

**Foundation Engineering**  
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**Lecture – 60**  
**Underground Conduits II**

So, this class, I will discuss about the load transfer mechanism of the conduit and in the last class I have discuss that.

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**Uses of underground conduits:**

- Drains
- Sewers
- Gas lines
- Water mains
- Culverts
- Tunnels

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**Marston's classification of underground conduits:**

**Ditch conduits** : Installed in a narrow ditch and covered with earth backfill.

**Examples:** sewers, drains, water lines, gas mains

**Positive projecting conduits** : Installed in shallow bedding with its top projecting above the surface of the natural ground and then is covered with an embankment.

**Examples:** Railway, highway culverts

**Handy and Spangler, 2007**

**a) Ditch conduits**  
**b) Positive projecting conduits**

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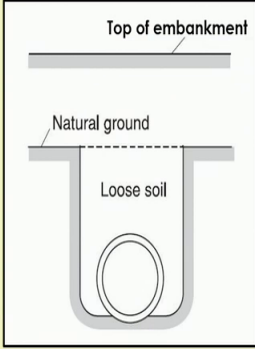
This is the application areas of the conduit. What are the different types of conduit? Ditch conduit, positive projecting conduits and then negative projecting conduit and then this is the your impact ditch conduits ok.

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**Negative projecting conduits :**

A negative projecting conduit is designed to reduce soil pressure on pipe under an embankment.

Conduit is installed in a shallow ditch with its top below the natural ground surface, the ditch is then backfilled with loose and uncompacted soil, and an embankment is constructed.



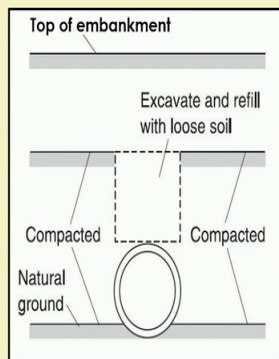
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**Imperfect ditch conduits :**


- Similar to negative projecting conduits
- In this case trenches are cut into the embankment over the conduit and backfilled with compressible material.
- Effective for reducing the soil load on a pipe.
- **Not recommended for embankments that serve as water barriers** because the loosely placed backfill will allow channelling of seepage water through the embankment



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**Marston's load theory:**

The theory of arching is used to compute vertical load on conduits. Because of soil arching, a significant amount of soil weight (above the top of conduit) is transferred to the ditch wall. Thus, the load on the conduit is reduced.



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So, now in the, that class also I have discuss about the, your soil arching theories and then what is the active arching what is the passive arching. That I have discussed.


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**Soil Arching : Transfer of pressure from a yielding mass of soil onto adjoining less yielding or rigid parts.**

Yielding part of soil mass has a tendency to move out from it's original position. This tendency is resisted by the shearing resistance at the zone of contacts between yielding and non-yielding parts.

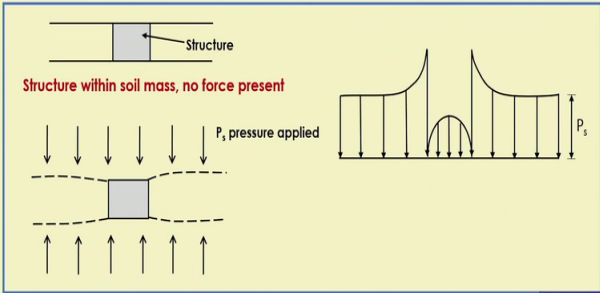
If the yielding part moves downward, the shear resistance will act upward and reduce the stress at the base of the yielding mass. On the contrary, if the yielding part moves upward, the shear resistance will act downward to reduce its movement and cause increase of stress at the support of the yielding part.



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Depending upon relative movements of a structure and the adjacent ground, active and passive arching can be distinguished

**Active arching:** The structure is more compressible than the surrounding soils



The diagram illustrates active arching. On the left, a cross-section shows a rectangular structure within a soil mass. Above the structure, horizontal arrows point outwards, indicating soil movement away from the structure. Below the structure, horizontal arrows point inwards, indicating soil movement towards the structure. The soil surface is shown as a dashed line that has moved downwards away from the structure. On the right, a pressure distribution graph shows vertical arrows representing soil pressure. The pressure is uniform over the top and bottom surfaces of the structure but significantly higher at the top corners, forming a peak. The total height of the soil mass is labeled as  $P_s$ .

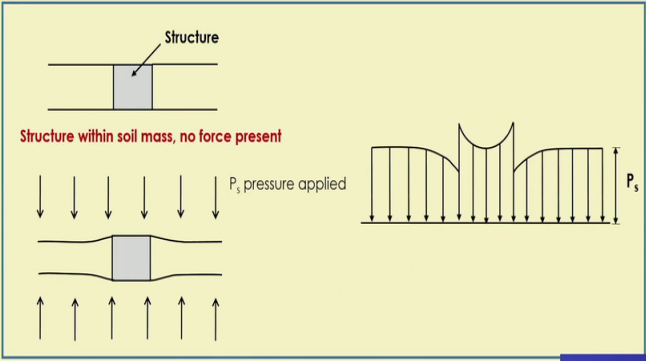
Structure within soil mass, no force present

$P_s$  pressure applied

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**Passive arching:** The soil is more compressible than the structure



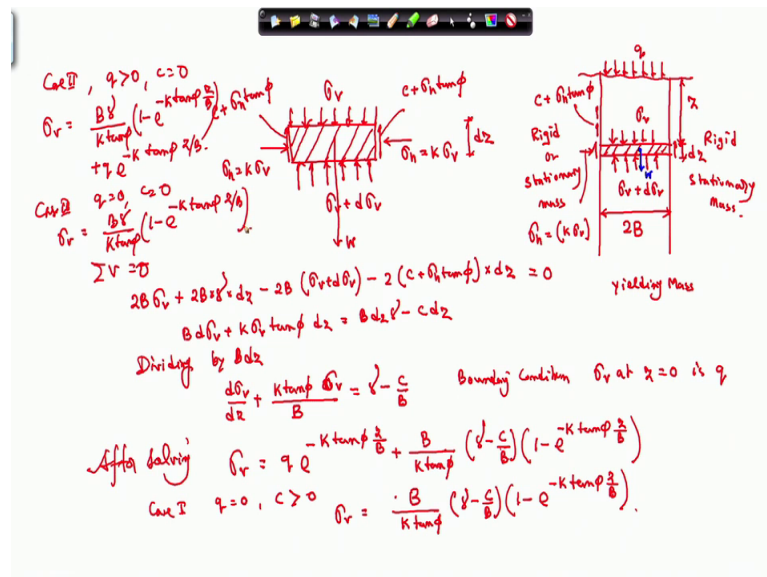
The diagram illustrates passive arching. On the left, a cross-section shows a rectangular structure within a soil mass. Above the structure, horizontal arrows point inwards, indicating soil movement towards the structure. Below the structure, horizontal arrows point outwards, indicating soil movement away from the structure. The soil surface is shown as a dashed line that has moved downwards towards the structure. On the right, a pressure distribution graph shows vertical arrows representing soil pressure. The pressure is uniform over the top and bottom surfaces of the structure but significantly higher at the bottom corners, forming a peak. The total height of the soil mass is labeled as  $P_s$ .

Structure within soil mass, no force present

$P_s$  pressure applied

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Now, this class what I will discuss about the how the load is transfer from this case ok. So, first I am considering that in my case that the stress on the conduit should be less it should be reduced. So, I will consider one case, where this is the, your narrow backfill or the backfill, which is loose. So, this will deform. So, this is the yielding part, where this is the ground surface ok. So, where the, we are applying a stress  $q$  ok. So, because that is the we will here that your, this is the yielding or moving part and this is the rigid part ok. So, this is the rigid part or the non less yielding part and this is the this side also rigid, rigid or less yielding this is the yielding part ok. So, this is the yielding mass and we can say rigid or stationary mass ok.

So, I am considering one particular strip, this is the particular strip which is at a depth of  $h$  from the ground surface and the thickness is  $dz$  ok. So, what is the stresses acting in this strip? the so, that mean the vertical stress that will act  $\sigma_v$  and in the bottom this stress will be  $\sigma_v + d \sigma_v$  and the weight of this stress the strip we will also act ok,  $w$  is the weight of the strip and this side there will be friction or shears because this is here this portion is moving and this portion is not moving. So, there will be a friction and that force is equal to your, this is the or the as I mention because of this movement a shear and plane is developed.

So, this shear stress or the shear plane this I can write that  $c + \sigma_h \tan \phi$  ok, this is this is again the soil versus soil, that is why I have written the  $\phi$  and why  $\sigma_h$  because, this is the  $\sigma_h$  is acting here this is the  $\sigma_h$  and this  $\sigma_h$  is equal to  $K$  into  $\sigma_v$  ok.

So, finally, if I take this strip; so, this will be the  $\sigma_v$ , this will be  $\sigma_v$  plus  $d\sigma_v$  and the weight of the strip will also act and here this is  $\sigma_h$ , which is  $K$  into  $\sigma_v$  this is also  $\sigma_h$  which is  $K$  into  $\sigma_v$   $K$  is the coefficient of earth pressure. So, this value will be your  $c$  plus  $\sigma_h \tan \phi$  and this side also there will be stress this is  $c \sigma_h \tan \phi$ , this is the shear plane. So, and this thickness of this or the width of this trench is  $2B$  ok.

So, now finally, if I take the summation of vertical force is 0. So, this is the first top  $\sigma_v$  is acting downward. So,  $2B$  is the width into the  $\sigma_v$  that is the force, then the weight of the, this strip, weight of the strip will be  $2B$  into  $\gamma$  into  $d$   $h$   $dz$  because this is  $dz$ . So, this is  $dz$  in to  $dz$ ; then the these force is acting upward direction. So, this will be minus  $2B$  into  $\sigma_v$  plus  $d\sigma_v$  and the shear stress that is also acting upward. So, this will be  $2$  into  $c$  plus  $\sigma_h \tan \phi$ , why  $2$ ? Because it is acting in the both side in to  $dz$  it is acting on the  $dz$  distance. So, that is equal to 0.

So, finally, after simplifying I can write  $Bd\sigma_v$  plus  $Kd\sigma_v$  plus  $K\sigma_v \tan \phi dz$  equal to  $b dz \gamma$  minus  $c dz$ . So, dividing by  $B dz$  we will get  $d\sigma_v$  divided by  $dz$  plus  $K \tan \phi$   $K \tan \phi$  into  $\sigma_v$  divided by  $B$  equal to  $B dz$  means  $\gamma$  minus  $c$  by  $B$  ok. So, this is the expression. So, after solving so, we have the boundary conditions how many boundary condition is required, because one boundary condition required.

So, the boundary condition is the  $\sigma_v$  at  $z$  equal to 0 is  $q$ , because this is the  $\sigma_v$  at  $z$  equal to 0 mean surface, where  $q$  is acting ok. So, after solving with the boundary condition you will get  $\sigma_v$  is equal to  $q e^{-K \tan \phi z / B}$  plus  $B K \tan \phi \gamma$  minus  $c$  by  $B$  into  $1 - e^{-K \tan \phi z / B}$  ok. So, this is the expression final expression. So, that amount of stress will now act on to the conduit ok.

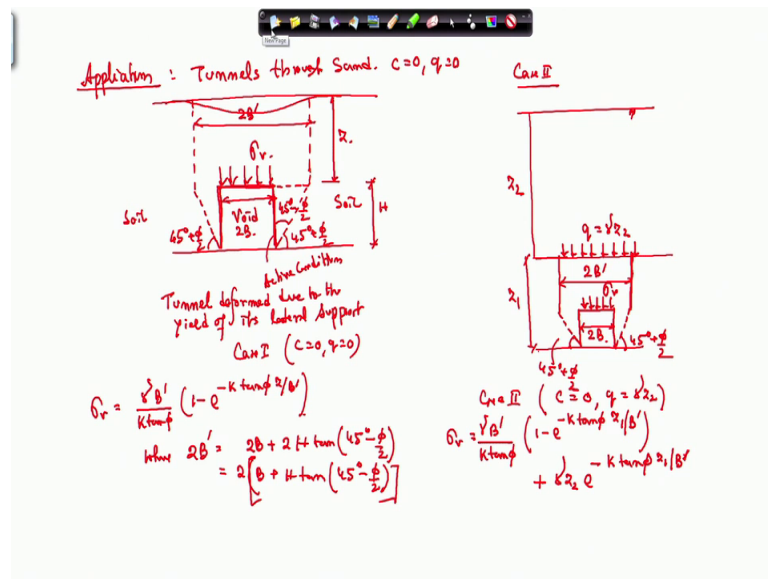
So, this will act on the conduit. So, because that this is the less amount of the stress or now for different condition that for the case 1, if your  $q$  is equal to 0 and  $c$  is greater than 0 or not equal to 0 then your  $\sigma_v$  will be  $q$  is 0. So, this part will be 0. So, this will be  $B K \tan \phi \gamma$  minus  $c$  by  $B$   $1 - e^{-K \tan \phi z / B}$  ok.

Now, case 2 that your  $q$  is not equal to 0  $c$  is equal to 0. So, in that case  $\sigma_v$  is  $B \gamma$  that is your  $c$  is equal to 0. So, this will be  $B \gamma$  divided by  $K \tan \phi$  and  $c$

part is  $0.1 - e - K \tan \phi z$  by  $B$  plus  $q - e - K \tan \phi z$  by  $B$ . Now case 3, that your  $q$  is equal to  $0$   $c$  is also equal to  $0$  ok. So, in that case  $\sigma_v$  is equal to  $B \gamma K \tan \phi (1 - e - K \tan \phi z)$  by  $B$  ok. So, these are the three cases we have considered ok.

So, now I will apply this one in tunnels, through sand ok.

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So, now, the next one, if I apply this, the application of this theory that we have a tunnels through sand ok. So, now, we have a if we have a tunnel through sand, suppose this is the tunnel or the you can use the culvert also; so, if this is the tunnel and this is the brace.

Now, you have a embankment on the or the soil above this tunnel. So, and this is. So, now, what will happen if it is a this is a within the relatively shallow depth. So, what will happen? This is the void or because this is tunnel this is void; so, here the soil this side also the soil.

So, so, the tunnel wall will deform with this wall will deform this side and this wall is also deform. So, because of deformation this soil will move ok. So, this there will be a failure plane will occur or the soil with the failure plane, because it is this wall is under active condition, because it is deformed because of the soil so; that means, we can say there will be a failure or the surface as it is an active condition. So, this will make an angle  $45$  degree plus  $\phi$  by  $2$  and this side also there will be active condition, where this

soil this surface will making an angle  $45^\circ$  plus  $\frac{\phi}{2}$  ok. So, this is the active condition, because this side is soil and this side also will soil.

So, if I and this surface if I so; that means, this portion of the soil will move. So, this portion of the soil will move so; that means, soil above this portion this also move ok. So, soil above this portion will also move. So, I can write that if this is twice B and this one is  $2B$  dash. So, I have derive the expression, where this is the twice B. So, here this total portion of the soil is moving here, this portion of the soil is moving because this soil this wall is deformed and this soil is move under active condition as these two parts of soil is move this soil also in stationary condition.

So, I can write that this case, tunnel deform due to the yield of it is lateral support, the support will move the soil is also moving so; that means, this soil is stationary and this soil is yielding ok, here the deformation pattern will be something like this.

So, now the stress on the on this tunnel will be. So, this is my case 1 ok. So, case 1  $\sigma_v$  stress which is acting on the tunnel is will be  $\gamma z$ , because here this is a sand. So,  $c$  value is 0 and  $q$  value is also 0 ok. So, in the case 1 your  $c$  value is 0  $q$  value is also 0. So, if the  $c$  value is 0  $q$  value is 0. So, this is the expression. So, instead of B, because here B, I will write twice B dash. So, instead of B it will be  $B$  dash divided by  $K \tan \phi$  into  $z$  by  $B$  dash ok.

So, you can write this is the, if it is the height. So, instead of this is the  $z$ . So, this is the  $z$  if it is  $h$  instead of  $z$  you can use the  $h$ . So, why this is the  $2B$  dash? So now, how I can write, where how I can write  $2B$  dash?  $2B$  dash, will be twice B, because this is this is the width of this tunnel. So, this will be twice B plus this angle is  $45^\circ$  minus  $\frac{\phi}{2}$  and this height is say  $H$  this height is  $H$ . So, this one this portion will be this is this is  $H \tan 45^\circ$  minus  $\frac{\phi}{2}$ . So, this portion will be  $H \tan 45^\circ$  minus  $\frac{\phi}{2}$ . So, and that is will be twice this side and this side. So,  $2B$  plus twice  $H \tan 45^\circ$  minus  $\frac{\phi}{2}$  or you can write that, this is twice B dash twice B dash is  $2$  into  $B$  plus  $H \tan 45^\circ$  minus  $\frac{\phi}{2}$ .

So, this is the application. So, now, if these values are given and it is said that you determine the stress acting on the top of the tunnel, then you use this expression and determine the stress acting on the tunnel. Now in the case 2, where your tunnel is in very deep ok. So, suppose this is the ground surface and your tunnel is somewhere here,



which is very deep again this is the twice B. So, this is the tunnel. So, again this is void the soil again here the this will be the 45 degree minus 45 degree plus phi plane and this is also 45 degree plus phi by 2 plane. So, and this soil we will deform ok.

And because of that there will be a stationary soil mass above the tunnel, but as the depth is very large. So, this deformation effect will not reach to the ground surface because here, case 1 it is the shallow depth relatively. So, deformation effect reaches the ground surface, but here it is the depth is very high. So, this deformation effect will not reach the ground surface. So, there will be a point where this deformation will not be there.

So, that point is say here, so; that means, here this deform after that this soil will not deform, because of this effect because it will not go up to the very large depth and it will not reach the ground surface so; that means, if I say this is the  $z_1$  and this is the  $z_2$ .

So, now what will happen in this case, this is again the  $2B$  dash and  $2B$  dash, I can calculate with this equation, but instead of this now addition force will act is the surcharge. Now here, in this plane now suppose this is my, a new ground level and this soil up within the  $z_2$  depth will act as a surcharge ok. So, this is the  $q$ , which is  $\gamma$  into  $z_2$ .

So, now in the case 2, your  $c$  is equal to 0, but  $q$  is equal to  $\gamma z_2$ . So, the  $\sigma_v$ , which is act on this on this the top of the tunnel that is  $\sigma_v$  is again,  $\gamma B$  dash divided by  $K \tan \phi_1$  minus  $e$  minus  $K \tan \phi$  into this will be the  $z_1$  ok. This is the  $z_1$  divided by  $B$  dash, then plus the  $q$  part that is  $\gamma z_2 e$  to the power minus  $K \tan \phi$  then  $z_1$  divided by  $B$  dash. So, you can see that, it is the  $q$  is there. So, this is  $q e$  to the power minus  $K \tan \phi z$  by  $B$ . So, this is also  $q$  is  $\gamma$  into  $z_2$  and  $e$  to the power minus  $K \tan \phi z_1$  and  $B$  dash and  $B$  dash value will calculate from this same expression. So, these are the two cases I have discussed, where you can apply this theory and you can calculate the stresses acting on the tunnel or the conduit ok.

So, now I will show you few more applications, that how you can apply these theories.

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**Analysis of loads on ditch conduits**

$$V = \gamma B_c^2 \frac{1 - e^{-2K\mu(h/B_d)}}{2K\mu}$$

$\gamma$  = total unit weight (including water) of the backfill material, in N/ m<sup>3</sup>;  
 $V$  = average vertical stress on any horizontal plane in backfill, in N/m;  
 $B_c$  = horizontal diameter or width of the conduit, in m ;  
 $B_d$  = horizontal width of the ditch at the top of the conduit, in m ;  
 $H$  = height of backfill above the top of conduit, in m ;  
 $h$  = distance from the ground surface down to any horizontal plane in backfill, in m ;  
 $C_d$  = a load coefficient for ditch conduits;  
 $\mu'$  = coefficient of friction between the fill material and sides of the ditch on an effective stress basis;  
 $K$  = ratio of lateral pressure of soil at the sides of the ditch to average vertical pressure;

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So, this is the your active and passive arching so, now the analysis of load on ditch conduit ok. So, so; that means, this conduit where I can calculate the stress, if this is the  $B_c$  is the diameter. So, we have the same expression, we are using that I have developed, but the where  $\mu$  value is here value is  $\mu$ . So, this  $\mu$  is nothing, but the  $\tan \phi$  ok. So, in my previous expression, I have use the so,  $\mu$  is  $\tan \phi$ . So, I have use the  $\tan \phi$  that is the  $\mu$   $K$  is the again your ratio of the lateral earth pressure at the side of the ditch to the average vertical pressure ok, that I have mention and this is the  $B_c$  is the horizontal diameter of the conduit and then  $h$  is the small  $h$  is the distance from the ground surface to any horizontal plane in the backfill. So, if it is up to here, if you want to calculate then instead of small  $h$  you have to use the capital  $H$ ,  $H$  is the any distance below the ground surface.

You can see the similar expression, they have also derived that I have derived, so and if you want to determine the stress acting on this conduit ok. So, then instead of small  $h$  it will be the capital  $H$  other thing  $B_d$  is the width here remember that, I have use  $2 B$  here, they are use the only  $B$  ok, that is why the equation is slightly different ok.

So, but the same way it is been derived and this is the so; that means, here remember that it is not the stress, because my case in the previous case the  $\sigma_v$ , which is the stress, but it is the force ok. So now, you know you have to multiply it to get the force. So, directly you get the much force is acting on the conduit ok.

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**Maximum loads on ditch conduits :**

In case of a very rigid pipes, when the side fills are relatively compressible, the conduits would carry practically all the loads

$$W_c = C_d \gamma B_d^2$$

$$C_d = \frac{1 - e^{-2K\mu(H/B_d)}}{2K\mu}$$

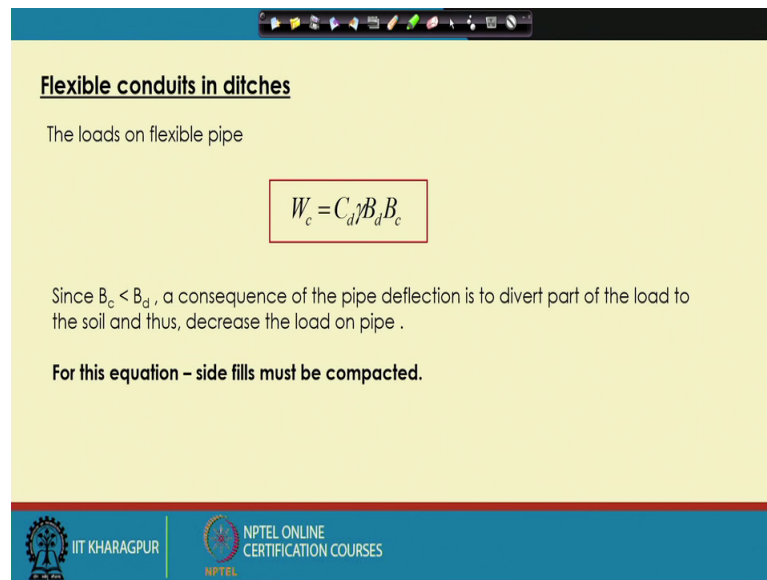
Graphs for determining  $C_d$  for various soil types.

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So, this is one thing now if it is the maximum load on a ditch conduit in case of very rigid pipe, if the conduit surface is conduit surface is very rich, when the side fills are relatively compressible then the conduit carried particularly all the loads as I mention, if the side surface are compress more compressible than the structure or the conduit, then the stress from the such surface to come on the on the soil on the structure ok.

So, here it will you will use this chart and then you will use this expression to get the forces. So, this is; that means, the all the all the forces will be taken by the conduit ok. So, this is the  $C_d$  is the coefficient that we will get  $H$ , is the and the  $B_d$  is this width,  $H$  is any height here, what is the, if you this is your  $H$  value calculate, what is the  $H$ ? You know the  $B_d$  so, from here depending upon the different types of soil ok. So, you get the  $C_d$  value from the curve or from the expression also use  $C_d$  value, then you calculate what is the force or what is the maximum load acting on a ditch conduit ok.

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**Flexible conduits in ditches**

The loads on flexible pipe

$$W_c = C_d \gamma B_d B_c$$

Since  $B_c < B_d$ , a consequence of the pipe deflection is to divert part of the load to the soil and thus, decrease the load on pipe .

**For this equation – side fills must be compacted.**

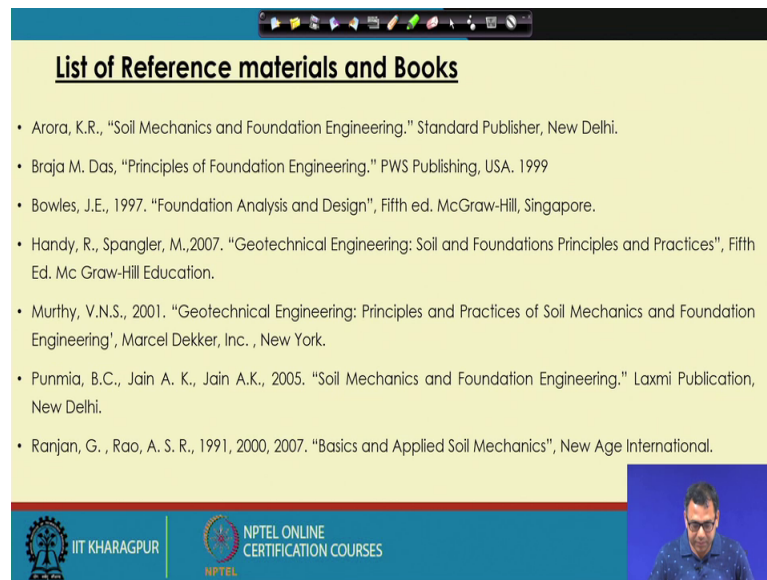
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So, now if it is the flexible conduit; that means, your conduit or a conduit is more compressible compared to the surrounding soil, then will be reduction of the stress so; that means, here you can use these expression  $B_c$  in a  $C_b$  also you will get from the from the chart that I have given.

So, now here so, in this equation side fills must be conduct compacted, because otherwise the because, side fill must become compacted means they are more rigid or stationary mass and the soil above the conduit or we will be a yielding mass or the moving mass. So, that mean the stresses will be reduced it will transfer from the conduit surface to the stationary or the rigid soil ok.

So, this way you can determine the stresses acting on different types of conduit ok.

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**List of Reference materials and Books**

- Arora, K.R., "Soil Mechanics and Foundation Engineering." Standard Publisher, New Delhi.
- Braja M. Das, "Principles of Foundation Engineering." PWS Publishing, USA. 1999
- Bowles, J.E., 1997. "Foundation Analysis and Design", Fifth ed. McGraw-Hill, Singapore.
- Handy, R., Spangler, M., 2007. "Geotechnical Engineering: Soil and Foundations Principles and Practices", Fifth Ed. Mc Graw-Hill Education.
- Murthy, V.N.S., 2001. "Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation Engineering", Marcel Dekker, Inc., New York.
- Punmia, B.C., Jain A. K., Jain A.K., 2005. "Soil Mechanics and Foundation Engineering." Laxmi Publication, New Delhi.
- Ranjan, G., Rao, A. S. R., 1991, 2000, 2007. "Basics and Applied Soil Mechanics", New Age International.

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So, now so before I end this course; I am giving the references or the books from, where I have taken the materials, I have given in each and every slides. We lecture the references, where I have taken the materials. So, these are the books. So, you can see where, I have taken the materials and I am use these books for the materials in addition to these books, I have taken the photographs and I have given the source information below the each and every photographs. I have use some Youtube videos also, I have given the source of those files in the in the video links. So, all these information you will get that the video link source, photograph source even, the even I have given the photo from the book. I have also given the reference, which book I have taken the photograph or the figure if the, I am using any table, I am also given the reference. So, these are the books mainly from where I am taken the material.

So, before I finish this course, I want to mention few thing that the in the shallow foundation part the tables for the different bearing capacity theories, Hansen, basic, Meyerhof or the Iosco at the table that, I am giving that is that you have to use for in the exam ok. So that, I will judge based on those tables and the charts that I have given, so you have to use those charts only, if you have getting different charts and different tables in various books, but you have to use the tables that is given, in this course and the pile foundation as I have mention, I have explain the how to calculate the bearing capacity of pile based on the critical length concept with or without ok.

So, my suggestion if it is a homogenous soil use the critical length concept, if it is a layer soil sandy then use the critical depth concept, but if it is a sandy soil then clay layer, thick clay layer again the sandy soil then, better to consider the or determine the bearing capacity without considering the critical depth concept ok. So, these are the few suggestions that will help you during yours exam. So, I wish all of you all the best for the exam.

Thank you.