Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 3, No. 5, May, 2017

Stability Analysis of Gabion wall with Tieback in Seismic Regions

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Received 06 November 2016; Accepted 12 May 2017

Abstract

One of the most important issues in the construction of highways, mountain and urban roads is known as slope stabilization. If the necessary actions for protection are not considered, it could lead to problems and events such as landslides, settlements and even destruction of roads. There are many methods for stabilizing slopes such as Gabion walls and Tiebacks. This study can be used as the beginning of a new synthetic method where the Gabion wall is combined with Tiebacks. Gabion walls and tiebacks can be known as the most flexible methods of slope stabilization methods, because of this reason, if they can be combined with each other, it should show very good results in front of dynamic and even static forces. This combination is the novel point of this research. In this study at first, the gabion wall will be analysed in different loading conditions, and then to deal with earthquake dynamic forces the tiebacks will be used to increase the gabion walls stability.

The software that is used in this study is GEO5 software, nowadays this software can be introduced as one of the best slope stability analysis software's. The results of this study showed that the designed gabion wall could be stable in dense silty gravel soil (GM) in 8.5-meter slope, and with magnitude of 0.25 horizontal coefficient of Manjil earthquake, but in the same geometry and material condition and impact of 0.4 magnitude horizontal coefficient of Bam earthquake it couldn't be stable alone. In this condition four rows of 18 meter tiebacks could stable the gabion wall very well. In this model, under loading condition 3 (with horizontal and vertical pseudo-static coefficient of Bam earthquake) that had the most vertical pseudo-static coefficient, the 23-meter tieback anchors with 12-degree inclination respect to horizontal could stable the considered gabion wall. This result could show that, the combination of gabion walls with tieback anchors gives a satisfactory result and it is an efficient and helpful method for stability of slopes in front of earthquake and dynamic forces.

Keywords: Gabion Wall; Tieback; Slope Stability; Dynamic Investigation; Geo5 Software.

1. Introduction

Slope stability is one of the most important and delicate problems in civil engineering, particularly encountered in large and important projects such as dams, highways and tunnels. Many methods exist for stabilizing the slopes, such as nailing, sheet pile, diaphragm wall, gabion, tieback and etc. Gabion walls and tiebacks can be known as the most flexible methods of slope stabilization methods, because of this reason, if they can be combined with each other, it should show very good results in front of dynamic and even static forces. In this study at first, the gabion wall will be analyzed in different loading conditions, and then to deal with earthquake dynamic forces the tiebacks will be used to increase the gabion walls stability. The software that is used in this study is GEO5 software, which is a software suite, providing solution for majority of geotechnical tasks.

In this study, three different loading conditions with assuming three different factor of safety are used, in seismic loading two deadly past earthquakes are used in this study with using horizontal and vertical pseudo-static earthquake

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coefficient in three different conditions. The results of this study showed that the designed gabion wall could be stable in dense silty gravel soil in front of traffic surcharge and horizontal coefficient of manjil earthquake, but with the impact of the horizontal and vertical coefficient of bam earthquake, the gabion wall couldn't stable the slope, in this condition the tieback anchors that are used for increasing the stability of wall, could stable the wall well enough.

2. Gabion Wall

The term gabion is defined as: a container made of wire mesh filled with rock, stone or crushed concrete, that is used for structural purposes. In hydraulic engineering gabions are used to protect banks, dikes, slopes and other structures against erosive forces of currents and waves. Gabions are used in a wide field of structures and can be found in many forms and sizes. Different gabion forms are: box, mattress, cylindrical or sack gabions. The first two are the most common applied shapes. Figure 1 shows the different alternatives [1].

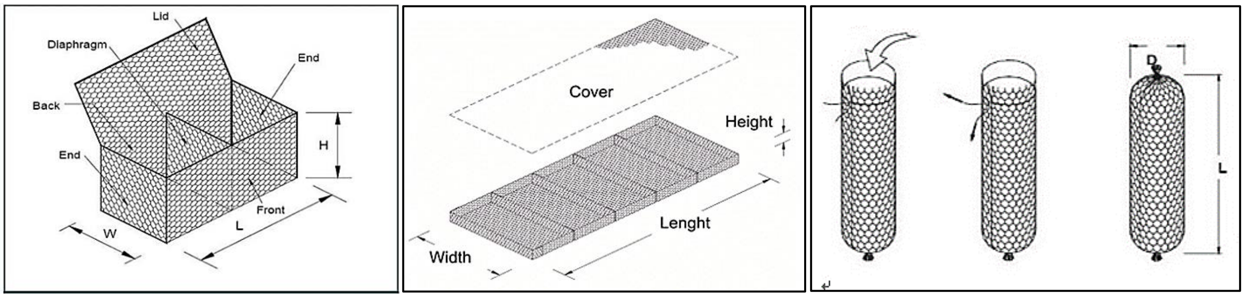


Figure 1. Box, mattress and cylindrical or sack gabion

Gabion containers are made from steel wire grid, from which two different types are available: double-twisted wire mesh and welded mesh. Most of the gabions are manufactured with the hexagonal double-twisted wire mesh. The advantage of this variant above the other is that a structure can deform significantly without failing. A welded frame is less able to do this without failure of the weld, because if a wire breaks the grid will start to unravel. Twisted wire mesh does not have this problem [1].

Before 1986 there was one widely recognized style of gabion mesh: twisted hexagonal, sometimes called double-twisted mesh. Then in 1986, Caltrans (California Department of Transportation) allowed the use of another style of mesh: welded square-grid. Based on full-scale demonstration tests, it was determined that gabions made from either twisted hexagonal mesh or welded square-grid mesh, have comparable strength and flexibility. Wires of both mesh styles are usually zinc-coated, typically hot-dip galvanized. Additionally, both mesh styles can be coated with polyvinyl chloride (PVC) [2].

A more innovative protection layer is the Galfan protection. A zinc-aluminium coating protects the wire and has the ability to recover itself to a certain level. Scratches not deeper than the protection layer will restore themselves. Aluminium is a more noble metal than zinc and will remain on the surface after the corrosion of zinc. This results in a more solid protection layer. Still the probability of corrosion exists in case of severe damage. Under normal conditions this protection can hold three to four times longer than regular galvanized protections, particularly in aggressive saline conditions. Figure 2. shows the galfan and PVC coatings [2].

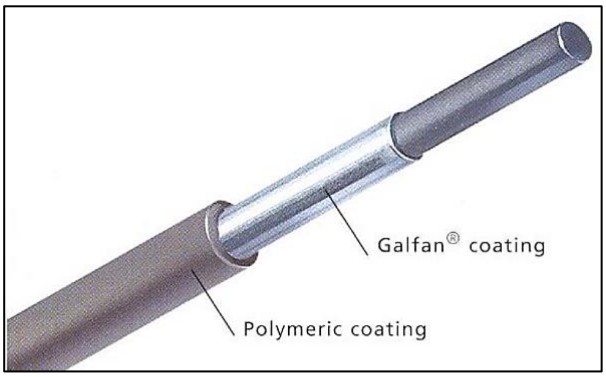


Figure 2. Galfan and Polymeric gabion mesh coating

3. Tieback

Tiebacks (also called ground anchors or simply anchors) are devices used to support retaining walls. A rod, wire, or tendon (cable) is anchored to the ground at one end and to the wall at the other. Anchoring in the ground is typically achieved by boring a hole in the soil or rock and encasing a portion of the wire or rod in a grout mixture. The grout forms a bond with the surrounding soil and tieback and secures the anchor. If a tendon is used, the wire is usually prestressed to a desired tension by hydraulic jacks. The tendon may be inclined at any angle. Design and installation of tiebacks requires specialized methods and equipment and post-installation monitoring [3].

Tiebacks are used for temporary or permanent applications. A temporary tieback is used during the construction of a project; its service life is usually less than two years. A permanent tieback is required for the life of a permanent structure. Figure 3. shows a typical tieback and its components [4].

3.1. Tieback Components

The tendon is made up of pre-stressing steel with sheathing, and an anchorage. The anchor transmits the tensile force in the pre-stressing steel to the ground. Cement grout, or polyester resin, or mechanical anchors are used to anchor the steel in the ground. The anchorage is made up of an anchor head or nut, and a bearing plate. The anchor head or nut is attached to the pre-stressing steel, and transfers the tieback force to a bearing plate which evenly distributes the force to the structure. Anchor heads can be restressable or nonrestressable. Are stressable anchor head is one where the tieback force can be measured or increased any time during the life of the structure. The load cannot be adjusted when an on restressable anchor head is used. A coupling can be used to transmit the anchor force from one length of pre-stressing steel to another [4].

The anchor length is the designed length of the tieback where the tieback force is transmitted to the ground. The tendon bond length is the length of the tendon which is bonded to the anchor grout. Normally the tendon bond length is equal to the anchor length. The unbounded length of the tendon is the length which is free to elongate elastically. The jacking length is that portion which is required for testing and stressing of the tieback. The unbounded testing length is the sum of the unbounded length and the jacking length. A sheath or bond breaker is installed over the unbounded length to prevent the pre-stressing steel from bonding to surrounding grout. The anchor diameter is the design diameter of the anchor. Anchor grout is used to transmit the tieback force to the ground. The anchor grout is also called the primary grout. Secondary grout is injected into the drill hole after stressing to provide corrosion protection for unsheathed tendons [4].

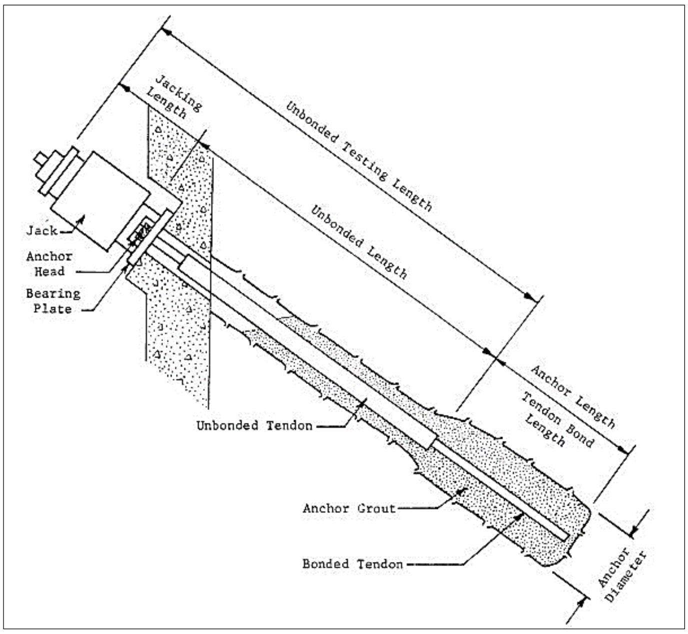


Figure 3. Components of a Tieback

4. Gabion Wall with Tieback

Gabion walls and tiebacks can be known as the most flexible slope stabilization methods, because of this reason, if they can be combined with each other, it should show very good results in front of dynamic and even static forces. In this method, the tieback anchors passes through the gabion boxes to give more stability to gabion wall. This method rarely is used, and there aren't any significant studies about this method. This study can be known as the first analysis of this new combination method. Figure 4. shows this combination method.

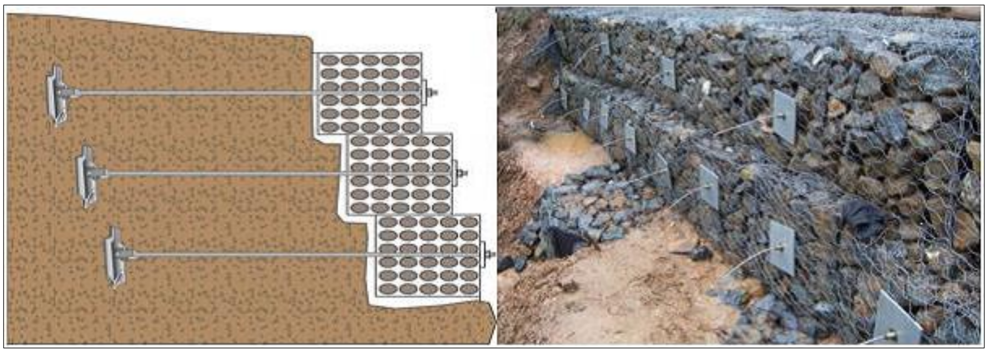


Figure 4. Gabion wall with Tieback

5. Slope Stability Analysis

The stability of retaining walls or slopes, as they are commonly called, should be very thoroughly analysed since their failure may lead to loss of human life as well as colossal economic loss. The primary purpose of slope analysis in most engineering application is to contribute to the safe and economic design of excavations, embankments, earth dams etc. The failure of a mass of soil located beneath a slope is called a slide. It involves a downward and outward movement of the entire mass of soil that participates in the failure. The failure of slopes takes place due to the action of gravitational forces, and seepage forces within the soil. They may also fail due to excavation or undercutting of its foot, or due to gradual disintegration of the structure of the soil. Slides may occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation [5].

In order to determine the stability of a slope, the factor of safety is calculated. A factor of safety of 1.0 indicates a failure condition, while a factor of safety greater than 1.0 indicates that the slope is stable. The higher the factor of safety, the higher the stability of a slope. If the factor of safety of the slope is deemed to be too low, then remedial treatments will be needed.

5.1. Limit Equilibrium Method

All limit equilibrium methods utilise the Mohr-Coulomb expression to determine the shear strength (τ_f) along the sliding surface. The shear stress at which a soil fails in shear is defined as the shear strength of the soil. According to Janbu (1973), a state of limit equilibrium exists when the mobilised shear stress (τ) is expressed as a fraction of the shear strength. Nash (1987) says, "At the moment of failure, the shear strength is fully mobilised along the failure surface when the critical state conditions are reached". The shear strength is usually expressed by the Mohr-Coulomb linear relationship, where the τ_f and τ are defined by:

Shear strength (available):

$$\tau_f = c' + \sigma' \tan \emptyset' \ or \ (a + \sigma') \tan \emptyset' \quad (1)$$

Shear stress (mobilised):

$$\tau = \frac{\tau_f}{FS} = \frac{c' + \sigma' \tan \emptyset'}{FS} \quad (2)$$

Where a, c' and $\emptyset'$ = attraction, cohesion and friction angle respectively in effective stress terms, and FS = factor of safety [6].

The available shear strength depends on the type of soil and the effective normal stress, whereas the mobilized shear stress depends on the external forces acting on the soil mass. This defines the FS as a ratio of the τ_f to τ in a limit equilibrium analysis (Janbu 1954), as defined in Equation 2. [6].

However, the FS can be defined in three ways: Limit equilibrium, force equilibrium and moment equilibrium. These definitions are given in Figure 5. As explained above, the first definition is based on the shear strength, which can be obtained in two ways: A total stress approach (s_u-analysis) and an effective stress approach ($a - \phi - analysis$). The type of strength consideration depends on the soil type, the loading conditions and the time elapsed after excavation. The total stress strength is used for short–term conditions in clayey soils, whereas the effective stress strength is used in long-term conditions in all kinds of soils, or any conditions where the pore pressure is known. The second and third definitions are based on force equilibrium and movement equilibrium conditions for resisting and driving force and moment components respectively [6].

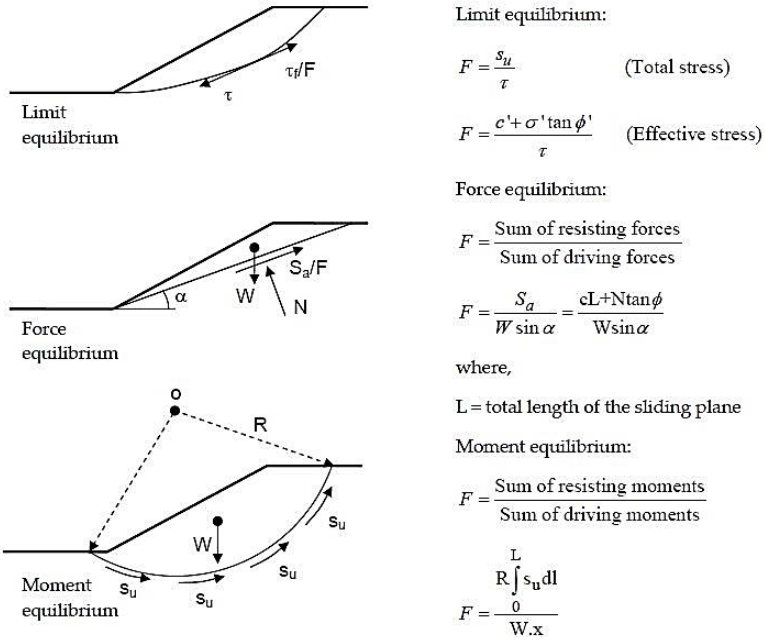


Figure 5. Various definitions of the factor of safety (FS) [6]

Several limit equilibrium (LE) methods have been developed for slope stability analyses. All (LE) methods are based on certain assumptions for the interslice normal (E) and shear (T) forces, and the basic difference among the methods is how these forces are determined or assumed. In addition to this, the shape of the assumed slip surface and the equilibrium conditions for calculation of the FS are among the others [6].

Currently, most slope stability analyses involve LE analysis due to its simplicity and accuracy. These methods consist of cutting the slope into fine slices and applying appropriate equilibrium equations (equilibrium of the forces and/or moments). According to the assumptions made on the efforts between the slices and the equilibrium equations considered, many alternatives were proposed, such as the Bishop and Fellenius methods. In most cases, they are shown to give similar results [7].

Slope failures are often observed following large earthquakes. evaluation of the stability of slopes has become an important part of geotechnical earthquake engineering. Several approaches for evaluation of seismic slope stability, ranging from simple to complex, are available and can be divided into: 1) pseudo-static methods, 2) sliding block methods and 3) stress-deformation methods [8].

The performance of earth structures subjected to seismic action can be evaluated through force-based pseudo-static methods, displacement-based sliding block methods, non-linear soil behaviour and fully coupled effective stress numerical analyses. In principle, numerical methods allow the most comprehensive analyses of the response of earth structures to seismic loading. However, reliable numerical analyses require accurate evaluation of soil profile, initial stress state, stress history, pore water pressure conditions, strength and deformation characteristics of the selected soil layers. Moreover, cyclic soil behaviour can be properly described using advanced constitutive models developed within the framework of bounding surface plasticity or kinematic hardening plasticity, which requires input parameters that are not usually measured in field or laboratory testing [9].

5.1.1. Pseudo-Static Method

The seismic stability of earth retaining structures is usually analysed by the pseudo-static approach in which the effects of earthquake action are expressed by constant horizontal and vertical acceleration attached to the mass. The common form of pseudo-static analysis considers the effects of earthquake shaking by pseudo-static accelerations that produce inertia forces, F_h and F_v, which act through the centroid of the failure mass in the horizontal and vertical directions respectively. The magnitudes of the pseudo-static forces are [10];

$$F_h = \frac{a_h.W}{g} = K_h.W \tag{3}$$

$$F_v = \frac{a_v.W}{g} = K_v.W \tag{4}$$

Where, a_h and a_v are horizontal and vertical pseudo-static accelerations, K_h and K_v are coefficients of horizontal and vertical pseudo-static accelerations, and W is the weight of the failure wedge.

This method is easy to understand and apply. The method ignores cyclic nature of earthquake and treats as if it is applying additional static force on retaining wall. Pseudo-static approach is to apply a lateral force upon retaining wall. This lateral force acts through the centroid of active wedge. The active wedge is zone of soil involved in the development of active earth pressure on the wall. It is inclined at an angle of $45^{\circ} + \emptyset/2$ from horizontal, as indicated in Figure 6. $\emptyset$ is angle of internal friction of soil [11].

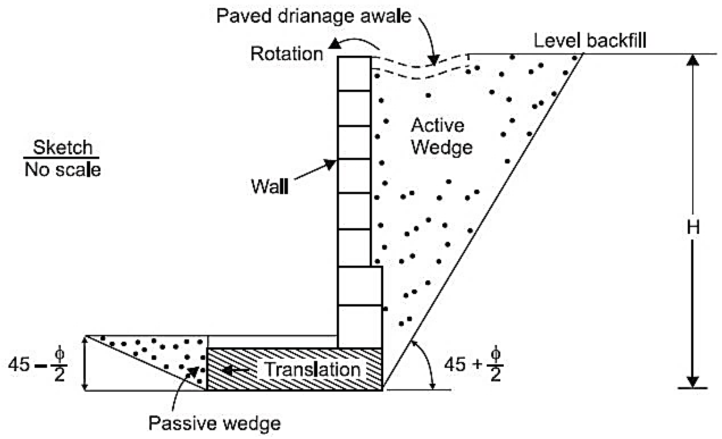


Figure 6. Active wedge behind retaining wall [11]

A pseudo-static analysis is relatively simple and very straightforward. Representation of the complex, transient, dynamic effects of earthquake shaking by a single constant unidirectional pseudo-static acceleration is obviously quite crude. Experiences have shown that pseudo-static analysis can be unreliable for soils that build up large pore pressures or show more than about 15% degradation of strength due to earthquake shaking [12].

5.1.1.1. Pseudo-Static Coefficient

The Choice of the pseudo-static coefficient value gives rise to some uncertainties and further uncertainties are related to the value of the factor of safety [13]. Even though the peak acceleration causes the safety factor value to drop below 1.0, this may be far v very short duration and the resulting displacement may be negligible. Therefore, use of peak ground acceleration as the seismic coefficient in conjunction with a safety factor of 1.0 has been shown to give excessively conservative assessments of slope performance during earthquakes [14]. In many building codes, empirical values based on judgment are used. Kramer [12] stated that recommendations given would be appropriate for most slopes, indicating that it should be based on actual anticipated level of acceleration in failure mass.

As shown in Figure 1, the weight of the soil mass inside the failure surface as well as the resultant horizontal and vertical forces acting on the failure surface must be known in order to compute the horizontal and vertical seismic coefficients. The total weight of the soil mass inside the failure surface can be computed once the failure wedge geometry is known [15].

In this study the horizontal and vertical pseudo-static coefficients of earthquakes are computed from the equation of Franklin and Hynse [16];

$$K_{h,v} = \frac{PGA}{2g} \tag{5}$$

Where, PGA is the Peak Ground Acceleration in horizontal or vertical.

5.1.1.1.1. Computation of Pseudo-Static Coefficient

For assuming critical dynamic loads for this study, tow deadly past earthquakes are used: Rudbar-Manjil earthquake and bam earthquake.

Manjil Earthquake: The 1990 'Manjil–Rudbar' earthquake occurred on June 21 at 00:30:14 local time in northern Iran. The shock had a moment magnitude of 7.3 and a Mercalli Intensity of X (Extreme). Widespread damage occurred to the northwest of the capital city of Tehran, including the cities of Rudbar and Manjil [17]. The earthquake data are driven from 'PEER Ground Motion Database' and the acceleration-time diagram of this earthquake is delivered from Seismosignal program outputs, Figure 7. shows the Rudbar-Manjils acceleration-time diagram.

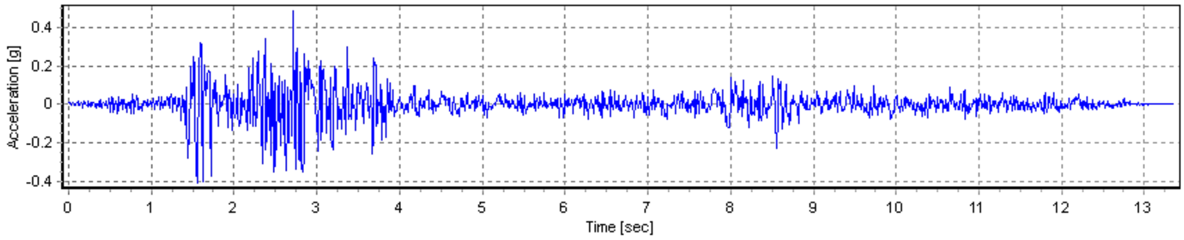


Figure 7. The acceleration-time diagram of Rudbar-Manjil earthquake

The result shows the horizontal peak ground acceleration is 0.515 g at the time of 2.72 sec, and the maximum displacement is 7.39 cm at the time of 13.36 sec. Thus, for computing the pseudo-static coefficient of manjil earthquake with using the equation of Frankline and Hynse (1984) [16], the K_h magnitude is achieved 0.25.

Bam Earthquake: The devastating earthquake of 26 December 2003 claimed more than 43,000 lives in the city of Bam in southeast Iran, and left the majority of the Bam population homeless. The earthquake had a magnitude of Mw = 6.5 (USGS) and an epicentre location of 29.00N, 58.34 E (USGS). The reason for this tragedy was an unfortunate combination of geological, social and human circumstances [18]. The earthquake data are driven from 'PEER Ground Motion Database' and the acceleration-time diagrams are gained from Seismosignal program, Figure 8. shows the Bam acceleration-time diagram.

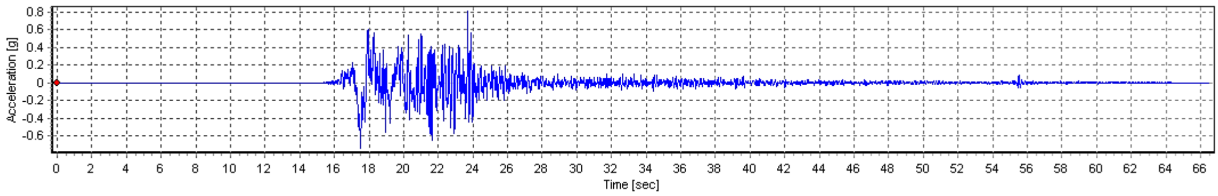


Figure 8. The acceleration-time diagram of Bam earthquake

The result shows the horizontal peak ground acceleration is 0.808 g, and the vertical peak ground acceleration is obtained 1g. For computing the pseudo-static coefficient of Bam earthquake with using the equation of Frankline and Hynse (1984) [16], the K_h magnitude is achieved 0.4, and the K_v magnitude is achieved 0.5.

6. GEO5 Software Introduction

GEO5 is a powerful software suite for solving geotechnical problems based on traditional analytical methods and Finite Element Method (FEM). Individual programs verify a specific structure, which keeps them intuitive and easy to use. Individual programs have the same user interface and communicate with each other, while each program verifies definite structure type. The basic geotechnical approaches implemented in the GEO5 software are applicable all over the world, although most countries adopt their own standards and conventions. GEO5 offers a unique way of applying standards which significantly simplifies the work of the designer and at the same time allows to verify the structure with all the required approaches [17].

GEO5 allows setting of standards and analysis methods centrally for all GEO5 programs. The program allows to perform the structure verification according to five methodologies: Verification according to safety factor (ASD), limit states, EN 1997, LRFD and Chinese standards. The method that is used in this study is safety factor (ASD), the active earth pressure calculation is determined with Coulombs theory, the passive earth pressure calculation is determined with Kaqout-Kerisel method and earthquake analysis is performed with Mononobe-Okabe method.

6.1. Analysis According to the Safety Factor (ASD)

The verification methodology based on the "Safety factor" is historically the oldest and most widely used approach for structure safety verification. The principal advantage is its simplicity and lucidity. In general, the safety is proved using the safety factor:

$$FS = \frac{X_{pas}}{X_{act}} > FS_{req} \tag{6}$$

Where, FS is computed factor of safety, X_{pas} is A variable resisting the failure (resisting force, strength, capacity), X_{act} is a variable the causing failure (sliding force, stress) and the FS_{req} is Required factor of safety.

When performing the analysis using the "Safety factor", neither the load nor the soil parameters are reduced by any of the design coefficients [17].

7. Loading Conditions

In this study three different loading conditions with three different factors of safety are used, the selection of this different loading conditions is just for determining the influences of tiebacks on the gabion wall; for this purpose, a road with traffic surcharge is assumed on the top of backfill slope, and of deadliest earthquakes (Manjil and Bam earthquakes) in Iran in used for seismic loading.

- *Loading condition 1:* in this loading, the structural dead loads and earth pressures are used, because this loading is permanent the factor of safety is assumed 1.5.
- *Loading condition 2:* in this loading, the structural dead loads, earth pressures and a traffic surcharge are used, the traffic surcharge magnitude is 12 KN/m^2 (according to AASHTO LRFD) with the length of 5 meters strip at the top of slope, because this loading is transient the factor of safety is assumed 1.3.
- *Loading condition 3:* in this critical loading, the structural dead loads, earth pressures, traffic surcharge and seismic loading are used, three different seismic loading are used in this study, at first the manjil horizontal pseudo-static earthquake coefficient is used, then bam horizontal pseudo-static earthquake coefficient is used, and in the third time the bam horizontal and vertical pseudo-static earthquake coefficients are used, because of the accidental nature of this loading the factor of safety is assumed 1.1.

8. Modeling Issues and Results

The software that is used in this study is GEO5 software, and the slope that is assumed is a dense cohesion-less silty gravel soil (GM) and the groundwater table is in 21 meters below the ground surface, with the unit weight of 20 KN/m^3 and the angle of internal friction of 32 Kpa, and there is a 1 meter front face resistance of GM soil in front of the wall. The filling material assumed for gabion boxes is sandstone with specific gravity of 25 KN/m^3, with 20% porosity in the boxes, the angle of internal friction and cohesion of the sandstone are assumed 35 degree and 35 Kpa respectively. Galvanized gabion mesh is assumed for gabion box mesh with the mesh tensile strength of 50 KN/m, and the connection strength of 50 KN/m. The spacing of vertical mesh partitions is assumed 1 meter. For tieback anchors the strands with capacity of 450 KN are assumed for the tendons.

8.1. Loading Case 1

At the first in loading condition 1 for achieving the best geometry of the gabion wall, four different geometry are analysed, and the analysis results shows that, the model number 4 have been achieved the minimum factor of safety (1.5) in loading case 1. These different models are shown in Figure 9.

a) Model number 1 b) Model number 2

c) Model number 3 d) Model number 4

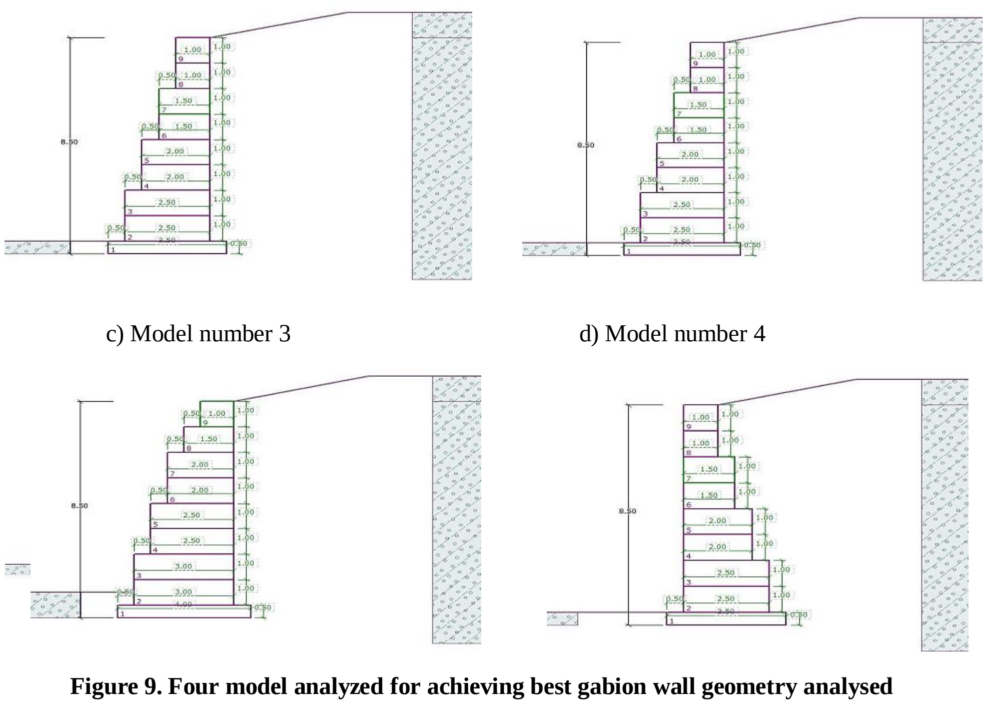
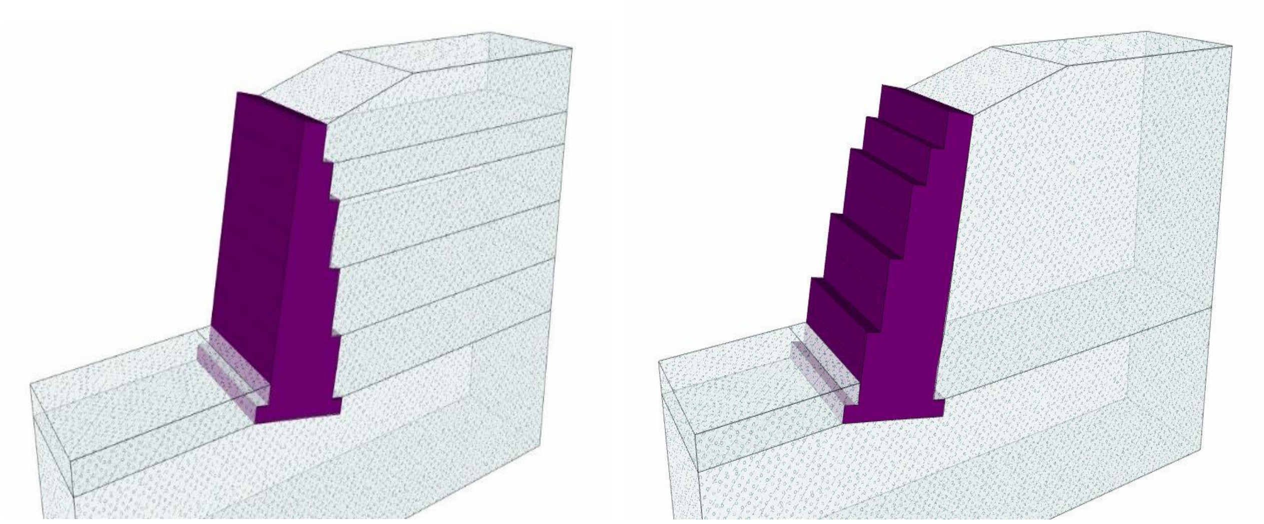


Figure 9. Four model analyzed for achieving best gabion wall geometry analysed

The gabion retaining walls can be designed and configured with a stepped front face or a smooth front face. Figure 10. shows three-dimensional condition of these stepped front face and smooth front face gabion retaining walls in GEO5 2016. The stability analysis of different models is presented in Table 1. The results show that, the gabion wall in model number 4 with a smooth front face has been achieved the minimum factor of safety in all of the analysis.



a) Smooth front face gabion wall b) Stepped front face gabion wall

Figure 10. 3D Smooth front face and stepped front face gabion walls

Table 1. Factor of safety for gabion wall geometry

Models of figure 9	Model 1	Model 2	Model 3	Model 4
Bishop	1.31	1.35	1.49	1.54
Spencer	1.31	1.13	1.49	1.54
Janbu	1.32	1.35	1.51	1.55
Morgenstern-Price	1.32	1.35	1.51	1.55

When utilizing a gabion wall with a smooth front face, the gabion wall shall always be placed on a 6-12 degree batter, thus 5 different degrees are analysed for determining the best degree for this smooth front face gabion wall. These analyses are presented in Table 2, these factor of safeties shows that the 12 degree for smooth front face gabion wall is the best degree in all of the analysis.

Table 2. Factor of safety for degree of smooth front face gabion wall

Degree of front face	0	5	8	10	12
Bishop	1.54	1.63	1.67	1.69	1.73
Spencer	1.54	1.63	1.68	1.70	1.75
Janbu	1.55	1.64	1.68	1.70	1.75
Morgenstern-Price	1.55	1.64	1.68	1.70	1.75

8.2. Loading Case 2

After determining the best geometry and degree for gabion wall in loading condition 1, the traffic surcharge is considered with the magnitude of 12 KN/m^2 and the length of 5 meter strip at the top of slope. The picture of this loading condition is presented in Figure 11, and stability analysis of different degrees for gabion wall front face is presented in Table 3.

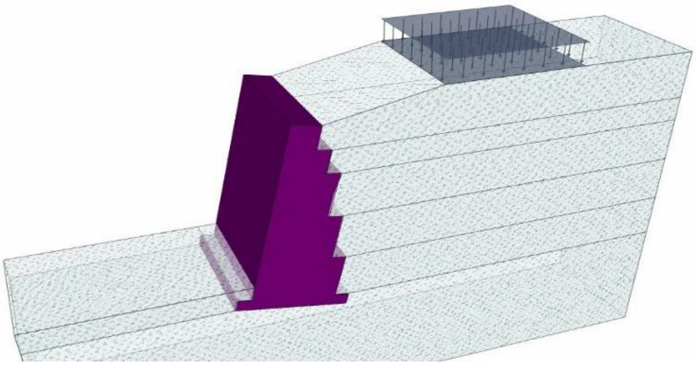


Figure 11. 3D view of the considered surcharge at top of slope

Table 3. Factor of safety in loading condition 2

Degree of front face	0	5	8	10	12
Bishop	1.49	1.59	1.62	1.64	1.67
Fellenius/Petterson	1.24	1.29	1.31	1.33	1.35
Spencer	1.5	1.58	1.61	1.65	1.68
Janbu	1.51	1.59	1.62	1.65	1.68

The results show the designed gabion wall could be stable in loading condition 2, and the reduction of the factor of safety are very little, for example the reduction of factor of safety in Bishop method is just 0.06. The results show that, the Fellenius/Petterson method has the least factor of safety among the others, and the other methods almost have the same factor of safety.

8.3. Loading Case 3 (Horizontal Pseudo-Static Coefficient of Rudbar-Manjil Earthquake)

In loading condition 3 at first, the horizontal pseudo-static coefficient of Rudbar-Manjil earthquake with the magnitude of 7.3 is considered in loading condition 2 [18]. The magnitude of K_h is 0.25, and the effect of vertical effect of earthquake is neglected. The result of analysis in this loading condition is presented in Figure 12.

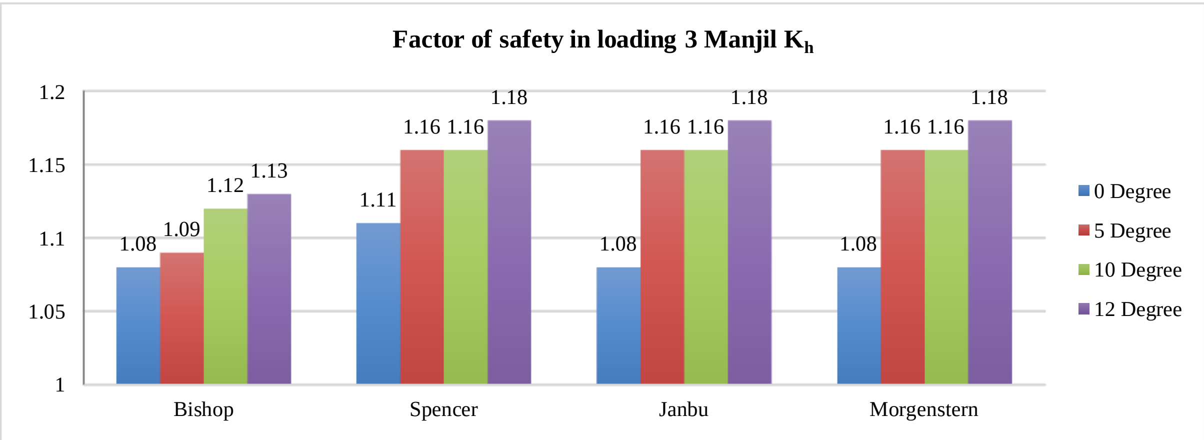


Figure 12. Factor of safety in loading 3 for angle of gabion wall (with Manjil K_h)

The results show designed gabion walls stability is satisfactory, it can be stable in loading condition 3 with horizontal coefficient of manjil earthquake, and there is no need for help of tieback here. The effect of horizontal coefficient of manjil earthquake is significant, for example the reduction of factor of safety in Bishop method is 0.54. The results show the factor of safety is so close in the different limit equilibrium methods. Figure 13. shows the slip surface of this loading condition in Bishop method.

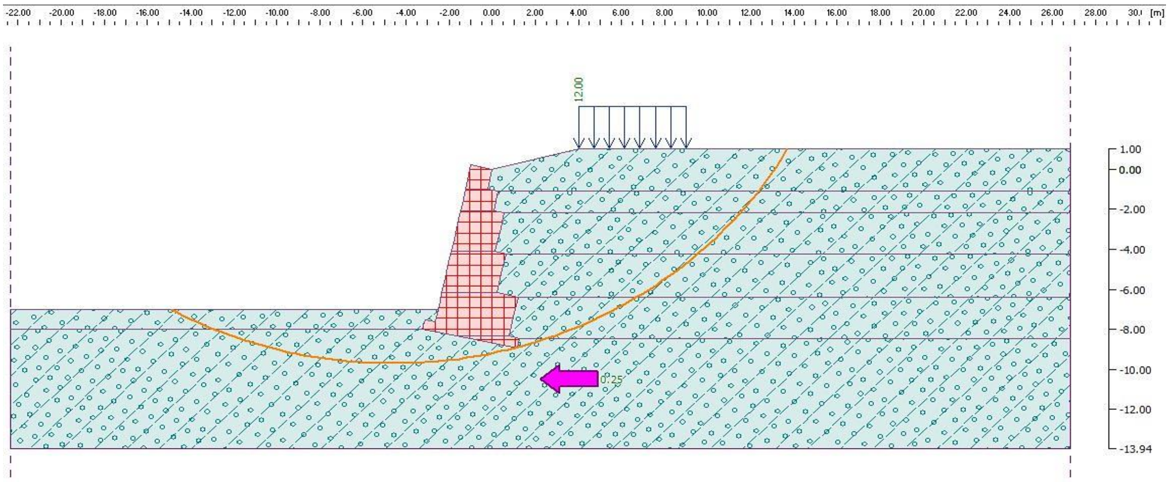


Figure 13. Factor of safety in loading 3 for angle of gabion wall (with Manjil K_h)

8.4. Loading Case 3 (Horizontal Pseudo-Static Coefficient of Bam Earthquake)

The magnitude of Bam earthquake was 6.6 and for this loading condition, the horizontal pseudo-static coefficient of Bam earthquake with magnitude of 0.4 is considered, and the effect of vertical effect of earthquake is neglected [19]. The result of stability analysis in this loading condition is presented in Figure 14.

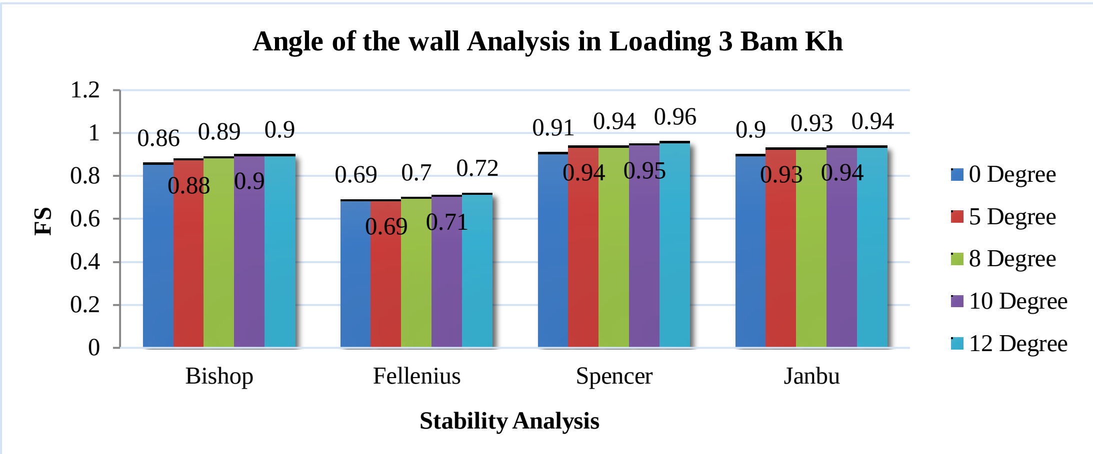


Figure 14. Factor of safety in loading 3 for angle of gabion wall (with Bam K_h)

The results show designed gabion walls stability is not satisfactory. The effect of horizontal coefficient of Bam earthquake is very significant, for example in reduction of factor of safety in Bishop method is 0.77. In this condition the tiebacks are designed to help the gabion wall to have stability, 4 rows of tiebacks are designed for this reason, for determining the best length and the angle of tiebacks, stability analysis are performed, the minimum length of tiebacks is determined 18 meter, and the best angle of tiebacks is determined 12 degree. The results of stability analysis of angle of the tiebacks are presented in Table 4.

Table 4. Factor of safety in loading condition 3 (Bam K_h)

Degree of tiebacks	0	5	10	12
Bishop	1.06	1.16	1.27	1.31
Fellenius/Petterson	0.99	1.03	1.08	1.1
Spencer	1.09	1.2	1.32	1.37
Janbu	1.08	1.2	1.31	1.36

The results presented in Table 4. shows that, four rows of 18 meter tiebacks with the angle of 12 degree could have a very significant effect on the stability of gabion wall, for example the increase of factor of safety in Bishop method is 0.41. The results show Fellenius/Petterson method has the least factor of safety among the others, and it is the minimum factor of safety (1.1) in loading condition 3. The others factor of safety are almost close to each other.

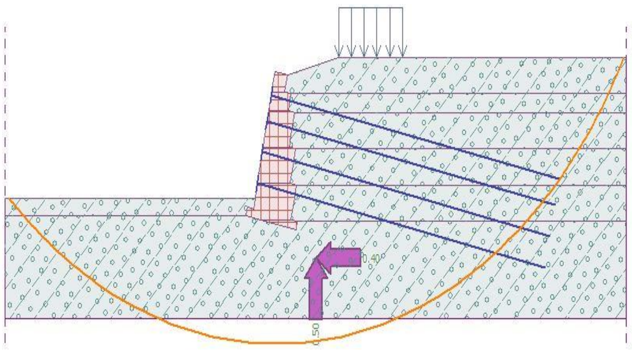
8.5. Loading Case 3 (Horizontal and Vertical Pseudo-Static Coefficients of Bam Earthquake)

In this loading condition, the horizontal and vertical pseudo-static coefficients of Bam earthquake with magnitude of 0.4 and 0.5 respectively are considered. The magnitude of 0.5 coefficient is the maximum seismic coefficient that it can be considered in GEO5 software. The results of stability analysis show that, the designed walls stability is not satisfactory again, for example the factor of safety in bishop method with considering vertical coefficient of bam earthquake with magnitude of 0.5, has been decreased from 1.31 in loading condition 3 with Bam K_h to 0.87, the magnitude of reduction of factor of safety is 0.44. this result show the effect of vertical coefficient of bam earthquake is significant in this retaining structure.

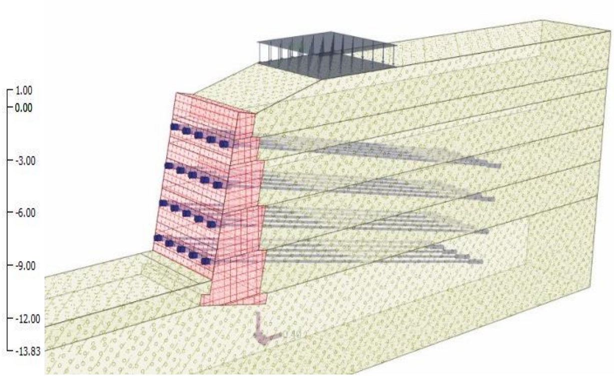
For increasing the factor of safety in this condition, the length of tiebacks is increased. The analysis for determining the minimum length of tiebacks is presented in Table 6. In this condition the factor of safety in Fellenius/Petterson method has the least value, and when this method is neglected, the length of 23 meter can be stable the retaining structure in all of the other limit equilibrium methods. These results show that, 5 meter increase of tiebacks length can resistance in front of vertical coefficient of bam earthquake in this condition. All of the factor of safeties in the lengths of 26 and 28 meter for limit equilibrium methods are constant, and it shows that, the increasing the length of tiebacks can't raise the factor of safety in this condition. The slip surface of bishop method and 3D picture of this model is presented in Figure 15.

Table 6. Factor of safety in loading condition 3 (Bam K_h and K_v)

Length of tiebacks	18	20	23	26	28
Bishop	0.87	0.93	1.15	1.24	1.24
Fellenius/Petterson	0.62	0.63	0.8	1.01	1.01
Spencer	1.03	1.07	1.26	1.39	1.39
Janbu	0.91	1	1.25	1.39	1.39



a) Slip surface of bishop method in loading 3 with tiebacks



b) 3D view of gabion wall with tiebacks in loading 3

Figure 15. Slip surface of Bishop method and 3D View of gabion wall with tieback in loading 3 (Bam K_h and K_v)

9. Conclusion

Nowadays the use of combination of different slope stability methods with each other has become an essential part of slope stability method in the world. This study can be known as the first study of analyzing the stability of a new method of slope stability methods that the gabion walls are combined with tiebacks. The results of this study show that, the designed gabion walls stability was satisfactory during loading condition 1, 2 and 3 in considering the horizontal effect of Rudbar-Manjil earthquake with magnitude of 0.25 alone, But the gabion wall lost its stability in considering loading condition 3 with horizontal effect of Bam earthquake with the magnitude of 0.4. Four rows of tiebacks with length of 18 meter and the angle of 12 degree with respect to horizontal could stable this designed gabion wall, but with considering the vertical effect of Bam earthquake with magnitude of 0.5, that it is the maximum allowable coefficient of earthquake that can be considered in the software, the designed retaining wall lost its stability again. In this condition, just 5 meter increasing the length of tiebacks could stable the retaining structure again. These results show that, this method of slope stability can be a remarkable method for stabilization of slopes in front of seismic loading, and it can be more significant with increasing the area of tiebacks bearing plates for give more stability to gabion boxes. Because this combination method is a newly introduced method of earth retention, its required to examine the dynamic response through strong numerical methods incorporating the interaction between different parts, it is recommended that the results from pseudo-static method should be compared with other precise methods.

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