# Design of Geosynthetic Reinforced Soil Wall with Rigid Facia Using Nailing

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**Abstract.** Facia is an important component of geosynthetic reinforced soil (GRS) system provided to control the erosion of backfilled material, to prevent the damage of reinforced material and to give the aesthetically pleasing appearance. The increased use of marginal fills in the construction of a GRS wall created certain issues of differential settlement between the facia system and reinforced fill. This differential settlement caused additional forces at the connection joint of facia and reinforcement and sometimes resulted in shear breakage of reinforcement and the collapse of the structure. Hence, the aim of the current research is to develop a design and construction sequence of a new kind of facia system for marginal fills that eliminate the issues related to the differential settlement and prevent the functionality of the structure. Soil nails are used in the proposed facia system to connect the full height panel facia to wrap around GRS wall. The design of GRS wall and soil nail are done according to the provisions given by design codes, and the steps for the combined design is discussed. An attempt was made to give the mathematical formulation of the additional pull-out force generated inside the soil nails due to the differential settlement. It is proposed to add this additional force in the design checks of soil nails for the combined system. The construction sequence of the proposed system is suggested by considering the easiness and stability at each stage of construction.

**Keywords:** Geosynthetic Reinforced Soil Wall, Soil Nailing, Marginal Soil, Differential Settlement, Construction Sequence

## 1 Introduction

The geosynthetic reinforced soil (GRS) system is made up of closely-spaced layers of geosynthetic materials called as reinforcement and compacted soil. This construction technology is used in many applications such as retaining wall, embankment construction of roadways and railways, slope stability structures, land-fill structures etc. The facia is a very important component of GRS wall both technically and economically. It is a relatively thin structure, mainly provided to control the erosion of backfilled material, to prevent the damage of reinforced material and to give an aesthetically pleasing appearance. The fraction of facia cost from the overall total construction cost of a GRS wall is about 30% to 40%. There are many types of facia systems available for GRS walls such as modular block facia, concrete segmental panel facia, full height panel facia, wrapped-around facia, etc. Nowadays locally available or marginal soils are used as a backfill material due to reduced availability of sands.

Marginal soils are low permeability soils with a relatively large amount of fine particles (<0.075mm) [1-7]. Due to its low permeability, ingress of water generates the excess positive pore pressure, and dissipation of it leads to huge deformation of the backfilled soil mass [1-3, 6, 7]. This deformation causes differential settlement between backfilled material and facia, which results in breakage or damage to the geosynthetic reinforcement material at the junction of facia and wall. Yoo and Jung [4] and Koerner and Koerner [5] reported that most failures of the reinforced soil slopes and walls occurred due to the usage of marginal soils in the construction. Koerner and Koerner [5] summarised the data of 171 failed GRS wall, out of which 44 walls failed due to excessive deformation with 61% of entire walls were constructed with marginal fills. Raisinghani and Viswanadham [6] experimentally investigated the behaviour of a geogrid reinforced slope with marginal backfill and reported catastrophic deformations and failures due to the generation of excess positive pore water pressure in the backfill. Balakrishnan and Viswanadham [8] conducted centrifuge tests on GRS wall reinforced with weak to strong geogrids and concluded that the development of tension cracks and deformation in soil mass reduces with increase in the strength and stiffness of geogrids.

The previous investigation indicates that marginal soil causes excessive deformation of reinforced fill, and that is sometimes deleterious for the facia-reinforcement joint and the whole structure. Hence, the aim of the current study is to develop a new kind of facia system using soil nails to possibly eliminates the problems associated with conventional facia. The detailed design and construction methodology was given for the proposed system with the use of existing international codes.

## 2 Nail Forces Determination during Differential Settlement

The differential settlement between the facia structure and reinforced fill generates the additional stresses in the soil nails. These additional stresses need to be evaluated to incorporate them into the design procedure of facia using soil nails. The deformation profile of soil nails during differential settlement is shown in Fig. 1. The deformation profile of the geosynthetic reinforced soil wall with nailing is not available both experimentally and analytically in any literature. Hence, the deformation profile of soil nail during the case of differential settlement was assumed to be similar to the profile around potential failure wedge in traditional soil nail wall. This assumption is valid as the mechanism and force distribution during both the system is very similar. The deformation profile were referred from the sources [12-14], based on the two-zoned model of soil nail system. The deformed shape of soil nails are generated because one end of them are fixed at the facia and other portion is moving downward with the soil mass. The enlarged view of deformed soil nail portion is shown in Fig. 1 along with the generated forces onto it. Because of the differential settlement additional pull force or tension force ($\Delta T$) is generated inside the soil nail and the aim of this calculation is to determine $\Delta T$.

The equilibrium of ‘dx’ size element can be determined as summation of forces in the nail deformation direction can be written as follows:

$$P = (T + \Delta T) - T - \mu W * \cos\theta \quad (1)$$

$$P = \Delta T - \mu W * \cos\theta \quad (2)$$

Where, T = tensile force already present inside the soil nail due to earth pressure; $\mu W^*\cos\theta$ = friction force generated at nail-soil interface due to component of soil weight ($W^*\cos\theta$) in that direction; $\theta$ = angle of nail deformation; W = weight of soil; $\mu$ = co-efficient of static friction. The strain generated in the deformed portion of nail due to the resultant of tensile and friction forces can be written as follows:

$$\varepsilon_A - \varepsilon_S = \frac{L_f - L_0}{L_0} \quad (3)$$

Where, $\varepsilon_A$ = axial strain due to tensile load $\Delta T$; $\varepsilon_s$ = shear strain due to friction force; $L_0$ = initial length of deformed portion; $L_F$ = elongated final length of deformed portion. Here, the summation of two different kinds of strains can be possible because of both the strains occurring in single direction and deformation of nail happens because of the combined effect of both. Again rewrite equation (3) by writing strains in terms of modulus and forces as:

$$\frac{\Delta T}{E\pi D_N^2} - \left(\frac{\mu W * \cos\theta}{G\pi D_N L_F}\right) = \frac{L_f - L_0}{L_0} \quad (4)$$

Where, E = young's modulus of nail material; $D_N$ = nail rod diameter; G = shear modulus of nail material. Resolve equation (4) to get $\Delta T$ and rewrite it as follows:

$$\Delta T = E\pi D_N^2 \left[\left(\frac{1}{\cos\theta} - 1\right) + \left(\frac{\mu W * \cos\theta}{G\pi D_N L_F}\right)\right] \quad (5)$$

From equation (5), $\Delta T$ can be determined and added to the initial nail force. Hence, due to differential settlement, the tensile load in the nail increases. The main limitation of this method is the determination of $L_0$ length. It can be determined by performing experiments or numerical simulations.

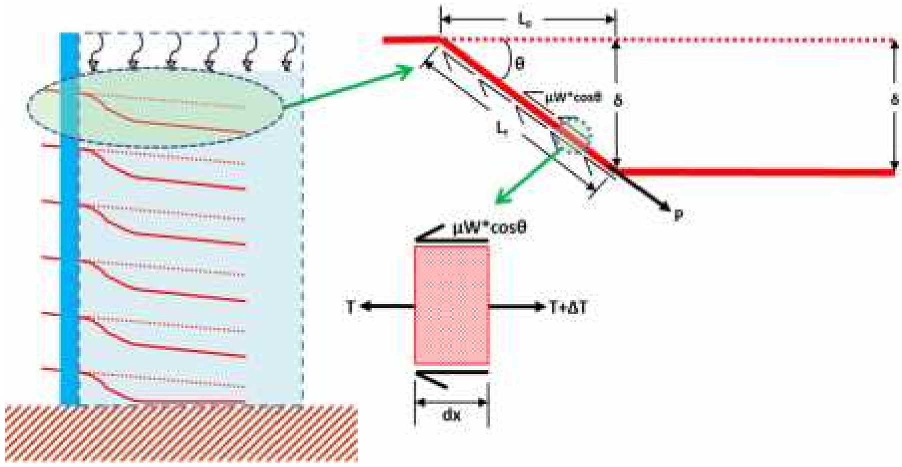



**Fig. 1.** Forces generated in soil nail due to differential settlement

## 3 Importance of Inclined Soil Nails

The soil nails should be provided at some degrees of inclination to the horizontal. The mechanisms behind the inclined nails are explained in Fig. 2. If the nails are provided at zero degree inclination of horizontal than the tensile load in the horizontal nails is calculated as follows:

$$T = P_a - \mu W \tag{6}$$

Where, $P_a$ = earth-pressure force. When the nail is provided at an inclination of ‘α’ angle, the tensile force in the nail can be calculated as follows:

$$T = P_a * \cos\alpha - \mu W * \cos\alpha - W * \sin\alpha \tag{7}$$

Hence, when nails are provided at certain degrees of inclination, the net tensile force generated inside the nail reduced due to additional component of soil weight. Due to this reason, it is beneficial to provide nails at certain degrees from horizontal. Even this may reduce the generation of bending stresses in nails due to differential settlement.

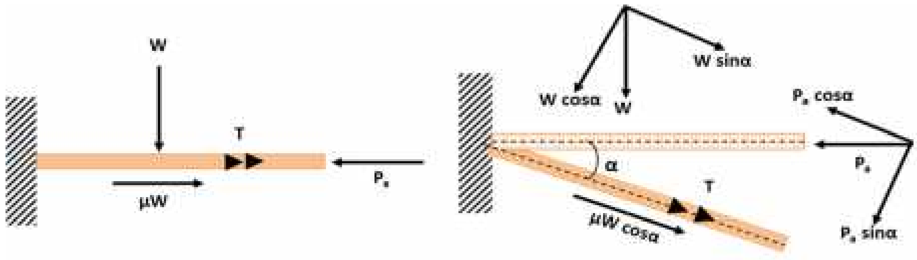



**Fig. 2.** Tensile forces generated in soil nails inclined at: (a) zero degree from horizontal (b) α degree from horizontal

## 4 Design Solution

The solution of above mentioned problem can be made by designing the facia and wall in such a way that they include following features:

- The facia is connected to the reinforced fill, but not to the geosynthetic reinforcement.
- The differential settlement between the facia and reinforced fill is allowed in certain amount and that will not cause any harm to the reinforcement or the overall structure.
- Space and time required to erect the full height panel facia should be minimum.

To include all of the above mentioned features, the new method of facia construction is proposed by using soil nails to connect the facia and wrapped around GRS wall. The design procedure developed here is by taking into account the codel provisions given for GRS wall and soil nail design by various organizations [9-11]. The international codes were chosen based on their applicability in Indian conditions and their used in the previously constructed geotechnical structures in India. The little modification in some provisions was made to fit the design of two different structures. The detail design methodology for the construction of hybrid structure is proposed as follows:

**Step 1:** Fix the engineering parameters of reinforced and back-filled soil.

**Step 2:** Calculate all the design loads acting on the structure.

**Step 3:** Design the wrapped-around GRS wall according to codel provisions given in British code BS 8006-1: 2010 [9]. The BS 8006-1:2010 uses Load and Resistance Factor Design (LRFD) for the design of GRS wall. The Tie-back Wedge method was commonly used for the analysis and design of GRS wall.

**Step 4:** Design soil nailing by considering the earth pressure at facia as 50% of total earth pressure [10] as per USA FHAW-NHI-14-007 manual [11]. The additional force generated due to differential settlement as calculated in section 2 was considered for the design in addition to loads given in the FHAW manual. The LRFD approach is used for external and internal stability calculations.

## 5 Design Example

For the better understanding and to check the suitability of proposed method, a detailed design example is done by following all the required steps. The problem statement for the design example is as follows:

- Design a suitable layout for the 6 m high vertical soil wall. Assume, reinforcement to be used is Tensar 80RE uniaxial geogrid with long term design strength (LTDS) of 34.7 kN/m. The soil properties of reinforced fill, backfill and foundation soil were assumed as follows:
  Reinforced fill: $\Upsilon_w$=19 kN/m$^3$, $\Phi'_w$=35$^0$, $c'_w$=0
  Backfill and foundation soil: $\Upsilon_w$=18 kN/m$^3$, $\Phi'_w$=30$^0$, $c'_w$=0

**Solution:**

The detailed designed solution of GRS wall with stabilized facia via soil nailing is shown in Fig. 3 as per the design procedure mentioned in section 4. The main reinforcement of Tensar 80RE geogrid in wrap-around position was provided at 0.4 m spacing with soil nails having 20 mm diameter were provided at 0.8 m spacing in vertical and horizontal directions. The distance $L_0$ for this design example was assumed as 0.8m. The facia was designed as a two-way slab resting on numbers of soil nails. Hence, the area of facia supported by one soil nail was chosen as the area between the two consecutives nails (0.8m*0.8m). The design of reinforcement was done in accordance with the provisions given in FHWA-NHI-14-007 for the limit state of bending and punching. Welded wire mesh (120*120- MW19*MW19) was designed as a main reinforcement and provided in the central thickness of facia slab. The additional waler bars of 10 mm diameter was designed around the nail head in the both the direction to provided additional support during bending deformation. Bothe the WWM and waler bars are of grade Fe 415. The spacing and number of bars with all the other details are given in Fig. 4. The concrete used for the design of facia slab is of grade M 20 and thickness of it was 100 mm based on the consideration of design requirements and minimum cover requirements. The bearing plate of thickness 25 mm with area of 225 mm*225 mm and grade of Fe 250 was provided at the nail head.

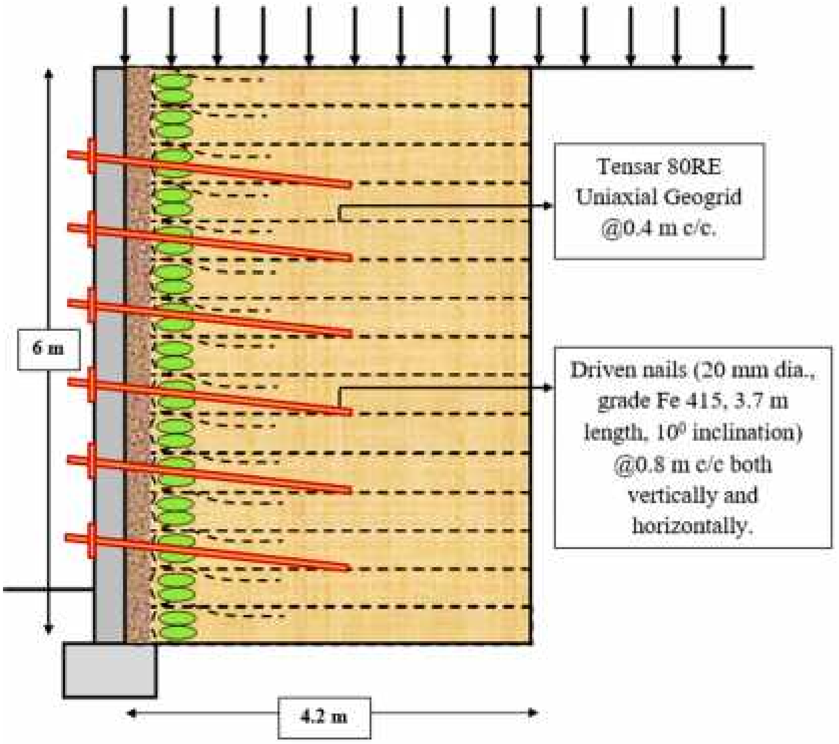



**Fig. 3.** Detailed design of Geosynthetic Reinforced Soil (GRS) Wall with Rigid Facia Using Nailing

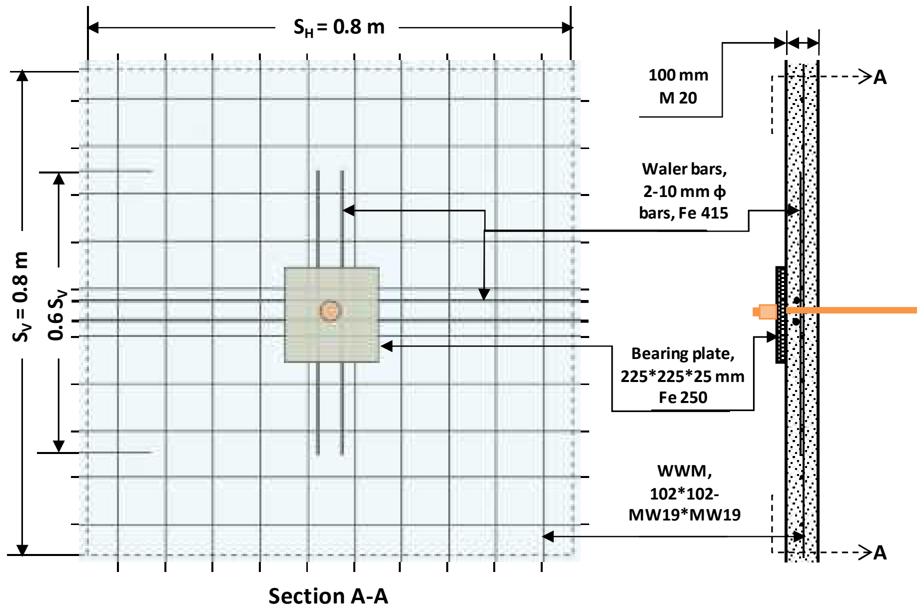


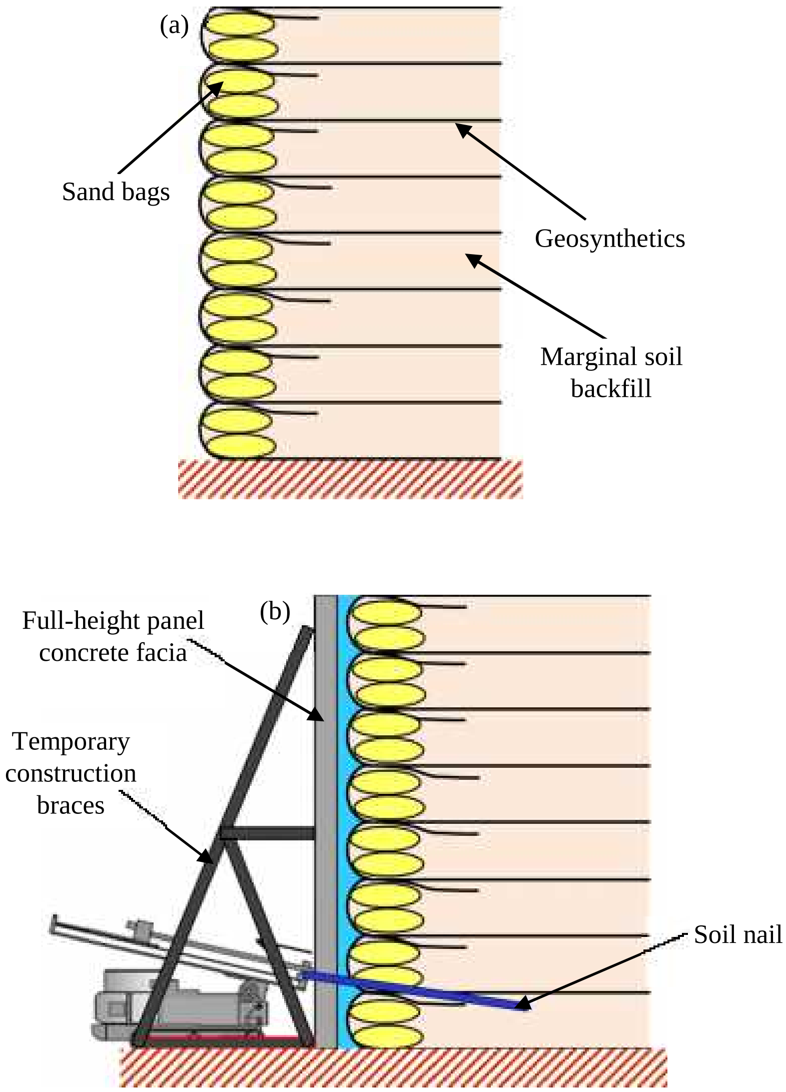

**Fig. 4.** Reinforcement details of designed facia unit

## 6 Construction Sequence

**Step-1**: Prepare the foundation properly and construct the geosynthetic reinforced wrapped-around wall for the full height as per the conventional construction techniques. While construction, the sand bags are provided at the outermost part of the wall to eliminate the effect of improper compaction in the outer layer. Proper drainage in the forms of non-woven geotextile layers is provided at regular intervals to allow water to escape and prevent the excess pore pressure generation. Step-1 of construction sequence is shown in Fig. 5(a).

**Step-2:** After constructing a full height wall, the full height pre-cast RCC facia is laid in the position with the help of temporary construction braces. In between step-1 and step-2, the wall is allowed to deforms in a very small amount to mobilize some percentages of total earth pressure act upon the wall facia. In the current research, the mobilized earth pressure was considered as 50%. Space is provided between the wrapped-around face, and FHP concrete facia for the drainage purpose and this gap can be filled by light porous materials (e.g. lightweight gravels or geofoams). The step-2 of construction sequence is shown in Fig. 5(b).

**Step-3:** The installation of soil nails can be recommended to do from bottom to top of the wall. This technique is in contradiction to traditional soil nail technique in which the construction is top to bottom. The wall is already stabilized here by primary reinforcement of geosynthetic and that is the reason for the selected bottom to top method in the current study. Bearing plates are installed for each soil nail. After erecting all the nails in position, the temporary construction braces are removed sequentially. Step-3 of construction sequence is as shown in Fig. 5(c).



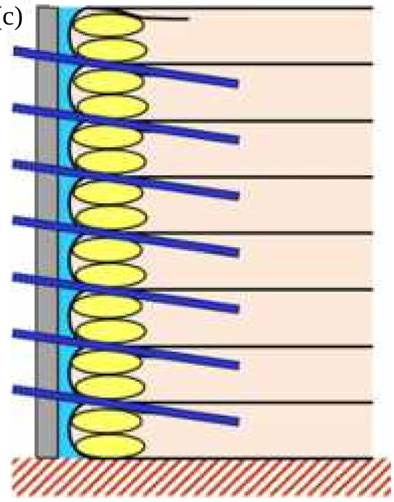



**Fig. 5.** Proposed construction sequence of new facia system: (a) Step-1 (b) Step-2 (c) Step-3

## 7 Advantages and Limitations of Proposed System

The main advantages of proposed system are mentioned as below:

- It eliminates the deleterious effect of differential settlement on the main geosynthetic reinforcement system.
- It requires very less time and space for the construction of facia unit.
- The structure might be more economical in the long run.

The main limitations of proposed system are mentioned as below:

- For the construction of soil nailed facia, skilled manpower is required.
- Design procedure is quite complicated.
- The initial length of deformed portion ($L_0$) for the soil nail needs to be determined through experimental or numerical procedure, which is still unknown.

## 8 Summary

An attempt has been made in the current study to provide the solution of problems created by differential settlement between GRS wall facia and reinforced fill. The soil nails were introduced as a secondary reinforcement to act as a sacrificing agent in order to maintain the integrity and functionality of GRS wall during the possible cause of reinforced fill settlement. The method was suggested to calculate the additional soil nail load generated due to deformation of fill. The detailed design procedure was given based on certain assumptions and clauses as per few international codes to design this hybrid system. The possible construction method was also given by considering the time, space and economical aspects.

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