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Seismic Analysis of Stability of Slopes – an Overview

Rajashekhar Malagihal[1], Dr. Vishwanath K. G.[2]

[1]*Assistant Professor & Ph.D. Scholar, Dept. of Civil Engineering, Jain College of Engineering, Belagavi*
[2]*Professor, Principal and Director, Jain College of Engineering, Belagavi*

Abstract - *India being the world's second most populated country, with more than 1.27 billion people (2014), that is more than one-6th of overall. In order to provide shelter and basic needs for the people, construction activities are going on hilly areas. Here it becomes prime responsibility of Civil Engineers to ensure the stability of slopes both statically and dynamically. Wide spread applications in slope engineering include excavation, mountain roads, railways, ditches, Earth dams, reservoirs, mines for the open quarry and stabilization of the ocean slope. Incline discontent among the most commonly expected disaster events on the planet is regarded as a standout. The slope's stability is greater due to the driving force's strength. Therefore, Studying of the slope stability is essential to protect the slope against failure and to decrease the likelihood of failure of the slope.*

In this review paper, it includes overall review of slopes, types and causes of failure of slopes and all historical methods of analysis on stability of slopes

Key Words: Stability of slopes, Seismic stability of slopes.

1. INTRODUCTION

Among all the natural calamities, earthquake is one of the most dangerous and unpredictable event, with which civil engineers have to deal. Understanding and finding the solutions for the hazards of earthquake is studied from many scientists of various fields of engineering. The damaging effect of earthquakes has been studied for centuries. Geotechnical engineering is the branch, which has direct connections and strong contribution to the responses from earthquake.

The most important seismic hazards one can study in civil engineering are; ground shaking, super structural hazard, foundation failure, liquefaction, landslide, collapse of slopes, retaining structure failure etc. In geotechnical engineering, both earth slopes and earth retaining structures are massive structures. The stability and safety of these structures to carry both static and dynamic loads is very important.

1.1 Types of Slopes

Slopes are generally classified into two types, they can be named **natural slopes** which have naturally occurred and the other one is **man-made slopes** which is also called as artificial slopes or engineered slopes. Considering the extent of dimensions of slopes, they can also be names as **infinite and finite slopes.**

Natural Slopes: The slopes designed by continuous process of erosion and deposition by natural agencies are called as natural slopes. Example; hill sides and river banks etc. These natural slopes are with large dimensions and especially height of the slope being very large compared to the study area of slopes. Therefore, natural slopes can be put into infinite slopes. The slope behaviour can be predicted easily in natural slope by knowing the presence of old slip surfaces. The other activities like valley rebound, glacial phenomena, and no uniform swelling of clays and clay-shale will cause the slip surface.

Engineered Slopes: The slopes which are man-made are called as engineered or man-made slopes. Example; slopes of embankments of dams, roads, rails, canals, cuts and fills for the roads and rails etc. In Engineered slopes height of the slopes becomes important dimension while analysing the stability of it. So such slopes are also called as Finite slopes.

1.2 Modes of Slope failure

Failure may be of three types - **Face failure:** If the slip surface intersects the slope above the toe, it is known as face failure. For the face failure, the slide may be a plane slide or a rotational slide. This is known as shallow failure. **Toe failure:** If the arc of failure passes through the toe, it is known as toe failure. **Base failure:** If the failure comes about along a sliding surface. That goes below the toe i.e. through the foundation the slide is referred to as the base failure.

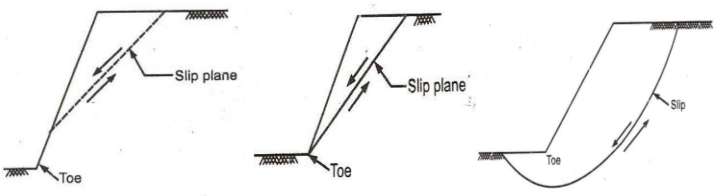

Fig – 1.1: (a) face failure, (b) toe failure, (c) base failure

2. METHODS OF ANALYSIS

When the shear stress goes above the shear strength, slope tends to fail due to sliding movements of materials. Hence the factors that will increase the shear stress or reduces the shear strength will have a high possibility of creating the slope failure. The quantitative determination of the stability of slopes is essential in a number of engineering actions. As it is with stresses acting on the slopes and strength of the slope material, in order to have stable slopes, one must ensure its factor of safety greater than unity.

Considering above statements and factors affecting slopes failure, presently following methods of analysis are available. Broadly all methods can be grouped under two headings; one

– Limit Equilibrium Method (LEM), second – Finite Element Method (FEM).

2.1 Limit Equilibrium Method (LEM)

LEM is generally based on the ideologies of the static equilibrium of forces and moments, traditionally the Analysis of slopes has been carried out by LEM. Various LEM have been developed for slope stability analyses. The first method was introduced by Fellenius in 1936, which was generally known as ordinary or Swedish slip circle method.

Swedish slip circle method: The method of sliding the surface developed by Swedish engineers is curved ring. The failure surface was assumed to be an arc of circle. To investigate stability, the easiest rounded study is used for a cylinder and accepts that it is only cohesive.

Log Spiral method: In this method the assumption is made that the sliding surface is in specific logarithmic spiral shape. For statically determination the logarithmic spiral procedure is used. The radius of the spiral shape varies with the angle of rotation about the centre of the spiral.

Ordinary method of slices: It is the simplest method of slice to use. The assumption was made that the resultant of the inter slice force acting on any slice is parallel to its base. Here the inter slice forces are neglected. This method is also referred to as "Fellenius' Method" and the "Swedish Circle Method".

Bishop method: In this method the forces acting on the sides of the slices where taken in to consideration by Bishop. Here also the assumption was made that slip surface is an arc of the circle and the ratio of actual shear strength of soil to the required to maintain limiting equilibrium. This method is quite upgraded method of Swedish slip circle method.

The Friction Circle Procedure: This technique is suitable for in homogenous soil with $ø > 0$ for complete or well organized stress assessment. The standard way of shear force and frictional component direction transfers along the surface to form a tangent to the circle with a radius R, called as friction circle.

Janbu's Simplified Method: This method is adopted for the non-circular slip surface. The assumption made in this method is that the inter slices forces to be horizontal and the shear forces are zero.

2.2 Finite Element Method

The method of finite elements is more respected than the method of limit equilibrium slope stability consideration because the method of finite elements fulfils the balance of any point in the quantity of soil (local area) and the surrounding soil (global area), while LEM is the only total force or moment balance that satisfies the quantity of sliding.

Therefore, the theoretical condition in FEM is merely to define the requests for failure, not the difficulty of source and models in LEM. The derived safety factor in FEM is also supposed to be more precise in investigation than the LEM.

The FEM can be analyzed in 2D and 3D as well. Plaxis also comes under finite element methods. Both LEM and FEM based software are commonly used in geotechnical computations.

3. HISTORY AND LITERATURE REVIEW

An effort is made here to find and review the published literature related to stability of slopes the available literature has been classified as follows.

3.1 Static Slope Stability Analysis

In the past a number of scientists have studied on the on stability analysis of slopes. All the studies are based on the assumptions of potential sliding surfaces. In brief and particularly, the oldest reference we get are from Coulomb (1776) and Culmann (1886); they obtained best results for vertical slopes by assuming soil as homogeneous and isotropic and critical slip surface as planar (straight). In earlier 19th century Petterson (1916), Fellenius (1927) used the concept called 'method of sliced'; they assumed that the critical slip surface as an arc of a circle. Taylor (1937) introduced a stability number and stability chart to find the factor of safety and critical slip surface for homogeneous soil with 'friction circle method'. Rendulic (1935) and Frohlich (1953) proposed similar theory as Taylor suggested, but with logarithmic spiral shaped rupture surface. Bishop (1955) introduced 'limit design' into stability analysis and introduced effective stress consideration into it. There were many researchers; Spencer (1967), Janbu (1954), Meyer (1958), Isao Minami (1963) gave the theory on stability of slopes for homogeneous, isotropic and for circular arc as slip surface.

Janbu (1954) generalized method of slices considering general shape for rupture surface. But, his solutions are applicable only for shallow slopes. Nonveiller (1965) proved that, Janbu's method gives error, if it implemented for deep slopes.

Margenstern and Price (1965) considered general shape for the slip surface, and assumed a more general functional relationship between normal stress and shear stress at the interface of the slices; these functional relations can be established by elastic theory or by field observation.

David M (1999); in his book 'finite element analysis in geotechnical engineering' explained the stress-strain behaviour of soil. When this method is applied on the slopes, stress-deformation analysis can predict the magnitude and patterns of stresses, movements and pore water pressures during and after construction. Thereby, most commonly, nowadays stability of static slopes are analyzed by finite element method for accurate results.

3.2 Dynamic Slope Stability Analysis (History)

Fellinius (1927), Terzaghi (1950), Prakash et.al (1968), studied on stability of slopes considering horizontal waves. They used 'Psudo-static method', for the analysis where earthquake loads are converted into pseudo-static loads by multiplying some coefficients. Terzaghi stated that "the concept it conveys of earthquake effects on slope is in-accurate, to say the least". This method ignores the vertical acceleration of seismic waves, which is completely rude.

After Pseudo static approach, many researchers worked with new method called "Displacement analysis" Few scientists who worked on it are follows. Newmark (1965)(Sliding block analogy), Seed et.al (1970)(Strain potential approach), Makdisi – Seed's (1978) analysis, Hamada et al. (1986)(Deformation failure analysis), Byrne et al. (1992), Baziar et al. (1992), Bartlett and Youd (1992) etc.

Previous section gives varies method for the analysis of stability of slopes under seismic loads. They all estimate the permanent displacement produced by deformation failures. Most of these methods are highly empirical and give approximate estimation.

3.3 Recent Studies on Dynamic Slope Stability Analysis

Chen et al. (2010) introduced Block Element Method for rock slopes subjected to seismic load. According to his conclusions in his paper, seismic stability of slopes by both pseudo-static method and dynamic method has got many demerits in them. The latter one is on the principles of finite element method. Still author found difficulties in FEM in the simulation of numerous rock discontinuities. They framed matrices of stiffness, mass and damping, the dynamic governing equation for rock block system is established.

Radoslaw et al. (2011) gave the stability charts for 3D failure of slopes subjected to seismic loads. They considered plain strain and substitution of a quasi-static load for the seismic excitation. In this paper, analysis is based on the kinematic theorem of limit analysis and used approximate method of limit equilibrium. A rotational failure mechanism is used with the failure surface in the shape of a curvilinear cone sector passing through the slope toe, typical of steep slope. This method is can be used only for specific, well defined slopes. This method is limited to steep slope with toe failure only.

Ellen et al. (2011) compared between fully probabilistic approach and pseudo-probabilistic approach on seismic sliding displacement of slopes. Permanent sliding displacement represents damage parameter typically used to evaluate seismic performance and stability analysis of slopes. According to authors, rather than relying on engineering judgment to decide whether slope performance is acceptable, it may be more useful to consider that poor performance will occur.

Ahangar-Asr et al. (2012) used the Genetic Algorithm (GA) techniques to find the most probable slip surface in 3D Slopes considering the effect of earthquake. Genetic Algorithm is random probability searching technique. Basically it is used in natural biological evolution for natural selection. GA operates on a population of potential solutions applying the principle of survival of the fittest to produce successively better approximations to a solution. Authors used this technique for optimization of critical slip surface and its stability safety factor. The overall process is included four main stages:

i. Definition of an initial slip surface as input for the program. Here inputs are soil properties like density, angle of internal friction, cohesion etc.
ii. Calculation of the coordination values of the boundary points of the elements (nodes) taking the advantage of the "Coordinate" subroutine,
iii. Determination of the stability factor of safety of the initially defined slip surface (first generation of the results) using "Stab 3D Quake" subroutine considering all static and earthquake loads applied and their orientations.
iv. Applying GA using "Optimization" subroutine and evaluating the fitness of the resulted factor of safety and slip surface and repeating stages (ii) to (iv) as many times as needed (increasing the number of generations) if necessary to find the minimum value of the factor of safety and its corresponding slip surface.

Qingchao et al. (2017) studied on rock slopes stability analysis subjected to earthquake based on back analysis of shear parameters. They conducted 3D analysis on existing slopes by FEM techniques and determined global stability of slope and identified the damage region. The shear strength parameter of the damaged region are determined by back based on stability and failure status before and after earthquake and monitoring the same. Then the evaluation under static, dynamic and rainfall conditions were carried out respectively. The result shows that the failure mode of the slope under seismic load is consistent with actual situation when the lowest material parameters are used.

4. CONCLUSIONS WITH FUTURE SCOPE

Since early 20th century, there were many researchers who gave theoretical and practical concept for the determination of the factor of safety and determination of critical slip circle for the static and dynamic slopes. Initially failure surface assumed to be planar (Coulomb 1776 and Culmann 1886); then later it is modified to arc of circle (Petterson 1916, Fellenius 1927 and others). At the end of the 20th century, few researchers consider the realistic nature of the slope, and assumed the general slip surface. In this era finite element analysis on permanent displacement method being the best method for the analysis of stability of slopes for static loads.

- Practically speaking, it is difficult to get a homogeneous and isotropic soil for the analysis. From the literature review it is observed that, many scientists assume soil to be homogeneous and isotropic. The studies on slopes made up of different layers of soil are very limited.

- Till 20th century, there were only three theories available, giving concept of factor of safety for slopes subjected to seismic waves. They are (i) pseudo-static (ii) plastic deformation (iii) dynamic analysis using finite element method (FEM). In early start of the 21st century, except third, rest two was proven as approximate and non realistic methods.
- Geosynthetics (especially Geogrid and geotextile) are recent soil reinforcement materials introduced into geotechnical field of engineering. After studying many research papers from various publications, it is concluded that, very limited research has happened on Geogrid reinforced slopes and earth retaining wall subjected to seismic waves.
- Genetic Algorithm (GA) is new emerging technique introduced into civil engineering for optimization techniques. In the present research work an attempt shall be made to implement this technique to determine the critical slip surface for all possible realistic conditions of slopes and retaining walls.

REFERENCES

[1]. Ahangar-Asr, A., Toufigh, M. M., & Salajegheh, A. (2012). Determination of the most probable slip surface in 3D slopes considering the effect of earthquake force direction. Computers & geosciences, 45, 119-130.

[2]. Bartlett S. F and Yound T. L. (1992) "Empirical analysis of horizontal ground displacement generated by liquefaction induced lateral spread" Technical report NCEER-92-0021, National Center for earthquake research, Buffalo, NW.

[3]. Bazira M. H., Dobry R., and Elgamel, A. W. MEnineering evaluation of permanent ground deformation due to seismically induced liquefaction" Technical report NCEER-92-0007.

[4]. Bishop A. W. (1955), "Use of the slip circle in the stability analysis of slopes", Proc. ASCE, Vol. 92, SM-5, pp 51-65

[5]. Chen D. (2010) "Some empirical formula for hazard analysis in China", Proceedings, 8th World Conf. on Earthquake Engineering, San Francisco, Vol 1 pp 173-180.

[6]. Coloumb, C. A. (1776), "Essai sur uneApplication des Maximis et Minimis a eueiques problems Sta-ique Relatifs a 1, 9 Architecture, Mem. Acad roy. Pres. Drivers Savants, Volume 7 paris.

[7]. Culmunn, K. (1886), :Die Grafische static, Zurich.

[8]. Ellen M, Rathje, M., Gokhan Saygli (2011), "Estimating fully probabilistic seismic sliding displacement of slopes from a Pseudoprobailistic approach", Journal of Geotechnical and Geoenvironmental Engineering ASCE, Vol. 137(3) pp 208-217

[9]. Fellenius W (1927) "Erdtische Berechung Unit Reibung and Kohaesion (Adhaesion)und unter Annahme kreiszy hindeisrher Gleitflaechen, Ernst Berlin

[10]. Frohlich O. K. (1953), "The factor of safety with respect to mass of soil along an arc of logarithmic spiral", Proceedings 3rd int. Conf. , SMFE Vol. 2, pp230-238.

[11]. Gabr, M. A., Rasdorf, W., Findley, D. J., Butler, C. J., & Bert, S. A. (2017). Comparison of Three Retaining Wall Condition Assessment Rating Systems. Journal of Infrastructure Systems, Vol. 24(1), 04017037.

[12]. Hamada M, Yasuda S, Isoyama R, and Emoto K, (1986), "Study on lequifaction induced permanent ground displacements", Report for the association for the development of earthquake prediction"

[13]. Isao, Minami (1963), "The stability table of slope of an earth dam", Proc. 2nd Asian regional Conference on SMFE, vol 1, pp 286-293.

[14]. Janbu (1954), "Stability analysis of slopes with dimensionless parameters", Harvard Soil Mechanics series No. 46

[15]. Lin, Y. L., Cheng, X. M., & Yang, G. L. (2018). Shaking table test and numerical simulation on a combined retaining structure response to earthquake loading. Soil Dynamics and Earthquake Engineering, 108, 29-45.

[16]. Makdisi, F. I. and Seed H. B. (1978), Simplified procedure for estimating dam and embankment earthquake induced deformation", Journal of Geotechnical Engineering Division, ASCE Vol 104, No GT7, pp 849-867.

[17]. Meyer O. H. (1958), "Computation of the stability of slopes", Proc. ASCE, Vol 84, SM-4, pp 1-12.

[18]. Mrgenstern, N. Price. V. E. (1965), "Analysis of the stability of General slip surfaces", A Geotechnique Vol 15, No. 1, pp 79-93.

[19]. Newmark N. M. (1965), "the effect of earth quake on dams and dam embankment", Geotechnique Vol XV, No 2, pp 129-160.

[20]. Nonveiller E. (1965), "The stability analysis of slopes with a slip surface of General shape", Proc. 6th int. Conf. SMFE, Vol 2 , pp 522-535.

[21]. Pain, A., Ramakrishna Annapareddy, V. S., & Nimbalkar, S. (2018). Seismic Active Thrust on Rigid Retaining Wall Using Strain Dependent Dynamic Properties. International Journal of Geomechanics, 18(12), 06018034.

[22]. Petterson K. E. (1916), "Meddelande angaende den av Goteborgs Hamnstyrelse tillsatta kajkammissioneus arbeteu, (information of the work of the quoy commission of the Harbour Board), Tekniska Samfundets Hand linear, Vol 6, No 1.

[23]. Prakash, S. Saran, S. and P. Raj (1968), "Seismic stability analysis of homogeneous slopes", Symposium on earth and rock fill dams", November, Beas Dam site, pp 10-20.

[24]. Qingchao Lv, Yaoru Liu, Qiang Yang, (2017), "Stability analysis of earthquake induced rock slope based on

back analysis of shear strength parameters of rock mass", Journal of 'Engineering Geology' 0013-7952, pp 39-49.

[25]. Rankine W (1857), "On the stability of loose earth" Philosophical Transaction of the Royal society of Landon, Vol 147.

[26]. Rodoslaw L. Michalowski, F. Tabetha Martel, S. (2011), "Stability charts for 3D failures of Steep slopes subjected to seismic excitation", Journal of Geotechnical and Geoenvironmental Engineering ASCE, Vol. 137(2) pp 183-189.

[27]. Ruan, X. B., Yu, R. L., & Sun, S. L. (2013). Analysis of seismic active earth pressure on retaining walls based on pseudo-dynamic method. Journal of Highway and Transportation Research and Development (English Edition), 7(2), 34-39.

[28]. Sadek, H., & Lissel, S. (2013). Seismic performance of masonry walls with GFRP and Geogrid Bed joint reinforcement. Construction and Building Materials, 41, 977-989.

BIOGRAPHIES

Prof. Rajashekhar Malagihal M. S.
Assistant Professor and HoD, Dept. of Civil Engineering, Jain College of Engineering Belagavi.

Dr. K. G. Vishwanath
Professor, Principal and Director Jain College of Engineering Belagavi.