Earthquake Geotechnical Engineering

Prof. B. K. Maheshwari

Department of Earthquake Engineering

Indian Institute of Technology Roorkee

Lecture 51

Slope Stability and Retaining Walls: Design of Retaining Walls

So, this is lecture number 51 and we are still in the module 5 of this earthquake geotechnical engineering. And we already covered in this module 5 lecture on slope stability another 5 lecture on retaining walls. This is the 6th lecture on retaining walls and this lecture we are going to talk about the last component which is seismic design considerations that when we design the retaining walls what consideration should be taken into account. So, this is a chapter number 9 of this module that is the last chapter of this module number 5 which is on slope stability and retaining walls. And in this chapter what topics we are going to cover. First is seismic design consideration and this design consideration we will discuss both for gravity walls as well as cantilever walls.

For gravity walls design which is based on seismic pressure as well as on the based on the displacement which is on the allowable displacement both will be discussed. Design consideration for retaining walls will be discussed then we will talk about backfill material also that what should be the desirable properties of the backfill material. Stability of gravity and cantilevers walls we will also discuss and then finally, we are going to talk about gravity wall design criteria. Coming to the seismic design consideration, the design of retaining walls for seismic condition is similar in many respects to design for static conditions.

Whether you design for seismic conditions or like there are many things common. Actually what happens you already seen when you consider seismic forces they are in addition to the static forces. So, basically you can if you want to take care of seismic forces then you need to increase the static loads. When you consider the static loads then you need to consider not only the vertical but horizontal thrust also required to be considered. So, in both cases whether seismic or static cases potential mode of failure are identified and then wall is to designed to avoid to initiate that this failure should not be initiated.

Although the response of retaining walls under seismic loading conditions is much more complex than under static conditions, conventional design processes make use of simplifying assumptions that renders the problem tractable. So, the problem can be dealt. So, here as for the gravity wall is concerned, gravity walls are normally designed for one of two approaches. One is called seismic pressure-based approach, another is called permanent displacement-based approach. So, although the gravity wall design processes are normally oriented towards prevention of sliding failure that means the gravity walls are mostly fail in the sliding.

However, the possibility of the overturning due to bearing failure of the soil beneath the base of the wall must also be considered in design. Mostly gravity walls are designed based on the sliding failure, but we should check for overturning failure also. The MO method is most commonly used along with an inertial forces using the same pseudo-static acceleration applied to the active ways applied to the walls itself. Pseudo-static accelerations are generally considered smaller than anticipated peak acceleration because pseudo-static acceleration cannot be same as PGA like peak acceleration otherwise the design will be very conservative. But values are considered for the pseudo-static acceleration, particularly for the AH which is what is AH? AH is equal to KH into g.

Horizontal pseudo-static acceleration is considered between value between 0.05 to 0.15 g. It corresponds to one-third to one-half of the PGA are commonly used with factor of safety 1 to 2. Here let us say typical PGA for let for example in our country Seismic, zone like 5 you have typical PGA around 0.36 g in zone 5 which is the highest zone. Now this the value of AH should be one-third, one-third means 0.12 to half 0.18 g. So, this will be there for the zone 5 and if you get the average of 0.12 to 0.18 you get the 0.15 g. So, considering the value of AH 0.15 g or if I simply say the value of KH 0.15 that should be okay for Seismic zone 5 for the design consideration.

Usually, the processor of Richard Elms used for designing the gravity wall which is based on seismic displacements. It involves calculations of the wall weight that would be required to ensure that permanent displacements are less than or equal to some allowable value. So, if you do the your design based on the seismic pressure then normally MO method is used. If you do design based on allowable displacement normally Richard Elms method is used. It involves calculations of the wall weight that would be required to ensure that permanent displacement is less than or equal to some of the allowable value.

So, this was all about gravity walls. But when we talk about cantilever walls, cantilever walls are also designed in much the same way as the gravity walls except that bending moment must also be considered. So, you can put it like this way because gravity walls are very heavy massive structures. They fail either in sliding or at the most in overturning. But they do not you know that flexural failure or bending failure is rarely considered for gravity walls.

But that is important for the design of the cantilever walls. So, the cantilever walls need to be designed in addition to what is designed from gravity walls it is also designed for the bending failure. Maximum bending moments are usually calculated using the MO method to compute the maximum soil thrust which is taken to act at the height calculated by MO method. So, the using the MO method this the bending moments may vary over the above the height of the. The maximum overturning moment used for structural design of wall elements to prevent flexural failure of the wall itself and to determine the size of the wall footing required to prevent bearing failure of the supporting soils.

So, in case of cantilever walls you have a base also which act like a footing of the cantilever walls and that should also be considered. Now, coming to the design consideration for retaining walls these are the following is the list. These are the points which need to be considered for the designing of retaining walls. First wall deformations and earth pressures, the second backfill materials, third soil parameters for retaining walls, fourth approximate estimation of earth pressure, fifth stability of gravity and cantilever walls. So, we will discuss one by one all these points which are important for the design consideration for retaining walls.

Let us say first wall deformation and earth pressure. We already discussed in detail and in general we can say this is the list which is kind of a summary. Earth pressure is a function of both the type and magnitude of wall deformations. In case of cohesion less soils this is the values which is listed is a kind of a thumb rule. In cohesion less soils deflection can be considered for active pressure about 0.001 times of H. What is H here? H is the height of the wall and for passive pressure it will be more and it is 0.05 times H. While in case of cohesive soils this is 0.00H for active pressure, for passive pressure it is not exactly defined in this way. Now, regarding the backfill material it is like you know it is advised that you should use the clean grain flow backfill material should be preferred. Your backfill material should be clean. If you have the clean backfill material? It is less likelihood to generate the hydrostatic pressure built up under adequate provisions of drainage. Some form of the filter should also be used just behind retaining wall to preclude pore pressure. So, if you have some filter is applied behind the retaining walls so you do not like built up the pore pressure. Water collecting the filter is laid away through weep holes which are provided within this section.

So, the filter needs to be provided, weep holes need to be provided. So, they will help you to drain out the water. The lateral pressure in case of backfill material it will be more than double when backfill changes from free draining to the one having water table at the top. So, in one case your backfill is kind of a dry or it is like you know free draining means water does not percolate inside it drained out. But in case of it does not drain out and you are considering water table on the top of the backfill that means it is completely saturated.

In that case the lateral pressure applied by this saturated backfill may be more than double when it was dry. It is desirable to provide drainage rather than designing wall for large pressure induced in the absence of drainage. So, this is very important. It is very important in the retaining walls that you provide the proper drainage. Otherwise, if you do not provide the drainage then what will happen due to the saturated backfill your wall will apply very heavy lateral pressure and as a result even your wall retaining wall could also be get damaged.

So, to avoid and if you want to design your wall for let us say for saturated conditions of the backfill then your section which is required will be higher so that need to be avoided. So, rather than we invest for rather than investing in the money for the like you know the heavy wall then we provide the proper drainage for the water. The clay backfill should be avoided why as far as possible sometime backfill you may not have choice because whatever is the naturally available. But if it is possible then clay backfill should be avoided. The reason being it is susceptible to swelling and shrinkage during rainy and summer seasons respectively.

So, like during rainy season or summer season the like you know that is during rainy season there will be swelling in the clay. But during summer when it dried up there could be shrinkage. Swelling is likely to cause unpredictable earth pressure and wall movement. So, when it is filled out so the earth pressure may be unpredictable and the wall movement. And the shrinkage may lead to tension cracks in soil which may later get filled with water adding to the lateral pressure.

Tension cracks may be generated and later on they may be filled out with the water. Drain values of phi that is effective phi for a granular soils this is normally associated with SPT data and for plane strain phi values can be also taken 1.1 times of phi which you obtain from triaxial test. What is phi? Phi is angle of internal friction. For cohesive soil cu is normally unconfined compressive strength is qu by 2 where qu is determined using unconfined compression test on remodeled samples.

Suitable value of delta, what is delta? Delta is friction between the wall and soil if Coulomb theory is used. Unit weight of soil which is for granular soils it is suggested gamma dry could be 16.5 to 17 kilonewton per meter cube. But for granular soils which is saturated it could be increased 17 to 19 kilonewton per meter cube. Now for approximate estimation of earth pressure on retaining walls can also be done using these charts. These charts are very crude and this is like you know like this can be used. For example, here what you need to do pH can be simply calculated half k h into h square while p v half k v into h square. Here k h and k v in these equations are not dimensionless horizontal seismic coefficient or vertical seismic coefficient. So, k h and k v used in these equations very different. What is k h and k v? k h and k v is pressure itself per unit length which is kilogram this should be read as a kilogram this is in fact force unit. So, this should be read as a kilogram force per meter square per meter for the k h which is varying from 0 to 2000. And what is beta? Beta is angle of inclination of the backfill. So, when the angle of inclination beta equal to 0, you see these the values are the minimum for these all the four curves. Once beta increases then these the values of k h are also increasing and of course not linearly rather than slowly initially and then after that exponentially.

So, this was the case for k h. Similarly, for k v your beta is increasing at the x axis while k v is given on the y axis. And here there are four curves 1, 2, 3 and 4. In this case also 1, 2, 3 and 4, 4 the fourth one is at the almost best. So, what these numbers 1, 2, 3 and 4 are represent that is listed here.

This is type of backfill. Four typical classes of backfill for design charts which is used are listed here. Type 1 of the backfill is coarse grained soils with no fines assuming there are no fines inside the soils very permeable such as clays and gravels. So, like permeability is high. Coarse grained soils with fines of low permeability. On another side you have the coarse-grained soils and those have fines with in the first case no fines.

So, fines are not there then they will be very permeable. But when you have the fines then you have the low permeability. Permeability will get reduced due to the presence of fines. The third case fine silty sand granular materials with clay cement or original soil with stones. Fourth one very soft or soft clay or organic silt or silty clay.

So, these are the fourth type of material type 1, type 2, type 3, type 4 used in these figures. Continue with that stability of gravity and cantilever walls. Let us have this. Gravity walls depends on the self-weight of the wall number 1. If the self-weight is heavy, it is expected that gravity walls will be more stable.

Usually constructed of the brick or stone masonry or mass concrete. The gravity wall will be either using brick or stone masonry or mass concrete. Wall material is vast full as it provide the dead weight. Cantilever walls effectively use the backfill which is resting on the projection of the base of the wall to provide a large proportion of the dead weight. So, like how it is used that we will show in the someone like slides here what it is said in case of cantilever walls here weight of soil this Ws that also act downward.

So, this combined with the W and this help in the stability of the base which we will discuss in detail later. Here both gravity and cantilever walls are liable to rotation or translation movements. Application of either Rankine or the Coulomb method depends upon type of wall backfill and surcharge. Coulomb's approach is generally used for walls with inclined backfill which we already discussed because if your wall is vertical then only you can use Rankine's theory. If your wall is inclined then you need to use Coulomb's theory.

So, as for the design consideration for gravity and cantilever retaining walls it is shown here. For gravity walls you have W which is the total weight of the wall acting downward direction, Pa is active earth thrust total active pressure and Pp is total pressure pressure. On the operation you have toe of the wall and heel of the wall. The distance between toe and heel is capital B and similarly for cantilever walls it is again capital B but in addition to W which is the weight of the wall itself you get Ws also which is basically weight of soil and here only Pa active pressure act rather than passive pressure. Passive pressure is not considered for the cantilever retaining walls.

So, what are the forces which are acting on a typical gravity wall? First is active earth pressure Pa, the weight of wall plus load which is carried by W, reaction R which is offered on the base of the wall, R is also resultant of Pa active pressure and W acting on the base. So, what you can see here from this figure, first active earth pressure Pa which is acting here on the wall and it may have two components, one a horizontal component another vertical component. Then you have weight W of the self-weight of the wall acting in downward direction. Third one is R reaction of the soil which will be acting let us say at the same point where your Pa the resultant of Pa and W is passing.

So, what you have? You have here Pa is Pab and Ph. So, Pa is if I come here then W which is acting downward and Pa max resultant is R, capital R and the capital R you have another capital R which is like you know that acting in the opposite direction of this R acting this will be the reaction which will try to establish. So, here R is also resistant to Pa and W, the passive earth pressure Pp in front of the wall is usually ignored because of possibility of disturbance. So, Pa is considered but normally in the calculation this Pp is ignored. Anyway this actually providing you stability also. When we consider active pressure condition the role of Pp will provide the stability.

So, even if we neglect, we are on the conservative side. So, what are the forces acting at the point R is shown here also that is hillside and toe sides and naturally this reaction R will not act at the center of the wall at the base of the center of the wall rather at some distance E which is called eccentricity from the base of the from the center of the wall. So, this point is basically your center of wall because b by 2 this side and b by 2 this side, but your this value of R is acting not at the center rather little away from the center which is shown in this figure. Some other things are also shown in this figure what you have in this figure again as I emphasize that you will have theta is this angle which is a that wall is inclined at an angle theta with respect to vertical. You have the hillside here and this pressure Pa act at this point whichever distance x2 from the hill, x2 is this distance between this and this. Then x1 is the distance from the hill to the this x1 is the distance from the hill to the point where R is acting and x bar is the distance where R is acting.

So, x1 will be the distance where the w is acting, x1 is the distance where the w is passing through this line. So, these are the forces acting. Now, we can work out to find out what we call the force equilibrium for this case. The maximum but before that maximum base pressure which occurs at the toe of the wall must not exceed the SBC of the soil.

So, this is the maximum. So, the value of this should be less than SBC that is a set bearing capacity of the soil. For masonry walls tension must not be allowed to develop at the base. The base pressure must remain compressive over the entire base width. The factor of safety against sliding between the base of the wall and the soil below must not be less than 1.5. So, the factor of safety which you consider Fs should be greater than 1.5 or so Fs should be greater than at least 1.5. It is more than 1.5 then it is okay. There should be adequate safety fraction against overturning of the wall also or a rotation. Factor of safety is a ratio of restoring moment to the disturbing moment. Restoring moment is due to w and disturbing moment is due to Pa. So, restoring moment the weight of the wall will provide to restoring moment that means it will try to establish while the Pa will try to overturn the wall.

So, we do some calculation here. First of all resolving the forces in the vertical direction. In the vertical direction what you have? One force w is acting and then here r v is that r v is the component of this which act in the vertical direction and then Pa v is also acting. So, w plus Pa v should be equal to r v. Similarly, in the horizontal direction you will have r h which will act in the horizontal direction and this Pa should be balanced. So, these are the force equilibrium in the vertical direction and the second in the horizontal direction.

Now, taking about all the forces about the heel of the wall, heel means about this point, this corner point. So, w for example, will make a w into x1 will be there. Similarly, Pa into x2 will be all the forces will be in the anticlockwise direction. So, w into x2, w into x1 and Pa v into x2 and then you will have another Pa h which is also acting in the Pa h into z. So, these three forces will be anticlockwise while r you will have vertical component multiplied by x bar will give you the clockwise.

$$R_V = W + P_{AV}$$

$$R_H = P_{AH}$$

Taking moment about the heel of the wall

$$R_V \bar{x} = Wx_1 + P_{AH} z + P_{AV} x_2$$

$$\bar{x} = \frac{Wx_1 + P_{AH} z + P_{AV} x_2}{W + P_{AV}}$$

So, when you see r v into x bar, r v is the vertical component of r into x bar will be, this is the moment clockwise and all these three moments are anticlockwise. So, with this you can find the value of x bar and because all other things are known and what is x bar? X bar is the distance from the heel to the point where this your reaction r acts. So, the minimum and maximum base pressures will be given by r v by b, r v is the vertical component of r divided by b 1 plus minus 6 e by b plus sign will give the maximum value and minus sign will give the minimum value. What is e here? Ascenticity is nothing but x bar minus b by 2. So, as a result once x bar is known, then e is also known and once e is known you can calculate the maximum and maximum value of the earth pressure.

$$q = \frac{R_V}{B}\left(1 \pm \frac{6e}{B}\right)$$

Eccentricity $e = \bar{x} - B/2$

For no tension condition $\bar{x} \le 2B/3$

The maximum base pressure

$$q = \frac{R_V}{B}\left(1 + \frac{6e}{B}\right) \le SBC\ of\ soil$$

For no attention condition this x bar should be at least it should be less than 2 b by 3. It should not be otherwise there will be tension and it may at the most it can be equal to 2 b by 3. Then for maximum base pressure which will be with the plus sign r v by b 1 plus 6, this should be less than SBC of soil seb bearing capacity. And the factor of safety, angle of sliding will be r v divided by r h r v into delta where delta is nothing but angle of friction between wall and soil.

So, this will give you a factor of safety against the sliding. Naturally, if you have delta if delta is increased you will get better factor of safety and this is the sliding where delta is the angle of friction between the base of the wall and the soil below the base. And this value of you find from this equation should be at least more than 1.5. As for stability against overturning is concerned, the resultant r must lie within the base. If the middle third rule is for no tension is satisfied, this rule that this is the middle third rule for no tension condition, the required F s against overturning is automatically ensured.

$$F = \frac{R_V \delta}{R_H}$$

So, here in this figure you can see that this value of E of course E is very difficult because if you all the forces are acting at B by 2 there is no eccentricity this is the best case. But there could be small eccentricity. However, this eccentricity that means this point can be like you know increase up to this point, but this distance from here to here should not be greater than two third by like you know two third by B. That means from this end the distance to this point should be less than this should be equal to or it should be equal to B by 3 or less than B by 3. So, this should be the distance should be let me put like this B by 3 this value should be equal to or less than B by 3.

So, this distance. So, this is the middle third rule and once middle third rule is applied then you will get no tension that means this triangle. The tension will be the case like you know the case this case or this will be the ideal case that means the maximum value. But the tension will be the case where this you this you go here and on another side you get the negative sign. So, that need to be avoided. Now, typical proportion for the when you design for gravity wall and cantilever walls are listed here.

For example, for gravity wall typically this is whatever is given in the slide is very crude very thumb rule like without much calculation and so the base of the wall should have about 0.5 to 0.7 times of h. What is h? h is the height of the wall that is the one thing.

Then depth of the wall at the base D capital D should be somewhere h by 8 to h by 6. So, this D is also designed. Then the setback this side should be half of D or to D. The top width of the wall should be minimum 0.3 meter that is 1 feet around to h by 12. Then minimum battering which is the inclination should be 1 to 48 on this side and other factors.

So, this is based on the and if you design based on this consideration then this is very conservative and your wall is going to be very much stable. So, this is without going in the much calculation and as a thumb rule which can be used by the you know that is like machines. Then cantilever walls typical proportion is given. The top width may be minimum is 300 mm if it is more no problem.

At the base capital B which is the width of the wall should be between 0.4 h to 0.7 h where h is again height of the wall and this thickness of the base should be between h by 12 to h by 8 and L the distance this side back is given from 0.2 b to 0.4 b. Then you can do this calculation that means depending on the thickness of your stem then remaining part will be for the heel and the batter of front face should be 1 by 48 to 1 by 16.

So, it should not be like you know that is more inclined than 1 by 16. So, this was typical proportion for gravity wall as well as cantilever walls. Thank you very much with your kind attention and this with lecture number 51 we completed all the components of module 5 which is on seismic slope stability as well as on retaining walls. So, this was the last lecture on the retaining walls. So, we finished the five modules and only one module the last module, module number 6 is left out which will be on the ground improvement techniques. Thank you very much for your kind attention. Thank you.