ANALYTICAL AND EXPERIMENTAL ANALYSIS OF RETAINING WALL IN STATICAND SEISMIC CONDITIONS

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ABSTRACT

This review study contemplates the relevant theories to understand response of retaining wall in static and seismic condition. The heavy soil mass is supported by retaining walls in various fields of civil engineering such as hydraulics, irrigation structures, highways, railways, tunnels, mining etc. Evaluation of lateral earth pressure is key factor to design retaining wall. In the static condition, the lateral earthpressure exerted by retained soil mass only. In some cases, the deformation in retaining wall due static loading may be negligibly small; in others it causes significant damage. In earthquake prone area, earthquake can induce large destabilizing force in retaining wall and backfill soil, seismically induced force has greater influence on lateral earth pressure. Earthquakes have caused permanent deformations in retaining wall in many historical earthquakes. In some cases, retaining walls have collapsed during earthquake with disastrous physical and economic consequences. Meanwhile,it is very much important to evaluate dynamic earth pressure accurately. This review shows the development of concept to evaluate dynamic lateral earth pressure based onanalytical, experimental and numerical method for computation of dynamic lateral earth pressure. The current research brings a comprehensive and categorized review of response of retaining wall system in static condition and dynamic condition.

Keywords: Retaining wall, Earthquake, plastic equilibrium, yield acceleration, dynamic lateral earth pressure

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1. INTRODUCTION

The retaining walls are often classified in terms of their relative mass, flexibility, and anchorage conditions shown in figure 1. The gravity walls are the oldest and simplest type of retaining wall. Gravity walls are heavy, thick and stiff enough that they do not bend; there movement occurs essentially by rigid body translation or rotation. Cantilever walls are bendas well as translate and rotate, rely on their flexural strength to resist lateral earth pressure. Counterfort retaining wall consist of a crossed beam type one extra element behind face of wall or in face backfill side of wall to resist moment in wall and buttered walls are same as this type but only buttress are provided in face of wall.

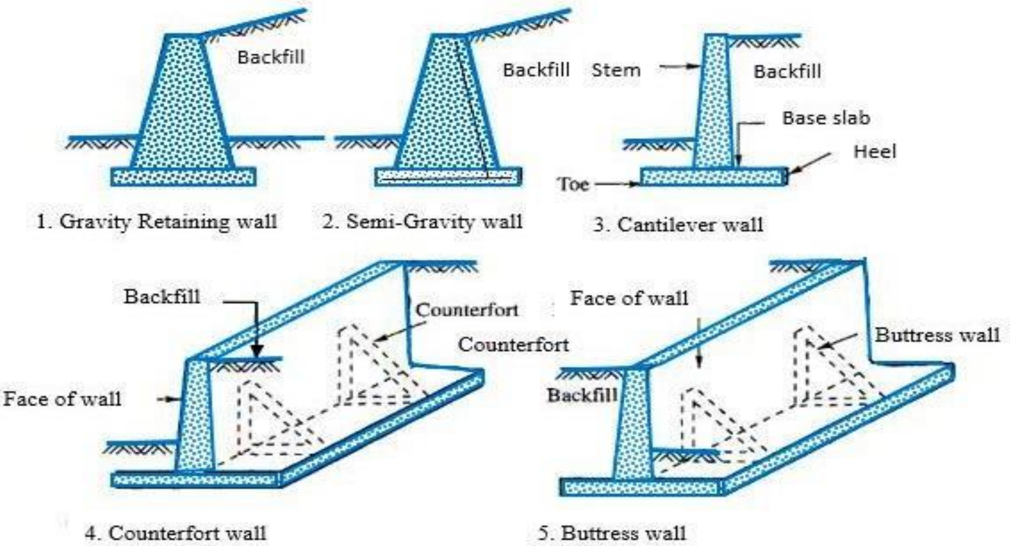


Figure 1 Various types of retaining wall

The soil at higher elevation would tend to move down without any structural support & it exerts pressure on the structure. The pressure exerted on structure called as lateral earth pressure. Under such lateral pressure, wall may slide or overturned cause structural and sub grade deformation. During earthquake, however, inertial forces and changes in soil strength may violate equilibrium and cause permanent deformation of wall. Failure, whether by sliding, tilting, bending or some other mechanism, occurs when permanent deformations become excessive (not in permissible limit). Dynamic/seismic force has greater influence on lateral earth pressure. There are several theories, experimental investigations & numerical studies done to evaluate dynamic response of the retaining wall system. This review study is categorized for two conditions, response of retaining wall in static condition and dynamic/seismic condition.

2. RESPONSE OF RETAINING WALL IN STATIC CONDITION: ANALYTICAL APPROACH

Earlier retaining wall structures were rigid retaining wall, which provides stability by its heavy mass. **Charles Augustine de Coulomb (1776) [1]** developed a method to calculate earth pressure in which he considers the soil behind wall is whole instead of as an element in soil & it is therefore reasonable to assume that if the wall moved forward slightly a rupture plane would develop somewhere between the wall and backfill. On the course of experiments,he found curved failure plane but he considered straight failure plane for mathematicalsimplicity. The triangular mass of soil between this plane of failure and the back of wall is referred to as sliding wedge. The limiting equilibrium of the sliding wedge, which formed when the movement of the retaining wall takes place. In active state, the sliding wedge moves downwards as shown in figure 2 and in passive state the sliding wedge moves upwards on slipsurface relative to intact backfill, in fact a force of reaction, which it has to exert to keep the sliding wedge in limiting equilibrium. The lateral pressure on wall is equal and opposite to reactive force exerted by wall in order to keep sliding wedge in limiting equilibrium. As shown in figure-2 and figure-3, the gravity retaining wall of height 'H', the back face of wallis inclined at angle 'θ' and backfill is inclined at angle 'β'. In active and passive state, the triangular failure wedge of soil along slip plane of weight (W) will exert pressure on wall and rest of backfill soil apart from it. The triangular failure wedge of soil must have two reactions and by applying sine rule over there as shown in figure, the formula for pressure on wall would derive in active and passive state. This analysis is type of limiting equilibriummethod. Coulomb assumed soil is dry, homogeneous, cohesionless, isotropic and ideallyplastic material. The wall is rough so the resultant pressure will incline at angle δ, it is angle of friction between wall and backfill and generally taken as $(\frac{2}{3}\text{Ø})°$.

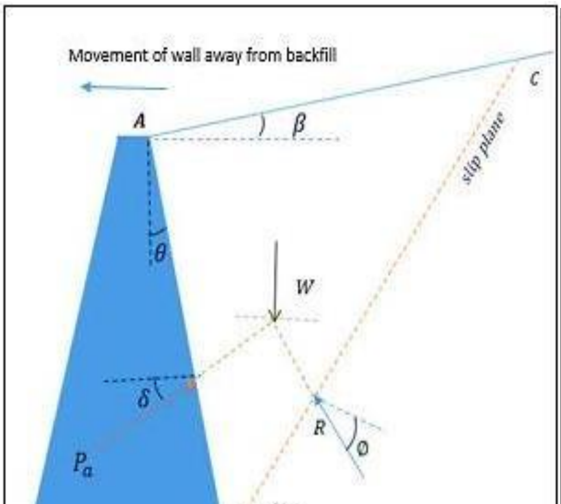


Figure 2 Coulomb's active state of wall

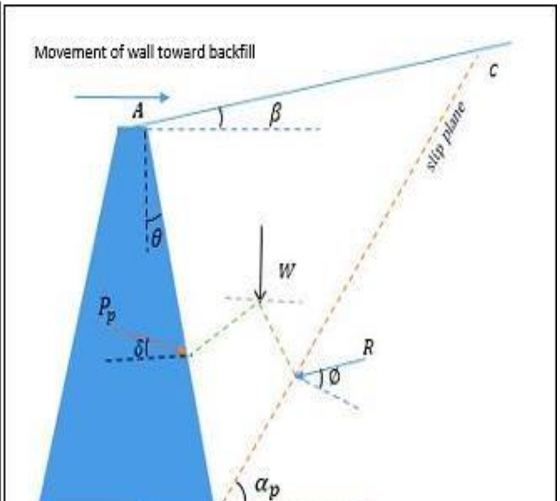


Figure 3 Coulombs passive state of wall

The sliding wedge itself act as a rigid body & the value of the earth pressure is obtained by considering limiting equilibrium of sliding wedge as a whole. The major drawback of coulomb's method, it does not give point of application of earth pressure.

Coulomb has derived formula for active state and passive state of retaining wall listed below

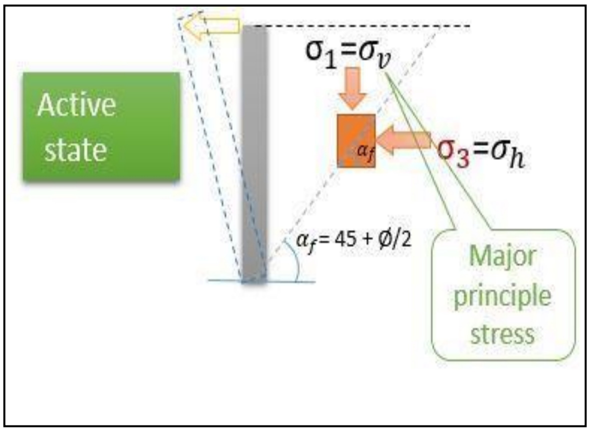
Coefficient of lateral active earth pressure $K_a = \frac{cos^2(Ø-\theta)}{cos^2\theta\cos(ð+\theta)**\left[1+\sqrt{\frac{\sin(ð+Ø)\ \sin(Ø-Q)}{\cos(ð+\theta\ \cos\ Q-\theta)}}\right]^2}$

Active earth pressure $P_a = \frac{1}{2} K_a \gamma H^2$

Coefficient of lateral passive earth pressure $K_p = \frac{cos^2(Ø+\theta)}{cos^2\theta\cos(ð-\theta)*\left[1+\sqrt{\frac{\sin(ð+Ø)\ \sin(Ø-Q)}{\cos(ð+\theta\ \cos\ Q-\theta)}}\right]^2}$

Passive earth pressure $P_p = \frac{1}{2} K_p \gamma H^2$

William john Macquorn Rankine (1857)[2] proposed to calculate lateral earth pressure on retaining wall by making assumption about the stress condition and strength envelope behind retaining wall in backfill soil. If the wall is rigid and does not move with pressure exerted on the wall, not every part of backfill soil is in incipient failure condition and this rest condition is known as general state of elastic equilibrium. In this condition, the lateral earth pressure is constant. A body of soil is in state of plastic equilibrium, if every part of it is in incipient failure condition. However, failure may imminent only in small portion of the soil mass such as that produce by yielding of retaining wall in the soil mass adjacent to it, such situation is referred as local state of plastic equilibrium. The state of active pressure occurs when the soil mass yields in such way that it tends to stretch horizontally as there is no horizontal restriction over soil element the horizontal stress reduces becomes minor principal stress, vertical stress becomes major principal stress. A state of passive pressure exists whenthe movement of wall is such that the soil tends to compressed horizontally at failure condition horizontal stress becomes major principal stress, vertical stress is minor principal stress. He considered soil is dry, isotropic, homogeneous, and cohesionless. soil mass is assumed in limiting plastic equilibrium, rupture surface (slip plane) is plane is straight and according to Mohr's Coulomb strength envelope theory the failure plane will inclined at $(45\pm\frac{Ø}{2})°$ and no wall friction



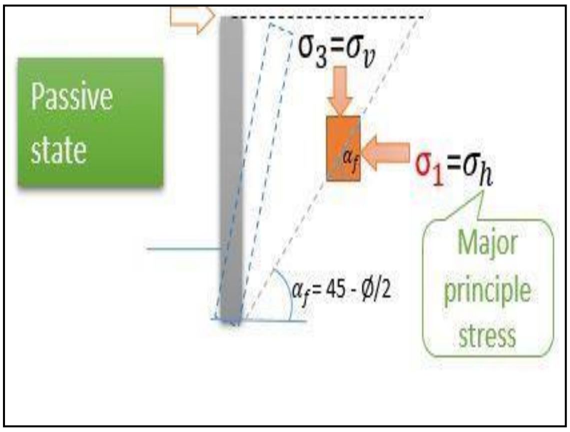


Figure 4 Rankine's active state of wall **Figure 5** Rankine passive state of wall

In active state, σ_v which is vertical pressure or overburden pressure and consider as major principal stress and σ_h is consider as minor principal stress. In passive state, σ_v which is vertical pressure or overburden pressure and consider as minor principal stress and σ_h is consider as major principal stress. Rankine used Mohr's-Coulomb relationship [3] between major principal stress and minor principal stress to derived lateral earth pressure on wall.

Rankine has derived formula for active state and passive state of retaining wall

Active earth pressure $P_a = \frac{1}{2} K_a \gamma H^2$,

Coefficient of lateral active earth pressure $K_a = \frac{1-\sin Ø}{1+sinØ}$

Passive earth pressure, $P_p = \frac{1}{2} K_p \gamma H^2$,

Coefficient of lateral passive earth pressure $K_p = \frac{1+\sin Ø}{1-sinØ}$

The earth pressure by Rankine's method is not accurate since there is no wall friction and no batter angle of retaining is considered. **Resal (1910)** and **Bell (1915)[4]** extended this theory for cohesive soil. Later on, in the course of Coulomb's theory underwent some alteration and several graphical methods were developed to calculate lateral earth pressure given by **Poncelet (1840)**, **Culmann (1866)**, and **Rebhann (1871)[4]**. They considered wall friction δ, irregularity of backfill, any surcharge (either concentrated or distributed) and angle of internal friction of soil. **Terzaghi (1943)** [4] gave a generalised theory to evaluate earth pressure by considering curved failure plane based on log spiral theory. According to Terzaghi, if the wall friction angle is greater than one third of internal angle of friction of soil the slip plane will strongly curved. Log spiral theory was assumed because of unrealistic value of earth pressure that obtained by different theories which assumed straight-line failure. This is all about lateral pressure in static condition. Next work is done to explore the response of retaining wall in earthquake condition.

3. RESPONSE OF RETAINING WALL IN DYNAMIC CONDITION: ANALYTICAL APPROACH

Earthquake is shaking of earth surface, resulting from sudden release of energy. The dynamic response of retaining wall under an earthquake excitation of even simplest retaining wall is quite complex. Beginning in 1920s, seismic stability of retaining wall has been analyzed by a pseudo-static approach in which the effects of an earthquake are represented by static horizontal and vertical force. **Mononobe-Okabe (1929)[5][6]** has developed a method to calculate dynamic earth pressure during earthquake based on pseudo-static approach that has popularly known as M-O method. This method is extension of static coulomb's wedge theory to pseudo-static condition.

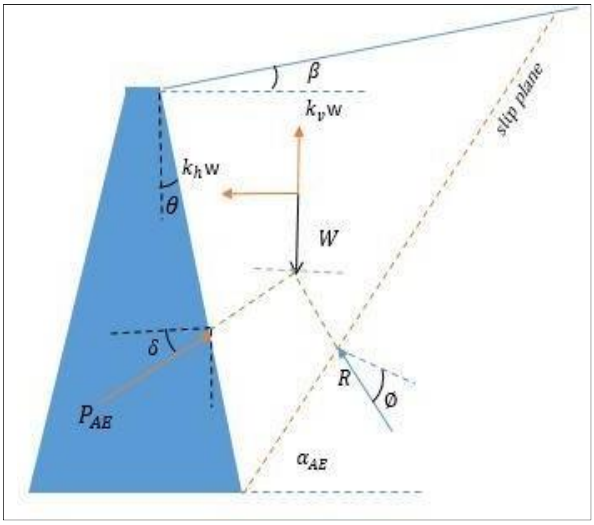


Figure 6 Dynamic active earth pressure

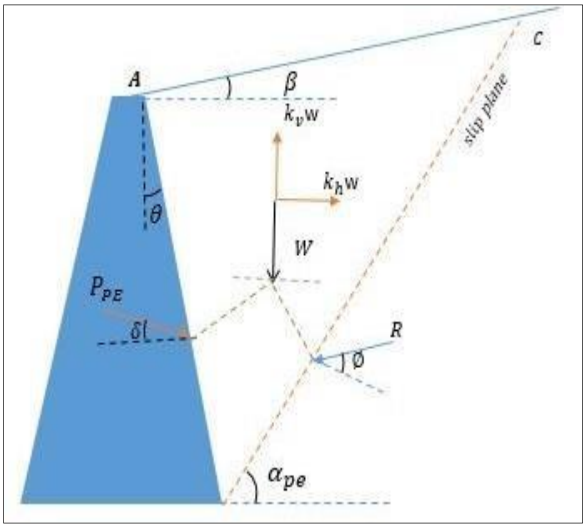


Figure7 Dynamic passive earth pressure

In addition to forces exist under static condition shown in figure, the wedge also acted upon by horizontal and vertical pseudo-static forces whose magnitudes are related to the mass of failure wedge by pseudo-static acceleration $a_h = k_h g$ and $a_v = k_v g$. Mononobe-Okabe considered wall friction and cohesionless backfill material. The total dynamic lateral earth pressure for active state and passive state given below.

Mononobe-Okabe has derived formula for dynamic lateral earth pressure

Dynamic active earth pressure coefficient $K_{AE} = \frac{cos^2(\emptyset-\theta-\varphi)}{cos\varphi\, cos^2\theta \cos(\delta+\theta+\varphi)\left[1+\sqrt{\frac{\sin(\delta+\emptyset)\sin(\emptyset-\beta-\varphi)}{\cos(\delta+\theta+\varphi)\cos(\beta-\theta)}}\right]^2}$

Dynamic Active earth pressure $P_{AE} = \frac{1}{2} K_{AE}\, \gamma H^2(1\text{-}k_v)$

Dynamic passive earth pressure Coefficient:

$K_{PE} = \frac{cos^2(\emptyset+\theta-\varphi)}{cos\varphi\, cos^2\theta \cos(\delta-\theta+\varphi)\left[1-\sqrt{\frac{\sin(\delta+\emptyset)\sin(\emptyset+\beta-\varphi)}{\cos(\delta-\theta+\varphi)\cos(\beta-\theta)}}\right]^2}$

Dynamic Passive earth pressure $P_{PE} = \frac{1}{2} K_{PE}\, \gamma H^2(1\text{-}k_v)$

This method is widely used as fundamental theory for new research. The major limitation of Mononobe-Okabe method, this method does not give the distribution of lateral earthpressure over the height of wall by making additional assumption of various authors, such as **Prakash and Basavanna (1969) [11]** have estimated the height of total dynamic earth pressure. **Wood (1973) [13]** considered the backfill is uniform and elastic; in this case, the dynamic thrust is 0.63H above the base of wall. **Seed-Whiteman (1970) [7][12]** studied the effect of various factors, such as angle of friction, wall friction, and horizontal and vertical acceleration. According to them, the dynamic earth pressure can be divided into static partand dynamic part. Seed and Whitman suggested the dynamic component of earth pressure acting at 0.6H, where 'H' is height of retaining wall. The height of combined static and dynamic earth pressure thus would fall between 0.33H to 0.6Hdepending upon intensity of ground motion

Seed-Whiteman has derived formula for Coefficient of dynamic lateral earth pressure

Dynamic active earth pressure Coefficient $K_{AE} = K_A + {}^3/_4\, K_h$

Dynamic passive earth pressure Coefficient$K_{PE} = K_p + {}^3/_4\, K_h$

As per stated above theories, which are based on pseudo-static approach, neglected the time effect of dynamic force, dynamic amplification and damping. **Steedman and Zeng (1990) [13][16]** considered pseudo dynamic approach to calculate dynamic earth pressure. This method takes into account the influence of phase difference and dynamic amplification factors on lateral earth pressure. They have considered fixed base cantilever wall. If the base is subjected to harmonic horizontal acceleration of amplitude (a_h), the acceleration at depth z, below the top of wall expressed by equation

Harmonic horizontal acceleration,

$$a(z,t) = a_h \sin\left[\omega\left(t - \frac{H-z}{v_s}\right)\right]$$

The dynamic lateral earth pressure

$$P_{ae}(t) = \frac{Q}{\tan\alpha}\frac{\sin(\alpha-\emptyset)}{\cos(\delta+\emptyset-\alpha)} + \frac{k_h\gamma z}{\tan\alpha}\frac{\cos(\alpha-\emptyset)}{\cos(\delta+\emptyset-\alpha)} \sin\left[\omega\left(t - \frac{H-z}{v_s}\right)\right]$$

The point of application of dynamic horizontal thrust for low frequency of motion is one third of height of wall from bottom of wall, at low frequency, dynamic amplification is not significant at low frequency and pseudo-static condition is satisfied. For high frequency, the point of application of dynamic earth pressure is higher on wall.

A new approach has been carried out by **Richard-Elms (1979)[6][13]** based on pseudo-static displacement approach. They derived an equation to evaluate displacement of rigid retaining wall during earthquake. This is the most acceptable method used to compute displacement of rigid retaining wall during earthquake and this method based on **Newmark's sliding block (1965)** theory that considers pseudo-static approach. They recommended that dynamic earth pressure be calculated using Mononobe-Okabe method and yield acceleration from **Makdisi-Seed (1978)[6][13]**. Yielding acceleration is level of acceleration large enough to cause the wall slide on its base. Peak ground velocity and peak ground acceleration are required to compute maximum displacement in retaining wall.

Permanent displacement 'd_{perm}' in retaining wall during earthquake

$$d_{perm} = 0.087 \frac{{v_{max}}^2 {a_{max}}^3}{{a_y}^4}$$

The yielding acceleration (a_y) given Makdisi-Seed

$$a_y = *tan\emptyset_b - \frac{P_{ae}\cos(ð+\theta+\emptyset) - P_{ae}\sin(ð+\theta+\emptyset)tan\emptyset_b}{w}$$

Whitman and Liao (1985) [13] identified several modelling errors that result from the simplifying assumptions of Richards-Elm's procedure of evaluating displacement of retaining wall during earthquake. According to Whitman and Liao, several factors are neglected by Richards-Elms.

Whitman and Liao Permeant Mean Displacement Formula

$$d_{perm} = \frac{37\,(v_{max})^2}{a_{max}}\, e^{\left(\frac{-9.4\,a_y}{a_{max}}\right)}$$

Choudhury and Nimbalkar (2005)[17], Katdare and Choudhury (2010)[18], and B. Giridhar Rajesh and Deepankar Chaudhury (2016)[20] studied dynamic lateral earth pressure, the pseudo-dynamic method is used to compute the distribution of seismic active earth pressure on a rigid retaining wall supporting cohesion less backfill in more realistic manner by considering time and phase difference within the backfill.

4. EXPERIMENTAL BASED STUDY OF RETAINING WALL

Every theory is extract of experimental study and it is generalization of natural phenomena exist in physical world. The experimental study includes a controlled environment, which stimulates same effects as retaining wall behaves in site condition. According to **Veletsos andYounan (1994)[13]**, the amplification of dynamic earth pressure at resonance is less than the amplification of peak acceleration in dynamic condition. This was very apparent in centrifuged model test by **Steedman (1984)** and **Andersen et al (1991)**. **Anissa Mariahidayati, Sri Prabandi Yani, Wayan Redana, 2015 [21]** found the increase in frequency of vibration and density of backfill soil on particular amplitude cause increment in dynamic pressure. **Agatino Simoni Lo Grasso, Michel Maugeri, and Ernesto Motta (2005) [22]** experimentally found the dynamic pressure distribution is strongly influenced by wall movement; an elastic displacement is exerted by wall during initial stage of motion and permanent wall displacement found at large acceleration level. A reduction of soil wallfriction observed at large increment of acceleration.

A. Bhattacharjee and A. Murali Krishna (2009) [23] found that the displacement of gravity retaining wall can be determined with considerable accuracy by using computer program FLAC 3D. The acceleration increased with the height of backfill. The accelerations are decreased with increase in damping of backfill. **Siavash Kouravand Bardpareh**, **Ashkan G. Holipoor Noroozi and Alborz Hajiannia (2016) [25]** found that the movement of retaining wall during excavation been increases. The influence of compaction behind the retaining walls were carried out with computer program (FEM) explored the effect of construction sequences on the behaviour of a backfilled retaining wall. The construction sequence is a critical factor to be considered in the design stage of gravity type walls.

1. DISCUSSION & CONCLUSION

A variety of different systems is used to retain the soil. Retaining walls may be fail by sliding, overturning, or gross instability but some wall can fail in bending. Ultimately, the type of failure of retaining wall is depends upon gross pressure and point of application. Coulomb's method and Rankine's method used to evaluate the lateral earth pressure on retaining wall for static condition. In static condition, the Rankine method gives greater value of earth pressure than the coulombs method, which may be safe to design retaining wall

In seismic condition, the M-O method is widely used method to estimate dynamic lateral earth pressure but this method does not give distribution of dynamic lateral earth pressure and point of application. According to Seed-Whiteman, the dynamic component of earth pressure acting at 0.6H. where 'H' is height of retaining wall. Steedman and Zeng (1990) takes into account the influence of phase difference and dynamic amplification factors on lateral earth pressure this method found more generalized in terms of pseudo-dynamic approach. Richard-Elms (1979) derived an equation to evaluate maximum displacement of rigid retaining wall during earthquake. Whitman and Liao (1985) identified several modelling errors that result from the simplifying assumptions of Richards-Elms procedure of evaluating displacement of retaining wall during earthquake.

Such complex behavior of retaining wall system can be modelled in computer program (Finite Element Analysis) to evaluate lateral earth pressure and displacement in retaining wall for static and seismic conditions. The construction sequence is a critical factor to be considered in the design stage of retaining walls. The construction sequences influence the stability of the wall both during and after wall construction for static and seismic conditions.

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