Report on

Rehabilitation Measures of Distressed RE Walls

of project

Four Laning of Sargaon - Bilaspur of NH-200 section (Package-III) from km 91+026 to km 126+525 section of Raipur-Bilaspur in the State of Chhattisgarh under NHDP-IV on EPC Mode

by

Prof. Guda Venkatappa Rao

Dr. Anil Dixit

Dr. Kolli Mohan Krishna

Geosynthetics Technology Advisory Services LLP

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Project Director, PIU, Bilaspur

National Highways Authority of India

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1.0 Introduction

A detailed technical inspection of the distressed Geosynthetic Reinforced Soil (GRS/RE) walls and earthen embankments was undertaken on 4th and 5th July 2025 for the project "Four Laning of Sargaon – Bilaspur section of NH-200 (Package-III) from km 91+026 to km 126+525 of Raipur–Bilaspur corridor in the State of Chhattisgarh under NHDP-IV on EPC Mode". The inspection was carried out by Dr. Anil Dixit and Dr. Kolli Mohan Krishna, following a request received from the Project Director, PIU–Bilaspur, NHAI (Ref: 13011/1/PD-BSP/SRGN-BSP/2025/1061 and 13011/1/2025/PD-BSP/SRGN-BSP/1075). Subsequent detailed technical discussions were also held on 6th July 2025 with officials of NHAI at the Regional Office, Raipur.

A total of four RE wall locations and three high embankment locations were inspected during the site visit. The RE walls in the project were constructed with precast concrete panel facia reinforced with polymeric geostrips. The project was executed by M/s Dilip Buildcon Limited (DBL) under EPC mode and RE wall were completed around 2018.

It was understood from site visits that bulging of RE wall facia panels had been observed during the previous year, following which remedial measures in the form of soil nailing were implemented discretely at certain locations. The nature and severity of distress varied across different locations. A detailed site visit report was submitted on July 15, 2025.

Based upon the above, the work of detailed geotechnical investigation, evaluation of existing distress mechanisms, review of earlier remedial measures, and development of appropriate rectification and strengthening solutions was entrusted to M/s Geosynthetic Technology Advisory Services LLP, Jaipur (Ref: 13011/1/2025/PD-BSP/SRGN-BSP/1678)

The present report presents the investigation findings, assessment of distress mechanisms, and recommendations for remedial measures of the RE walls.

2. Site Observations

During the site visit, following critical observations were made.

- Significant bulging of RE walls (km 106+224 (Figure 1); km 102+570 (Figure 2); km 96+426 (Figure 3); km 91+861 (Figure 4)) was observed across multiple chainages, with many locations displaying 10 m to 30 m stretches of distress. In multiple locations, panels were seen displaced 10 cm to 15 cm (relative to adjacent panels), indicating severe distress and critical condition of these walls.
- Soil nailing, wherever done, was found to be inadequate, with only one or two nails per panel in many locations.
- Cracks/crushing in panels and local surface settlement at several locations.
- Cracks and open joints in the CC pavement at the top of the wall were observed, allowing water to ingress into the wall system

a)  b) 

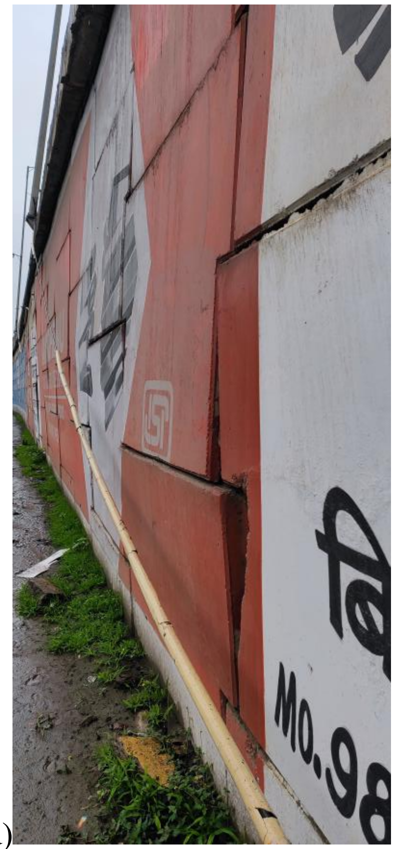
c)  d) 

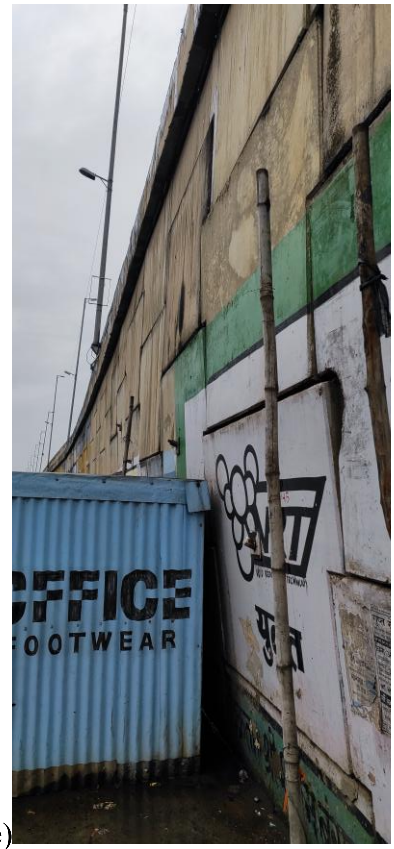
Figure 1 Photographs depicting bulging of RE wall at km 106+224

a)  b) 

Figure 2 Photographs depicting bulging of RE wall at km 102+570

c) 

d) 

e) 

f) 

Figure 2 (Continued)Photographs depicting bulging of RE wall at km 102+570

g) h)

Figure 2 (Continued)Photographs depicting bulging of RE wall at km 102+570

a) b)

Figure 3 Photographs depicting bulging of RE wall at km 96+426

Figure 3 (continued) Photographs depicting bulging of RE wall at km 96+426

g) h) i) j)

Figure 3 (continued) Photographs depicting bulging of RE wall at km 96+426

Figure 4 Photographs depicting bulging of RE wall at km 91+816

3. Investigations

To identify the causes of the above bulging and to evaluate the existing soil properties, bore hole was undertaken near the bulged zones. As per design, reinforced and retained fill shall be same type**.** In total, thirteen boreholes were executed for four structures at their RE wall approaches:

- km 106+224 – two boreholes on A1 side and two boreholes on A2 side at median location to a depth of 12 -13 m (refusal).
- km 102+570 – two boreholes on A1 side and two boreholes on A2 side at median location to a depth of 9 m (refusal).
- km 96+426 – two boreholes on A1 side and two boreholes on A2 side at median location to a depth of 12 m (refusal).
- km 91+816 – one borehole in the A1 median, to a depth of 12 m (refusal).

In each borehole, SPT and undisturbed soil sampling were carried out alternately at successive depths to establish a representative soil profile. Laboratory testing of the collected samples were carried out for soil properties.

The detailed results of these investigations are presented in **Annexure-I**, and relevant findings are discussed in the following sections.

4. Investigations Summary and Reasons for Distress

4.1 Fill Material

The RE wall fill is predominantly composed of sandy clay (SC). The testing of reinforced fill collected from the trial pits and boreholes revealed that the **fill soil contains more than 15% fines, which is beyond the permissible limits specified in IRC and MoRTH for reinforced soil structures (Table 1). The Plasticity Index was also found to be greater than 6% in most of the samples. Such fill materials are not permitted as reinforced backfill. The clay content in fill soil is around 18-28% with low-medium swell type clay. The consolidation tests of fill soil also indicated fill soil is of medium compressible type.**

The direct shear tests at field density indicated that the friction angle values of the soil fill (26^0-31^0). The friction angle adopted in the original design is 32^0. It confirms wide variations in fill type, density and shear strengths in all RE walls with soil fill.

In reconstructed portion of km 106+224, flyash soil was used earlier which is also tested. For flyash, the direct shear tests at field density indicated that the friction angle values of the soil fill (30^0-34^0). The friction angle adopted in the original design is 32^0. It confirms wide variations in density in flyash portion of km 106+224.

Table 1 Comparison of fines content and PI of **reinforced fill (Soil fill)** with permissible values – Summary of all structures

Major Fill Soil type	Fines content	Permissible limit for fines content	PI	Permissible limit for PI	Clay content
SC soil	14-57%	15%	~18-28%	6%	~16-26%

4.2 Foundation Soil

The foundation soil is majorly stiff silty clay type soil with medium to high compressibility. The thickness of clay foundation below RE wall was found to be from 2-5 m resting on rock.

4.3 Reasons for Distress

From investigations, bulging observed in the RE walls is predominantly attributed to the use of non-select, high fine-content plastic soil as backfill material. The relatively low shear strength and stiffness characteristics of the backfill soil have resulted in excessive lateral deformation, leading to pronounced bulging of the wall facings. This condition is further aggravated by settlement of the underlying clayey foundation soil.

Signs of panel distress, including localized crushing and settlement at the top of the wall, are indicative of both backfill settlement and foundation soil deformation. These observations clearly confirm inadequate performance of the fill and foundation strata.

To mitigate further progression of bulging in the affected locations, it is recommended to stabilize the reinforced soil mass through soil nailing at the presently observed bulging zones, particularly in slightly and moderately bulged stretches.

For locations exhibiting significant bulging and structural distress, dismantling and reconstruction of the affected RE wall stretches is recommended to ensure long-term stability and serviceability.

A summary of recommendations based on the site visit observations and geotechnical investigations is presented below.

Table 2 Summary of Recommended Remedial Observations

Structure Chainage	Bulging Category	Corresponding Chainages (Stretch)	Recommended Remedial Measure
km 106+224	Slight Bulging	A2 LHS (106+270 – approx. 20 m); A1 LHS (105+750–700); A1 LHS (105+810)	Nailing
km 106+224	Moderate Bulging	A1 RHS (106+250 – approx. 100 m); A1 RHS (106+200); A1 RHS (105+950); A1 RHS (105+840); A1 RHS (105+800 – soil/flyash junction); A1 LHS (105+840–860)	Nailing
km 106+224	Significant / Heavy Bulging	A2 LHS (106+550 – 10–15 m); A1 RHS (106+000); A1 RHS (105+790–750); A1 RHS (105+836); A1 LHS (105+830)	Reconstruction
km 102+570	Slight Bulging	A2 RHS (102+880); A2 RHS (102+650); A1 RHS (102+310); A1 LHS (102+328)	Nailing
km 102+570	Moderate Bulging	A2 RHS (102+900); A2 RHS (102+776); A2 RHS (102+762–730); A1 RHS (102+425); A1 RHS (102+360–356); A1 LHS (102+290); A1 LHS (102+424–450); A1 LHS (102+450–480); A2 LHS (102+660); A2 LHS (102+780)	Nailing
km 102+570	Significant / Heavy Bulging	A2 RHS (102+830 – 20–30 m); A2 RHS (102+810); A2 RHS (102+716 – 10–15 m); A2 RHS (102+600); A1 RHS (102+580 – 20 m); A1 RHS (102+546); A1 RHS (102+512); A1 RHS (102+502 – 15 m); A1 RHS (102+476–403); A1 LHS (102+340); A1 LHS (102+410); A2 LHS (102+608 – 25 m); A2 LHS (102+684 – 20 m)	Reconstruction
km 96+426	Slight Bulging	A1 RHS (96+242); A1 RHS (96+156); isolated minor stretches along A1 LHS	Nailing
km 96+426	Moderate Bulging	A2 RHS (96+682); A2 RHS (96+673–677); A2 RHS (96+605); A2 RHS (96+587); A2 RHS (96+485–493); A2 LHS (96+450); A2 LHS (96+640); A2 LHS (96+680); A1 RHS (96+176)	Nailing
km 96+426	Significant / Heavy Bulging	A2 RHS (96+645–615); A2 RHS (96+555 – 10 m); A2 RHS (96+455–461); A2 RHS (start stretch around 100 m); A2 LHS (start stretch around 25–30 m); A2 LHS (96+582 – approx. 150 m); A1 RHS (96+290); A1 RHS (96+210–198); A1 RHS (96+148–140); A1 RHS (96+128–078); A1 RHS (96+038); A1 LHS (96+100); A1 LHS (96+300)	Reconstruction
km 91+861	Moderate Bulging	A1 LHS wing wall	Reconstruction
Any other chainages recently observed or missing in above list may be also treated as per above recommendation appropriately			

5.0 Stabilization of Slightly and Moderately Bulged Zones of the RE walls by Soil Nailing

In view of the varying level of bulging observed across all walls, which seems to be increasing with time, soil nailing seems to be the one of the appropriate options to stabilize the distress zones. Keeping this in mind, trial nails were installed, and pullout tests were conducted in order to assess the appropriate fill-nail friction properties for stability analysis.

5.1 Trial Nails Installation

Eighteen trial nails – (9 solid nails and 9 SDA) were installed at km 106+224 and km 96+426 (Figure 3) for pullout testing to assess nail bond strength randomly. Subsequently, NHAI/contractor installed the trail nails. A brief installation procedure for solid nails is as follows:

- Mark the location of the soil nail with marker/paint.
- Use a man basket arrangement attachment to the Hydra or appropriate safe platform for access to the nail drilling point.
- Use core cutting, to drill suitable dia. (~ 115-120 mm) hole in RE panels in marked locations.
- Use a ~115 mm dia. drill bit to drill into the soil for the required length (6 m) as per specification at a 15-degree downward angle.
- A PVC pipe of about 1000 mm length shall be inserted inside the hole to act as a casing and unbounded area. This is to prevent the ingress of cement grout into the filter media area in case of drainage media presence.
- Then a solid nail of 25 mm diameter and specified length (5 m + 0.5 m) with spacers shall be inserted into the hole. The protruded nails should be threaded to fix pull-out test equipment.

- Cement grout can be prepared at the site using cement and water (cement: water < 1:0.5).
- The grout material is then pumped under gravity to fill the hole.

A brief installation procedure for SDA nails is as follows:

- Mark the location of the soil nail with marker/paint.
- Use a man basket arrangement attachment to the Hydra or appropriate safe platform for access to the nail drilling point.
- Use core cutting, to drill suitable dia. (~ 100 mm) hole in RE panels in marked locations.
- A PVC pipe of about 1000 mm length shall be inserted inside the hole in case of drainage media presence.
- Then an SDA nail of 32 mm diameter with ~72 mm drill bit and specified length (6 m + 0.5 m) installed by rotary and percussion action.
- Cement grout can be prepared at the site using cement and water (cement: water = 1:0.5).
- The grout material is then pumped under pressure around 100 kPa to fill the hole through SDA nail.

The summary of specifications of trial nails is as follows:

- Solid Grouted Nail diameter: 25 mm – ~115 mm hole diameter
- SDA Grouted Nail diameter: 32 mm; ~72 mm drill bit.
- SDA Nail Length: 6 m inside soil and 0.5 m outside panel for allowance to pullout test. Total nail length required in 6.5 m.
- Solid Nail Length: 5 m inside soil and 0.5 m outside panel for allowance to pullout test. Total nail length required in 5.5 m.
- Nail Inclination: 10-15 degrees.
- Grade: Fe 500 Nails

5.2 Pull-Out Tests of Nails

Pull-out testing of soil nails is identified as the appropriate test for analyzing the soil-nail interaction and assessing its performance. Besides checking the feasibility of installation, this installation and testing will also help in checking and verifying the bond strength between soil and grout adopted during design.

The procedure involves initially application of an arbitrary load not more than ~5 kN to take up slack in the equipment. The load was applied uniformly but at a slow rate to avoid any jerk in the bar till the bar started coming out. The nail pullout test is carried out using a hydraulic pump, hydraulic jack, calibrated pressure gauge, dial gauges, and a reaction mechanism using suitable platform. The soil nail was tested by increasing the load in increments of 10 kN until failure. The failure criteria are defined as the load at which the nail cannot resist further load or total extension of 40 mm is reached or bolt yields or fractures, whichever is early. During the application of pressure, the dial gauge observation was recorded at regular load intervals after both load and extension were stabilized. The data collated after the test was used for calculating the bond strength and shown in Table 3. Pullout testing was performed on 29/12/2025-31/12/2025, and Figure 5 depicts a few photographs of testing. FHWA recommends minimum 7 days after installation to carryout testing, which is followed without fail.

Figure 5 Photographs taken during trial nail installation and pullout testing

Table 3 Results of pullout tests (Ultimate load and corresponding displacement)

S.No.	Chainage	Type of nail	Approximate Elevation from OGL, m	Length of Nail inside soil, m	Ultimate Pullout Load, kN	Pullout displacement, mm
1	96+418	Solid	3	5	210	40
2	96+419	SDA	4	6	200	40
3	96+420	Solid	1.5	5	170	40
4	96+421	SDA	3.7	6	190	40
5	96+422	Solid	2	5	180	40
6	96+423	SDA	3	6	190	40
7	96+424	SDA	1.4	6	225	40
8	96+425	Solid	3.7	5	190	40
9	96+426	SDA	1.4	6	195	40
10	106+224	SDA	1.2	6	115	40
11	106+224	Solid	4.4	5	95	40
12	106+224	Solid	1.2	5	155	40
13	106+224	SDA	1.2	6	170	40
14	106+224	SDA	4.4	6	170	40
15	106+224	Solid	4.4	5	120	40
16	106+224	SDA	7.4	6	145	40
17	106+224	Solid	7.4	5	105	40
18	106+224	Solid	7.4	6	95	40

*Above values are after excluding seating/slack load & displacement.

**In 106+224, fill is fly ash. In 96+418, fill is clayey sand soil

In soil fill, Solid nail performance is slightly better and in fly ash, both solid nail and SDA performance is similar.

Hence, Solid nails were recommended as uniform nail type for all stabilization works in the present project.

The safe nail bond strength of solid nail in soil is 18 kN/m and in fly ash is 11 kN/m.

5.3 Design of Nailing System

The soil nail design with reinforced soil mass was carried out in the commercially available slope stability programme “GEO5” using limit equilibrium methods. The overall reinforced soil system was analyzed iteratively with a different configuration of nails and existing geogrids with *safe* input material parameters as per FHWA-NHI-14-007. The LRFD and FOS concept was used in combination as per FHWA-NHI-14-007.

In internal overall wedge stability, LTDS and interaction properties of geostraps are considered as per design documents and drawings. Maximum height of wall is considered in the given approaches where treatment required as a critical case for design. Foundation data is considered from the borehole investigation data, trial pits and reports shared by NHAI.

The FOS ensured in different modes are given below in Table 4. The design inputs and steps for a maximum height case are given Annexure - II.

Table 4 Required FOS for design of nailing system

Failure mode	FOS required - Static	FOS required- Seismic
Internal overall wedge stability	1.35	1.1
For safe tensile capacity (Rupture check: CDR ≥1)	2.0	1.5
For safe pullout capacity (Pullout check: CDR ≥1)	2.0	1.5
Global stability	1.3	1.1

5.3.1 Design outcomes

Design check outcomes for the configurations detailed later in Table 5 are given below:

Table 5 Factor of safeties of soil nailing of RE wall treated sections

RE wall with Soil fill		
Failure mode	**Static**	**Seismic**
Internal overall wedge stability	FOS:1.36≥1.35	FOS:1.33≥ 1.1
Rupture check	CDR:1.8≥1	CDR:2.5≥1
Pullout check	CDR:1≥1	CDR:1.3≥1
Global stability	FOS:1.6≥1.3	FOS:1.5≥1.1
RE wall with Fly ash Fill		
Failure mode	**Static**	**Seismic**
Internal overall wedge stability	FOS:1.36≥1.35	FOS:1.28 ≥ 1.1
Rupture check	CDR:1.8≥1	CDR:2.7≥1
Pullout check	CDR:1.≥1	CDR:1.28≥1
Global stability	FOS:1.4≥1.3	FOS:1.2≥1.1

5.4 Final Nail Specifications for Slightly and Moderately Bulged Zones (Figure 6 and Figure 7)

5.4.1 Final Design Nail configuration:

Table 6 Design Nail Configurations for Bulged zones

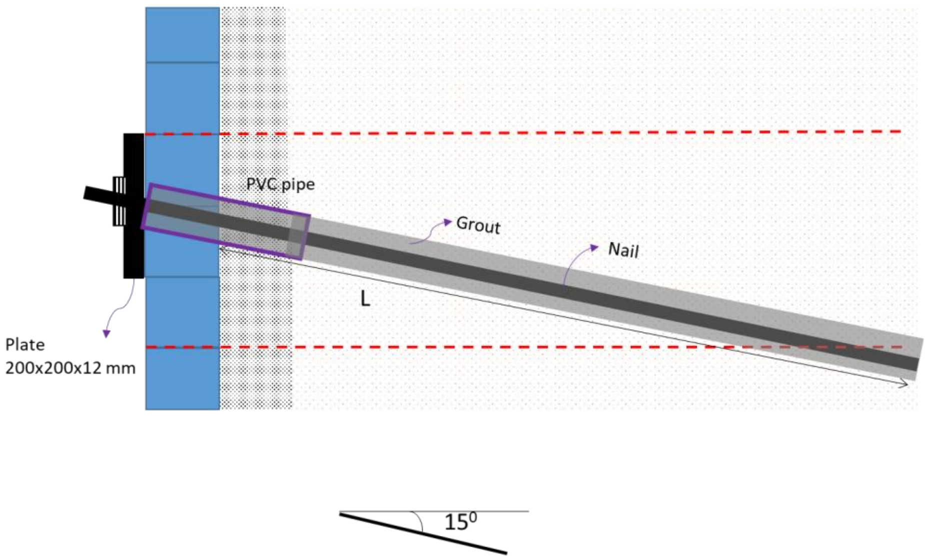
Walls Chainage	**Length of nail***	**Nail Specifications and Spacing**
km 106+224 km 102+570 km 96+426	0.8 H	Grouted nails in panels Alternate nails along height with spacing (Figure 7) 0.8 m Horizontal x 0.8 m Vertical 2 m Horizontal x 0.8 m Vertical Uniform throughout height above GL

**Provide additional length ~0.3 m to 0.5 m to accommodate panel thickness and plate and bolting*
***H: Design height of RE wall (FRL-Top of leveling pad)*

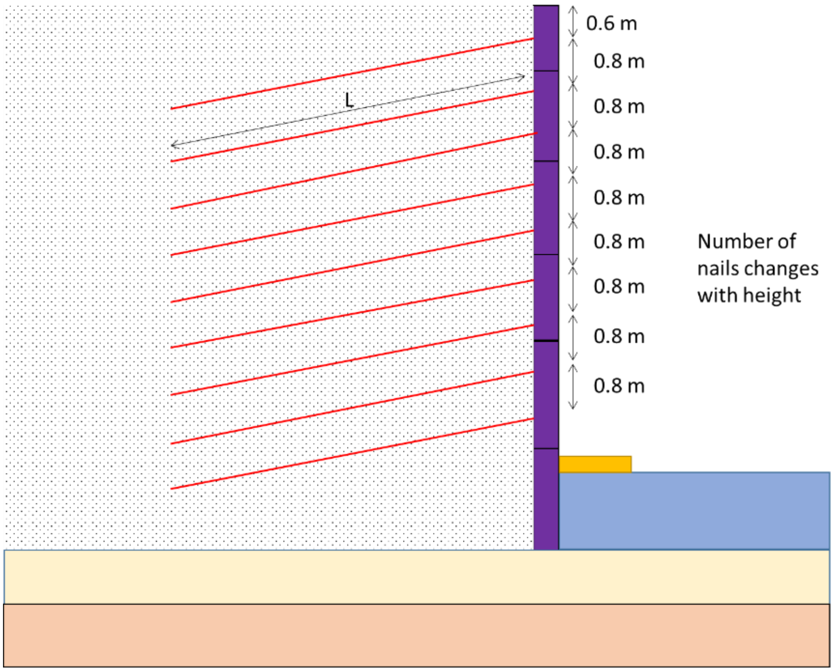
5.4.2 Specifications of Nails for Bulged Zones:

- Grouted Nails in panels: 25 mm solid nails with ~115 mm grout hole diameter.
- Grade of nails: Minimum 500 MPa yield strength solid nails – hot-dip fully threaded and galvanized.
- Nail installation angle: 10-15^0
- Spacing and length: As per Table 6
- Plate dimensions = 200 x 200 x 12 mm
- Nuts: compatible with 25 mm diameter rods
- **Any deviation of location of nail by +/- 200 mm is acceptable to accommodate site specific challenges during installation.**
- **Ensure no connection is cut/damaged in panel by proper marking of location of nails.**

- Installation of nails and grout specifications shall be followed as per FHWA-NHI-14-007.
- Corrosion protection to nails is preferable. However, exposed nails, plates, and nuts should be painted additionally with corrosive-resistant paints such as epoxy paints or zinc coating in any case.
- Use PVC pipe of diameter 105 mm compatible with a hole diameter of around 0.9-1 m length to avoid the escape of grout into drainage media. If geocomposite is present instead drainage media, 0.3 m length pipe is sufficient.



a)



b)

Figure 6 Sectional view of nailing configuration

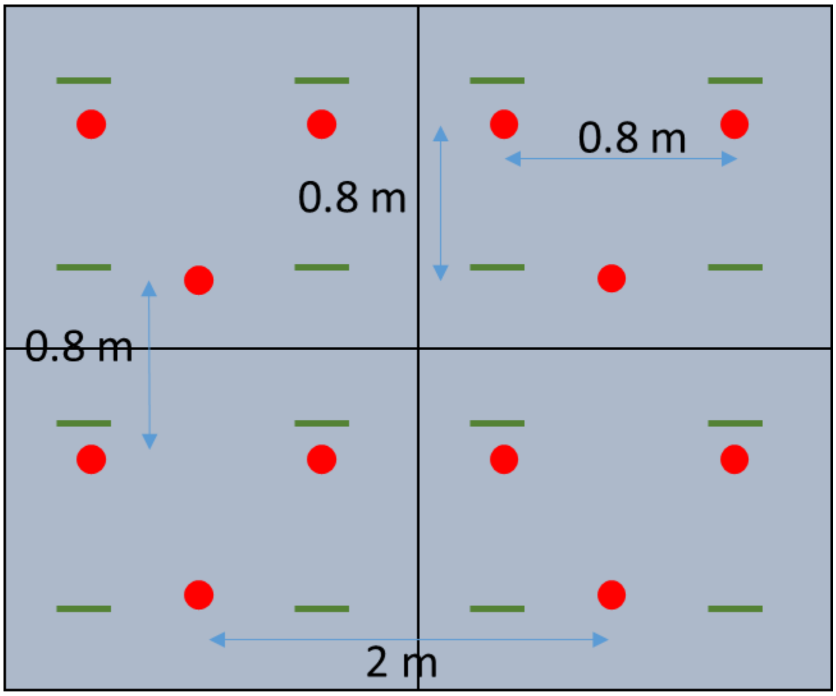


Figure 7 Elevation view of nailing configuration for bulged zones

5.4.3 Treatment Regions

The regions mentioned in Table 7 shall be nailed which are primarily identified. In addition, any newly identified regions shall also be nailed.

Table 7 Treatment stretches for nailing of slightly and moderately bulged zones

Structure Chainage	Stretched Required Nailing (Specifications as per Table 6)
km 106+224	A1 RHS (106+000); A1 LHS (105+750–700); A1 LHS (105+810); A1 RHS (105+836);
km 106+224	A1 RHS (106+250 – approx. 100 m); A1 RHS (106+200); A1 RHS (105+950); A1 RHS (105+840); A1 RHS (105+800); A1 LHS (105+840–860)
km 102+570	A2 RHS (102+880); A2 RHS (102+650-600); A1 RHS (102+310); A1 LHS (102+328)
km 102+570	A2 RHS (102+900); A1 RHS (102+425); A1 RHS (102+360–340); A1 LHS (102+290); A1 LHS (102+424–410); A1 LHS (102+440–480); A2 LHS (102+780)
km 96+426	A1 RHS (96+242); A1 RHS (96+156); isolated minor stretches along A1 LHS; A1 RHS (96+130–070); A1 RHS (96+038);
km 96+426	A2 RHS (96+682); A2 RHS (96+673–677); A2 RHS (96+605); A2 RHS (96+587); A2 RHS (96+485–493); A2 RHS (96+510); A2 RHS (96+555 – 10 m); A2 LHS (96+450); A2 LHS (96+460-480); A2 LHS (96+500); A2 LHS (96+560-580); A2 LHS (96+640-20); A2 LHS (96+680); A1 RHS (96+176); A1 RHS (96+198-210); A1 RHS (96+210–198)
km 91+961	A2 LHS wing wall
Any other identified location at current condition	

Note:

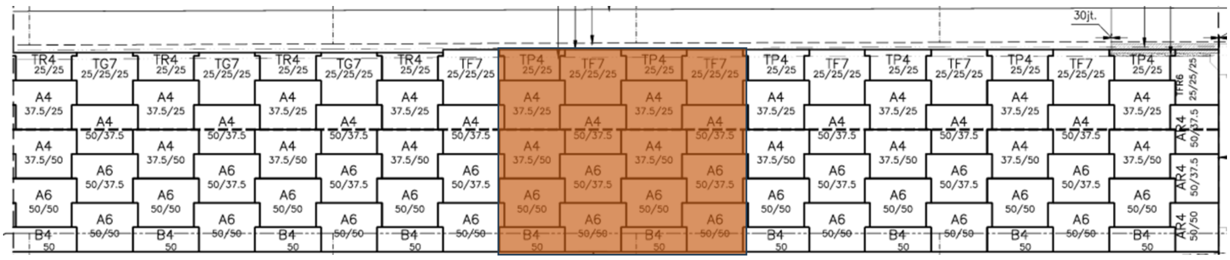
- Nailing shall be performed for all panels and uniformly throughout height for any observed bulging.
- In addition to bulged zones, adjacent 2 panels stretch shall also be nailed.
- Above are approximate chainages noted during site visit. Exact chainages shall be identified and marked for nailing before execution of work under presence of NHAI. Any recently observed additional stretches in addition to above chainages shall also be marked for nailing.
- It was found previous nailing was installed discretely. However, they shall be neglected as part of the overall nailing system recommended.

6. Reconstruction of Heavily Bulged Zones

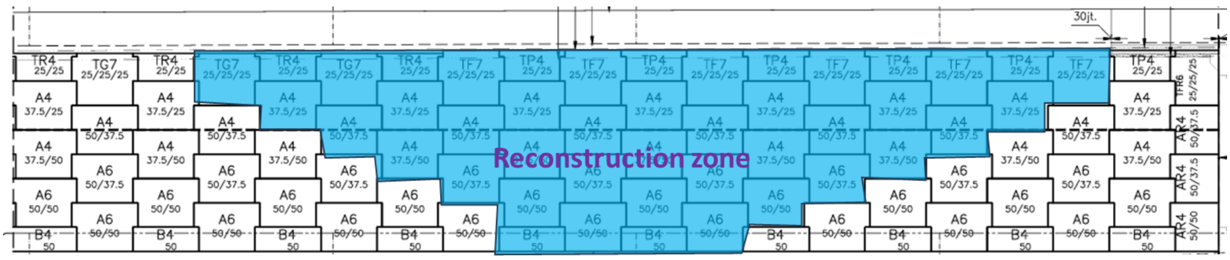
It is recommended to reconstruct new RE walls or Shored MSE walls of heavily bulged zones.

The general methodology of reconstructions is as follows:

Step-1: Mark Significantly Bulged Zone:

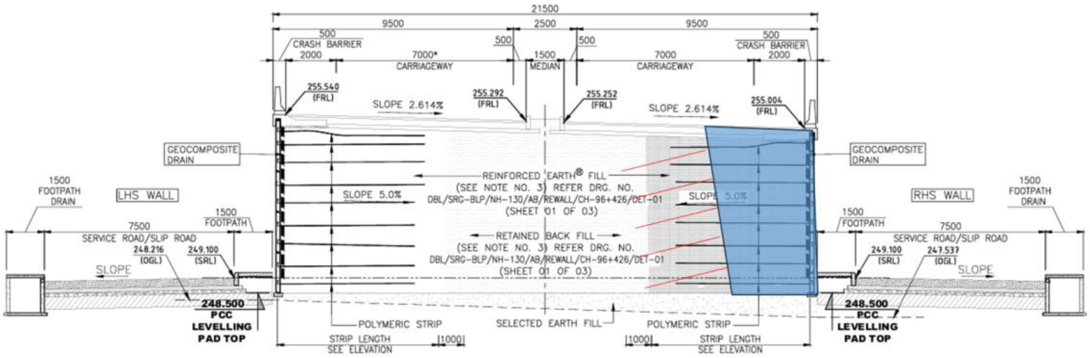


Step-2: Mark Reconstruction are as follows in addition to heavily Zone:



Step-3:

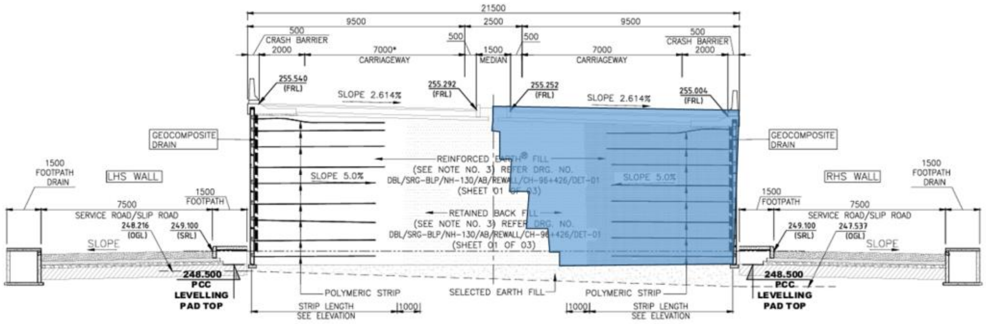
Reconstruction with Shored MSE wall:



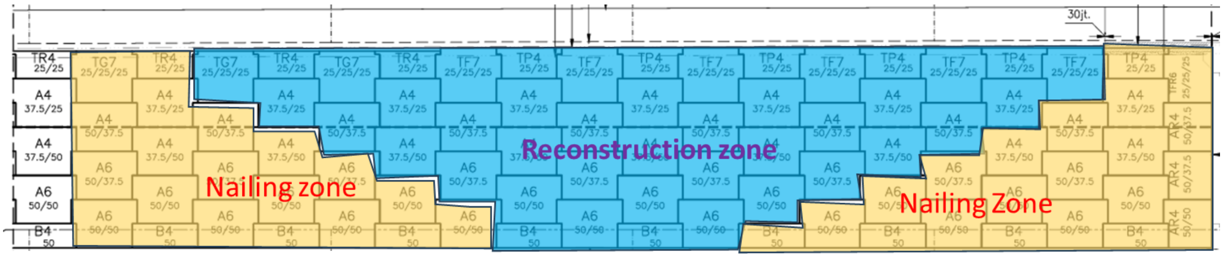
Advantage: With minimal cutting width, reconstruction can be carried out

(or)

Reconstruction with Conventional RE wall:



Step-4: After Reconstruction, Perform nailing of adjacent zones:



The stretches to be reconstructed are summarized in Table 8. The stretches mentioned are approximately noted during site visit. Exact stretches shall be marked as per present conditions under presence of NHAI. Detailed design and drawing of reconstruction may be submitted for review before construction activity starts.

Table 8 Stretches Identified for Reconstruction

Structure Chainage	Stretched Required Nailing
km 106+224	A2 LHS (106+550 – 20 m stretch) A1 RHS (105+790–105+750) A1 LHS (105+830 – 10 m stretch)
km 102+570	A2 RHS (102+830 – 102+700) A1 RHS (start of wall - 102+400) A1 LHS (102+340 – 20 m stretch) A2 LHS (102+600 – 102+700);
km 96+426	A2 RHS (96+645–96+615) A2 RHS (96+460–start of wall) A2 LHS (start stretch – 25–30 m) A2 LHS (96+582 – 10-15 m stretch) A1 RHS (96+290-10-15 m stretch) A1 RHS (96+150–96+140) A1 LHS (96+100- 20 m stretch) A1 LHS (96+300- 20 m stretch)
km 91+861	A1 LHS wing wall
Any other identified location at current condition	

Note:

- Reconstruction shall be performed for stretch mentioned above + 1V:2H longitudinal cut.
- In addition to reconstruction zone, adjacent zone shall be nailed.
- Above are approximate chainages noted during site visit. Exact chainages shall be identified and marked for reconstruction/nailing before execution under presence of NHAI.
- Any recently observed additional stretches in addition to above chainages shall also be marked for nailing.

7. Ground Improvement

For any further foundation settlement reduction of the clay deposit, it is imperative to improve the foundation soil. Perform pressure/jet grouting methodology. Grouting shall be done at a horizontal spacing of 1 m along the length of the wall and upto rock level below leveling pad level.

Detailed methodology to be implemented by contractor based on available equipment shall be submitted for review.

Foundation strata about 3 m lateral extent from wall toe and upto full width of wall shall also be treated as much as possible. It should be ensured that the foundation soil below the wall is grouted as much as possible (Figure 8). It may not prevent all the settlements happening long term, however differential settlements near fascia can be avoided and distress near facing zone can be minimized to certain extent. The nailing additionally provides lateral restraint to bulging and provides vertical stiffness in sudden differential settlement between facing panels and fill soil ensuring minimal stress concentrations in connections and reinforcements.

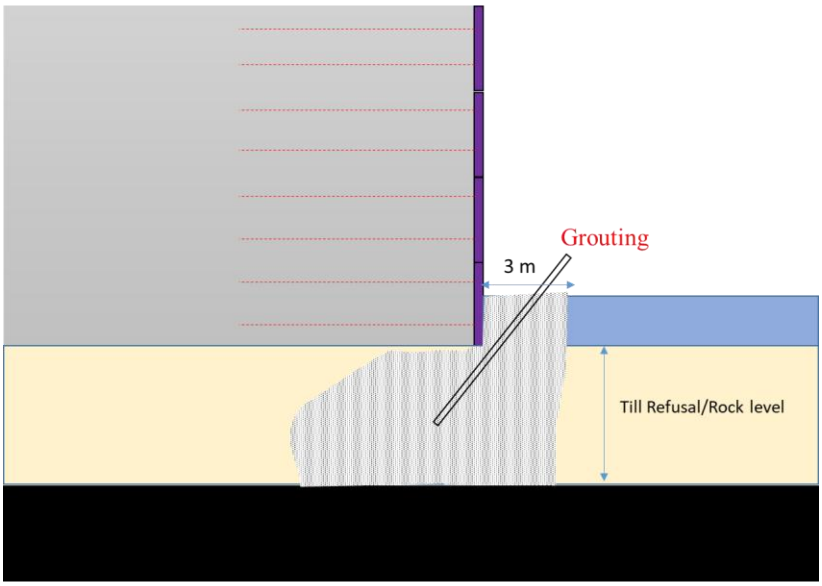


Figure 8 Schematic of ground improvement scheme

8. Repair of Cracks of Panel

The longitudinal and transverse cracks of the panels observed all along the length of wall in different stretches needs to be repaired with a suitable grout injection method. Any gaps between panels shall be filled with compressible material to prevent the movement of drainage media from gaps. The process recommended as follows:

1. Stitching horizontal/inclined cracks using Crack-Locks (steel bars) with epoxy mortar/non-shrink anchoring grout.
2. Injecting epoxy resin into cracks using injection ports.
3. Applying carbon fiber straps on the face for additional strength.

Typical sketches are given in Figure 9.

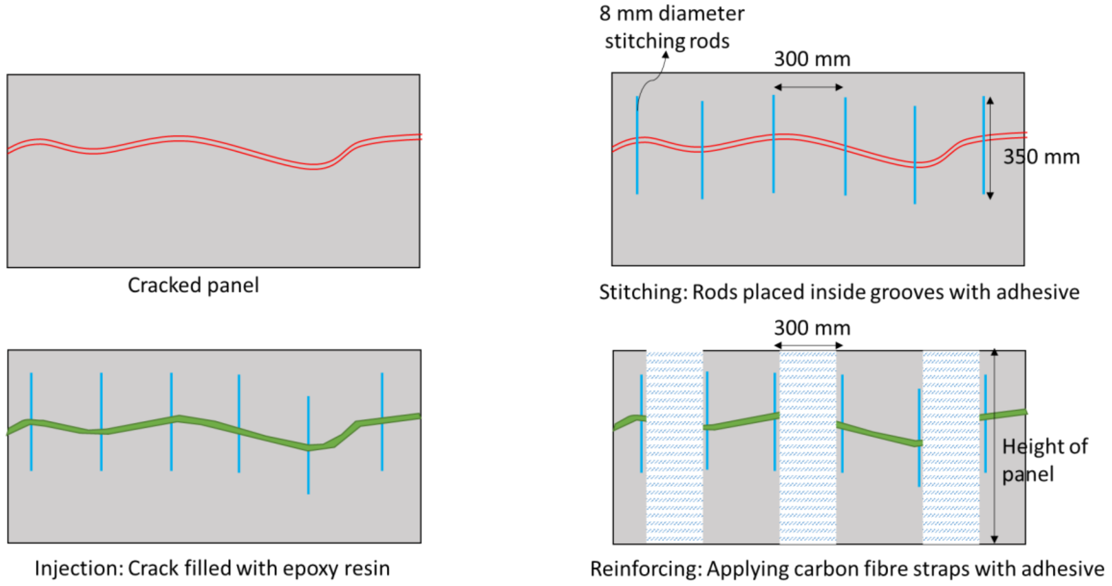


Figure 9 Repair methodology of cracked concrete panels (not to scale)

9. Additional Recommendations

9.1 Surface drainage

Proper surface drainage on top of wall needs to be provided such that ingress of water into reinforced soil mass is minimized.

It is preferable to replace PCC slab pavement with Flexible pavement with medians sealed with PCC.

In case of km 91+861, slope protection using Geocell infilled PCC shall be provided. It shall be anchored at edge of carriageway covering full shoulder. A saucer drain shall be used along toe walls. Cross drains/chute drains at 20 m spacing along with a longitudinal drain at edge of shoulder (if required) shall also be provided.

All drainage measures shall ensure minimal infiltration of surface water into reinforced walls.

Good for construction drawings of slope protection may be provided for review before construction.

9.2 Nail Proof load tests

A total of around 5% of the total number of execution nails shall be proof tested. Testing of soil nails shall not be performed within 3 days of grouting nails or unless the strength of the grout has reached 50 percent of the 7-day strength. Proof load test load shall be a conducted upto a load calculated using safe bond strength reported in Section 5. At proof load test, the nail should not fail. If any nails fail in the proof load test, additional nails shall be provided around it in the same panel.

10. Summary

Based on the site inspections, field observations, and analysis of available data, the following conclusions and recommendations are made for the bulged RE wall sections:

Slightly and Moderately Bulged Portions:

- Nail specifications shall conform to Section 5.4.
- Provide soil nailing treatment at bulged RE walls of stretches mentioned in Table 7.

Heavily Bulged Stretches:

- Reconstruction using new RE walls or Shored MSE walls be carried out as per methodology provided Section 6. (Zones mentioned in Table 8). The system selected by contractor shall be designed and detailed by contractor and may be submitted for review before construction.

Ground Improvement:

- Perform ground improvement for all walls as per Section 7.0. Detailed methodology to be implemented by contractor based on available equipment shall be submitted for review.

Repair of Cracked Panels:

- Cracked panels shall be retrofitted as per Section 8.0.

General Recommendations:

- Ensure proper surface drainage and repair of any surface cracks on carriageway/slopes to prevent water ingress and loss of backfill strength. Follow section 9.1 for surface drainage measures.
- Periodic inspection and maintenance of nail head plates, bolts, wall panels, erosion protection, and pavement surfaces shall be conducted to ensure long-term performance.

- Regular monitoring of all walls shall be continued after repair during maintenance of walls.

Final Good for construction drawings of all remedial measures including reconstruction may be provided for review before construction to verify with present report.

Acknowledgement

We extend our sincere gratitude to the National Highways Authority of India (NHAI) for entrusting us with this prestigious work. We also extend our heartfelt thanks to Savinaya Infratech for their help in Trial Nail installation and Testing.

K·Mohan Krishna

(G. Venkatappa Rao)
Chairman,

M/s Geosynthetics Technology Advisory Services, LLP, Jaipur

31/1/2026

(Anil Dixit)
Managing Director,

M/s Geosynthetics Technology Advisory Services, LLP, Jaipur

31/1/2026

(Kolli Mohan Krishna)
Technical Expert,

M/s Geosynthetics Technology Advisory Services, LLP, Jaipur

31/1/2026

ANNEXURE I

LANDMARK
Material Testing And Research Laboratory Pvt. Ltd.

Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	22.11.2025 to 24.11.2025	A1 (RE Wall-Wing Wall) top of slope	-	91+861	-	Not Encountered	12.00 m	601239	2421416	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	8	1.00	8	Silty Clay of Medium Plasticity with Gravels	CI	19.72	23.04	57.24		47.3	26	21.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Gravels	GC	30.48	24.24	19.15	26.13	51.1	28	23.1	1.91	1.61	18.92	2.70	70	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	29	1.00	29	Clayey Gravels	GC	40.41	35.39	24.20		46.9	26	20.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	8.96	57.66	10.81	22.57	50.7	28	22.7	2.16	1.88	15.03	2.70	65	-	0.241	DST (CD)	0.00	29	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	39	1.00	39	Clayey Gravels	GC	48.15	24.75	27.10		48.4	30	18.4	-	-	-	-	45	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Clayey Silts of Medium Plasticity	MI	0.00	27.28	52.55	20.17	47.7	29	18.7	2.20	1.83	20.19	2.69	36	-	-	UUT	0.65	6	-	-	-	-	-	-	-	-
SPT	10.50 - 10.73	>50	-	-	Clayey Sand with Gravels	SC	13.97	66.20	19.83		40.0	24	16.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Core	10.73 - 12.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.75	15.00	2.68	0.84	1.21	65.3	-	-

Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Location	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	01.12.2025 to 02.12.2025	A1 (RE Wall) Near median	-	96+360	-	Not Encountered	12.00 m	603964	2424683	Sr-80-1225

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	11	1.00	11	Clayey Sand with Gravels	SC	33.83	43.12	23.05		45.2	29	16.2	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Sand with Gravels	SC	20.28	50.54	8.59	20.59	40.0	22	18.0	2.12	1.86	13.90	2.68	17	-	0.175	-	-	-	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	30	1.00	30	Clayey Sand with Gravels	SC	35.25	52.34	12.41		45.7	22	23.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	7.60	60.24	10.80	21.36	45.6	26	19.6	2.20	1.84	19.58	2.69	64	-	-	DST (CD)	0.00	30	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	17	1.00	17	Clayey Silt of Medium Plasticity	MI	0.60	10.84	88.56		47.1	28	19.1	-	-	-	-	60	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Clayey Silt of Medium Plasticity	MI	1.01	11.24	67.61	20.14	47.2	29	18.2	1.88	1.54	22.15	2.69	36	-	-	UUT	0.60	7	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	23	1.00	23	Clayey Silt of Medium Plasticity	MI	0.71	10.12	89.17		48.4	30	18.4	-	-	-	-	45	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	12.00	>50	-	-	Clayey Sand with Gravels	SC	25.54	44.47	29.99		46.4	26	20.4	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Location	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	30.11.2025	A1 (RE Wall) Near median RHS	-	96+360	-	Not Encountered	12.00 m	603981	2424682	Sr-80-1225

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm²)	Cc	Type of test	c kg/cm²	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	10	1.00	10	Clayey Sand with Gravels	SC	12.14	56.74	31.12		36.2	20	16.2	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Gravel	GC	44.22	29.32	7.23	19.23	40.0	22	18.0	2.04	1.88	8.23	2.68	17	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	49	1.00	49	Clayey Sand with Gravels	SC	14.32	57.98	27.70		39.5	22	17.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	14.04	55.44	11.96	18.56	37.6	21	16.6	2.09	1.98	5.81	2.68	27	-	0.153	DST (CD)	0.00	30	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	20	1.00	20	Clayey Sand with Gravels	SC	10.94	55.08	33.98		47.4	28	19.4	-	-	-	-	60	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Clayey Silt of High Plasticity	MH	3.22	11.98	62.39	22.41	50.6	31	19.6	2.14	1.75	22.24	2.70	70	-	-	UUT	0.59	6	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	33	1.00	33	Clayey Silt of High Plasticity	MH	1.34	8.50	90.16		54.1	33	21.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	12.00	>50	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Location	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	29.11.2025 to 29.11.2025	A2 (RE Wall) Near median RHS	-	96+480	-	Not Encountered	12.00 m	604026	2424793	Sr-80-1225

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	9	1.00	9	Clayey Sand	SC	0.25	61.37	38.38		36.2	20	16.2	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Sand with Gravels	SC	12.44	64.18	6.15	17.23	40.1	20	20.1	2.04	1.73	18.12	2.68	-	-	0.197	DST (CD)	0.00	31	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	10	1.00	10	Clayey Sand with Gravels	SC	22.30	48.08	29.62		45.7	22	23.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	13.58	51.86	18.26	16.30	40.3	22	18.3	2.20	1.91	15.46	2.68	17	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	25	1.00	25	Silty Clay of Medium Plasticity with Gravels	CI	5.80	33.22	60.98		38.4	24	14.4	-	-	-	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Clayey Sand with Gravels	SC	16.12	48.98	15.02	19.88	47.2	29	18.2	2.03	1.68	20.82	2.69	36	-	-	UUT	0.58	9	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	21	1.00	21	Clayey Silt of High Plasticity	MH	0.00	17.82	82.18		54.1	33	21.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	12.00	>50	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Location	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	24.11.2025 to 28.11.2025	A2 (RE Wall) Near median LHS	-	96+550	-	Not Encountered	12.00 m	604027	2424833	Sr-80-1225

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample: Grain Size Analysis: Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits %: Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	Shear Strength Parameter: c kg/cm^2	ϕ Degree	Rock Sample: Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	Remark
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	28	1.00	28	Clayey Sand with Gravels	SC	21.64	47.09	31.27		45.2	27	18.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Silty Clay of Medium Plasticity with Gravels	CI	20.21	23.47	34.20	22.12	46.0	27	19.0	2.06	1.73	19.07	2.69	45	-	0.231	-	-	-	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	30	1.00	30	Clayey Sand with Gravels	SC	39.34	45.26	15.40		35.6	20	15.6	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	9.86	65.56	7.84	16.74	40.3	22	18.3	2.10	1.87	12.56	2.68	17	-	-	DST (CD)	0.00	31	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	41	1.00	41	Clayey Sand with Gravels	SC	15.39	61.60	23.01		45.7	22	23.7	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	9.00 - 10.50	-	-	-	Clayey Sand with Gravels	SC	7.82	66.34	25.84		46.1	26	20.1	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	32	1.00	32	Silty Clay of Medium Plasticity	CI	0.30	15.22	84.48		46.7	26	20.7	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	12.00	>50	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Material Testing And Research Laboratory Pvt. Ltd.

Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	04.12.2025 to 05.12.2025	A1 LHS (RE Wall) Near Median	-	102+480	-	Not Encountered	9.00 m	607417	2429645	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	14	1.00	14	Clayey Sand with Gravels	SC	17.00	63.34	19.66		43.3	23	20.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Sand with Gravels	SC	14.78	50.76	11.98	22.48	49.8	25	24.8	1.88	1.63	15.49	2.70	40	-	0.234	DST (CD)	0.00	27	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	24	1.00	24	Clayey Sand with Gravels	SC	13.60	71.68	14.72		37.5	21	16.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	6.00 - 7.50	-	-	-	Clayey Sand	SC	9.02	64.22	26.76		41.0	22	19.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	24	1.00	24	Clayey Sand	SC	2.16	71.22	26.62		38.0	21	17.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	9.00	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	07.12.2025	A1 RHS (RE Wall) Near Median	-	102+530	-	Not Encountered	9.00 m	607470	2429674	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	7	1.00	7	Clayey Sand	SC	5.28	67.16	27.56		42.4	23	19.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Sand with Gravels	SC	28.80	34.92	12.73	23.55	52.0	27	25.0	1.95	1.71	14.05	2.70	40	-	0.269	DST (CD)	0.00	26	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	25	1.00	25	Clayey Sand	SC	9.88	70.22	19.90		41.0	22	19.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	16.78	52.40	10.50	20.32	46.0	24	22.0	2.09	1.82	14.57	2.69	30	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	23	1.00	23	Clayey Sand with Gravels	SC	25.34	42.58	32.08		48.0	25	23.0	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	9.00	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	06.12.2025	A2 RHS (RE Wall) Near Median	-	102+630	-	Not Encountered	9.00 m	607551	2429750	Sr-80-1125

							Soil Sample																	Rock Sample							
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	Remark
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	8	1.00	8	Clayey Sand with Gravels	SC	11.96	56.30	31.74		47.4	25	22.4	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Sand	SC	7.46	72.40	1.94	18.20	41.0	22	19.0	2.11	1.89	11.81	2.68	20	-	0.192	DST (CD)	0.00	31	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	12	1.00	12	Clayey Sand	SC	7.02	74.72	18.26		42.5	24	18.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	21.72	57.86	1.09	19.33	48.0	27	21.0	2.17	1.87	15.92	2.69	33	-	-	DST (CD)	0.00	29	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	21	1.00	21	Clayey Sand	SC	9.40	70.32	20.28		42.6	23	19.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	9.00	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	05.12.2025	A2 LHS (RE Wall) Near Median	-	102+650	-	Not Encountered	9.00 m	607554	2429774	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %			Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	Shear Strength Parameter		Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)									c kg/cm^2	ϕ Degree								
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	5	1.00	5	Clayey Sand	SC	6.34	61.84	31.82		42.3	23	19.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Clayey Sand with Gravels	SC	12.46	57.76	7.90	21.88	45.0	25	20.0	2.07	1.85	11.88	2.68	-	-	0.206	DST (CD)	0.00	28	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	10	1.00	10	Clayey Sand with Gravels	SC	21.38	46.38	32.24		48.0	26	22.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Clayey Sand with Gravels	SC	11.98	55.72	10.20	22.10	44.6	24	20.6	2.10	1.82	15.08	2.68	-	-	-	DST (CD)	0.00	27	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	23	1.00	23	Clayey Sand	SC	9.44	43.28	47.28		49.3	26	23.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS	9.00	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	08.12.2025	A1 LHS (RE Wall) Near Median	-	105+950	-	Not Encountered	13.00 m	609963	2432006	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample: Grain Size Analysis: Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Atterberg Limits %: Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm²)	Cc	Type of test	Shear Strength Parameter: c kg/cm²	ϕ Degree	Rock Sample: Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	Remark
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	30	1.55	46	Flyash	-	13.38	39.98	46.64		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Flyash	-	0.00	41.22	58.78	0.00	-	Nil	NP	1.30	1.05	23.57	2.35	-	-	-	DST (CD)	0.00	30	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	50	1.15	58	Flyash	-	0.00	32.62	67.38		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Flyash	-	1.78	46.84	51.38	0.00	-	Nil	NP	1.42	1.12	26.47	2.38	-	-	-	DST (CD)	0.00	32	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	42	0.96	40	Flyash	-	2.18	15.50	82.32		-	Nil	NP	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Flyash	-	0.00	66.86	33.14	0.00	-	Nil	NP	1.52	1.25	21.32	2.40	-	-	-	DST (CD)	0.00	33	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	26	1.00	26	Clayey Silts of High Plasticity	MH	1.82	18.30	79.88		54.8	30	24.8	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	12.00 - 13.00	52	1.00	52	Silty Clay of High Plasticity with Gravels	CH	10.62	37.52	51.86		50.5	28	22.5	-	-	-	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	13.00	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	11.12.2025	A1 RHS (RE Wall) Near Median	-	105+960	-	Not Encountered	13.00 m	609977	2431995	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_c)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	25	1.59	40	Flyash	-	0.00	23.60	76.40		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Flyash	-	0.00	60.74	39.26	0.00	-	Nil	NP	1.16	1.01	15.12	2.38	-	-	-	DST (CD)	0.00	31	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	43	1.22	52	Flyash	-	1.50	41.62	56.88		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Flyash	-	0.56	57.82	41.62	0.00	-	Nil	NP	1.25	1.07	16.98	2.36	-	-	-	DST (CD)	0.00	32	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	40	1.02	41	Flyash	-	1.90	35.46	62.64		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Flyash	-	0.00	60.40	39.60	0.00	-	Nil	NP	1.21	1.03	17.53	2.40	-	-	-	DST (CD)	0.00	33	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	48	0.92	44	Silty Sand with Gravels	SM	18.48	62.44	19.08		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	12.00 - 13.00	-	-	-	Clayey Sand	SC	8.02	56.56	11.27	24.15	52.1	31	21.1	2.06	1.89	8.92	2.69	-	-	-	UUT	0.76	6	-	-	-	-	-	-	-	-
SPT	13.00	>50	-	-	Clayey Sand	SC	8.98	67.50	23.52		48.1	29	19.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	10.12.2025	A2 RHS (RE Wall) Near Median	-	106+320	-	Not Encountered	13.00 m	610329	2432073	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm^2)	Cc	Type of test	c kg/cm^2	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	14	1.00	14	Clayey Sand with Gravels	SC	17.10	52.36	30.54		41.4	23	18.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Flyash	-	0.00	59.78	40.22	0.00	-	Nil	NP	1.17	1.02	15.23	2.32	-	-	-	DST (CD)	0.00	30	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	46	1.22	56	Flyash	-	0.30	21.18	78.52		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Flyash	-	0.00	56.58	43.42	0.00	-	Nil	NP	1.13	1.00	13.20	2.35	-	-	-	DST (CD)	0.00	31	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	51	1.03	52	Flyash	-	0.00	19.42	80.58		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Flyash	-	0.00	45.36	54.64	0.00	-	Nil	NP	1.24	1.06	16.92	2.37	-	-	-	DST (CD)	0.00	33	-	-	-	-	-	-	-	-
SPT	10.50 - 12.00	34	1.00	34	Clayey Sand with Gravels	SC	17.00	47.08	35.92		38.2	23	15.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	12.00 - 13.00	>50	-	-	Clayey Sand with Gravels	SC	10.36	44.06	45.58		39.1	22	17.1	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	13.00	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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Project : Four Laining of Sargaon - Bilaspur NH-200 (PKG-III) Chhattisgarh	Date of field Testing	Borehole Locations	R.L.	Chainage	Structure	Depth of Water Table	Termination Depth	Easting	Northing	Ref. Code
	09.12.2025	A2 LHS (RE Wall) Near Median	-	106+350	-	Not Encountered	11.50 m	610364	2432072	Sr-80-1125

Type of Sample	Depth (m) from EGL	Observed N Value	Correction Factor (C_n)	Corrected N Value (N_n)	Soil/Rock Description	Soil Classification	Soil Sample																	Rock Sample							Remark
							Grain Size Analysis				Atterberg Limits %											Shear Strength Parameter									
							Gravels (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Bulk Density (g/cc)	Dry Density (g/cc)	Natural Moisture Content (%)	Specific Gravity	Free Swell Index (%)	UCS (kg/cm²)	Cc	Type of test	c kg/cm²	ϕ Degree	Core Recovery (%)	RQD (%)	Specific Gravity	Water Absorption (%)	Porosity (%)	UCS (N/mm2)	PLI (MN/m2)	
DS	0.00 - 1.00	-	-	-	Pavement Crust	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	1.50 - 3.00	23	1.00	23	Clayey Sand with Gravels	SC	13.56	70.72	15.72		41.3	23	18.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	3.00 - 4.50	-	-	-	Flyash	-	0.00	50.64	49.36	0.00	-	Nil	NP	1.31	1.02	27.96	2.30	-	-	-	DST (CD)	0.00	31	-	-	-	-	-	-	-	-
SPT	4.50 - 6.00	57	1.07	61	Flyash	-	0.00	53.16	46.84		-	Nil	NP	-	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	6.00 - 7.50	-	-	-	Flyash	-	0.00	55.54	44.46	0.00	-	Nil	NP	1.31	1.09	20.46	2.34	-	-	-	DST (CD)	0.00	33	-	-	-	-	-	-	-	-
SPT	7.50 - 9.00	67	0.99	67	Flyash	-	0.00	56.70	43.30		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UDS	9.00 - 10.50	-	-	-	Flyash	-	0.00	48.12	51.88	0.00	-	Nil	NP	1.37	1.05	30.12	2.35	-	-	-	DST (CD)	0.00	34	-	-	-	-	-	-	-	-
SPT	10.50 - 11.50	>50	-	-	Flyash	-	8.30	43.30	48.40		-	Nil	NP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SPT	11.50	>50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ANNEXURE II

Design of Nailing System for Distressed GRS Wall (Full Height Wall – Soil fill)

Geometry and Configuration

Height of wall = 7.6 m

The location of geostraps is considered as per the original design report.

Nail Spacing: Alternate nails along height with spacing: 0.8 m Horizontal x 0.8 m Vertical; 2 m Horizontal x 0.8 m Vertical.

The design nail configuration is shown in Figure IIA.

Nail length = 6 m; Nail Inclination = 15^0

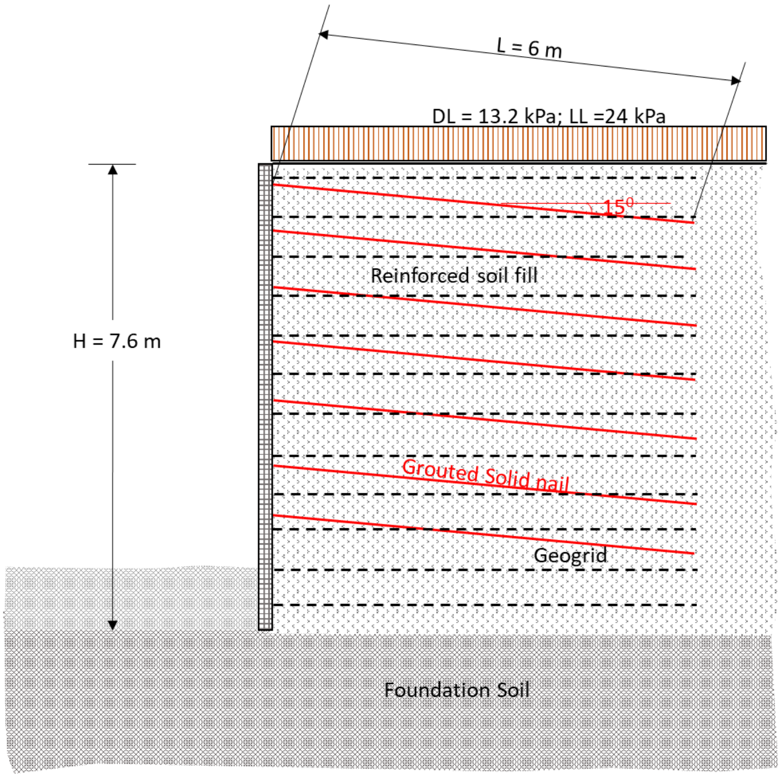


Figure IIA Schematic of GRS wall with grouted soil nail system depicting geometry

Nail specifications

25 mm Fe 500 solid nails with minimum 105 mm grout hole diameter.

Nail yield strength = 245 kN

Length = 6 m

Spacing: Alternate nails along height with spacing: 0.8 m Horizontal x 0.8 m Vertical; 2 m Horizontal x 0.8 m Vertical.

Safe bond strength: 18 kN/m

Wall Fill Properties

Reinforced fill:

Unit weight = 20 kN/m^3

Average Friction angle = 28^0

Cohesion = 0 kPa

Retained fill:

Unit weight = 20 kN/m^3

Average Friction angle = 28^0

Cohesion = 0 kPa

Foundation soil properties

Depth	Soil type	Unit weight	Shear strength parameters
0-5 m	MH/CI type clayey Soil	19 kN/m^3	C_u =60 kPa
Below 5 m	Hard strata/Weathered rock	20 kN/m^3	C_u =100 kPa

The water table is considered at the base of the wall.

External loads

Dead load surcharge = 13.2 kPa

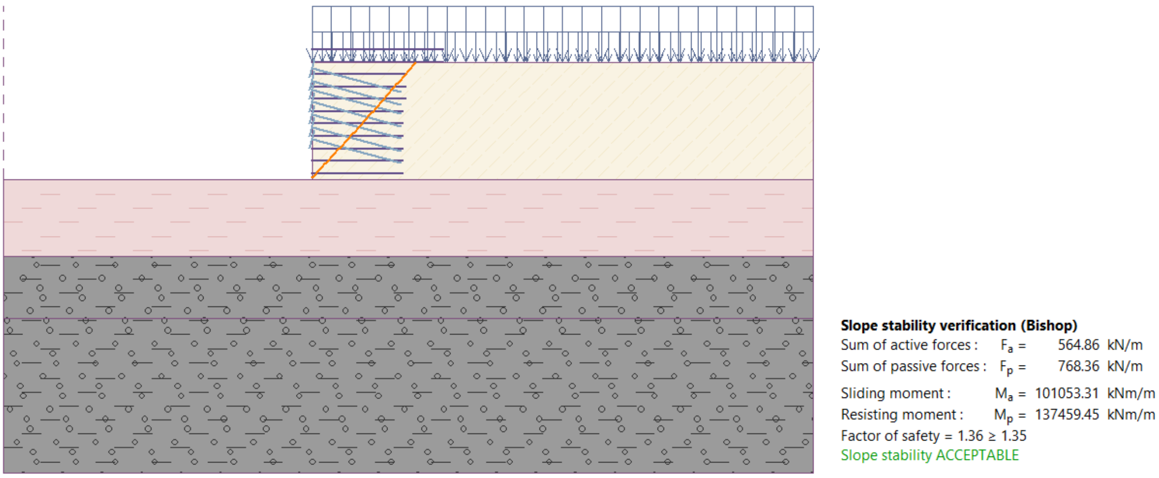
Live load surcharge = 24 kPa

Seismicity: Zone-2: K_h = PGA = 0.1g

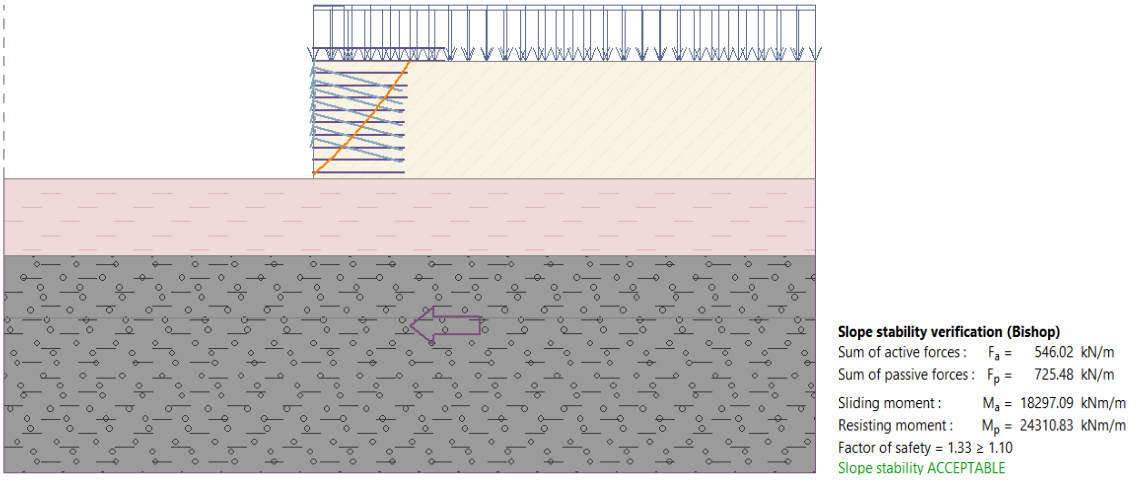
Design

In internal overall wedge stability, LTDS and interaction properties of existing geostraps are considered as per design documents and drawings. The Geo5 slope stability programme was used to perform the design for different checks.

Internal Wedge stability: Circular slip analysis



STATIC CASE – Critical Slip Circle



SEISMIC CASE – Critical Slip Circle

Maximum nail force mobilized noted from software analysis for critical circle in static case = 73 kN/m in bottom most nail

Maximum nail force mobilized noted from software analysis for critical circle in seismic case = 71 kN/m in bottom most nail

Nail Rupture and Pull-out Check

Rupture check:

$$Static\ CDR = \frac{\emptyset_T R_T}{\gamma T_{max}} = \frac{0.75*245}{1.35*73} = 1.8 \geq 1$$

$$Seismic\ CDR = \frac{\emptyset_T R_T}{\gamma T_{max}} = \frac{0.75*245}{1.0*71} = 2.5 \geq 1$$

$\emptyset_T$ = resistance factor for tensile resistance of the nail

R_T = nominal tensile resistance of the nail

γ = load factor selected for verification

T_{max} = maximum mobilized force

Pullout check:

$$Stati\ CDR = \frac{\emptyset_T R_{po}}{\gamma T_{max}} = \frac{0.65*(4.1*38)}{1.35*73} = 1 \geq 1$$

$$Seismic\ CDR = \frac{\emptyset_T R_{po}}{\gamma T_{max}} = \frac{0.65*(3.8*38)}{1.0*71} = 1.3 \geq 1$$

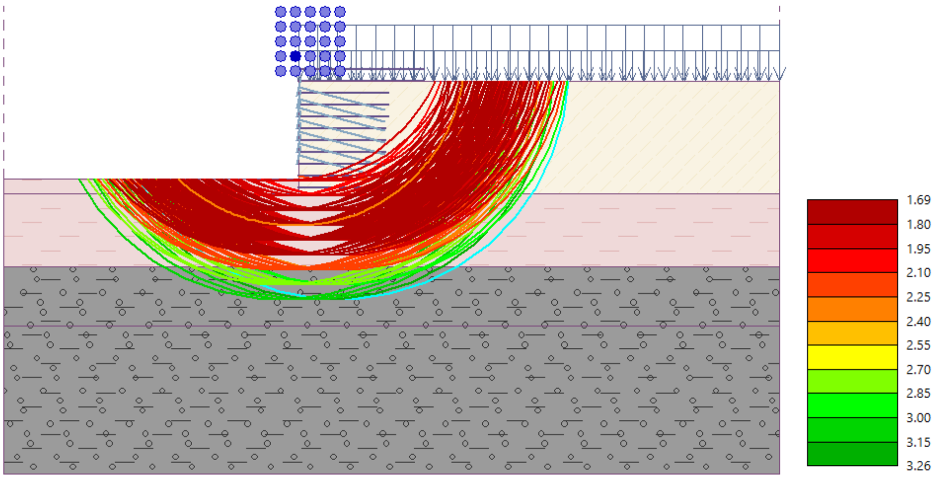
$\emptyset_T$ = resistance factor for tensile resistance of the nail

R_{po} = nominal pullout resistance of the nail

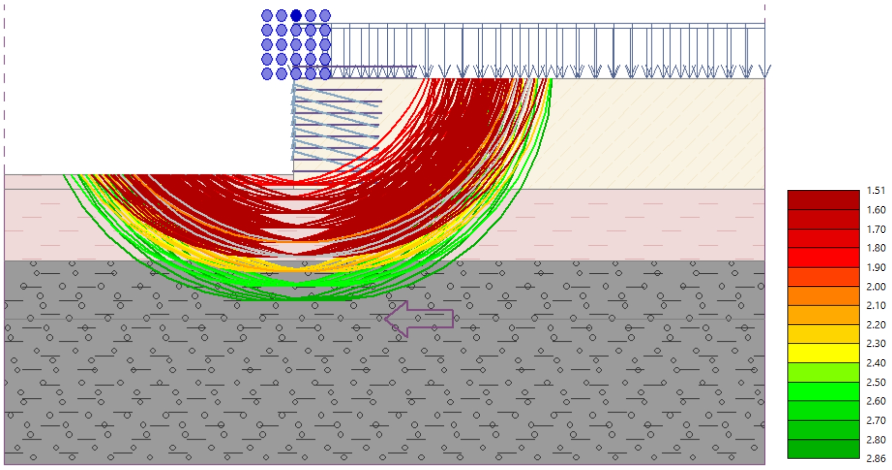
γ = load factor selected for verification

T_{max} = maximum mobilized force.

Global and Compound stability



STATIC CASE



SEISMIC CASE

Summary of Stability Analysis

Failure mode	Static	Seismic
Internal overall wedge stability	FOS:1.36≥1.35	FOS:1.33≥ 1.1
Rupture check	CDR:1.8≥1	CDR:2.5≥1
Pullout check	CDR:1.≥1	CDR:1.3≥1
Global stability	FOS:1.6≥1.3	FOS:1.5≥1.1

Design of Nailing System for Distressed GRS Wall (Full Height Wall – Flyash fill)

Geometry and Configuration

Height of wall = 10.4 m

The location of geostraps is considered as per the original design report.

Nail Spacing: Alternate nails along height with spacing: 0.8 m Horizontal x 0.8 m Vertical; 2 m Horizontal x 0.8 m Vertical.

The design nail configuration is shown in Figure IIB.

Nail length = 8.3 m; Nail Inclination = 15^0

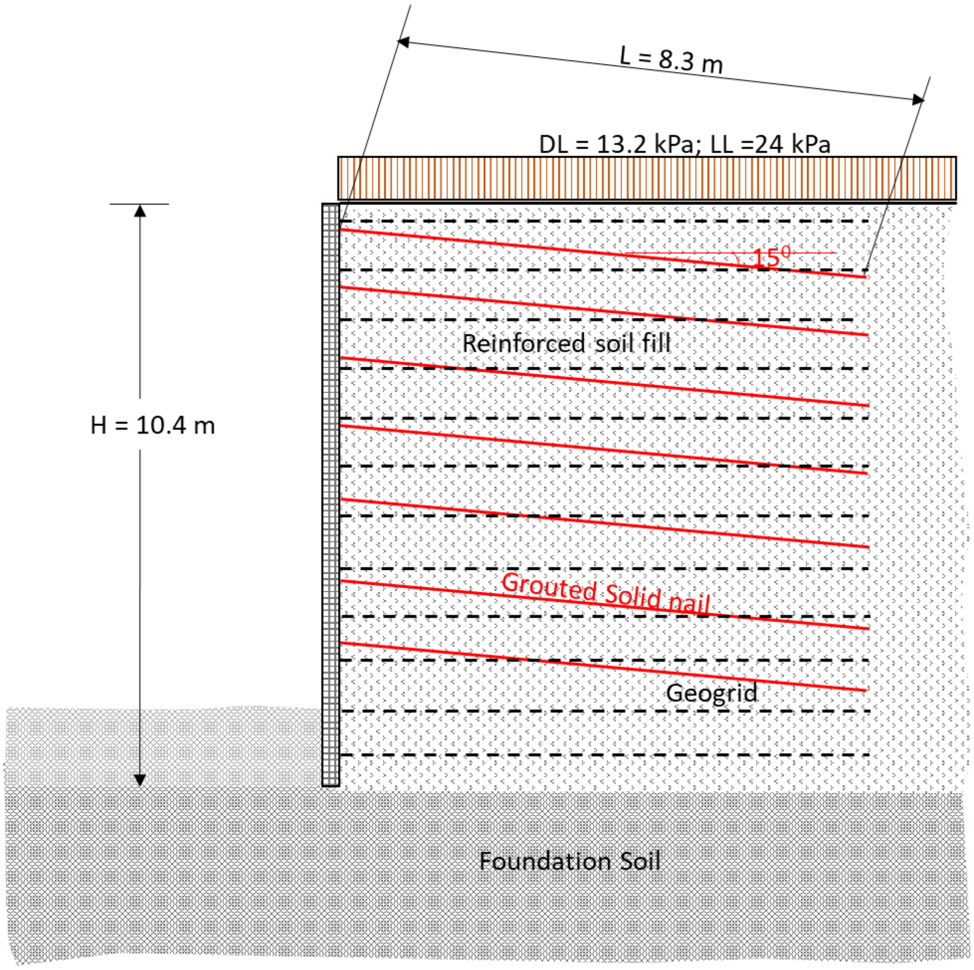


Figure IIB Schematic of GRS wall with grouted soil nail system depicting geometry

Nail specifications

25 mm Fe 500 solid nails with minimum 105 mm grout hole diameter.

Nail yield strength = 245 kN

Length = 8.3 m

Spacing: Alternate nails along height with spacing: 0.8 m Horizontal x 0.8 m Vertical; 2 m Horizontal x 0.8 m Vertical.

Safe bond strength: 11 kN/m

Wall Fill Properties

Reinforced fill:

Unit weight = 20 kN/m^3

Average Friction angle = 32^0

Cohesion = 0 kPa

Retained fill:

Unit weight = 20 kN/m^3

Average Friction angle = 32^0

Cohesion = 0 kPa

Foundation soil properties

Depth	Soil type	Unit weight	Shear strength parameters
0-5 m	MH/CI type clayey Soil	19 kN/m^3	C_u =70 kPa
Below 5 m	Hard strata/Weathered rock	20 kN/m^3	C_u =100 kPa

The water table is considered at the base of the wall.

External loads

Dead load surcharge = 13.2 kPa

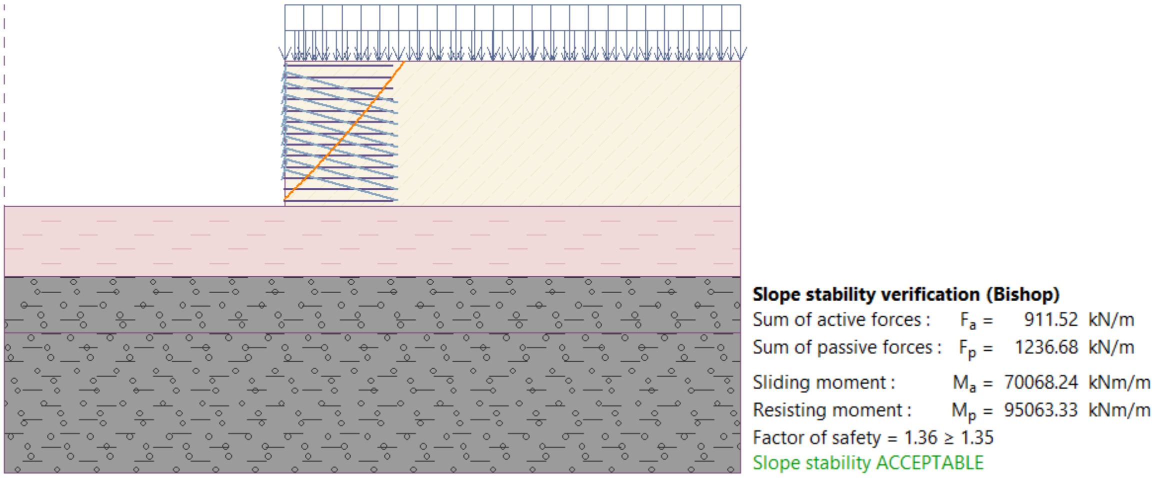
Live load surcharge = 24 kPa

Seismicity: Zone-2: K_h = PGA = 0.1g

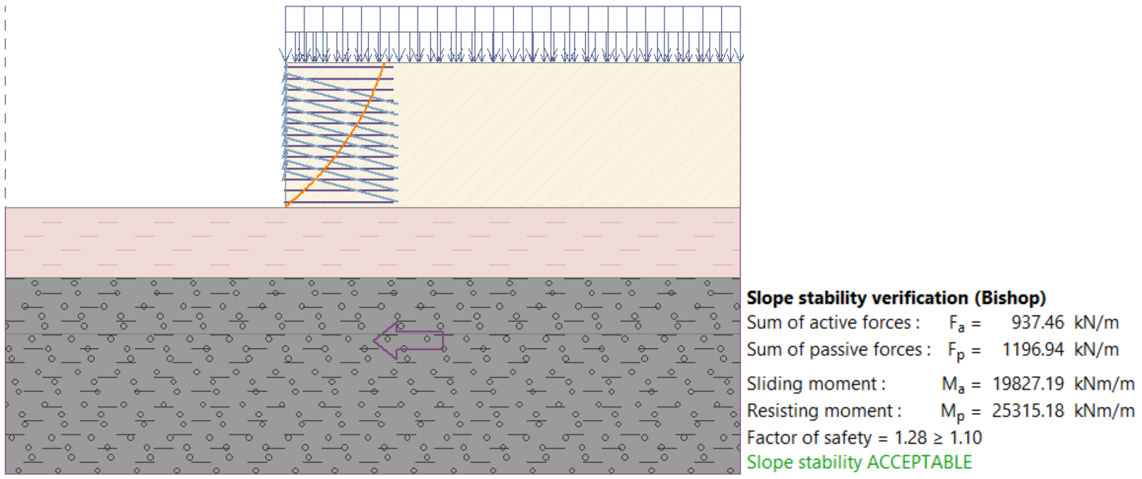
Design

In internal overall wedge stability, LTDS and interaction properties of existing geostraps are considered as per design documents and drawings. The Geo5 slope stability programme was used to perform the design for different checks.

Internal Wedge stability: Circular slip analysis



STATIC CASE – Critical Slip Circle



SEISMIC CASE – Critical Slip Circle

Maximum nail force mobilized noted from software analysis for critical circle in static case = 72 kN/m in bottom most nail

Maximum nail force mobilized noted from software analysis for critical circle in seismic case = 67 kN/m in bottom most nail

Nail Rupture and Pull-out Check

Rupture check:

$$Static\ CDR = \frac{\emptyset_T R_T}{\gamma T_{max}} = \frac{0.75*245}{1.35*72} = 1.8 \geq 1$$

$$Seismic\ CDR = \frac{\emptyset_T R_T}{\gamma T_{max}} = \frac{0.75*245}{1.0*67} = 2.7 \geq 1$$

$\emptyset_T$ = resistance factor for tensile resistance of the nail

R_T = nominal tensile resistance of the nail

γ = load factor selected for verification

T_{max} = maximum mobilized force

Pullout check:

$$Stati\ CDR = \frac{\emptyset_T R_{po}}{\gamma T_{max}} = \frac{0.65*(6.7*23)}{1.35*72} = 1 \geq 1$$

$$Seismic\ CDR = \frac{\emptyset_T R_{po}}{\gamma T_{max}} = \frac{0.65*(6*22)}{1.0*67} = 1.28 \geq 1$$

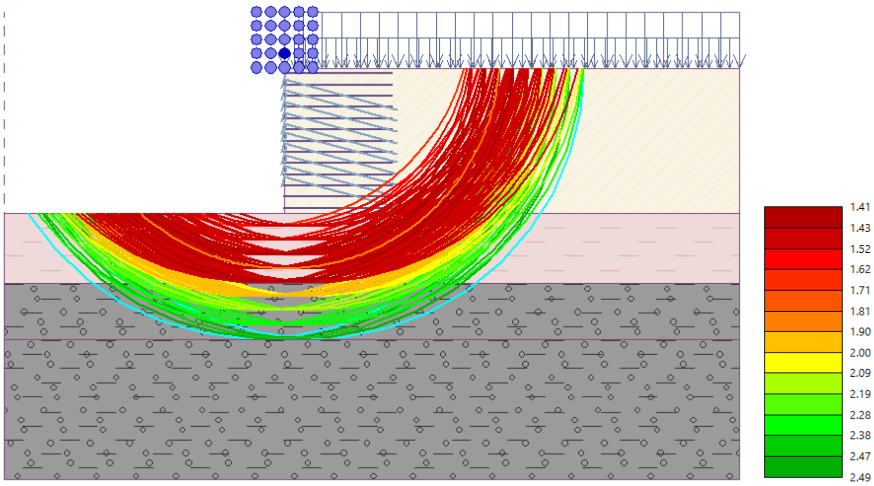
$\emptyset_T$ = resistance factor for tensile resistance of the nail

R_{po} = nominal pullout resistance of the nail

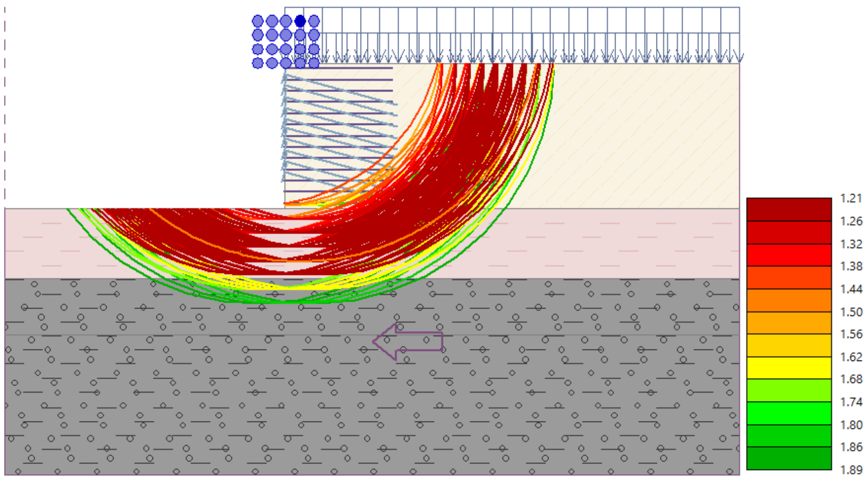
γ = load factor selected for verification

T_{max} = maximum mobilized force.

Global and Compound stability



STATIC CASE



SEISMIC CASE

Summary of Stability Analysis

Failure mode	Static	Seismic
Internal overall wedge stability	FOS:1.36≥1.35	FOS:1.28 ≥ 1.1
Rupture check	CDR:1.8≥1	CDR:2.7≥1
Pullout check	CDR:1.≥1	CDR:1.28≥1
Global stability	FOS:1.4≥1.3	FOS:1.2≥1.1