**Review on “Assessment of the effect of lateral dynamic forces on rcc cantilever l-shaped and t-shaped retaining wall with height variations”**

Jayesh Harode¹, Dr. Kuldeep Dabhekar², Dr. P.Y.Pawade³, Dr. Isha Khedikar⁴

¹ PG Student, Department of Civil Engineering, G H Raisoni College of Engineering Nagpur, Maharashtra, India
², ⁴ Assistant Professor, Department of Civil Engineering, G H Raisoni College of Engineering Nagpur, Maharashtra, India
³ Professor, Department of Civil Engineering, G H Raisoni College of Engineering Nagpur, Maharashtra, India

**Abstract:** It is now becoming very essential to analyse the behaviour of retaining structures due to their wide infrastructural applications. The important factors which are affecting the stability of the retaining wall are the distribution of earth pressure on the wall, material of backfill & its reaction against earth pressure. There are several types of retaining walls, out of them the cantilever retaining wall is adopted for present design and study. In this paper, the study of literature based on the design of the cantilever retaining walls under seismic or dynamic conditions is studied. From the studied literature, many authors performed their calculations in Excel sheets by a manual method. Then the Results obtained from the manual calculation are then validated in STAAD pro. Several authors show the calculated quantity of steel and concrete required for various heights of walls. It is also concluded from the study that the design of cantilever retaining wall is suitable, safe, and economical up to a height of 6m, after that banding moment at toe increases. Some authors have also shown the calculated factor of safety for different height conditions. From the study of mentioned literature, we can recommended to also show the graph of bending moment with height variation.

Both the designs are done for various heights ranging from 3 m to 6 m.

**Keywords-** Cantilever Retaining wall, Inverted Walls, Earth Pressure distribution, manual design, Indian Standard Code, STAAD Pro.

1. **Introduction**

Cantilever retaining wall is widely used for cross-drainage works, for maintaining slope stability, for road embankments, etc. Sometimes retaining walls cause serious damage due to earthquakes and other dynamic forces. It is now the responsibility of structural engineers to improve the design and stability of the retaining wall and also make it more economical [4, 6]. We can define concrete CRW as the construction of RCC retaining structure to retain the backfill material or soil by their cantilever action. The bottom portion of CRW i.e. base slab acts as fixed support, and it provides stability to...
the wall from sliding and overturning effect [5]. The cantilevered stem portion is wide and rigid at the bottom and is gradually less at the top [7]. In the seismic condition, analysing the behaviour of retaining structures has been a very important task due to their large applications in several areas of infrastructure. This study aims to design inverted T and L-shaped retaining walls under dynamic conditions, and comparing quantities of steel, concrete, and factor of safety requirement [8]. From the result of this study, designers can directly use the calculated factor of safety for their design and also can assume the percentage of steel and concrete required for 3 m to 6 m height for both inverted T-shaped and L-shaped retaining walls [9]. The height of the cantilever retaining wall is suitable up to 6 m whereas the gravity wall is up to 10 m hence this study consist of a design for height up to 6 m.

We can classify retaining walls into two major types,

1.1 Gravity type retaining wall: This type of retaining wall attains stability by its weight, that’s why it’s called gravity type wall. This type of wall is constructed by using materials like concrete, stone masonry, reinforced and unreinforced material. The main drawback of this wall as it is economical only for small heights [21].

1.2 Semi Gravity type retaining wall: This type of wall has less cross-section area as compared to gravity type wall. To reduce its cross-section, some amount of steel bars are provided. This is classified into two types, cantilever and counterfort retaining wall [21].

2. Literature Review:

The following literature reviews are related to the response of retaining walls subjected to static and dynamic loadings. Also, it includes the study of strengthening the retaining wall and make it more stable and economical.

Abood T, et.al. 2015 [1] have done their work on a T-shaped cantilever retaining wall of 4 m height. All their calculations are based on the ACI code. The author did their work in two parts, which includes evaluation of the complete structure under service load, which includes the checks for overturning, bearing, and sliding, and the second part is the design of components of the retaining wall like heel, stem, and toe portion. All the standard geotechnical data were assumed. They design all the components of the retaining wall for shear and bending modes of failure.

Mahure A, et.al. 2019 [2] have done a design of cantilever T-shaped and L-shaped walls to study the dynamic behaviour. He designed both the walls for heights span of 3 m to 6 m for comparing their factor of safeties. The active earth pressure is calculated based on Rankine’s and coulomb’s theory, and various checks for stability are performed. As per IS 456:2000, a factor of safety is calculated and compared for various heights for both the wall. He also prepared a table of steel and concrete required for various heights and present it in graph form. He concluded that the L-shaped retaining wall consumes more steel and concrete than the T-shaped retaining wall.

Rouili A, 2013 [3] have done numerical analysis on L-shaped retaining wall. The author considers three walls of different heights (3 m, 5 m, and 9 m). To find earth pressure on the wall base, four different bases to height ratios are considered (0.3, 0.5, 0.8, and 1). The model is 28 m long at the base and 14 m in height. Their analytical study shows that, for B/H ratio less than 0.5, rotational is high on the toe side of the wall whereas, for ratio more than 0.8, translation is high in toe portion. Hence, a B/H ratio between 0.5 to 0.8 is considered good for design.

Dhamdhere D, et.al. 2018 [4] have worked on retaining walls with reliving platforms. He designed a retaining wall with and without a relieving platform. In their design, they fixed the dimension of the retaining wall and checked the stability conditions. After computing bearing pressure, all the other
components of the retaining wall are designed. They fixed the position of the reliving platform at mid-height of the wall. After designing all the components they perform various checks for stability like overturning, sliding. Finally, they compared the structural costing with and without reliving platform and concluded that for walls having the larger height of backfill, reliving platform reduces the earth pressure to some extent, which results in a safe structure.

Sichani M, et.al. 2012 [5] have carried out their study by considering three models of inverted T-shaped cantilever retaining walls with and without the shear key to see the effect of seismic forces. The models are of height 3 m, 6 m, and 10 m, which is considered for design. The author used the finite element method for their design and compared the design moment of stem and stability of wall to find out the effect of a shear key. The wall models are subjected to two real predominant frequencies. Their parametric study concluded that the wall with a shear key shows much more moment than a wall without a shear key. Also, the wall without a shear key can move away due to earth pressure in the given earthquake conditions, but the provision of a shear key prevents it.

Sari U, et.al. 2019 [6] used PLAXIS 2D software for modelling the gravity type retaining wall. He assumed the dimension of the gravity wall by trial and error method because if any component of the wall gets failed then we can change the dimension and reassumed the safe dimension. He worked on retaining all with 3 m high vertical slopped backfill. The active earth pressure on the wall is produced by two cohesive soil layers. He designed eight wall structures and concluded that the retaining wall retaining cohesive soil with 90-degree vertical slope, the factor of safety increases with the dimension of the retaining wall.

Conti R, et.al. 2019 [7] have done the numerical investigation on the real model of the retaining wall and aimed to simplify the design. Their study consist of the pair of retaining wall with backfill material of dry sand and is subjected to original earthquake acceleration values. The model of soil selected for study is such that it follows the Mohr-Coulomb failure criteria and three past seismic acceleration is used which is related to the real earthquake. He concluded that the cantilever retaining wall with dry sand backfill causes permanent displacement before its actual critical point.

Yadav P, et.al. 2018 [8], have studied and given a brief review on the design and analysis of the retaining walls under static and seismic conditions. The author has given a brief review of traditional methods like Coulomb, Rankine, Terzaghi, and Mononobe-Okabe methods. He said that Coulomb and Rankine’s method is only used to evaluate earth pressure in a static condition, whereas Mononobe-Okabe method is used to evaluate earth pressure in dynamic conditions. All the above methods have some limitations, hence Steedman and Zeng (1990), Whitman and Liao (1985), Richard-Elms (1979), and many more authors tried to complete these limitations.

Patil S, et.al. 2015 [9] have designed and analyse the cantilever retaining wall to reduce the stresses generating on the face of the wall and to locate the economic position for the step. He studied various failures occurs in-wall and factor of safety required. He designed and analyse the cantilever and counterfort retaining wall and compared it with the model of retaining wall provided with step. Furthermore, he said that for the backfill of height more than 10 m, the design of retaining wall becomes uneconomical because of its massiveness. He designed a wall for a height of 6 to 15 m and estimated the quantities of steel and concrete required. For the stepped cantilever retaining wall, he concluded that it is very economical for heights 10 to 15 m, and it can become the best option against the walls of large heights.

Puri S, et.al. 2018 [10] have done their study on retaining walls with Geogrid Reinforced Soil and compared it with RCC retaining wall concerning their properties, construction process, cost of construction, and time required to construct it. For their study, they had chosen a bridge construction site where the Geogrid Reinforced Soil retaining wall is to be constructed with 6 to 8 m height. They
design the same height of the RCC retaining wall for study. They concluded that the final cost of Geogrid Reinforced Soil and RCC retaining wall for 6 m height is Rs.19170 and Rs.46125 respectively. Hence, Geogrid Reinforced Soil retaining wall saves cost around 58% and 65% respectively for both 6 m and 8 m height. Also, it requires less amount of time for construction.

Upadhyay A, et.al. 2011 [11] have done their study on cantilever retaining walls subjected to seismic forces. They aimed to find out the response of the retaining wall subjected to dynamic conditions. For finding out the seismic behaviour of the walls, they developed a numerical model by using the finite element method. They validate their model with the physical model studied in the literature. This validated model wall is then subjected to seismic forces. They concluded that Y-directional stresses increases at the toe side and decrease towards the heel side.

Sharma C, et.al. 2014 [12] assumed a trial section of the cantilever retaining wall. The study is done on various heights of stem varies from 3.5 to 5.5m and for various densities of soil varies from 18 to 40 KN/m². They did design and perform various checks against overturning and sliding. Soil pressure distribution and bending failure are also computed. They designed the heel as a cantilever component of the wall and it causes both upward and downward forces. They show various graph charts for moment v/s total width of heel slab. The variation in the graph changes with the height of the stem. By using this chart, the percentage of steel required can be calculated easily. The same graph is prepared for the toe side and the percentage of steel required can calculate. Finally, they concluded that if we increase the density of material overturning moment increases.

Santhil K, et.al. 2014 [13] have adopted four retaining walls for their study. These walls have different geometries. The main aim of this study is to determine the response of cantilever and counterfort walls under lateral earth pressure by using FE simulation. The data obtained from the study are then compared with other walls. They concluded that as the height of the stem increases, the displacement and stresses of the wall also increases. They also showed the cost estimation chart for all four models of retaining walls.

Kayabekir A, et.al. 2020 [14] have done their study on the design of L-shaped retaining walls to optimize the cost and size of retaining walls by considering the effect of soil properties, loads, and depth of foundation. This parametric study is performed in two steps, in the first step he investigates the change in cost of material and many reference cases. In the second step, he investigates the change in wall dimension and did the calculation of base thickness and width of the foundation. All this study is performed by using the Jaya algorithm and used 5 different shear strength angles and soil unit weights, and 4 bearing pressures acting on the base. Also considers 5 different surcharge loadings and depths of foundation. The author concluded that the depth of excavation is the most effective factor in the design of an L-shaped retaining wall. As the excavation depth increases, the width of the foundation also increases, and hence cost of the structure increases.

Cameron W et.al. 2004 [15] have done this study on cantilever retaining walls to develop the improved method to calculate dynamic earth pressure for designing a flexible retaining wall. The research contains three steps, first is the characterisation of seismic event data, the second step is numerical analysis to find out the seismic response of the wall. The third step is the development of an improved method to find out seismic earth pressure for the flexible design of the cantilever retaining wall. The analysis is performed on a retaining wall of height 6.1m. The backfill is considered as medium dense granular with dense soil below the foundation. The result of the study provides an improved method to design a flexible retaining system and lower the seismic risk.

Uray E et.al. 2019 [16] have done a detailed parametric study on cantilever retaining walls to study the design optimization of the wall. This study aims to minimise the weight of the wall. The other parameters of the wall like base width, base thickness, toe and, heel with safe stability are also determined by a
design algorithm considering different soil parameters. The author used a harmony search algorithm coded by using MATLAB. He performed 120 wall designs by considering different unit weights and internal friction angles with a height of wall ranging 4, 5, 6, 7, 8m. Their detailed parametric study shows that the change in a unit weight of soil does not affect the design weight of the wall.

Gursoy S et.al. 2009 [17] have carried out a linear and non-linear analysis of retaining walls by using a structural analysis program named LUSAS based on the finite element method. The value obtained from this method is compared with values obtained by the method given in Eurocode-8. The structural analysis is performed on the model of cantilever retaining of height 8m in LUSAS. After this analytical study, the conclusion drawn is the value of overturning moment calculated with non-linear analysis with FEM of the wall is found greater than the value obtained from linear analysis of FEM and other methods.

Ahani M et.al. 2019 [18] have performed this study for the optimum design of retaining walls by minimising the displacement and cost of wall construction. The author used a non-dominated sorting genetic algorithm that is NSGA-2 for their study. The analytical model of retaining walls consists of nine variables and is implemented in MATLAB. The analysis is performed in three cases to find out the displacement. In the first case, the wall is considered with both toe and heel portions and in the second case, it is considered without toe and heel. In the third case, the wall is considered without a toe slab. Finally, the computer program is developed for designing a cantilever retaining wall of 8m height.

Garini E et.al. 2016 [19] have carried out numerical investigation on T-shaped flexible retaining wall having two layers of sandy soil strata to find out the dynamic response of wall and is subjected to ground acceleration. In this paper author trying to validate the result of the centrifuge experiment performed by other authors. He compared the result obtained by centrifuge experiment with the Mononobe-Okabe method. The result is presented in the form of acceleration-time history for three earthquake events.

Tafreshi S et.al. 2008 [20] have done a study on a pseudo-static equilibrium of RCC gravity retaining wall by considering horizontal acceleration and illustrate the modified limit equilibrium approach in dynamic conditions by considering seismic inertial force as pseudo-static. Also, he performed a stability check of a wall for finding the reinforcement required and the inclination of the angle of failure. He concluded that as the angle of internal friction increases, the inclination of the angle of failure increases. The failure angle of soil is also determined.

Khan S et.al. 2017 [21] have done their study on an underground retaining wall designed for pumping stations by using the seismic coefficient method. They did the seismic analysis by considering the parameters of earthquake zone IV. The important thing in this study is that they consider column and beam arrangement with retaining wall which acts as a buttress for the wall. A 9.4m retaining wall is modelled in STAAD Pro. v8i. In their model, the force acting on X and Z-direction is considered. Their analysis shows that after applying load the columns act as the beam and the beam acts like the column. They concluded that if the station wall structure is divided into some parts, the earth pressure gets divides and thus the thickness of the wall can be reduced. They also show the table of the summary of displacement in X and Z-direction and found that after provision of beam and column, the maximum displacement is caused only 5.6mm.

Sobana U et.al. 2018 [22] have performed this study to determine the lateral earth pressure and its effect on the stability of the retaining wall by using ACI code. The model of the structure is created in STAAD Pro. After designing and analysing the cantilever retaining wall by considering different heights and various soil conditions in STAAD Pro., they calculate various factors of safety for height 2 to 10m height for different backfill and foundation soil. From their study, it is clear that FOS for overturning is very large if the material present below the foundation and beside the backfill is cohesive like clay. It is also clear that the displacement of retaining wall is found very large for materials having a low angle of
internal friction like gravels. From this study, we can directly use calculated FOS for design of cantilever retaining wall.

3. Methodology:

3.1 Study of IS codes for seismic design of retaining wall
IS: 14458(part2): 1997 that is Retaining wall for hill area guidelines, Part 2: design of Retaining walls [22], this IS code is very useful for designing earth retaining structure. It gives very guidelines about hill areas for the construction of retaining structures.

IS: 1893: 1984 Criteria for Earthquake resistant design of structures [23] and IS: 1893(part 1): 2002 Criteria for Earthquake resistant design of structures, Part 1: General provisions and buildings [24]. All the design steps for retaining walls subjected to seismic loads are taken from this IS code.

IS 456:2000 Plain and Reinforced Concrete [25]. Various checks performed for the safety of the cantilever retaining wall are mainly taken from this IS code.

3.2 Design steps of RCC cantilever retaining wall [1]
Sichani M [5] said the design of a retaining wall involves the following steps,
1.) Selection of primary dimensions of the wall
2.) A finding of pressures and loads acting
3.) Check for the overturning of wall
4.) Check for sliding of wall
5.) Check for bearing capacity of base
6.) Design of reinforcement for various elements of wall
Also if the wall gets failed in the sliding check, the design of the shear key is required. It protects the wall from sliding.

3.3 Separate design of T-shaped and L-shaped cantilever retaining wall
The designs steps of both the walls are nearly the same. The design is performed by taking the heights of the stem of both the walls ranging from 3m, 3.5m, 4m, 4.5m, 5m, 5.5m, and 6m [2]. The complete design is performed in excel sheets by manual design and arranged in table format. The coefficient of active earth pressure is found out by the Mononobe-Okabe method.

3.4 validation of design data in STAAD pro.
The same model design in the excel sheet is again design in STAAD pro. All the bending moments and stresses developing in both the walls again find out. The difference seen in both the designs is showing in table format for comparison.

3.5 Preparation of chart showing Factor of safeties calculated
The factor of safeties calculate for overturning, sliding, and bearing failure modes are shown in table format for both T-shaped and L-shaped cantilever retaining walls so that designers can able to see height wise FOS required for the safe design of the wall. From this chart, we can also check the shear key provision.

3.6 Preparation of chart showing quantity of steel and concrete required
The quantity of steel and concrete estimated from the design performed for stem heights 3m to 6m is shown in table format for both T-shaped and L-shaped cantilever retaining walls so that we can see the height-wise material quantity required for these types of walls.
4. Conclusion:

From the above literature survey, it can be observed that seismic analysis of retaining wall structure is now become very essential due to its wide applications in infrastructural projects. Now it becomes important for structural engineers to improve the stability of retaining wall structures. The cantilever retaining wall is found safe up to a height of 6m after that bending moments on the stem wall increase. For height, more than 6m, gravity type retaining wall is considered safe but it requires a large quantity of concrete hence consider uneconomical.

The backfill material present behind the wall provides stability to the wall in static condition but if a seismic event occurs it can push the wall. For avoiding wall sliding and if the wall gets failed in sliding check, a shear key is provided at the wall base. Some authors [5] said that the provision of shear key increases moments on the stem wall. So provision of a shear key should provide whenever necessary and not for every wall.

For larger heights of backfill, many authors provide a reliving platform on the backfill side because it divides and reduces the earth pressure on the wall. Retaining wall of backfill height more than 10m consider as uneconomical because of its massiveness. Author [9] said that stepped cantilever retaining wall is very economical for heights ranging from 10 to 15m as compared to other types of wall.

Author [2] from their analytical study, found that in L-shaped retaining wall area of steel and concrete required is more as compare to T-shaped wall because the thickness of stem wall in L-shaped retaining wall is required more as compared to cantilever retaining wall.

Further study can be carried out by validating the manual design parameters in STAAD Pro by designing models of T-shape and L-shaped cantilever retaining wall in STAAD Pro by considering height variations.

5. References:

[1] Abood T, Eldawi H and Abdulrahim F, 2015 design of cantilever retaining wall with 4m height International Journal of Civil and Structural Engineering Research 3, pp. 318-26

[2] Mahure A and Umare M, 2019 investigation on dynamic behaviour of different types of retaining walls with different heights International Journal for Research in Applied Science & Engineering Technology 7, pp. 2350-58.

[3] Rouili A, 2013 design of rigid l- shaped retaining walls International Journal of Civil Science and Engineering 7, pp. 80-3.

[4] Dhamdhere D, Dr. V. R. Rathi, and Dr. P. K. Kolase, 2018 design and analysis of retaining wall International Journal of Management, Technology And Engineering 8, pp. 1246-63

[5] Sichani M and Bargi K, 2012 Seismic behaviour of concrete retaining wall with shear key, considering soil-structure interaction 15th World Conference on Earthquake Engineering

[6] Sari U, Sholeh M, and Hermanto I, 2019 the stability analysis study of conventional retaining walls variation design in vertical slope The 8th Engineering International Conference 2019, Journal of Physics: Conference Series

[7] Conti R, Viggiani G and Burali D’Arezzo F, 2019 some remarks on the seismic behaviour of embedded cantilevered retaining walls Géotechnique 64, pp. 40-50
8

[8] Yadav P, Padade A, Dahale P and Meshram V, 2018 a review on analytical and experimental analysis of retaining wall in static and seismic conditions International Journal of Civil Engineering and Technology 9 pp. 522–30

[9] Patil S and Bagban A, 2015 analysis and design of stepped cantilever retaining wall International Journal of Engineering Research & Technology 4, ISSN: 2278-0181

[10] Puri S and Salgude R, 2018 study of geogrid reinforced soil retaining wall & its comparison with r.c.c. retaining wall with respect to cost & time International Journal of Science Technology & Engineering 5, pp. 8-12

[11] Upadhyay A, Krishna M and Singh K, 2011 behaviour of cantilever retaining walls under seismic conditions 5th International Conference on Earthquake Geotechnical Engineering pp. 10-13

[12] Sharma C and Baradiya V, 2014 evaluation of the effect of lateral soil pressure on cantilever retaining wall with soil type variation Journal of Mechanical and Civil Engineering 11, pp. 36-42

[13] Santhil K, Iqbal M and Kumar A, 2014 behaviour of cantilever and counterfort retaining walls subjected to lateral earth pressure International Journal of Geotechnical Engineering 8, pp. 167-81

[14] Kayabekir A, Arama Z, Bekdas G and Dalyan I, 2020 L-shaped reinforced concrete retaining wall design: cost and sizing optimization Challenge Journal of Structural Mechanics 6, pp. 140-9

[15] Cameron W and Green R 2004 development of engineering procedure for evaluating lateral earth pressures for seismic design of cantilever retaining walls 5th International PhD Symposium in Civil Engineering 2

[16] Uray E, Carbas S, Erkan I and Tan O, 2019 parametric investigation for discrete optimal design of a cantilever retaining wall Challenge Journal of Structural Mechanics 5, No.3, pp. 108-20

[17] Gursoy S and Durmus A, 2009 investigation of linear and nonlinear of behaviours of reinforced concrete cantilever retaining walls according to the earthquake loads considering soil-structures interactions Structural Engineering and Mechanics 31, No.1, pp. 75-91

[18] Ahani M and Sarani A 2019 performance-based optimal design of cantilever retaining walls Periodica Polytechnica Civil Engineering 63, No.2, pp. 660-73

[19] Garini E, Tsantilas L, and Gazetas G 2016 seismic response of cantilever retaining walls: verification of centrifuge experiments 1st International Conference on Natural Hazards & Infrastructure

[20] Tafreshi S and Nouri T 2008 seismic stability of reinforced retaining wall the 14th World Conference on Earthquake Engineering
[21] Khan S, Hiwase P and Pachpor P 2017 analysis and design of underground retaining wall by using beam and column as buttresses International Journal for Science and Advance Research In Technology 3, No.5, pp. 936-40

[22] Sobana U and Gayathri S 2018 design and analysis of lateral earth pressure effect on cantilever retaining wall 1st International Conference on Recent Innovation in Civil Engineering and Management 7, No.5, pp. 538-43.

[23] Diwalkar A 2020 analysis and design of retaining wall: a review International Conference on Communication and Information Processing

[24] IS: 14458 (part2) :1997 retaining wall for hill area –guidelines, (Part2: design of Retaining wall)

[25] IS: 1893: 1984 criteria for earthquake resistant design of structures.

[26] IS: 1893(part 1): 2002 criteria for earthquake resistant design of structures, part 1: general provisions and buildings.

[27] IS 456:2000 plain and reinforced concrete