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SEISMIC RESPONSE OF REINFORCED SOIL RETAINING WALLS WITH BLOCK FACINGS

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ABSTRACT

Reinforced soil walls have become very popular in seismic areas owing to their flexible nature and cost effectiveness when compared to the conventional retaining structures. Although the use of reinforced soil walls with modular block facings and gabion facings is growing world wide at a rapid rate, the seismic response of these walls is yet to be analyzed. This paper discusses the response of these walls in terms of lateral facing deflection, reinforcement tensile force and crest surface settlement when subjected to seismic loading simulated by means of a variable amplitude harmonic vibration using the finite element analysis package, PLAXIS V8. From the study, it was found that there is significant effect of seismic loading on the response of reinforced soil walls and the analyses and design of these walls are to be done only after considering the dynamic earthquake loading in seismic prone areas. The gabion faced reinforced soil walls were found to be more effective than the segmental walls in resisting the dynamic excitations due to earthquake loading. The study also confirmed that various reinforcement design parameters and backfill parameters play an important role in minimizing the facing deflection and the settlement of the wall subjected to dynamic earthquake excitation.

INTRODUCTION

The reinforced soil retaining walls have proved to be very stable statically. After some severe earthquakes, it was observed that reinforced soil retaining walls remained intact and this proved that they were structurally sound under earthquake loading conditions as well. The greater seismic resistance of reinforced soil walls compared to conventional retaining wall structures has led to their increasing use for new permanent structures and to replace conventional structures damaged in recent earthquakes, especially in countries like Japan. This is due to the good seismic performance of reinforced soil walls observed during the 1995 Hyogoken-Nanbu (Kobe) earthquake.

Improvements over the reinforced earth walls were brought about by changing the facing type and material, to improve their performance as well as cost effectiveness. This led to the development of segmental walls and gabion faced walls. Block-faced geosynthetic reinforced soil retaining walls are referred to as segmental retaining walls. Gabion walls are mass gravity structures that are formed by filling wire mesh gabion boxes with dry stones, stacking them one above the other and securing them properly. Both these walls are commonly used these days for a variety of applications such as earth retaining structures, river training works, soil erosion protection and embankment protection.

The present paper discusses the response of reinforced soil retaining walls with block facings under the action of seismic loads. Two types of reinforced soil walls were considered in this study, gabion faced walls and segmental walls. The work was focused on the main objectives like:

- Development of a finite element model for the segmental wall and gabion faced reinforced soil wall.
- Analyzing the response of segmental and gabion faced reinforced soil walls subjected to seismic loading.
- Studying the effect of different material and geometric parameters on the performance of reinforced soil retaining walls with block facings subjected to seismic loading.

LITERATURE REVIEW

Ling et al. (1997) conducted parametric studies to illustrate the effects of seismic acceleration on the design of reinforced soil structures having different slope angles and soil properties.

Seismic design procedures were proposed for geosynthetic reinforced soil structures. The procedures were based on a pseudo-static limit equilibrium analysis, which considers horizontal acceleration and incorporates a permanent displacement limit. Guler and Demirkan (2000) carried out finite element studies on segmental retaining walls and showed that the frequency content is not the sole dominant parameter that determines the magnitude of wall response but has a very influential role on the wall seismic behaviour. They also showed that the horizontal wall displacements and the reinforcement tensile loads increased when the peak horizontal acceleration increased from 0.2g to 0.4g in all simulations. Also, the location of the maximum horizontal displacement was the top of the wall and the reinforcement load was the greatest at the bottom layer. Helwany and McCallen (2001) conducted shake table tests on block-faced geosynthetic reinforced soil retaining walls, so as to study their response to cyclic loading. The Ramberg-Osgood model was used to simulate the nonlinear hysteretic behaviour of soil, and the results were consistent with the observed results from laboratory shake table tests on segmental walls. Burke et al. (2004) conducted numerical simulation using finite element procedure on a full-scale model of block faced geosynthetic-reinforced soil structure, compared with experimental results and proved that the finite element procedure is able to simulate the seismic response of the reinforced soil retaining wall very well. Ling et al. (2004) used a validated finite element procedure for conducting a series of parametric studies on the behaviour of reinforced soil walls under construction and subject to earthquake loading. They concluded that the effects of soil properties, earthquake motions and reinforcement layouts are issues of major design concern under earthquake loading. The deformation, reinforcement force and earth pressure increased drastically under earthquake loading compared to end of construction. El-Emam and Bathurst (2004) proved that the reinforcement design parameters like stiffness, length and vertical spacing have a significant effect on reinforced soil retaining walls with thin facings.

The response of reinforced soil retaining walls under dynamic gravity loading have been investigated by several researchers using numerical simulation approaches. But relatively few studies have been reported for the simulation of dynamic behaviour of block faced reinforced soil retaining walls. The dynamic response of even the simplest type of retaining wall is quite complex. Wall movements and pressures depend on the response of the soil underlying the wall, the response of the backfill, the inertial and flexural response of the wall itself, and the nature of the input motions. So it is not currently possible to analyse all aspects of the dynamic response of retaining walls accurately. As a result, simplified models that make various assumptions about the soil, structure, and input motion are most commonly used for dynamic design of block faced reinforced soil retaining walls.

The literature survey shows that the research works on the dynamic response of block faced reinforced soil walls are very limited. Thus, a work in this area would prove to be highly useful as reinforced soil walls are an emerging construction today. Hence as an aid to the practical problems, theoretical studies are essential and the present work is aimed in this direction.

FINITE ELEMENT MODELLING

The finite element method has been widely used to simulate a variety of geotechnical structures like retaining walls, steep slopes, earth dams, shallow and deep foundations etc. In the case of analysis of reinforced soil structures, the method also renders additional information like internal stresses, tensile load in reinforcement, deformation of internal components etc. compared to conventional limit – equilibrium analysis. This paper describes the finite element studies conducted on two types of retaining wall systems with block facings – one with cement concrete block facing and the other with gabion facing. The internationally accepted geotechnical FEM software, PLAXIS V8 was used for the analyses. The program is capable of carrying out plane strain analyses under static as well as dynamic loading conditions. It can also simulate construction sequence and the interaction between soil and reinforcement which is predominant in the analysis of reinforced soil structures.

The system selected for the analyses was the one selected by Guler and Demirkan (2000) for their studies and is described below. The authors used the same PLAXIS V8 software for the studies. Hence the same system was modelled for the present study also and the results were validated.

The system consisted of a natural fill which is to be retained by a 6m high wall with cohesionless backfill. The entire system was assumed to rest on a stiff base. The wall was designed for horizontal peak acceleration amplitude of 0.2g. The geometry of the model is shown in Fig. 1. A 6 m high wall with cement concrete block facing and geotextile sheet reinforcement comprised the retaining system. The vertical spacing between the reinforcements was 50 cm. Cement concrete blocks were of 0.5 m width and 0.25 m height. In this model, three soil zones were distinguished: backfill soil, natural fill and base soil. The backfill soil was of cohesive type which was reinforced with geotextile sheets. The reinforced cohesive backfill zone was provided in front of a natural fill. In order to simulate the field construction procedure, a slope of 2:1 was chosen in front of the natural fill. The natural soil was assumed as stiff clay and dry conditions were assumed, neglecting the effect of water table. The base soil was chosen as a stiff soil in order to minimize the influence of base soil on the behaviour of the reinforced soil zone. The Mohr-Coulomb material model was used for modelling all the soils as well as the cement concrete block facing elements. The material properties used for modelling of soil media are given in Table 1. The reinforcements were slender objects with normal stiffness but with no bending stiffness. The main material property of reinforcement is the elastic axial stiffness, EA and for geotextile it is taken as 2000 kN/m. The reinforcement length was selected as L = 4.2 m (0.7H) throughout. Uniform spacing of 0.5 m was adopted for the reinforcements.

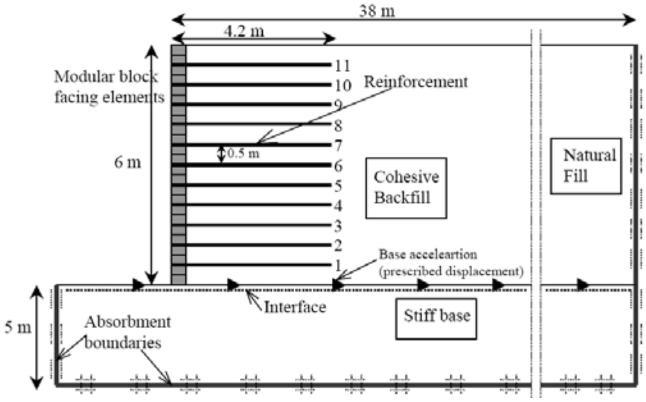

Fig. 1 Geometry of the cement concrete block faced reinforced soil wall (Guler and Demirkan, 2000)

Table 1 Material properties used for modelling of soil media (Guler and Demirkan, 2000)

Material type	Unit weight γ_{dry} (kN/m^3)	Elasticity modulus E (kN/m^2)	Poisson's ratio ν	Cohesion c (kN/m^2)	Internal friction angle Φ (degrees)
Backfill	18	30000	0.3	5	40
Natural fill	19	35000	0.2	10	35
Base soil	22	200000	0.1	50	38
Facing	20	30000	0.1	20	15

In order to properly simulate the frictional effects of reinforcement in the behaviour of reinforced soil zone, interfaces were used above and below the reinforcements. The interfaces were also used at zones of base and backfill intersection, backfill and natural fill intersection and between all modular blocks. The vertical boundaries were given horizontal fixity and the bottom boundary had vertical and horizontal fixity. Also all these boundaries were specified with special absorbent boundary conditions to avoid the disturbance of reflections from boundaries on the results. The element type used in the analysis was fifteen nodded triangular element. The model composed of 3739 elements and 8247 nodes.

In the analysis, the wall was constructed with a staged construction procedure, which simulates the real construction process of these structures. The wall was constructed layer by layer in the order of facing assembly, fill compaction and laying of reinforcement and the process was repeated for each layer till the required height was reached. The plot of the generated mesh is shown in Fig. 2.

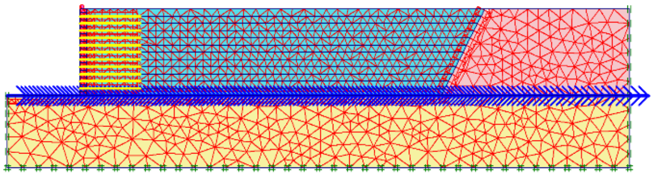

Fig. 2 Generated mesh for analysis

After the construction of the wall, it was subjected to seismic shaking from all nodes at the base line of the wall. It is already established that simple harmonic functions can be used to simulate the dynamic behaviour of reinforced soil walls to establish the relative performance of reinforced soil retaining wall systems (Bathurst and Hatami, 1998). Hence, the seismic load was a variable amplitude harmonic motion at equal time intervals of 0.05 seconds with a total duration of 6 seconds. The acceleration data was defined by the following formula:

$$\ddot{U}(t) = \sqrt{\beta.e^{-\alpha t}.t^{\zeta}}\,\sin(2.\pi.f.t) \qquad (1)$$

Where, α = 5.5, β = 55 and ζ = 12 are coefficients for 0.2g peak acceleration amplitude. f is the frequency of loading and in the present study it is taken as 3 Hz. The acceleration data represented by the formula with 3 Hz frequency and 0.2g peak acceleration is shown in Fig. 3.

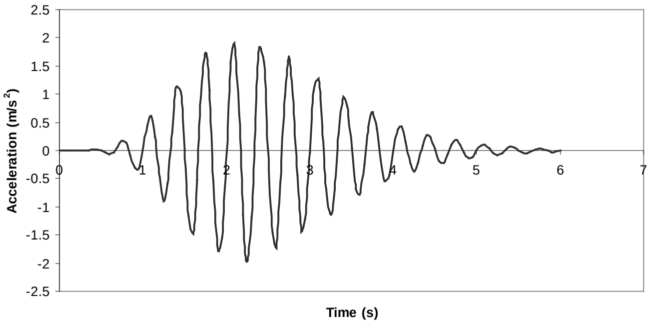

Fig. 3 Time – acceleration data of seismic load

The results of the analysis are represented in terms of horizontal wall displacements at the location of the reinforcement layers and the maximum reinforcement tensile loads recorded along the reinforcement layer after the seismic loading is finished. It can be seen that the results of this work matched exactly with the literature as in Guler and Demirkan (2000). The horizontal wall displacement ratio at the end of seismic excitation along the wall elevation is shown in Fig. 4. The displacement values are the values caused only by the earthquake load in front of the reinforcement locations. In the analysis, the maximum deformation is observed at the top of the wall. The reinforcement tensile load at the end of harmonic seismic load is shown in Fig. 5. The distribution of the loads on the reinforcement shows that the maximum reinforcement load occurs at the bottom reinforcement. Encouraged by the results obtained from the validation studies, the same model was adopted for further studies.

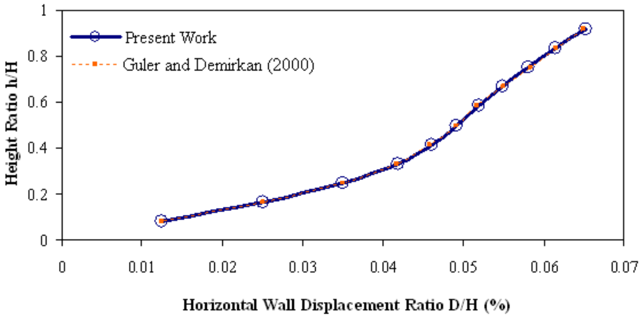

Fig. 4 Horizontal wall displacement at the end of seismic loading

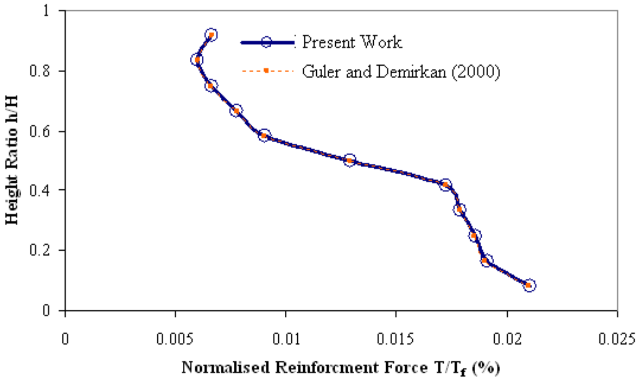

Fig. 5 Reinforcement tensile loads along the wall elevation after seismic excitation

REINFORCED SOIL WALL WITH CEMENT CONCRETE FACING SUBJECTED TO SEISMIC LOADING

The geometry of the model wall developed by Guler and Demirkan (2000) shown in Fig. 1 was used for conducting further dynamic studies on reinforced soil walls with cement concrete block facings. The only difference was that the backfill was assumed as a cohesionless soil by taking cohesion value for backfill in Table 1 as 0 kN/m^2. In order to observe the response of the segmental wall due to seismic excitation, the wall was analysed before and after earthquake loading (that is, at the end of construction and after seismic excitation). The seismic excitation was simulated by means of a variable amplitude harmonic wave represented by the Equation (1). A harmonic input load of peak acceleration amplitude of 0.2g and a frequency of 3 Hz was applied. The response of the reinforced soil wall was represented in terms of lateral deflection of facing, maximum force developed in the reinforcement, lateral earth pressure developed behind the facing and crest surface settlement at the top of the wall. The variations of horizontal displacement as well as settlement of the topmost point of the facing with time and acceleration amplification factor with height were also studied.

Facing Deflection

The horizontal deflection of the wall facing was normalised as Δ/H in order to non dimensionalise the output, where H is the height of the wall and Δ is the horizontal deflection of any point on the facing. The variation of the lateral facing deflection along the elevation of the wall is shown in Fig. 6.a. The maximum lateral displacement for the facing was found to be at the top at the end of construction as well as after seismic loading. At the end of the construction, the maximum displacement for the wall was 0.17% of the wall height at the top of the wall. But after the seismic excitation the wall face deflected in larger magnitudes outward from the static position. In this case also, the maximum horizontal deflection was observed at the top point and it was 6.9% of the wall height. Thus, the maximum lateral displacement of the segmental retaining wall increased by 40 times after the seismic excitation.

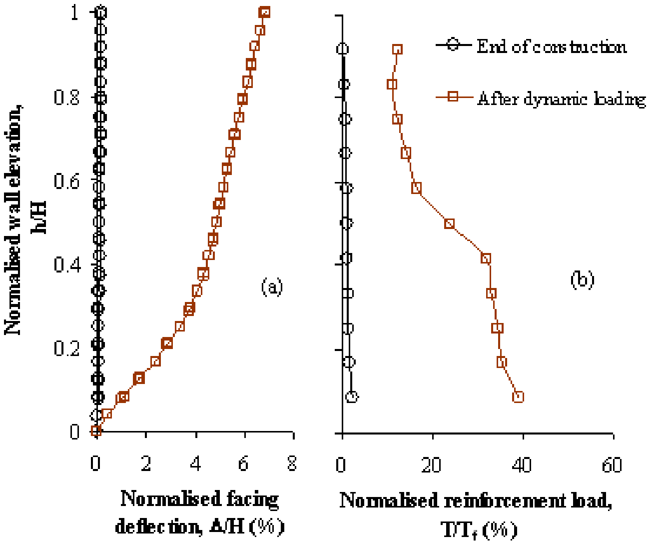

Fig. 6 Response of the reinforced soil wall with cement concrete facing subjected to seismic loading

Tensile Load in Reinforcement

The variation of maximum tensile force developed in the reinforcements along the height of the wall is shown in Fig. 6.b. The reinforcement load was non-dimensionalised as T/T_f where T is the maximum reinforcement load developed in each reinforcement layer and T_f is the tensile strength of the reinforcement. The reinforcement tensile load also increased immensely after the dynamic excitation. From the figure, it can be seen that the maximum reinforcement tensile load at the end of construction was for the bottom most reinforcement, and it was 2% of the reinforcement strength. But after the seismic excitation, there was considerable increment in the tensile load and the maximum tensile force was about 40% of the reinforcement tensile strength (at the bottom most reinforcement). Thus the maximum tensile load increased by 17 times after the seismic excitation in the segmental retaining wall.

Lateral Earth Pressure

The lateral earth pressure was normalized as p/γH, where p is the lateral earth pressure at any point behind the facing, γ is the unit weight of backfill soil and H is the height of the wall. The variation of lateral earth pressure distribution along the elevation of the wall is plotted in Fig. 7. The earth pressure variation was triangular at the end of construction as well as after seismic loading. After the excitation, it can be seen that there was an increment in the lateral earth pressure value throughout the height of the wall.

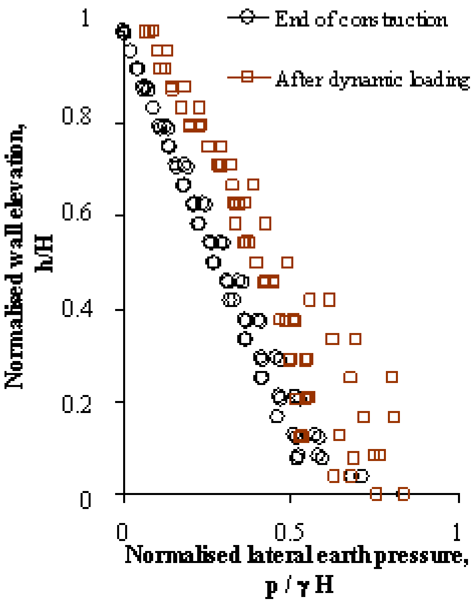

Fig. 7 Lateral earth pressure distribution in reinforced soil wall with cement concrete facing subjected to seismic loading

Crest Surface Settlement

The crest surface settlement (S) along the backfill length (X) was plotted as shown in Fig. 8. From the figure, it can be seen that at the end of construction there was an average settlement of 0.0018H from the surface of the backfill. But after the dynamic excitation, it can be seen that the backfill heaved and maximum vertical displacement was 0.014 times the height of the wall and it was at a distance of 0.75 times H, from the face of the wall.

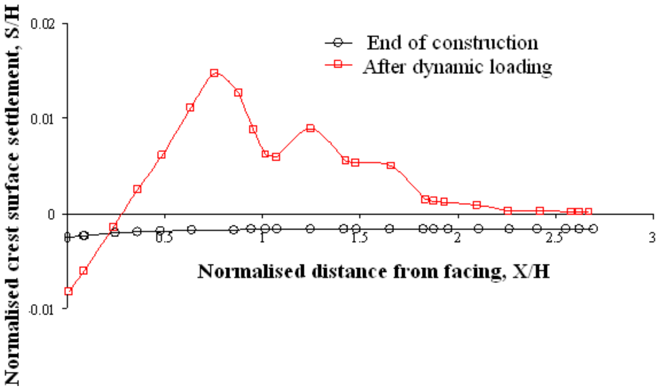

Fig. 8 Settlement of the crest surface of the backfill in reinforced soil wall with cement concrete facing subjected to seismic loading

Displacement vs. Time

In order to understand the effect of displacement with time, displacement time plots were prepared for both the components of the displacements – horizontal as well as vertical. The horizontal displacement of a point on the top of the wall facing during the application of seismic load is plotted against time and shown in Fig. 9. During the initial stages of loading, there is not much variation in the horizontal displacement till about 1 second, but after 1 second as the amplitude of loading increases the horizontal displacement is also found to increase. Again as the amplitude of input load decreases after 4 seconds the rate of increase of horizontal displacement also starts decreasing. The vertical settlement vs. time plot was also similar to the horizontal displacement – time plot as shown in Fig. 10, where in there was a linear increment in settlement after 1 second and as the amplitude of applied acceleration decreased, the rate of increment of settlement also decreased. Finally after the 6 second excitation, the settlement of the top most point on the wall was 0.11m.

Acceleration Amplification Factor

The peak acceleration amplitude of the input loading was 0.2g and the excitation was given at the base of the wall. After the excitation the acceleration amplification in the backfill was determined behind the facing blocks. The acceleration amplification factor is defined as the ratio of the maximum acceleration at that point to the peak amplitude of the input loading. The plot of the acceleration amplification factor along the height of the wall is shown in Fig. 11. From the plot it can be inferred that even though the excitation was given at the base, the acceleration inside the backfill was minimum at the base of the wall, and the amplification factor was found to increase along the height of the wall. Thus the maximum amplification factor was obtained as 10.5 for the top most point.

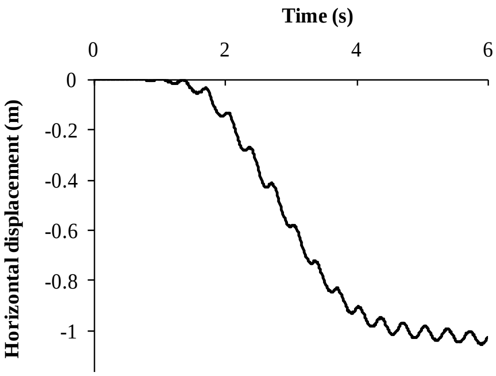

Fig. 9 Variation of horizontal displacement with time in reinforced soil wall with cement concrete facing subjected to seismic loading

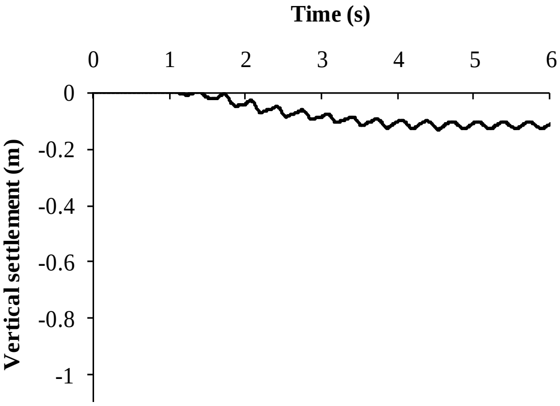

Fig. 10 Variation of settlement with time in reinforced soil wall with cement concrete facing subjected to seismic loading

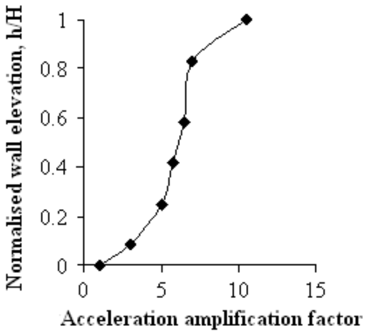

Fig. 11 Variation of acceleration amplification factor with height in reinforced soil wall with cement concrete facing subjected to seismic loading

REINFORCED SOIL WALL WITH GABION FACING SUBJECTED TO SEISMIC LOADING

After carrying out the dynamic analysis on a flexible reinforced soil retaining wall with cement concrete block facings, by subjecting it to a variable amplitude harmonic load, another model was developed under similar site conditions using gabions as the facing materials. The material properties of gabions were obtained from Jayasree (2008) and given in Table 2. The geometry model developed in PLAXIS is given in Fig. 12. The gabion faced walls fall in between the rigid conventional retaining walls and the flexible reinforced soil retaining walls. The performance of these walls under seismic loading was studied using the finite element model developed using PLAXIS V8. The results of the analysis are discussed below.

Table 2 Material properties of gabion facings (Jayasree, 2008)

Unit Weight, γ_{dry} (kN/m^3)	Elasticity Modulus, E (kN/m^2)	Poisson's Ratio, ν (-)	Cohesion, c (kN/m^2)	Internal Friction Angle, Φ (degrees)
22	12700	0.25	13	42

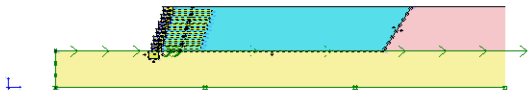

Fig. 12 Geometry model of gabion faced wall developed in PLAXIS V8

Facing Deflection

The deflection pattern obtained for the gabion faced reinforced soil retaining wall was similar to that of the cement concrete block faced retaining wall as shown in Fig. 13.a. The gabion faced reinforced soil wall also deflected outward under the action of seismic load and the deflection was much more than that at the end of construction. At the end of construction the maximum deflection was at the topmost point of the wall facing and it was 0.14% of the wall height. After the seismic excitation for 6 seconds the wall deflected further outward and the maximum deflection reached to 3.4% of the wall height at the top.

Tensile Load in Reinforcement

The variation of maximum reinforcement tensile force along the elevation of the wall is given in Fig. 13.b. Unlike the cement concrete block faced wall, the maximum tensile load was seen for the reinforcement just above the bottom most one. This may be due to the base sliding which occurred in the case of gabion faced wall. The maximum reinforcement load was 1.4% of the tensile strength of the reinforcement at the end of construction and it increased to 27% of reinforcement strength after the seismic excitation.

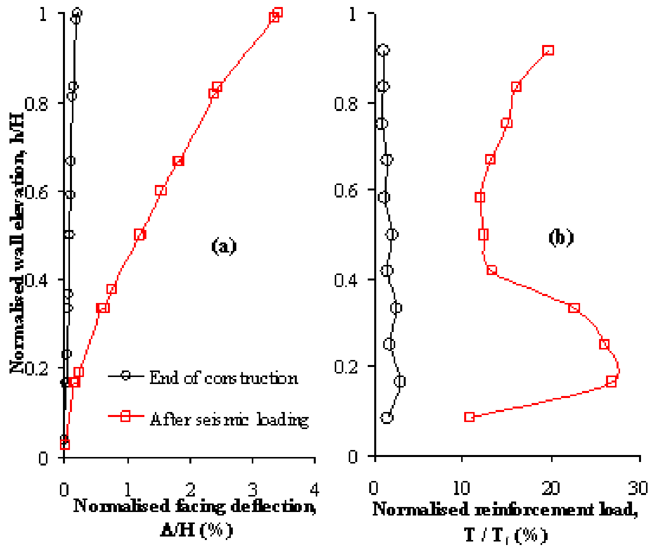

Fig. 13 Response of the reinforced soil wall with gabion facing subjected to seismic loading

Lateral Earth Pressure

When the gabion faced reinforced soil retaining wall was subjected to a seismic load of peak amplitude 0.2g for duration of 6 seconds, the lateral earth pressure behind the facing increased from that at the end of construction. The increment in earth pressure was more prominent towards the bottom portion of the wall. The variation of earth pressure along the elevation of the wall is shown in Fig. 14.

Crest Surface Settlement

The crest surface settlement along the length of the backfill at the end of construction and after the application of a variable amplitude harmonic load is plotted and represented in Fig. 15. At the end of construction the backfill beyond the gabion facings is found to settle and the settlement varied from 0.004H near the facing to 0.0015H at a distance of 1.6H from the facing of the wall. But after the seismic excitation for 6 seconds, the crest surface heaved resulting in a positive vertical displacement. A maximum crest surface settlement of 0.012H was observed at a distance of 0.8H from the facing.

Displacement vs. Time

The horizontal displacement vs. time plot obtained for the gabion faced reinforced soil retaining wall was similar to that of a segmental wall as shown in Fig. 16. For the top most point of the facing, the displacement in the horizontal direction increased with respect to the increment in the amplitude of the applied acceleration. The maximum horizontal displacement for the top point was 0.54 m in the case of gabion faced reinforced soil wall. For the same point, the settlement vs. time plot for the gabion faced wall subjected to seismic loading is given in Fig. 17. The settlement is found to increase with time and the rate of increment is more when the applied acceleration amplitude is more.

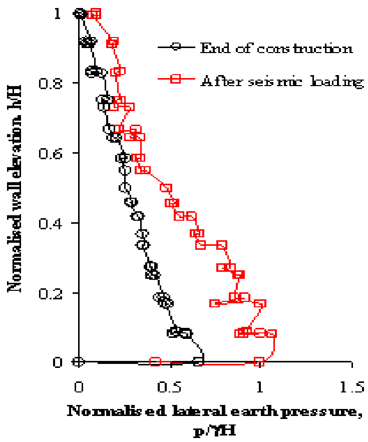

Fig. 14 Lateral earth pressure distribution in reinforced soil wall with gabion facing subjected to seismic loading

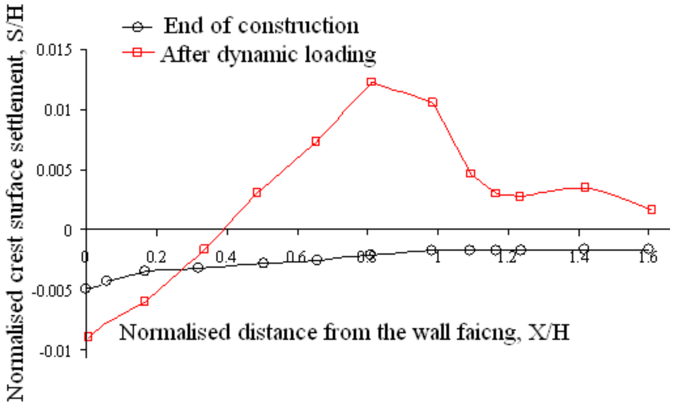

Fig. 15 Settlement of the crest surface of the backfill in reinforced soil wall with gabion facing subjected to seismic loading

Acceleration Amplification Factor

The acceleration was found to amplify along the elevation of the wall as shown in Fig. 18. The behaviour is similar in the case of cement concrete block faced walls also. The acceleration was maximum at the top of the backfill and the amplification factor at the top of the wall was 5.

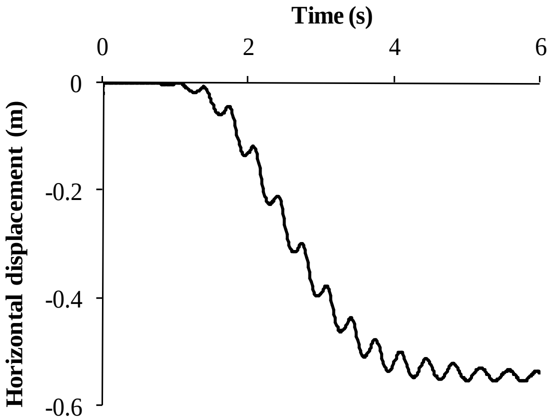

Fig. 16 Variation of horizontal displacement with time in reinforced soil wall with gabion facing subjected to seismic loading

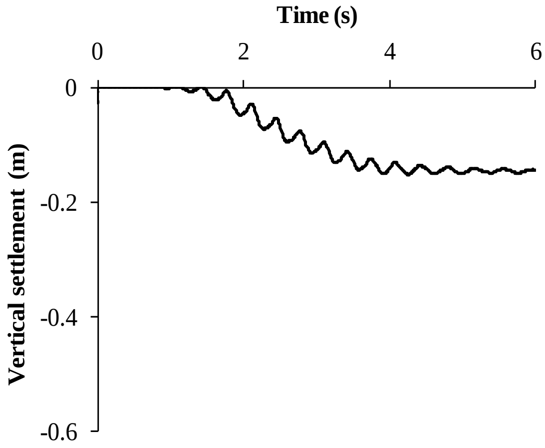

Fig. 17 Variation of settlement with time in reinforced soil wall with gabion facing subjected to seismic loading

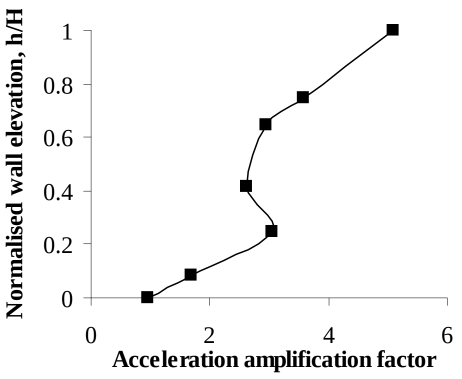

Fig. 18 Variation of acceleration amplification factor with height in reinforced soil wall with gabion facing subjected to seismic loading

PARAMETRIC STUDIES

In order to investigate the effect of various design parameters on the performance of reinforced soil walls with cement concrete block and gabion facings, parametric studies were conducted on these walls. The variables of investigation were input loading parameters, backfill properties and various reinforcement parameters. The reinforcement parameters included length, spacing, stiffness and distribution of reinforcement. The effect of soil properties and various design parameters on the performance of both segmental wall and gabion faced wall under seismic loading were investigated based on the lateral deformation of the wall face, reinforcement tensile load and settlement of the crest. To study the effect of a single input parameter on the behaviour of the wall systems, the same alone was varied keeping all the other parameters constant.

<u>Effect of Loading Parameters</u>

<u>Peak Acceleration Amplitude.</u> The peak amplitude of input motion has got a significant effect on the response of the wall under dynamic loading as depicted in Fig. 19. For peak acceleration amplitude of 0.2g, the maximum lateral deflection for the cement concrete block faced wall was 6.9% of the wall height and for the gabion faced reinforced soil wall it was 3.4% of the wall height. In the case of cement concrete block faced wall, the maximum horizontal wall displacement increased from 6.9% to 12.4% (5 times) when the peak amplitude was changed from 0.2g to 0.4g (twice) for an applied frequency of 3 Hz. Similarly the lateral deflection of the facing increased from 3.4% to 12.4% of the wall height for the gabion faced wall. Thus at higher peak amplitudes of motion, the response of both the type of walls are found to be the same. Considering the reinforcement tensile force, shown in Fig. 20, the effect of peak acceleration amplitude was more prominent in the case of cement concrete block faced wall, and the variation was more pronounced at the bottom portion of the wall. The maximum reinforcement tensile load increased from 14% to 33%. In the case of gabion faced wall, even after incrementing the peak amplitude two times, there was only a slight variation in the maximum load, which increased from 22.5% to 26.5%. This shows that the cement concrete block facing is able to resist the earthquake loads of lower amplitude more effectively, by transferring only lesser portion to the reinforcement. The crest surface settlement, shown in Fig. 21 is also found to increase with the increase in peak acceleration amplitude in both the walls and maximum heave is observed near to the facing portion. At both amplitudes, only slight variation of heave is noted in the cement concrete faced walls when compared to the gabion faced walls. This may be due to the flexible nature of the gabion facing as against the rigid cement concrete facing.

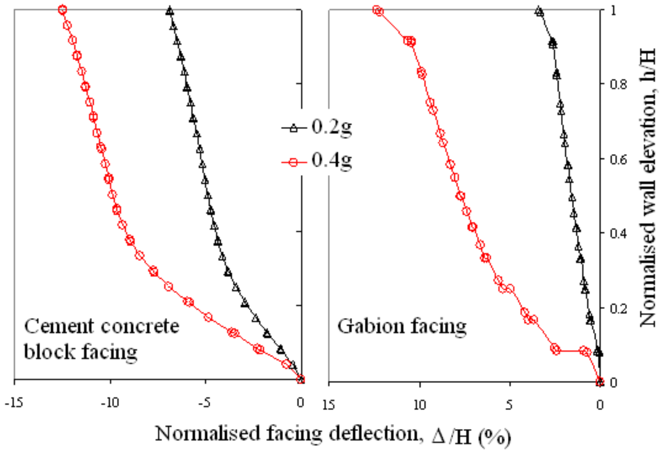

Fig. 19 Wall facing deflection for different peak amplitudes of input motion

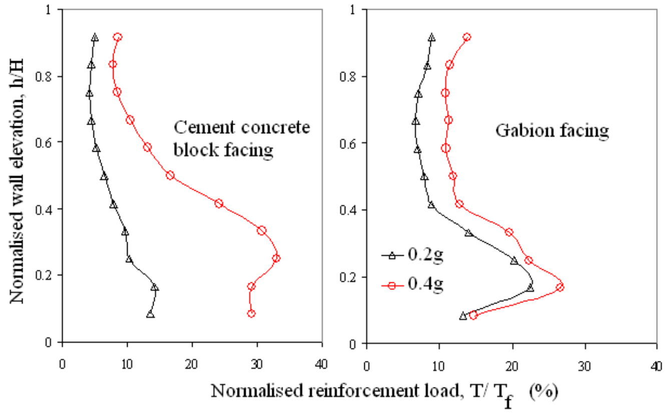

Fig. 20 Reinforcement load for different peak amplitudes of input motion

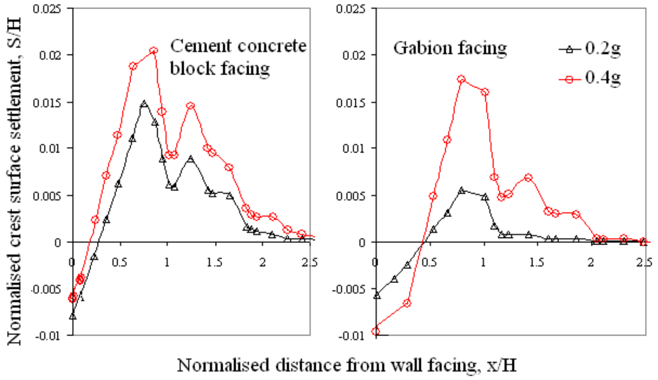

Fig. 21 Crest surface settlement for different peak amplitudes of input motion

Frequency. Both the cement concrete block faced wall and the gabion faced wall were analyzed by varying the frequency of the dynamic load also, in order to find the fundamental frequency of the system. The response of the system will be maximum for a frequency near the natural frequency, and from the result shown in Fig. 22, in the case of cement concrete block faced wall, the wall displacement was maximum for a frequency of 3 Hz suggesting that the fundamental frequency of the wall system is near 3 Hz. For the gabion faced wall system, the maximum wall deflection was obtained for a frequency of 2.5 Hz suggesting that the fundamental frequency of the gabion faced reinforced soil wall is somewhere near 2.5 Hz. Considering the reinforcement tensile load, the effect of input frequency was evident in the case of cement concrete block faced wall as shown in Fig. 23. There was much variation in the reinforcement tensile load with the variation in the applied frequency. But for the gabion faced walls, there was a slight variation in the reinforcement tensile load with the variation in the frequency of input loading, but the effect was not considerable when compared to the cement concrete block faced walls.

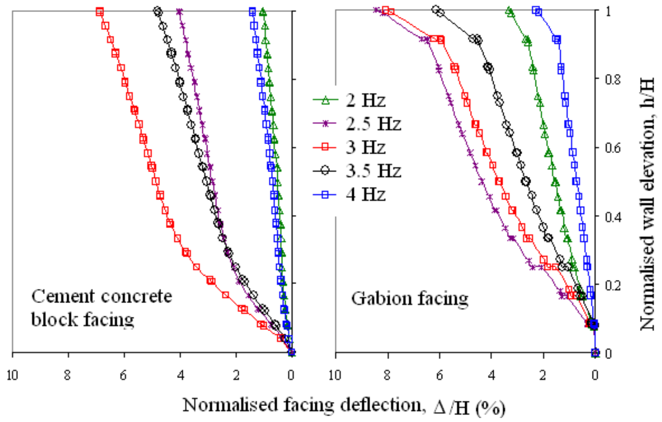

Fig. 22 Wall facing deflection for different frequencies of seismic loading

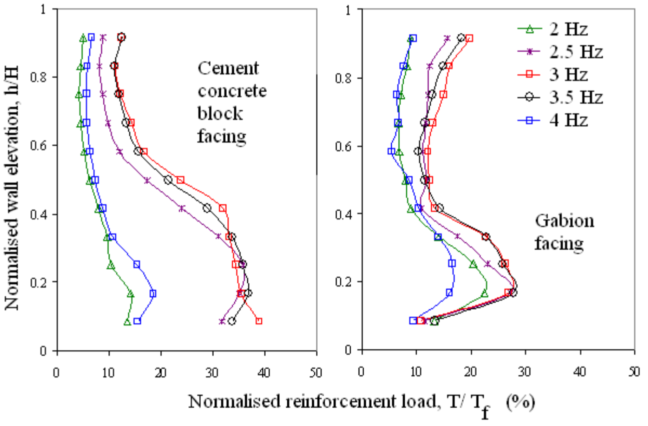

Fig. 23 Reinforcement load for different frequencies of seismic loading

Effect of Backfill

Backfill properties are an important parameter affecting the behaviour of a retaining wall system subjected to any type of loading and hence this was selected as one of the parameters in the present study. The different types of backfill chosen for the analyses are hard clay, silty sand, loose sand and dense sand. The main parameters for backfill soils in the analysis were elasticity modulus (E), Poisson's ratio (ν), cohesion (c), unit weight (γ) and internal friction angle (Φ). The properties are listed in Table 3. The effect of the different types of backfill on the behavior of the cement concrete block faced wall and gabion faced wall is shown in Fig. 24.

Table 3 Material properties of different types of backfill

Backfill type	Unit Weight γ_{dry} (kN/m^3)	Elasticity Modulus E (kN/m^2)	Poisson's Ratio, ν (-)	Cohesion c (kN/m^2)	Int. Friction Angle, Φ (degrees)
Hard clay	21.3	15000	0.3	19	0
Silty sand	21.3	20000	0.35	10	40
Loose sand	21.3	25000	0.35	0	36
Dense sand	22.1	60000	0.3	0	42

It can be seen that, the response of both the walls to different types of backfill is almost the same. The lateral facing displacement was maximum at the top most point in the case of silty sand, loose sand and dense sand, but for hard clay the deflection pattern was different and the maximum facing deflection was at a depth of 0.4H. The maximum lateral deflection at top was obtained for loose sand (6% of wall height) and the minimum was for dense sand (3%). The silty sand backfill showed intermediate facing deflection behaviour when compared to loose and dense sand, probably due to its cohesive nature. The hard clay backfill shows clearly a distinct behaviour which may be attributed to its high cohesion and negligible friction. The pattern of variation of reinforcement tensile load along the elevation of the segmental wall was similar for the different types of backfill, as seen in Fig. 25. In the case of segmental wall the maximum reinforcement load was 32% for loose sand, 31% for silty sand, 30% for stiff clay and 22% for dense sand. For the gabion faced wall the pattern of variation of reinforcement load was different for different types of backfills. This can be due to the fact that gabion facings have high absorbing capacity when compared to segmental walls, and hence they will absorb the vibrations resulting in variation in reinforcement tensile force. Fig. 26 shows the variation of crest surface settlement along the length of the wall. In the case of segmental wall the crest surface deflection is less for the reinforced section, that is up to a distance of 0.7H and after that the settlement is found to increase. In the case of gabion faced walls there is considerable settlement at the back of gabions and after that the settlement is decreasing in the reinforced section. The settlement is found to increase beyond the reinforced section for the gabion faced walls also.

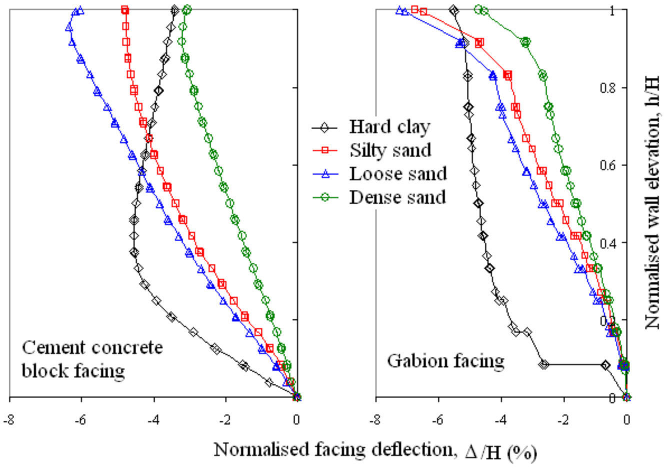

Fig. 24 Wall facing deflection for different backfill soils

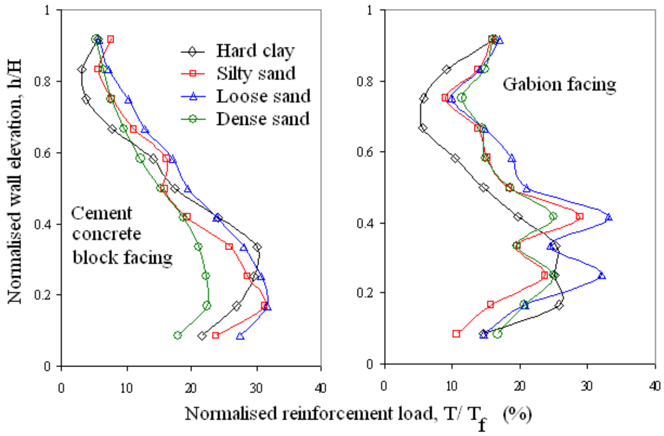

Fig. 25 Reinforcement load for different backfill soils

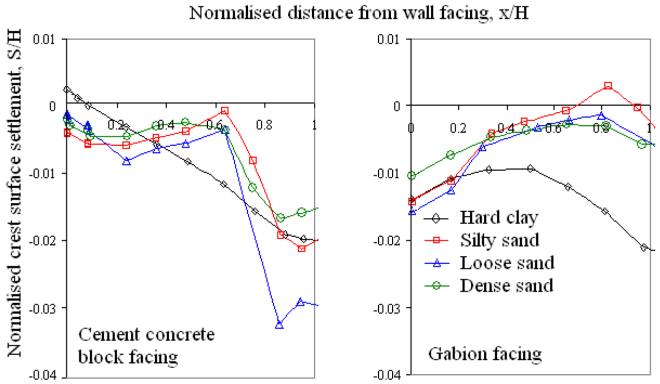

Fig. 26 Crest surface settlement for different backfill soils

Effect of Length of Reinforcement

In order to study the effect of reinforcement length on the response of the wall to dynamic excitation, the length was varied from 0.3H to 0.9H. The analysis showed that in the case of cement concrete block faced walls, the lateral displacement increased with a reduced reinforcement length, as shown in Fig. 27. It is also clearly seen that the conventional assumption of 0.7H as reinforcement length is correct here also, as beyond this value, the variation in response is small. Almost similar response was obtained in the case of gabion faced reinforced soil walls. It was seen that as the reinforcement length increased from 0.3H to 0.9H, the horizontal deflection also decreased considerably. But the variation in deflection with the increment in reinforcement length was almost the same for all lengths. In the case of cement concrete block faced walls, the reinforcement tensile load was found to increase with an increment in the reinforcement length as shown in Fig. 28. There was an average 5% increase in the reinforcement tensile load when the length of the reinforcement was increased from 0.3H to 0.5H. Similarly the reinforcement load increased by about 4% in each reinforcement, when the length increased from 0.5H to 0.7H. But when the length was varied from 0.7H to 0.9H, the reinforcement load increment was found to be very small, enforcing that the standard length of reinforcement in the case of segmental wall subjected to dynamic loading can be taken as 0.7H. In the case of gabion faced reinforced soil wall, the tensile load was maximum for the reinforcement length equal to 0.9H at the top of the wall, but at the bottom of the wall the tensile load was maximum for 0.3H. Thus the reinforcement tensile load behaviour was varying along the elevation of the wall for gabion faced walls. The crest surface settlement shown in Fig. 29 was found to decrease with an increment in reinforcement length for both types of walls, evidently by showing that the effect of reinforcement reduces the surface settlement.

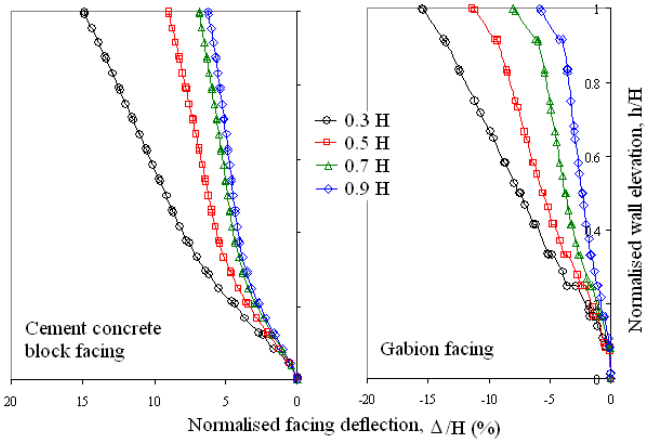

Fig. 27 Wall facing deflection for different reinforcement lengths

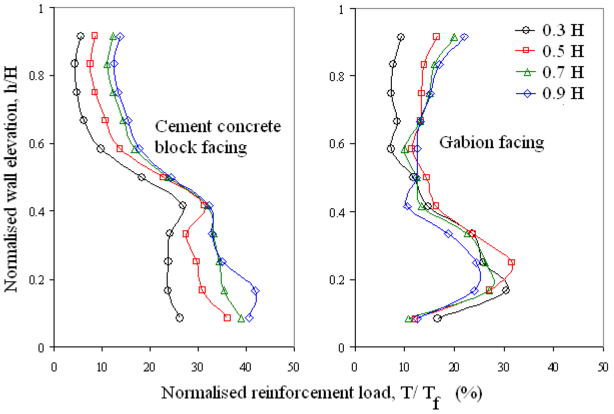

Fig. 28 Reinforcement load for different reinforcement lengths

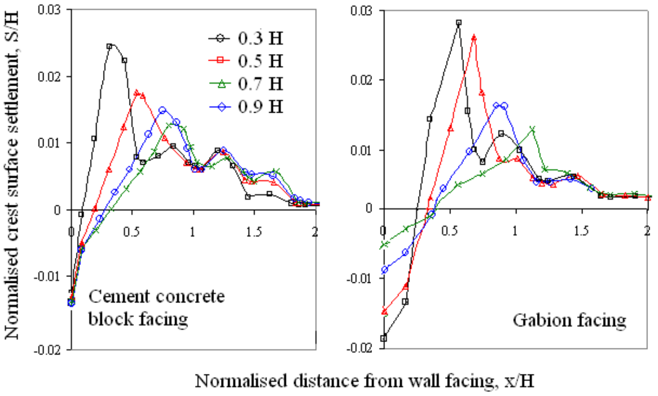

Fig. 29 Crest surface settlement for different reinforcement lengths

DISCUSSIONS

In the study, the response of reinforced soil walls with cement concrete block facings and gabion facings subjected to a seismic load of peak acceleration amplitude of 0.2g were analysed. Since both the walls were of same height, simulated under similar field conditions and were subjected to the same type of loading, a comparative study can be made between the two on the performance under seismic loading.

In the case of cement concrete block faced wall, the lateral facing deflection increased from 0.17% at the end of construction to 6.9% after the seismic excitation, while in the case of gabion faced wall the facing deflection increased from 0.14% at the end of construction to 3.4% after the seismic excitation. Thus the lateral deflection was found to increase after the seismic excitation for both the walls. For the same dynamic loading the wall facing deflection was found to be lesser for the gabion faced walls than the reinforced soil walls with cement concrete block facings. Considering the response of both the walls in terms of maximum reinforcement tensile force, the maximum tensile force in the reinforcement increased from 2% at the end of construction to 40% after the earthquake loading for the segmental wall. In the case of gabion faced walls, the maximum reinforcement tensile force increased from 1.4% at the end of construction to 27% after the seismic excitation. Thus after the dynamic excitation, the reinforcement tensile force was more in the case of segmental walls than the gabion faced walls. This may be due to the fact that gabion facings can absorb vibrations and hence the ground vibrations are not transmitted much to the reinforcements in the case of gabion faced reinforced soil walls. In the case of segmental walls, the maximum reinforcement force was seen in the bottom most reinforcement, but for gabion faced walls the reinforcement force was maximum for the reinforcement just above the bottom most one, which may be attributed to the bas e sliding which occurred in the case of gabion faced walls. The variation in lateral earth pressure behind the wall facing was also found to be more for the gabion faced walls. The maximum crest surface settlement observed for the segmental wall was 0.014H and it was at a distance of 0.75H from the face of the wall. For the gabion faced wall, after the seismic excitation, the maximum crest surface settlement of 0.012H was observed at a distance of 0.8H from the facing. Thus the surface settlement was also lesser for the gabion faced walls than the cement concrete block faced walls.

Peak acceleration amplitude of 0.2g was applied at the base for both types of walls and it was observed that the acceleration amplified along the elevation of the wall for both types of walls and it was maximum at the surface. In the case of segmental walls the acceleration amplified by 10 times of the applied maximum amplitude (0.2g) but for gabion faced walls the acceleration amplification factor was 5 that is, the acceleration amplified by 5 times at the top of the wall.

Thus by comparing the response of segmental walls and gabion faced walls subjected to seismic loading it can be stated that the gabion faced reinforced soil retaining walls perform better than the segmental walls under seismic loading.

CONCLUSIONS

The following conclusions can be made from the studies presented here.

1. For segmental walls and gabion faced reinforced soil walls, the residual lateral facing deflection and reinforcement tensile forces due to earthquake loading were several times larger than that at the end of construction. The largest lateral displacement occurred at the top of the wall and the reinforcement tensile force was maximum for the bottom most reinforcement for both types of walls.
2. The reinforced soil retaining walls with gabion facings were found to perform better than the cement concrete block faced walls under earthquake loading.
3. In both the walls, it was observed that the acceleration given at the base of the wall, amplified along the elevation of the backfill, and was maximum at the top of the wall. The acceleration amplification factor was 10.5 for cement concrete block faced wall and 5 for gabion faced wall at the top.
4. The frequency of input loading is an important parameter affecting the response of the reinforced soil wall, along with the peak amplitude of loading. But the current dynamic method of analysis (pseudo-static method) considers only the peak acceleration amplitude. So some modifications have to be done by incorporating the effect of resonant frequency of vibration of the system.
5. The backfill soil was found to affect the response of the wall. The deflection pattern for hard clay was different from that of sands, where the maximum facing deflection was at a depth of 0.4H from the base. For sands, the maximum facing deflection was at the top of the wall.
6. The results of the analyses confirmed that the length of reinforcement played an important role in minimizing wall deformations and strains in the reinforcements.

REFERENCES

Bathurst, R. J. and K. Hatami [1998]. "*Seismic Response Analysis of a Reinforced-Soil Retaining Wall*", Geosynthetics International (special issue on Earthquake Engineering), Industrial Fabrics Association International (IFAI), USA: 5(1-2), pp. 127 – 166.

Burke, C., H. I. Ling and H. Liu [2004]. "*Seismic Response Analysis of a Full – Scale Reinforced Soil Retaining Wall"*, Proc. 17th ASCE Engineering Mechanics Conference, University of Delaware, Newark, DE.

El-Emam, M. and R. J. Bathurst [2004]. "*Experienced Design, Instrumentation and Interpretation of Reinforced Soil Wall Response Using a Shake Table"*, International Journal of Physical Modelling in Geotechnics, 4, No. 4, pp. 13 – 32.

Guler E. and M. M. Demirkan [2000]. "*Numerical Analysis of Geosynthetic Reinforced Soil Walls with Cohesive Backfill under Seismic Loads"*, Geotextiles and Geomembranes, 4, pp. 213 – 219.

Helwany, S. M. B. and D. McCallen [2001]. "*Seismic Analysis of Segmental Retaining Walls"*, ASCE Journal of Geotechnical and Geoenvironmental Engg., 127, No.9, pp. 750 – 756.

Jayasree, P. K. [2008]. *"Performance of Gabion Faced Reinforced Earth Retaining Walls"*, Ph. D. Thesis, CUSAT, Kerala, India.

Ling, H. I., D. Leshchinsky and E. B. Perry [1997]. "*Seismic Design and Performance of Geosynthetic Reinforced Soil Structures*", Geotechnique, 47, No. 5, pp. 933 – 952.

Ling, H. I., H. Liu, N. K. Victor and D. Leshchinsky [2004]. "*Analyzing Dynamic Behaviour of Geosynthetic Reinforced Soil Retaining Walls*", ASCE Journal of Engineering Mechanics, 130, No. 8, pp. 911 – 920.