

# A Comparative Study on the Design of Flexible Faced and Rigid Faced Geosynthetic Reinforced Soil Walls



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**Abstract** In practice, Geosynthetic reinforced soil (GRS) walls are constructed using different types of fascia with different levels of rigidity. It is believed that fascia does not have any role on the load transfer behavior. It was observed that only RTRI (Railway Technical Research Institute) guidelines of Japan utilizes stability effects provided by the fascia while considering it as rigid and proposes entirely different design approaches compared to the design guidelines in other countries. RTRI guidelines also consider fascia as a load-carrying member in rigid faced GRS walls. This study is focused on the comparative study of design approaches involved in the design of flexible faced GRS walls (BS 8006) and rigid faced GRS walls (RTRI). Some of the key aspects like physical phenomena involved in both design approaches have been explained with a real-life example of design of bridge approach which is located near Bhagur in Nashik, India. An approximate material cost comparison study is also made which showed 30–40% cost reduction with rigid faced systems. Some of the construction and stability advantages of rigid faced GRS walls have been highlighted in this study.

**Keywords** Design · GRS walls · BS 8006 · RTRI · Flexible fascia · Rigid fascia

## 1 Introduction

Geosynthetic reinforced soil walls (GRS walls) are widely used in the construction of retaining walls and abutments due to their low cost, reliability, durability, ease in construction and ability to tolerate large deformation without structural failure

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compared to conventional concrete retaining wall. Those benefits made reinforced earth walls play an important role in the development of infrastructure around the world. Geosynthetic reinforced soil walls typically consist of four components: (1) Reinforcement, (2) Reinforced fill (soil), (3) Fascia and associated connections, and (4) Drainage. The mutual interaction of these components influences the overall mechanical response of the wall. Stiffness of each component impacts the overall behavior and is majorly governed by the reinforcement stiffness, length, and spacing for a given fill [6] a part from fill. In these GRS walls, fascia is not generally considered as structural component instead considered for covering the reinforced fill from erosion and local failures.

In practice, different types of fascia are used to construct GRS walls which have different types of rigidities. Recent studies showed that fascia can play a considerable role in behavior of walls. Tatsuoka [13] reported that full height rigid fascia stabilizes active zone, which is the result of high tensile force of reinforcement produced at fascia creating a high confining pressure within the active zone as reaction. It was also reported that different from the conventional reinforcing method, short planar reinforcement with rigid facing structure is more economical one. Liu et al. [8] also reported that rigidity of fascia forms an additional confining pressure that directly applies back to the reinforced zone. All these studies also reported that there is reduction in the lateral deformations of reinforced zone with increase in global stiffness of fascia and also full earth pressure/maximum reinforcement tension mobilization at rigid facings. It was observed that load can transfer to toe of facing (globally) which resulted in decrease of strains in reinforcement [3]. Allen et al. [1] based on the measurement from the field monitoring developed a new working stress method for internal stability analysis called as “K-stiffness” method which considers stability effects of fascia as one the influence factor. This factor is the result of resistance provided by the stiffness of facing and restraint at toe which reduced the reinforcement forces.

Guidelines like FHWA (No. FHWA-RD-89-043) and BS 8006 do not suggest anything about the design of fascia and its stabilizing effects on reinforced zone, as they depend on the design of flexible faced wall, they suggest to provide sufficient connection strength. EBGeo guidelines have suggested design of fascia for a part or full earth pressure mobilized on facing but does not consider the stabilizing effects of fascia rigidity on reinforced fill. RTRI guidelines (Design standards for railway structures) are the only design guidelines consider stabilizing effects of full rigid fascia. The key steps of rigid faced GRS wall design as per RTRI guidelines include (a) Use shorter reinforcement, (b) Double wedge method of stability analysis with failure plane evolution from toe only, and (c) Design of fascia for full earth pressure by analyzing it as beam connected to springs.

In this study flexible GRS wall design as per BS 8006 and rigid faced wall design as per RTRI guidelines has been carried out to evaluate the consistency in load transfer mechanisms, stability, and economical aspects. In this study, a real case of

highway bridge approach which exists in India was considered for the design as per both guidelines. For the comparison, the wall is designed at three different sections along the alignment while loading conditions were kept constant for both designs.

## 2 Description of Data for Design

The bridge approach to be constructed near Bhagur in Nashik, India has been considered for this study which has a length of 135 m and width of 24 m with maximum height of 8.8 m and minimum height of 1.9 m as shown in Fig. 1. The soil investigation report showed that morrum soil layer exists till 3 m below the ground level and basalt rock is below morrum and groundwater was not observed up to 13 m depth of investigation. The reinforced soil, backfill soil and foundation soil properties are listed in Table 1.

TechGrid polyester Geogrids U-40, U-60, U-80, U-100, U-120, and U-150 are considered for the design with interaction coefficient of 0.9 for pullout and 0.8 for internal sliding. Wall was divided into three sections according to the height of the wall such as 8.8, 7.3, and 5 m as shown in Fig. 1 and each section is designed as per

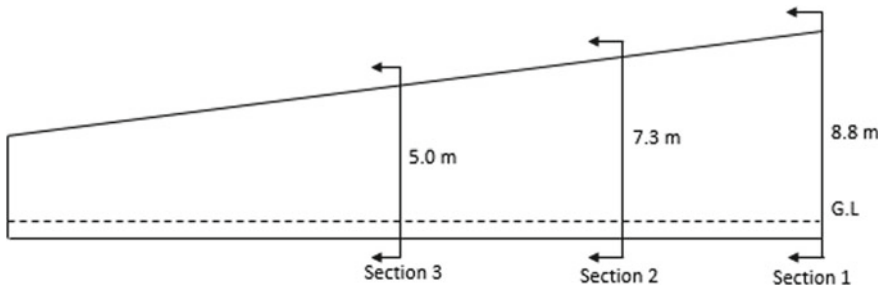


Fig. 1 Side view of the bridge approach

Table 1 Soil properties

Material properties	Friction angle (°)	Unit weight of the soil (kN/m <sup>3</sup> )	Cohesion (kPa)
Reinforced fill	30	18	0
Back fill	30	18	0
Foundation fill	32	20	0

both codes with dead load of 15.4 kPa, live load of 24 kPa and strip vertical load due to crash barrier of 12 kN/m.

### 3 Design of Flexible Faced GRS Wall as per BS 8006

The British standard follows limit state principles which are ultimate limit state and serviceability limit state. Accordingly, the design wall is carried out as per three load combinations where stability of reinforced wall is analyzed to check against external stability and internal stability. The analysis of internal stability is essentially checking against tension failure and ensuring no pullout by providing sufficient anchorage length into the stable soil behind potential failure surface. Failure mode of forward sliding, overturning, internal sliding failure, and bearing failure were considered in external stability. Settlement of foundation and deformation in wall are considered in serviceability limit state with load combination C which consider the dead load only with partial load factor of one and does not include the live load. Tie back method is generally used for walls with extensible reinforcement and coherent method is used for walls with inextensible reinforcement. In this study only tie back wedge method is used which involves linear failure wedge.

The strengths of reinforcement used in BS 8006 are listed in Table 2. As this study is to compare both flexible and rigid fascia designs, 0.3 m spacing is fixed which is suggested as vertical spacing by RTRI. The MSEW software is used to design the reinforced wall as per BS 8006. The final designs of the three sections as per BS 8006 are shown in Table 3 and Fig. 2.

**Table 2** Long-term design strength of reinforcement as per BS 8006

Property	U-40	U-60	U-80	U-100	U-120	U-150
Short term strength (kN/m)	40	60	80	100	120	150
Long-term strength (kN/m)	19.2	28.9	38.5	48.1	57.7	72.2

**Table 3** Design details of three sections

Section	Height of wall, $H$ (m)	Length of geogrid, $L$ (m)	Reinforcement strength (kN/m)
1	8.8	9.4	150
2	7.3	8	120
3	5	6	100

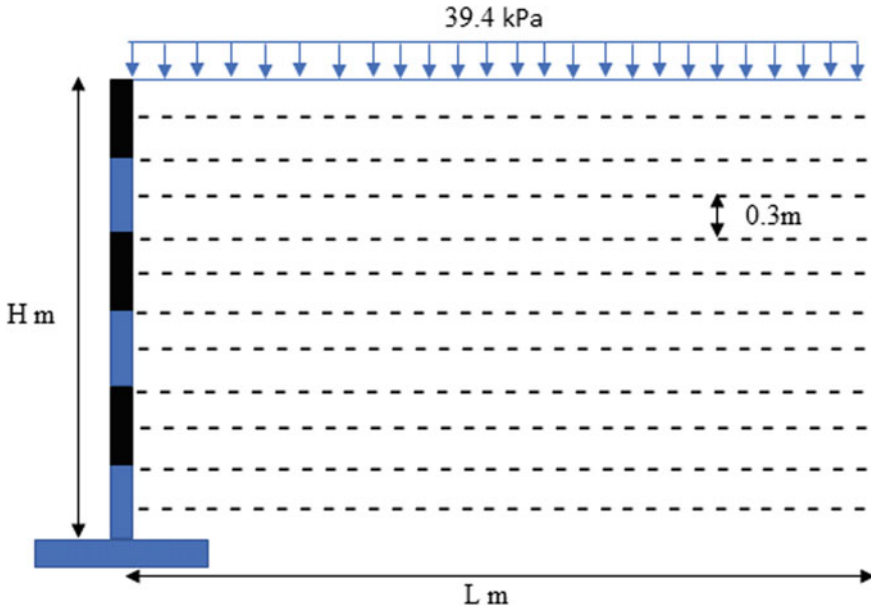


Fig. 2 Designed flexible wall section

#### 4 Design of Rigid Faced GRS Wall as per RTRI (Japanese Code)

Design standards for Railway Structures of Japan (of RTRI) consider the stability effects provided by the rigid fascia and accordingly developed their design method for the GRS walls. This code follows performance-based design with limit state design procedure. The performance-based design suggests three required performance such as safety performance, serviceability performance, and restorability performance. Rupture of reinforcement, pull out of reinforcement, and stability of supporting ground, wall external stability, and wall internal stability are checked under the safety performance. The appearance is evaluated in serviceability performance. Wall residual displacement and wall damage are accounted in restorability performance.

RTRI, which considers different kinds of reduction factors compared to BS 8006 such as alkaline reduction factors, mechanical reduction factors, creep reduction factors, material reduction factors, instant load reduction factors, and trainload reduction factors results in different long-term strength as shown in Table 4.

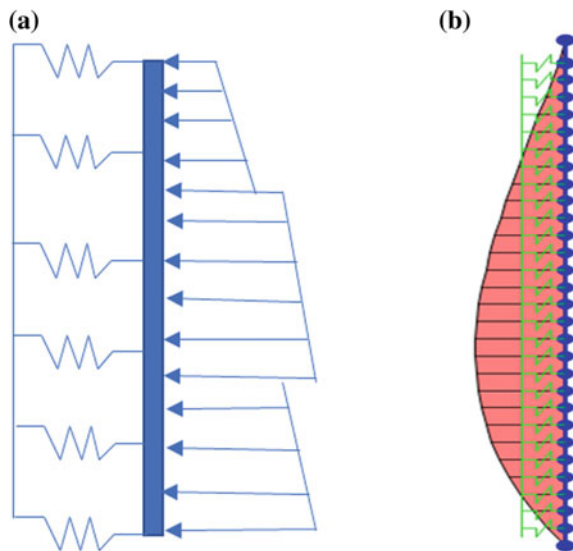
As per the design, reinforcement should be placed at the spacing of 0.3 m and the reinforcement has to be placed up to the line drawn from the toe of wall at the angle equal to the internal friction angle of the backfill for every 1.5 m height. The same is shown in Fig. 4. Wall internal stability has two failure modes which are overturning and sliding failure of fascia with reinforcement connected to it and anchored in stable zone. The wall external stability accounts the overall slip circle

failure. The reinforcement tension failure is checked by force developed in spring when fascia is modeled as beam column with reinforcement as springs and loaded with a rest earth pressure. So, the fascia should be a full height rigid fascia. The facing of reinforced wall is modeled in SAP 2000 as continuous beam supported by a series of spring which is represented reinforcement layer and beam subjected to earth pressure as external force as shown in Fig. 3. From the bending moments and shear force developed, fascia having height of 8.8 m is designed with thickness of 0.3 m at the top, 0.4 m at bottom with concrete grade M-30. Bending moment and deflection have been found to be safe. The stiffness of springs is to be taken as strength of reinforcement at 5% strain over 1.5 m length of reinforcement. A code developed in MATLAB is used to check walls internal stability for double wedge method and Geo 5 is used to check global stability. The final design as per RTRI is given in Table 5 and Fig. 4. The line drawn at angle of friction angle in Fig. 4 should not be confused with failure wedge as it represents the maximum line till which reinforcement has to be extended.

**Table 4** Long-term design Strength of reinforcement as per RTRI

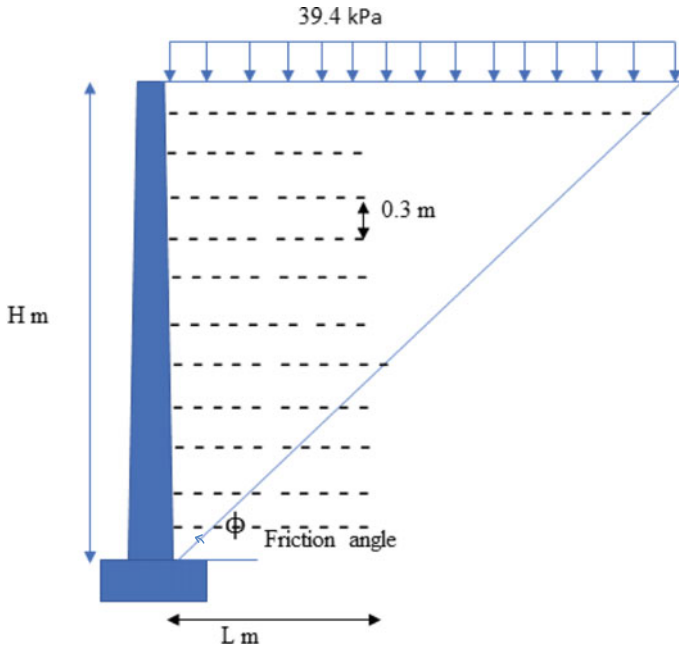
Property	U-40	U-60	U-80	U-100	U-120	U-150
Short term strength (kN/m)	40	60	80	100	120	150
Long-term strength (kN/m)	16	24	32	40	48	60

**Fig. 3** (a) 1-D model and (b) bending moment diagram of the fascia as per RTRI



**Table 5** details of final three design section as per RTRI

Section	Height of wall (m)	Length of geogrid (m)	Strength of geogrid (kN/m)	Normal layers	Extended layers
1	8.8	4	150	23	5
2	7.3	3.5	120	19	4
3	5	3	100	13	3



**Fig. 4** Designed section as per RTRI

## 5 Comparison of Design

### 5.1 Configuration

In general,  $0.7H$  is the minimum reinforcement length as per BS 8006, while,  $0.6$  m is the restriction for maximum vertical spacing. Maximum of  $1.5$  m and  $0.35H$  is to be used as minimum reinforcement length in rigid faced wall with constant vertical spacing of  $0.3$  m as per RTRI. The final design of bridge approach walls resulted in reinforcement length equal to  $H$  and  $0.4H$ , respectively, for flexible and rigid wall. There is considerable difference in the length of reinforcement, i.e., base width of

wall among two design codes. This is due to the considerations of difference in the load resistance mechanisms of two systems followed by the two codes. Flexible walls as per BS code involves whole internal load to be resisted by the reinforcement itself. While in the rigid faced wall system, the weight component of fascia is going to come into picture. The earth pressures are resisted by base resistance of fascia and tensile force of reinforcement behind failure wedge. In a way this is a hybrid system, where load is distributed among the fascia and reinforcement. This can be thought of a gravity wall (fascia) tied into the retained soil by reinforcement. The whole load should be taken by reinforcement in flexible wall while fascia and reinforcement share the load in rigid fascia wall, so that small length of reinforcement is good as per RTRI.

Further, both BS 8006 and RTRI code are silent about the minimum vertical spacing of reinforcement which should be specified for the full mobilization of the force in the reinforcement. BS 8006 specified the maximum vertical spacing as 0.6 m while RTRI code fixed the vertical spacing as 0.3 m that cannot be changed.

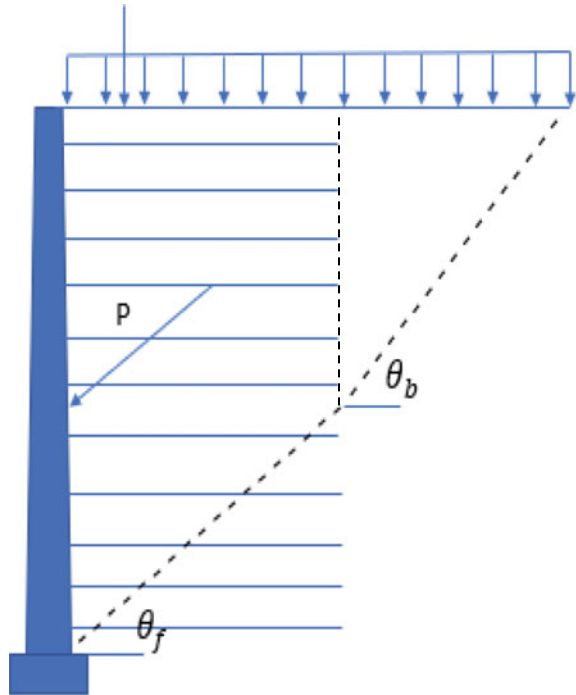
## ***5.2 Earth Pressure Force***

Rankine and coulomb wedge method can be used to find out the earth pressure acting on the reinforced fill made of extensible reinforcement by assuming the active condition throughout the wall for both ultimate and serviceability limit states in BS 8006. Coherent gravity method is used for inextensible reinforcement used reinforced wall with the assumption of active earth pressure that is acting on the bottom of the wall and at rest earth pressure at the depth 6.0 m and constant beyond 6.0 m depth. Using those two methods mentioned above, the lateral force is calculated in flexible wall. Several failure planes have to be investigated as the failure planes in flexible fascia system can evolve from any level of fascia.

Two-wedge stability analysis is the fundamental approach of rigid wall to compute the earth's pressure that acting on the wall facing. As fascia is rigid, failure planes can only start from the toe of the wall. In two-wedge method, for various failure plane angles and reinforcement load mobilized in the cut portion (minimum of pullout and breaking force) the minimum factor of safety against sliding and overturning is calculated by equilibrium. Since the minimum of long-term design strength and pullout resistance is taken as force on the Geogrid, the maximum earth pressure does not necessarily provide the minimum factor of safety. The wedge destabilizing force is resisted by the force mobilized in the anchored reinforcement and the weight of fascia. It was assumed that the reinforcement which was cut the failure plane only will resist the force, but not all the reinforcements. The equilibrium equations of two-wedge method have been solved using MATLAB to get directly factor of safety values. The schematic free body diagram of two-wedge method is shown in Fig. 5.



Fig. 5 Two-wedge method



### 5.3 Fascia

The BS codes commonly suggest the flexible fascia of discrete panel, full height panel, wrap-around facing and segmental block facing even though they vary in their stiffness relatively Flexible fascia is only intended to prevent local failure, accommodates settlement and gives esthetic appearance. Tatsuoka et al. [13] classified different fascia systems as facing system that can provide local stiffness like wraparound fascia, overall axial rigidity like block panel fascia, overall bending–shear rigidity like full height panel fascia and overall bending-shear-gravity rigidity like full height rigid fascia. According to RTRI full height rigid (FHR) wall is constructed by casting concrete on the wrapped face of Geogrid reinforcement, so that the facing and reinforcement layer is firmly connected to each other by fresh concrete. Rigid fascia gives confining effect to the reinforced mass and further improves the performance of system [11]. This effect is completely utilized in RTRI code by taking gravity effect of fascia in the limit equilibrium design. Flexible facing lacks to exhibit the high resistance against to loads like Full height rigid (FHR).

## 5.4 Cost

The cost of material required per meter length of wall is estimated in both codes to find out the economical different of flexible and rigid fascia. The material costs (not included construction costs) for flexible wall designed as per BS 8006 are 62,000, 45,000 and 25,000 Indian rupees for Sects. 1, 2 and 3, respectively, while the rigid fascia is costing 34,500, 26,500, and 17,000 as per RTRI for Sects. 1, 2, and 3, respectively. Sections 1, 2, and 3 have material cost reduction of 40%, 35%, and 32%, respectively, if rigid fascia is constructed rather than constructing flexible. Since the flexible wall requires higher length of geogrid and backfill than rigid wall, so that reinforcement quantity and reinforced fill quantity vary very much in both designs so that the cost also varies in both designs. Rigid fascia saves more money and becomes a more economical design. The rates of material used for the cost calculations are shown in Tables 6 and 7.

**Table 6** Cost of the flexible facing reinforced zone in Indian rupees per meter run

Description	Unit	Rate	Quantity in BS 8006			Cost		
			S1	S2	S3	S1	S2	S3
GSB below leveling pad	m <sup>3</sup>	943	0.15	0.15	0.15	142	142	142
Leveling pad	m <sup>3</sup>	2000	0.12	0.12	0.12	240	240	240
Fascia	m <sup>3</sup>	1200	8.8	7.3	5.0	10,560	8760	6000
Selected filling in RF zone	m <sup>3</sup>	300	83	58.4	30	24,816	17,520	9000
Geogrid	m <sup>2</sup>	100	264	184	96	26,320	18,400	9600
Total cost						62,000	45,000	25,000

**Table 7** Cost of the rigid facing reinforced zone in Indian rupees per meter run

Description	Unit	Rate	Quantity in RTRI			Cost		
			S1	S2	S3	S1	S2	S3
GSB below leveling pad	m <sup>3</sup>	943	0.15	0.15	0.15	142	142	142
Leveling pad	m <sup>3</sup>	2000	0.12	0.12	0.12	240	240	240
Fascia	m <sup>3</sup>	4000	3.1	3.0	1.8	12,320	10,240	7000
Selected filling in RF zone	m <sup>3</sup>	300	35	26	15	10,260	7665	4500
Geogrid	m <sup>2</sup>	100	112	81	48	11,200	8050	4800
Total cost						34,500	26,500	17,000

## 5.5 Safety

Since factor safety against every condition in both designs is found as safe as per both codes, both code designs are considered as safe design. As per past studies, flexible fascia is being failed even in static condition but having a rigid fascia let the wall to be safe even in seismic conditions [12]. Since RTRI codes following rigid fascia showed no failure in the past, it appears to be more stable than flexible fascia.

## 5.6 Construction Issues

The staged cast-in situ fascia construction method is used for rigid faced wall construction as per RTRI. The staged construction method of FHR faced walls is constructed using Cast-in situ concrete fascia with reinforcement layers firmly connected to fascia by means of fresh concrete after the wraparound reinforced zone is constructed. The main advantage of staged cast-in-situ fascia construction method is that the major deformations of wall had happened when the wraparound wall is constructed itself and when rigid fascia is casted; it enhances stability and further deformations will be negligible. These types of constructions were very helpful when there are stringent limitations of settlement/lateral deflections like in high-speed rail embankment.

The main constructional difficulty in FHR facing is to maintain a strong connection between fascia and reinforcement. It requires steel reinforcement rods inserted into reinforced zone extended from fascia for high compatible connection to provide confining effect. So, utmost care is required for connections in FHR fascia construction.

Flexible fascia like wraparound fascia is easy to construct and need not to wait for full deformations to get happen like in FHR fascia. It can easily accommodate to vertical settlements. These types of constructions were practiced when there are no stringent limitations of settlement/lateral deflections.

## 6 Conclusions

Design of rigid and flexible fascia has been compared to highlight their difference by taking a real scenario into consideration. BS 8006 and RTRI have completely different design concepts such limit state design procedure and performance based with limit state design procedure, respectively. The rigid and flexible fascia have unique method of design process. The major difference was the rigid fascia is considered as load-carrying element along with reinforcement while flexible is not considered. The rigid fascia was completely considered as load-carrying element in RTRI while in BS 8006 there is not much concern about fascia since it is not used for carrying loads. The

material cost of rigid fascia wall is less than cost of flexible fascia. The rigid fascia wall gives cost reduction of about 30–40% according to the design considered in this study.

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