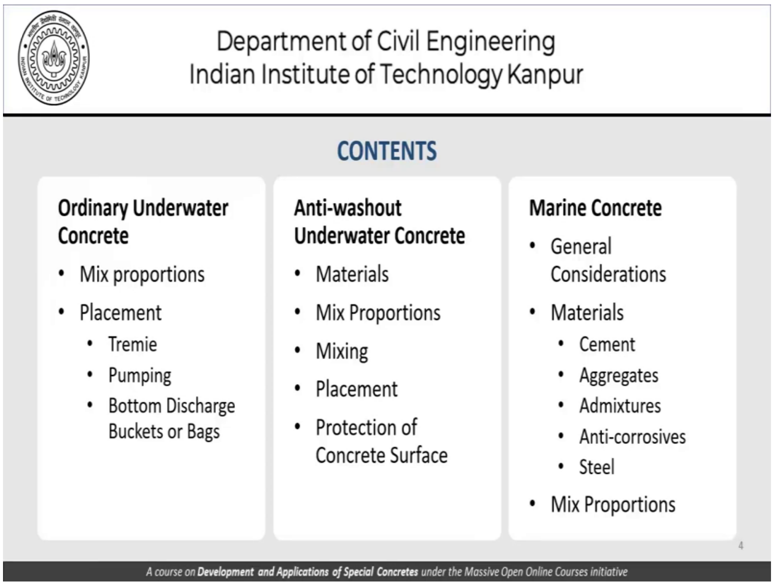
Development and Applications of Special Concretes
Dr. Sudhir Misra
Department of Civil Engineering
Indian Institute of Science – Kanpur

Lecture 16
Concreting Underwater

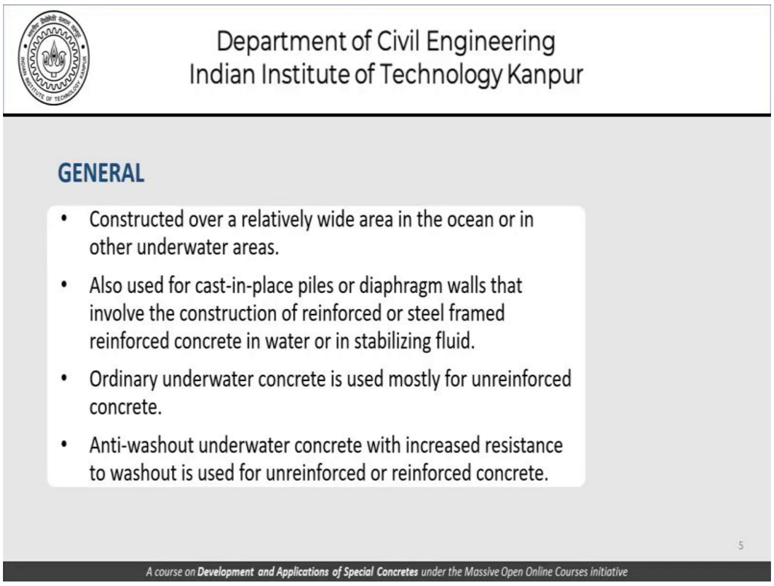
Hello and welcome back to another lecture on development and applications of special concretes. We will continue from where we left last time in our discussion on anti-washout underwater concrete.

(Refer Slide Time: 00:25)



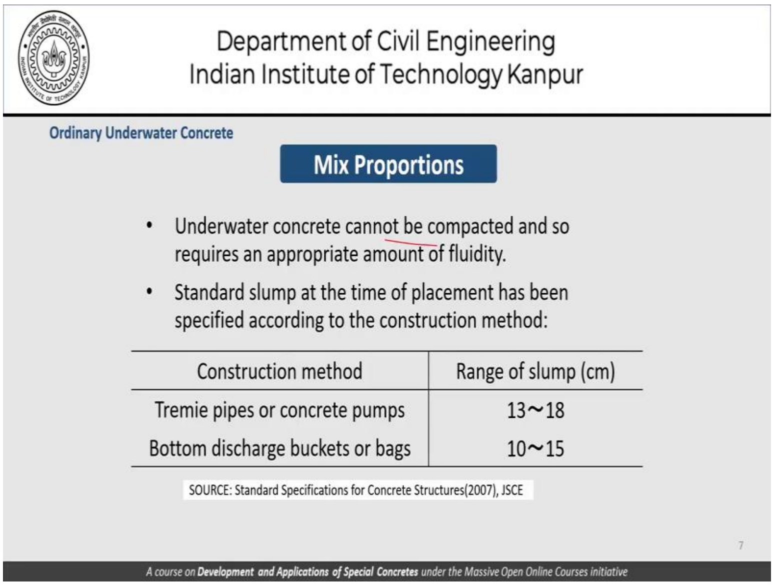
And today we will be talking about ordinary underwater concrete the mixed proportions the placement methods tremie pumping bottom discharge buckets or bags. We will be talking about anti-washout underwater concrete in terms of materials mixed proportions mixing placement and protection of the concrete surface. And we will also talk about marine concrete general considerations involved the materials as well as the mixed proportions.

(Refer Slide Time: 00:52)



So, starting our discussion we often need to carry out a concrete construction activity over a relatively wide area in the ocean or other underwater areas. We can also use the construction methods for underwater concrete for cast in place piles or diaphragm walls that involve the construction of reinforced or steel framed reinforced concrete in water or in stabilizing fluid. Ordinary underwater concrete is used mostly for unreinforced concrete and anti-washout underwater concrete with increasing resistance to wash out is used for un-reinforced or also for reinforced concrete works.

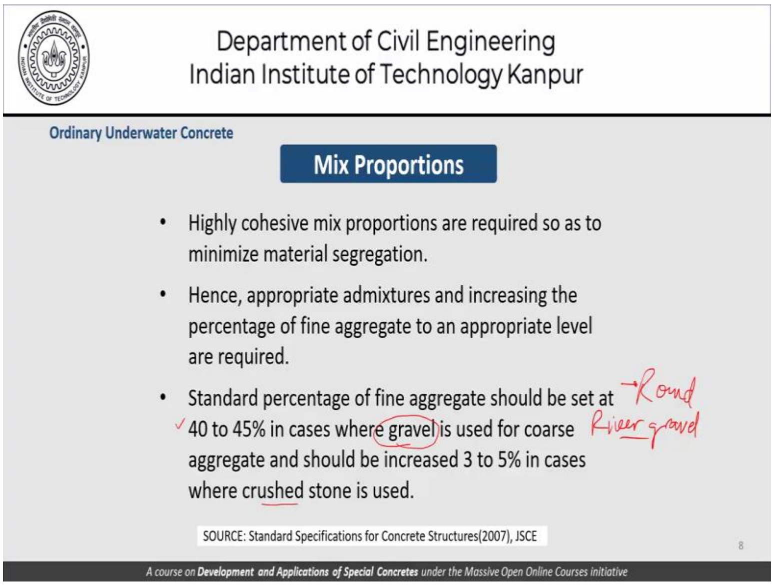
(Refer Slide Time: 01:32)



So as far as the ordinary underwater concrete is concerned the proportions of this concrete have to be determined keeping in mind the fact that underwater concrete cannot be compacted. And so, it requires an appropriate amount of fluidity to begin with standard slump values at the time of placement have been specified according to the construction methods. For example, the JSC tells us that if we are using tremie pipes or concrete pumps.

The range of slump could be 13 to 18 centimetres. If it is bottom discharge buckets or bags then we could have a slump range of 10 to 15 centimetres.

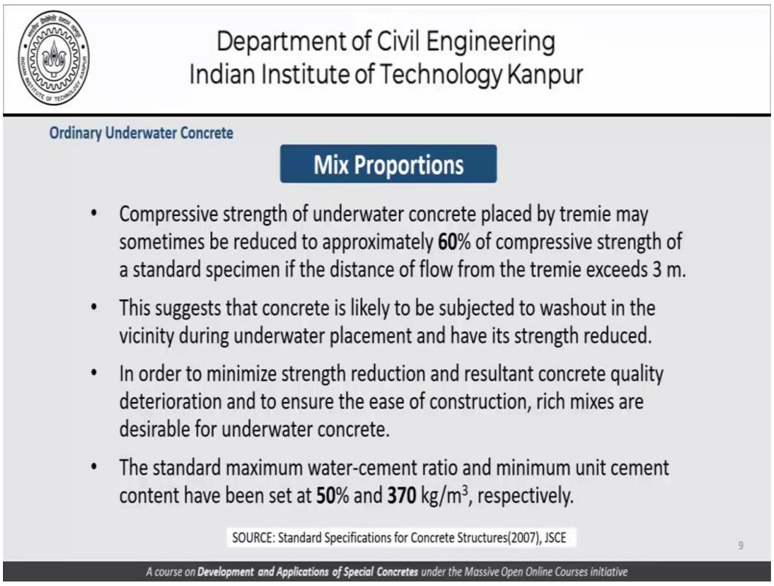
(Refer Slide Time: 02:07)



Continuing with our discussion on mixed proportions the concrete needs to be highly cohesive proportions so that we are able to reduce or minimize the material segregation. And appropriate pictures and increasing percentages of fine aggregate to an appropriate level are required. So basically, the idea is the paste content and the mortar content has to be pushed up. The standard percentages of fine aggregate should be set at 40 to 45% in cases where gravel is used for coarse aggregate and should be increased by another 3 to 5% in cases crust stone is used.

So, gravel here refers to the round gravel that is the river gravel. So, the gravel here refers to the round gravel or the river gravel and in case of crushed stone further increase of 3 to 5% is recommended over and above the 40 to 45% which is supposed to use which is supposed to be used as a base.

(Refer Slide Time: 03:09)

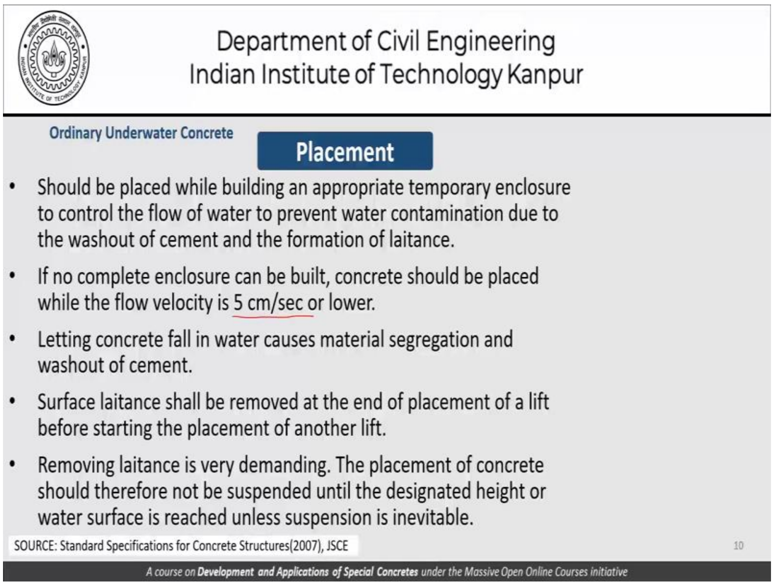


Compressive strength of underwater concrete placed by tremie may sometimes be reduced to approximately 60% of the compressive strength of a standard specimen if the distance of flow from the tremie exceeds 3 meters. An appropriate account of that has to be made that suggests that concrete is likely to be subjected to wash out in the vicinity during underwater placement and have its strength reduced.

In order to minimize the strength reduction and result in concrete quality deterioration and to ensure ease of construction rich mixes are desirable for underwater concrete. At times additional cement is recommended to be added over and above what is prescribed or determined by way of mixed proportions. The standard maximum water cement ratio and the minimum cement content have been said to be 50% and 370 kgs per cubic meter.

Now this is for JCE and I would encourage you to find out what are our specifications as far as Indian standards are concerned for construction of structures where we are trying to place concrete under water. For example, in the case of bridge piers.

(Refer Slide Time: 04:18)

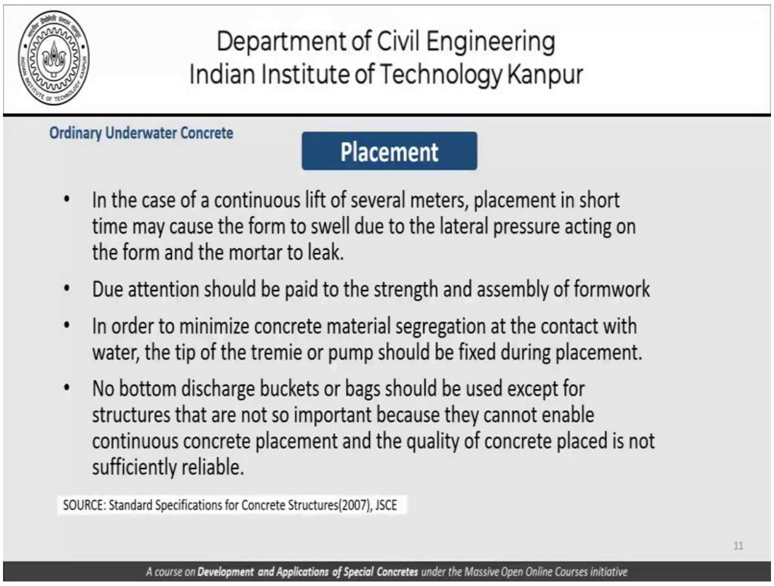


As far as placement is concerned when we are using ordinary underwater concrete. The concrete should be placed while building an appropriate temporary enclosure to control the flow of water and to prevent water contamination due to the washout of cement and formation of latent. If no complete enclosure is built or if no complete enclosure can be built concrete should be placed at least by ensuring that the flow velocity has been reduced to 5 centimetres per second or lower.

So, this value of course is up to us one specification can give one value another specification can give another value depending on the stop rate construction situation. Letting the concrete fall in water causes material segregation and washout of cement. And therefore, the fall through water for normal concrete must be minimized. Surface latency shall be removed at the end of placement of a lift before starting the placement of another lift that's the usual practice that we follow.

Removing latency is very demanding especially in the case of underwater concrete and the placement of concrete should therefore not be suspended until the designated height or the water surface is reached when suspension is inevitable. So, these are things which are often laid down as guiding principles and the actual construction procedures drawn up based on that.

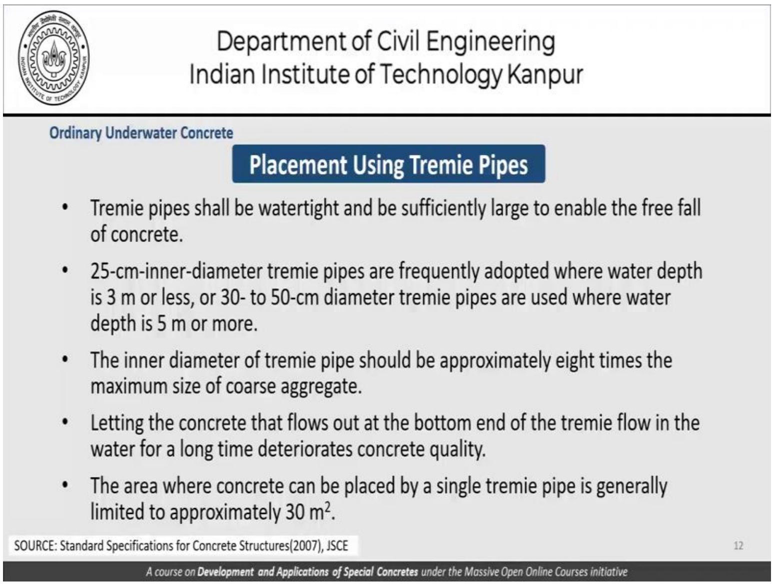
(Refer Slide Time: 05:47)



In case of continuous lift of several meters placement in a short time can cause the form to swell due to lateral pressure acting on the form and the mortar to leak. And therefore, due attention needs to be paid to the strength and assembly of the form work in order to minimize concrete segregation at the contact of water. The tip of the trimming and pump should be fixed during placement no bottom discharge buckets or bags should be used except for structures that are not so important because they cannot enable a continuous concrete placement and the quality of concrete placed is not sufficiently reliable.

So, what this document for example the JSC document gives is that bottom discharge buckets or bags is not highly recommended method of construction using ordinary underwater concrete because it is not continuous and the quality of concrete is not sufficiently reliable.

(Refer Slide Time: 06:47)

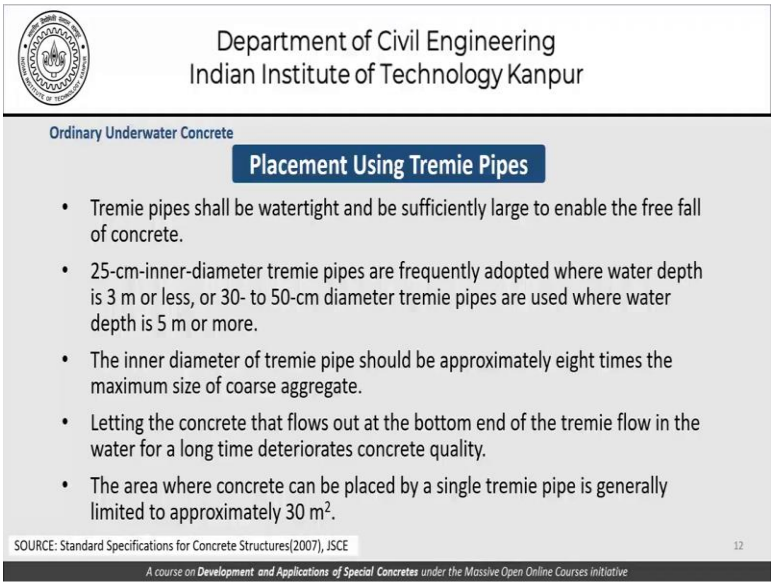


When you are using tremie pipes the tremie pipes shall be watertight and should be sufficiently large to enable the free fall of concrete. 25 centimetres inner diameter tremie pipes are frequently adopted where the water depth is 3 meters or less. But that diameter could be in the range of 30 to 50 centimetres if the water depth is more than 5 meters. The inner diameter of the tremie pipe should be approximately eight times.

The maximum size of coarse aggregates if you are looking at 25 to 40 mm of coarse aggregate then obviously you are going to need what 35 to 40 centimetre or 30 centimetres, 50 centimetres kind of a diameter which is mentioned here. Letting the concrete that flows out at the bottom end of the tremie flow in the water for a long time deteriorates the concrete quality and therefore we need to be sure how many tremies that we will use?

And one of the guiding principles available to you is that the area where the concrete can be placed by single tremie is generally limited to approximately 30 square meters. I can work out the diameter and try to see that okay for a given tremie what is the kind of radius over which the concrete is expected to flow from that particular tremie and we need to have another tremie in case the required diameter is more than that.

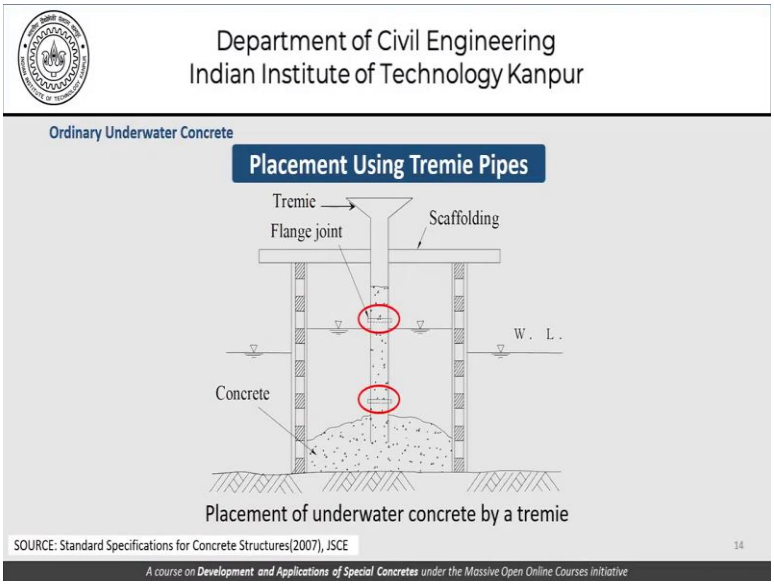
(Refer Slide Time: 08:07)



Continue with our discussion on placements using tremies the contact of water and concrete should be prevented by using the tremie pipe with a cap at the tip or inserting a plunger at the start of concrete placement. To prevent water from entering the tremie pipe during concrete placement the bottom end of the tremie should be embedded and kept embedded in the concrete already placed.

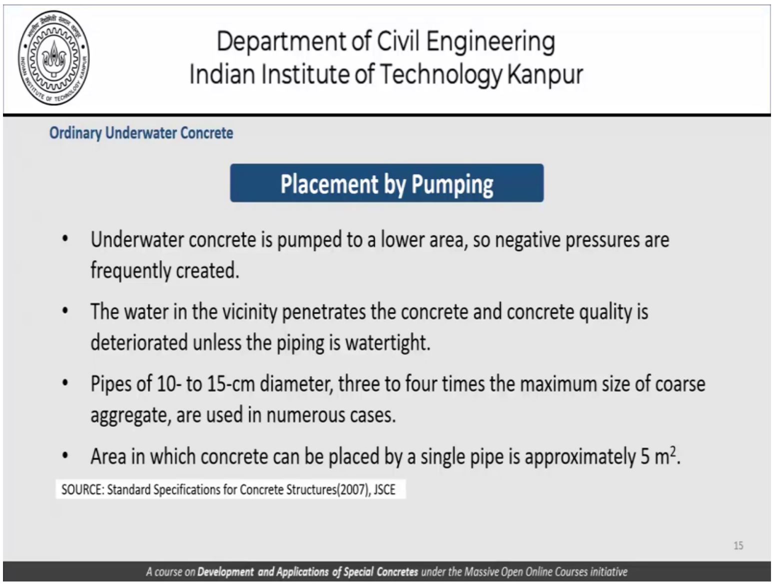
And when using a special tremie pipe its applicability and use shall be examined carefully we should be careful about the material the thickness and the diameter of the tremie pipe this picture here shows the placement using tremie pipes.

(Refer Slide Time: 08:43)



So, we may need to use flange joints as shown here because those pipes come in certain lengths and make sure that this end always remains in the concrete it has been placed. And the diameter here over which we can use a single tremie is also given to you the 30 square meter guideline. So, these are some of the things that you can take as guidelines when you are using underwater concrete ordinary underwater concrete using a tremie and doing underwater construction.

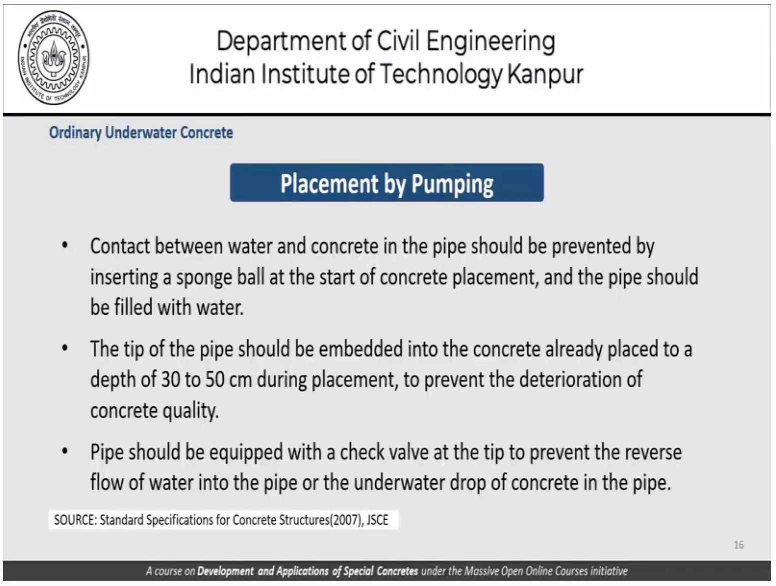
(Refer Slide Time: 09:24)



When we are trying to place concrete by pumping. Underwater concrete is pumped to a lower area negative pressures are frequently created and the water in the vicinity penetrates the concrete. In the concrete quality deteriorates unless the piping is watertight. So, pipes of 10-50 centimetres diameter which is three to four times the maximum size of the coarse aggregate are used in numerous cases.

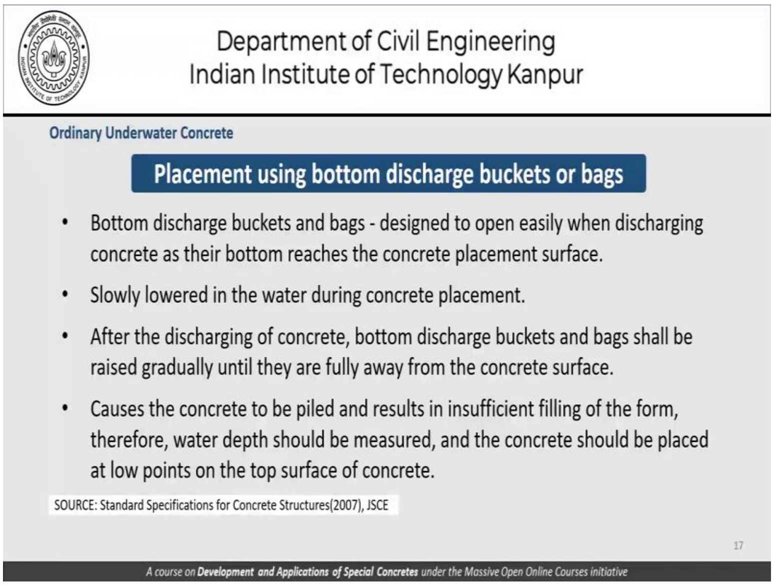
The area in which the concrete can be placed if you are using pumping is approximately or is limited to five square meters.

(Refer Slide Time: 09:56)



Continuing with the discussion on the same lines the contact between water and concrete in the pipe should be prevented by inserting a sponge ball at the start of the concrete placement and the pipe should be filled with water. The tip of the pipe should be embedded into the concrete already placed to a depth of 30 to 50 centimetres during placement. To prevent the deterioration of concrete quality the pipe should be equipped with a check valve at the tip to prevent the reverse flow of water into the pipe or the underwater drop of concrete in the pipe.

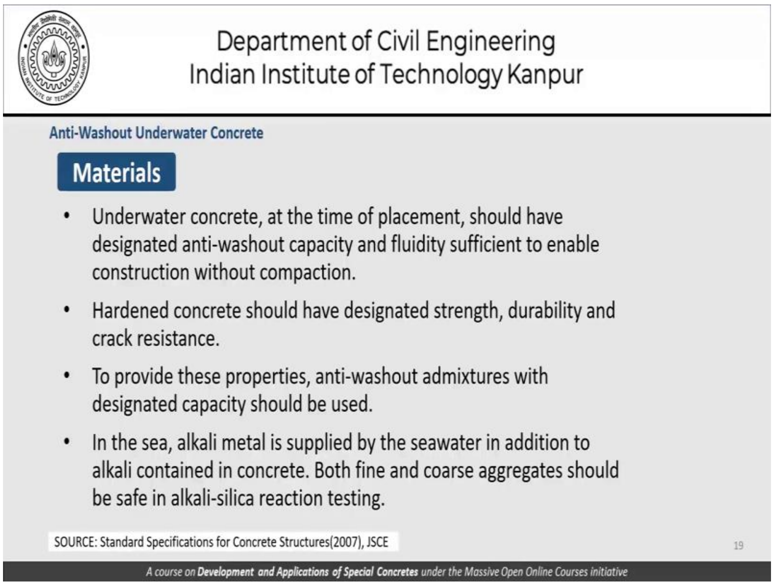
(Refer Slide Time: 10:29)



When we are using bucket discharges or bags as a placement method they are designed to open easily when discharging the concrete as the bottom reaches the concrete placement surface. They are slowly lowered into the water during concrete placement and discharging the concrete the bottom discharge bags or buckets are gradually raised until they are fully away from the concrete surface.

And this causes the concrete to be piled and results in insufficient filling of the forms at times and therefore the water depth should be measured and the concrete should be placed at low points on the top surface of concrete.

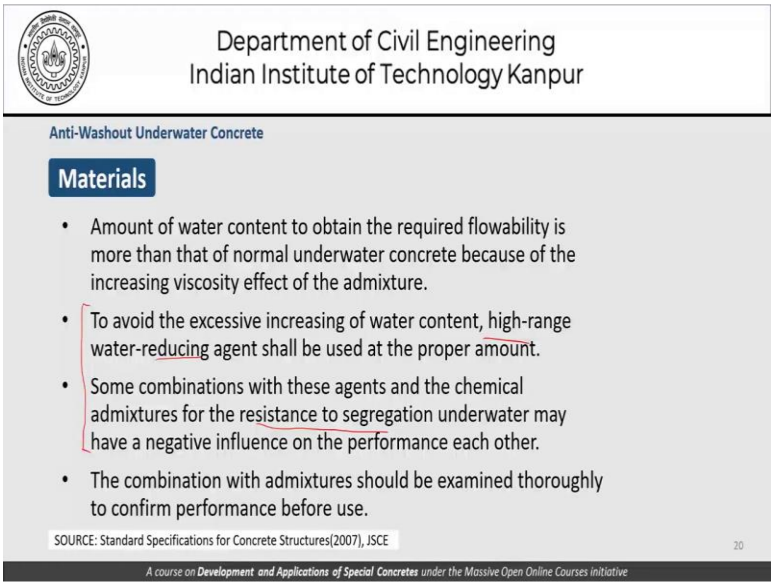
(Refer Slide Time: 11:12)



Now coming to our discussion on the special anti-washout underwater concrete that's what we saw in our last discussion. As far as the materials are concerned in underwater concrete at the time of placement should be designated to have the right kind of anti-washout capacity and fluidity sufficient to enable the construction without compaction. Hardened concrete should have the designated strength durability and crack resistance and provide these parameters.

Anti-washout admixtures with the designated capacity should be used that is what we are talking about the viscosity agents. In the sea the alkali metal is supplied by the sea water in addition to the alkali container in the concrete and therefore both the fine and the coarse aggregates should be safe from an alkali silica reaction point of view.

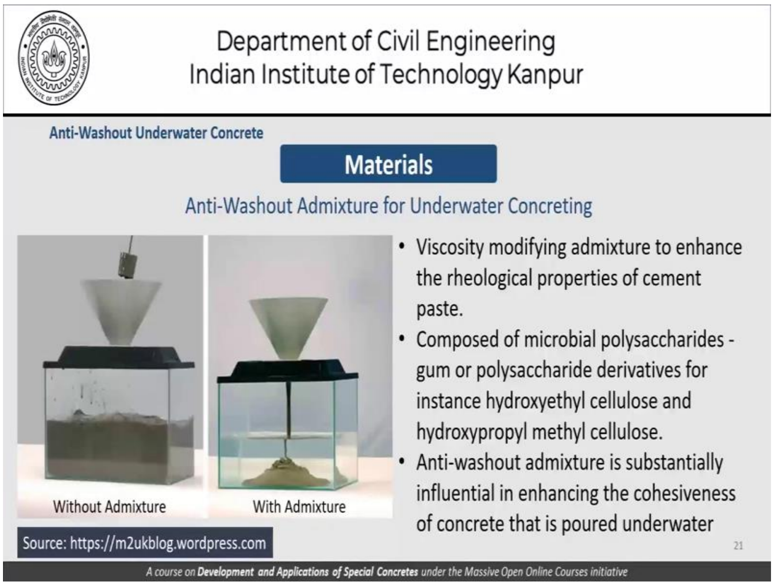
(Refer Slide Time: 12:07)



The amount of water content to obtain the required flow ability is more than that of normal underwater concrete because the increased viscosity effect of the admixture. To avoid the excessive increasing of water content high range water reducers are used in appropriate amount. And some combination with these agents and the chemical admixtures for the resistance segregation which is the viscosity agents may have a negative effect on the performance of each other.

So, basically these viscosity agents and the high range water reducers they are pulling the concrete into opposite directions and therefore the compatibility the dosages will need to be determined together through appropriate trials. And the combination of these admixtures should therefore be thoroughly confirmed before we actually try to use them at size.

(Refer Slide Time: 13:05)



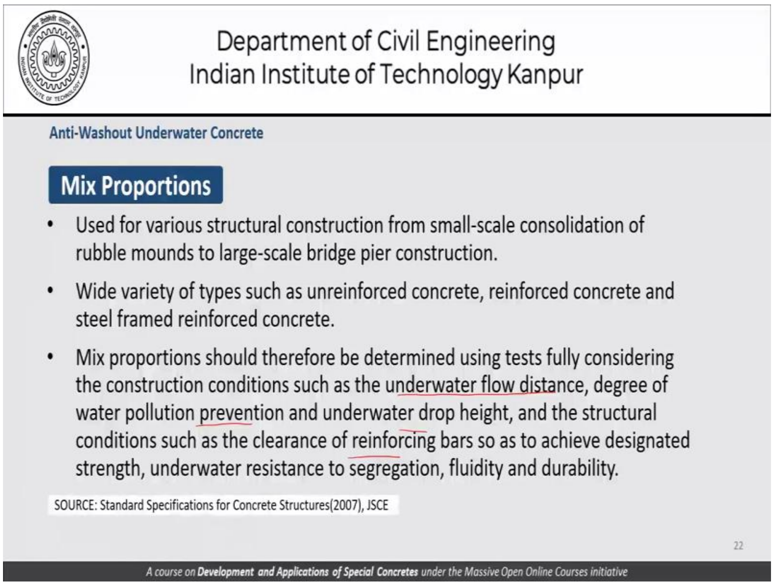
So, this picture here is just a representation of what we saw last time also that without the admixture we have this kind of a slightly murky or a muddy picture as far as reinforcement is concerned. Whereas here with the admixture that is the viscosity agents the viscosity modifying admixtures that we are calling them we can see that the mortar is being placed very cleanly and is settling within the water tank.

So, this viscosity modifying admixture to enhance the logical properties of cement paste and this comprises often off microbial polysaccharide gum or polysaccharide derivatives for instance hydroxyl ethyl cellulose or hydroxyl profile methyl cellulose. So, these are the kind of chemicals that actually become part of the viscosity modifier which becomes a part of the concrete which helps us achieve this segregation resistance in concrete, which facilitates the development and use of the anti-washout concrete.

The anti-washout mixture is substantially influential in enhancing the cohesiveness of concrete that is poured in water. So, we are now using this word cohesiveness as another property of concrete. So, it is not only consistency and workability but we are not talking in terms of cohesiveness. So, if the mix is more cohesive then it is more segregation resistant. If the mix is less cohesive the concrete will segregate easily.

The particles are not bound to each other they do not have much of an affinity with each other. So that is the idea of cohesiveness so I am leaving it to you to just think about this cohesiveness as a property and have your own image as to what the cohesive nature of the paste would be and keep this picture in mind. That this is the normal cement paste this is with an admixture which has imparted a certain amount of cohesiveness to the paste.

(Refer Slide Time: 15:29)



Now as far as proportions are concerned used for various structural constructions from small scale consolidation of rubble mounds to large scale bridge pier constructions. Wide variety of types such as unreinforced concrete reinforced concrete and steel framed reinforced concrete. And the mixed proportions need to be determined using tests that appropriately take into account conditions such as the underwater flow distance.

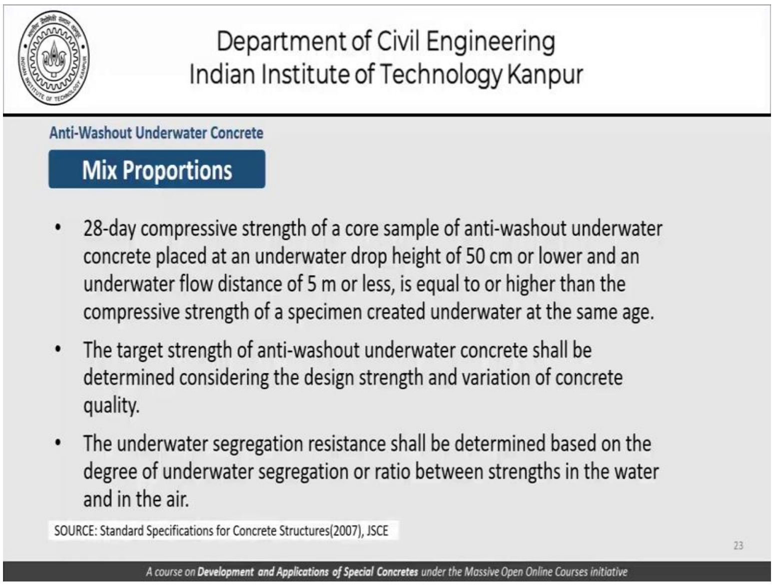
Degree of water pollution prevention and underwater drop height and the structural conditions such as the clearance of reinforcing bars. So as to achieve designated strength underwater resistance to segregation fluidity and durability. So here are the parameters which will govern the choice of mixed proportions. This parameter here is the degree of water pollution prevention that is somebody can say that well I do not want more than a certain amount of cement to wash out.

This can be laid down in any quantitative manner and we have to design our proportion in a manner that that particular anti-washout requirement is met. And your proportion has to also meet requirements such as the underwater flow distance the distance between reinforcing bars and so on. So that is the standard method except that now we are talking of special conditions being imposed on a particular concrete given the special nature of the environment of constructions.

So, the properties of fresh concrete are not simply limited to slump and slump flow or air but now we are bringing in special characteristics like the amount of segregation the amount of washout the amount of flow distance and so on. And all this needs to be established using tests so you will recall that we talked about mock-ups. In one of our initial lectures. This emphasizes the importance of carrying out mock-ups.

Because in an underwater situation which I showed you when we are actually using divers and so on. It is virtually not possible to make any on course corrections or mid-course corrections are very difficult to carry out. So long as we carry out a mock up resolve all the problems at site from a test it becomes so much easier.

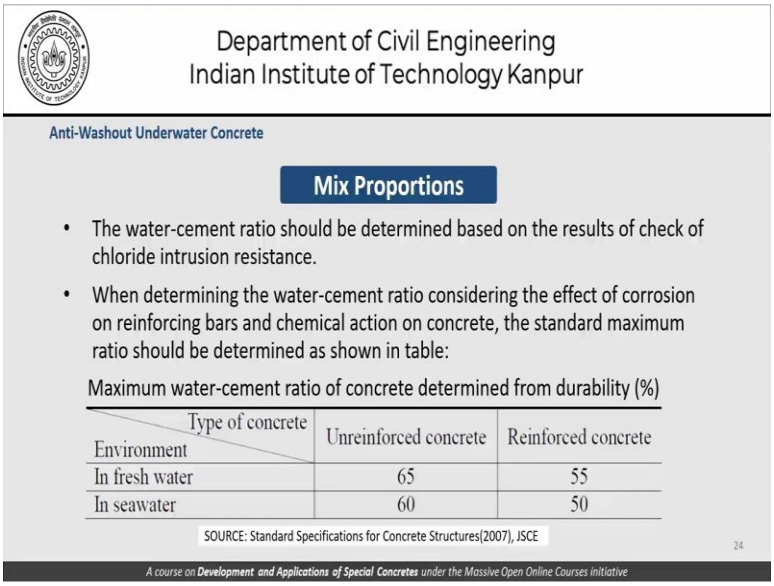
(Refer Slide Time: 17:50)



28 days compressive strength of a core sample of anti washout underwater concrete placed at an underwater drop of 50 centimetre of height or lower and an underwater flow distance of 5 meters or less is equal to or higher than the compressive strength of a specimen created underwater at the same age. The target strength of anti-washout underwater concrete shall be determined considering the design strength and the variation of concrete quality that is the standard thing we do.

And the underwater segregation resistance should be determined based on the degree of underwater segregation or the ratio between the strengths in the water or in air. So, we can have different tools different methods which can be used to quantify one parameter or the other.

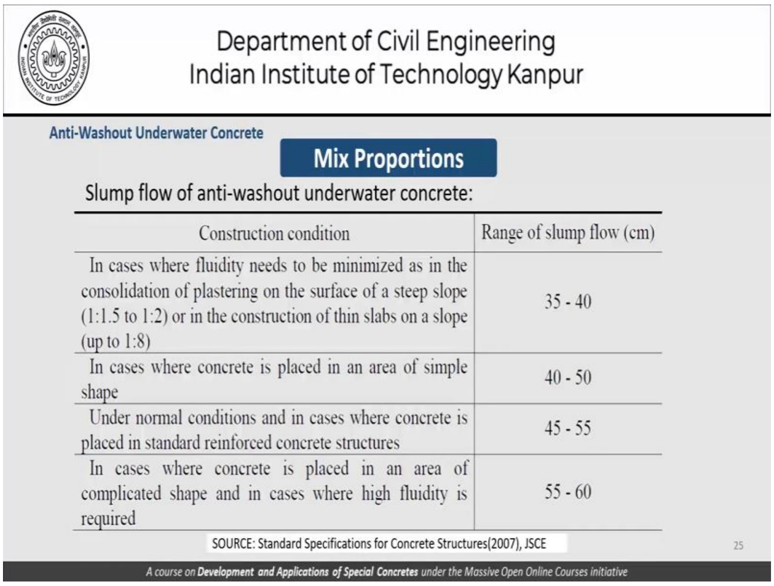
(Refer Slide Time: 18:36)



As far as a guideline for the proportions is concerned the water cement ratio should be determined based on the results of checking the chloride intrusion resistance or the diffusion coefficient of chloride that can be expected or acceptable. When determining the water cement ratio considering the effects of corrosion on reinforcing bars in chemical actions of concrete. The standard maximum water cement ratios are shown here.

So, in fresh water sea water for unreinforced concrete the maximum values are 65 and 60 but for reinforced concrete the maximum values are 55 and 50. So here are the maximum permissible water cement ratio values from the point of durability. Of course, these are the maximum values and therefore the actual values can be actually smaller.

(Refer Slide Time: 19:23)

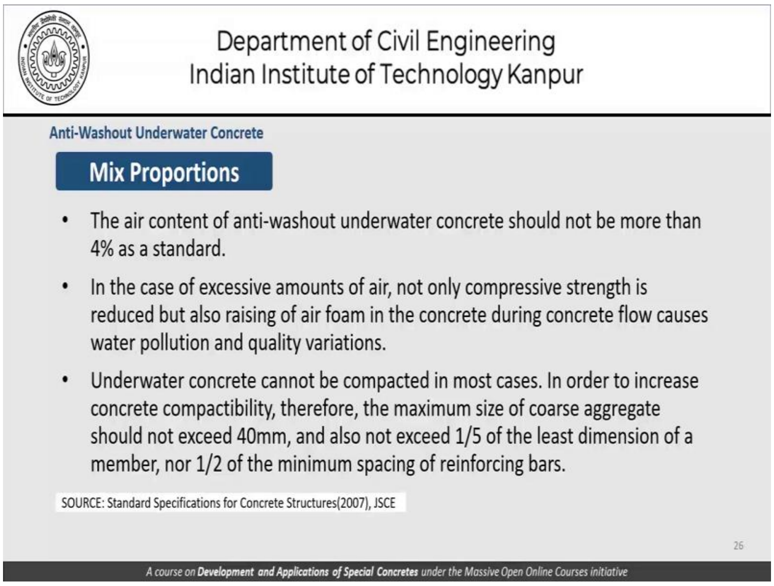


As far as slum flow is concerned which is the consistency requirement. Depending on the construction condition the range of slum flow is different beginning with 35 it goes up to 60 centimetres. In case where fluidity needs to be minimized as the consolidation of plastering on the surface of a steep slope 1 is to 1.5, 1 is to 2 or the construction of thin slabs on a slope of 1 is to 8. We need to have reasonably smaller values of slump float 35 to 40 centimetres in case where concrete is placed in an area of simple shapes.

It could be 40 to 50 under normal conditions in cases where the concrete is placed in standard reinforced concrete structures it its 45 to 55. But when the shapes become complicated and we need a higher fluidity for the concrete to be able to flow around we need a slump flow in the range of 55 to 60 centimetres. So basically, we are talking of a range as low as 35 to 40 to a range of about 55 to 60 centimetres.

But given the fact that we are talking of anti-washout concrete we also need to bring in the parameters like T_{500} which we talked about in the last class.

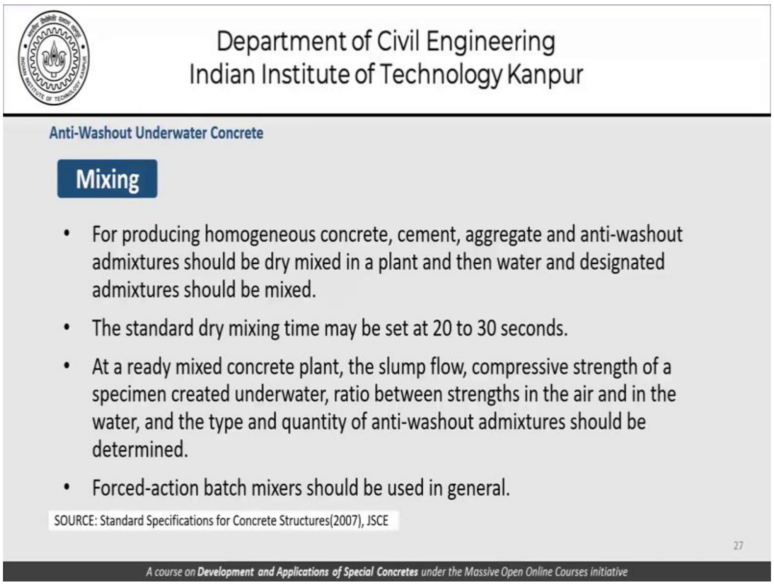
(Refer Slide Time: 20:42)



The air content in the anti-washout underwater concrete should not be more than 4% and the case of excess amount of air not only compressive strength is reduced but also has air form in the concrete during concrete flow causes water pollution and quality variation. So, we need to be careful about air content in this kind of concrete. And underwater concrete cannot be compacted in most cases obviously and therefore in order to increase the concrete compactability the maximum size of coarse aggregate should not exceed 40 mm.

And should not exceed one fifth of the least dimension of a member or one half of the minimum spacing of the reinforcing parts. So, these are some of the standard conditions that we use when trying to determine the right kind of material and the right kind of proportions for anti-washout underwater concrete.

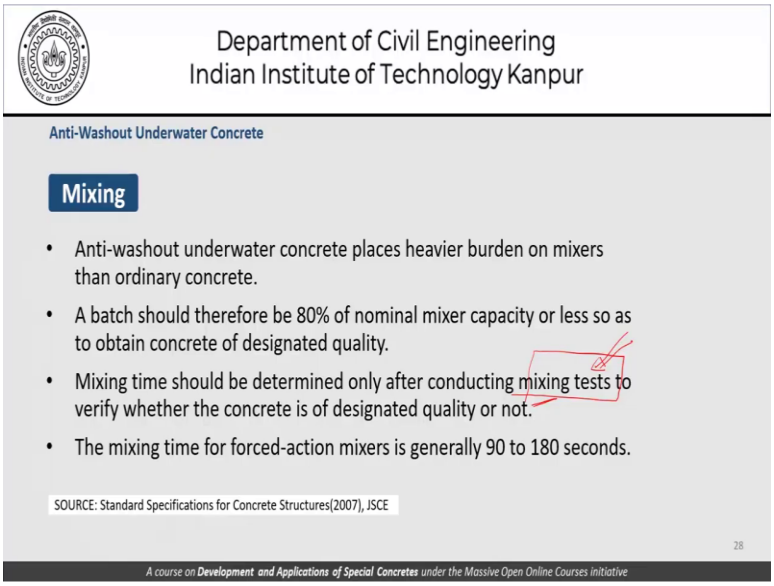
(Refer Slide Time: 21:34)



For producing homogeneous concrete cement aggregate and anti-washout at mixture shall be dry mixed in a plant and then water and designated admixture should be mixed. The dry mixing time could be 20 to 30 seconds and followed by the wet mixing time as we saw in the last class as well at the RMC plant the slump flow compressive strength of a specimen created under water the ratio between the strengths in air and in water and the type and quantity of the anti-washout that mixture should be determined. And forced action batch mixers should generally be used.

So as far as we are concerned as far as this whole idea of mixing is concerned, we have to make sure that the mixing process as well is properly documented. And is part of our regular SOP as far as quality control is concerned. As far as our ability to produce quality concrete is concerned and carry out a quality job in anti-washout underwater construction, we need to be careful about all the processes the mixing included in terms of the mixing method the mixing time and trying to take the right kind of samples.

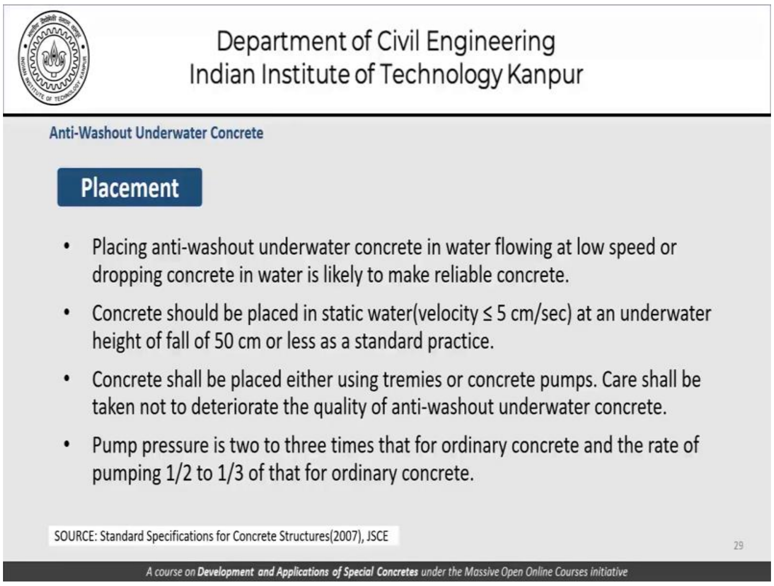
(Refer Slide Time: 22:49)



Anti washout underwater concrete places heavier burden on mixers than ordinary concrete and the batch should therefore be 80% of the normal capacity of the mixer or less. So as to obtain the concrete of a designated quality. So, we should not try to overload mixers because that will compromise the ability of the mixer to actually produce homogeneously mixed properly mixed concrete. Mixing time should be determined only after conducting mixing tests to verify whether the concrete is of a designated quality or not. So, the bottom line basically is that we should not be shy of carrying out tests whether it is for determining the mixing process the mixer use the mixing time the placing method and so on.

Everything boils down to the right kind of tests again emphasizing the idea of mock-ups to be used if it is required. The mixing time for forced action mixers could be about to 180 seconds depending on what kind of concrete is being produced? what kind of aggregate being used and so on.

(Refer Slide Time: 23:56)

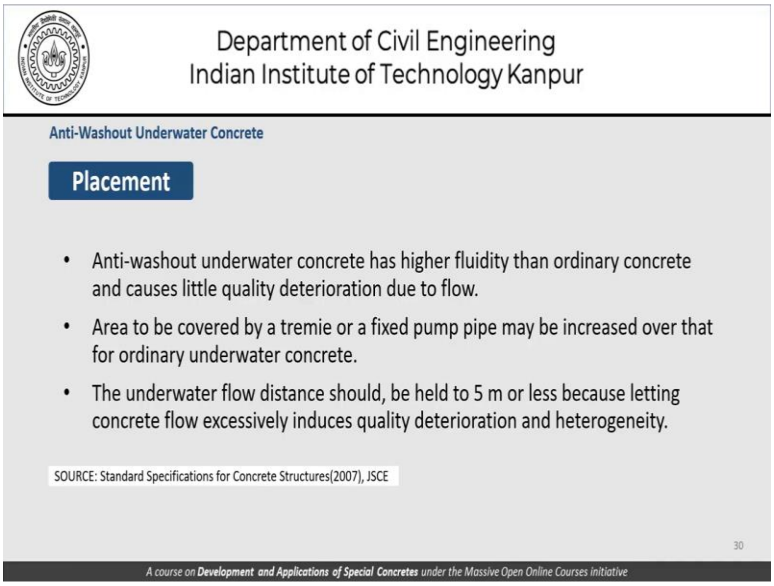


As far as placement is concerned placing anti washout concrete in water flowing at speeds which is low or dropping the concrete in water is likely to make reliable concrete. So basically, we have to ensure that the concrete is placed in still water that would be the best solution. As far as we are concerned, if possible, otherwise we have to make sure that the speed or the velocity at which the water is flowing while we are placing the concrete is brought under control by some means of the other.

Concrete should be placed in static water with velocities less than 5 centimetres per second at an underwater height of fall of 50 centimetres or less that is the standard practice. And concrete shall be placed either using tremies or concrete pumps and obviously it needs to be ensured that the quality of the anti-washout underwater concrete does not deteriorate or is not lower than what it is supposed to be.

As far as the pump pressure is concerned, we need to have pump pressures twice or thrice that for ordinary concrete and the rate of pumping is only about half to one third for that of ordinary concrete. That is possibly related to the fact the concrete that we are using here is extremely viscous. So as the viscosity of the fluid being pumped increases you need to have more powerful pumps and their capacities the utilizations the rate of pumping will go down.

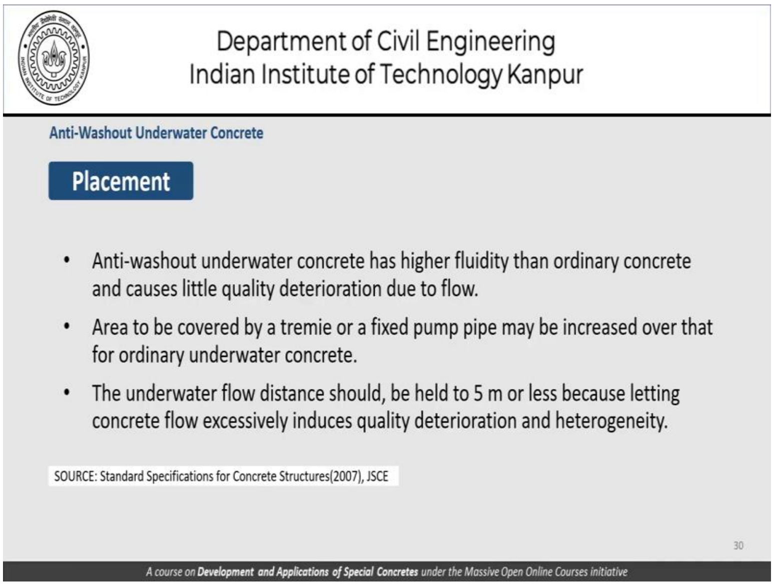
(Refer Slide Time: 25:20)



The anti-washout concrete has higher fluidity than ordinary concrete and causes little or no deterioration as far as flow is concerned. Ideally placed anti-washout concrete has higher fluidity than ordinary concrete and properly placed. There is no cause for any deterioration in the quality due to flow. Area to be covered by a tremie or a fixed pump pipe may be increased compared to an ordinary underwater concrete.

And the underwater flow distance should be held to 5 meters or less because letting the concrete flow excessively induces quality deterioration and heterogeneity in the concrete mass.

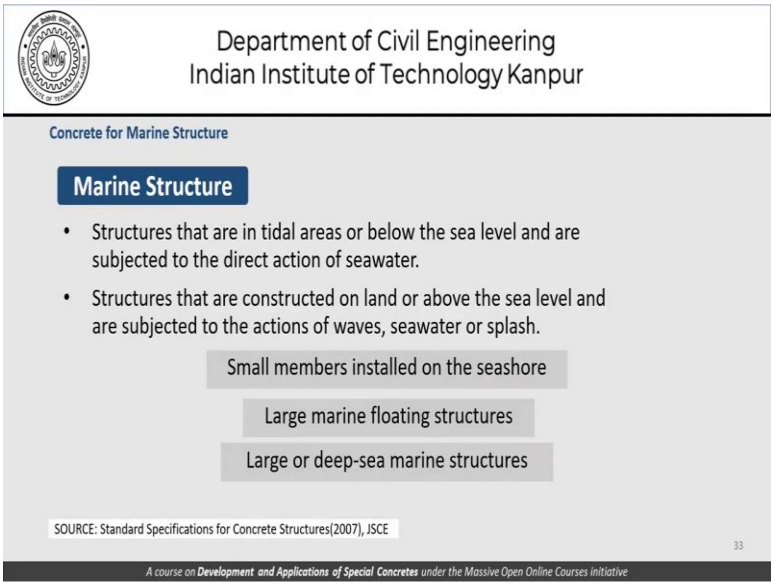
(Refer Slide Time: 26:04)



As far as protection of the concrete surface is concerned, we must be careful since anti-washout underwater concrete requires a long setting time. The concrete shall be protected from the surface's cover by flowing waters or waves before the concrete hardens after placement. So, we have to make sure that the concrete is properly protected the surface is properly protected from flowing water or waves at least till the time that it is hardening.

If subjected to direct effect of flowing water or waves the cement may flow out and the concrete surface may get is covered. Protective measures should be taken by covering the concrete surface with a membrane or installing a form to the height required to prevent the flowing of water or waves from directly affecting the concrete surface.

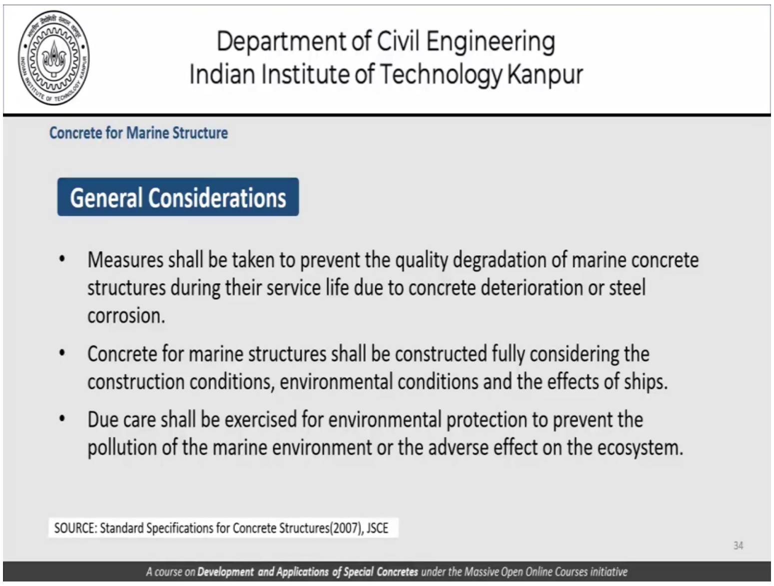
(Refer Slide Time: 26:50)



Coming to the last part of our discussion today which is the concrete for marine structures. Marine structures are those that are in tidal areas or below sea level and are subjected to direct action of sea water. And structures that are constructed on land or above the sea level and are subjected to the action of waves, sea water splash, small members installed on the seashore, large marine floating structures, large or deep-sea marine structures.

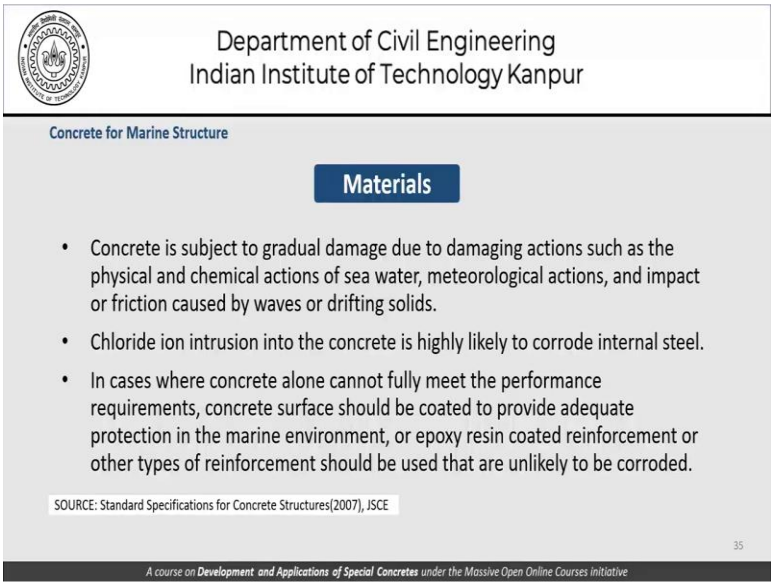
These are some of the examples of what we call marine structures or what we are including in our ambit of definition of marine structure.

(Refer Slide Time: 27:31)



As for a general consideration involving the concrete for use in marine structures concerned measures need to be taken to prevent the quality deterioration of marine concrete during the service life due to corrosion or any other reason. And concrete for marine structures shall be constructed fully considering the construction conditions environmental conditions and the effect of ships. Due care shall be exercised for the environmental protection to prevent the pollution of the marine environment or adverse effect on the ecosystem in the neighbourhood of the construction site.

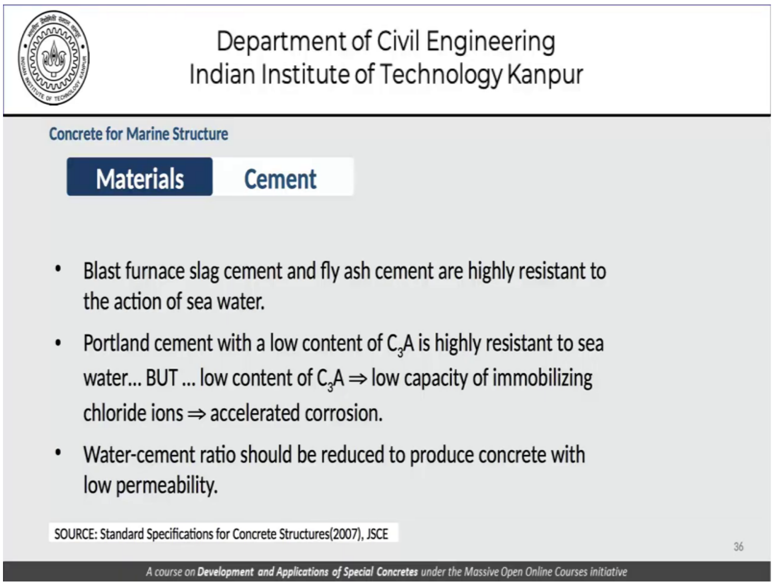
(Refer Slide Time: 28:09)



And concrete in marine structures is subject to gradual damage due to damaging action such as physical or chemical actions of sea water metallurgical actions and impact or friction caused by waves or drifting solids in the sea. Chloride ion penetration into concrete is highly likely to corrode the internal steel that we have if it is a reinforced concrete structure. And in cases where concrete alone cannot meet the performance requirements.

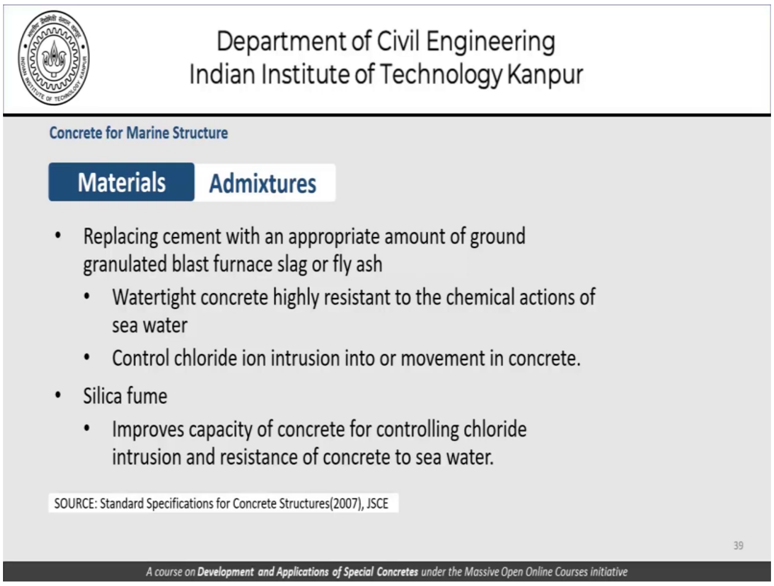
The concrete surface should be coated or provided with adequate protection in the marine environment or epoxy coated reinforcement should be used such that the appropriate kind of service life to the structure is ensured. So, without getting into a detailed discussion of reinforcement corrosion and the kind of steps that need to be adopted to address this problem. Let us quickly go through some other materials.

(Refer Slide Time: 29:05)



The blast furnace slag cement and fly ash cements are highly resistant to the action of seawater, Portland cement with a lower C 3 A content is highly resistance to sea water. But with the low C 3 A it has a lower capacity for immobilizing the chloride ions and therefore it can have some implications as far as corrosion is concerned. Water cement ratio should be reduced to produce a concrete with a low permeability.

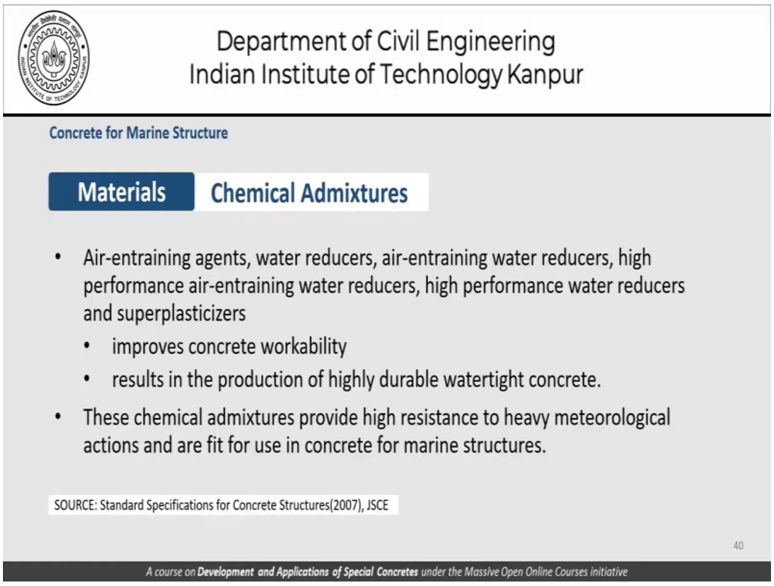
(Refer Slide Time: 29:30)



Now as far as aggregates are concerned there are undesirable properties in aggregates which you must avoid crumble easily have joints low strength, high absorption, swelling and sea water may accelerate alkali aggregate reaction. And therefore, the reactivity of aggregates needs to be fully examined before a final decision to use a particular aggregate is made. As far as admixtures are concerned replacing cement with appropriate amounts of ground granulated blasphemous slag or fly ash could be options as we have discussed before.

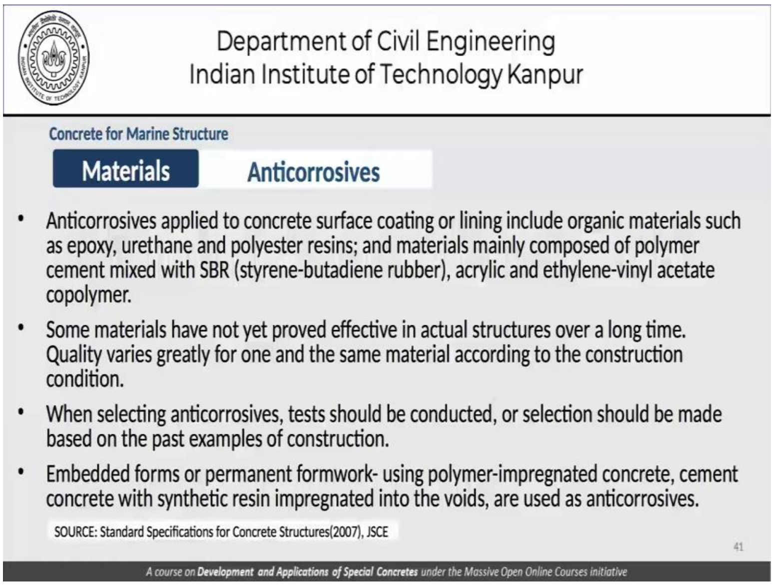
Watertight concrete highly resistant to chemical actions of seawater control. The chloride diffusion or the movement of chlorides in concrete. Silica fume is another possible mineral admixture to be used that improves the capacity of concrete for controlling chloride penetration and resistance of chloride to sea water.

(Refer Slide Time: 30:22)



When it comes to chemical admixtures, air entraining agents, water reducers, air entraining water reducers, high performance air entraining water reducers and so on. They are all candidates for use in these concretes. They improve the concrete workability and result in production of highly durable watertight concretes. These chemical admixtures provide a high resistance to heavy metalogical action and are fit for use in and marine environment.

(Refer Slide Time: 30:55)

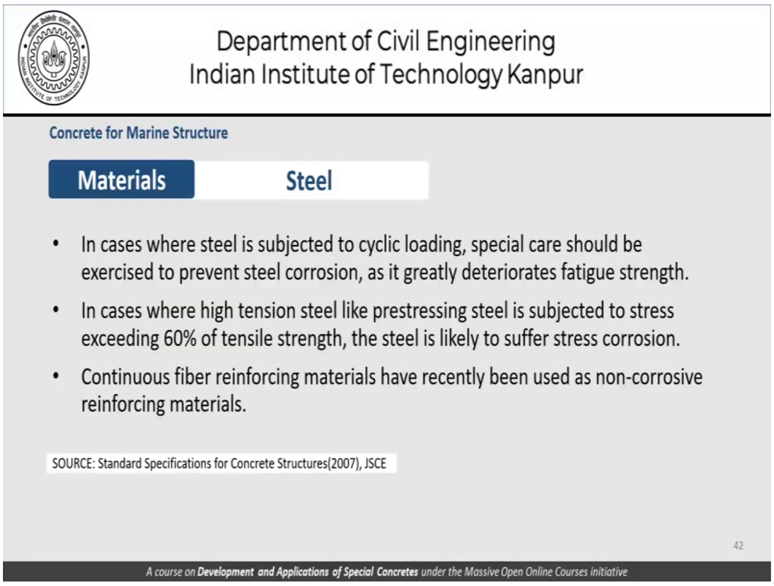


Continue our discussion with the materials for use in marine structures as far as anti-corrosives are concerned these are applied to the concrete surface. And it could be linings in the form of organic material such as epoxies urethane or polyester resins and materials mainly comprising polymer cement mixed with SPR which is styrene butadiene rubber and acrylic and ethylene vanilla acetate copolymers.

Engineers must be careful that materials may not have been proved effective in actual structures or long-term behaviour is not known. And therefore, we should be careful in accepting or trying to use a material for the first time in a site unless it has a proven track record either by way of actual use or by way of some appropriate tests carried out under certain conditions.

And the quality often varies greatly for one and the same material according to the construction conditions. When selecting anti-corrosives tests should be conducted and carried out or selection should be based from past examples of construction. Embedded forms of permanent formworks using PIC which is polymer impregnated concrete or cement concrete with synthetic resin impregnation in the voids can be also used as anti-corrosive measures.

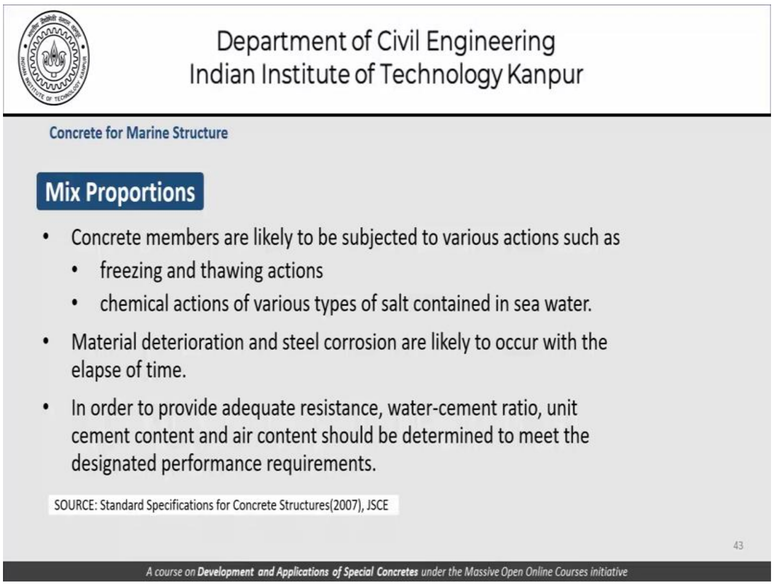
(Refer Slide Time: 32:16)



As far as steel is concerned in cases where steel is subjected to cyclic loading special care needs to be taken to ensure prevention of corrosion as it could greatly reduce the fatigue strength. In cases where high tension steel like pre-stressing steel is subjected to stress exceeding 60 of its tensile strength the steel is likely to suffer stress corrosion. As well and appropriate counter measures need to be taken in that case.

Continuous fibre reinforcing materials have recently been used as non-corrosive reinforcement and a discussion of continuous fibre reinforced material is not part of this discussion. If we have the time, we will touch upon it towards the end of this series of lectures.

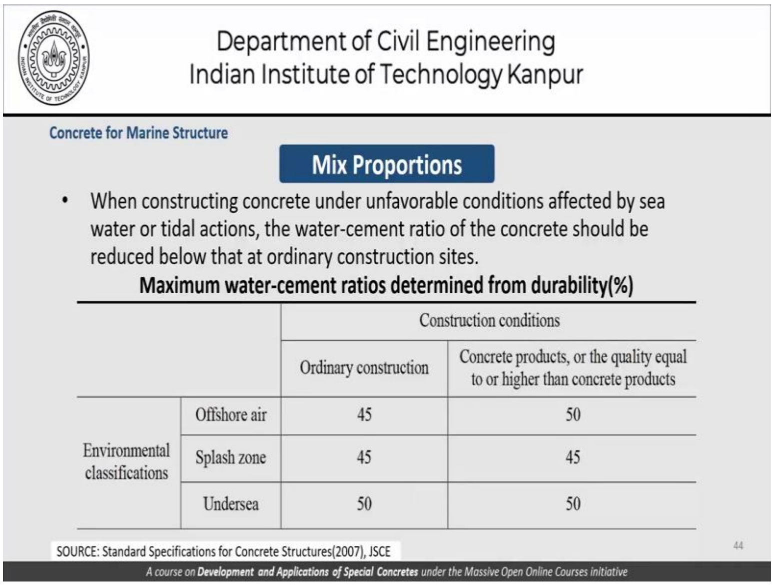
(Refer Slide Time: 32:59)



Coming to the mixed proportions for concrete and marine structures the concrete members are likely to be subjected to various actions as freezing and thawing depending on the temperatures involved. Chemical action of various types of salts contained in sea water. And what we are encountering is two situations the material deterioration of concrete and the steel corrosion these two things are likely to happen over a long period of time.

In order to provide adequate resistance, the water cement ratio the unit cement content and air content should all be specified in an appropriate manner and determined to meet the designated performance requirements. So that again places such a lot of responsibility on the designer has to specify the parameters and the expected level of performance for each of those parameters.

(Refer Slide Time: 33:49)



When constructing concrete under unfavourable conditions affected by sea water or tidal action which is typical in the case of marine structures. The water cement ratio of the concrete should be reduced and in fact this table tells us the maximum water cement ratio values determined from durability considerations depending upon the environmental classification. Of course, this environment classification is different from the environment classification given in IS456.

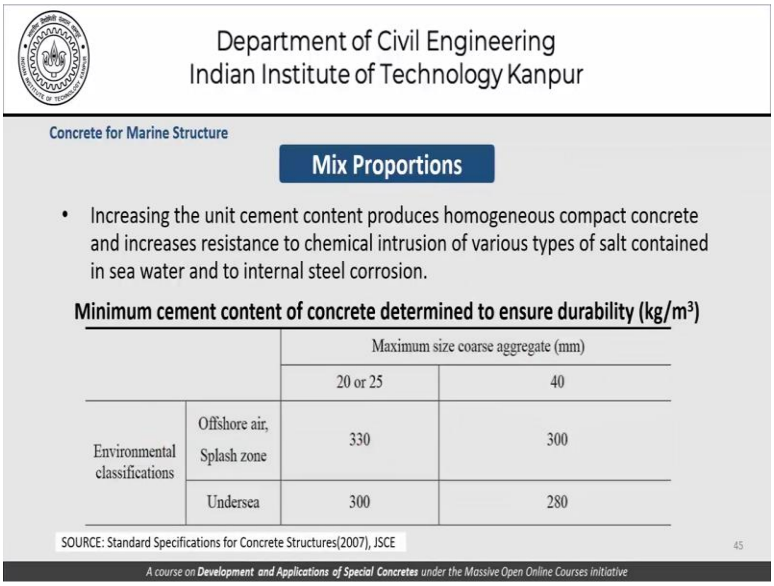
And you can go and take a look at that as to what is the kind of classification that is given in IS456 versus the kind of classification here. Here it is given as offshore air splash zone and under sea and we can see that the water cement ratio values given here are for ordinary construction. When we are using concrete products or a concrete in a situation or of the nature that its quality is as much or as high as that of concrete products.

Then we have some benefit in terms of the water cement ratio permitted as far as offshore air construction is concerned but note difference is allowed to you here. So basically of course this is a 2007 specification from JSC and these numbers could have changed they probably will change in the future depending on the technology that we use. The idea is to draw your attention to choosing the right kind of what a cement ratio choosing the right kind of construction method that we use and having a match between the two for different environmental conditions.

Of course, the whole game begins with classifying the environmental conditions as far as 456 is concerned please remember that IS 456 and that is what we keep referring to in India 456 is not a document which is specially written for marine concrete. It is a document which has been written for general use as far as concrete is concerned. It is concerned from a specialized point of view we need to look at more specialized literature and develop our own specifications.

Our own construction methods as our own acceptance criteria for special constructions special materials special concretes that we are talking about in this particular set of lectures.

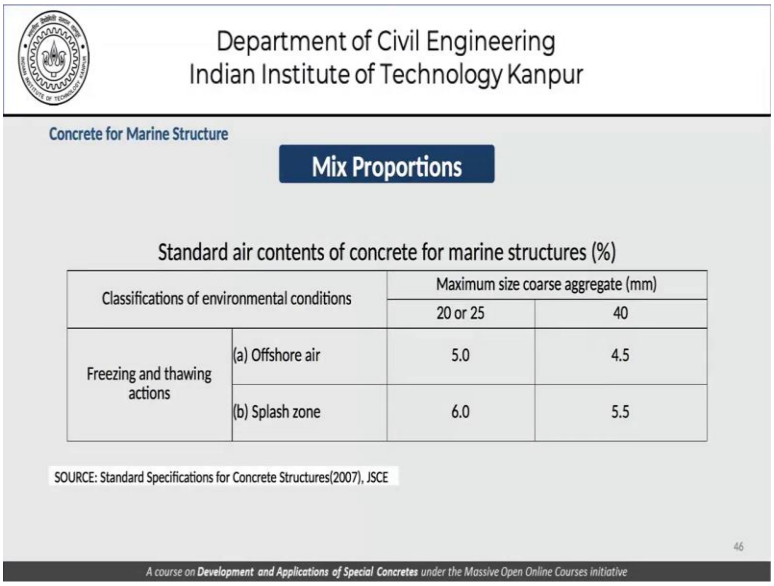
(Refer Slide Time: 36:14)



Apart from the water cement ratio there are requirements for the unit cement content and this table here talks about the minimum cement content of concrete determined to ensure durability for different conditions. These are the environmental conditions which we saw previously. These are the two columns for different sizes of coarse aggregate if it is 20 or 25 or it is 40. So, depending on the aggregate peak used and the conditions the cement content has been set as 330, 300, 300 here and 280 kgs cubic meter here.

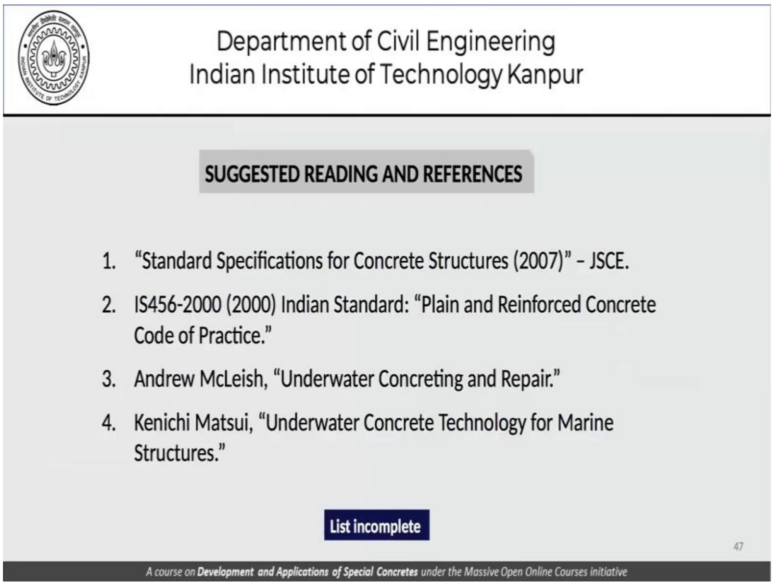
Now you can always compare the requirements that are laid down here which is as for the JSC specifications of 2007 with other similar specifications when you are doing that keep in mind that the exposure conditions have to be the same. So only then there is a level playing field that for a given exposure condition given size of aggregate what is the kind of minimum cement content that is being asked.

(Refer Slide Time: 37:25)



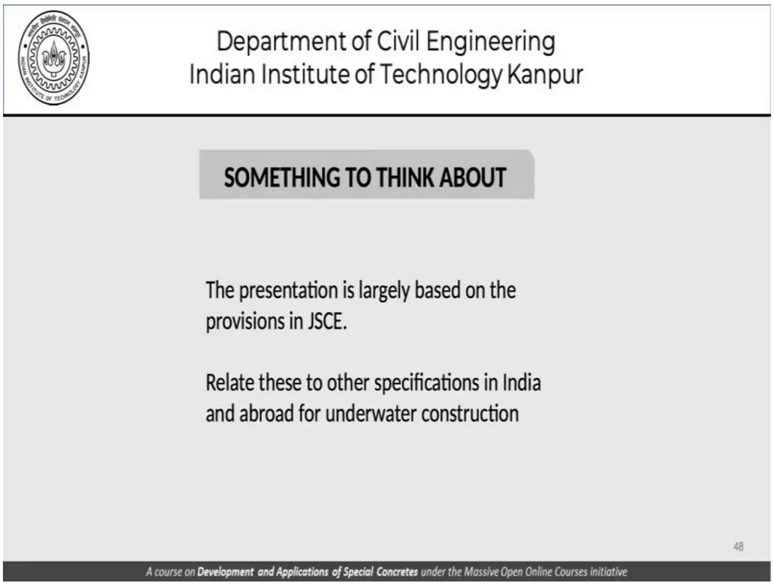
And lastly coming to standard air contents of concrete for marine structures if they are subjected to freezing and throwing actions for offshore and splash zones the numbers given range from 4 and a half to say 6% depending on the maximum size of course aggregate.

(Refer Slide Time: 37:39)



This slide gives the suggested reading and references which you might find useful in following the material which has been presented today. However, this list is by no means exhaustive and in fact it is for that reason that I have written this incomplete and you are requested and encouraged to look at the internet look for more relevant material and try to understand the subject matter better.

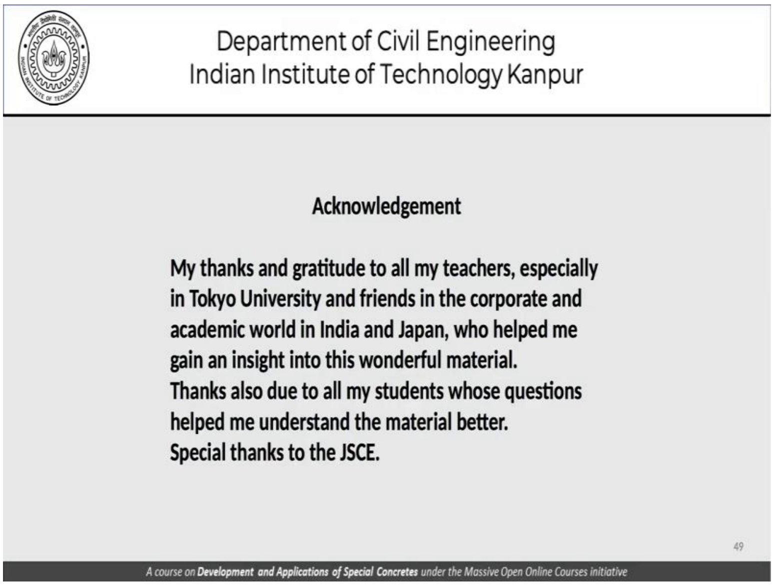
(Refer Slide Time: 38:04)



Moving on these are some things to be thought about homework to do compare the specifications not only IS456 but also some other specifications the kind of provisions that we discussed today were based on those given in JSC. You must do something about relating them to IS456 try to find out if there are other specifications than 456 dealing with underwater construction.

Marine construction as far as India is concerned compare them with other construction conditions or specifications not only in India for example ACI or European conditions the BS codes.

(Refer Slide Time: 38:46)



With this I come to an end of our discussion today expressing my thanks as usual to all my teachers, friends, colleagues and students. And I look forward to seeing you again in the discussion of another special concrete. Possibly we will talk about roller compacted concrete the next time which is a very different kind of concrete. Today we talked of concretes which are flowing in nature.

Roller compacted concrete is a concrete which does not flow at all it has a zero-slump concrete and that is something which we probably take up in the next class, thank you.