Advanced Marine Structures

Prof. Dr.SrinivasanChandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 32
Ultimate Capacity of Tubular Joints

So, in the last lecture we discussed about what are the different kinds of joints, we made a sketch and showed you what are the different kinds of joints, how are they named after the shape of the connections between the brace and the chord. Brace is the branch which is taken from the chord and usually the chord diameter is larger than the brace diameter and chord thickness is generally larger than the brace thickness.So, in this lecture we will talk about the ultimate strength capacity. Now, before we start discussing thisultimation capacity, one can let us say expects some kind of an analytical model or a derivation for explaining the ultimation capacity.

The moment we talk about plastic capacity or plastic models, we did a derivation. We made a mathematical modeling, then we analyzed and then we found out the equations.Unfortunately as far astubular joints are concerned of the complex interaction between the brace and the chord, it is very difficult to analytically modelthis behavior under the given combination of loads.So, what essentially people have been looking in the past research is that, if the brace is subjected to either tensile, axial tensile or axial compressive, what would be the ultimate strength carrying capacity or ultimate capacity of the joint as a whole.

Most of the cases you will see in the literature, they have been always based on, these values are always based on the experimental results, because analytical modeling is difficult. I will tell you, why there are two important aspects? why this kind of mathematical modeling is difficult. So, the emphasis was made on estimating the capacity by conducting or fabricating these joints on one is to one scale or scaled modelsand estimating the capacity interms of the joint until it is failure, we are talking about yield value.Because in certain cases there have been difficulties of plastic section or plastic hinge formation, after the plastic hinge is formed, because of the behavior or interaction behavior between the brace and the chord.

As we all understand,that the failure theory can be as complex as five numbers, what we discussed in the previous lectures. People are really not able to make out during analytical model, through analytical studies that can we really find out the ultimation capacity of the sections.So, people entirely focused majority of the studies were focused on experimental results.Of course, these results arrived at a summary which landed up in what we call empirical formulas. So, we will discuss those empirical formulas as a designer’s interest, instead of looking at how these equations would have beenformulatedor what would be the other parameters which will influence on this.

So, what I mean to say is, still there isa wider scope of research in this segment of estimating the ultimation capacity of tubular joints, in terms of analytical numerical modeling’s. Still there is a large scope of research available in this sector, was most of the equations which are derived based on experimental investigations, what we call them as empirical relationships.So, we will see them as a designer’s interest because this course as I told you, advanced marine structures is not talking about advancements in the marine structures.It is talking about the different applications of the design, selection of form, selection of geometry or analysis methodologies like ultimate strength design, plastic design, plastic analysis etcetera, reliability studies, fatigue analysis etcetera.

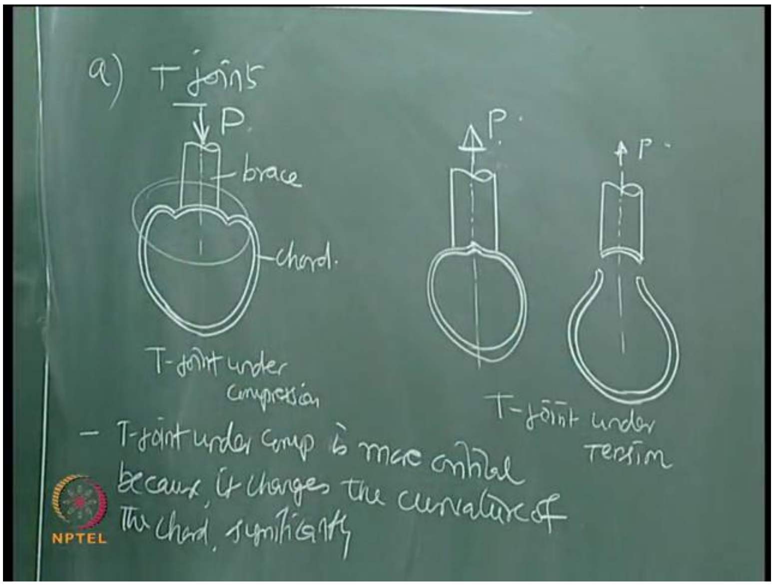
So, the term adjective of advanced attachedonly to that kind of advancements.It is not talking about any fantastic or any let us say,thirdgeneration or new generation of the structures addressed in this course. This has been clearly told in the first lecture itself, the advancement adjective is only attached to the method of analysis method of understanding in the whole design process, okay?In that context as far as ultimate strength of the tubular joints are concerned. We are restring to use the empirical relationships, which are available in different course, but I will put them all in one goal in this lecture. Sothat, this becomes a ready reckoner for a designer or the viewers to use this as an equation for finding out the capacity of the joints why we are focusing on joints.

I think, this question we already answered we already know, marine structures are highly indeterminate, in highly indeterminate structures like marine structures. Take for example, of any off shore platform like a jacket structure or like a tlp or a spar etcetera, where, there are more number of joints, there are possibilities of plastic hinges being formed in these joints.If at all they fail, these hinges should have enough ductility or ductility strength or let us say theductility ratio. So, that redistribution occurs and the applied load or the moment carrying capacity of the structure is enabled or increased by redistribution of these moments from the joints, where plastic hinges are formed to the next successive critical sections, or the other section could also be a tubular joint.

So, tubular joints are susceptible for failure,that is number one. So, we look at this strength specifically, number two we our environmental load generally acting on, marine structures are reversible in nature. May be their velocity, may be their wave white, may be their direction, may be their wind speed, may be their wind direction, they can keep on changing throughout the service life of the structural system. What we are looking at open sea states therefore, we are now looking for low magnitude high cycles of stresses or forces concentrating on the structure and the worst part in a general structures affected at joints.Therefore, we have to look at the strength of the joints. The third aspect is most of the marine structures which are formed innovative.For example, triceratops,for example, tlp as well for example, articulated structures.

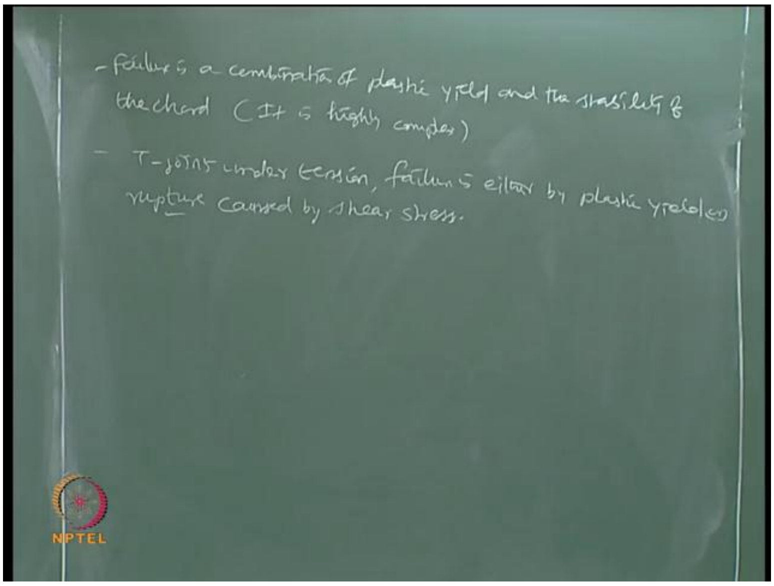
You have deliberately introduced certain joints, where there is a possibility of higher probability of failure at the joints. So, we have to look at these joints, so under three important stages or three important points we are concluding that, ultimate strength capacity of the system basically or critically depends on the strength of the joints. Why tubular because most of a structural members are tubular in nature, we do not use any other section. Most commonly we use tubular because, we need to have a large surface area, a high draft structure, for heavy bouncyat the same time we do not have to have weight therefore, they are tubular structures,somostly we are looking for ultimate strength tubular joints.

(Refer Slide Time:07:10)



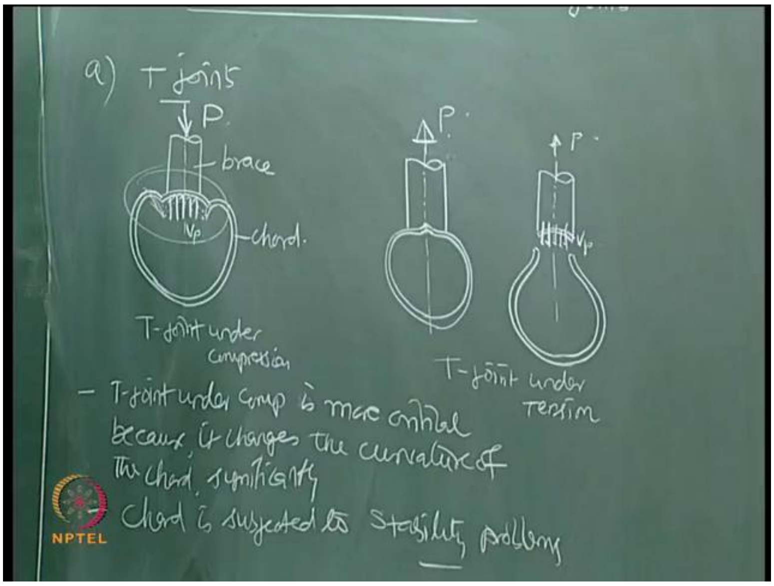
To start with, we discuss withT joints, let us quickly see how do they behave graphically in two nature of force like tension and compression?This is what we call as brace, this is what we call as a chord, this is a T joint, under compression,this T joint under tension. There are some important observations we can make, which is critical in both these behavior.Amongst both these behaviors,T joints under axial compression of brace is more criticalbecauseit changes the curvature of the chordsignificantlyand see the curvature of the chord is changed.Significantly, where as in this case the chord is openedbecause of the open ring the chord gets opened here, where as here the curvature changes. So, what happens in this case is when such curvature changes occur significantly in the chord. The chord is subjected tostability problems.

(Refer Slide Time:11:42)



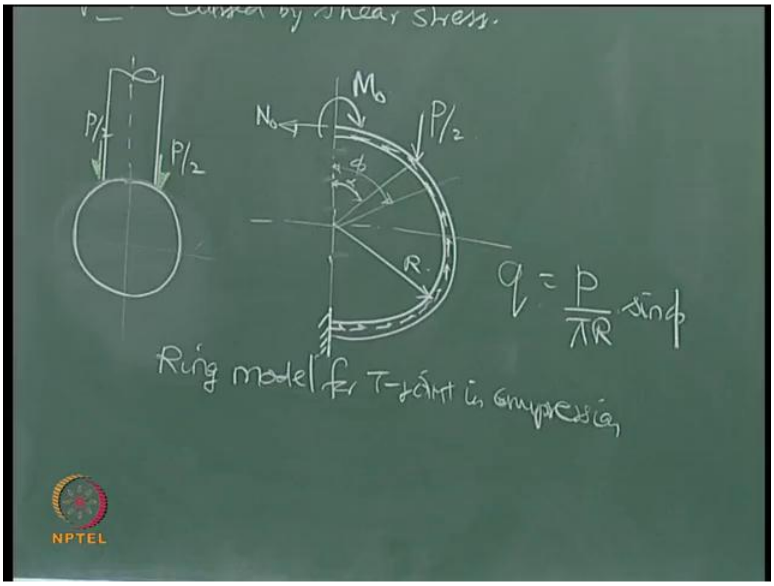
So, the failureis a combination ofplastic yieldandthe stability of the chord therefore, we can sayit is highly complex,where as in T joints in the tensionthe failure iseither by plastic yield, or rupturecausedby shear stress.So, here the chord gets separated at these junctions.

(Refer Slide Time:13:18)



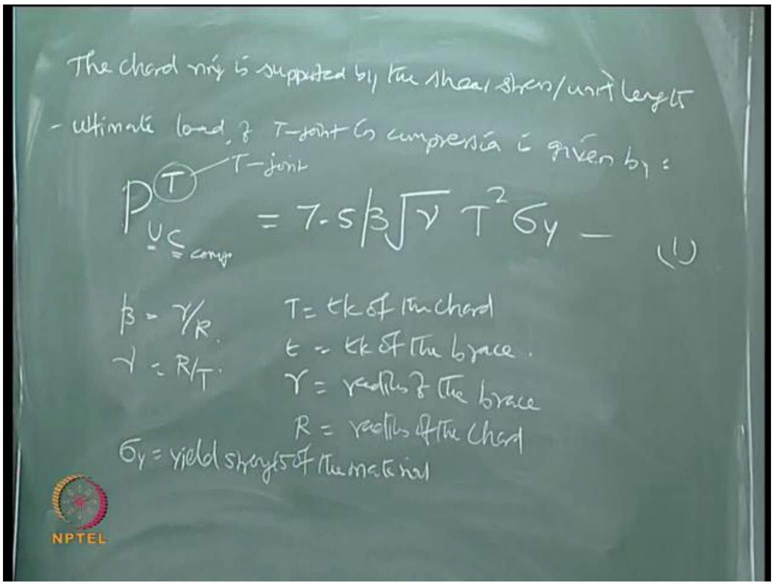
So,I am drawing it here separatelyand to oppose this,there will be shear stress and in this case to oppose this,there will be shear force. So, the chord will get disassociated or the curvature of the chord changes significantly to the dotted line and then subjected to shear stresses. So, in compression it is a combination of plastic yield plus stability problem of the chord where as in T joints under tension it is either plastic yield or rupture caused by the shear stresses. Obviously in the moment, we say the rupture caused by shear stress, the major shear stress will be only above 0.57 or 0.59,0.6633 depending upon the theory of failure after using for the major shear stresses etcetera.

(Refer Slide Time:14:33)



So, let us say this is my brace,which is imposing the forceto the chord,the total force is p. We can say this is p by 2 and this is p by 2.So, if you cut open a section and see…Subjected to axial force n naught and subjected to moment,m naught and p by 2 is acting somewhere here. Let us say a variable of phiand let us say this angle is alphaand the shear flowand of course, this is r. And the shear stress per unit length qis p by phi R sine phi.There is ring modelfor t jointin compression, where it is more critical.So, we are examining the joint in compression.

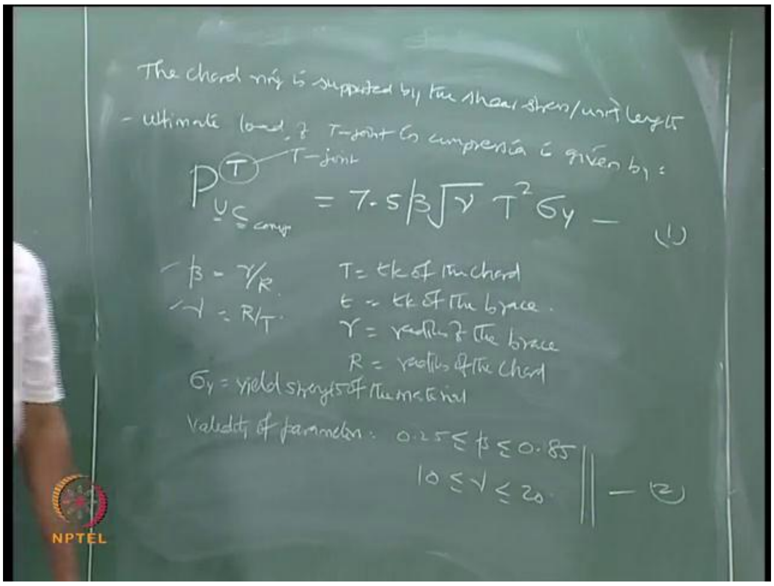
(Refer Slide Time:17:58)



Looking at this we can understand, the chord ring is supported bythe shear stress per unit lengthand we can say now,the ultimate loadof the T jointin compressionis given byP ultimate compression the T joint. Please remember, how I am writing it p stands for the load U stands for the ultimate,C stands for compression.I am looking for compression T stands for T joint, that is how the symbol states. Empirically this value is given by7.5 betamu T square sigma ywherebeta is R by R mu is R by t. Of course, sigma y is the yield value and t is the thickness of the chordand small t is the thickness of the bracesmall r is the radius of the braceand capital R is the radius of the chord and of course, sigma y is the yield strengthof the material.

So, for a given design or for a given combination of the brace and chord thickness in the diameter, you know all these values, butone can easily see that this equation based on empirical calculations or empirically ensured is not valid for a wide range of beta and muthere isis a limitation of this validity.

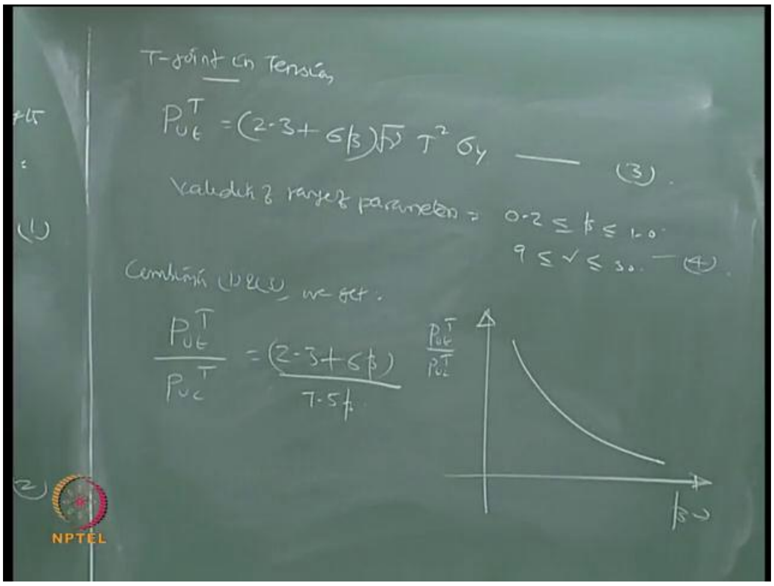
(Refer Slide Time:20:39)



So, validity of parameters.What are the parameters?A parameters are in this case beta and mu0.5less than beta less than 0.85and mu is 10 to 20.These are the validities call this as 2. So, empirical relationships will always get combined with the validity of application, in the design. To understand this, let us take 0.85 as beta. What does it mean, is the brace radius will be approximately over85 percent of the chord radius or can be as slow as 0.25 or25 percent of the chord radius. It is this equation, is valid only for the combination of R, you cannot have a very smalldiameter brace with a very large chord,cannot have this kind of a design, is that clear?

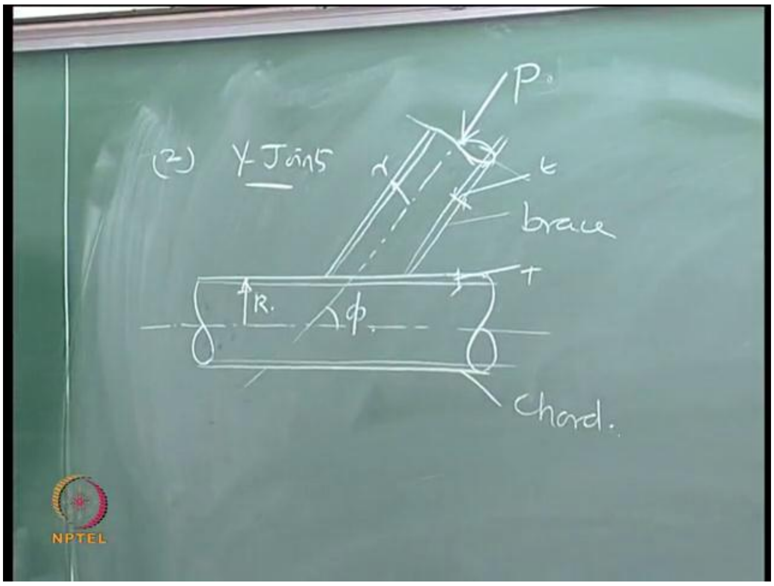
So, it is all combined with the specific relationshipsimilarly, even R by T is also combined. Can you tell me, why this R by T is very important here? Getting can you guess me, why R by t is important?R is that radius of the chord and t is the thickness of the chord. Why we are talking about Rby T, is here as I said in the beginning as for as failure of T joints and compression is concerned stability of the chord is also important. Stability of the chord in this case is an R by T value, right? That is why mu is important, this is for an empirical value which gives me the ultimate strength or ultimate load carrying capacity of a T joint, in compression obviously. Now we look for T joint in tension.

(Refer Slide Time:23:02)



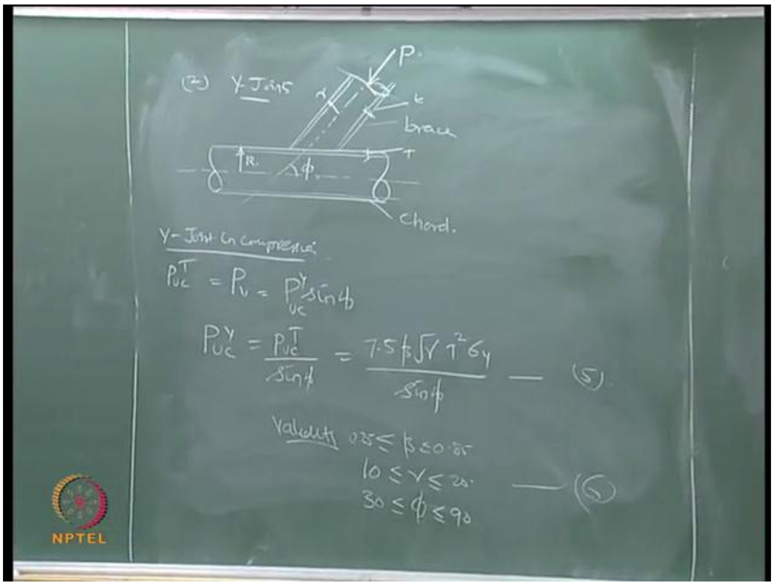
Remember the tension or compression is only the load applied on the bracenot on the chord.Meaning of expression remains still, for all this parameters the validity is changing.0.,0.21,0.0 and930.I will call this equation number 4,now combining two, sorry combining one and three,we can get one is here and there is here. So,I can write an expression which saysP u t T by P u c T, yes2.3 plus 6 betaby 7.5,I can plot thisasP u t T by P u c T and this is betaand variations is like this.

(Refer Slide Time:25:35)



Let us talk about ultimate strength capacity of Y joints.Y joints can also be again in tension and compression depending upon what is the load applied on the braceis the typical Y joint.This is what we call as a brace,this is what we call as chord,this is mythickness of the chord,the radius of the chord as this thickness of the brace,this is I say small t. This is I say capital T, this is I say small r and this angle is phi.So, let us say thisis subjected to compression or tension,let us say P.

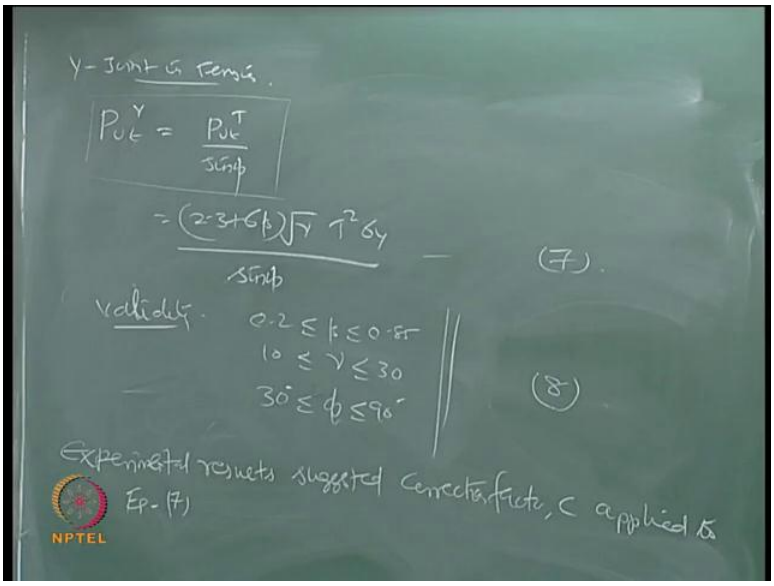
(Refer Slide Time:27:32)



Now,Y jointsin compressionY joints we may get typically as same as T joints, provided I convert this force or the load applied on the joints to the normal to the direction of the axis of the chord.I just equally convert this to normal to the axis of the chord again. Apply whatever equation you had for t joints directly to knowY joints also, in that case I should say equivalent forcewhich isP, vertical yes.Psine phi is it not vertical force,I can call this as P u c Y. u stands for ultimate, c stands for compression, this y stands for not yield this is Y joint. Now,I can say P u c Y can be simplyP u Tu c of Tby sine phi.

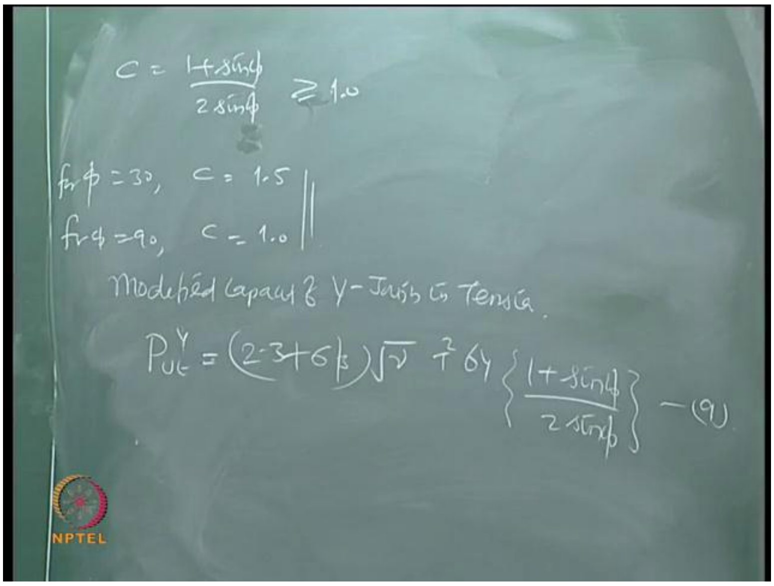
This is nothing butP u c on T, soP u c of T already we know, in tension or in compression. We already know this equation, we can substitute that, what is the value in compression for a T joint? It is 7.5 betaroot mu T squaresigma Y bysine phi,equation number5. The validityof the parameters 0sorry 0.25,0.85 is for beta 1020 is for mu and for phi it is 3090, equation number 6.

(Refer Slide Time:30:20)



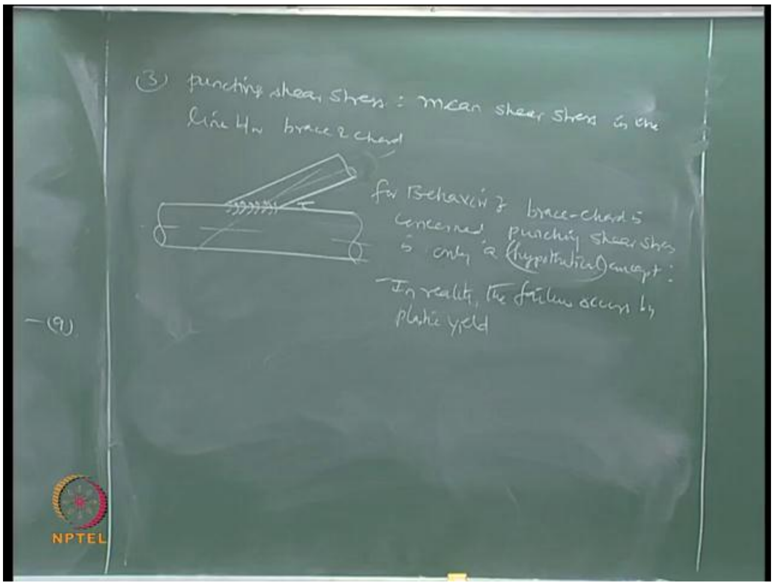
Now,I want to look for Y jointin tension.so,I must substitute. Let us sayP u TY that is 10side is p u t T by sine phicorresponding tension.What is this equation? We already have it with us this 2.3 plus 6 b plus 6 betaroot muT square sigma Yby sinephi and validity I call this equation number 7and validity2.8510 to30 and 30 to 90,equation 8. Now,experiment have shown that the T joints as Y joints in tensionhas slightly higher capacity.Therefore, what I apply a correction factor to it, so experiment is results suggested correction factor c applied to equation 7. What is the correction factor?So, c is nothing but1 plus sin phi by 2 sin phi which is a function ofthe angle phi which the inclination of the brace, with respect to the axis of the chord.

(Refer Slide Time:33:02)



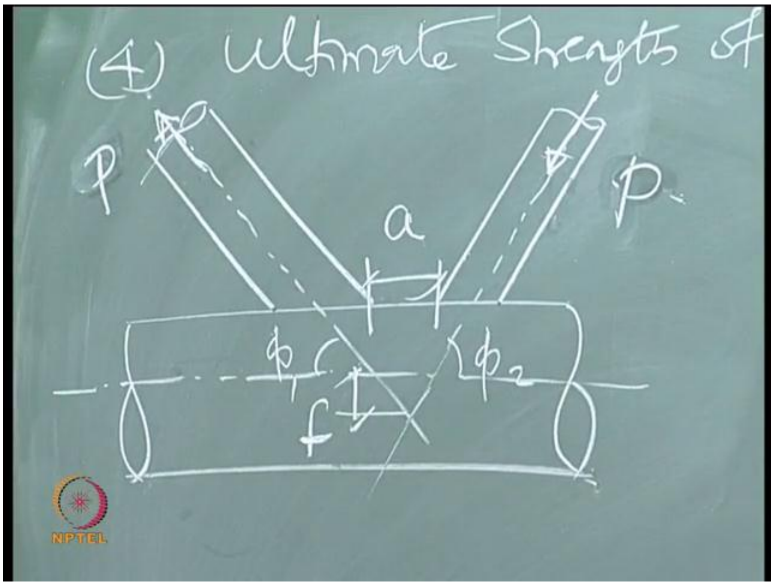
Which is always greater than one.Therefore, for phi of range of 30c, can you give me what is this value1.5? Is it not?And for 590 is 1, is it not?That is the validity of c therefore,the modifiedcapacityof y jointsin tension can be P u TY. It is2.3 plus 6 betaroot muP square sigma y1 plus sine phiby 2 sine phi to multiply this correction factorequation.

(Refer Slide Time:34:56)



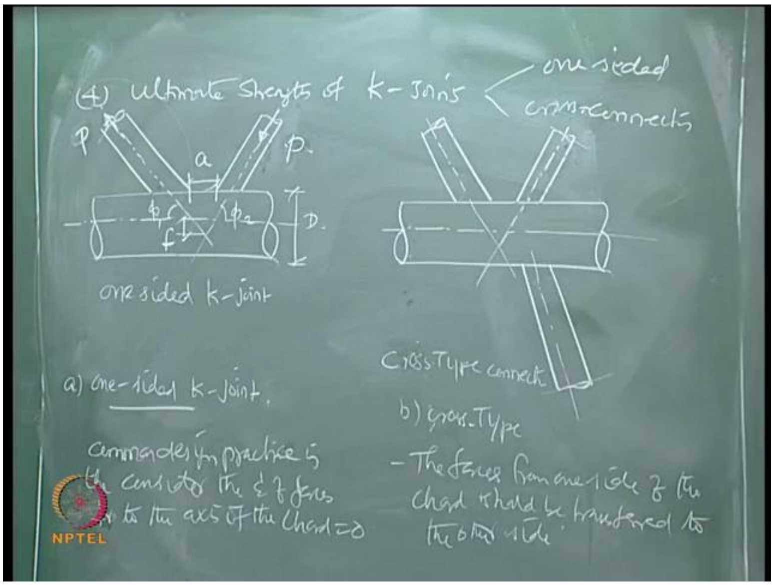
There is something calledpunching shear stress, which applies at the junctions of the brace and chords, it is actually nothing butthe mean shear stressin the line,which is betweenthe brace and the chord.If you look at the figurethis is my memberpunching shear stress, will act at this junctionwithout… Then as far as the behaviorof bracechord is concerned,the punching shear stressis only a conceptin realitythe failure occurs by plastic yield.Let us look at ultimate strength of K joints.

(Refer Slide Time:37:23)



K joints are two types of connection,one is called as a one sided connection,other is called as a cross connectioncall this as phi1,this as phi2, may be this is intension,this can be in compressionand the gap between themis what I call as a and existence between the intersection of the braces with that of the axis of the chord is what I call as f, and it is the chord diameter capital D. And of course, it is a brace diametersD1 and D2 will talk about, that why D1 and D2 are not very important.We will either consider D1 or D2,we will see why? This is what we call, one sidedK joint.

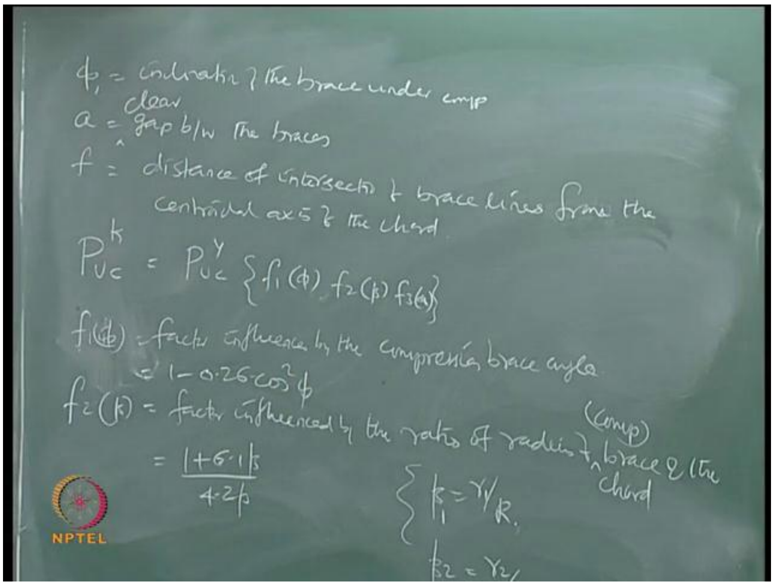
(Refer Slide Time:39:29)



Now, something called cross connection, where the connection looks like this.It is calledcross type connection.Let us first look at the one sided connection,in a one sided of connection, you can always see that both the brace are connected to one side of the chord,where as in cross type it isthe other way. It is extending the other side and the previous discussionson Y and Tjoints, we have already seen that both of them are very critical as far as compression is concerned,when the compressive force applied to the brace, that they govern. Actually the design strength compared to that of strength of the intension, so we will not consider this brace subjected to tensile forces.

We will talk about this brace subjected to compressive force, so for common design practiceisto considerthe summation of the forcesnormal to the axis of the chordto be 0.In the cross type instead of saying do not say x type, it is cross type.Very specific cross connection because x type is another joint, in the cross typethe forcesfrom one side of the chord should be transferredto the otherside,that is the design principle. HereI make a small modification in this figure,please note it carefully.

(Refer Slide Time:43:15)



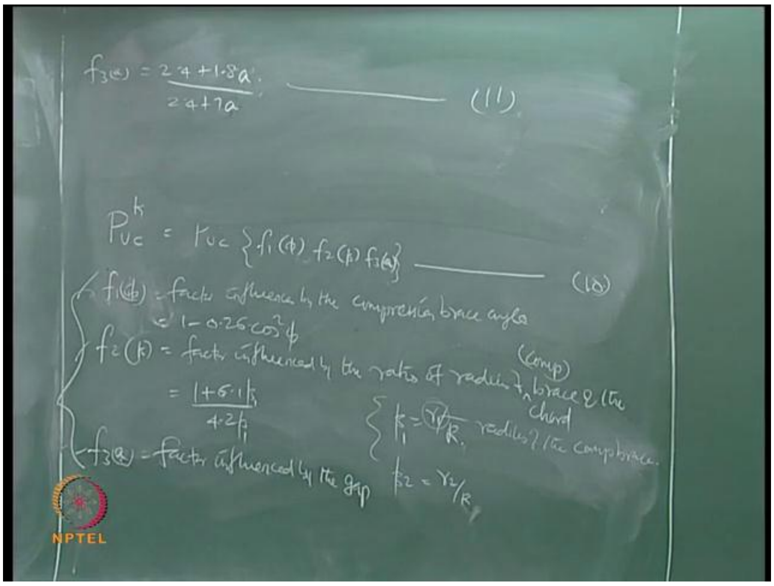
I say that, let the angle of inclination of the brace,which is having compression is phi1 is having intension is phi 2. So,phi1is the inclinationof the braceunder compression a is the gap between the braces.Some literature saythis has as a clear gap also you can do it anyway is a clear gap between the braces.This is af whichis the distance ofintersectionof brace linewith or from the centroidalaxis’s of the chord.This is here,so experiments conducted on this kind of joints, in case of one sided Kjoint, it showed very clearly, that the failure is essentially governed by the compressive force.

Therefore, they say the ultimate strength in compression of a K jointis similar to the, that of a ultimate strength on compression of an Y joint because I am ignoring the tensile brace. It is like a Yjoint provided,I multiply this with certain factors which aref 1 of phimultiplied by f 2 of betamultiplied by f 3 of a. Now, you can easily see f 1 of phiis a factor influenced bythe compressionbrace angle. Remember that compression brace angle, which is given by1 minus 0.26 cos square phi.I am using phi here,I am neither using phi 1 nor phi2. We can always say compression brace strictly speaking in association to this figure,I must use phi1 here,it is angle of inclination of the compression brace.

So,I must use phi1 there, f 2 of betais the factorinfluenced bythe ratio ofradiusof braceand the chord the moment I say.Brace I must say here, compression bracewhich is equal to,if you have got 2beta’s, what is beta? It is r by R, is it not betais actually r by R.

r is a radius of the brace and R is the capitalized radius of the chord. So,I can say simply beta 1 is r one by R1and beta 2 is r 2 by there is only 1 r,where r 1 is radius of the compression brace.So,I must write here r 1 where as this is,so focus only on the compression brace. So,I get phi 2 beta as 6 point. Now,I can clearly write this as beta 1 and beta Y for our clarity.The third factoris influenced by the gap,I will write it here.

(Refer Slide Time:48:55)

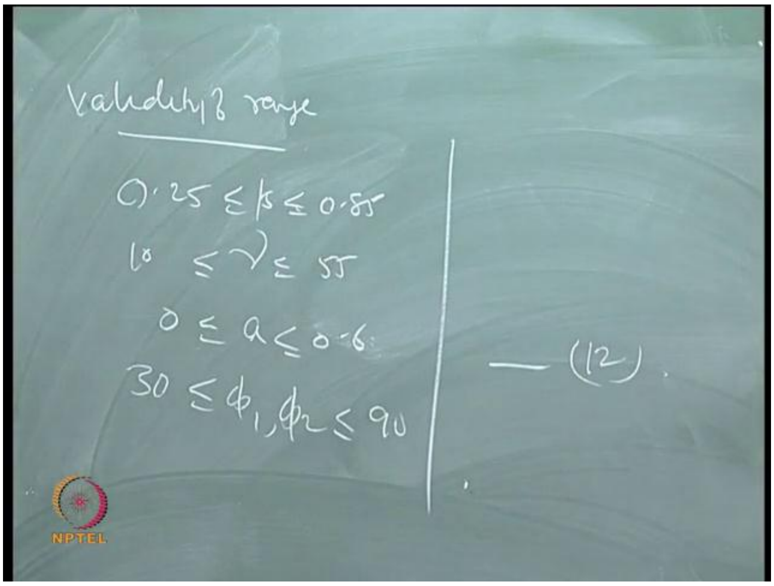


This is a not g,this is what f 3 g is.I can make it as a there is no g make it as a, make it as a we call the gap as a. So, these are empirical formulas will give you, let me call this equation number will it be 8 or and all these 3 equation’s,10. All these 3 equation’s put together,I call them as11.So, in this lecture we discussed about the ultimate strength capacities of various joints. We understood that compression brace is governing thedesign. Why we are not looking for analytical model or analytical behavior of these kind of joints because the failure is a combination of plastic yield, as well as stability problems into the compression.

The moment we have stability problem, we have got p m interaction, we already saw in the last lectures. That whenever you have caught combine combination of loads than the effect of one on the other is influencing.Therefore, different theories say the different kinds of failure can occur. Therefore, extensive experimental conducted by researchers in therecent past and they suggested lot of empirical values with the validity of the ranges, which is given by the researchers. So, what we are giving here, is a summary of them, so that, so as designer you can directly use them, butstill there is a lot of scope for research and finding out the real behavior.

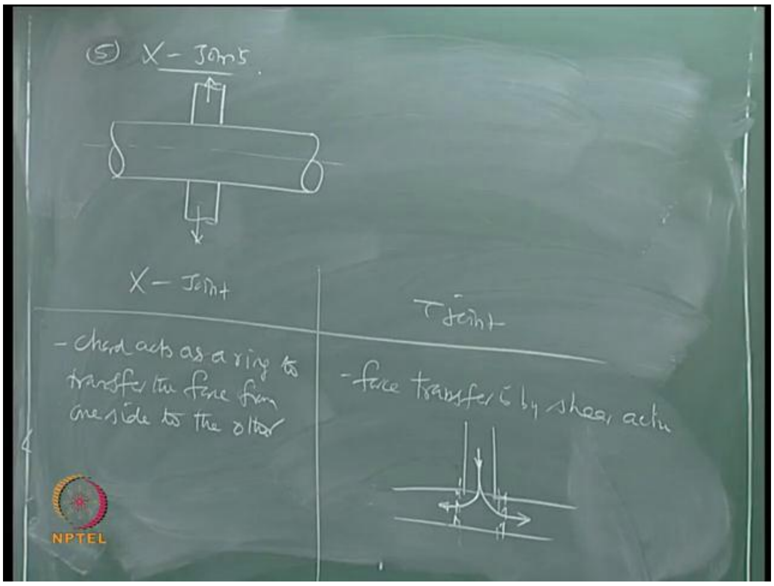
Analytically numerically and experimentally validating them for different kinds of joints for different parameters as beta, mu, g etcetera or a etcetera.There are lot of scope available, butas a designer we are now said to be using these equation. So, in the next lecture,we will discuss about one of the type of joint, then we will move on to fluid structure interaction very quickly,orfor few minutes we can complete that also in this lecture.

(Refer Slide Time:51:37)



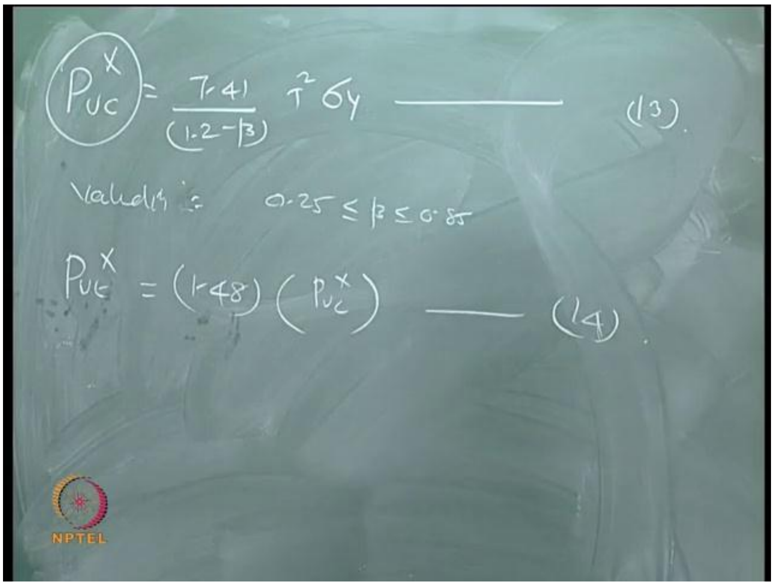
Talk about the validityof range of the parametersbeta is from 0.25to 0.85 muis from 10 to 55a is from 0to 0.6 andthe brace angles 30 to 90, these are validities, which I call them as equation number12. These are all for your K joints,let us talk about X joints.

(Refer Slide Time:52:46)



X joints look like this.v v both of them tensile, both of them compressive, there is a fundamental behavior difference betweenan X joint and anT joint because T joint you may see a connection is only on one side and the X joint has got two. Is it not?Let us highlight this difference, will stop then. We will speak up about the strength capacity in X joints essentially the chord acts as a ringto transferthe force from one sideto the other, this acts as a ring actually, where as in T joints, the first transferis by shear.So, shearsoff the moment it comes it transfershere.If shears offhere, the force transferred is where shear action, so there is a resistance of your both sidesoccurthat is the fundamental difference between an X jointand the T joint in behavior.

(Refer Slide Time:55:06)



Therefore the ultimate strength ofX joint in compressionsigma Y, you can call this equationnumber,what is the number?

Student: 13.

Whereas the validity0.25,0.85 and the ultimatestrength intention of an x joint is simply a factor of 1.4a tobe multiplied with P u c X.So, we can very well see here in most of the experimental results,itis been observed that the ultimate strength of any joint be it Y. Be it T, be it X, be itK, the strength is slightly highercompared to that compression,that is why compressive force governs the design of tubular joints because, the failure is a combination of plastic hinge formation, with that of the stability in case of T joints as per...And you always see in case of Yin case ofK there equivalently converted to T,then one can wonder what is difference between a T joint with that of X joint?

Where the brace is taken the other side of the chord also, in that case here the behavior is the caller the chord acts only. As the collar or ring just to transfer the force, where as in this case the chord fails wereshearthat is a difference.Now, it is for your academic interest to compare which joint is better? If you want to provide a joint, what joint would better?Of course, it depends essentially on, what is the functional requirement? Whether you want to have brace on all the sides, want to brace only one side etcetera. Other than that, you can always compare. So,this comparison has been done and available in beautiful in the literature, can see that how they vary interms of it is strength.

This ends, this lecture on first module, so in the first module we have covered elaborately starting from different forms andfunctions of the shore structures and marine structures different materials used environmental loading coming on them. What are the uncertainties involved in them? How uncertainties are handled?For example, like incorporating hydrodynamic admittance function etcetera, then we spoke about plastic analysis and design lower bound and upper bound theorems kinematic and static theorem. On the other hand we compare them, we did problems on beams on frames, then we also find out what is actually the safety part involved in plastic design compared to that of conventional design.

And how to estimate that from problem, we did some numerical examples to understand them, how to pickup the highest or the lower bound values. How both the theorems are important? Then what is the uniqueness theorem,which is a combination of these two,then we studied about the even theories of failure. And we understood in detail, what would be the significance of estimating sigma y as my yield strength or at failure,then we spoke about the capacity of joints in terms of… And we also studied fundamentals concepts of impact analysis on marine structures. So, this end the discussions on first module,the next lecture will pickup lectures on second module.

Thank you.