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Seismic Analysis And Design of Cantilever Retaining Walls

Shoeb Mohammed Sayeed, Sunandan Reddy, K .Mythili
Shoebsayeed7@Gmail.Com
Aurrora's Scientific Tehnological & Research Acadamy (Bandlaguda,Hyd)

ABSTRACT

This project deals with analysis and design with an emphasis laid on effect of earthquake on an important soil retaining structure like cantilever retaining wall. This work also throws light on earthquake damages to retaining structures with help of some case studies. The determination static as well as dynamic earth pressure of cantilever retaining walls will give an idea on the how less intense or severe load combination can result in for a retaining wall to bear it. Retaining walls should be designed for the most onerous load case which could be applied over the lifetime of the structure giving due regard to water table levels and water pressures, parapet loads, consolidation of soils action of by tree roots, collision loads etc. Careful consideration is required to devise all the load cases for which the wall should be designed.

The overall stability of the retaining wall against sliding and overturning must be determined prior to construction giving due regard the site soil condition in particular the bearing capacity of the foundation strata based upon the ability of the ground to withstand the combined actions of vertical, horizontal and rotational loading that the wall transfers to the ground.

1.0 INTRODUCTION

1.1 MOTIVATION

The retaining walls are being constructed since pre-historic times and some of finest ones have been across greatest civilizations like Mesopotamia, Indus-valley and most notably one that built by Incas on Mount Machu Pichhu in South America stands example of superior engineering skill developed by ancient people in constructing 'Retaining walls' many centuries ago. In present day scenario, retaining walls are most widely constructed structures and in variety of forms depending on the need, function, importance, economy, efficiency and aesthetics.

1.1.2 Since the retaining wall construction is of paramount importance they are not only built in urban or rural areas but sparsely populated places also, where terrain, loose soil contribute to difficulties on natural slopes. Lot of research is being done on retaining walls worldwide and newer ways of retaining soil are being developed. This gives way to investigate the retaining wall working and its response for loads in its lifetime. So through this project humble effort has been made to a perform analysis of a simple but effective retaining system like T-shaped cantilever retaining wall and this has been done with regard to seismic effect on them under different combinations of heights, soil backfill and degree of seismicity.

1.2 GENERAL

A retaining wall is defined as a structure whose purpose is to provide lateral support for soil or rock. Retaining walls are used to provide stability for earth or other material where conditions disallow the mass to assume its natural slope. They frequently represent key elements of ports and harbors , transportation systems, life lines and other constructed facilities. In some cases, the retaining wall may also support vertical loads. Examples include basement walls and certain types of bridge abutments. Earth retaining structures such as cantilever retaining walls, bridge abutments, quay walls, anchored bulkheads, braced excavations and mechanically stabilized walls, have been constructed throughout world in seismically active areas.

Some of most common types of retaining walls are shown in fig.1 and include gravity walls, cantilever walls, counter-fort walls, and crib walls. Next section describes various types of retaining walls and backfill conditions.

The problem of retaining soil is one the oldest in the geotechnical engineering; some of the earliest and most fundamental principles of soil mechanics were developed to allow rational design of retaining walls. Many approaches to soil retention have been developed and used successfully. In the recent years, the development of metallic, polymer, and geo-textile reinforcement has also led to the development of many innovative types of mechanically stabilized earth retention system.

Walls might be constructed from materials such as fieldstone, reinforced concrete, gabions, reinforced earth, steel and timber. Each of these walls must be designed to resist the external forces applied to the wall from earth pressure, surcharge load, water, earthquake etc. Prior to completing any retaining wall design, it is first necessary to calculate the forces acting on the wall.

1.3 PURPOSE OF THE PROJECT

The project is being done to explore the problem of cantilever retaining wall in different situations and whether it is an efficient system of retaining soil in relation with its height , backfill type and its dry or partially submerged condition, and seismicity of area.

1.4. CLASSIFICATION OF RETAINING WALLS

Retaining walls can be broadly classified based on two criteria. They are as follows-

a) Based on purposes(Figure 1.1)

b) Based on stability criteria(Figure 1.2)

1.4.1 .GRAVITY WALLS

A gravity wall is usually constructed in stone masonry, brick or plain concrete. The weight of the wall provides the required stability against the effects of retained soils. The practical use of gravity retaining walls is controlled by height limitations(< 6 m),where by the required wall width starts to increase significantly with height because the magnitude of approximate triangular soil pressure distribution behind also increases on the wall. Gravity walls are also built occasionally in plain concrete. The need to eliminate or limit tensile stresses govern the thickness of wall. To eliminate tensile stresses, the 'middle third rule' id generally applied, wherein the wall thickness is made sufficiently large, to ensure that the resultant thrust at any cross-section falls within the 'middle third' region of the section. Unless really necessary, Plain concrete gravity walls are not used for heights exceeding about 3m, for economic reasons.

1.4.2 SEMI GRAVITY WALLS

This type of walls are constructed in concrete, and derives stability up to an extent from its weight. Certain amount of reinforcement is provided to reduce the amount and weight of concrete.

1.4.3 CANTILEVER WALLS

For a cantilever wall, the earth pressure is applied to a plane extending vertically up from the heel of the wall base, and the weight of soil to the left of the vertical plane is considered as part of the wall weight. The resultant force makes an angle δ with the perpendicular to the wall, where δ is the friction angle between fill and wall. These walls are suitable for retaining backfills of moderate heights(H=5 to 7 metre).

1.4.4 COUNTERFORT RETAINING WALL

For large heights, in a cantilever retaining wall, the bending moments developed in the stem, heel slab and toe slab become very large and require large thicknesses. The bending moments (and hence stem/slab thicknesses) can be considerably reduced by introducing transverse supports, called *counterforts* ,spaced at regular intervals of about one-third to one-half of the wall height), interconnecting the *stem* with the *heel slab*. The toe slab is also frequently interconnected with the stem (in the front side of the wall) by means of a 'front counterfort', whose height is limited by the ground level on the toe side, so that it is concealed and provides free usable space in front of the wall. The counterforts are concealed within the retained earth(on the rear side of the wall, and is economical for heights above (approx.) 7m. The counterforts subdivide the vertical slab(stem) into rectangular panels and support them on two sides (suspender-style), and themselves behave essentially as vertical cantilever beams of T-section and varying depth. The *stem* and *heel slab* panels between the counterforts are now effectively 'fixed' on three sides(free at one edge), and for the stem the predominant direction of bending(and flexural reinforcement) is now horizontal (spanning between counterforts), rather than vertical(as in the cantilever wall).

1.4.5 BUTTRESSED RETAINING WALL

A buttressed retaining wall is similar to counterfort retaining wall, except that the transverse stem supports, called *buttresses* are located on the front side, interconnecting the *stem* with the *toe slab* (and not with the *heel slab,* as with counterforts). Although buttresses are structurally more efficient (and more economical) than counterforts ,the counterfort wall is generally preferred to the buttress wall as it provides free usable space (and better aesthetics) infront of the wall.

1.4.6 CRIB WALL

A crib wall is formed of timber, pre-cast concrete are prefabricated steel members and filled with granular material. Except for the exposed front face, crib walls are completely covered with soil so that the cribbing is not visible. These are economical for small to moderate heights(4.0m to 6.0m).

1.4.7 BRIDGE ABUTMENTS

Bridge abutments are often retaining walls with wing wall extensions to retain the approach fill and provide protection against erosion they differ into major respects from the usual retaining wall, namely: a)They carry end reactions from the bridge span and b)They are restrained from the top so that earth pressure is unlike to develop.

1.4.8 BASEMENT WALL

Foundation walls of buildings including residential construction are retaining walls whose function is to contain the earth out of basements. 1.4.9Retaining walls often form part of a bigger structure, in which case their structural behavior depends on their interaction with the rest of the structure. For example, the exterior walls in the basement of a building and wall-type bridge abutments act as retaining walls which also carry substantial axial loads. In both these situations, the vertical stem is provided an additional horizontal restraint at the top ,due to the slab at the ground floor level(in the case of the basement wall) and due to the bridge deck (in the case of bridge abutment). The stem is accordingly designed as a beam-column, fixed at the base and simply supported or partially restrained at the top. The side walls of box culverts also acts as a closed rigid frame, resisting the combined effects of lateral earth pressures, dead loads(due to self weight and earth above),as well as live loads due to highway traffic.

1.4.10 Retaining walls are longer in length. The usual design procedure is to analyze a section of one unit in length except in case of counterfort or buttressed is considered. The height of soil is to be retained will usually vary along the length of the wall, and with homogeneous backfill and foundation conditions the most severe designs loading occurs where the height is greatest. The wall cross section required for this crucial location is also assumed for adjacent locations although the height constructed may be lower.

1.4.11 Gravity retaining walls are routinely built of plain concrete or stone, and the wall depends primarily on its massive weight to resist failure from overturning and sliding. Counterfort walls consist of a footing, a wall stem, and intermittent vertical ribs (called counterforts) which tie the footing and wall stem together. Crib walls consist of interlocking concrete members that form cells which are then filled with compacted soil.

S. No	Types of retaining walls	Suitability(H)
1	gravity wall	<6.0m
2	Semi gravity wall	5.0 to 6.0m
3	Cantilever wall	4.0 to 7.0m
4	Counter fort wall	<7.0m
5	Buttressed wall	4.0 to 6.0m
6	Crib wall	4.0 to 6.0m
7	Bridge abutment	6.0 to 7.0m

Although mechanically stabilized earth retaining walls have become more popular in the past decade, cantilever retaining walls are still probably the most common type of retaining structure. There are many different types of cantilevered walls, with the common feature being a footing that supports the vertical wall stem. Typical cantilevered walls are T-shaped, L-shaped, or reverse L-shaped. Table 1.1 explains suitability of retaining walls with respect to height.

1.5 BACKFILL MATERIAL

Clean granular material (no silt or clay) is the standard recommendation for backfill material. There are several reasons for this recommendation:

1. *Predictable behavior:* Import granular backfill generally has a more predictable behavior in terms of earth pressure exerted on the wall. Also, expansive soil-related forces will not be generated by clean granular soil.
2. *Drainage system:* To prevent the buildup of hydrostatic water pressure on the retaining wall, a drainage system is often constructed at the heel of the wall. The drainage system will be more effective if highly permeable soil, such as clean granular soil, is used as backfill.
3. *Frost action:* In cold climates, frost action has caused many retaining walls to move so much that they have become unusable. If freezing temperatures prevail, the backfill soil can be susceptible to frost action, where ice lenses form parallel to the wall and cause horizontal movements of up to 0.6 to 0.9 m (2 to 3 ft) in a single season. Backfill soil consisting of clean granular soil and the installation of a drainage system at the heel of the wall will help to protect the wall from frost action.

Plane strain condition: Movement of retaining walls (i.e., active condition) involves the shear failure of the wall backfill, and the analysis will naturally include the shear strength of the backfill soil. Similar to the analysis of strip footings and slope stability, for most field situations involving retaining structures, the backfill soil is in a plane strain condition (i.e., the soil is confined along the long axis of the wall). As previously mentioned, the friction angle Φ is about 10 percent higher in the plane strain condition compared to the friction angle Φ measured in the tri-axial apparatus. In practice, plane strain shear strength tests are not performed, which often results in an additional factor of safety for retaining wall analyses.

2. STABILITY REQUIREMENTS

STABILITY REQUIREMENTS

In retaining walls it is not sufficient if we design the sections of the various parts for moments and shear. It is necessary to check the retaining wall for the following two types of complete failure. The code(Cl.20) Specifies that the factors of safety against overturning (Cl.20.1) and sliding (Cl. 20.2) should not be less than 1.4. Furthermore, as the stabilising forces are due to dead loads, the code specifies that these stabilizing forces should be factored by a value of 0.9 in calculating the factor of safety, F.S. Accordingly,

$$FS = \frac{0.9 \times (Stabilising\ force\ or\ moment)}{destabilizing\ force\ or\ moment} \geq 1.4$$

Check for overturning: Earth pressure on the stem causes overturning moment about the toe. The weight of the backfill earth, surcharge, self weight of retaining wall causes stabilizing moment about the toe. Hence factor of safety against overturning is given by

$$Fo = \frac{0.9 \times Ms}{Mo}$$

The resisting moment (stabilizing moment) should be more than the overturning moment so as to get a factor of safety not less than 1.4.

Where M_o is overturning moment above toe.

M_s is stabilizing moment about toe.Check for sliding- The horizontal pressure force H on the stem tries to slide the retaining wall away from the backfill. This is resisted by frictional force between the soil, heel and toe slab. If μ is the coefficient of friction and W is the total downward load' the maximum resisting frictional force is

$$F = \mu W$$

$$Fs = \frac{0.9\,F}{Pa \times cosi}$$

6.4.3.1 The restoring force against sliding should be more than the sliding force so as to get a factor of safety not be less than 1.4.

6.4.3.2 This is in accordance with clause 19.2 of IS 456-2000 "the structure shall have a factor of safety against sliding of not less than 1.4 under the most adverse combination of the applied characteristic forces. In this case only 0.9 times the characteristic dead load should be taken into account".

6.4.3.3 Shear key is provided, when active pressures are relatively high(as when surcharge is involved). The shear key is constructed such that the formwork is not used while casting. This should be expected to develop the passive resistance. The base key along with toe develops a passive resistance equal to

$$Pp = \frac{1}{2} \times Kp \times \Upsilon \times h^2$$

Where $h^2 = h_1^2 - h_2^2$, where h_1 is height from ground level to bottom edge of shear key (includes foundation depth which is 1.57 m in our case)and h_2 is the depth of shear key.

For example, figure shows passive resistance by shear key. In this figure, h_1 =2.779m and h_2=1.57m.

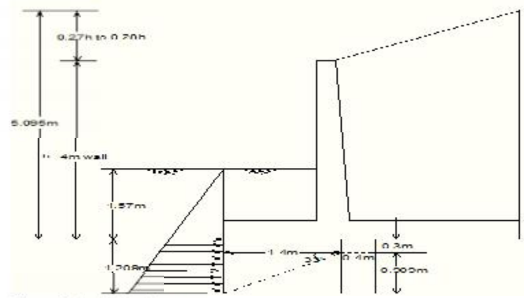

Fig. 6.1 Passive resistance provided by the shear key.

Now the factor of safety against sliding would be $Fs = \frac{0.9(\mu W + Pp)}{Pa} \geq 1.4$

6.4.4 Check for bearing capacity failure

The width 'b' of the base slab must be adequate to distribute the vertical reaction R to the foundation soil without causing excessive settlement or rotation. The eccentricity may be calculated by using

$$e = \frac{b}{2} - \frac{(Ms - Mo)}{W}$$

Then ,

$$Pmax = \frac{total\ vertical\ forces}{b \times 1}\left(1 + \frac{6e}{b}\right)$$

The value should not exceed bearing capacity of the soil.

6.4.5 Check for base shear failure:

If the base soil consists of medium to soft clay, a circular slip surface failure may be developed as shown in fig. the most dangerous slip circle is actually the one that penetrates deepest into the soft material. The critical slip surface must be located by trial. Such stability problems may be analyzed either by the method of slices.

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