
Study on Permanent Displacement of Slopes and Retaining Walls Subjected to Seismic Force

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Abstract

Slopes and retaining walls are widely used for roads, railways, river training works, canal works, dam etc. The economy and safety of these earth-retaining structures can be accomplished by adopting proper methods of design, construction and maintenance. The failure of these structures is likely to result in huge loss of life and damage to property. In the present work, an attempt has been made to estimate the permanent displacement of the slopes and retaining walls from pseudo static approach. MATLAB is used as a tool and programs are developed. To evaluate permanent displacement of slopes and retaining walls considering factors such as height of slope, inclination of slope, cohesion of soil and density of soil. Newmark's method, the popular method of analysis has been used and parametric studies have been carried out. To calculate permanent displacement of retaining walls, Richards-Elms method has been adopted. In addition, Newmark's method has been modified to suit the requirements of retaining walls. The present work has been carried out in three stages. In the first stage, a program has been developed in MATLAB to evaluate the permanent displacement of slopes using Newmark's approach. For this purpose, pseudostatic analysis has been carried out considering the effect of height of slope, inclination of slope, cohesion of soil, density of soil on the yield acceleration. The effect of input motion on the permanent displacement has been brought out by considering different earthquake motions, In the second stage of work, importance is given to the development of a computer program for the evaluation of permanent

displacement of retaining walls using Richards-Elms approach. For this purpose, yield acceleration that develops under the given soil properties, mobilized earth pressure and geometry of retaining wall were determined by iterative procedure. A parametric study has been made to consider the effect of various factors influencing the permanent displacement of retaining walls such as geometry of wall, properties of backfill soil, condition of soil and soil and wall interaction angle. In the last stage, an attempt has been made to modify the Newmark's approach to suit the retaining wall problem. For this purpose, a combination of analysis using Richards-Elms method to calculate yield acceleration and Newmark's method to estimate permanent displacement from the data of earthquake motion and yield acceleration as in the analysis of slopes has been incorporated. A comparison is made with Richards-Elms approach. From the present work, it has been brought out that Newmark's method gives more realistic results as Richards-Elms approach is an empirical relation and Newmark's approach considers the region of the earthquake motion above the yield acceleration more accurately.

Keywords-: *slopes; retaining walls; Earth-retaining structures; Design; Displacement; Pseudostatic approach; MATLAB; Program development; Newmark's method; Richards-Elms method; Yield acceleration; Cohesion of soil Earthquake motions.*

INTRODUCTION

There are frequent landslides everywhere in the world. Although landslides occasionally happen on slopes created by humans, they frequently happen on natural slopes. The slopes might be in states ranging from extremely stable to barely stable at any given time. When an earthquake happens, the ground shaking that is caused by the earthquake is frequently enough to cause slopes that were just slightly to moderately stable before the earthquake to fail.

Northern India's Garhwal Himalayas experienced an earthquake on October 20, 1991, around 2.53 a.m. local time. The Uttar Pradesh districts of Uttarkashi, Tehri, and Chamoli experienced significant ground shaking as a result of the earthquake. Based on body wave data, the Indian Meteorological Department (IMD) determined the earthquake's magnitude to

be 6.1. Surface waves were given a magnitude of 7.1 by the USGS. Due to the disintegration of slopes, retaining walls, and bridges, the area's roads sustained considerable damage.

Due to many landslides and the collapse of a significant bridge, the road link between Uttarkashi, Harsil, and Nelong was entirely shut down for several days. The embankment on the approach road to the bridge at Kishanpur collapsed, cutting off the road connection between Uttarkashi and Lumgaon. The Uttarkashi-Harsil road had numerous sizable landslides, particularly in a 42 km section between Uttarkashi and Bhatwari. According to Sudhir et al. (1992), the maximum horizontal ground acceleration in the area was at 0.30 g.

On September 21, 1999, Taiwan had the Ji-Ji or Chi-Chi Earthquake, which had a Richter magnitude of 7.3. At a depth of 7 km, the primary shock was detected in central Taiwan at 23.87 N and 120.75 E. The Chelungpu fault ruptured, causing the earthquake. More than 19 (9.81 m/s²) was the highest value of peak horizontal ground acceleration ever measured. The vertical to horizontal acceleration ratio was extremely high. Close to the fault, numerous slopes and retaining-wall systems collapsed. (2005) Hoe et al.

Several distinct types of retaining walls for railway embankments were destroyed to varying degrees during the 1995 Hyogoken-Nanbu earthquake in Japan. Complete overturning or severe tilting were regular problems for gravity type retaining walls. Conversely, the amount of tilting in cantilever-style retaining walls was less severe. However, one cantilever-style retaining wall supporting sloped backfill had substantial tilting and severe cracking, it should be highlighted. (1995; Koseki).

The failure of the slope and retaining wall in the aforementioned examples due to an earthquake highlights the necessity of designing structures to be earthquake resistant, especially slopes and retaining walls since they act as lifelines in such situations. Undoubtedly one of the most crucial aspects of geotechnical earthquake engineering is the evaluation of seismic slope stability. A thorough study of slope stability must take into account each of the various elements that affect slope stability. The stability of a given slope is influenced by geological, hydrological, topographical, geometrical, and material properties.

Designs for retaining walls, earth dams, abutments, foundations, etc. are major

geotechnical engineering issues. The force equilibrium based pseudo-static analysis, pseudodynamic analysis, and displacement based sliding block methods are the most often used techniques for designing retaining structures under seismic circumstances. To calculate the earth forces and their point of application in the construction of such retaining structures, knowledge of earth pressures under active and passive situations is essential. When analysing an earth dam utilising a pseudo static seismic force analysis method, slope stability is mostly utilised. The pseudo-static methodology is typically used to study the seismic stability of earth retaining structures. In this method, the impacts of earthquake forces are described as constant horizontal and vertical accelerations related to the inertia. The current method for designing geotechnical constructions is gradually moving away from a strength-based method and towards a displacement-based method. In this context, it's crucial to assess the permanent displacement of geotechnical structures under various loading scenarios. As a result, the proposed study has a lot of value in the current debate

IMPORTANCE OF THE PRESENT STUDY

Numerous case studies of retaining walls and slopes failing as a result of earthquakes can be found in a variety of literature around the globe. The failure of waterfront buildings in the Port of Kobe during the 1994 Hyogo-ken Nambu earthquake in Japan and the failure of the upstream slope of the Lower San Fernando Dam during the 1971 San Fernando Earthquake are two of the more well known examples among them. Because of the quick cyclic nature of the ground motion, earth-retaining structures and soil slopes must be able to sustain cyclic inertial stress in addition to other permanent and incidental loads for satisfactory performance during an earthquake

Pseudo static, pseudo dynamic, and comprehensive dynamic methods are frequently used to examine the performance of the slope stability during an earthquake or dynamic excitation. For various horizontal earthquake coefficients (k_s), the factor of safety is determined using the pseudo static method. For a rigid block sliding on an inclined plane, the predicted displacement obtained from the integration of the equation of motion is evaluated using Newmark's approach. The predicted displacements resulting from the soil mass's stress-strain relationship are calculated using numerical techniques. Newmark's method has become standard procedure due to the rough approximation of the pseudostatic approach and the sensitivity of input parameters required for numerical techniques. Given the frequency of

seismic events leading to the failure of retaining walls and slopes, as well as the need for further improvements. In numerous case studies conducted around the world, failures of retaining walls and slopes during earthquakes have been thoroughly recorded. Examples of notable failures include the waterfront buildings in the Japanese port of Kobe that collapsed during the 1994 Hyogo-ken Nambu earthquake and the Lower San Fernando Dam's upstream slope that failed during the 1971 San Fernando earthquake. Earth-retaining structures and soil slopes must be able to endure cyclic inertial loads brought on by the quick and cyclic nature of ground motion, in addition to other permanent and incidental stresses, to ensure satisfactory performance during earthquakes.

Three methods are generally used to analyze the stability of slopes during earthquakes: pseudostatic, pseudo dynamic, and comprehensive dynamic methods. The pseudostatic technique evaluates various horizontal earthquake coefficients (k_h) to find the factor of safety. It is usual practice to assess predicted displacements using Newmark's approach, which integrates the equation of motion for a stiff block sliding on an inclined plane. Expected displacements are calculated using numerical methods that rely on the stress-strain relationship of the soil mass. Newmark's method is still frequently used in spite of the shortcomings of the pseudostatic approach and the sensitivity of the input parameters needed for numerical approaches. The current work is very relevant given the frequency of seismic events leading to slope and retaining wall failures and the need for better analysis techniques.

OBJECTIVES OF THE STUDY

The objective of the present work are divided into two broad groups and are mentioned as given below

Slopes

1. To estimate the possible permanent displacement of the slope.
2. To study the influence of yield acceleration on parameters such as cohesion, density, angle of internal friction of soil media and height of slope.
3. To study the effects of motion parameters, k_h and k_v on the behaviour of slopes.

Retaining walls

1. To estimate the possible permanent displacement of retaining walls under seismic loads using Richards-Elms approach.

2. To study the influence of different, backfill slopes, soil properties, backfill with water and without water, etc.
3. To develop an algorithm to evaluate permanent displacement of retaining wall by modifying Newmark's method adopted for slopes.
4. To compare the permanent displacement obtained from Richard-Elms method with those from modified Newmark's method.

Procedure used to reduce stiffness from initial value, G_r to final value, G_r , in Stiffness reduction approach

The following are some of the shortcomings of the present study.

- Analysis is carried out considering homogeneous slopes and embankments.
- In present study, effect of groundwater table and seepage is not considered for slopes.
- Pseudostatic approach is used to estimate earth pressure.
- Comparison with actual displacement during earthquake is missing.

SEISMIC PERFORMANCE OF SLOPES AND RETAINING WALLS

SLOPES

An unrestrained slope refers to an exposed ground surface that is inclined with respect to the horizontal plane. This slope can occur naturally or be created by human activities. When the ground is not level, the force of gravity exerts a downward influence on the soil. If this gravitational force exceeds a certain threshold, it can lead to the failure of the slope

Types of Slopes

Slopes are of two types,

Infinite Slope: An infinite slope is one where the soil parameters are constant at all identical depths below the surface and the slope represents the boundary surface of a semi-infinite soil mass. In nature, there are no infinitely steep slopes.

Finite Slope: A slope is referred to as finite if its range is restricted. The incline faces of earth dams, embankments, and cuts are examples of limited slopes.

Slope Failures

Slope failures are caused, in general, by natural forces, human misjudgment and activities, and burrowing animals, following are some of the main factors that provoke slope failures.

Erosion

Both natural and artificial slopes are continually eroded by wind and water. Erosion alters the slope's shape, which ultimately leads to slope failure. Rivers and streams continuously undermine the slopes of their banks, whether they are man-made or natural.

Rainfall

Long periods of rainfall saturate, soften, and erode soils. Water enters into existing cracks and may weaken underlying soil layers, leading to failure.

Geological Feature

Unknown geological factors frequently cause several failures. Drilling operations may easily ignore a narrow seam of silt beneath a thick layer of clay, or one may be negligent when examining borehole logs, only to discover later that the silt's presence was what ultimately led to a disastrous failure. Sloping, layered soils are more likely to slip along weak strata during translation. When evaluating slope stability, geological features must be taken into consideration.

External Loading

Loads put on a slope's crest increase the gravitational stress and increase the risk of slope failure. The stability of the slope will be improved by a weight known as a berm placed at the toe.

Construction activities

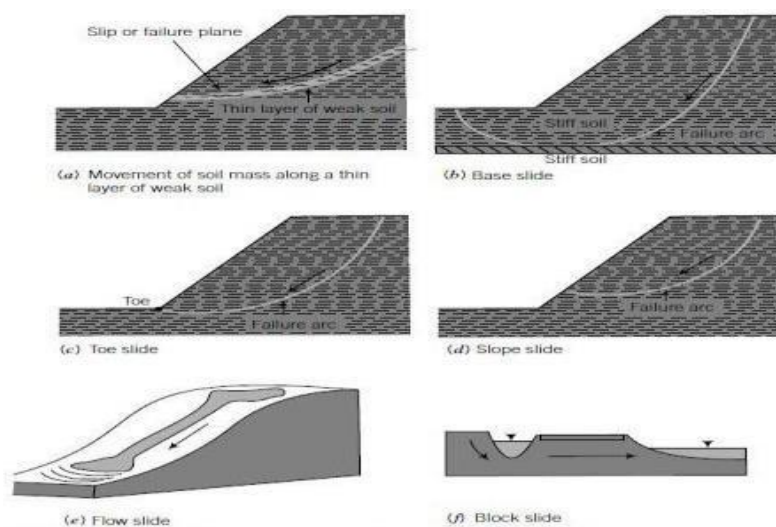
Because lateral resistance is reduced while construction is underway close to the toe of an existing slope, failure may result. Slope failures brought on by construction activity can easily be divided into two categories. Excavated slope is the first type of slope, and fill slope is the second.

A dynamic force is produced by an earthquake, particularly a dynamic shear force, which weakens the soil's shear strength and stiffness. A condition known as dynamic liquefaction occurs when the pore pressure in saturated coarse grained soil reaches a level equal to the total mean stress and causes these soils to behave like viscous fluids. Buildings built on these soils would crumble, while those buried within them would rise. Even coarse grained soils cannot drain the extra pore pressures due to how quickly the dynamic forces are created. Thus, failure in a seismic event frequently happens in untrained circumstances.

The failure of a finite slope is assumed to be along a curved surface. For computations, this curve is assumed to be represented by an arc of a circle or logarithmic spiral (Punmia 1994). The basic types of failure of a finite slope are:

1. Slope failure
2. Base failure.

A failure of an embankment is referred to as a slope failure when it happens along a surface of sliding that intersects the slope at or above its toe. If the arc crosses above the toe of the embankment, the slope fails, which is also known as a face failure (Fig. 2.1a). If the arc goes across the toe, slope failure is known as toe failure (Fig. 2.1 b). Base failure is the term used to describe the collapse of slopes that occur over a surface that runs some distance below the toe of the embankment when the soil mass underneath the toe of the embankment is weak (Fig. 2.1 c). Depth factor D_f is the proportion of depth H to the total depth $(H+D)$.



Slope failure

Fig 2.1 Types of finite slopes

Requirements for the Analysis and Design of Slopes

The qualities of the slopes' materials, stresses brought on by the chosen slopes, placement techniques, and pore water pressures brought on by soil consolidation are the main elements affecting slope stability. Slope analysis is divided into two parts:

- The identification of the internal surface that is under the greatest shearing stress, the extent of the shearing stress to which it is subjected, and the shearing strength along this surface. The unit weight of the material and the slope's geometry determine the shearing stress that can be applied to any slope, and the type of soil, the density, and the drainage conditions determine the shearing strength that can be mobilized to withstand the shearing stress.

SLOPE STABILITY

Undoubtedly one of the most crucial aspects of geotechnical earthquake engineering is the evaluation of seismic slope stability. Numerous factors, including geological, hydrological, topographical, geometrical, and material qualities, affect how stable a given slope is. When the shear forces necessary to maintain equilibrium reach or exceed the available shearing resistance on a probable failure surface, slopes become unstable. The additional dynamic stresses needed to cause instability may not be as great on slopes where the shear stress needed to maintain equilibrium under static gravitational loading is substantial. As a result, the slope's static stability has a significant impact on its seismic stability.

The methods for analysing the stability of a slope under static conditions are widely known. Currently, the most popular techniques for static slope and stress deformation analysis.

Limit equilibrium analysis

Analysis of limit equilibrium takes into account the equilibrium of force and/or moment for a mass of soil above a potential failure surface. It is assumed that the soil is stiff above the possible failure surface. All sites on the possible failure surface are considered to experience the same rate of mobilization of the available shear strength. A popular statistic used to quantify slope stability is the factor of safety (FS), which is typically defined as

$FS = \frac{\text{Available shear strength}}{\text{Shear strength required for equilibrium}}$

Stress-deformation analysis

The finite element approach is most frequently used to perform stress deformation analyses, which allow consideration of the stress-strain behaviour of soil and rock. Stress-deformation analysis can be used to forecast slope stresses, motions, and pore pressure before, during, and after construction or deposition. Modern finite element analysis may take into account non-linear stress-strain behaviour, complex boundary conditions, irregular geometries, and a range of construction techniques.

SEISMIC SLOPE STABILITY ANALYSIS

It is difficult to examine the seismic stability of slopes since you have to take earthquake shaking's effect on dynamic stress into consideration. The consequences of these pressures on the slope materials' strength and behaviour under stress and strain.

There are two types of seismic slope instabilities.

1. Inertial instabilities, where slope deformations are caused by momentarily exceeding the strength by dynamic seismic pressures while the soil's shear strength stays mostly unchanged.
2. Weakening instabilities occur when an earthquake weakens the soil to a point where it can no longer withstand the forces brought on by an earthquake.

Analysis of Inertial Instability

Significant horizontal and vertical dynamic stresses are created on slopes by earthquake motion. Along the slope's probable failure surfaces, these stresses result in dynamic normal and shear stresses. The dynamic shear pressures may be greater than the soil's available shear strength when added to the static shear forces that already existed, causing the slope to become inert. Similar to how static limit equilibrium analysis develops factors of safety against static slope failure, pseudostatic analysis generates a factor of safety against seismic slope failure. The other methods all make an effort to assess the long term slope displacements brought on by earthquake shaking.

Pseudostatic analysis:

A pseudostatic approach has been used to analyse the seismic stability of earth structures, where the impact of an earthquake is represented by a constant horizontal and/or vertical

acceleration. Pseudostatic analysis (figure 2.2) represents the influence of an earthquake shaking by producing inertial forces (F_h and F_v) that act through the centroid of the failure mass. Quantities of pseudostatic forces are

$$F_h = \frac{a_h \cdot W}{g} = k_h \cdot W$$

$$F_v = \frac{a_v \cdot W}{g} = k_v \cdot W$$

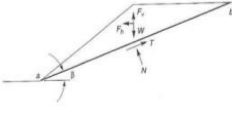
$$FS = \frac{c l_{ab} + [(W - F_v) \cdot \cos(\beta) - F_h \cdot \sin(\beta)] \cdot \tan(\phi)}{(W - F_v) \cdot \sin(\beta) + F_h \cdot \cos(\beta)}$$


Fig2.2 Force acting on triangular wedge

W is the weight of the failure mass and coefficients. The severity of the predicted ground motion should be correlated with the magnitudes of the pseudostatic accelerations. the forces acting on the mass that might fail being resolved parallel to the failure surface.

where l_e is the length of the failure plane and c and d are the Mohr-coulomb strength parameters. The horizontal pseudostatic force increases the driving force while decreasing the resistive force and safety factor. The factor of safety is less affected by the vertical pseudostatic force.

Calculating the overturning and resisting moments for static and pseudostatic circumstances is necessary for determining the factor of safety. For static situations, the weight of the soil above the failure surface causes the overturning moment. The sum of the overturning moment for static conditions and the overturning moment brought on by pseudostatic forces is the overturning moment for pseudostatic conditions.

The seismic coefficient k affects the pseudostatic coefficients' findings. The magnitude of the inertial force created in the potentially unstable material should be related to some measure of the seismic coefficient's value since it regulates the pseudo static force on the failure mass. The inertial force exerted on a hypothetical slide would be equal to the product of the actual horizontal acceleration and the mass of the unstable material if the slope material were rigid. When the horizontal acceleration reaches its maximum magnitude, this inertial force will also reach its maximum value.

When choosing a pseudo static co-efficient for design, there is no set formula. The pseudo static coefficient should, it seems obvious, be dependent on the actual anticipated level of acceleration in the failure mass and should correspond to some fraction of the predicted peak acceleration

To investigate the impact of k_v , different values of k were used in the current work. If the place is close to the epicenter, K is calculated as $k_e - 1/3km$.

Newmarkslidingblockanalysis

The pseudostatic method of analysis provides an index of stability but no information on deformation associated with slope failure. Since the serviceabilityof a slope after an earthquake is controlled by deformations, analysis that predict slope displacement provide a more useful indication of seismic slope stability. Since earthquake induced accelerations vary with time, the pseudostatic factor of safety will vary throughout an earthquake.

If the inertial forces acting on a potential failure mass become large enough that the total driving forces exceed the available resisting forces, the factorof safety will drop below 1.0. Newmark considered the behavior of slope under such conditions. When the factor of safetyis less than 1.0, the potential failure mass is no longer in equilibrium; consequently, it will be accelerated by the unbalanced force. The situation is analogous to that of a block resting onan inclined plane. Newmark used this analogy to develop a method for prediction of the permanent displacement of a slope subjected to any ground motion (Fig. 2.3).

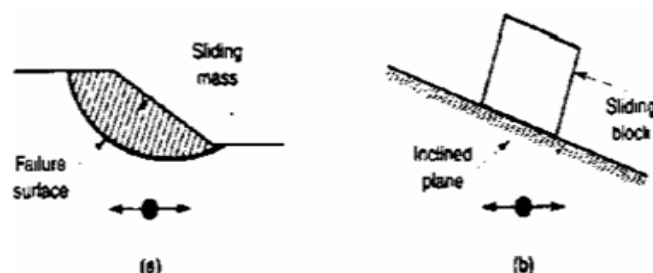


Fig2.3Newmark'sslidingblockconcept

Assuming the block's resistance to sliding is solely frictional, consider the block in stable, static equilibrium on the inclined plane. Equilibrium of the block requires that the available static resisting force, R_s , surpassed the static driving force, D_s

$$FSd(t) = \frac{\text{Available resisting force}}{\text{pseudostatic driving force}} = \frac{R_d(t)}{D_d(t)} = \frac{[\cos \beta - k_h(t) \sin \beta] \tan \phi}{\sin \beta + k_h(t) \cos \beta}$$

Fig2.4 Force acting on the block in Newmark's method

Here is the angle of friction between the block and the plane. Now consider the effect of inertial forces transmitted to the block by horizontal vibration of the inclined plane with acceleration $a_s(t) = k_a(t)g$ the effect of vertical acceleration is neglected for simplicity. At a particular instant of time, horizontal acceleration of the block will induce a horizontal inertial force, $k_h W$ when the inertial force acts in the down slope direction, resolving forces perpendicular to the inclined plane gives The dynamic factor of safety decreases as k_h increases and there will be some positive k_h that will produce a factor of safety of 1.0. This coefficient, termed as yield coefficient, k_y , corresponds to the yield acceleration, a_y , $k_y g$. The yield acceleration is the minimum pseudostatic acceleration required to produce instability of the block. It is given by

$$k_y = \tan(\phi - \beta) \qquad k_y = \frac{\tan(\phi - \beta)}{1 + \tan \phi \tan \beta}$$

When a block is on inclined plane and is subjected to a pulse of acceleration that exceeds the yield acceleration, the block will move relative to the plane. To illustrate the procedure by which the resulting permanent displacements can be calculated, consider the case in which and inclined plane is subjected to a single rectangular acceleration pulse of amplitude A and duration Δt . if the yield acceleration, a_y , is less than A , the acceleration of the block relative to the plane during the period from t_0 to

$$a_{rel} = a_b(t) - a_y = A - a_y \qquad t_0 \leq t \leq t_0 + \Delta t$$

Whereas is the acceleration of inclined plane. The relative moment of the block during this period can be obtained by integrating the relative acceleration twice that is

$$v_{rel}(t) = \int_0^t a_{rel}(t) dt = [A - a_y](t - t_0) \qquad t_0 \leq t \leq t_0 + \Delta t$$

$$d_{rel}(t) = \int_0^t v_{rel}(t) dt = \frac{1}{2} [A - a_y](t - t_0)^2 \qquad t_0 \leq t \leq t_0 + \Delta t$$

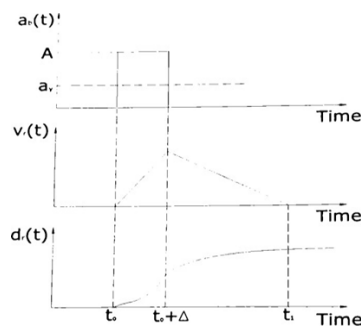


Fig2.5 Variation of relative velocity and relative displacement between sliding blocks and plane due to rectangular pulse that exceeds yield acceleration

Makdisi-Seed Analysis

Makdisi and Seed used average accelerations computed by the procedure of Chopra and sliding block analysis to compute earthquake-induced permanent deformations of earth dams and embankments. By making simplifying assumptions about the results of dynamic finite element and shear beam analysis of such structures, a simplified procedure for prediction of permanent displacements was developed. In this simplified procedure, the yield acceleration for a particular potential failure surface is computed using the dynamic yield strength of the soil.

Stress-Deformation Analysis

Similar to how static finite element analysis is typically used for stress deformation analyses of static slope stability, dynamic finite element analysis is typically used for stress-deformation analyses of seismic slope stability. In this approach, the permanent deformation of the slope is obtained by integrating the seismically induced permanent strains in each element of the finite element mesh. Different methods can be used to assess permanent strains inside certain elements. The stiffness of soils due to seismic loading is determined using laboratory test data utilizing the strain potential and stiffness reduction methodologies. In nonlinear analytic methods, the behaviour of the soil's nonlinear inelastic stress-strain relationship is used to calculate how permanent strains form throughout the course of an earthquake.

(a) Strain Potential Approach

In this method, the cyclic shear stresses are computed in each element of a dynamic finite-element analysis. Using the results of cyclic laboratory tests, the computed cyclic shear

stresses are used to predict the strain potential, expressed as a shear strain, for each element. Deformations are then estimated as the product of the average strain potential along a vertical section through the slope and the height of that section. The method implicitly assumes that the strains that develop in the field will be the same as those that develop in a similarly loaded laboratory test specimen and that the maximum shear stress acts in the horizontal direction in all elements.

(b) Stiffness Reduction Approach

Another method for estimation of permanent slope displacement was developed by Lee and Serff et. al. In this approach, computed strain potentials are used to reduce the stiffness of the soil as shown in Fig. 2.6 Earthquake-induced slope displacements are then taken as the difference between the nodal point displacements from two static finite- element analysis: one using the initial shear moduli and the other using the reduced shear moduli. The technique can be used with linear or nonlinear models. Unlike the strain potential approach, the stiffness reduction approach can estimate vertical as well as horizontal movements. It is an approximate procedure and is subject to many of the limitations of the strain potential approach. Work-energy principles can be used to provide a more fundamental procedure for stiffness reduction.

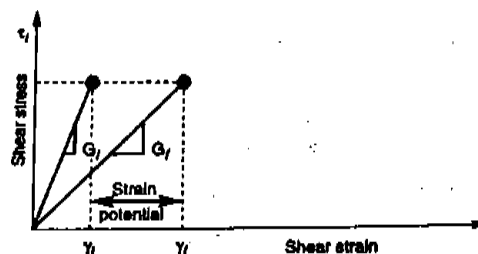


Fig.2.6: Procedure used to reduce stiffness from initial value, G_i to final value, G_r , in Stiffness reduction approach

Retaining wall

Designing retaining walls, earth dams, abutments, and other geotechnical engineering issues are crucial issues. Researchers pay close attention to the calculation of earth pressures and the point of applications to lessen the destructive impact of earthquakes on retaining structures. The force equilibrium based pseudo static analysis is the technique that is most frequently used to design retaining structures in seismic circumstances. Retaining walls fall into one of two categories. One is a concrete wall that is stiff and depends on gravity for stability. Cast-in-place gravity and semi-gravity walls are what these are known as. The other class, which is

flexible and made up of long, thin components made of steel, concrete, or wood, depends on anchoring and passive soil resistance for stability.

Rankine Theory

The easiest method for calculating the lowest and maximum passive earth pressures was created by Rankine. By assuming certain things about the soil's strength envelope and stress conditions behind a retaining wall Rankine stated the pressure at a spot on the rear of a retaining wall for the least active situations.

Coulomb Theory

The issue of lateral earth pressures on retaining structures was initially investigated by Coulomb. In order to calculate the size of the soil thrust acting on the wall for both the minimum active and maximum passive conditions, Coulomb employed force equilibrium. He used the assumption that the force pressing on the rear of a retaining wall was caused by the weight of a wedge of soil above a planar failure surface. The active thrust on a wall holding a cohesionless soil.

Seismic Pressure on Retaining Walls

Retaining wall seismic design entails determining if the wall can withstand the loads placed on it during an earthquake shaking. It is quite difficult to predict how exactly retaining walls will be loaded during earthquakes. Typically, simplified techniques are used to assess the seismic stresses on retaining walls.

Yielding Walls

Yielding walls are retaining structures that can flex enough to create either the lowest active or highest passive earth pressures. Pseudo static methods are typically used to estimate the dynamic pressures acting on yielding walls.

a) Mononobe Okabe Method Okabe, Mononobe, and Matsuo added the effects of dynamic earth pressures on retaining walls to Coulomb's notion of static active and passive earth pressures. The soil mass that makes up Coulomb's active wedge (or passive wedge) within the backfill is subjected to a constant horizontal acceleration in units of g , a_h kg , and a constant vertical acceleration in units of g , a_v kg , according to the Mononobe-Okabe hypothesis.²⁷ As with Coulomb's active and passive earth pressure theories, the

Mononobe Okabe theory makes the assumption that the wall movements are sufficient to fully mobilize the shear resistance along the backfill wedge. The wall movements are towards the backfill for the passive dynamic earth pressure force, P_r , and away from the backfill for the dynamic active earth pressure force, P_A . The net static and dynamic force is presented by the Mononobe-Okabe hypothesis. Positive $k > 0$ results in P_A larger than static P and P_r smaller than static P_r .

Non-yielding Walls

Massive gravity walls supported by rock or basement walls braced at the top and bottom are examples of retaining structures that do not move enough to mobilize the shear strength of the backfill soil. Therefore, neither the minimum active nor maximum passive earth pressures can be reached. Wood examined how a homogenous, linear elastic soil would react when it was imprisoned between two stiff walls that were attached to a rigid base. The forces on one wall won't be much impacted by the existence of the other if the two walls are considered to be far apart. Wood demonstrated that for motions occurring at less than half the fundamental frequency of the uncontrolled backfill, dynamic amplification was insignificant.

Richards-Elms Method

A approach for the seismic design of gravity walls based on permitted permanent wall displacements was suggested by Richards and Elms. To do this, the yield acceleration for the wall-backfill system must be assessed. The resulting inertial forces will act away from the backfill when the active wedge is subjected to acceleration acting towards the backfill. The yield acceleration is the magnitude of acceleration just great enough to have the wall slide on its base.

Modified Newmark's Approach

Newmark's approach is modified in the present analysis to suit the retaining wall. Here, Richards-Elms method is used to calculate yield acceleration and Newmark's approach to estimate permanent displacement for the data of earthquake motion.

SEISMIC PERFORMANCE OF SLOPES AND RETAINING WALLS

SLOPES an inclined surface exposed to the ground is referred to as a slope. Slopes can occur naturally or be man-made. When a slope is not horizontal, the force of gravity tends to move

the soil downwards. If this force is sufficiently large, slope failure can occur. 4.1.1 Types of Slopes Slopes can be classified into two types: Infinite Slopes and Finite Slopes. Infinite slopes are boundary surfaces of semi-infinite soil masses, assuming constant soil properties at identical depths below the surface. However, truly infinite slopes do not exist in nature. Finite slopes, on the other hand, have limited extents and include inclined faces of earth dams, embankments, and cuts. Slope Failures Several things, including natural forces, human actions and poor judgements, and burrowing animals, can be blamed for slope collapses. The following are some of the major causes of slope failures.

1. Erosion: Both natural and artificial slopes are continuously eroded by wind and water, changing their shape and eventually causing failure. Slope failure can result from river and stream banks being undermined in particular..
2. Rainfall: Rainfall that lasts for a long time saturates and softens the soil, possibly causing it to erode. The risk of a slope failing is increased when water seeps into already- existing fissures and weakens the underlying soil layers.
3. Geological Features: Slope failures frequently result from unidentified geological characteristics. For instance, during drilling operations, a thin layer of silt beneath a thick layer of clay can be disregarded, leading to a catastrophic breakdown later. Because sloping, stratified soils are more likely to translate along weak strata, geological factors must be taken into account while evaluating.
4. External Loading: Extra weight on a slope's crest or toe might increase the gravitational pressure and perhaps lead to slope failure. Slope stability can be improved by using a berm, which is a load placed near the toe.
5. Construction Activities: When construction takes place close to the toe of an existing slope, lateral resistance might be disrupted, which can cause slope failure. Both fill slopes and excavated slopes are susceptible to failure.
6. Earthquake: Earthquakes produce dynamic forces, such as dynamic shear forces, which weaken soil's shear strength and stiffness. Increased pore pressure in saturated coarse-grained soils can lead to dynamic liquefaction. Due to sudden and induced dynamic stresses, structures on these soils may collapse, while subsurface structures may rise. A curved surface is often thought to be where a finite slope fails. Depending on where the failure surface is in respect to the slope, these failures can be categorized as base failures or slope failures (face failures or toe failures). The shearing strength along the interior surface that is under the most severe stress must be determined for the slope stability

study. Properties of slope materials, stress arising from slope geometry and placement techniques, and pore water pressures resulting from soil consolidation are all factors that affect slope stability.

SLOPE STABILITY

One of the most important aspects of geotechnical earthquake engineering is evaluating the seismic stability of slopes. Numerous elements, such as geological, hydrological, topographical, geometrical, and material features, have an impact on slope stability. When the shear forces necessary for equilibrium are greater than the available shearing resistance along possible failure surfaces, slopes become unstable. Since dynamic forces from earthquakes are added to pre-existing static shear stresses, slopes' static stability has a significant impact on their seismic stability. Limit equilibrium analysis and stress-deformation analysis are two frequently used techniques for analysing slope stability. The force and/or moment equilibrium of a soil mass above a probable failure surface is taken into account by limit equilibrium analysis. Typically, slope stability is described using a factor of safety (FS), which compares available shear force to the shear force necessary for equilibrium. The examination of soil and rock behaviour, including stress-strain connections and construction activities, is possible with stress-deformation analysis, which is frequently carried out using the finite element method.

SEISMIC SLOPE STABILITY ANALYSIS

Because dynamic forces brought on by earthquake shaking must be taken into consideration, assessing the seismic stability of slopes is complicated. Earthquake motions provide considerable horizontal and vertical dynamic stresses in slopes, which lead to inertial instability. When paired with the slope's already-existing static shear loads, these stresses may be too great for the slope's limited shear strength, causing slope failure. While Newmark sliding block analysis predicts that earthquake shaking will result in permanent slope displacement, pseudo static analysis simulates earthquake shaking using constant horizontal and/or vertical accelerations. Seismic slope stability analysis seeks to assess the stability and potential displacements of slopes under earthquake conditions by taking into account elements including inertial forces, pore water pressures, and the dynamic response of slopes. Different forces, such as seepage, mass factors, and other forces, affect the stability of slopes. It is crucial to take into account the geological, hydrological, topographical, geometrical, and

material aspects unique to each slope in order to determine slope stability effectively. In this work, we use Newmark's sliding block idea to determine the slopes' permanent displacement. A MATLAB programme has been created to accomplish this using the approach shown in Figure 4.1. A parametric analysis has also been carried out to look at the impacts of slope height, slope angle, soil cohesiveness, and soil density.

FLOWCHART

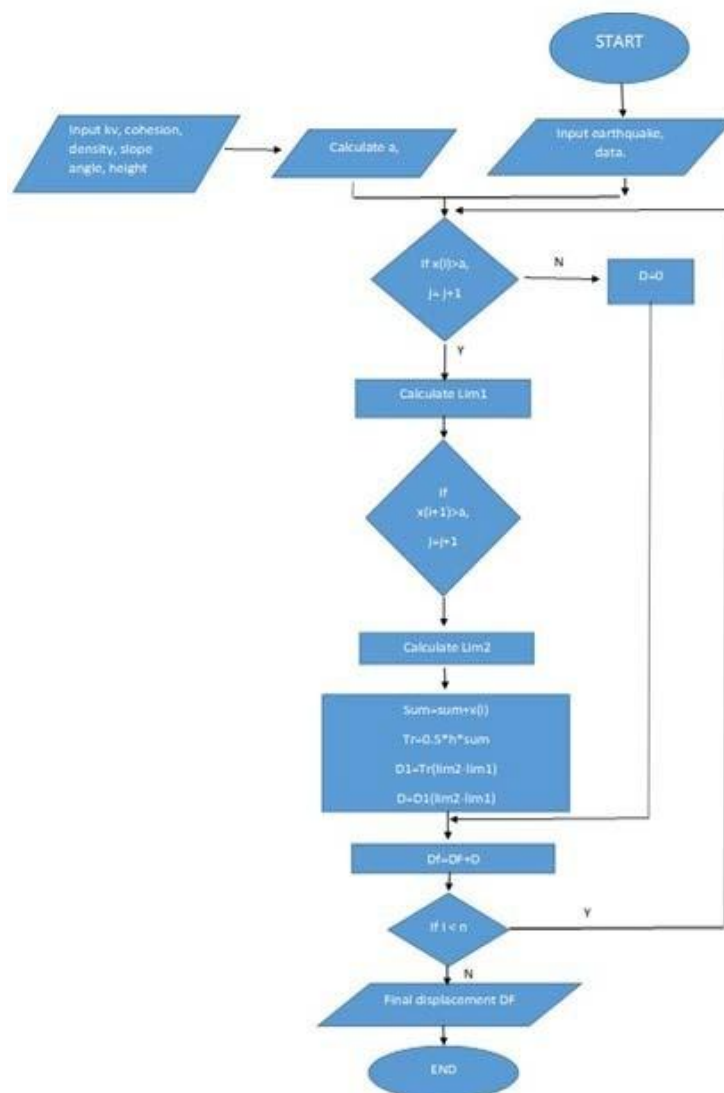


Fig3.1.Presents the flowchart for the determination of permanent displacement of slopes using Newmark's approach

VALIDATION

For a slope with the following details subjected to a sine wave of amplitude 0.5m/s² and period 0.55 second as shown in Fig., a manual calculation has been done in order to

understand the performance of the MATLAB programme, and a comparison between the two ways is presented in Table.

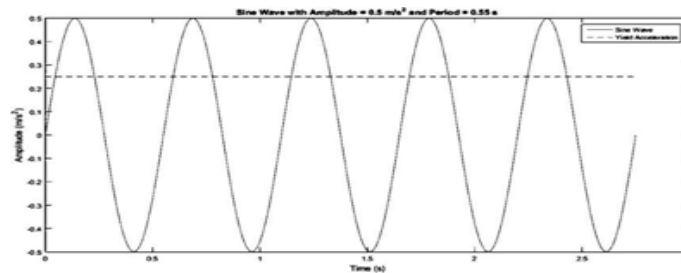


Fig3.2 Sinewave validation of MATLAB

Table3.1 Comparison between the MATLAB program and Manual calculation

PROBLEM NO		MANUAL CALCULATION	PROGRAM	%VARIATION
	Area of hatched portion in fig-4.1	0.03100	0.02989	3.56452
	Limit 1(s)	0.09620	0.09624	-0.04667
1	LIMIT 2(s)	0.27717	0.27698	0.06746
	Relative velocity (m/s)	0.00561	0.00540	3.74451
	Relative displacement (m)	0.00101	0.00098	3.31099

The above variation of about 3% maybe attributed to the fact that the area of hatched portion in time history of acceleration is not calculated accurately by manual calculation.

PARAMETRIC STUDY

In the current study, the focus was on examining how the yield acceleration varies when different parameters, such as density of soil, cohesion of soil, height of slope, and angle of internal friction of soil, are changed. The research employed various material properties to investigate these variations.

EFFECT OF DENSITY OF SOIL

The impact of soil density on slope stability was investigated by varying the density between 12 kN/(m³) and 24 kN/(m³). The weight of the soil per volume, or density, has a big impact on the stability of the slope. The chance of a slope failing by displacement rises as density rises because the weight of the soil in the wedge likewise rises. In order to show the link between soil density (horizontal axis) and yield acceleration (vertical axis) for various

situations, such as $k=0$, $k_v=1/3*k_h$, and $k_v=1/2+k_h$, graphs were created. The findings showed that yield acceleration decreased as density increased. When these graphs are combined, it becomes clear that the parameter k decreases yield acceleration, which in turn decreases resistance to motion and slope stability.

EFFECT OF ANGLE OF INTERNAL FRICTION

The effect of angle of internal friction was investigated by varying the internal friction angle of soil from 0° to 40° . The internal friction angle, which is one of the shear parameters and influenced by various factors such as geological and geotechnical aspects, plays a crucial role in slope stability analysis. Graphs were plotted to depict the relationship between the angle of internal friction (horizontal axis) and yield acceleration (vertical axis) for different conditions, including $k=0$, $k=1/3*k_h$, and $k=1/2*k_h$. The findings indicated that the yield acceleration increases with an increase in the angle of internal friction. Combining these graphs, it was observed that the influence of k on slope stability is negligible up to an angle of internal friction of $4-15^\circ$, beyond which the yield acceleration slightly decreases with an increase in k_v .

EFFECT OF COHESION OF SOIL

The effect of cohesion of soil on slope behavior was examined by varying the cohesion from 0 kN/m^2 to 100 kN/m^2 . Graphs were plotted to illustrate the relationship between cohesion of soil (horizontal axis) and yield acceleration (vertical axis) for different conditions, including $k=0$, $k=1/3*k_h$, and $k=1/2*k_h$. The results showed that as the cohesion increases, the yield acceleration also increases, indicating improved slope stability. In summary, the study investigated the variations in yield acceleration concerning changes in density of soil, angle of internal friction, and cohesion of soil. The findings highlighted the influence of these parameters on slope stability and provided insights into the behavior of slopes under different conditions.

PERMANENT DISPLACEMENT OF SLOPES

The permanent displacement of slopes on earth dams or embankments caused by earthquakes is estimated using Newmark's sliding block theory. Newmark reduced the sliding dirt mass to a stiff plastic block. Only when the ground acceleration surpassed the critical or yield acceleration of the soil mass was predicted for the block to move laterally. It was expected

that sliding would continue after it had started, with a constant acceleration equal to the critical acceleration, until the relative velocity between the sliding mass and the base was zero. The earthquake-induced displacement was calculated for a given ground acceleration time history and a known critical acceleration of the sliding mass by integrating the portions of the acceleration history above and below the critical acceleration until the relative velocity between the sliding mass and the ground decreases to zero.

This approach states that displacement occurs each time the critical value of ground acceleration is exceeded. Here, an effort was made to determine the slopes' permanent displacement for various strong motion data. Ground motion information from various earthquakes was employed for this purpose. Table 4.2 lists the characteristics of these earthquakes. The slopes that were taken into account for this analysis have the following characteristics.

Density of soil = 15 kN/m³ Cohesion of soil = 21 kN/m² Slope = 1 in 2.5 Height

of slope = 20 m

Angle of internal friction of soil = 25 deg

Characteristics of different earthquake ground motion

SL NO	1	2	3	4
Name of earthquake	Chichi	El-Centro	Gilroy	Kobe
Year	1999	1940	1989	1995
Richter Magnitude	6.2	7.1	6.9	7.2
Site	CHY014,N(CWB),	USGS STATION 117	CDMG STATION 47380	TAKARAZU STATION
Amax (m/s ²)	2.3123	2.8999	4.3411	3.5895
Vmax (m/s ²)	0.2048	0.2363	0.2669	0.6221
Dmax (m)	0.0657	0.1304	0.0805	0.2666
Duration(s)	140	40	39.94	40.95
Predominant frequency(Hz)	2.0142	1.4648	2.6855	0.5859
Permanent displacement(mm)	68.91	7.04	39.58	506.71

- FFT analysis was performed from acceleration time history
- Permanent displacement calculated from present program

Table presents the final results of permanent displacement for various earthquake motions.

4.2. It should be emphasised that the permanent displacement changes based on the energy that each seismic motion conveys.

SUMMARY

The present study has created a MATLAB programme to assess the slopes' permanent displacement using Newmark's sliding block method. The effect of many parameters, including soil cohesion, density, slope height, and angle of internal soil media friction with yield acceleration, has been studied parametrically. It was discovered that a particular slope's permanent displacement varies for various earthquake movements and is mostly dependent on the yield acceleration and earthquake motion.

PERMANENT DISPLACEMENT OF RETAINING WALLS

INTRODUCTION

The permanent displacement of retaining walls refers to the long-term movement or shifting of these structures beyond their intended design limits. It occurs due to various factors such as soil settlement, external forces like seismic activity, water pressure, and inadequate design. Soil settlement causes uneven pressure on the wall, while external forces like earthquakes and adjacent construction activities induce movement. Water pressure from accumulated water behind the wall can also contribute to displacement. Inadequate design, including material selection and reinforcement, can weaken the wall's stability. Addressing permanent displacement requires careful engineering considerations, including proper design techniques, construction methods, and ongoing monitoring. The permanent displacement of retaining walls refers to the long-term movement or shifting of a retaining wall from its original position. They are structures designed to hold back soil or other materials and prevent erosion or collapse of the surrounding land. Here are some potential causes:

1. **Settlement:** Over time, the soil beneath and behind a retaining wall can settle, leading to a shift in the wall's position. Settlement can occur due to a variety of reasons, including consolidation of loose or compacting soils, changes in groundwater levels, or the decomposition of organic materials in the soil.
2. **Slope movement:** Retaining walls are often built on slopes or hillsides to stabilize the soil and prevent landslides. However, if the slope experiences movement or instability, it can

cause the retaining wall to shift or rotate. Factors such as soil composition, slope angle, and groundwater conditions can contribute to slope movement.

3. External forces: External forces, such as heavy rainfall, seismic activity, or changes in adjacent structures, can exert pressure on a retaining wall. If these forces exceed the wall's design capacity, it may lead to permanent displacement or failure.
4. Inadequate design or construction: Poor design or construction practices can contribute to the long-term displacement of retaining walls. Insufficient reinforcement, inadequate drainage, or improper selection of materials can all affect the wall's stability and increase the likelihood of displacement.
5. Aging and deterioration: Retaining walls, like any structure, can deteriorate over time due to aging, weathering, or lack of maintenance. This deterioration can weaken the wall and contribute to its permanent displacement. To mitigate the risk of permanent displacement, it is crucial to ensure proper design, construction, and ongoing maintenance of retaining walls. Working with experienced engineers, following established industry standards, conducting regular inspections, and addressing any signs of distress or movement promptly can help minimize the potential for permanent displacement.

PARAMETRIC STUDY

In the present study attempts have been made to understand the variation of yield acceleration with respect to change in various parameters like, backfill slope, angle of internal friction, height of retaining wall, angle of interface friction between wall and the soil.

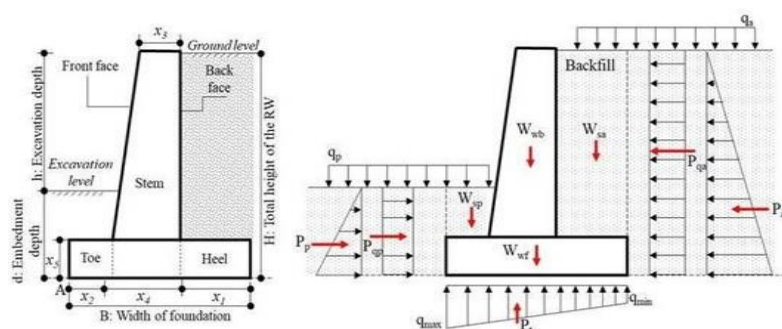


Fig.4.1: Cross section of RETAINING WALL

VALIDATION

In order to understand the accuracy and performance of the MATLAB program, it has been calculated with numerical example problems available in literature and the comparison is shown. To validate the modified Newmark's method a manual validation has been made with

following details subjected to the sine wave of amplitude 0.5 m/s² and period 0.55 second as in fig and the comparison between the two approaches is shown.

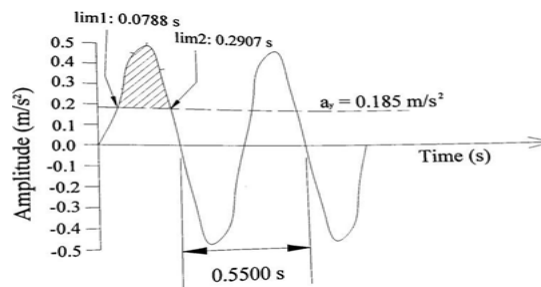


Fig4.2 Sinewave for MATLAB program.

Comparison between the MATLAB Program and Manual calculation

Table 4.1. comparison between the program and manual calculation

PROBLEM NO		MANUAL CALCULATION	PROGRAM	%VARIATION
1	Kae	0.3623	0.362	0.082
	Pae KN/m	72.3	72.3375	0.051
2	Kae	0.4069	0.4071	0.049
	Pae KN/m	118.03	118.2556	0.190
	Area of hatch as shown	0.0431	0.04292	0.417
3	Limit 1(s)	0.0788	0.0842	-6.852
	Limit 2(s)	0.2907	0.2907	0
	Relative displacement	0.00193	0.0018	5.328

The angle of internal friction was changed from 0° to 40° to examine its impact. The internal friction angle was plotted along the horizontal axis, while the yield acceleration was recorded along the vertical axis. The related graphs for several situations, including $k=0$, $k=1/3*k$, and $k=1/2*k$, were taken into consideration. It was found that as the angle of internal friction increased, the yield acceleration also did. But it was shown that the effect of k was minimal up to an angle of 4– 15°, beyond which there was a minor drop in yield acceleration with an increase in k . Another characteristic that was examined was the soil density used as the backfill. The density of the soil, measured as a unit weight, ranged from 12 kN/m³ to 24 kN/m³. For various situations, graphs were drawn with soil density along the horizontal axis and yield acceleration along the vertical axis. An increase in yield acceleration was noted with an increase in density, much like the angle of internal friction. Investigated was how the backfill slope affected yield acceleration. The backfill's slope ranged from 0° to 32°. The

findings demonstrated the connection between yield acceleration and backfill slope. The retaining wall's height was also taken into account as a criterion.

The vertical distance between the top of the wall and the ground it is holding back was used to determine the wall's height. When calculating the height, lateral pressures and slope angle were taken into consideration. Safety and stability were prioritized, and proper design and construction that complied with regional building requirements were stressed. Regarding the ongoing safety concerns and the permanent displacement brought on by earthquakes, comparisons were drawn. The need to take into account not only conventional failure criteria but also the magnitude of displacement that could negatively influence the infrastructure's performance was emphasized in the discussion of risk maps and design criteria for 60 infrastructures subjected to seismic loading. In conclusion, the study investigated the impacts of internal friction angle, soil density, backfill slope, and retaining wall height on long-term displacement. Insights into the behaviour and stability of retaining walls were gained from the findings, which emphasized the connections between these factors and yield acceleration

COMPARISON OF PERMANENT DISPLACEMENT

A huge number of earth and or rockslides can be triggered by an earthquake, and some of these slides can seriously destroy vital infrastructure including bridges, railway tracks, dam reservoirs, and other major structures. As a result, it is crucial to create risk maps that depict the displacements caused by earthquakes, the safety margins, and the likelihood that slopes, embankments, and retaining walls may fail at certain seismic intensities. Establishing precise design standards for infrastructures (such as highways) subject to seismic loading is also crucial. Such requirements must go beyond the standard failure criteria, which states that a system fails when the slope safety factor falls below one.

A more reasonable failure criterion for cut slopes, embankments, and retaining walls along highways is that the slope/embankment fails when it has moved a predetermined distance under seismic loading, which will significantly alter this infrastructure or affect the performance of the slopes and retaining walls. The evaluation and review of the Richards-Elms and simplified block-on-plane methods for evaluating/estimating the permanent displacements triggered by earthquakes is the primary goal of this study.

Characteristics of different earthquake ground motion

SL NO	Name of earthquake	Year	Magnitude	Amax (m/s ²)	Vmax (m/s)	Duration (s)	Predominant frequency(Hz)
1	Bhuj	2001	5.3	0.226	0.0052	12.16	1.88
2	Chichi	1999	6.2	2.3123	0.2048	140	2.01
3	El-Centro	1940	7.1	2.8999	0.2363	40	1.46
4	Gilroy	1989	6.9	4.3411	0.2669	39.94	2.69
5	Kern	1952	7.5	1.5270	0.0836	54.4	1.37
6	Loma prieta	1989	7.1	2.7036	0.3115	40	1.71
7	Mexico city earthquake	1995	6	0.8937	0.3803	180.12	0.49

The following properties were used to compare the Richards-Elms and modified Newmark's methods, they are

Density of soil = 18 kN/m³ Back

fill Slope = 0 deg.

Angle of internal friction of soil (φ) = 40 deg. Height of retaining wall = 6 m

Pore pressure ratio = 0

Coefficient of vertical acceleration (k) = 0 m/s² Angle of soil and wall interaction = 0.5*

Top width of retaining wall = 0.9 m

Bottom width of retaining wall = 2.4 m

Comparison of Richards-Elms and modified Newmark's method.

SL NO	Name of earthquake	Year	Richard elms method	Modified Newmark's method	Yield acceleration
1	Chichi	1999	14.42	0.173	0.23
2	El-Centro	1940	37.83	0.161	0.23
3	Gilroy	1989	162.05	0.054	0.23
4	Kern	1952	0.692	0.033	0.23
5	Loma prieta	1989	53.32	0.198	0.23
6	Mexico city earthquake	1995	2.689	1.989	0.23

When a_y/A_{max} , Richards-Elms technique produces more permanent displacement than modified Newmark's method, even if both methods give permanent displacement at higher a_y/A_{max} in good agreement with one another.

SUMMARY

The Richards-Elms technique has been used in the current work to construct a MATLAB programme to analyze the permanent displacement of retaining walls. To assess retaining wall permanent displacement, a new Modified Newmark and Richards-Elms Method has been devised. The effect of many parameters, including soil density, backfill slope, internal friction angle, height, and angle of friction between the wall and the soil, on yield acceleration, has been studied parametrically. To determine the effectiveness of the two approaches, modified Newmark's and Richards-Elms were compared. It was discovered that Newmark's approach takes into account the energy of the seismic motion while Richards-Elms method is an empirical approach. The permanent displacement of a specific slope is evaluated as well, and it is discovered that it primarily depends on the yield acceleration for various earthquake motions.

CONCLUSIONS AND SCOPE FOR FUTURE WORK

INTRODUCTION

The current work used a MATLAB programme to estimate the long-term displacement of geotechnical slopes and retaining walls under the effect of genuine seismic force. Here, pseudo static analysis was performed using the Richards-Elms approach for retaining walls and Newmark's sliding block approach for slopes. Additionally, a comparison of the modified Newmark's and Richards-Elms methods was done along with the development of a modified Newmark's analysis for determining the permanent displacement of retaining walls. Additionally, an effort was made to investigate the effects of soil cohesion, density, height, and angle of internal friction on the behaviour of slopes and backfill slopes, as well as the effects of internal friction, height, angle of friction at the wall-soil interface, and soil density on the performance of retaining walls.

CONCLUDING REMARKS

Based on the analysis of slopes and retaining walls, following conclusions were drawn in the present study.

Slopes

1. Increase in the density of slope of soil mass, increases the weight of the wedge. This allows the slope to fail at a lower yield acceleration, hence at lower magnitude of earthquake.
2. The effect of coefficient of vertical acceleration, k_v on yield acceleration is negligible. As the angle of internal friction increases the chances of failure slope decreases.
3. As the height of slope increases the yield acceleration mobilized decreases resulting in failure at lower magnitude of shaking.
4. Increase in cohesion increases the bonding. This increases the safety of slopes even at higher magnitude earthquake.
5. The permanent displacement of slope is different for different earthquake motions.
6. The permanent displacement mainly depends on the yield acceleration of the slope and the type earthquake motion.

Retaining walls

1. As the back fill slope increases, the yield acceleration decreases. Hence at higher slope angles the wall is subjected early failure.
2. The yield acceleration increase with the increase in interface angle between wall and soil. At lower values of interface angle, the structure fails at lower magnitudes. But at higher interface angles the base width of the wall increases their by inducing more resistance to failure.
3. As the height of retaining wall increases, the structure fails at lower yield acceleration. It means that a structure is more prone early failure even at lower magnitude earthquake because increased height increases weight of the wedge their by causing failure.
4. Modified Newmark's method gives more realistic output as it considers the area above the yield acceleration in acceleration time history, where as Richards-Elms is more an empirical method.
5. The advantages of Modified Newmark's approach is that it considers the actual shape of earthquake motion, where as in Richard-Elms method only maximum acceleration and maximum velocities are considered.
6. At higher a_y/Bax both Richards-Elms and modified Newmark's method give permanent displacement in good arrangement with each other but when $a_y \ll a_{rms}$, Richards- Elms method gives higher permanent displacement than modified Newmark's method.

SCOPE FOR FUTURE WORK

1. Slope stability analysis can be performed by considering the effect of groundwater table.
2. Slope stability analysis can be made for layered soils.
3. The retaining walls analysis can be extended to reinforced retaining walls.
4. Comparison of displacement methods can be extended to more realistic and actual earthquake data.

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