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Review Article

SEISMIC ANALYSIS OF REINFORCED EARTH WALL: A REVIEW

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The concept of seismic analysis of reinforced earth wall along with soil structure interaction is reviewed and discussed. A systematic summary of history and status of seismic analysis of reinforced earth wall and soil structure interaction is proposed in these paper. Various methods for analysis considering different seismic parameters different soil conditions are discussed along with work in numerical modelling. Parametric studies illustrate the effects of seismic acceleration on the design of reinforced retaining wall and also the forces in the reinforcements.

Keywords: Finite Element Modelling, Seismic Analysis, Soil Structure Interaction, Reinforced Earth Wall

INTRODUCTION

Reinforced soil retaining walls or reinforced earth walls (commonly grouped as Mechanically Stabilized Embankments – MSE) which are advantageous over traditional retaining walls due to its long height. Reinforced earth wall was developed in 1970's in USA. Reinforced earth is a composite material constructed with artificial reinforcing formed by interaction between frictional soil and reinforcing strips. MSE walls are typically constructed using four structural components: (1) geogrid reinforcement; (2) wall facing; (3) retained backfill; and (4) reinforced backfill soil (Kishan, 2010).

The facing also plays an important role in the stability of the wall, which includes precast concrete panels, dry cast modular blocks, metal sheet and plates, gabions, welded wire mesh, shotcrete, wood lagging and panels, and wrapped sheet of geosynthetics. One of the most important characteristics of RE is its flexibility. For this reason it is ideal for structures such as retaining walls on soft foundations.

The reinforcement improves the earth by increasing the bearing capacity of the soil and reduces the settlement. It also reduce the liquefaction behavior of the soil. (Government of India, 2005). Reinforcement of soil, is

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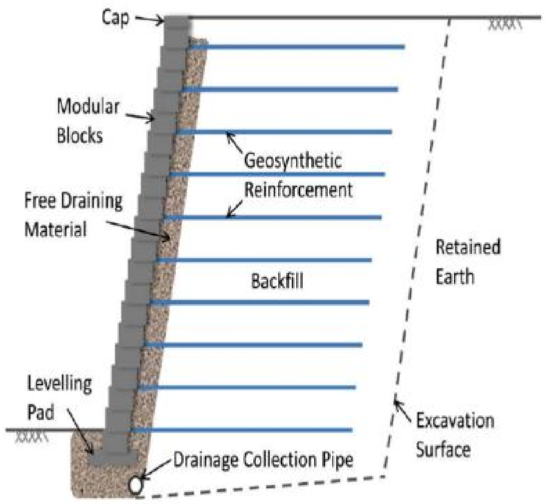
practiced to improve the mechanical properties of the soil being reinforced by the inclusion of structural element such as granular piles, lime/cement mixed soil, metallic bars or strips, synthetic sheet, grids, cells, etc.

This mobilization of tensile strength is obtained by surface interaction between the soil and the reinforcement through friction and adhesion. The reinforced soil is obtained by placing extensible or inextensible materials such as metallic strips or polymeric reinforcement within the soil to obtain the requisite properties.

Figure 1: Cross Section of Reinforced Earth Wall



DESIGN AND ANALYSIS OF REINFORCED EARTH WALL

There are various methods used for the design of the reinforced earth wall. From the traditional till date all the methods are listed here. Mainly there are two approaches for the design of the reinforced earth wall they are pseudo static approach and pseudo dynamic approach for the design.

Two methods found in current engineering practice for the dynamic response analysis of reinforced-soil retaining-wall structures are: The first method is an iterative equivalent linear classic approach, and the second is an incremental elastic approach (Muthucumarasamy Yogendrakumar, 1992).

The problem of determining pseudo dynamic pressure and its associated forces on a rigid vertical retaining wall is solved analytically using the horizontal slices method for both reinforced and unreinforced walls. The use of this method in conjunction with the suggested equations and unknowns offers a pseudo-dynamic method that is then compared with the results of an available software. In the proposed method, different seismic accelerations have been modelled at different soil structure heights (Ghanbari, 2008).

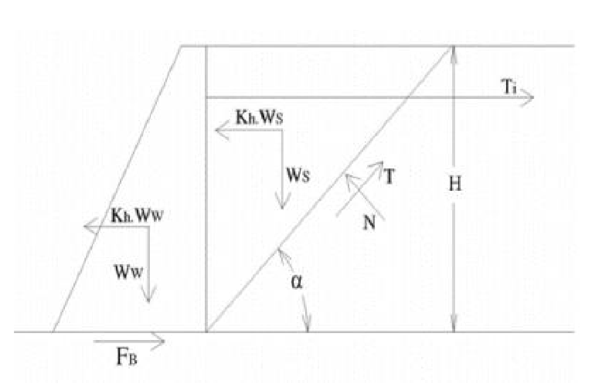
Seismic designs of geotechnical earth structures, such as slopes, retaining walls, embankments and dams, are conducted routinely using a pseudo-static approach. The Mononobe (1924) and Okabe (1924) approach for retaining wall design, is the most wellknown pseudo-static procedures (Nouri, 2008).

The internal stability of MSE walls relies on protection against two Ultimate Limit States (ULSs): pull out and structural failure of reinforcements. This study proposes equations for the resistances and loads that reflect the physical processes involved in the pull out and structural failure ULSs and quantify the uncertainties (Dongwook Kim and Rodrigo Salgado, 2012).

It is considered an earth pressure approach where the solution is obtained by extending Coulomb's analysis. Pseudo-static stability analysis that uses a mechanism at a prescribed failure plane has been addressed by several investigators (Seed and Goodman, 1964; Sarma, 1975; and Ling and Cheng, 1997).

These studies all assume the inertia force due to an earthquake horizontal acceleration for a failure soil mass along a prescribed plane. The first seismic design procedure for metal strip reinforced soil structures was proposed by (Richardson, 1975). It was based on the Mononobe–Okabe analysis (1924) (Mononobe, 1924; Okabe, 1924). A planar failure surface was assumed and a dynamic earth pressure component was added to the static component in determining the required reinforcement force. Bonaparte *et al.* (1986) proposed a pseudo-static limit equilibrium approach for designing reinforced slopes. The geosynthetics length and strength required to resist these failure modes were presented in several design chart. This approach does not consider permanent displacement. Ling *et al.* (1997) conducted a seismic design for designing geosynthetics-reinforced slopes base on a pseudo-static limit equilibrium analysis, which considers horizontal acceleration and incorporates a permanent displacement limit. Internal and external stability analysis conducted to determine the required strength and length of geosynthetics, considering different modes of failure. Different forces acting on the wall are shown in Figure 2.

Figure 2: Geometry and Acting Forces



Design of Reinforced earth wall is to be checked for both

a) External Stability
b) Internal Stability

External stability is often examined based on the (Mononobe, 1929) a pseudo static limit equilibrium method that is a direct extension of the static Coulomb theory for gravity walls (Mononobe and Matsuo, 1929). Internal stability is checked by dividing the reinforced zone into an active and a resistive zone, based on the premise that the horizontal inertial forces caused by the seismic acceleration on the mass of the active zone must be resisted by the geosynthetic reinforcement, which must be sufficiently anchored within the resistive zone (Rebecca M Walthall and Judith Wang, 2013).

Table 1: Seismic Stability used in Pseudo Static Method

Failure Mode	Factor of Safety in PWRI	Factor of Safety in Limit Equilibrium
Circular Sliding	FS = 1.0	FS = 1.0
Sliding	FS = 1.2	FS = 1.0
Overturning	$e \leq L/3$	$e \leq L/2$

The sliding displacement behavior of the overall system between the wall and the underlying soil is typically examined using the Newmark sliding block method in conjunction with the M-O method. Design of MSE walls with inextensible reinforcements was, and still is, performed by assuming the MSE structure behaves as a rigid body, sizing it to resist external loads applied by the retained soil and by any surcharge, then verifying internal stability by checking reinforcement pullout and tensile rupture. This design method, derived from basic soil mechanics, is known as the Coherent Gravity Method (Peter L Anderson, 2013). Some standard factor of safety in PWRI and equilibrium are shown in Table 1.

The Tieback Wedge Method was developed by Bell (1975) as an extension of the trial wedge method from traditional soil mechanics (Huntington, 1957), and has always been the appropriate design method for geosynthetic-reinforced MSE walls. In an MSE wall with geosynthetic reinforcements, the failure plane is assumed to develop along the Rankine rupture surface defined by a straight line oriented at an angle of $45+\phi/2$ from the horizontal and passing through the toe of the wall. This contrasts sharply with the Coherent Gravity Method, where the shape of the bilinear boundary between the active and resistive zones is based on the location of maximum reinforcement tension, the failure plane does not actually develop, the active wedge does not displace, and the inextensibility of the steel reinforcements prevents structure deformation.

SEISMIC ANALYSIS AND MODELLING

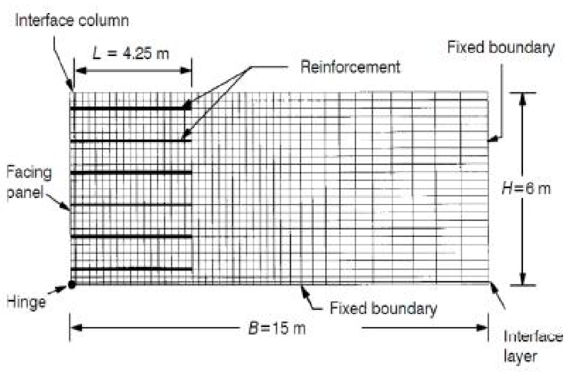
Bathrust and Hatami studied in their research work the analysis of reinforced soil retaining wall.

The numerical models were excited at the foundation elevation by a variable-amplitude harmonic motion with a frequency close to the fundamental frequency of the reference structure.

The two-dimensional, explicit dynamic finite difference program Fast Lagrangian Analysis of Continua (FLAC) was used to carry out the numerical experiments. The response of the same wall excited by a scaled earthquake record was demonstrated to preserve qualitative features of wall displacement and reinforcement load distribution as that generated using the reference harmonic ground motion applied at 3 Hz.

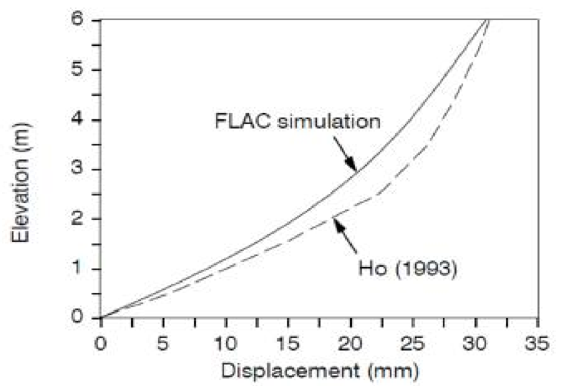
The reference continuous panel wall is 6.0 m high with six uniformly spaced reinforcement layers (Figure). The wall facing was modelled as a continuous concrete panel with a thickness of 0.14 m. The bulk and shear modulus values of the wall were Kw = 11,430 MPa and Gw = 10,430 MPa, respectively. Poisson's ratio for the panel material was taken as Vw = 0.15. The panel was hinged at its base, as illustrated in Figure 1. The soil was modelled as a purely frictional, elastic-plastic material with a Mohr-Coulomb failure criterion and non-associated flow rule. The friction angle of the soil was µ =35, dilatancy angle · = 6, and unit weight γ = 20 kN/m^3.

Figure 3: Numerical Grid for Reference Static Load Case



The results of the FEM simulation of reinforced continuous panel walls which is numerically modelled in Figure 3 have been demonstrated to be sensitive to mesh construction details and material properties at the reinforcement-wall connections (Rowe and Ho, 1997; Andrawes and Yogarajah, 1994). In the current study, a simple connection model was adopted that involved attaching the end of the cable elements (reinforcement) to a single grid point at the back surface of the continuous panel region.

Figure 4: Result Elevation > Displacement



The wall-soil interface was modelled using a thin soil column, 0.05 m thick, directly behind the facing panel. A no-slip boundary was used between the thin soil column and the facing panel. The soil-wall interface column material was assigned a friction angle µ*i* =20 and a dilatancy angle · *i* = 0. A similar thin soil layer was introduced at the base of the soil region but was assigned the same properties as the reinforced and retained soil materials. Comparison of elevation v/s displacement graph is shown in Figure 4. Rajagopa and Bathrust (1995) evaluated that the strength and stiffness properties of component materials can be determined from the results of independent routine laboratory tests and then successfully implemented in finite element modelling of the composite structure.

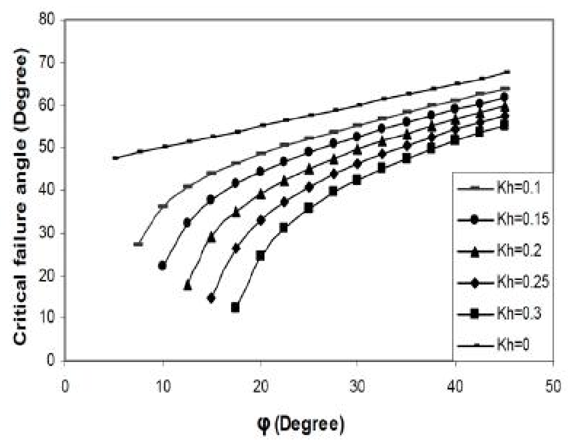
To illustrate the behavior of reinforced retaining wall under seismic inertia force, a computer program has been developed, which can be used to attain the critical inclination of the failure plan angle and required total geosynthetic force. The Geometric of soil-wall system (H, B1 and B2 in Figure) utilized in the parametric analysis is that considered by Nadimand and Whitman (1983) (Whitman, 1983). A series of parametric study have been carried out in two cases (1) without presence of the wall; and (2) with presence of the wall using the geotechnical, geometrical and design parameters detailed in Table 2. The obtained results of system, with presence of wall are compared to those obtained for the case of system without presence of wall.

Table 2: Parameters

Description	Value
Height of the wall	8
B1	0.8
B2	5
Unit weight of soil	18 kN/m^3
Unit weight of wall	24 kN/m^3
Internal angle of soil friction	10, 15, 20, 25, 30, 35, 40, 45
Soil Cohesion (C)	0
Coefficient of Seismic acceleration (Kh)	0, 0.1, 0.15, 0.2, 0.25 0.3
Coefficient of Seismic acceleration (Kv)	0

Figure 5 shows the critical inclination of the failure plan angle; ~ for different internal angle of soil friction (¤) under static and seismic loadings (k_h=0.0, 0.1, 0.15, 0.2, 0.25, and 0.3). The results show that for the certain value of *kh*, the value of ~ increases with increasing the internal angle of soil friction (¤). It means that when internal angle of soil friction (¤) increases, the volume of the critical sliding mass reduces. Also, for the certain value of ¤, the critical inclination of the failure plan angle (~) decreases with increasing the value of k_h. It means that when *h k* increases, the weight of the soil failure wedge; Ws (the volume of the critical sliding mass) increases.

Figure 5: Failure Angle



The wall facing was comprised of five half and ten full precast concrete panels, each panel measuring 1.5 m _ 1.5 m. Each structure was overlaid by an untreated gravel sub layer, a ballast layer and one sleeper. The sleepers were 2.4 m long, 0.3 m wide and 0.27 m high, perpendicular to the facing and in the centre of the interval between the concrete walls shown in Figure 6.

Bourgeois (2011) evaluated that numerical models makes it possible to reproduce the tensile-force increments in the strips and the displacements induced by loads varying over a wide interval of values ranging from 90 to 850 KN, this latter value being much larger than the standard axle loads. These models can also be useful to discuss the influence of geometric parameters or mechanical parameters on the global response of a reinforced earth structure. Results are shown in the form of load v/s displacement graph in Figure 7.

Figure 6: Model Reinforced Earth Wall

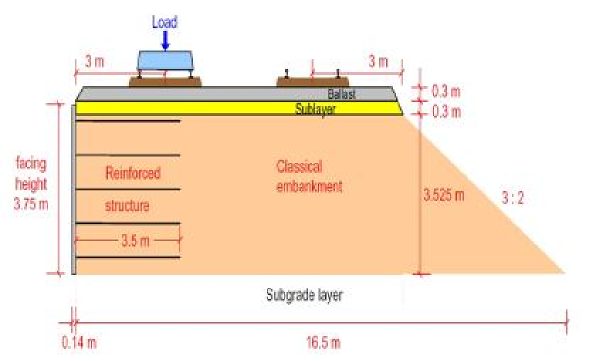
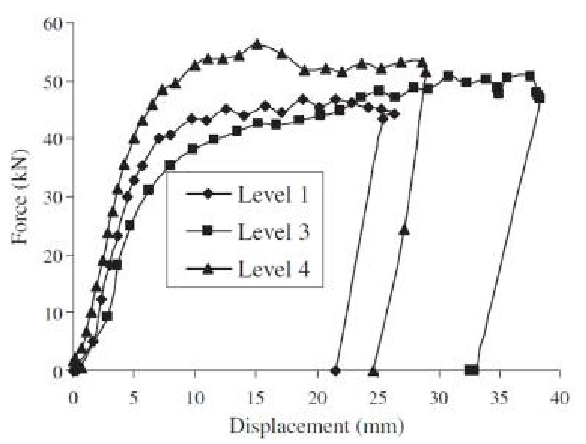


Figure 7: Load v/s Displacement



There are various finite element programs such as Pl axis, FLAC, ANSYS, ABAQUS, MSC.MARC, etc., in which analysis can be performed and different seismic parameters can be evaluated.

COMPARING DESIGN METHODS

Various methods were discussed above for the design of Reinforced earth wall, at present stage many traditional methods are outlined. From the above discussion it can be concluded that extension of M-O equation, i.e., Pseudo static approach is efficient method for the designing of Reinforced Earth Wall.

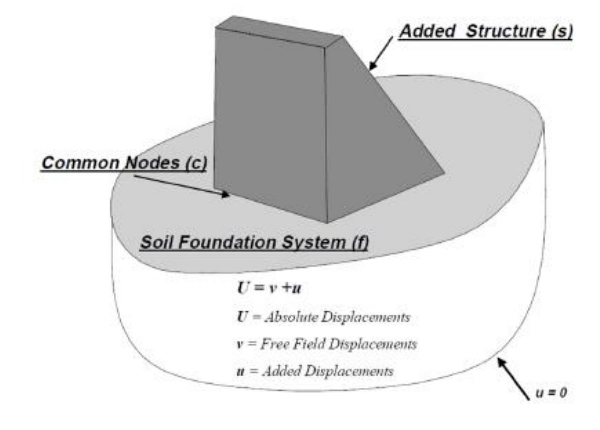
SOIL STRUCTURE INTERACTION

Soil structure interaction phenomena concern the wave propagation in a coupled system: buildings erected on the soil surface (AK, 1974). One of the important reasons for this difference is that part of the vibrational energy of the flexibly mounted structure is dissipated by radiation of stress waves in the supporting medium and by hysteretic action in the medium itself. Analytical methods to calculate the dynamic soil structure interaction effects are well established (Wolf, 1985).

Structure Soil Structure Interaction (SSSI), put forward in recent decades, means the dynamic interaction problem among the multi-structure system through soil-ground. To the writer's knowledge, it is (JE, 1973) in 1973 to come up first with the SSSI designation for this area of study. Its additional name is Dynamic Cross Interaction (DCI).

Finite Element Method (FEM), an efficient common computing method widely used in civil engineering, discretizes a continuum into a series of elements with limited sizes to compute for the mechanics of the continuum. FEM can simulate the mechanics of soil and structures better than other methods, deal with complicated geometry and applied loaded, and determine non-linear phenomena. SSI effects turn out to be significant, and one immediate consequence is that erecting or dismantling a building or a group of buildings could change the seismic hazard for the neighborhood. This leads to significant conceptual changes, especially concerning seismic micro zonation studies, land-use planning, and insurance policies. The basic concept of SSI is visualized in Figure 8.

Figure 8: SSI Model



The most common soil-structure interaction SSI approach, used for three dimensional soil-structure systems, is based on the "added motion" formulation (Clough, 1993). This formulation is mathematically simple, theoretically correct, and is easy to automate and use within a general linear structural analysis program. In addition, the formulation is valid for free-field motions caused by earthquake waves generated from all sources. The method requires that the free-field motions at the base of the structure be calculated prior to the soil structure interactive analysis.

CONCLUSION

It can be evaluated from the above review that various factors such as height of wall, internal friction, and type of soil were considered in the design of reinforced earth wall yet it has shown considerable amount of damage in earthquake so it becomes important to study the effect of soil structure interaction in the analysis of reinforced earth wall to resist against the earthquake load. Thus soil structure interaction becomes vulnerable in the analysis of reinforced earth wall.

Various seismic parameters along with soil structure interaction has to be consider in the design of reinforced earth wall. Changing the different parameters of reinforced earth wall can lead to the efficient design but the effect of soil structure interaction can't be neglected.

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