS:

6.1 Resistance factor:

There are numerous ways to check for resistance element. The most complex calibration methods rely on reliable statistical data and use the right statistical methods, and produce a system-wide level of reliability that is acceptable. However, as stated in NCHRP Report 701, there are a number of obstacles to creating a uniform and comprehensive database for soil nails. **(Lazarte 2011)**

In that study the record of soil nail load testing was used to adjust the resistance factor for soil nail pull out. Data inconsistencies, a lack of information about the installation processes for soil wedges poor load test paperwork and other shortcomings in the load testing were found.

Most importantly, none of the load tests applied enough pressure to maximise the test fingernail pullout resistance. Due to these resistance factors based on reliability was achieved. **(Carlos A.Lazarte et al. 2015)**

6.2 Load Combinations

It is necessary for structural design to take into account the immediate incidence of several consignment type in load combination. The following load combinations are frequently taken into account for clay wedge design in public road projects using the LRFD structure

- State of repair Limit
- Stage I power Limit
- Extreme-Even Limit State I (including the earthquake load)

6.2.1 Load Factors:

There are permanent transitory and peak incident loads among the load combinations listed above. These loads assigned load factors are:

- Dead loads from structural elements and non-structural attachments (DC)
- Dead loads from worn surface and utilities (DW), while sustaining a connection abutment or the road; and dead loads from utilities.
- Vertical forces brought on by the dead load from earth fill (EV)
- Earth pressure load (EH)
- Earth surcharge load (ES) **(AASTHO 2014, Carlos A. Lazarte et al. 2015)**

6.3. BENDING MECHANISMS:

The following formulas for reinforced concrete design are used to estimate the bending resistances

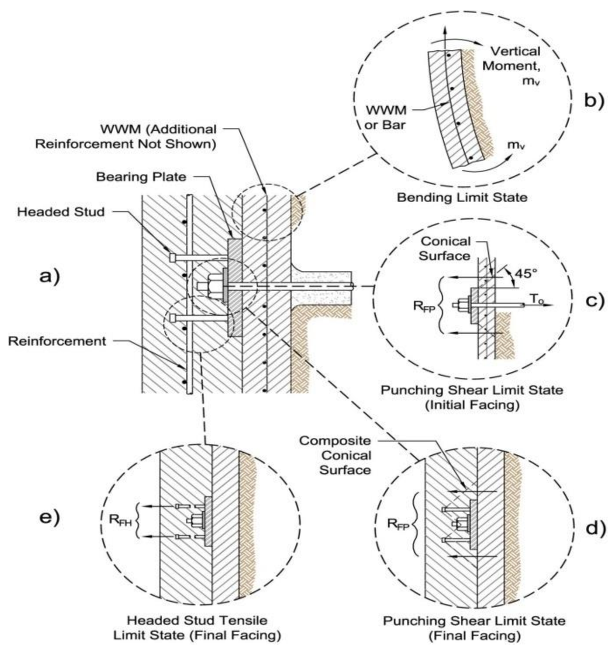

Fig6: Limit the dirt nail wall's sides. the tension of the headed stud; the tendency of a facing segment; the punch shear in the initial opposite; the punch shear in the final facing; and (a) a typical facing scheme. from Modified after Lazarte ,2011**(CarlosA.Lazarte,2015)**

For the initial face, a normalised section of reinforced shotcrete or thick concrete (or thick hf for the final facing) is used schematically depicted in the figure, with the reinforcement in the centre of the section. WWM alone or in combination with rebar can be used as reinforcement. The height of hi (or hf) will be represented by the thickness.

According to the reinforced concrete design, a similar beam can withstand pure bending. The figure show the instant per unit length (mv) rotating along a horizontal axis. **(Carlos A. Lazarte et al. 2015)**

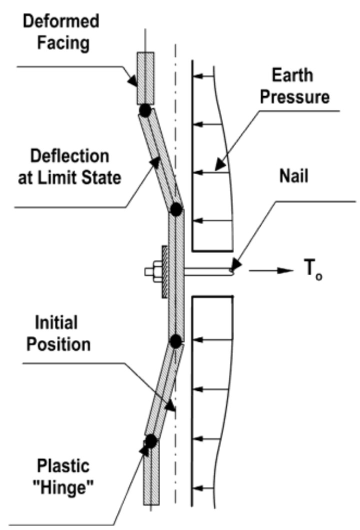

Fig7: Illustration Bending mechanism and nail force in facing. Modified after Lazarte (2011). **(Carlos A.Lazarte, 2015)**

7. FAILURE MADE OF SOIL NAILING:

Following are the three possible causes of soil nailing failure:

a) **A face failure:-** When a soil nail wall with long nails that have both high and low tensile strengths collapses, it results in this type of failure. when a failure undermines the active region's ability to remain stable., the strength of the head will emerge.

b) **Pull-out failure**:- This occurs when the strength and tensile capacity of the soil nail are high, as well as restricted penetration into the passive withstand area. The force produced by the nails in the active zone will depend on the length of the reinforcement in the passive zone, and this force is expressed as.

$\mathbf{Q = \pi q D_{DH}}$

D_{DH} stands for the effective diameter of the nail hole, Q for the mobilised pull-out per unit length, and Q for the mobilised shear stress acting on the vicinity of the soil nail. By consider a only nail section that is subject to a tensile strength, T_0, at one stop and applying a balance of forces along the degree of difference length section (Dx) of the nail, it is possible to determine the tensile force from the interface shear stress:

$$\mathbf{dT=p\ qDDHdx = Qdx}$$

The anticipated total pull-out force (F) is given as follows if the passive region's soil nail's implanted length is LP:

$$\mathbf{F = Q.L_P}$$

c) **Nail tendon Failure:-** Failure of the nail tendon happens when there is enough nail length but a little amount of tensile stress.**(Arindam Dey 2015)**

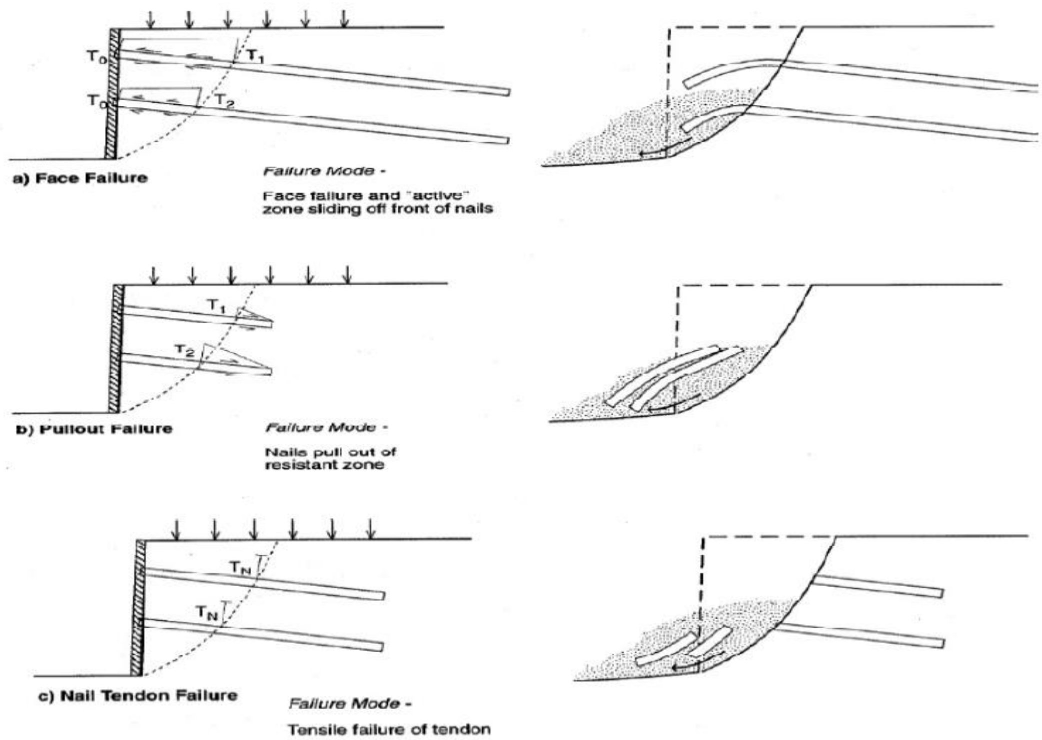

Fig8:-Potential causes of soil nail walls failing **(Byrne et al., 1998)**

8. RESULT AND DISCUSSION:

The suggested closed-form result is used to calculate the resistance factor (2017) by Bathurst et al. The approach bias statistics the relationship between the nominal load and resistance terms as well as the uncertainty in the nominal load and resistance terms' amounts for various combinations of load and resistance models, method bias values, and dependence between nominal standards are all taken into consideration in the method for calibrating resistance factors. Closed-form solutions also offer the advantage of simplifying the calculation of resistance factors using an Excel spreadsheet and the evaluation of the pressure of method bias and input limitation variability on the final resistance factor values. **(Lazarte et al. 2015; Lin et al.2017a, b; GEO 2008)**Soil wedges are passive additions that increase the soil's ability to withstand shear. Zones that are active and passive can be seen in the soil-nail system. The active zone becomes distorted during slope collapse, whereby the soil nails positioned across the slip plane experience axial displacement. The soil wedge experiences tensile pressures as a result. a passive zone that prevents the active region's deformation. This tension causes an increase in force reduces the driving shear force and the normal force on the fall jet. The rubbing of dirt and nails on the slope is prevented by clay nails inserted in the passive zone. **(Arindam Dey 2015)**

8.1 LIMITATIONS

1. Because this method creates dynamic friction resistance with ground deformation, it cannot be employed in situations where strict distortion control is necessary.

2. For soil nailing, sand and gravel might not be suitable.

3. Areas with high water tables should not be used.

4. Extremely high soil nail densities may be necessary for soil nailing in soils with very low shear strengths.

5. For long-term, permanent applications, soil nailing is not advised in expansive soils and sensitive soils. **(Arindam Dey 2015, Piyush Sharma)**

8.2 ADVANTAGES OF SOIL NAIL WALL

The following are some benefits of a dirt nail wall:

• Simple adjustment of soil nails while dealing with piles and other underground obstructions.

• Lessens the impact on the environment and the disruption of traffic.

• The quick construction could be to blame.

• Affordable at difficult-to-reach places and distant regions.

• Successful in restoring landslides that aren't on the slide trail.

• Fairly adaptable, allowing for both large aggregate and differential movements.

• It functions flawlessly under earthquake loading.

Due to the greater redundancy than ground anchors, a passive system with relatively moderate tensile stresses exerted by the reinforcing elements, a well-established construction quality assurance programme, and the higher density of reinforcing components per unit area.

• More affordable than conventional earth retaining systems for lengths of over 15 feet.

• Ground anchors are typically equally as cost-effective as walls, if not more so.

9. FUTURE SCOPE:

Soil nailing is most commonly used for new building projects, including foundation excavation and slope stabilisation, both temporarily and permanently. Given the current economic trends, it is most likely that this industry in India will be where nailing finds its most widespread use. The technology is equally useful for a variety of corrective tasks. It is envisioned that practical research collaboration between industry, universities, and government will support the development of technology in India, much like it does in developed nations like Germany, France, It is most likely that this industry in India will be where nailing finds its most widespread use. **(Piyush Sharma)**

10. CONCLUSIONS

1) An all-inclusive technique for this work presents resistance factor calibration for nail pullout and tensile yield strength of steel bar (nail tendon) limit states.

2) Resistance factors were created utilising a number of load and resistance model combinations for the load and resistance factor design of nail pullout and tensile yield strength limit states.

3) For the two cases, the resistors were calibrated for target reliability indices of 2.33 to 3.54 and load factors of 1 to 2. One method involves directly estimating employing the Hong Kong CDG and CDV soil characteristic data, the uncertainty in the nominal load and resistance values at the time of design.
The second method, which was founded on the idea of understanding level, employed a more expansive definition of nominal load and the coefficient of variation of nominal resistance.

4) The calibrated resistance factors for the nail pullout limit state utilising the current load and resistance model were typically greater than 1.00 due to the model's inherent conservatism. The resistance factors were ascertained using the

modified model. For the nail tensile yield strength limit condition, the expected resistance factors were all less than 1.00. An example design for soil nails supporting a 10-metre-high wall in Hong Kong CDG soil was used to show how calibrated resistance factors are implemented in the LRFD framework using various combinations of load and resistance models.

5) The resistance factors in the example design were set to 1.00 in order to meet the supplies of the LRFD devise code. The plan outcomes showed that the enhanced load and resistance model, combined with longer largely lengths of soil spikes and minor steel bar diameters, provided better solutions than the existing load and resistance model.

6) This stresses the benefit of refining weight and resistance models for soil nail wall inside stability devise by empirical modification, as established in other related works. LRFD is a subset of reliability theory-based analysis and design, as described in the introduction. LRFD provides the designer with straightforward boundary-state equations for foundation design issues, including soil-structure interaction.

7) Since the true margin of safety is unknown, there are fewer possibilities for the designer to further optimise plan choices or possibly adopt a better boundary of security than that suggested by this learn or the one used to determine resistance factors. The same data, model, and example from this study were used by Lynn, an LRFD code writer, to offer a reliability-based devise (RBD) advance for dirt nail walls.

8) Even though this research focuses on the resistance side, LRFD calibration was performed using Hong Kong soil nail data; however, load-side models are more broadly applicable.

9) As a result, the resistance factors found for Case 2 in this study may be used as default values for initial design purposes if the designer is confident that the soil type, nail type, and installation method will be reasonably similar for subsequent projects.

10) The similar is true of the determined tensile bound state resistance factors in this article. In a perfect world, load and resistance bias data from the same type of structure and for the same ground conditions would be used to calibrate any basic soil-structure boundary states. To the authors' knowledge, there is currently no information available regarding the contributions from load and resistance to the two limit states examined in this study. The LRFD calibration approach suggested in this research can be used with a variety of nail and soil type combinations if matching load and resistance data are supplied.

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