Comparative Study Of A Retaining Wall Under Static & Dynamic Loading

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Abstract- *This paper presents a comparative study on a retaining wall by different methods of analysis. The effect of internal friction angle, soil wall friction angle, wall inclination and seismic coefficient is shown graphically as well as in tabular form and a comparison of active and passive earth coefficients is presented for different methods. As the soil-structure interaction during the earthquake is very complex, Comparison of the various methods of analysis of retaining walls under seismic loads, .is also discussed in this study. The most commonly used methods for the seismic design of retaining walls are the Rankine method, Coulomb method, Pseudo static method, Seed- Whitman method and Mononobe - Okabe method. The retaining wall analysis includes determining the factor of safety for overturning, and sliding as well as the resultant location of the forces, which must be within the middle- third of the footing,. A concrete retaining wall is considered with a certain height and base width, and then analyzed for the static case as well as the earthquake loading condition. By parametric we have realized that change in internal friction angle and soil-wall friction angle affect the earth pressure coefficients considerably specially in passive condition. The most accurate values for active and passive coefficients are obtained by Seed-Whitman method. Based on this study, it is found that factor of safety for sliding and overturning obtained by Seed & Whitman method (1970) is lowest as compared to others methods, so the method is highly recommended for earthquake prone areas.*

Keywords- Essential Steps, Mononobe-Okabe Method, Passive earth pressure.

I. INTRODUCTION

Earthquake resistant design of earth retaining structures like retaining walls, earth dams, foundations are very important area of research to reduce the devastating effect of seismic hazards. Retaining wall is a structure whose primary function is to prevent lateral movement of retains earth and water. To design a retaining wall an engineer must know the basic soil parameter which includes unit weight, angle of internal friction, angle of wall friction, cohesion, wall inclination and height of retaining wall. Knowing the properties of soil behind the wall helps the engineer to determine the Lateral pressure distribution that has to be considered in the design. After computation of point of application, Active earth pressure and Passive earth pressure, retaining walls are checked for stability, which includes possible overturning, sliding and bearing capacity failures. If broadly categorized, forced-based and displacement based analysis are used to compute the seismic earth pressures but in the study we have only concentrated on the Force-based analysis. The seismic stability of earth retaining structures is usually analyses by Pseudo-static approach in which effects of earthquake forces are expressed in the form of horizontal and vertical accelerations. This study presents the role of soil parameters in the design of retaining wall and suitability of different methods to compute the active and passive earth pressures under a seismic conditions and seismic conditions for retaining walls.

II. LITERATURE REVIEW

A. **Coulomb Theory (1776) --** Coulomb was the first to study the problem of lateral earth pressures on retaining structure. By assuming that the force acting on the back of a retaining wall resulted from the weight of a wedge of soil above a planar failure surface, Coulomb used force equilibrium to determine the magnitude of the soil thrust acting on the wall for both minimum active and maximum passive conditions Rankine Theory (1857) - Rankine developed the simplest procedure for computing minimum active and maximum passive earth pressures. By making assumptions about the stress conditions and strength envelope of the soil behind a retaining wall (the backfill soil), Rankine was able to render the lateral earth pressure problem determinate and directly compute the static pressures acting on retaining walls.

B. **Mononobe- Okabe (1929, 1926)** – Mononobe and matsuo developed the basis of pseudo static analysis of seismic earth pressures on retaining structures that has become popularly known as Mononobe- okabe method. The M-O analysis is a direct extension of the static coulomb theory to pseudo static condition, In this analysis accelerations are applied to coulomb active or passive wedge Log Spiral Method(1948)-- Caquot and Kerisel gave the values of active earth pressure coefficient and passive earth pressure coefficient based on the logarithmic spiral method, Although the major principal stress axis may be nearly perpendicular to the backfill surface at some distance behind a rough wall (δ>0), the presence of shear stresses on the wall-soil interface can shift its position near the back of the wall. If the inclination of the principal stress axes varies within the backfill, the inclination of the failure surface must also vary. In other words, the failure surface must be curved. A logarithmic spiral function has been used to describe such curved failure surfaces for active and passive earth pressure conditions.

C. **Terzaghi (1943) -** showed that active earth pressures determined assuming a planar rupture surface almost match the exact or experimental values of earth pressures, while for the passive case, when wall friction angle, δ, exceeds one-third of soil friction angle, φ, the assumption of planar failure surface seriously overestimates the passive earth pressures.

D. **Newmark (1965) -** The first analysis of permanent displacement induced by an earthquake has been carried out by newmark, referring to the simple case of a rigid block sliding on a plane surface subjected to an acceleration time history.

E. **Slip Line Method (1965**) **--** Sokolovskii (1965) introduced a theory termed the “Slip-Line Field Theory”. In this analysis, it is assumed that failure occurs at constant volumes of soil along slip lines that meet the Mohr-Coulomb failure criterion. This method has the advantage of providing a statistically admissible stress state that satisfy the following equations of the plane equilibrium involving the normal, σ, and shear, τ, stresses and using a system of rectangular coordinates x, y with x-axis oriented in the vertical direction.

F. **Scott (1973) -** An approximate model proposed by scott represents the retaining action of the soil by a set of massless, linear horizontal springs. The stiffness of the springs is defined as subgrade modulus. Veletsos and Younan (1994a, 1994b, 1997, and 2000) improved the Scott’s model, by using a semi-infinite, elastically supported, horizontal bars with distributed mass, to include the radiational damping of the soil and using horizontal springs with constant stiffness, to model the shearing action of the stratum. Li (1999) included the foundation flexibility and damping into the Veletsos and Younan analyses.

G. **Whitman- Liao Method (1985) -** He identified several errors that result from the simplifying assumptions of the Richard-Elms procedure. The most important of these are neglecting of dynamic response of the backfill, Neglection of kinematic factors, neglecting of tilting mechanism, neglecting of vertical accelerations Stedman-Zing Method(1990)– It is possible to account for certain dynamic response characteristics in a relatively simple manner. To account for phase difference and amplification effects within the backfill behind a retaining wall can be considered using a simple pseudo dynamic analysis of seismic earth pressures.

H. **Veletsos and Younan(1994)** The system examined by Veletsos and Younan consists of a semi-infinite, uniform layer of linear viscoelastic material of height h that is free at its upper surface, is bounded to a rigid base, and is retained along one of its vertical boundaries by a rigid wall.

I. **Choudhury and Subba Rao (2002) -** They gave design charts for the estimation of seismic passive earth pressure coefficient for negative wall friction case. (Canadian Geotech. Journal, 2002). Green and Ebeling (2003) **-** A research investigation was undertaken to determine the dynamically induced lateral earth pressure on the stem portion of a concrete cantilever earth retaining wall with dry medium dense sand by Green and Ebeling (2003). The numerical model has been developed using FLAC finite difference code.

J. **Nimbalkar and Choudhary (2005**) **-** Planar rupture surface is considered in the analysis. Effects of a wide range of parameters like wall friction angle, soil friction angle, shear wave velocity, primary wave velocity and horizontal and vertical seismic accelerations on seismic active earth pressure have been studied.

K. **Shukla et al. (2009) -**have described the derivation of an analytical expression for the total active force on the retaining wall for c-ϕ soil backfill considering both the horizontal and vertical seismic coefficients.

L. **Puri and Prakash (2011)-** The method includes the effect of cohesion in the soil, adhesion between the retaining wall and backfill, the inclination of the backfill, horizontal and vertical seismic coefficients, surcharge on the backfill, and the inclination of the wall face and the backfill.

III. ESSENTIAL STEPS OF ANALYSIS

Sliding: The factor of safety for sliding can be expressed as the resisting force divided by the driving force.

$F.S = (N \tan \delta + P_p)/p_H$ (eq^n-1)

wall, footing and vertical component of the active earth pressure resultant force.

N = Sum of the weight of the

Pp = allowable passive resultant force divided by the reduction factor

PH = Horizontal component of the active earth pressure resultant force

For static conditions the typical recommendation for minimum factor of safety for sliding are 1.5 to 2.

Overturning: The factor of safety for overturning of the retaining wall can be calculated by taking moments about the toe of the footing and is

$F.S = W_a/(1/3PH_H - P_v e)$ (eq^n-2)

a=lateral distance from the resultant weight W of the wall and footing to the toe of the footing.

PH = horizontal component of the active earth pressure resultant force

Pv = active earth pressure resultant force (vertical component)

e = lateral distance from the location of PVto the toe of the wall.

For static conditions, typical recommendation for minimum factor of safety for overturning is

1.5 to 2.

1) PARAMETRIC STUDY BASED ON DIFFERENT METHODS

To design a retaining wall an engineer must know the basic soil parameters which include unit weight, angle of internal friction, angle of wall friction, cohesion, wall inclination maximum acceleration and height of retaining wall. Knowing the properties of soil behind the wall helps the engineer to determine the Lateral pressure distribution that has to be considered in the design.

Rankine theory-

Rankine (1857) developed the simplest procedure for computing minimum active and maximum passive earth pressures. By making assumptions about the stress conditions and strength envelope of the soil behind a retaining wall (the backfill soil), Rankine was able to render the lateral earth pressure problem determinate and directly compute the static pressures acting on retaining walls.

Active earth pressure: Active earth pressure occurs when the wall tilts away from the soil,It can be found by the following relation:

$(P_a) = k_a \gamma H^2$ (eq^n-3)

$kA = \tan^2(450 - \phi)$ (eq^n-4)

Passive earth pressure:

Passive earth pressure occurs when the wall is pushed into the soil,It can be found using following relation

$(P_p) = k_a \gamma D^2$ (eq^n-5)

$K_a = \tan^2(45^0 + \phi)$ (eq^n-6)

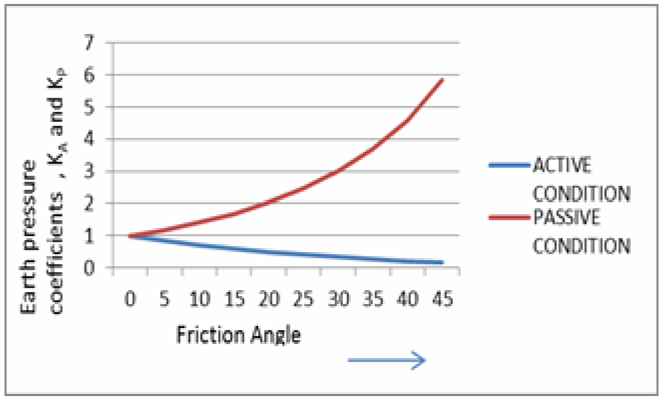

Figure 1. Variation of active pressure coefficient and passive pressure coefficient w.r.t Friction Angle.

We have observed that increase in friction angle increases the passive earth pressure coefficient (KP) and decreases the active earth pressure coefficient (KA).

This method do not take account of wall friction angle but Height of retaining wall, Passive and active earth pressure coefficient and weight of backfill are directly proportional to Active and passive earth pressure and hence increases for larger values of such parameters.

Coulomb method :

Coulomb method used force equilibrium to determine the magnitude of the soil thrust acting on the wall for both minimum active and maximum passive conditions.. In contrast to the Rankine approach, Coulomb theory can be used to predict soil thrust on walls with irregular backfill slopes, concentrated loads on the backfill surface, and seepage forces.

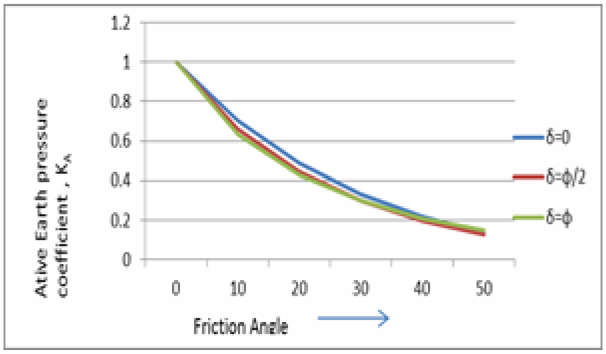

Figure 2. Variation of active pressure coefficient coefficient w.r.t friction Angle.

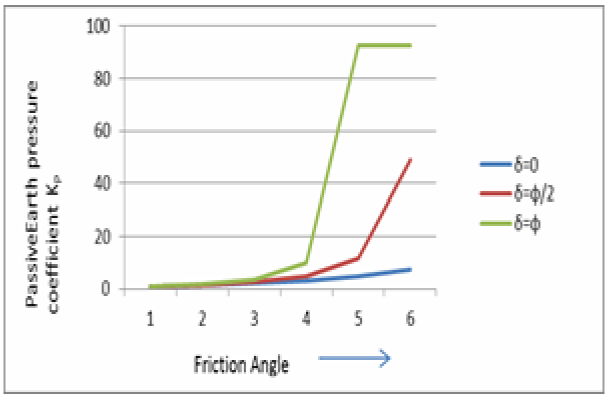

Figure 3. Variation of passive pressure coefficient w.r.t Friction Angle

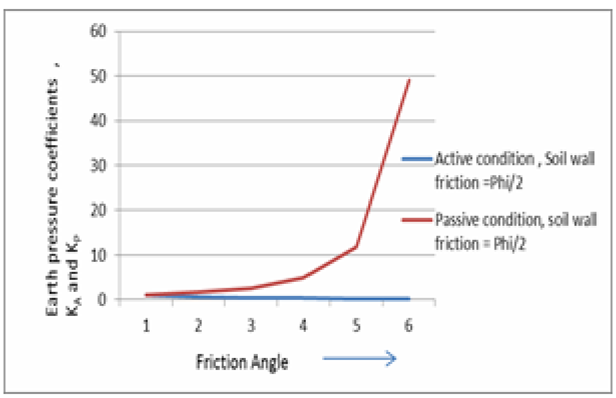

Figure 4. variation of active and passive pressure coefficients w.r.t Friction Angle

By Coulomb method we have observed that increase in friction angle increases the passive earth pressure coefficient (KP) and decreases the active earth pressure coefficient (KA).This method take account of wall friction angle, inclination angle of the wall internal face respect to vertical inclination and angle of the backfill respect to horizontal. Increase in wall friction angle decreases the active pressures coefficients and increases the passive pressure coefficients.

Logarithmic spiral method:

If the inclination of the principal stress axes varies within the backfill, the inclination of the failure surface must also vary. In other words, the failure surface must be curved. A logarithmic spiral function has been used to describe such curved failure surfaces for active and passive earth pressure conditions. The effect of wall friction on the shape of the critical failure surface is more noticeable for passive earth pressure conditions. The passive failure surface also has curved and linear portions, but the curved portion is much more pronounced than for active conditions.

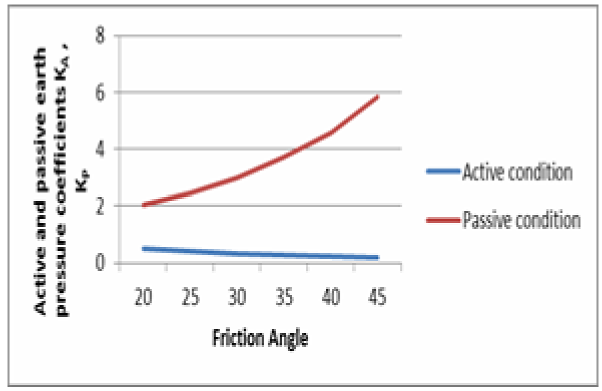

Figure 5. variation of active and passive pressure coefficients w.r.t Friction Angle

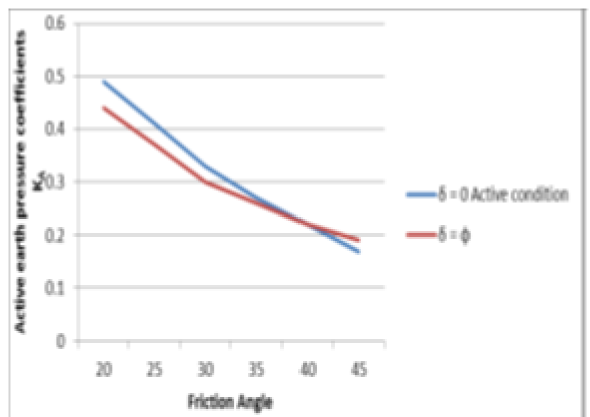

Figure 6. variation of active pressure coefficient w.r.t Friction Angle

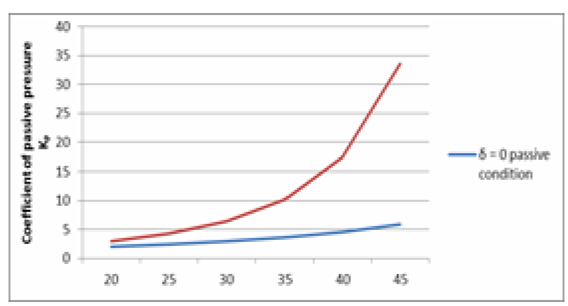

Figure 7. variation of passive pressure coefficient w.r.t Friction Angle

The active earth pressure coefficients given by the log spiral approach are generally considered to be slightly more accurate than those given by Rankine or Coulomb theory, but the difference is so small that the more convenient Coulomb approach is usually used. The passive earth pressure coefficients given by the log spiral method are considerably more accurate than those given by Rankine or Coulomb theory; the Rankine and Coulomb coefficients tend to under predict and over predict the maximum passive earth pressure, respectively. Rankine theory greatly under predicts actual passive earth pressures and is rarely used for that purpose. Coulomb theory over predicts passive pressures (an un-conservative error) by about 11% for $\delta=\varphi/2$ and 100% for $\delta=\varphi$. For that reason, Coulomb theory is rarely used to evaluate passive earth pressures when $\delta>\varphi/2$.

Mononobe-Okabe method:The M-O method is a direct extension of the static Coulomb theory to pseudo static. In a M-O analysis, pseudo static accelerations are applied to a Coulomb active (or passive) wedge. The pseudo static soil thrust is then obtained from the force equilibrium of the wedge. In addition to those under static conditions, the forces acting on an active wedge in a dry cohesion less backfill wedge are constituted by horizontal and vertical pseudo static forces whose magnitudes are related to the mass of the wedge by the pseudo static accelerations ah = khg and av =kvg. The total active thrust can be expressed in a form similar to that developed for static conditions, as a pseudo static extension of the Coulomb analysis; however, the M-O analysis is subject to all of the limitations of pseudo static analyses as well as the limitations of Coulomb theory. The determination of the appropriate pseudo static coefficient is difficult and the analysis is not appropriate for soils that experience significant loss of strength during earthquakes (e.g. liquefiable soils). Just as Coulomb theory does under static conditions, the M-O analysis will over predict the actual total passive thrust, particularly for $\delta > \varphi/2$. For these reasons the M-O method should be used and interpreted carefully.

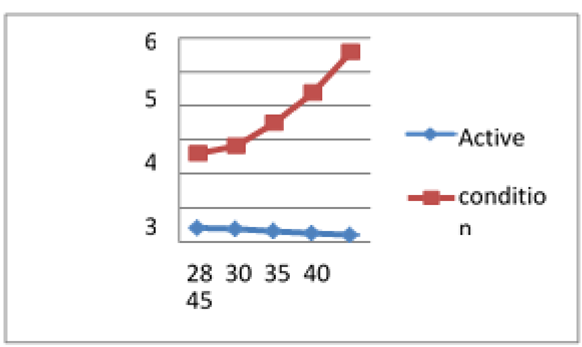

Figure 8. variation of active and passive pressure coefficients w.r.t Friction Angle

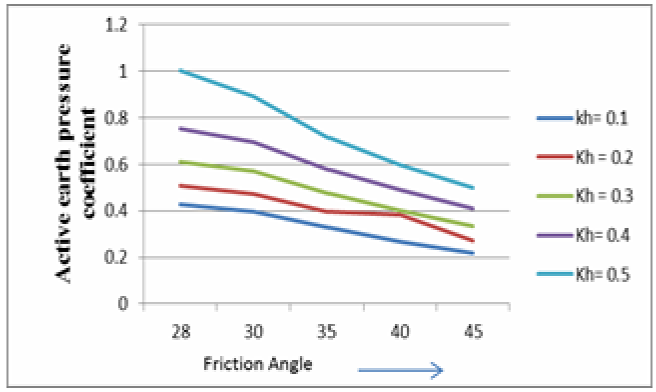

Figure 9. variation of active pressure coefficient w.r.t Friction Angle

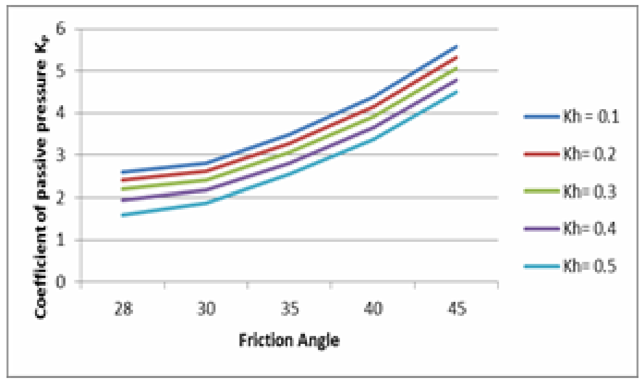

Figure 10. variation of passive pressure coefficient w.r.t Friction Angle

The graphical representations of the seismic earth pressure coefficients and the critical failure surfaces in active and passive conditions evaluated with the M-O method for vertical walls retaining a horizontal backfill are plotted. The figures denote a slight influence of the soil- wall friction on the seismic active conditions while, as in the Coulomb method, strong differences exist in the passive case. Although conceptually quite simple, the M-O analysis provides a useful means of estimating earthquake-induced loads on retaining walls. A positive horizontal acceleration coefficient causes the total active thrust to exceed the static active thrust and the total passive thrust to be less than the static passive thrust. Since the stability of a particular wall is generally reduced by an increase inactive thrust and/or a decrease in passive thrust, the M-O method produces seismic loads that are more critical than the static loads that act prior an earthquake. For the passive case, the most critical sliding surface is much different from a planar surface as is assumed in the M-O analysis. The KPEn values are seriously overestimated by the M-O method. They are, in most cases, higher than those obtained by the limit analysis. This is especially the case when the wall is rough and the angle of wall repose is large.

2) SEED AND WHITMAN METHOD-

Seed and Whitman in 1970 derived an equation which can be used to find the lateral pseudo static force acting on the retaining wall According to Seed and Whitman the location of the Pseudo static can be assumed to be acting at a distance of 0.6H above the base of the wall and in this method earth pressure coefficients are calculated by adding additional factor of ΔKA ,ΔKP for seismic considerations

$$KAE = KA + \Delta KA = KA + 0.75Kh \qquad (eq^n\text{-}7)$$

$$KPE = KP + \Delta KP = KP - 2.125Kh \qquad (eq^n\text{-}8)$$

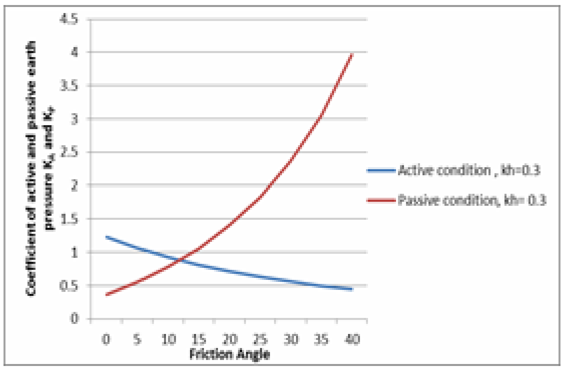

Figure 11. variation of active and passive pressure coefficients w.r.t Friction Angle

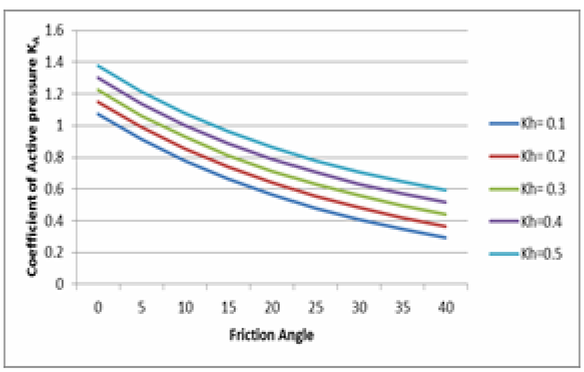

Figure 12. variation of active pressure coefficient w.r.t Friction Angle

In this method we can see that at one point when friction angle is between 100 to 150, we get a common value for passive and active condition, which do not happen in any other method. These methods give low values for Active and Passive conditions as compared to overestimated values by M-O method.

IV. RESULTS AND DISCUSSIONS

Comparison of different force methods.Comparison of different force methods for analysis of retaining wall based on the lateral earth pressures i.e active earth pressure coefficients and passive earth pressure coefficients is presented in the fig.6.

Table 1. Comparison of active earth pressure coefficients for different methods.

Sl. NO.	Name of the Method	Angle of Internal Friction ϕ (Degree)									
		0		10		20		30		40	
		K_A	K_p	K_A	K_p	K_A	K_p	K_A	K_p	K_A	K_p
1	Rankine	1	1	0.704	1.42	0.4902	2.039	0.333	3	0.217	4.599
2	Coulomb	1	1	0.634	1.73	0.426	3.5	0.297	10.1	0.21	92.58
3	Log Spiral	1	1	0.69	1.61	0.44	3.01	0.3	6.42	0.22	17.5
4	Mononobe Okabe	1	1	0.767	1.48	0.519	3.1	0.372	9.02	0.274	83.25
5	Seed and Whitman	1.075	0.788	0.779	1.208	0.5652	1.826	0.408	2.787	0.292	4.386

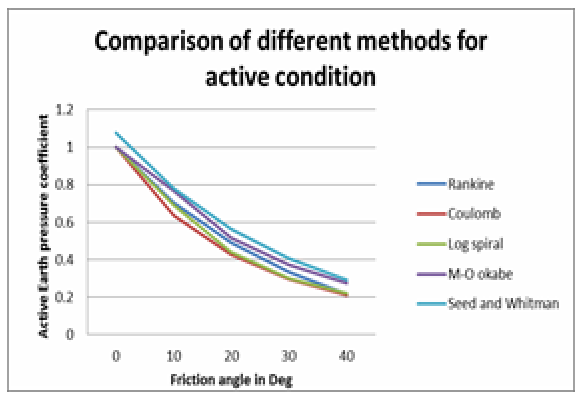

Figure 13. Variation of KA w.r.t. friction angle by different methods

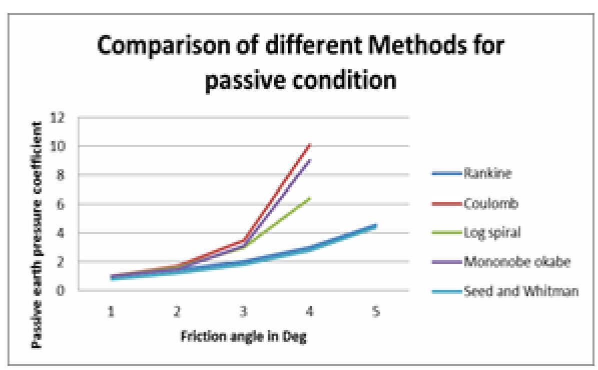

Figure 14. Variation of KA w.r.t. friction angle by different methods

Comparisons between the different static methods.As can be noted from the graphical representations of the results obtained from the application of the different theories, the active earth pressures coefficients is not strongly affected by the soil wall riction angle δ, while, small variations of δ produce large differences on KP values calculated with the various methods.

Figure 4. the comparisons between the normal components to the wall of the active and passive earth pressure coefficients evaluated with the different methods for a horizontal backfill (ε=0) retained by smooth (δ=0) and rough (δ=φ) vertical walls are plotted. Note that the earth pressure coefficients was estimated till to a soil friction angle φ=40°. The passive earth pressure coefficients are more sensible to the soil wall friction. If the log spiral method can be interpreted as the most accurate determination close to the exact solution, the Coulomb method provides KP values very similar to those expected while Rankine method gives conservative and easy-to-calculate passive coefficients.

Comparison between different seismic methods

For the passive case, the most critical sliding surface is much different from a planar surface as is assumed in the M-O analysis. The KPE values are seriously overestimated by the M-O method. They are, in most cases, higher than those obtained by Seed-Whitman. This is especially the case when the wall is rough and the angle of wall repose is large. The condition φ = δ = 40° carries out very high KPE values larger than 20, unreported in figures. For smooth walls, the potential sliding surface is practically planar and the different methods give almost identical results.

Problem Considered

We have considered a retaining wall shown in Fig. whose height is 4m and thickness of the reinforced concrete wall stem is0.4 m, the reinforced concrete wall footing is 3 m wide by 1.5 m thick, the unit weight of concrete =23.5 kN/m3. The wall backfill will consist of sand having ϕ =32° and γt=20 kN/m3. We have also assumed that there is sand in front of the footing with these same soil properties. The friction angle between the bottom of the footing and the bearing soil is δ=38°. We will find factor of safety for sliding, and factor of safety for overturning for static conditions and earthquake conditions by different methods and a comparison between them is shown. We have assumed the wall to be present in the earthquake critical zone(IV) of north east where KhE =0.36 . Factor of safety was determined by considering static as well as seismic loading.

The values of factor of safety for sliding and overturning from the static and seismic analysis using KhE = 0.36 are summarized below.

Table 2. Factor of safety for sliding and overturning.

Type of loading condition		P_E or P_{AE} kN/m	Location of P_E or P_{AE} above base of wall(m)	Factor of safety for sliding	Factor of safety for overturning
Rankine Method		$P_E = 0$	--	1.17	2.2
Coulomb Method		$P_E = 0$	--	1.775	2.3
Seismic Loading ($K_{hE} = 0.36$)	Pseudostatic	P_E = 31.91	2H/3 =2.66	0.81	1.14
	Seed and whitman	P_E = 43.2	0.6H = 2.4	0.7	1.0
	Mononobe - -okabe	P_{AE} = 118.24	H/3 =1.33	1.06	1.31

For the analysis of sliding and overturning of the retaining wall, it is common to accept a lower factor of safety (1.1 to 2.2) under the combined static and earthquake loads. It is evident from Table 6.2 that Seed & Whitman method (1970) gives lower value of factor of safety as compared to other methods considered in this study. Thus, it is recommended method for the design of retaining walls in earthquake prone region.

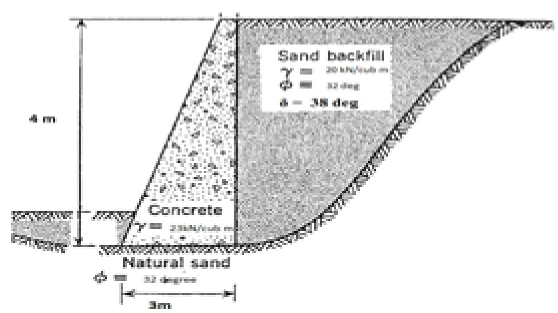

Figure 15. Sketch of Typical Retaining Wall Factor of safety for sliding and overturning

V. CONCLUSION AND FUTURE SCOPE

It has been observed by parametric study that active earth pressure coefficient are almost identical by different methods, it can be noted from the graphical representations of the results obtained from the application of the different theories, the active earth pressures coefficients is not strongly affected by the soil wall friction angle δ, while, small variations of δ produce large differences on KP values calculated with the various methods.

- In active and passive conditions, for a smooth wall, the computed KA and KP values are practically the same. For a rough wall, in the active conditions, the difference becomes relatively much larger. Rankine and Coulomb methods give the upper and lower threshold trends, while the other methods carry out almost similar results.
- The passive earth pressure coefficients are more sensible to the soil wall friction. If the seed and Whitman method can be interpreted as the most accurate determination close to the exact solution, M-O method gives overestimated values.
- It has been observed that for the seismic analysis of retaining wall withdifferent methods we obtain different results for the sliding and overturning. In the Table 6.2, it is evident that the factor of safety in sliding is equal to 0.7 and factor of safety in overturning is 1 based on the Seed and Whitman method. This factor of safety obtained is lowest as compared to one obtained using other methods considered in this study. It is also found that the factor of safety under seismic loading is more critical than in case of static a seismic loading. Thus, it is highly desirable to design the retaining walls in earthquake prone regions by Seed and Whitman method.
- The Mononobe-Okabe equation does not account the effect of cohesion, because of that the lateral earth pressure coefficients calculated from dynamic analysis are less than those calculated using Mononobe-Okabe method.. The conclusion drawn from this study may not apply to retaining wall systems of differing geometry and/or material properties. Further research is required in order to draw more general conclusions regarding the appropriateness of the Monotone- Okabe method to evaluate the dynamic pressures induced on retaining walls.

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