Earthquake Geotechnical Engineering

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Lecture 46

Introduction to Retaining Walls

I welcome you again for this NPTEL online lecture on earthquake geotechnical engineering and what we are going to talk is the lecture number 46. That means we already finished three fourth of this course and we are in the last phase of this course. Here we have the fifth module of the course which is on slope stability and retaining walls. We already covered five lectures on the slope stability. Half part of this module is over and today we are going to start the retaining walls. First of all, retaining walls and you sometime call it RW or RE walls. RE wall is different than retaining wall. RE wall in this case you have reinforced earth wall. So do not get confused with retaining walls with the RE walls. In the terminology sometimes it is used RE walls.

So, RE walls are used mostly under the bridges and that is man-made walls and RE is of course it is also retaining wall, but RE stands for reinforced earth walls. So, in this retaining walls are used in the hilly areas. If you go in the hilly areas in the Himalayan region or other or let us, say in the Uttarakhand then you passes near to hills. To protect the hills from falling you see some walls are there and that is basically retaining walls. So, we are going to talk introduction to retaining walls, then static pressure on retaining walls, then seismic pressure on retaining walls, then we are going to talk the displacement also, seismic displacement of retaining walls and then finally we are going to talk the seismic design considerations for the retaining walls.

So, these will be the topics which will be covered in the next five lectures including this lecture. So coming to the first introduction to retaining wall that is today lecture number 46 what we are going to talk today in this lecture. First introduction, what are the types of retaining walls in general and then we are going to talk about types of retaining wall based on the code IS 14458 part 1 which is published in the last version 1998. Then next we are going to talk gravity types of retaining structures and then types of retaining wall failures also going to be discussed today. So let us start from introduction.

Earth retaining structures such as retaining walls, basically what is the job of the retaining walls? To retain the earth, it will protect from falling the earth material and this is used retaining walls, bridge abutments, so retaining wall is a general word but bridge abutment is also kind of a retaining wall. Then you have clay walls, anchored bulkheads, braced

excavation and mechanically stabilized earth walls are used throughout seismically active areas. So different names are given, so even the clay wall is also a retaining wall, anchored bulkhead is also a kind of a retaining wall. So, these frequently represent key elements of ports and harbors, transportation systems for example as I said bridges, lifelines and other constructed facilities. Retaining wall is not only used in the hilly area, they use near the coastal areas also where you have the clay walls and other things. They are used to protect the abutment of a bridge. So, it is very widely used, and this is also because they also have slope, so that is why we are discussing after slope stability. Coming to this part, when we talk about earthquakes, this cause permanent deformation of retaining structures in many historical earthquakes. It has been observed in the past earthquake that there are permanent deformations. In some cases, these deformations were negligibly small, in others they cause significant damage.

In some cases, retaining structures have collapsed during earthquakes which disaster physical and economic consequences. The behavior of retaining walls during earthquakes has been discussed in this case. So what are the behavior? So this is IS 14458 retaining walls for hilly areas and these are the guidelines basically. So there are three parts of the code, part 1, part 2, of course there are numbers, it is not only three, there are I think 14 codes for this number 14458. But first three, part 1 and part 2, part 3 are important for us. The part 1 of this code which is on retaining wall for hilly area talk about selection of type of walls. Then part second, how to design of retaining or breast walls. Part third, construction of dry stone walls. So, we will be discussing the first one today, that is selection of type of wall, and I will suggest that you keep like you know you can download all this code I 14458 at least these three parts and go through those like this code. So let us say selection of type of walls.

When we talk about type of retaining walls, let us talk first in general then we will talk about what is given in the code. Retaining walls are often classified in terms of their relative mass, flexibility and anchorage conditions. So, when we say stiffness and flexibility, this will be a relative term because retaining wall is mostly used to retain the earth, soil. Normally the soil compared to the retaining wall it will be flexible. So now the how much difference between the stiffness between earth material and the retaining wall that will govern the design part and then you have many different approaches to soil retention have been developed and used successfully.

Recently the development of metallic polymer and geotextile reinforcement has led to the development of many innovative types of mechanically stabilized earth retention systems. So what is here? In gravity walls are the oldest and simplest types of retaining walls which is given in the next figure. Gravity walls are thick and stiff enough that they do not bend. Their movement occurs essentially by reached body translation or rotation. So these are the first of all they are the simplest oldest walls and which is given in the like in the next.

Similarly, these were quite thick or massive walls. So as a result we can consider that these are the reached body translation occurs. Certain types of composite wall systems such as crib walls and mechanically established walls are thick enough that they bend very little, and concern often designed as a gravity walls with consideration of internal stability. So here is the types of retaining walls in this figure. The first one is a gravity walls.

In gravity wall you could see the thickness is large compared to other figures A. So, this figure so the first one is thicker and when you make thicker natural thickness will be higher. This is basically cross section then it is going in the longer direction longitudinal direction. So, the cross section at the base is larger and at the top it is smaller which is expected to make for more stability. Cantilever walls are normally thinner quite thinner compared to gravity walls but then you could have the base pedestal also like here in this case.

So naturally this is going to be more stable than the second one. Both are cantilever walls because thickness of their stem is quite small compared to gravity wall. Then you have reinforced soil wall. In this case you are providing some bracings anchoring which is going inside the soil earth to protect that wall should not fall due to earth pressure. Then you may have basement walls so which is given here in the basement like this is the earth to protect the earth here and this side you have basement of residential building or maybe like so this will act.

Then you have bridge abutment wall. So in the bridge abutment wall this side you have the soil and on another side you have abutment. So here you could have water or maybe free space on this side. So, one side it protect the earth, another side it could be open or maybe water bodies or something might be there. Then anchored bulk head.

So, this is bulk head which is anchored on the top and this side. Then tie back wall. So these are the different types of common types of earth retaining structures used. Coming to the cantilever walls. Gravity walls are the massive and they normally do not bend, rather they slide which we are going to discuss later. Cantilever walls which bend as well as translate and rotate and the cantilever walls rely on flexural strength to resist lateral earth pressure. Flexural when the flexural wall comes it means bending it is due to the bending action to resist lateral earth pressure. External distribution of lateral earth pressure on a cantilever wall is influenced by the relative stiffness and deformation of both the wall and the soil. So, when we talk about relatives it means what is the properties of the wall and what is the property of the soil.

For designing retaining wall certainly, you need to know what the property is of the backfill which need to be retained. Braced walls are constrained against a certain type of movement by the presence of external bracing elements. In the cases of basement walls and bridge abutment walls lateral movement of the tops of the walls may be restrained by

the structure they support. So lateral movement can be restrained. Then you have tie back walls and anchored bulkheads are restrained against lateral movement by anchors which is embedded in the soil behind the walls.

The provision of lateral support at different locations along the braced wall may keep bending moments to be low that relatively flexible structural sections can be used. So this is like here. So, this was in general but what is like suggested by this code IS 14458 part 1 the different types of retaining walls has been classified based on the types of construction and mechanics of behavior. So gravity walls we already discussed. In the cantilever wall they says simply rather than driven cantilever walls.

Then you have reinforced earth walls. So as this was as just, I said this is in the short called RE walls. Then you have the RCC walls. The different types are there, and the figures are given here. So, like for example the gravity walls the first one A.

In the case of gravity walls, it is very massive and at the base the thickness is more at the top it is less. In the gravity walls which is according to this code what you have let us discuss this in detail what you have this line is original ground profile before putting up this wall. Originally there was no wall, and this was there. Now what is done and this wall is normally used to protect some road or like this. So, what is done here this part is cut down and a wall is created here.

Now this wall will protect this earth here which is earth here and assume failure plane is this one. So ultimately when we want to stability, we need to check the slope stability this part of this ways and this will try to apply the force on this wall lateral direction. So this wall should be enough strong enough to resist that earth pressure which is coming from this side. This is cut down so and then this way it is created.

Now another case is tie back walls. In case of tie back wall looks like a cantilever walls it is thin is compared to quite thin compared to gravity walls and ties are used. These ties will try to keep the wall at the its position wall panels are there, anchor are there. So in this case this is one type inclined anchors here you have the horizontal anchors grouted anchors bad rock earth anchors in backfill these all are done here. So third one driven cantilever walls. So, in the driven cantilever walls you have like again very thin wall and assume failure plane is here.

This is the bed rock which means you have the quite good condition; stiffness is quite high compared to the soil. Then you on the top of field you weathered rock and soil is here. This is the original line, and this is cut down this is field here this is field and then this will protect this will protect completely. Then you have reinforced earth wall in case of reinforced earth wall what is done you apply the reinforcement; reinforcement strips are done. So, this is the wall and on this wall reinforcement strips keep at the wall like you know at in the horizontal direction.

Anything which try to put it down like due to wind action or due to our lateral earthquake force then these ties will try to keep them in line. Then you have RCC walls which is shown in this figure. In RCC wall which is reinforced cement concrete wall. So inside the wall the reinforcement is done that means it is not a plain concrete rather reinforcement is done that is why and the heavy surcharge. But once you provide the reinforcement then thickness of the cantilever one can be reduced.

Coming to the gravity types of retaining structures. Normally though it is called retaining wall but in the hilly areas it is divided in two parts one is called beast wall another is simply called retaining walls. Normally the beast walls normally constructed of stone masonry walls and products of slope cutting in natural ground. So beast wall are used in cutting but contrary to this retaining walls are used commonly used in hill roads in partly in cutting and partly in filling. So beast wall are used in cutting only while the retaining walls are done here and these are built to resist the earth pressure of filling and traffic roads.

So, this is the figure which shows the difference between the retaining walls and the beast wall. So let us first discuss the retaining wall. Retaining wall is the down one and in this case to understand it try to understand the original position. Original position before putting the retaining wall was this. Now what is done? We want to create a road here like, so we want to protect this here this part.

This part need to be protected. Because why it is need to be protected? This is a road. So what is done here? First of all this part is filled out to provide the stability to the road. Now what will happen? If I do not put a retaining wall then whatever is filled artificially will again come down. So, a retaining wall is put, and this retaining wall will not start from here it is going quite deep and quite massive. So, it will be even this earth pressure will not try to even the lateral earth pressure and nothing will happen because it is going up to down here.

So, in this case this portion will be filled, and this portion will be cut down to prepare the retaining wall. So, for the cutting will be done for wherever cutting this was already empty. But this part there was earlier in this part there was a some so this will be cutting this this part will be going and cutting and this part will be in filling. So both cutting and filling is done in the retaining wall. And the weep holes are provided weep holes are those holes and weep holes inclination is like it is going downward towards the outwards.

And so, weep hole is basic idea of the weep hole is in the rain water comes out of it inside earth you may have some water and then this water should percolate, and it should come down out of this one. So, this was retaining wall. In case of this wall you are doing only cutting no filling. So, you see like here originally whatever this you have let us say original position was this. So, you will cut down some material and to put the wall you have this, and this is inclined.

This base is also inclined, in this case base is horizontal. So, this was about gravity type of retaining walls which could be the retaining wall simply. According to the how the constructions are done, and which type is good here. So there are the same like you know the retaining walls has been four figures are here A B C D 1 A 1 B 1 C 1 C. So, what you have 1 A is retaining wall of very small strength while 1 D last one is retaining wall with good filling.

So, the last one is the best one D is the best one and the A is the worst case. Why? In this case you have only face stones are well placed rest is dumping of stone. So, in this case this has been created just by dumping of the stone without any engineering work or anything. Then you have raised top overstocked drainage. In the second case you have changed stone layers that have been used which is better than the last case sloping outwards.

But in the third case you do some shoulder top is shouldered slope. So, and here you now have in this case you filled using hand picked stone filling. So, this is done here also it is using hand picked stone filling. But in this case in the D case, you are providing toe pitching also. This was completely missing in A B C D and here the slope is also maintained 1 2 3 and this dense soil filling is done compared to what has been done in the C case.

So thus, D case is the best one out of 4 cases considered. So further you can go in the detail of this. Coming to the types of retaining wall failure. Now let us discuss what types of failure takes place. To design retaining walls it is necessary to define failure and to know how wall can fail. So, it is important that the how the failure of the retaining walls takes place.

Under static conditions retaining walls are acted upon by body forces which are related to the mass of the wall or by soil pressure and by external forces such as those transmitted by braces. So you have body forces, or you have this mass soil pressures. A properly designed retaining wall will achieve equilibrium of these forces without inducing shear stresses that approach the shear strength of the wall. So once we design properly then it will be the forces will be in equilibrium and there is no issue related. During an earthquake inertial forces and changes in soil strength may violate equilibrium and cause permanent deformation of wall.

Why changes in soil strength? Because during earthquake your material goes under nonlinear. Once your material is going under nonlinear phenomena then the strength of the material may lose during earthquake loading and there could be permanent deformation may occurs. Failure could be by sliding, tilting, bending or some other mechanism when they occurs when these permanent deformation become excessive. So, when these permanent deformations are excessive then the failure will occur and there could be many

reasons of mechanism of failure. It could be sliding failure; it could be overturning which we are going to discuss.

The question what level of deformation is excessive will depends on many factors and that could be decided on site specific basis. Now coming to the gravity walls that how the types of retaining wall failure. They usually fail by rigid body mechanism because they are massive walls, gravity walls are massive walls and rigid body mechanism means for example sliding, mostly gravity walls could fail in the sliding or they could fail in overturning or by gross instability. Sliding occurs when horizontal force equilibrium is not maintained that is when the lateral pressures on the back of the wall produce a thrust that exceeds the available sliding resistance on base of wall. Sliding failure occurs when moment equilibrium is not satisfied, bearing pressure at the base of the wall are often involved.

So, you have first like you know sliding failure or you can have overturning failure. So, in this case of sliding failure how the sliding failure is taking place in the typical failure mechanism for gravity retaining walls are shown in this figure. So, in the first figure a it is sliding wall is sliding and in figure b it is overturning. In the case of rigid body motion the slide without overturning, but there could be sliding as well as overturning also. So, it could like you know if it is simply overturning then rather than sliding it may like an overturn, but there could be slide as well as overturn also.

It is possible that two phenomena taking place together. So, in this case typical failure mechanism a sliding or translation failure, second is overturned or rotation of failure, third is gross instability failure where both sliding is taking place as well as overturning is also there. So, it could be possible when you have weak or liquefied layers. So, these type of failure and these failure are mostly in gravity walls. Coming to gravity walls may also be damaged by gross instability as we discussed. Such failure may be treated as slope stability failure that encompass the wall.

Then you have composite wall systems for example, crib walls, bin walls and the mechanical wall can fall in the same ways by number of internal mechanism that involve shearing pull out or tensile failure of various wall elements. So, the number of mechanism failure could be one or a number of combination of these two. Cantilever walls are subjected to the same failure mechanism as gravity walls and also to flexure failure mechanism. So, when we have the cantilever walls, you have gravity walls. So, and in addition to gravity wall because the concept of cantilever walls are based on the what you call flexural the bending action.

So, they also can fail using flexural failure mechanism. Soil pressure and bending moments and cantilever walls depend on the geometry, stiffness and strength of the wall soil system. If the bending moments required for equilibrium exceed the flexural strength of the wall,

flexural failure may occur. The structural ductility of the wall itself may influence the level of deformation produced by flexural failure. So, the flexural failure, the structural ductility like it will depend on the structural ductility of the wall and it could produce. So, for example, in case of cantilever walls, what type of failure is taking place is shown in the slide.

But you have the in the first figure a, you have soil pressure. In the soil pressure and then you have bending moments here. So, this failure will take place due to the soil pressure. That means, soil pressure exceed the capacity of the wall. So, here the maximum soil pressure will be at this point. Then this is like on one direction compressive, on this side this is active and then passive here you have.

So, it may fail. Then it could be due to flexural failure mechanism. Flexural failure is basically related to what we call the bending moment. If bending moment is maximum for which the wall is not designed. So, maximum bending moment is going here in this case at this point. So, peak well.

Then they could also fail this bending moment failure which is b. Then you have flexural failure mechanism is here where what is happening the vault get tilted and this is the maximum is ever happening at the like you know at the top part of this one. So, depending when we talk about design of failure naturally the maximum value will govern in this case it will govern here, in this case this will govern here, this will govern the design. Bass wall usually fail by gross instability, tilting, flexural failure or failure of bracing elements. Tilting of base wall typically involved rotation about the point at which the brace acts on the wall, often the top of the wall as in the cases of basement and bridge abutment walls.

Anchored walls with inadequate penetration may tilt by kicking out at their toes. So, this is like here done. Types of retaining wall failure. So, this in case of like and this is basically what is this we discussed it looks like a wall of abutment of a bridge. So, what happens this was dotted line was the initial position, original position. When it get failed this could be a deck of this one. So, earlier you know when this was straight. So, they were like you know perpendicular to each other, but now there is a gap because your wall which was like this now it get tilted like this. As a result you have a gap here, this gap was not there earlier. So, when the wall get failed. So, the wall tilted, and this may be tilted due to this like more soil pressure at the base less at the top.

Similarly, here this is an another this was gravity wall a case. So, rotation of bridge abutment about top this is then rotation of anchored bulkhead due to lack of passive resistance which is called kick out and this is looks like a cantilever wall anchored this is anchoring here. So, this anchored bulkhead is done here. So, anchoring is done at the top, but at the base it is free. So, it is done like this was here or it rather than it is not going this direction due to anchoring rather it tilted straight was this.

So, the top portion move inside the bottom is outside. Then another could be that in this case it was top is moving inside bottom is out. Here top is moving out bottom is in. So, this is like a lack of adequate anchor capacity.

So, this could be another type of failures. Then we have type of continue with this one. In the case of cantilever walls anchored walls may fail in flexure although the point of flexure, what is the point of flexure where you get the maximum moment is likely to be different. Then failure of bracing elements can include anchor pull out, tie road failure or bridge buckling. Then you have backfill settlements that can also impose additional axial and transverse loading on bracing elements such as tie roads and tie backs. So, these are all different types of retaining wall failures depending on the type of wall whether you have the gravity wall, whether you have the cantilever walls, anchored walls there may be number of failures also. So, with this I conclude this the first lecture on retaining walls which was an introductory lecture and then now we will go further in the design part.

First, we will talk about static then we will go on seismic. First of all, we are going to talk about forces and then we are going to talk about displacement and finally design constraints. So, with this I conclude today's lecture. Thank you very much for your kind attention. Thank you.