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Original Research Article

Current Status of Seismic Design of Retaining Walls

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Abstract:

This paper provides insight into the performance of retaining walls considering seismic conditions by referring to past studies. Inappropriate construction of retaining walls due to incorrect analysis and design causes economic and physical losses. To prevent this, the type and behavior of the soil must be informed to the designer prior to structural design, especially in areas with severe earthquakes. So far, this paper has reviewed different approaches taken by different researchers.

Key words: earthquake zone, retaining wall, soil quality, structure

Introduction

Retaining wall are the important and most common earth retaining structure in civil engineering. It is provided to retain the soil in slope area. Many approaches have been carried out among which Mononobe-Okabe method is the most common method to determine the lateral earth pressure on retaining structure in seismic condition whereas in static condition the Coulomb's and Rankine's theory are commonly used to determine lateral earth pressure. Many attempts have been made by various researcher to determine the seismically active earth pressure on retaining wall which is caused due to loading of earthquake. Due to the earthquake force both the retaining structure and the ground where it is supported got impacted. Under the dynamic loading with the decrease in resistance and bearing capacity of the supporting ground the impact of lateral earth pressure on retaining wall decreases.

Review of Available Literatures

Sudhir K. Jain and Ronald F. Scott (1989) In this study cantilever retaining wall was represent as an Euler-Bernouli beam which was made as connected to the backfill of soil and it was modelled by a shear beam, through the winkler springs. They proposed a simpler linear method for flexible retaining wall under seismic analysis condition. However their method gives forces and moment which has lower value as compare to the value which was obtained by treating the wall as rigid, but as compared to Monobe-Okabe method the results obtained by this method was higher. Their major finding are as follow: -

i **i)** As a result of increment in wall stiffness, forces too increase.

ii **ii)** They also observed decrement in forces when the shear modulus increases.

iii iii) Decrement in mass of wall in combination with mass of soil decreases the forces as well

Susumu lai (2001) The main objective of their study was to review the retaining wall performance subjected to seismic activity which is near the source zones as well recent development in this field.

According to their study number of approach have been developed to analyse the retaining wall under seismic condition. Like simplified analysis in which it is performed according to the conventional limit equilibrium approach and the evaluation of effect of backfill soil and pressure under earth is calculated by refering M-O equation. Simplified dynamic analysis, it is same as simplified analysis and it refer structure as sliding rigid block and it is based on non-linear FEM/FDM analysis of soil structure. Based on the case history of Hyogoken-Nambu, kobe, japan, earthquake occurred on 1995 applicability analysis of effective stress on caisson quay wall confirmed, in which on loose saturated backfill foundation of decomposed granite retaining wall was constructed.

Earthquake motion parameter mostly govern the retaining wall by soil structure interaction analysis. Design of retaining wall under performance based approach is also mentioned in which it is performed according to the dual level of earthquake motion.

S. Caltabiano et al. (2005) Their study was based on a closed form solution design procedure for seismic design of wall and proposed safety factor against sliding and driving moments on the retaining wall and failure mechanism was evaluated.

They assumed that failure surface was plane on coulomb failure mechanism. Difference in the solutions for the passive limit state was significant, mostly for the high value of the soil wall friction angle, whereas it was negligible for active limit state. Theory used in their analysis for seismic design of retaining wall was based on the M-O pseudo static approach.

It was assumed that soil behave as a rigid body which implies that acceleration of seismic wave does not vary within the soil wedge and was coincident with the acceleration at the base of the wall. In their studies, it was found that design of retaining wall done by limit equilibrium procedure satisfied the equilibrium against sliding and tilting.

Koseki, J et al.(2006) In this paper, performance of reinforced retaining walls which was effected during an earthquakes by using the case history which was already published, they used the case history like the retaining wall which was damage during earthquake was replaced by conventional structure and also reviewed the use of shaking tables as well as approaches for the displacement and collapse analysis of retaining soil structure by numerically and analytically. They mentioned that in japan for new permanent structure there is use of greater seismic resistance of geosynthetic-reinforced soil walls as compared to conventional retaining wall structure. Here use of limit state design for geotechnical engineering structure was given importance.

S.N Moghaddas Tafreshi et al. (2008) In this paper, they made a comparison between a traditional method and a new solution which depend upon the pseudo-static equilibrium of the soil wall reinforcement and which was considered as horizontal acceleration. The main difference in this approach with respect to the traditional method was that in this approach, the presence of wall was considered in the equilibrium equation. The result shows that for some value of seismic loading there is increase in the internal angle of soil friction then the value of the critical inclination of the failure plane decreases but there is a decreasing of maximum total geosynthetic force as well as the stability of retaining wall increase. For some value of internal angle of soil friction, there is a increasing of maximum total geosynthetic force along with increasing value of seismic loading, which means when there is increase of seismic loading, the weight of soil failure wedges, it means in order to provide stability of retaining wall there should be improvement of total geosynthetic force is needed.

Dr. M.A Chakrabarti and P.T Mestri (2010) In this paper, improved Rayleigh-Ritz method was used to obtain the natural period of cantilever retaining wall with leveled backfill which was precisely correct. Under the active and passive earth pressure condition the shear force, the bending moment as well as the fundamental natural period of the retaining wall was computed. In this analysis natural period of retaining wall was found out were as response on the retaining wall are found out from IS 1893(3) and they used the response analysis of shear force and the bending moment. Therefore it was concluded in such a manner that the use of IS code analysis gives additional force on retaining wall and as this method was referred from pseudo static approach so, it does not depend on the frequency of ground movement whereas it is only depend onto the maximum amplitude and the value of bending moment and shear force which is computed by IS code method are the maximum.

Mahmoud Yazdani et al. (2013) Mononobe-Okabe was revised in this paper. That method was modified version of coulomb's theory to evaluate the lateral earth pressure. Even though mononobe-okabe method was the prominent choice of civil engineer during design of retaining wall, there was some limitation in that method. Here the problem was created according to simplifier assumption of mononobe-okabe method in a closed form fashion to solve the equation. The main aim of this study was to overcome that limitation and to solve other problem. The modified version of this method was ability of considering cohesion of backfill soil, soil-wall interaction and water table consider to behind the retaining wall. This method was based on the limit equilibrium analysis and a semi analytical without considering any approximation. Seismic active and passive earth pressure can be computed and to clear the methodology there was a parametric study of 10m wall also done. In which it was relieves that standard M-O method was unable to give an answer because of its simple assumption, designing with M-O method is unsafe and turn it into uneconomical design. But the proposed methodology relieves approximate method.

Manya Deyanova et al.(2014) The main aim their paper was to bring new concept for the seismic response of earth-retaining gravity walls. Nowadays gravity retaining wall mostly built with reinforced concrete. It is the most popular and oldest earth retaining structure it mainly fails due to tilting, instability and sliding. Here two types of backfill was considered such as dense and loose sand, dense sand was used for base soil and they is a used the FLAC models and Newmark's block-on-plane models were it was tested and validated. Result shows that gravity retaining wall under seismic condition was considered in three parts i,e foundation of soil, rigid wall and non-linear soil wedge. In the FLAC model observation of failure pattern shows that formation of a failure surface at backfill leads to deformation of the soil under the toe of the wall and soil with settlement behind the wall. Two types of failure was noticed in which first one was due to large deformation in the soil base and second was due to residual wall lateral displacement which was greater than 0.1H. A comparison between Newmark's block-on-plane and numerical model of yielding acceleration was computed from static equilibrium with mononobe-okabe soil wedge, there was underestimate of residual lateral wall displacement by the latter method.

Siddharth Mehta and Siddharth Shah(2015) In this paper they reviewed and discussed the seismic analysis of reinforced wall with soil structure interaction with numeric modelling different method for different soil to analyse seismic condition. It was mentioned that use of reinforced earth walls are far better than traditional retaining wall because of its long height. During 1970 in USA reinforced earth wall was reinforced. It was constructed with the composition of interaction between reinforcing strip with frictional soil. With reinforced earth there was an increase in bearing capacity of the soil and less settlement was noticed as well as the liquefaction of the soil was reduced. It was also reviewed that even though various factor such as type of soil, internal friction of soil and height of wall considered in design of reinforced earth wall, there was some amount of damage in retaining structure during earthquake therefore it become prominent to study the soil structure interaction effect in case of analysis of reinforced wall to prevent damage against the earthquake load. The analysis of reinforced earth wall soil structure interaction become vulnerable and effect of soil structure interaction can't be ignored, difference parameter of reinforced wall show the efficient design.

Kenan Hazirbaba et al.(2018) In this paper, they presented the design of earth retaining structure in which condition was under dynamic loading. Here they mentioned three methods for earth retaining structure design, which are displacement-based approach, finite element/finite difference based approach and force-based approach. According to the above approach/method it was concluded as-(i) designing of earth retaining structure is complex in case of earthquake loading, but it can be possible by using finite element/finite difference method.(ii) For the design of strong ground motion, the displacement based-approach more experienced calculation was required.(iii) If lateral earth pressure under seismic loading increases then, resistance and bearing capacity decreases.(iv) Earth retaining structure which is commonly used can provided with a good design by using the existing solution.

Monica Joseph & Subhadeep Banerjee(2018) In this paper it was reviewed that based on the displacement based approach using finite difference software flac-2D conducted to analyse the seismic response of gravity retaining wall with the actual data of recent earthquake in India. In order to conducted an analysis of gravity retaining wall they have highlighted many work under seismic analysis of retaining wall like monobe-okabe work in which by incorporating coefficient called seismic vertical and seismic horizontal coefficient, dynamic force is converted into the static inertial forces, monobe-okabe has many limitation even if this method is used for finding the passive and active force acting. It is only valid for the situation were the fluctuation of water table is ignored and only work for continues granular backfill. Seed and Whiteman(1970) says that by monobe-okabe method active earth pressure shows appropriate result with actual cases whereas passive earth pressure need to be renew with the actual case. It was concluded that validation their work was done with an existing journal. The dynamic and static analysis carried out in gravity retaining wall. There was comparison between static analysis with Rankine's theory and classic coloumb which shows result of classic theory are on the conservative side.

P.A Yadav et al. (2018) In this paper, they reviewed the analysis of retaining wall in static and seismic condition. The deformation due to static load may be negligibly small whereas in case of seismic condition earthquake can cause large deformation on structure that means they induced greater influence on lateral earth pressure. The static coulomb's and

Rankine's method are being used for the evaluating the earth pressure on retaining structure. Their results shows that, the coulomb's method gives lesser value as compare to Rankine's method ,so it is reliable to design retaining wall. In seismic condition, the monobe-okabe is largely used to evaluate dynamic lateral earth pressure but there is drawback in this method which is it does not give distribution of dynamic lateral earth pressure. According to Wood(1973) that backfill was elastic as well as uniform, in which dynamic thrust was 0.63H from the base of wall. Seed-whiteman(1970) studied that at the 0.6 height of retaining wall dynamic component of earth pressure was acting whereas height of combination of both static and dynamic earth pressure vary between 0.33H to 0.6H according to intensity of ground motion. Steedman and zeng(1990), to calculate the dynamic lateral earth pressure pseudo dynamic approach was considered. Whitman and Liao(1985) had identified many modelling error which was resulted from the assumption of Richards-Elms procedure of evaluating displacement of retaining wall during the earthquake. This type of complicated behavior of retaining wall can be computed in computer program called finite element analysis to evaluate displacement and dynamic earth pressure in retaining wall for static as well as seismic conditions.

Dipali Ahire et al. (2019) In this paper, comparison of different method of analysis such as pseudo dynamic method, kinematic limit analysis, limit equilibrium method, conjugate stress method as well as displacement based approach. Result shows that, for different method of approaches, seismic earth pressure also varies, with increasing the parameter of slope of backfill, angle of wall friction there is increase of seismic earth pressure. It was also shown that the method like displacement based approach, horizontal slice method as well as kinematic limit analysis providing higher value than the Monobe Okabe method on the other hand pseudo dynamic approach providing favorable value of seismic earth pressure coefficient.

Liang Jia et al. (2019) In this paper, they assumed log spiral slip surface based on the horizontal slice method (HSM), they analyze the stability of reinforced retaining wall under seismic loads by calculating the tensile force of the reinforcement. The slice method is used to find out the critical failure angle of the backfill wedge under the complicated conditions whereas interactive calculation method is used to find out the tension crack depth of active earth pressure under seismic loads. Their result shows that tensile force increases with increase of seismic acceleration coefficient as well as unit weight on the other hand, the tensile force of reinforcement decreases with the increase of soil friction angle. With regard of the log spiral slip surface, it was same in various cases. The slip surface of the retaining wall moved towards the wall side with increase in seismic load, soil cohesion, and unit weight and friction angle.

Sanjay Nimbalkar et al. (2019) In this paper coulomb's method was used to determine the behavior of retaining structure under static condition whereas mononobe-okabe approach was used to determine the behavior of retaining structure under seismic condition. Pseudo-dynamic method could be used for computation of retaining structure under seismic condition in a more realistic manner as compare to mononobe-okabe approach but pseudo-dynamic approach done without effect of seismic wave and time. Here retaining wall was considered as rigid and cohesive nature of backfill soil and the analysis of earth pressure in cohesive soil which was carried out by the horizontal flat element method. In their result it was shown that with the increment of soil cohesion there was decrement of lateral active earth pressure and height of point of application of active thrust increases whereas with the increment in internal friction angle of cohesive soil lateral active earth pressure decreases and as friction angle increases there is increase of tension crack from the surface of the cohesive soil.

Conclusion

All researchers concluded that the lateral earth pressure coefficients for non-cohesive backfill calculated from the Mononobe-Okabe analysis are quite good with the values obtained in small scale structures. In the case of retaining structures, most researchers agree that the increase in lateral pressure due to base excitation is greater at the top of the wall, and the resulting increment is effective at a height of 0.5H to 0.67H above the base of the wall. An increase in lateral pressure due to dynamic action may be accompanied by an outward movement of the wall, with the amount of movement increasing with an increase in the amount of base acceleration.

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