

Seismic performance of GRS walls with gabion fascia vis-à-vis segmental block fascia retaining walls

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Abstract. Geosynthetic-reinforced soil (GRS) walls are widely used in seismic regions due to their flexibility, cost-effectiveness, and favorable deformation characteristics. However, the influence of fascia type on their seismic response is not yet fully understood. This study presents a comprehensive numerical investigation of the seismic behaviour of GRS walls with segmental block and gabion fascia systems using finite element modelling. To isolate the effect of fascia type, both wall configurations are designed with identical geometry, backfill properties, reinforcement layout, and construction sequence. The GRS wall response is evaluated under static using gravity load and dynamic loading conditions using the 1995 Kobe earthquake motion as input. The analyses focus on mobilized reinforcement and connection loads, acceleration amplification along the wall height, lateral earth pressure distribution, and the development of potential failure surfaces. A realistic field construction scenario is simulated through staged construction, including the application of transient compaction loads, and results are assessed at the end-of-construction (EOC) condition. The results indicate that reinforcement and connection loads increase toward the lower portion of the wall due to combined overburden and seismic effects, with gabion fascia walls consistently mobilizing lower loads than segmental block walls. Acceleration amplification is higher near the wall face than within the reinforced zone because of reduced confinement, while gabion fascia walls exhibit slightly higher amplification associated with internal void rearrangement. Lateral earth pressures generally follow a Rankine-type triangular distribution, but segmental block facias develop higher pressures, particularly near the wall base under seismic loading. Failure surfaces inferred from peak reinforcement loads deviate from classical Rankine assumptions, curving toward the face in segmental block walls and developing deeper within the reinforced zone in gabion walls. Overall, the study demonstrates that gabion fascia GRS walls exhibit superior seismic performance compared to segmental block systems and highlights the limitations of conventional Rankine-based assumptions in capturing the actual failure mechanisms of GRS walls under dynamic loading.

1 Introduction

Geosynthetic-reinforced soil (GRS) walls have become an integral part of modern geotechnical engineering practice due to their cost-effectiveness, rapid and straightforward construction, and reliable performance under a wide range of loading conditions [1,2]. Compared with conventional rigid retaining structures, GRS walls offer greater flexibility and deformation tolerance, which makes them particularly attractive for transportation and infrastructure projects in seismic regions. Their satisfactory performance during past earthquakes has further reinforced confidence in their use under dynamic loading conditions [3,4].

Among the various components influencing the seismic response of GRS walls, the facing (fascia) system plays a critical role in controlling wall deformation, load transfer, and overall stability. The facing not only provides external support and erosion protection but also governs confinement of the reinforced soil mass

and the mobilization of reinforcement forces under seismic excitation. Segmental block fascia systems are the most commonly used facing type and are well established in design practice, with detailed guidance provided in National Concrete Masonry Association (NCMA) design manuals and related studies [5, 6]. However, alternative facing systems, such as gabion facias, have attracted increasing interest due to their inherent flexibility, energy dissipation capacity, and potential for improved seismic performance [4, 7].

Despite the growing application of gabion-faced GRS walls, the current understanding of their seismic behavior remains limited. In particular, systematic and direct comparisons between gabion and segmental block fascia systems under strong earthquake loading are scarce [1]. Existing studies have largely focused on static or pseudo-static behavior, while comprehensive dynamic evaluations that capture the evolution of failure mechanisms, reinforcement-facing interaction, and acceleration amplification characteristics are still

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lacking. This gap in the literature hinders the development of robust design recommendations for selecting appropriate fascia systems in seismically active regions.

To address this limitation, the present study conducts a detailed numerical investigation into the seismic response of GRS walls with gabion fascia and compares their performance with that of conventional segmental block-faced GRS walls using finite element (FE) modelling. The analyses focus on key response parameters, including wall reinforcement-fascia connection loads, reinforcement mobilization, development of potential failure surfaces, and acceleration amplification along the wall height under earthquake loading.

The dynamic behavior of both wall systems is evaluated using the 1995 Kobe earthquake motion as the input ground motion, which is representative of strong near-field seismic excitation. Wall designs are developed in accordance with established guidelines from the Federal Highway Administration (FHWA) [2] and the National Concrete Masonry Association (NCMA) [5], ensuring consistency with current engineering practice and design standards. To enable a direct and meaningful comparison, both wall configurations are modelled with identical geometry, backfill properties, and reinforcement layouts.

The outcomes of this study provide new insights into the role of fascia type in governing the seismic response of GRS walls. The findings highlight differences in deformation characteristics, internal force redistribution, and failure mechanisms between gabion- and segmental block-faced systems, thereby contributing to improved understanding and more informed design of GRS walls in earthquake-prone regions.

1.1. Validation study for segmental block fascia GRS wall

Yu *et al.* [8] conducted a detailed numerical modelling investigation of two geogrid-reinforced modular block retaining walls (Wall C: 10.7 m, Wall D: 6.4 m) constructed for the SR-18 highway in Washington State, using FLAC2D finite-difference simulations validated against extensive field monitoring data. In the present study, we employed the FE program for a verification and validation analysis of Wall C (10.7 m) of SR-18, shown in Fig. 1(a). The soil was modelled using the Mohr-Coulomb failure criteria with a non-associated flow rule (with dilation angle of reinforced fill (ψ_b) = 14°). The soil properties which used in the validation model are presented in Table 1.

Three different HDPE geogrid products were used in this wall. The geogrid with the highest ultimate tensile strength (Geogrid-3: T_{ult} = 115 kN/m) was used for the bottom nine reinforcement layers. Reinforcement layers 10, 11, and 12 from the bottom of the wall were geogrid with the intermediate ultimate tensile strength (Geogrid-

2: T_{ult} = 70.3 kN/m). The remaining layers were geogrid with the lowest ultimate tensile strength (Geogrid-1: T_{ult} = 54 kN/m). The reinforcement layers were placed at a vertical spacing of S_v = 0.6 m. The reinforcement length from the facing is 8.8 m. The embedment of Wall C at the toe is 1.1 m.

Table 1 Reinforced soil material properties

	Backfill [8]
Unit weight (γ), (kN/m ³)	21.7
Poisson's ratio (ν)	0.3
Young's Modulus (E), (kPa)	80,000
Angle of internal friction (ϕ)	54°
Cohesion (kPa)	2
Dilation angle (°)	14°

Interface behaviour between soil and reinforcement was simulated using joint elements to allow appropriate stress transfer and slip behaviour. The reinforcement and backfill soil interface presented here define the structural and mechanical behavior of the reinforcement-backfill interface in GRS wall which is modelled following Mohr- coulomb failure criteria, the interface properties are presented in Table 2. The reinforcement elements are modelled as a liner element. The normal and shear stiffness parameter, k_{sr} = 1 MN/m, signifying its ability to resist relative displacements at the reinforcement-backfill soil. In terms of shear strength properties, the interface is defined by a adhesion value, $c_{a,sr}$ = 1.33 kN/m², which reflects its bonding capacity, and an interface friction angle, ϕ_{sr} = 43°, which represents its resistance to shear sliding along the interface.

Table 2. Material interface properties [8]

	Block to Block	Block to Soil	Soil to geogrid
Adhesion (kPa)	58	2	1.33
Angle of internal friction (°)	36	44	43
Normal stiffness (MPa/m)	1,000	100	100
Shear stiffness (MPa/m)	40	1	10

Comparison of present study results with the field and FLAC2D results [8] showed close agreement. The lateral displacement profile along the wall height predicted by the model agreeable with the measured displacements at the facing, both in magnitude and deformation pattern, as shown in Fig. 1(b). The peak reinforcement and connection load distribution captured in the numerical analysis aligned with the measured tensile loads, with peak forces occurring near the mid-height of the wall and tapering off toward the top and bottom layers, as shown in Fig. 1(c) and (d). The validated model demonstrated the capability to realistically simulate the static behaviour of GRS walls, providing a reliable foundation for subsequent dynamic analyses.

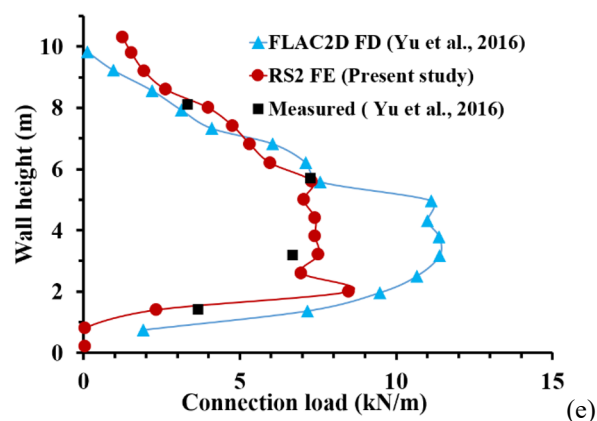
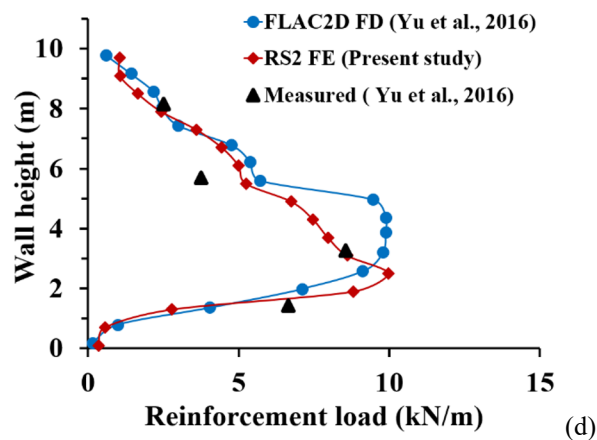
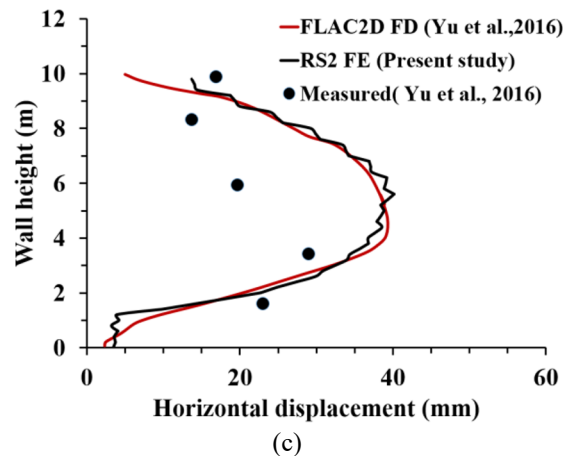
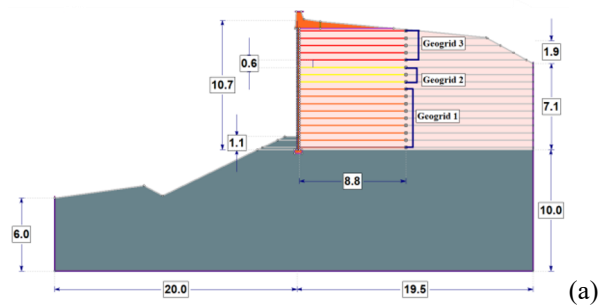


Fig. 1. SR-18 wall C model and validation results: (a) SR-18 wall C detail, (b) horizontal wall face displacement, (c)

reinforcement strain, (d) reinforcement load, and (e) connection load.

2 Methodology

This study employs a numerical modelling approach to evaluate the seismic performance of geosynthetic-reinforced soil (GRS) walls with gabion and segmental block fascia systems. Two-dimensional finite element models are developed to analyse stress, deformation, and dynamic response under static and seismic loading. The modelling framework incorporates realistic construction sequencing, reinforcement-soil interaction, and wall-soil behaviour to capture the seismic response of the systems.

2.1 Wall Geometry and Configuration

Two wall configurations were analysed: one with segmental block (SB) fascia and the other with gabion (GB) fascia, as shown in Fig. 2. Both wall systems were designed in accordance with the guidelines of the Federal Highway Administration (FHWA) and the National Concrete Masonry Association (NCMA), ensuring consistency in geometry and reinforcement layout. To enable a direct comparison, identical geometric parameters were adopted for both configurations. The wall height was 12 m, the reinforcement length was set to 0.7H, and the vertical spacing between successive reinforcement layers was 1 m. The only variable between the two systems was the type of facing, namely segmental block or gabion fascia. The numerical models were developed to replicate a realistic construction sequence. The wall was constructed in successive lifts, with each layer placed sequentially. A transient compaction surcharge of 8 kPa was applied at the top of each lift prior to the placement of the subsequent reinforcement layer to accurately simulate field compaction effects.

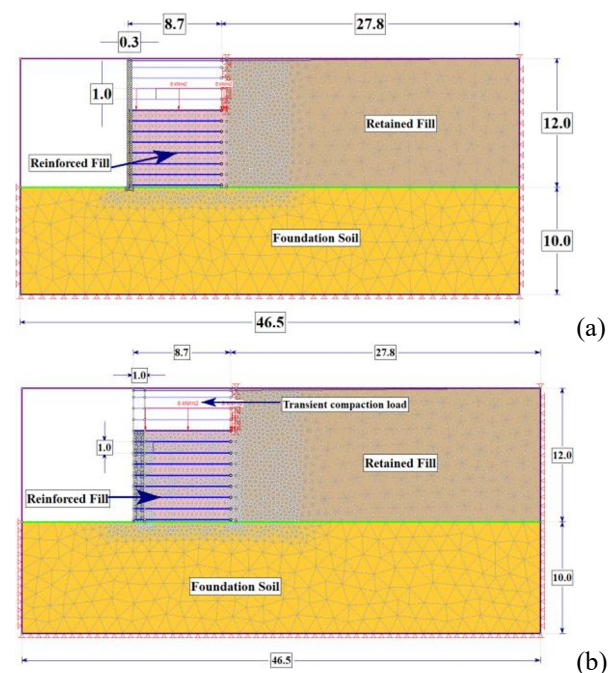


Fig. 2. wall details for (a) segmental block fascia and (b) gabion fascia GRS wall.

2.2 Numerical Modelling Approach

Finite element (FE) analyses were conducted using RS2 (v11.024) to investigate the stress-deformation behaviour and seismic response of the wall systems. A two-dimensional plane strain model was employed for all analyses. The domain was discretized using six-noded triangular elements, as shown in Fig. 2., and mesh refinement was applied in regions where significant interaction between wall components was expected to achieve accurate representation of stress transfer and deformation patterns.

2.3 Boundary and Loading Conditions

For static FE analyses, the vertical boundaries were restrained in the horizontal direction while allowing vertical movement, and the base was fixed in both horizontal and vertical directions. For dynamic analyses, transmitting boundaries were applied along the vertical edges to allow the propagation of seismic waves into and out of the model, while absorbing boundaries were imposed at the base to reduce wave reflections. The 1995 Kobe earthquake ground motion was applied at the model base in the horizontal direction to evaluate the dynamic response of the wall systems.

2.4 Material Properties

2.4.1 Reinforcement

Geogrid was adopted as the reinforcement material, and the reinforcement layers were modelled as two-noded linear elastic-plastic elements. The geogrid had a tensile modulus of 1440 kN/m and a design tensile strength of 51 kN/m. The reinforcement was extended up to the end of the reinforced fill zone but was not connected to the existing retained fill, allowing for realistic simulation of interaction and load transfer within the reinforced soil mass.

2.4.2 Soil Fill and Facing Materials

The retained fill, reinforced soil, and foundation soil were modelled as homogeneous, elastic-perfectly plastic materials governed by the Mohr-Coulomb failure criterion, while the wall fascia was modelled as a linear elastic material. Material properties included unit weight, Young's modulus, Poisson's ratio, cohesion, and internal friction angle.

2.4.3 Soil-Reinforcement Interaction

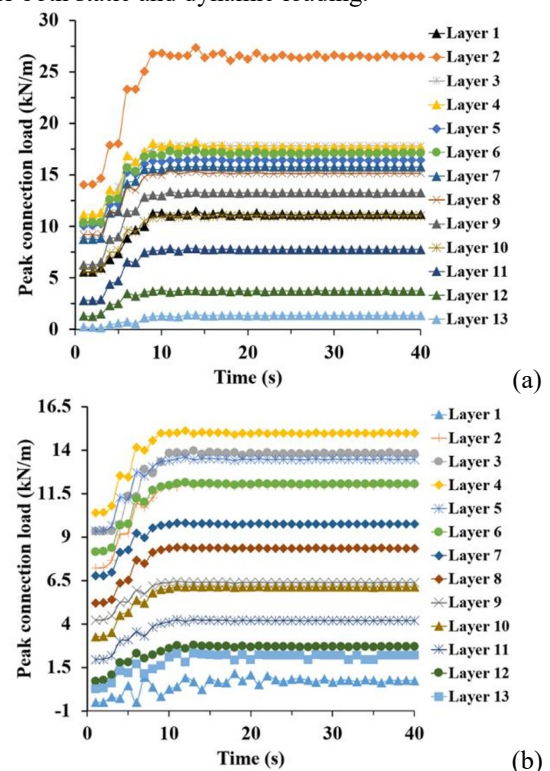
The soil-geogrid interface was modelled using Mohr-Coulomb strength parameters combined with interface stiffness values to capture both strength and deformation behaviour. A peak interface friction angle of 43° and a peak adhesion of 2.5 kPa were assigned, while the shear

and normal stiffness values were taken as 10 MPa/m and 100 MPa/m [8], respectively.

2.5 Results and Discussions

2.5.1 Facing-reinforcement connection load

In the present study, the connection between the GRS wall fascia and the geogrid reinforcement was modelled at a distance of 0.3 m from the wall face for the segmental block fascia wall, corresponding to the width of the block, and 1.0 m for the gabion fascia wall. Fig. 3(a) and (b)., illustrate the mobilized connection loads along all reinforcement layers for dynamic loading conditions. The results show that the connection loads are generally higher toward the lower portion of the wall, primarily due to the combined effects of overburden pressure and seismic loading. Furthermore, the gabion fascia exhibits superior performance compared to the segmental block fascia, which can be attributed to its inherent flexibility and the stabilizing effect of its self-weight. Fig. 3(c) compares the connection loads mobilized under static and dynamic conditions for both wall systems, indicating that the gabion fascia also demonstrates better performance under both static and dynamic loading.



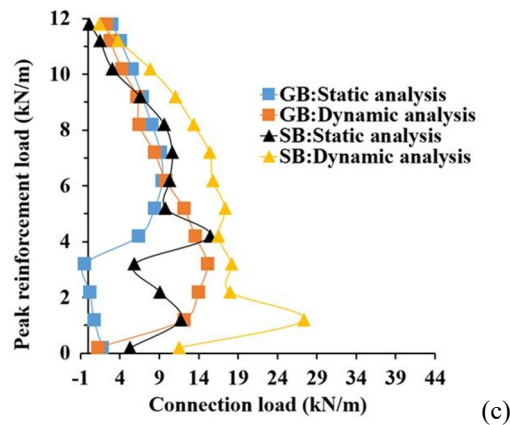


Fig. 3. Mobilized peak connection load for: (a) segmental block fascia GRS wall (b) gabion fascia GRS wall and (c) comparison of static and dynamic analysis.

2.5.2 Acceleration amplification

Acceleration amplification factors at the immediate wall face and at the ends of the geogrid reinforcements for both wall types are shown in Fig. 4. Acceleration-time history query points located at wall face as presented in Fig. 3(a). to compute acceleration amplification factor. Higher amplification is observed at the wall face due to lower confinement, whereas amplification is reduced at the reinforcement ends because of the confining effect of the reinforced soil zone. Similar behaviour has been reported in the literature. [Cai et al. \[9\]](#) observed higher RMS acceleration amplification near the face of reinforced soil retaining walls compared with the reinforcement ends in shaking-table tests, attributing this to reduced confinement and differential settlements near the face. [Ling et al. \[10\]](#) reported amplification factors greater than unity near the facing in dynamic centrifuge tests on GRS structures at low input accelerations, with amplification decreasing at higher shaking levels due to nonlinear soil-reinforcement interaction. In the present study, the gabion-facing GRS wall shows slightly higher amplification at both locations, which is attributed to internal void rearrangement within the gabion cages during seismic excitation.

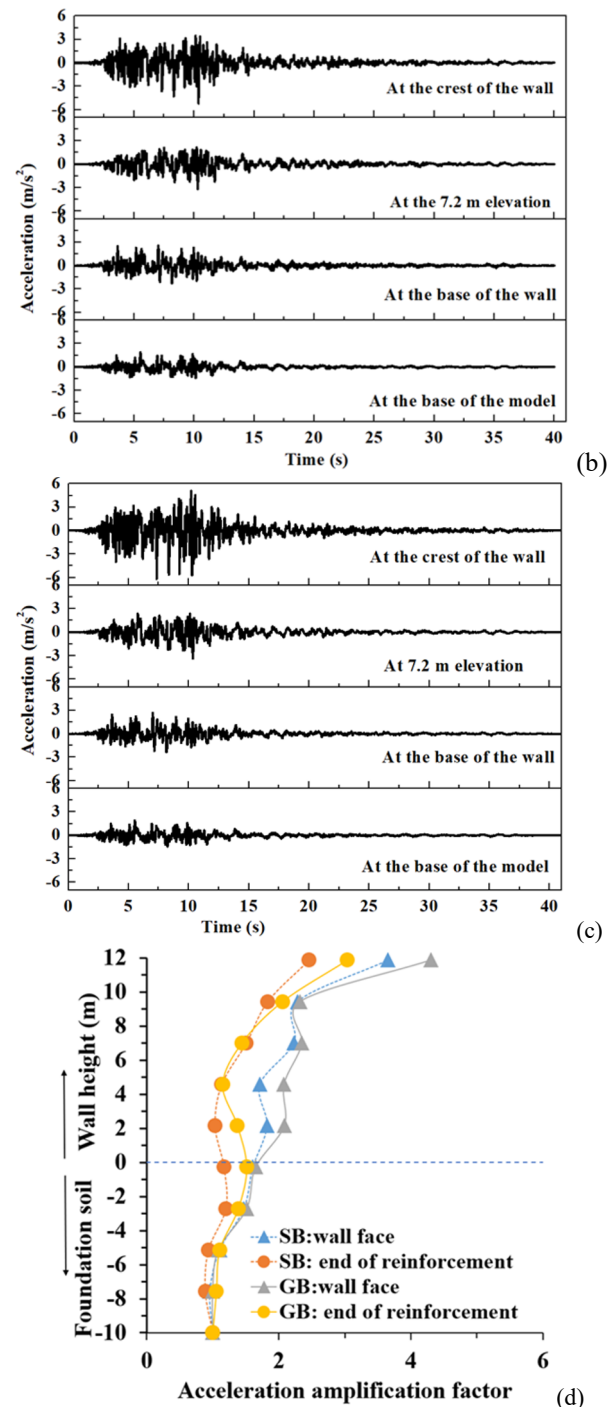
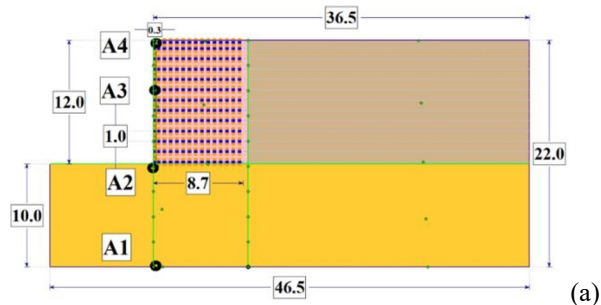


Fig. 4. Acceleration amplification (a) segmental block fascia and (b) gabion fascia GRS wall and (c) acceleration amplification factor.

2.5.3 Lateral earth pressure

As shown in Fig. 5, the lateral earth pressure distributions measured from the base to the crest of the wall at an interval of 2 m elevation for both segmental block and gabion fascia GRS walls generally follow a Rankine-type triangular profile under static and dynamic conditions, increasing approximately linearly with depth. However, the segmental block fascia consistently exhibits slightly higher pressures because its lower stiffness permits greater localized deformation, whereas the stiffer gabion fascia provides improved confinement and load redistribution. Fig. 5(a) and 5(b) further show that under seismic excitation, lateral pressures increase significantly toward the wall base in both systems due to overburden-controlled amplification of inertial forces. This basal pressure

concentration is more pronounced in the segmental block wall, where reduced facing rigidity exacerbates dynamic thrust. Similar deviations from ideal Rankine behavior under dynamic loading have been reported in shaking-table and numerical studies; *Kilic et al. [11]* observed elevated dynamic pressures in the lower third of geogrid-reinforced walls with modular facings due to reinforcement-soil interaction and facing flexibility, while *Majumder et al. [12]* reported that stiffer facias, analogous to gabions, reduce peak dynamic basal pressures through enhanced confinement.

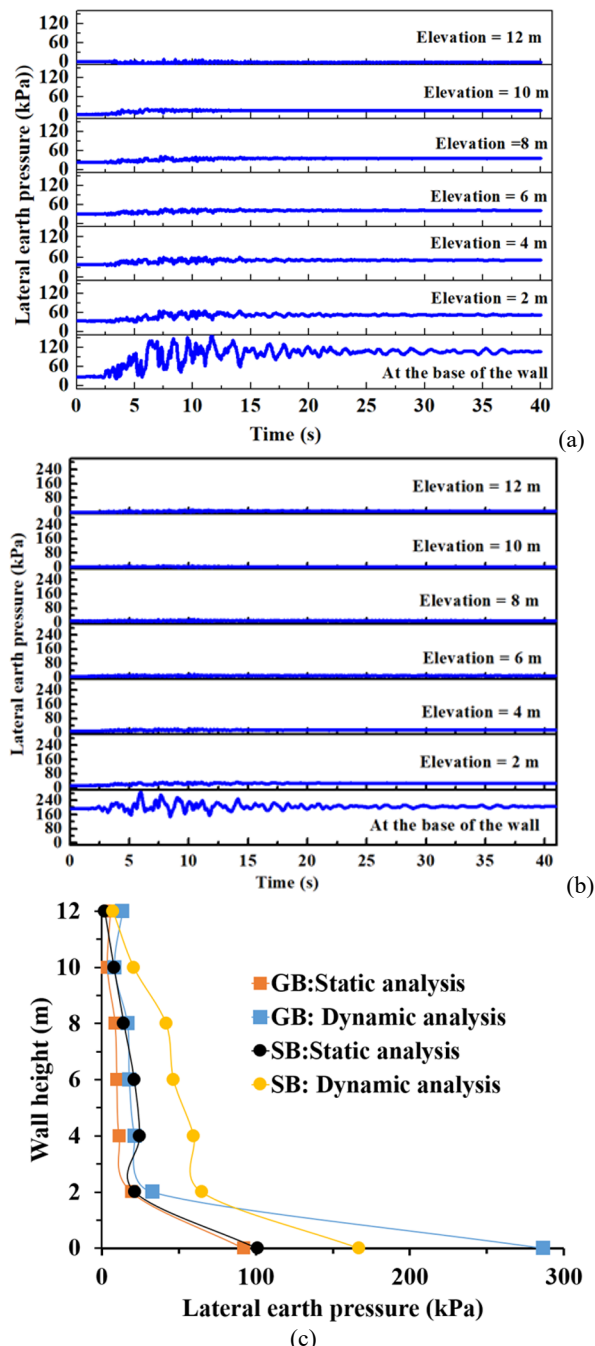


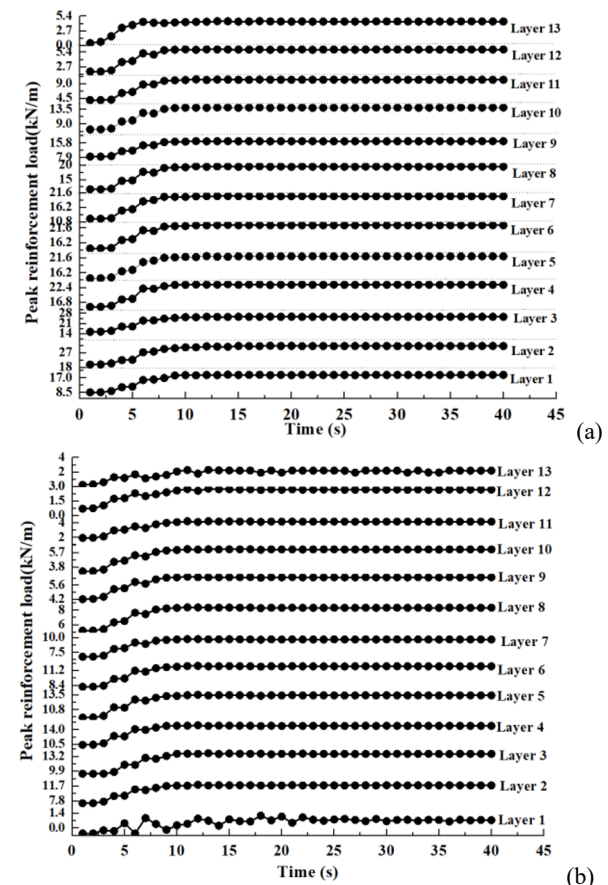
Fig. 5. Lateral earth pressure with time and peak lateral earth pressure: (a) segmental block fascia and (b) gabion fascia GRS wall and (c) Peak lateral earth pressure.

2.5.4 Potential failure surface

The potential failure surfaces within the reinforced zone, determined by connecting peak mobilized

reinforcement loads at each geogrid layer for both segmental block and gabion fascia GRS walls under static and dynamic conditions, are presented in Fig. 6. For the segmental block fascia, the failure surface deviates markedly from conventional Rankine assumptions ($45^\circ + \phi/2$), ϕ is angle of internal friction of reinforced soil curving sharply toward the wall face, which indicates a high risk of reinforcement rupture or snap failure due to excessive connection loads intensified by large vertical reinforcement spacing.

In contrast, the gabion fascia wall exhibits a failure surface located farther from the facing. This response is attributed to the higher stiffness and self-weight of the gabion cages, which enhance confinement, promote load redistribution, and reduce tensile demand concentration in the reinforcement. As observed in Fig. 5, neither configuration follows the classical Rankine failure trend; instead, the failure surfaces develop farther from the wall face, particularly in the upper zones. This behavior is mainly governed by reduced overburden pressure and amplification of seismic acceleration at higher elevations, which shifts the locus of maximum shear demand inward. Similar outward-curving and near-face failure mechanisms have been reported in physical model studies of flexible geotextile-reinforced walls [13] and in field case histories of geosynthetic-reinforced bridge approaches, where reinforcement rupture occurred along slip surfaces controlled by concentrated connection loads rather than by Rankine geometry [14].



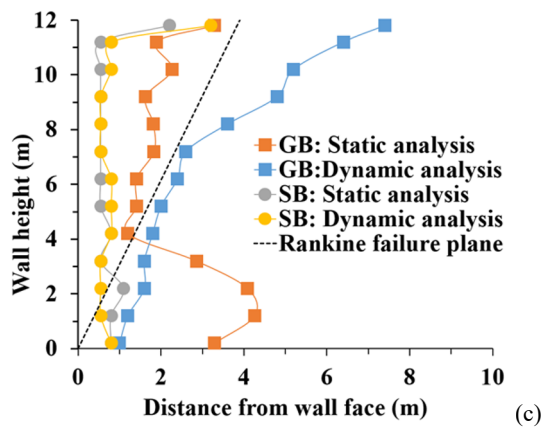


Fig. 6. Potential failure surface for (a) segmental block fascia GRS wall under dynamic loading, (b) gabion fascia GRS wall under dynamic loading, and (c) profile of the locus of peak mobilized reinforcement load.

Conclusions

This study numerically investigated the seismic performance of GRS walls with segmental block and gabion fascia, focusing on reinforcement-facing connection load, acceleration amplification, lateral earth pressure distribution, and failure mechanisms under static and dynamic loading conditions. The main conclusions are summarized as follows:

- Connection loads along the reinforcement layers increase toward the lower portion of the wall due to higher overburden pressure combined with seismic demand. Under both static and dynamic conditions, the gabion fascia consistently mobilizes lower connection loads than the segmental block fascia, indicating improved load sharing due to its flexibility and self-weight.
- Acceleration amplification is higher at the wall face than at the reinforcement ends because of reduced confinement near the facing and enhanced confinement within the reinforced soil zone. The gabion fascia shows slightly higher amplification at both locations, attributed to internal void rearrangement within the gabion cages during seismic excitation.
- Lateral earth pressure distributions generally follow a Rankine-type triangular trend under static and dynamic loading. However, segmental block facias exhibit higher pressures due to lower stiffness and greater localized deformation, whereas gabion facias provide improved confinement and load redistribution. Under seismic loading, pressure amplification is concentrated near the wall base, with a more pronounced effect in the segmental block wall.

- Failure surfaces derived from peak reinforcement loads deviate from classical Rankine assumptions. Segmental block facias show failure surfaces curving toward the wall face, indicating higher rupture risk, whereas gabion facias develop deeper failure surfaces due to enhanced confinement.

Overall, the results demonstrate that gabion fascia GRS walls exhibit superior seismic performance compared to segmental block fascia walls, and that conventional Rankine-based failure surface assumptions do not adequately represent the actual failure mechanisms of GRS walls under dynamic loading.

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