Foundation for Offshore Structure
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Module 1
Lecture No 31
Special Foundation 3

So will continue with the gravity base structures I think as I mentioned in the last class the primary purpose of gravity base structures was one is the foundation designed driven the second one is storage requirement and in earlier stages of Nazi development quite a few location you see these kind of gravity base structures. One of the examples is (())(0:35) the other one I think one of this largest gravity base system in Narsi and basically we need to understand our disconcerted means in comparison to you know the fixed type of steel structures, so this will be slightly different it is going away from frame work wherein you drive piles, so in that case the requirement for construction and installation will be slightly different.

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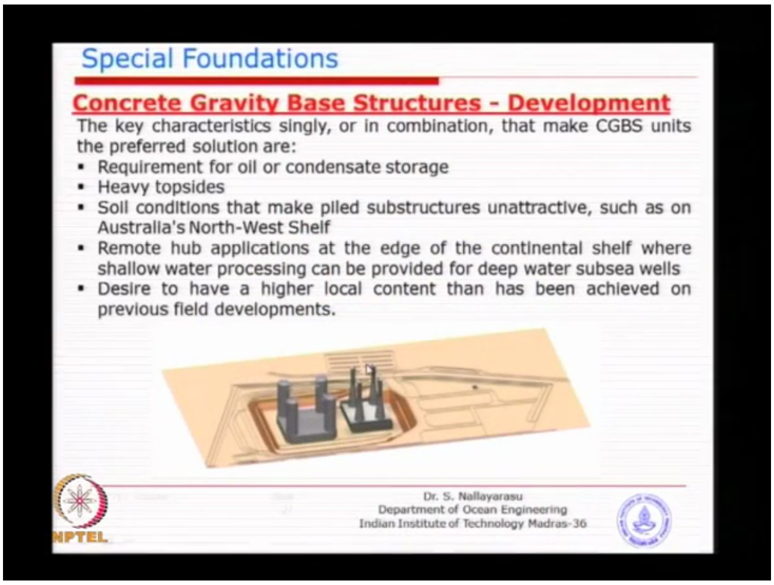

As you can see here concrete as I mentioned it cannot be instructed under water for several reasons that you cannot achieve strength, so you need to do a dry construction of course and then see how it can be installed. The major problem with this is heavyweight and we need to see how it can be transported or in fact transfer from a dry place to water and conventional jacket type of structures you have several methods of deploying barges and then transfer by either by lift or by skidding whereas here it is because of the weight we will be talking about several hundred thousand tonnes, so in such a case transfer becomes problem.

So one of the simplest way is to float out at means you require a dry dock when you construct this in a dry condition and then fled the dock and it gets buoyancy sufficient enough to float itself and you can either tow only the sub-structure or you can tow together with the superstructure placed on it depending on the design conditions that means the primary the design requirement will be buoyancy, so you have to manipulate the buoyancy in such a way that…

If you have too much of buoyancy is also a problem because during tow if we have substantial portion of the shaft as well as the superstructure is about water, not very good because during tow your vertical center of gravity will be very important, the higher that you go stability becomes more problem. So we have to give this VCG as low as possible but also have sufficient buoyancy to float out, so in such a case you should have variable ballast possibility that at a different situation you can ballast you can remove ballast, so that things can be manipulated. So that is why you need to design these shafts and the bottom with all hollow cells which can be ballasted and de-ballasted.

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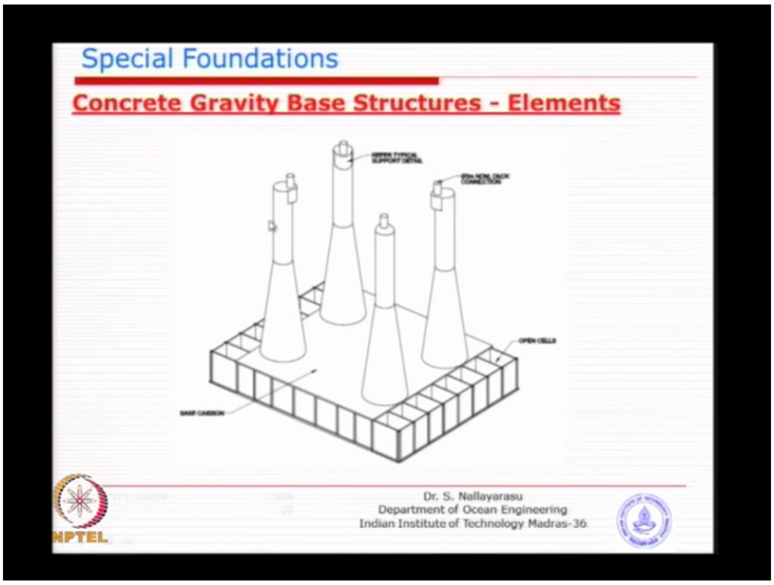

A typical concrete based structure you can see here is a rectangular cells of many of them assembled together, so for us as foundation engineer what is important is the interface between the structure and the ground, so you can see this is a rectangular shape, so as far as you want to construct designer foundation it is nothing different from a mud mat what you have learned is exactly the same because we do not have a skirt and only difference is you got large site structure instead of mud mat or smaller size you got a bigger size and the material is concrete instead of steel that is the change that you are looking at and then basically a different times you will get a different buoyancy, so the weight is going to be different.

For example when the whole gravity structures is sitting on seabed, in the initial condition no production is there so it could be lower later when you are actually ballasting and then doing production, you may store oil and gas oil inside the shaft, the weight will increase on one side, so variable loading condition can exist, so that is something that you have to evaluate, so you can see here there are 2 types of cells at the bottom, the bottom is called base caisson or base foundation you can call either way just a rectangular structure which has got sufficient wait and buoyancy, so you can see open cells and closed cells, this is closed cells always having vision for ballasting and de-ballasting controlled manner whereas the open cells will automatically get filled with water ones you submerge them but why they are requiring to be open because you can actually have possibility of ballasting solid iron ore or you may actually dump rocks, many a times people dump rocks, granite rocks or you can use iron ore which will be even heavier than the basically the granite rock.

If it is closed it is not feasible, so that is why you keep them open but then keep them open at what stage they provide buoyancy, it will be providing buoyancy in the initial stage for example in during the construction of these kind of gravity structures you will be doing in a very shallow water basin, so that time once you raise the construction to this level then you fled you bring this one to a slightly deeper area and then start constructing the columns because this this height will help in achieving buoyancy self-support the bottom base caisson and then after that it comes to a deeper water area this provides the buoyancy, so various sequences have to be worked out and that is the major issue there and it need not be 4 columns, it can be 3 columns sometimes you have 4 columns a mostly in olden days Narsi platforms most of them will have 4 columns in fact (())(5:54) was 4 columns.

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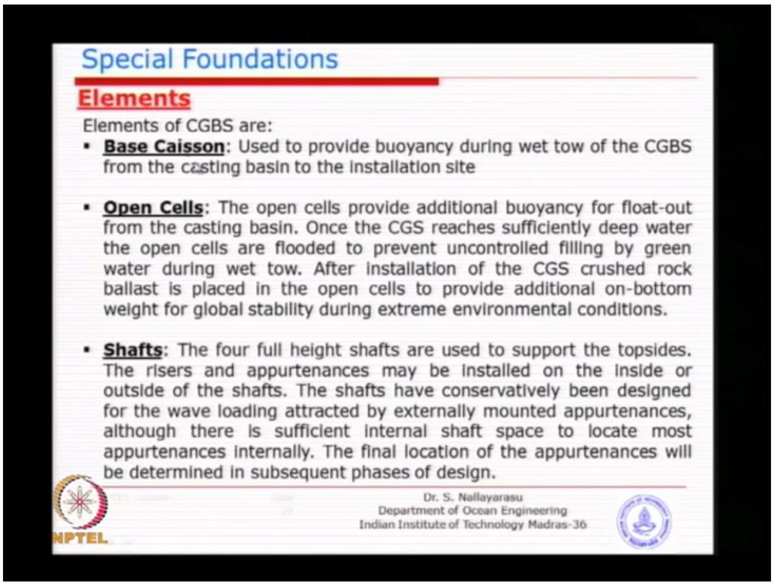

So base caisson base foundation structure which is typically rectangular. You could also go for circular which is more efficient in terms of bearing pressure but then construction become little bit difficult. Open cell versus the closed cell, this is the purpose the closed cell always have controlled ballasting de-ballasting which can pump water or you can no water from the cells where is the open cells only automatically fled their own it gets submerged but the advantages you have provision to go and fill up solid ballasting.

Shafts basically one each shaft can be used for specific purpose, one of them for raises another one for drilling and basically interface between ground and the superstructure. The others can be used for utilities for example you may have to go down to inspect, so most of these gravity structures will have accessibilities by means of either lift mostly lift or you may have other means. Then you can have a storage, so you can see each one is serving individual purposes that means the center of gravity not going to be symmetric may have actually one side heavier the other side is lighter.

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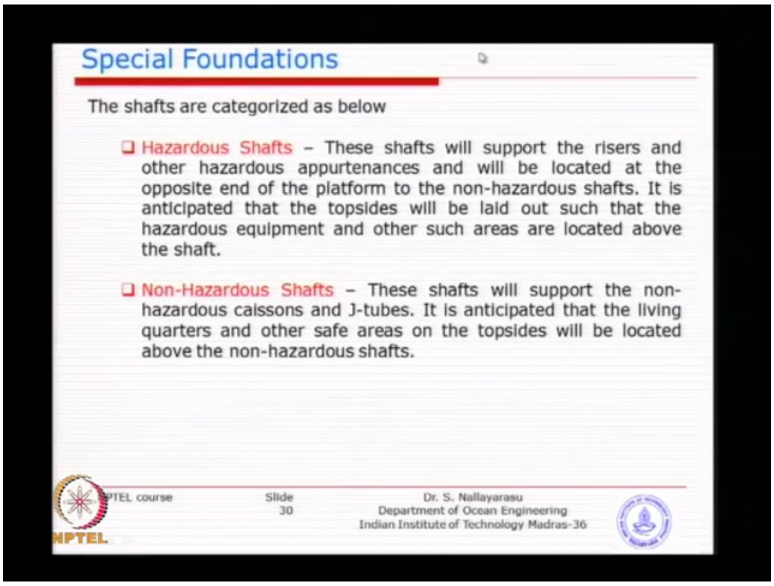

So you can actually classify into hazardous and non-hazardous witches not that much important for us as far as the foundation designs concern but of force which will affect… hazardous means you will keep all the oil and gas or related activities in one side, so that you know the other side is non-hazardous where you can locate all your safe facilities like living quarters and things like that, lifts.

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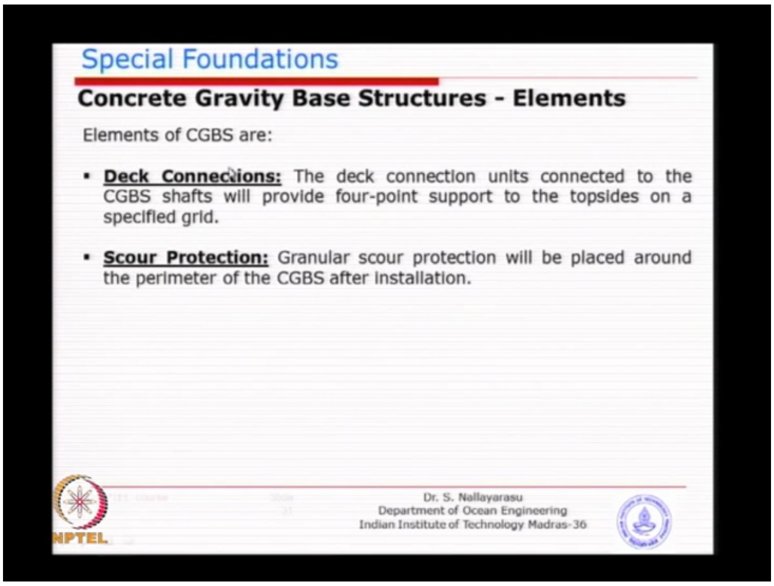

Deck connections, I think the interface is little bit difficult not like our…because the superstructure is going to be steel whereas the substructure is concrete, so you may have to find a methodology which you can transfer the lots. Normally we go for you know the pin connections and the scour protection something very essential because you have a large size rectangular structure which is sitting on seabed we can see here now scouring becomes a predominant activity and you may have to do a scour protection means of rock dumping or engineered fills around the structure.

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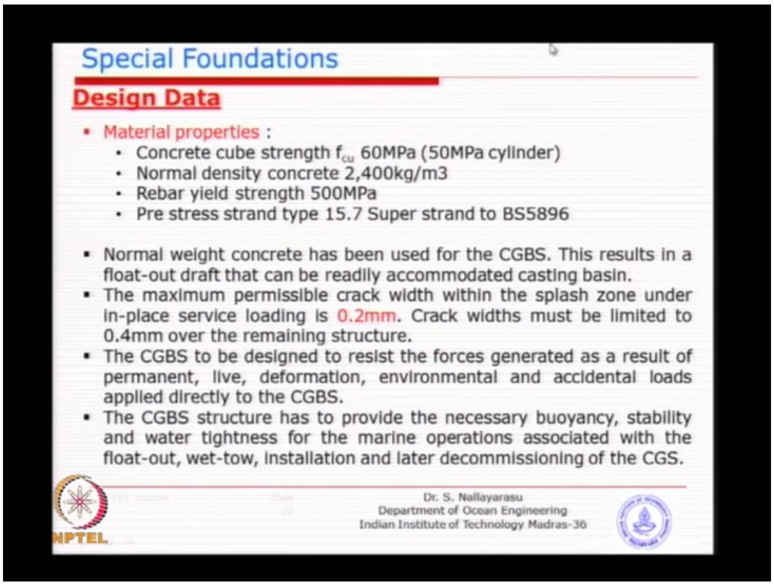

Typically the design of concrete structures is any civil engineering based calculations but mostly we use because of the large hydrostatic pressure it is designed using pre-test concrete not conventional concrete you know very well conventional RCC structures cannot spend too much and the loading also will be very limited, so that is why you go for pre-stressing mechanism especially self-structures pre-stressing is very good you can take large amount of pressure external or internal.

So that is why you normally most of the gravity-based structures will be pre-stressed and can take any high-pressure and typically we need to design…because we are using this one for ballast and de-ballast you should have limitations on crack width I think those who have studied concrete design will understand very easily that crack width is an important parameter for you know stress control in terms of actual crack as well as leakage proof then corrosion protection of the steel reinforcement within the concrete itself. So you have to design in such a way that the crack width is limited to 0.2 mm sometimes nowadays is 0.1 mm. As you can see water retaining structures we go for 0.1 mm especially like for example water tanks but here the courts are not mandatory but you can control the stresses in such a way that 0.2 is also acceptable.

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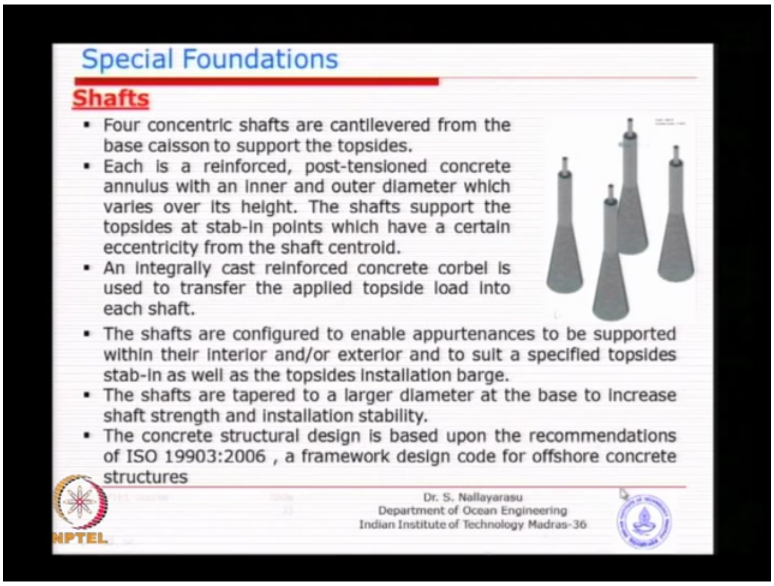

Shafts which we have discussed various purposes and various specifications I think need not be like this, this is only a typical example it can be parallel shaft, it can be a conical shaft which depends on the design a mostly conical because the requirement is very limited on the top end because bending moments are going to be very small, so you do need a larger size because larger the size what happens is the sea wave attraction and the forces will be higher unnecessarily, so you normally try to taper it in such a way that the (())(10:08) are reduced at the top because you will see that top area from water surface to 30 percent of the water depth most of the water particles (())(10:18) will be very high and the loads are very high, so you can design using IS ISO codes witches 903 19903 specifically for concrete base structures.

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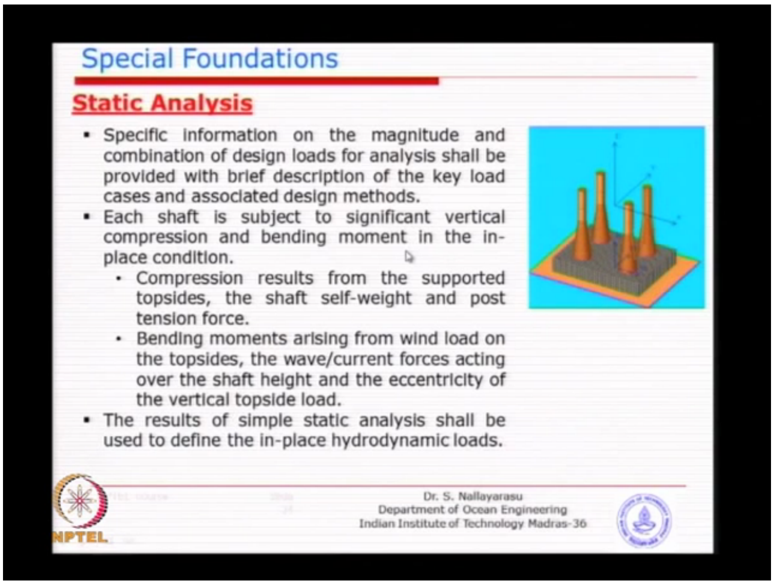

How do we do analysis this is something we do think about it is completely different from what we were doing fixed structures, soil structure interaction, so here is a large size concrete base so the interface between the structure and the soil going to be special-purpose devices to be taken care means instead of putting files soil interaction in the way that we were doing for tubular piles, we have to slightly deviate from their because here everything is on the surface, maybe might have a penetration of few hundred millimetres due to settlement but nothing more than that.

So we have to device a methodology by which soil springs can be modelled at the bottom of the the foundation and they cannot take tension very similar to what we were doing for mud mat but mud mat we go for a simplified method not using piles (())(11:32) interaction. So doing a simplified service analysis is going to be the case, so you cannot be able to do complete non-linear analysis, you can simplify the non-linear spring into linear spring which we accept as a methodology for this type of structures that means when you do a TZ curve which you have already idea how to develop TZ curve, so you need to linearize and give that spring in here and basically that will be then the reaction between the soil and structure.

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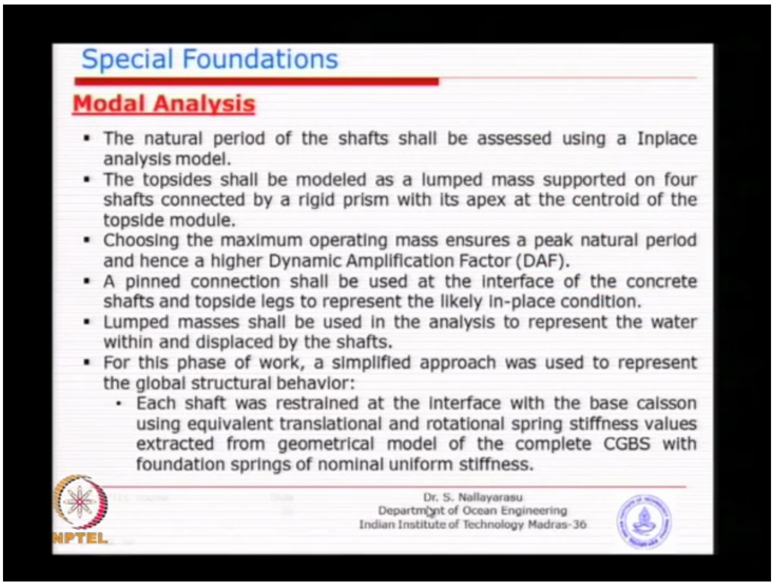

Modal analysis, basically tried to figure out what is the dynamic you know the frequency of vibration will be normally required for any offshore structures in order to find out the wave interaction with the structure but most of the gravity platform since the foundation size is larger you will not encounter any dynamic effect because it will be very good number 1, number 2 is damping is very high, so in such cases you will not encounter in case if you do then you will have to multiply your load into dynamic amplification factor by simplified means.

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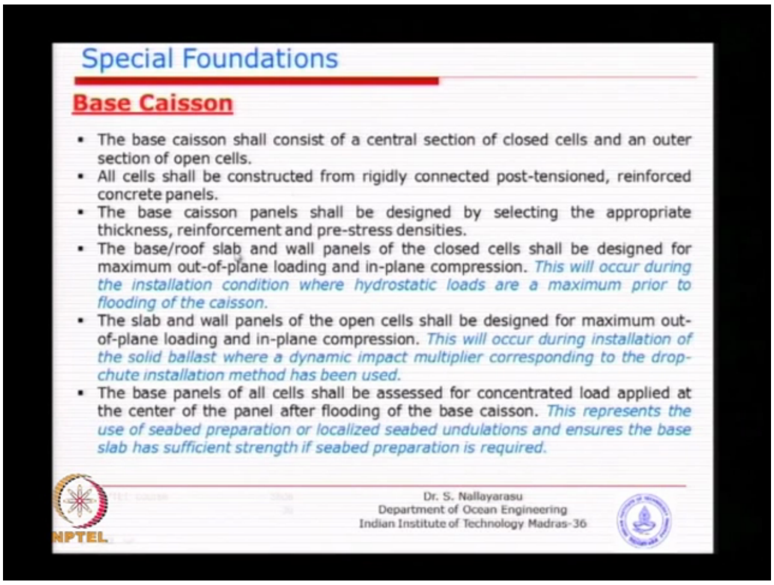

Base caisson which we were discussing earlier on is used for 2 purposes providing sufficient area for foundation calculation that means a batting percent needs to be kept within control, the 2nd purpose is to have variable ballasting, 3rd purpose is to have fixed ballast on the open cells, so that is what is given. The purpose of base caisson needs to be understood so you should have provision for filling and removing and also have sufficient area where bearing process can be kept within control and also to control the deflection or the settlement of the foundation you will have bigger size, so manipulation of area you can make it bigger or smaller, the spacing can be reduced depending on what is the load coming in.

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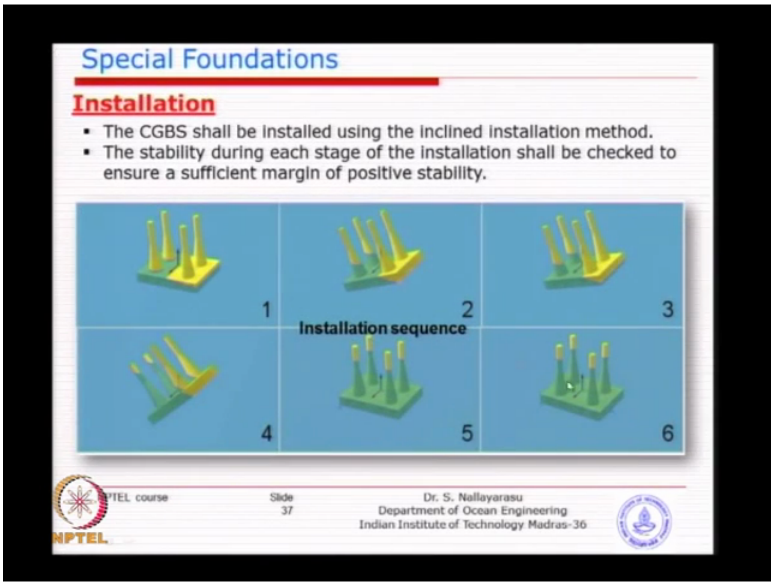

The typical installation just to give you an idea how it is installed once the fabrication is done in the dry dock you pull this whole structure into a slightly (())(13:37) water and start making this construction of the shaft means the 1st the base caisson will be made in shallow water or shallow depth dry dock where in you will have access to all the equipments and you construct this. Once you raise the bottom caisson into the top-level of this level then you pull out into a wet dock when you float out and start raising your shafts or if you have facility to float out completely you can actually complete the shaft also in the dry dock itself and then floated out.

Then once you bring to as right location where it is going to be either towed out or going to be installed then you start ballasting the base caisson, always do from one side multiple ballasting is not possible so you will see that depending upon the bars in direction you will see the tilting then you go and counter ballast on the other side, so that it can be…so this needs to be calculate at any one stage the stability needs to be maintained that means you do a GM calculation, make sure that GM is positive and positive to a reasonable number, so that stability can be not compromised, so once you do all that then you can sit down on the seabed and it will sit, so basically this is a temporary condition at the time of installation.

Now imagine the wave loads at that time could be smaller because you not going to install this at very high sea state, so what needs to be done now you need to look for permanent blasting in addition to this you need to see because (())(15:14) storm condition horizontal load could be substantially larger, so that is a time when you do solid ballast at the bottom which will make the structure heavier enough and also install the superstructure, so this is the delta weight what you are increasing will be able to compensate for the overturning coming from horizontal loads of wave current and wind.

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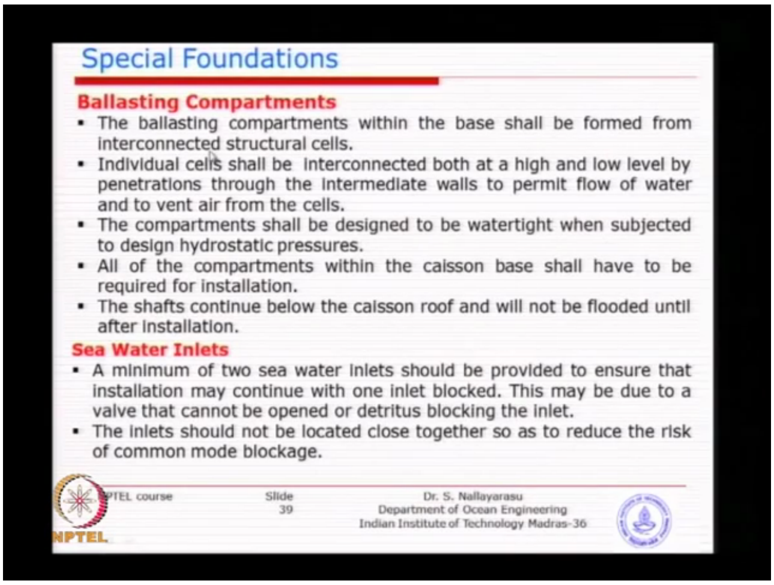

I think we have discussed about ballasting and seawater inlets basically just the utilities required to fill water and remove water just a matter of interest. A typical picture just to give you an idea how size wise how much bigger than a conventional steel type of structures, so you can see here it is been divided into several compartment. I think already should have an idea why we are dividing into compartments? You know why not simple compartment?

Not normally very good because redundancy will not be there so it have multiple compartments even one damage may not cause substantial problem to the structure, so that is why you divide them into several sub compartments, so you can see here it is just done in a very small area. You do not even have a depth, too much debt because once it is constructed to this level you fled this area because you got substantial amount of buoyancy which will start floating and basically you can tow to another location and you can…

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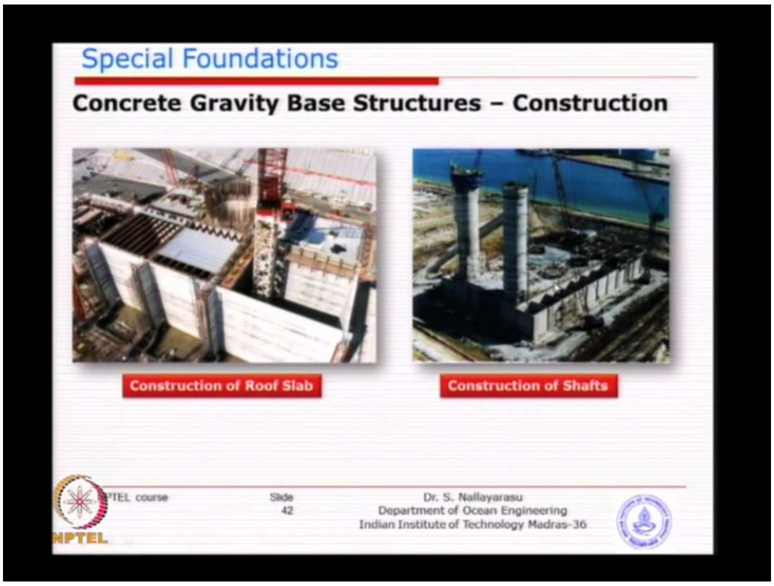

So you can do it in sequence and then you do the raising of shafts which is also very much shallow I can see because this particular project they were just trying to do everything and then float out, so this typically about 6 to 10 metres is the height of the base and depending upon the water depth this could be 3 meter 4 meter up to 10 meter diameter shafts are constructed.

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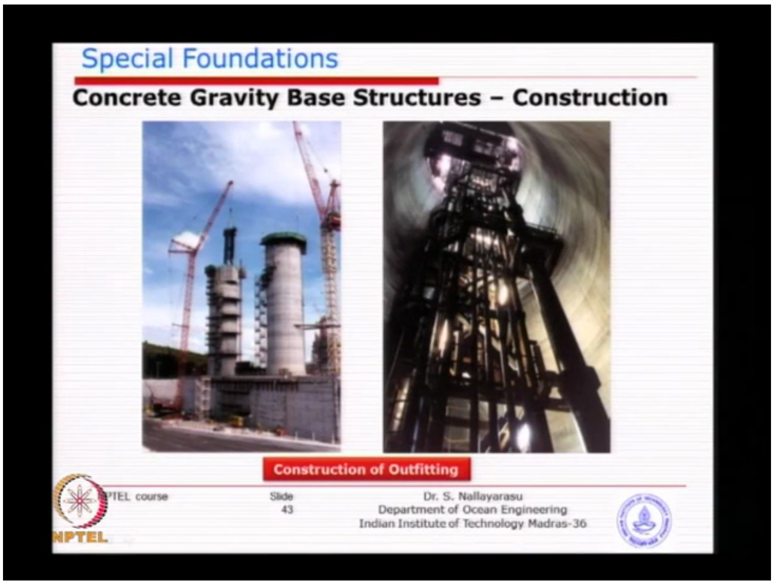

So from the inside of the shaft you can see here these are rises and conductors you can see one of the shafts is utilised for that purpose for drilling as well as for interface between the superstructure to the seabed, you can transfer oil and gas through rises, so you dedicate only for that purpose.

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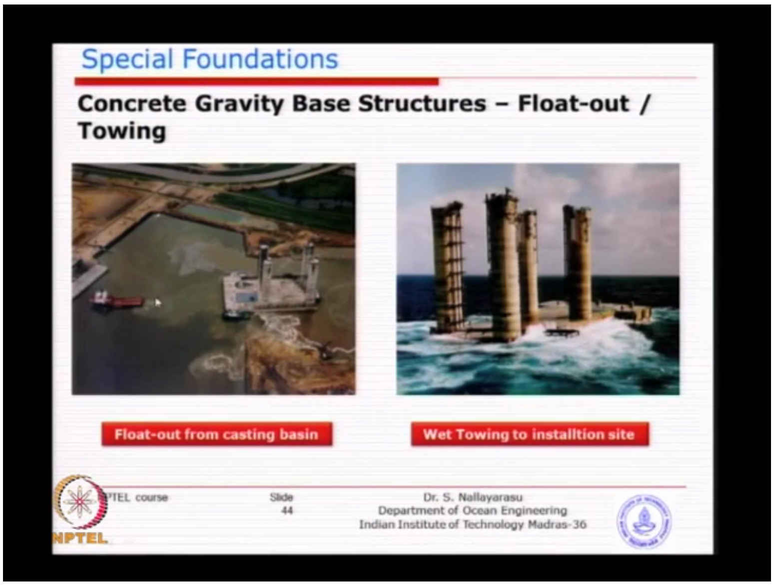

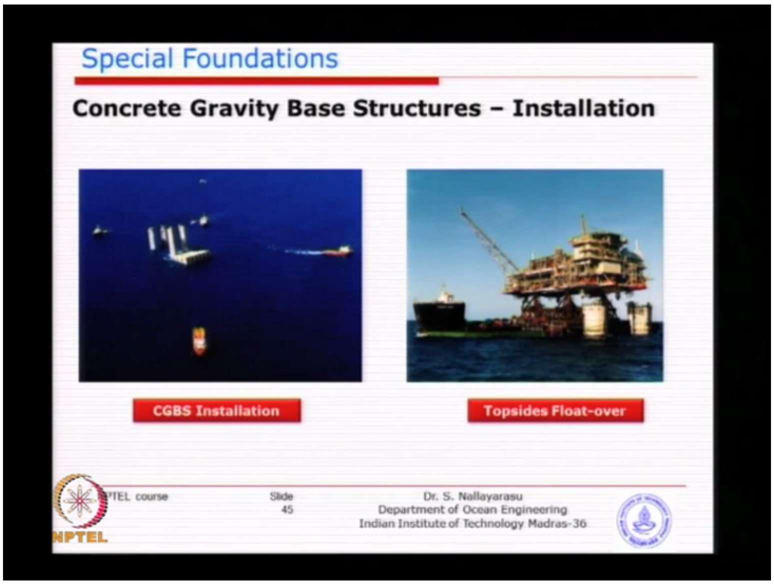

So you can see on this just on shallow water because of this large size you got enormous buoyancy, so it can actually you know support all the weight of the shaft as well as the bottom caisson, the draft would be 3 to 4 metres and sticking very high but of course when you are towing you do not want to tow this high unless during the tow route the sea conditions are very low, you have to actually ballast down so that only small portion is sticking above, so depending on the design you can tow either this way or tow with a higher

(())(18:07) and you can see in the open condition just it has come outside the dry dock, so initially it was dry and then have been flooded and has been floating and you can tow using tugboats.

It has come to open sea conditions, so it is slightly rough sea, so now only you need to verify whether the sea conditions can be okay for stability and calculations has to be made and it is going through open sea condition with several tug boat assisting and when it comes to the site, so you can see here the installation of the top sites, so this particular project basically the installation of topside is at the site not at the…some of the project they have done the topside also installed in the yard itself and the whole structure together with substructure and superstructure together is towed, of course the buoyancy requirement is higher.

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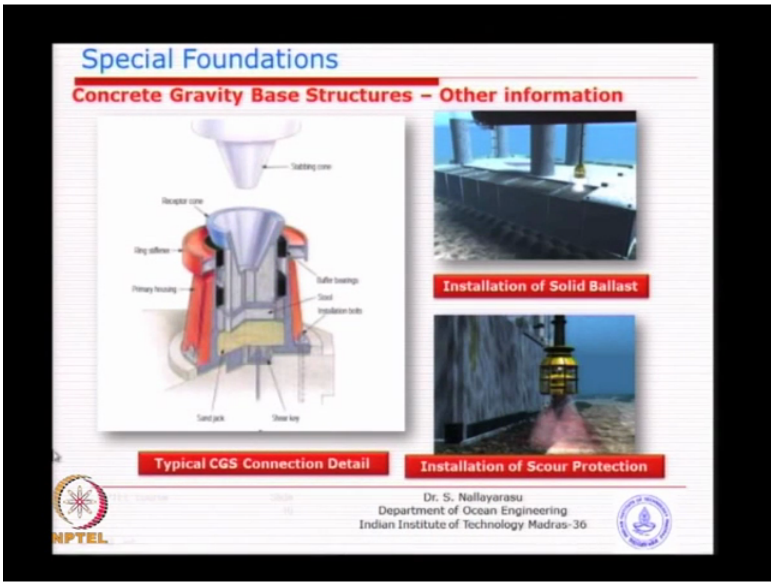

The typical interface between the superstructure and the substructure you will have such kind of receiving cones basically for matting purpose, so that the load transfer is not critically injuring the concrete because you see the conquered is brittle, so you need to have a good interface, so that this load transfer is becoming easy, so that is why you have this shock absorbing mechanism by which the load transfer from this cone or from the superstructure is transferred to a multi-element load transfer into the concrete itself, so something very important.

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And basically that gives you an idea of complete concrete base gravity structures, sometimes we go for composite or mixed steel concrete gravity structures, bottoms concrete and the top is steel, very similar that means you will have 4 jackets and one single concrete base. One of the projects which I was involved in Turkmenistan is very similar, it is basically a large base concrete structure and on top this 4 numbers of vertical jackets are installed separately, so that is a good idea that minimising the weight of the structure that is being transported.

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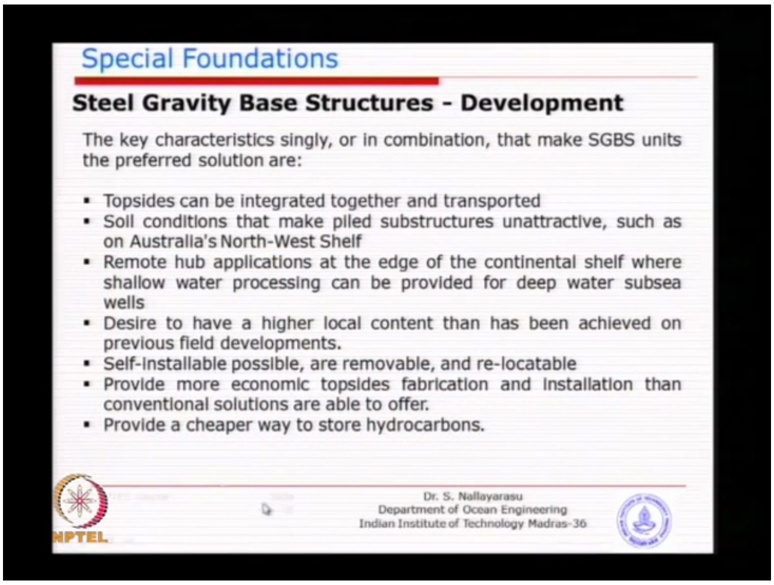

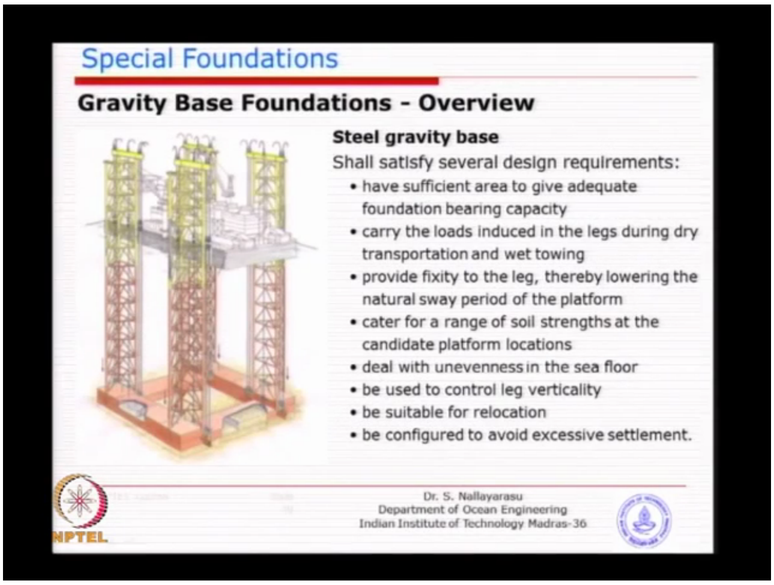

So typically the reason why you are going for this, the storage is not required in that particular field, storage is not required. What they require is a large size foundation and the remaining can be steel because once storage is not required do not really need such type of structures but still we need to go for gravity because you got very much shallow rock out crop in which piles cannot be driven, so that is one of the ideas and economising basically installation wise this composite structure was economical and useful, so something like this you see here 4 vertical towers with superstructure and basically the bottom, some of them are re-locatable in fact if you see this picture it is re-locatable because this concrete gravity base can be lifted off after de-ballasting, so you can actually move like a (())(21:09) which I think we discussed about (())(21:11) in reasonable length in the previous course it is exactly similar.

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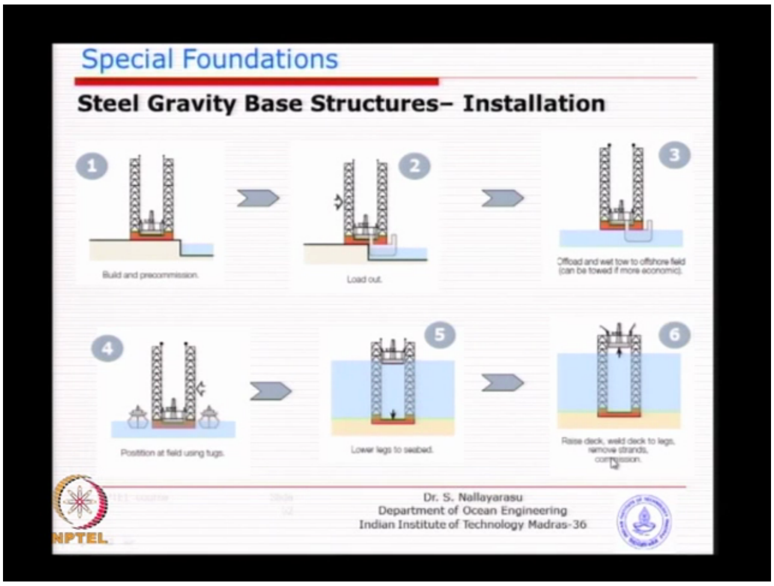

So this steel gravity base structures insulation again you can have 2 choices either you can go together with the base and the steel gravity or the steel legs or you can install the legs later on after you put the gravity base at the bottom, in this particular picture it is going together, so you can install them as very similar to a jack up except that the spotcan is not individual it is combined together.

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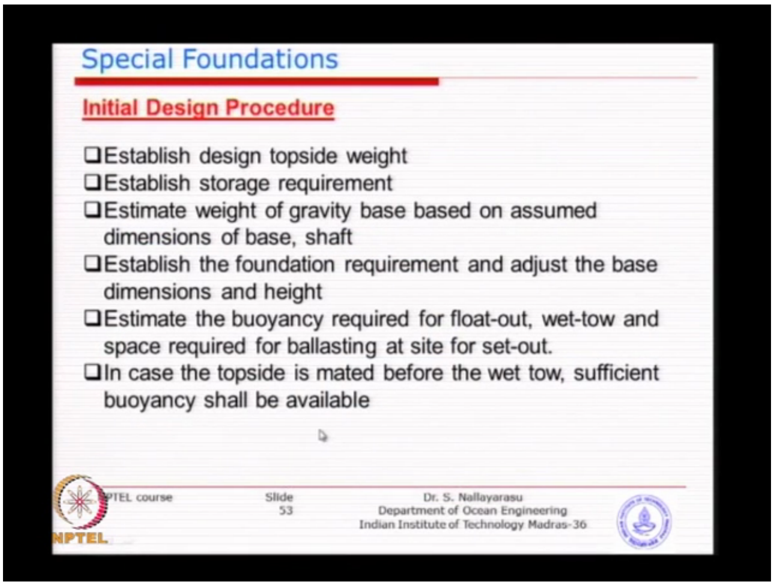

So how do we make a design of a gravity structure is very simple idea logical sequencing, so establish the design weight of the superstructure. Storage requirement, how much volume of storage and what is the weight of that and what is the location of it? Estimate the weight of the base which will come from the soil mechanics calculation of allowable bearing capacity, so you can find out what area is required and based on the area what is the weight required in order to get the stability and you look for the dimensions and the shaft, so basically all 3 is making sure that weight estimation is correct because that is based on which you are going to make the base dimensions and then once you know the soil properties, establish the allowable or ultimate bearing capacity work backwards to find out what size will give you the sufficient factor of safety.

Once you do that then look for the buoyancy because you have several requirement of buoyancy, buoyancy at this stage of construction, buoyancy at this stage of float out, buoyancy at the time you are just shutting down and at the last stage where the structure is on the seabed, you do not need buoyancy but it needs to be negative buoyancy but how much is required in order to make sure that you do not get negative pressure that means the tension in the soil interfaces not there, so that means you have to make sure that right compartment is flooded at the right time you do not go and flood it different time then you do not get it, so basically the buoyancy calculation is an iterative.

Once you know the initial weight estimates in fact this is what one of the problems we were trying to do in assignment or in the exams, so basically you should you should learn this procedure of trying to figure out what will be the requirement of buoyancy, what is the requirement of weight at what instant of time and then if you have the buoyancy requirement…if suppose if you have the topside also installed in the yard itself, your buoyancy requirement will be larger and which will require to be exactly opposite when you shut down because you make too much of buoyancy you should have sufficient compartments to ballast otherwise you will not be able to set the structure under seabed. So this initial once you do the initial design procedure of trying to balance the buoyancy, weight and the size then you go for actual design of concrete or steel elements then redefine the weights and recalibrate the buoyancy, so it will be as several iterations before you could see a structure is complete.

So in this stage you will find the foundation design come into picture, so your foundation design will have bearing capacity check which is basically vertical equilibrium and your sliding capacity which will make sure that you have sufficient interface friction or you will provide a skirt pile skirt foundation and then the 3rd one is the overturning stability that means your size of the rectangular base caisson will be determining basically if you have negative sure then you have to increase the size, whereas we do allow negative pressure in case of and mud mats because it is only temporary whereas in this case this is a permanent foundation there is no other alternative, so you may not actually permit negative pressure, so it means you have to make the foundation size large enough.

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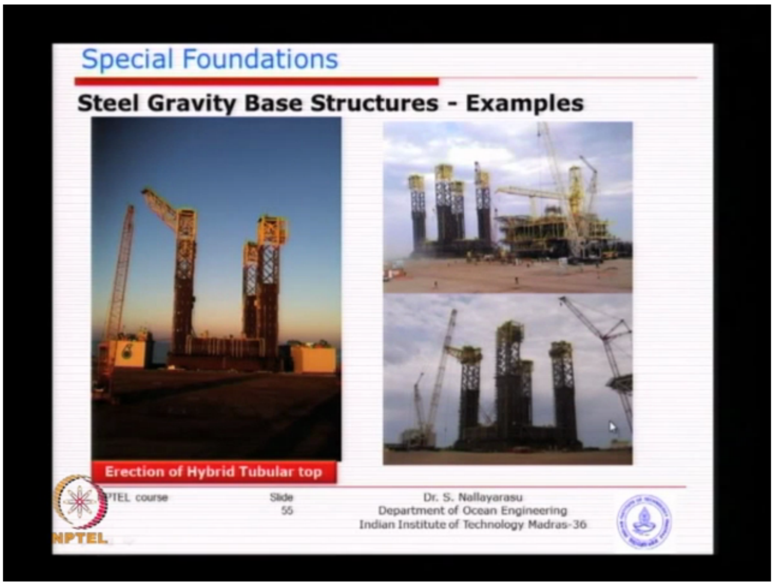

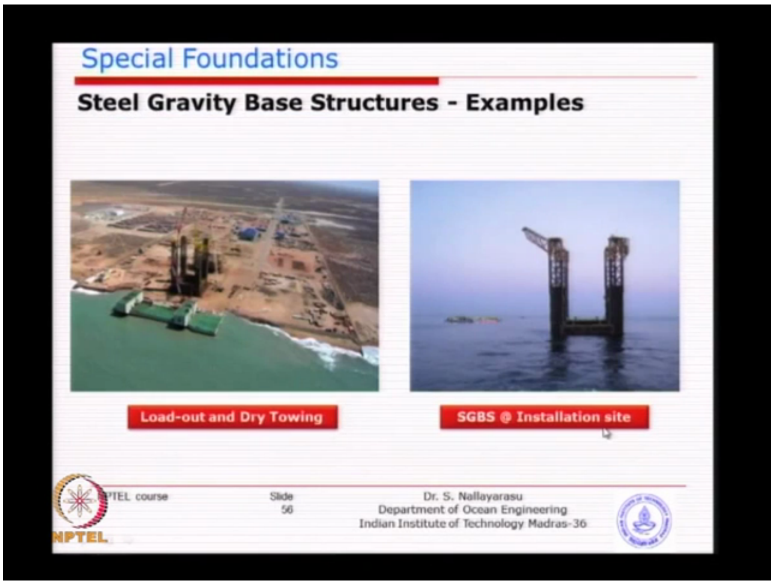
Special Foundations
Steel Gravity Base Structures - Examples
Load-out and Dry Towing
SGBS @ Installation site
NPTEL course
Slide
56
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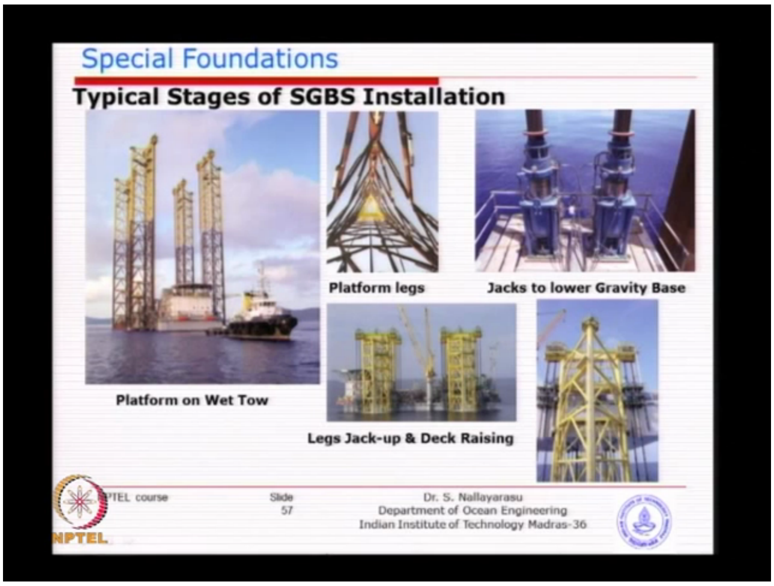
Special Foundations
Typical Stages of SGBS Installation
Platform legs
Jacks to lower Gravity Base
Platform on Wet Tow
Legs Jack-up & Deck Raising
NPTEL course
Slide
57
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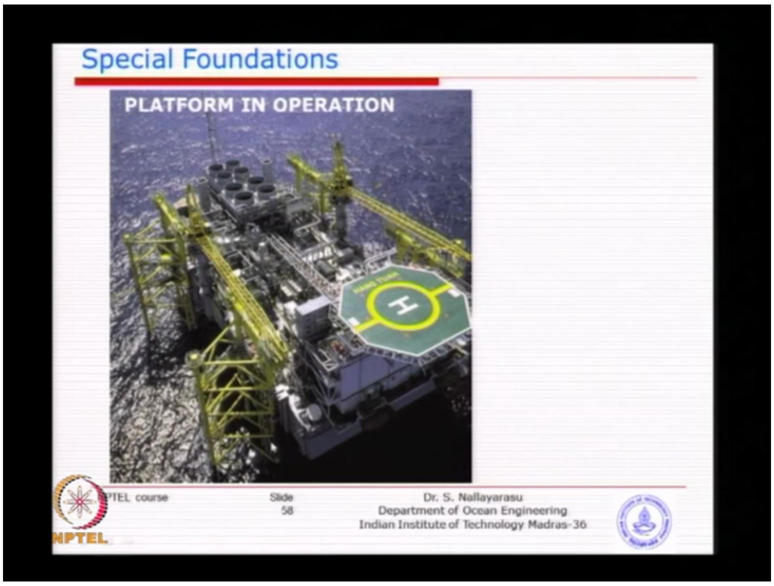
Special Foundations
PLATFORM IN OPERATION
NPTEL course
Slide
58
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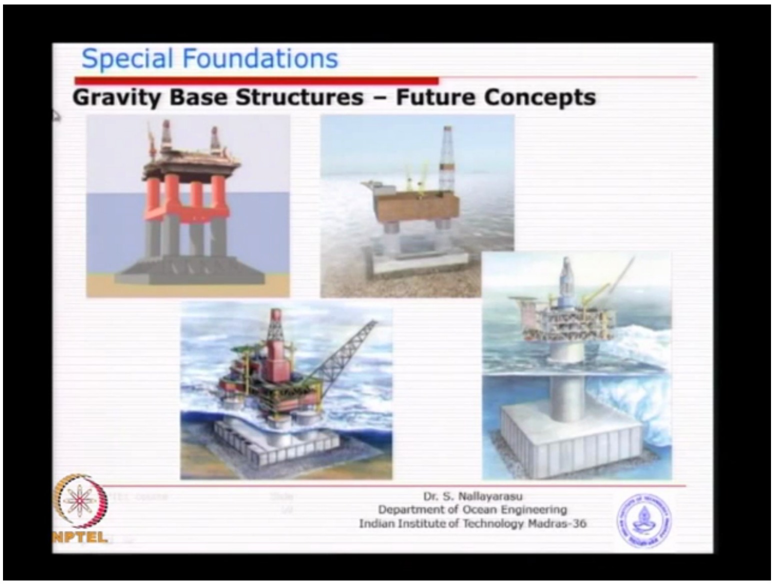

So typical picture of the gravity base structure being constructed in this case you can see here one part of it is still concrete and having steel jackets on top which was quite tall about 120 metres or so, so part of it is concrete caisson, the 2nd part of it because the top part not necessarily to be that heavy they wanted to minimise the weight because the top soil is about 11 metres was clay and if you make it too heavy also problem because 2 settlement becomes issue, it is almost like a tubular jacket type of structures and installed on top of the caisson itself. Typical picture of just under construction almost going on to towing I think at the installation site matty almost done with installation.

Various other forms of this type of gravity structures you can imagine you know what kind of structures are required for making sure that stability can be achieved both in terms of installation and service. You can see here imagination single large diameter shaft with a bigger space dimensions all that what is required you can see here it is only 2 columns not necessary that you need to have 4 because the area requirement is smaller, so you can have 2 but again design needs to be make sure that in which orientation it is better because basically you need to have stability in this direction perpendicular because the sea waves are larger, you will get you know the, the negative pressure at the side which is not very good, so that is why…normally we do not prefer 2, 3 means at least we can manage but then 4 is always preferred you will get a symmetry and also get a better design requirement.

Okay so the next topic is pile group effect I think you already have family ideas with PUI TZ and QZ also axial capacity of a single pile in single layer and multiple layers I think all of you have already practised and constructing such diagrams for multiple layers I think one of the examples problem also you have solved. Now what we are looking at, you are not going to have single pile or sure, the reason being for offshore structures we have 4 corners isolated foundations unlike onshore structures you have facility to distribute the foundations either pile or shallow footings, here we have got group of piles going to be at one corner or other places, so when you have piles closely spaced what happens to the load sharing.

This is something that we need to take into account because you cannot put the piles very far for example you have a jacket leg and you do not put the pile foundation 20 metres away and connect them because the load transfer is not going to happen, so always you try to bring the foundation closer to the load transfer location itself that means you have one pile and put another pile in the vicinity. So what really happens? When you have a pile the load is transferred from the pile to the soil and the soil stressed and soil goes through deformation.

Now you put another pile in the vicinity and that pile also transfer the load, so there will be a situation where the soil in between 2 piles will get loading from both. Now the calculations that we have made so far we have not looked (())(28:46) but we are looking at is nobody else is in the vicinity, the soil gets only loading from one pile that means the stresses calculated by whichever the method is that we have learned is based on loading from one pile. If you get multiple loads from various piles for the same soil mass that means it cannot take it will fail before what we expect, so how much is that? And whether the pile is close by or too far, we need to determine what is the better and what is the best for this current situation? In the case of onshore structures we do not do this, we will just relocate the pile little bit far away, so that we do not need to look at this interaction at all because we got you know the flexibility in foundation design or basically distribution of loads.

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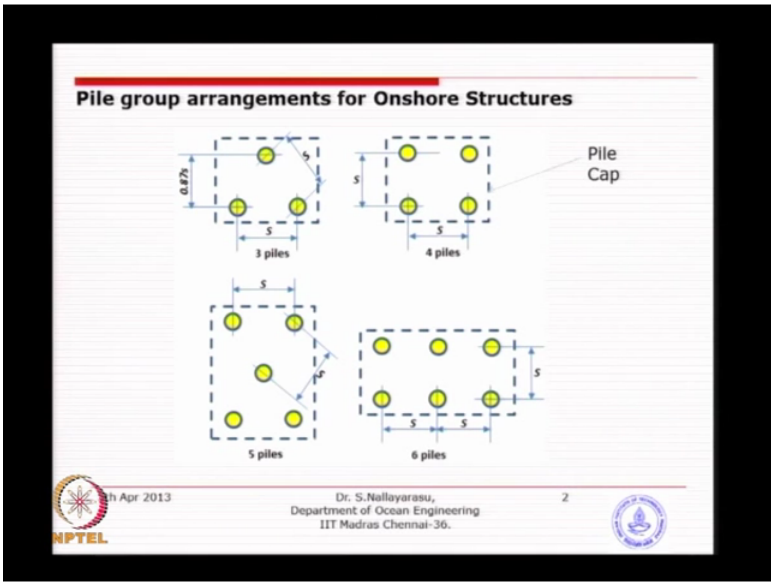

Whereas in case of offshore structures such facility is not there for the reason that I explained earlier that mostly the loads are carried by jacket legs and legs in an around you need to locate the piles. Typical if you look at this picture you know when you look at industry structures onshore you will have several buildings and structures mostly go for this kind of piling layout you will arrange according to you where is the loads and you have a flexibility of locating them anywhere you like, so if you look at spacing, so the spacing matters because you bring them too close you will have this problem which we are talking about, the interaction between piles, so the spacing of pile is going to be a matter.

Now if you if you if you just go by rule of thumb, you keep them say 10 diameter away for example if you look at diameter of offshore pile is 2 metres typical, so 20 metres away is too far for a jacket because the jacket itself will be only about 20 metres, 30 metres, 40 metres, so we have to bring them together by say 2 diameters, 2 meters 2 diameters is 4 metres, 4 metres itself is quite far, so you can see their criticality of that means is going to actually not obtain whatever the calculation we make for vertical capacity as well as for lateral capacity, you may bring in one number say hundred tons but actual capacity could be only be half of it because another pile is in the vicinity is going to produce similar effects on the soil, so there is something that we need to evaluate given the constrained, we need to calculate and apply.

So that means instead of deciding the penetration as 100 metres you may actually look for may be slightly more depending on the contribution from other pile. So that is why it is called pile group effects or effects of pile spacing on capacities and deflections, so normally you decide on a spacing and then work backwards what is the effect? We do not actually look at the effects and then position the pile because the restriction of spacing on jacket is more than the effects because you do not want to just in moving the pile outward because our capacity is reducing because already we know we have to keep the pile very close unlike onshore structures.

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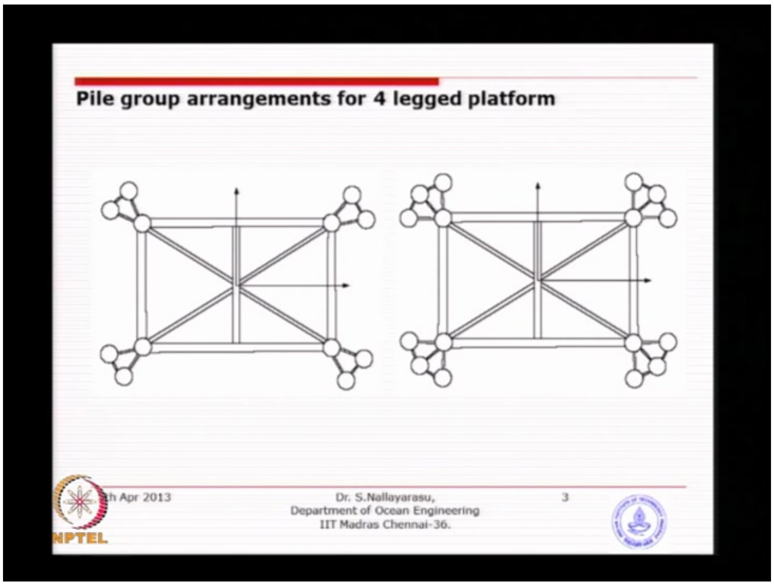

So typically if you look at this picture, we can see here this is the leg one of the legs and you got 2 piles attached to it, now the distance between this pile to this pile and also if you have a main pile this pile to this pile has to be taken into account. In this particular one there is no main pile, so you actually you can see here the distance from here to here is little larger but this piles between the spacing between the 2 skirt piles are kept as much required and also you can see here pile is added another pile because capacity was not enough, so you have 3 piles together.

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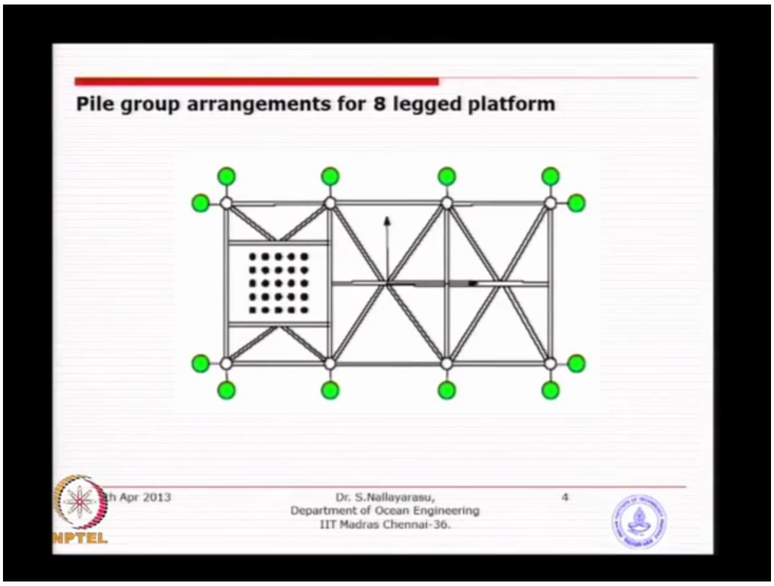

You could come up with any configuration depending on the requirements, so you can see here in this case it introduces a larger spacing because there is no main pile but only skirt pile you can see here the distance has increased reasonably and in other places you have only a single pile, so between this to this definitely will not be a problem because it will be already very large spacing, so the problem will be mostly associated with too many piles at one particular corner and that is something that we need to look at.

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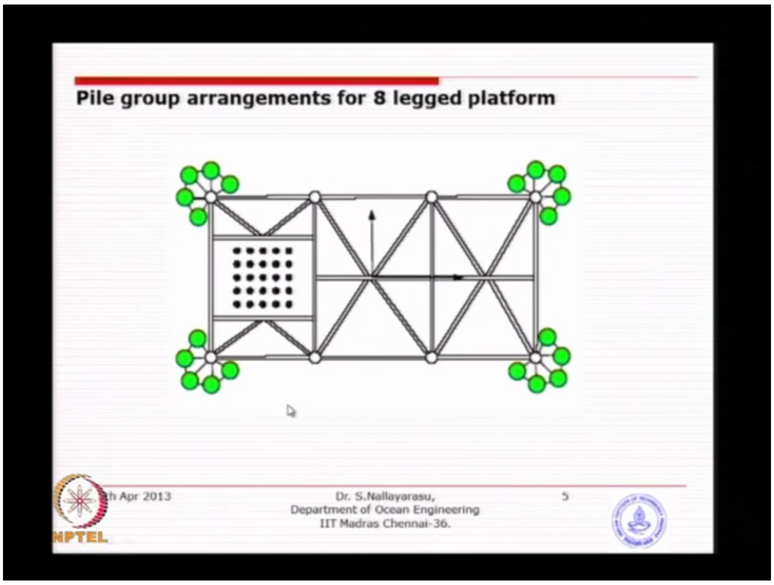

In some of the platforms cluster pile like this you see the piles are distributed around when you go for this basically when you are not allowed to go beyond a certain depth because you may have a very hard layer like sand or you may have rock, so in such cases limit the penetration, increase the diameter or increase the number of piles. So increased diameter is not a very good idea because we may not be able to install, so increased number but reduced penetration and also reduce the diameter, so in such cases you will see you see call it cluster pile, in some of the projects we have 2 more piles inside, it will be almost like a circular cluster.

So you got so many of them connected together with…so in these cases should be take the capacity of this corner as capacity of 1 pile multiplied by the number of piles, so that is what we normally do think, if you have a group of piles why not calculate the capacity of 1 pile and just simply multiplied by 5 if it is 5 number of piles or we should look at a failure of the group of pile as complete cluster failure for example you just make sure that you put all the piles together and you look at the perimeter diameter of combined action and times your length, times your perimeter, times the interface the failure say friction between the cluster and the soil which will be very similar to your pile calculation, so you make a calculation of group capacity and calculate the individual capacity multiplied by the number of piles you see which ones smaller, the smaller has to be taken because before the individual file fails maybe the cluster might fail as a total that is what is basically issue, if you locate them very close, so that is why we have to look at this aspect.

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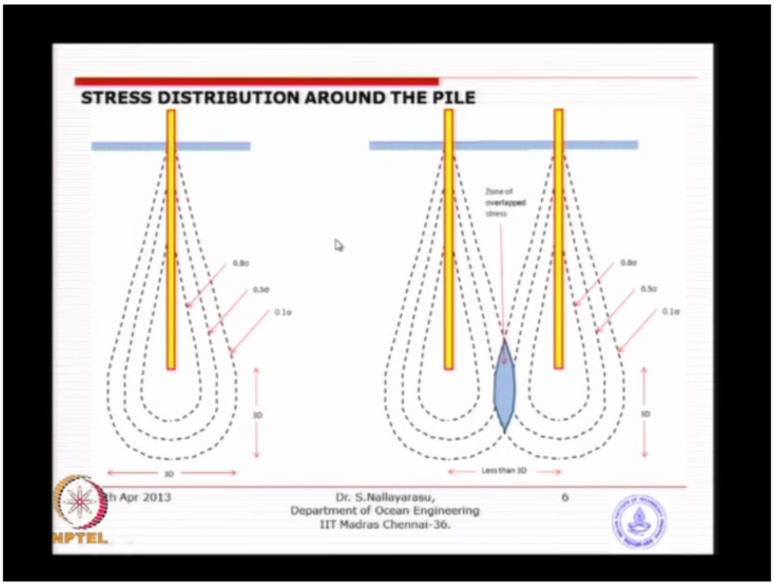

So typically if you look at this picture individual pile versus pile in the vicinity, you see here certain area of…if you give them very close almost overlap of stresses is going to happen from shallow depth but if you keep them little bit away, you can see here most part of it is (()) (35:11) overlap but there is overlap of stresses on a bottom part of the soil where the stresses are actually low, so basically that is…so this interface what is going to be the contribution on reduction of the capacity and the first pile which we are going to look at it.

So that is something that going to be there for both vertical loading as well as for horizontal loading and more problems for horizontal loading less problem for the vertical loading because by the time the overlap reaches its the the stress level will be slightly smaller whereas when you have horizontal loading the soil must here will be almost affected in the vicinity quickly than the vertical loading, so that is why mostly for vertical capacity degradation we normally do not do it but horizontal we have to be careful.

The typical number you can see here you know the stress distribution or we call it the stress bulb at the bottom of the pile is about 3 to 4 diameter will be more critical beyond which is going to be almost less than 10 percent of the total stress, so you can see the last diagram the third one almost about less than 10 percent whereas a 1st one you can see within the 3 diameter, you can see 80 percent of the stresses are going to be (())(36:33) within the smaller distance from the pile surface, so that is why if you keep them more than 3 diameter typically the issues are very less especially for vertical loading, so that is why by rule of thumb even the course also asked you to keep the pile spacing as at least 3 diameters or more so that you can avoid doing all these calculations for the group interaction.