Offshore structures under special loads including Fire resistance
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Module – 03
Fire Resistance
Lecture – 53
Design Approach- II

Friends, we will continue to discuss the design approach for fire resistant design as applicable to offshore structures in lecture 53, in module 3 titled fire resistant design.

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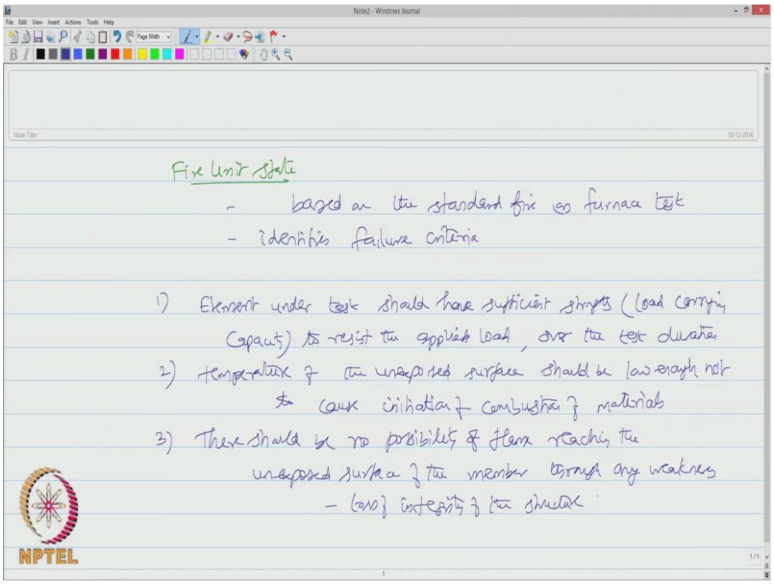

So, as continuation we know that fire limit state is based on the standard fire or of furnace test. So, this actually identifies different failure scenarios or failure criteria; one element under test should have sufficient strength or what we call as load carrying capacity to resist the applied load over the test duration, temperature of the unexposed surface should be low enough not to cause irritation, initiation of combustion of materials. Thirdly, there should be no possibility of flame reaching the unexposed surface of the member through any weakness; the weakness can be loss of integrity of the structure, faulty construction, excessive deformation etcetera.

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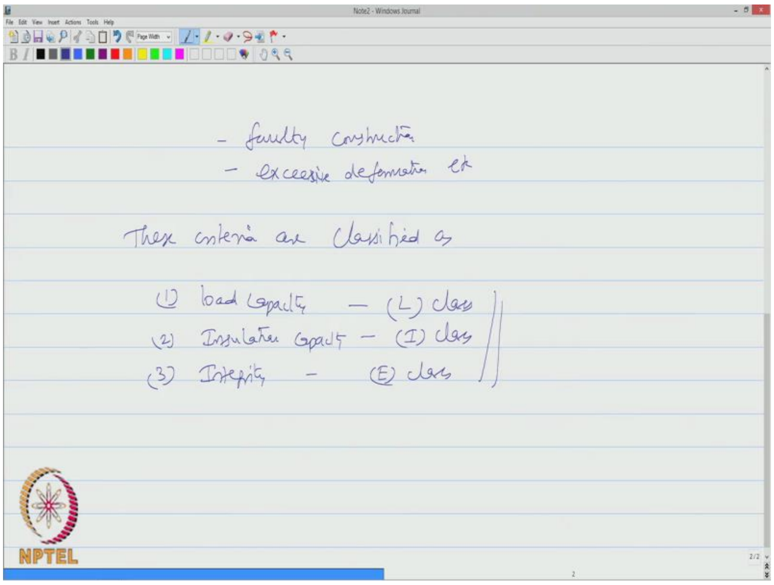

Now, these criteria are classified as one the load capacity which is identified as L class; second the insulation capacity identified as I class and thirdly the integrity capacity which is identified as E class, let us see these capacity or load classes separately one by one in detail.

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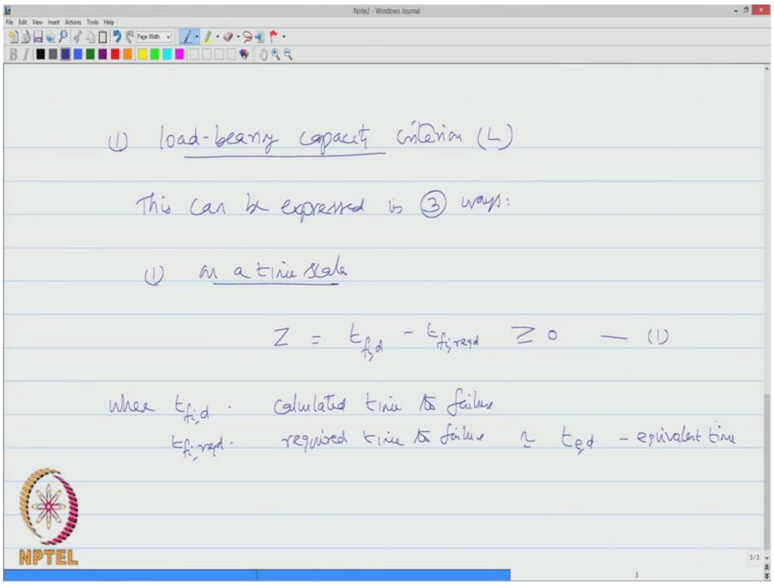

Let us start with the load bearing capacity criteria, this can be expressed in 3 ways namely on a time scale that is Z is equal to t f i d minus t f i required should be greater than or equal to 0, where t f i d is the calculated time to failure, t f i required is the required time to failure, which will be approximately equal to t e comma d which is called equivalent time.

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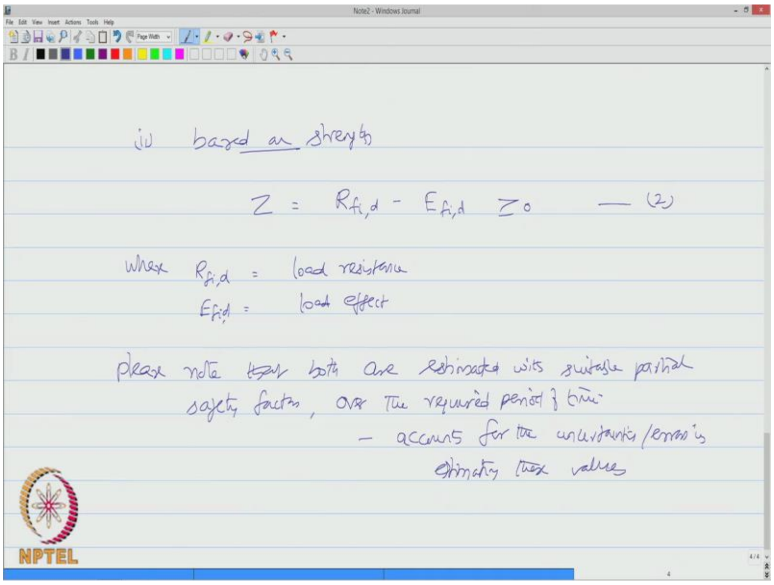

So, one can estimate the capacity based on the time scale, alternatively one can estimate also based on strength Z is R f I, d minus E f I, d which should be greater than 0; where R f I, d is the load resistance and E f I, d is the load effect. Please note that both are estimated with suitable partial safety factors over the required period of time, which accounts for the uncertainties or errors in estimating the values.

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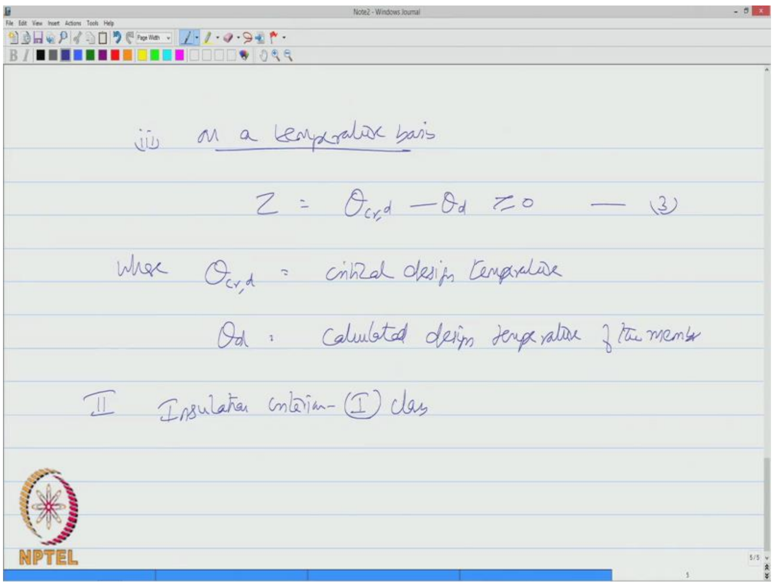

The third could be on a temperature basis. So, Z is theta c r d minus theta d, which should be greater than 0; where theta c r, d is the critical design temperature and theta d is the calculated design temperature of the member. The second criteria could be insulation criteria which is I class.

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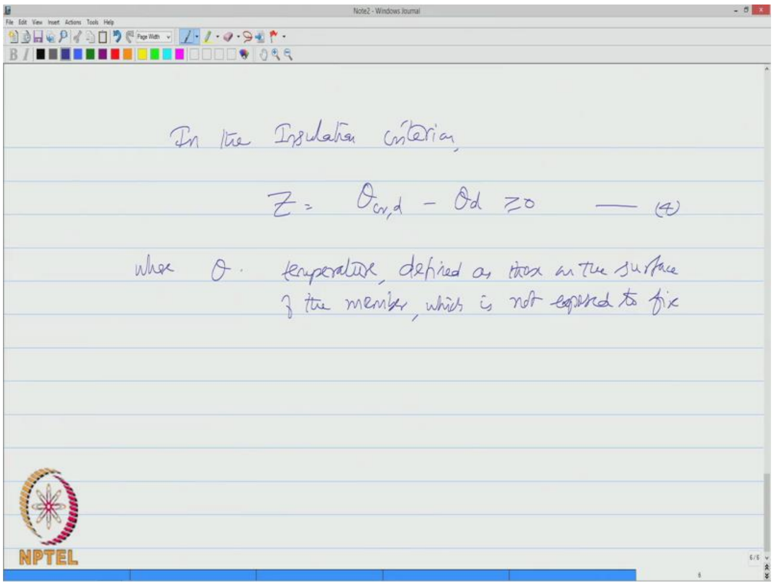

In the insulation criteria Z can be expressed as theta c r, d minus theta d greater than 0 where theta is the temperature defined as those on the surface of the member, which is not exposed to fire.

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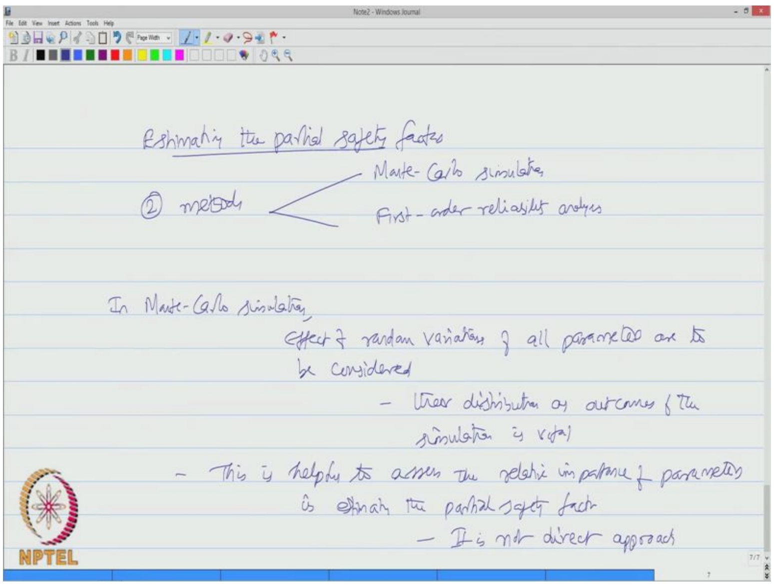

Now, the question comes how will you estimate the partial safety factors? Estimate of partial safety factors to account for uncertainties, in estimating the fire load as well as strength at elevated temperature needs to be addressed because they are very complex phenomena. There are two ways by which we can do this: one is by a Monte-Carlo simulation, the other is by First-order reliability analysis.

In Monte-Carlo simulation the effect of random variable are random variations of all parameters are to be considered. In fact, the distribution as outcomes of the simulation is vital, this is helpful this method is helpful to assess the relative importance of parameters in estimating the partial safety factor it is not a direct approach.

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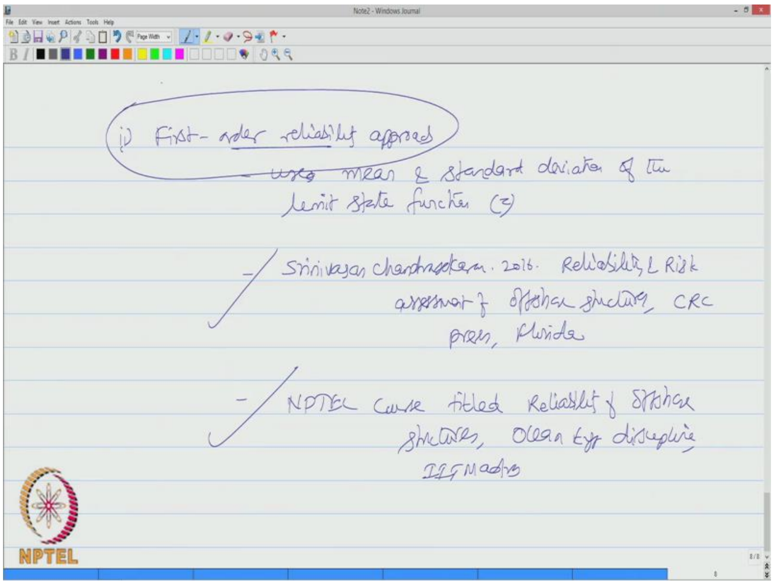

Whereas, the first order reliability approach uses mean and standard deviation of the limit state function Z. One can know more about this in the book titled reliability and risk assessment of offshore structures authored by me and published by CRC press Florida, one can also look into an NPTEL course titled reliability of offshore structures offered by ocean engineering discipline at IIT madras.

So, please look into these two references in detail to know more about the first order reliability approach as applicable to conventional design procedures.

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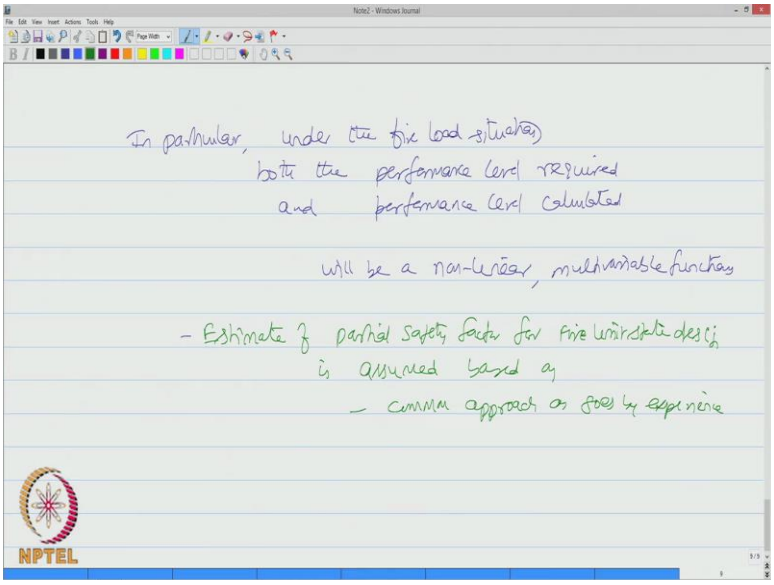

In particular, under the fire load situation both the performance level required and the performance level calculated will be non-linear multi variable functions therefore, in general estimate of partial safety factor for fire limit state design is assumed based on common approach as driven or goes by experience.

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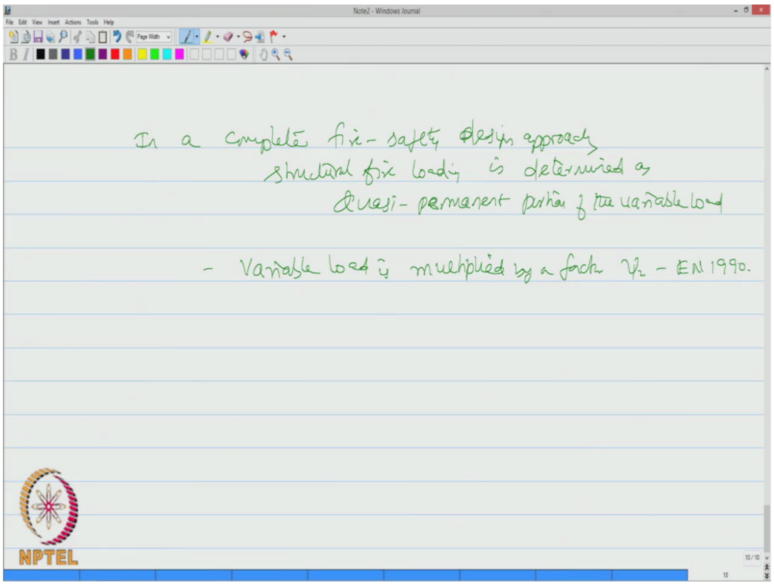

To be very specific in a complete fire safety design approach, structural fire loading is determined as Quasi-permanent portion of the variable, that is a variable load is multiplied by a factor psi 2 based on Euro code 1990.

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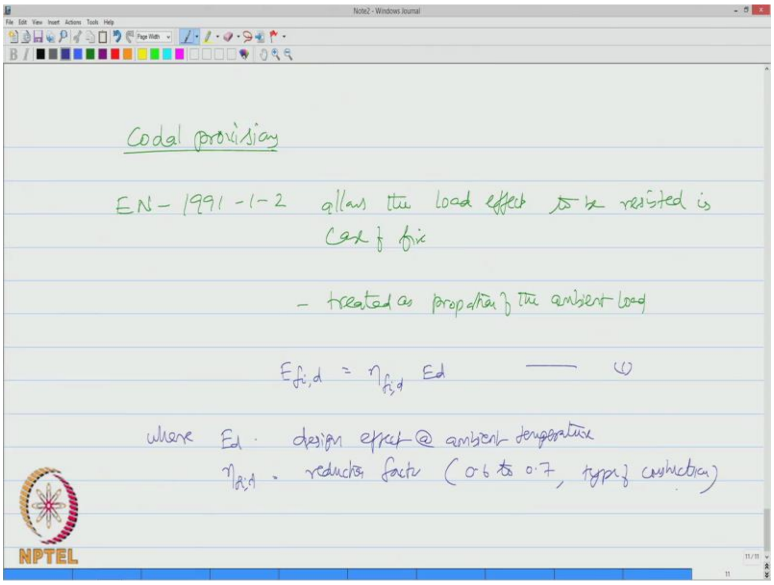

Now, let us see the codal provisions EN-1991 allows the load effect to be resisted in case of fire. This is treated as proportion of the ambient load E f i, d is taken as f i, d into E d where E d is the design effect at ambient temperature and eta f i d is reduction factor taken as 0.6 to 0.7 depending upon the type of construction being used.

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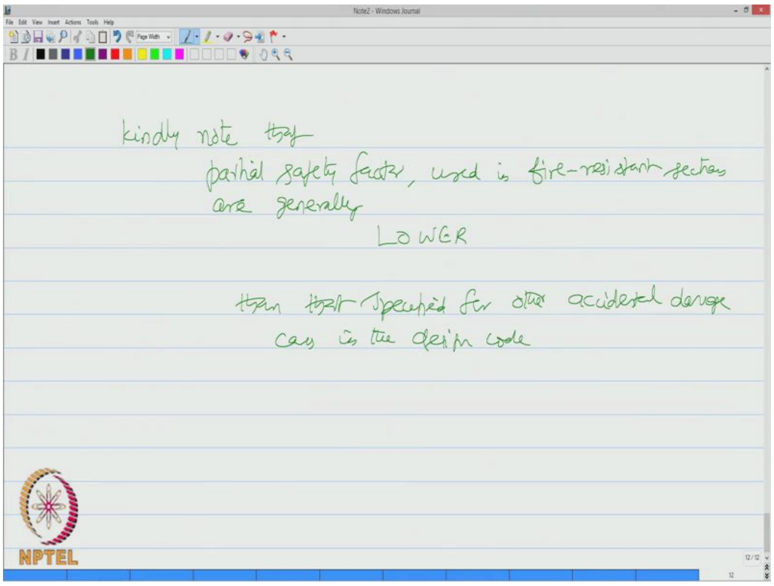

So, kindly note that partial safety factor used in fire resistant sections are generally lower than that specified for other accidental loads in the design code.

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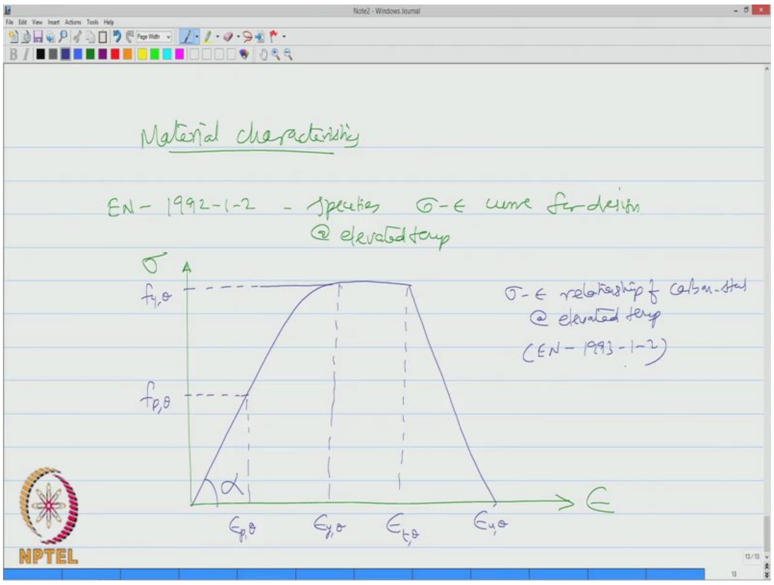

Now, let us look at the material characteristics. So, EN-1992-1-2 - specifies stress strain curve for design at elevated temperatures, let us try to look at this curve. So, this is my strain value my stress value, the typical curve looks like this and drops off. So, this is alpha, this value is what we call as f p theta and this value is E p theta and this value is specifically E y theta and this is of course, f y theta and this is strain t theta and this is strain u theta, typical stress strain relationship of carbon steel at elevated temperature as described by EN-1993-1-2.

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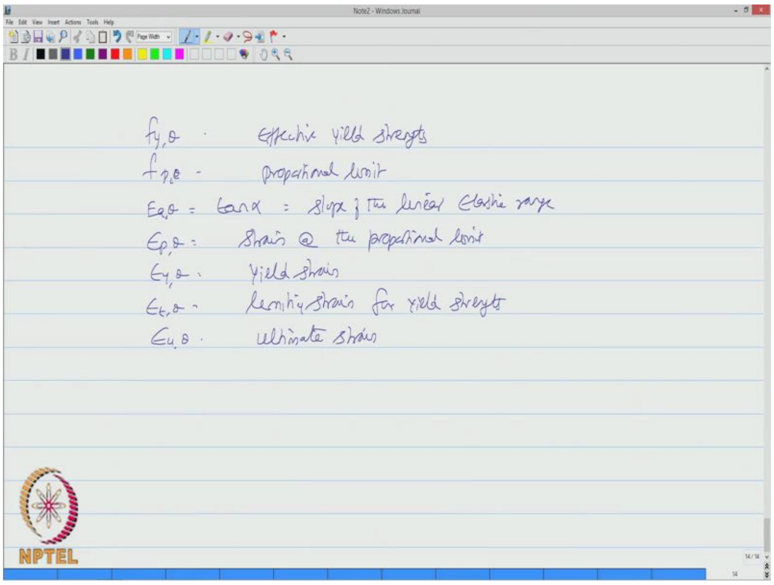

In this case f y theta is what we call as effective yield strength, f p theta is called the proportional limit, E a theta is tan alpha which is slope of the linear elastic range, epsilon p theta is the strain at the proportional limit, epsilon y theta is the yield strain, epsilon t theta is the limiting strength for yield strength and epsilon u theta is the ultimate strain.

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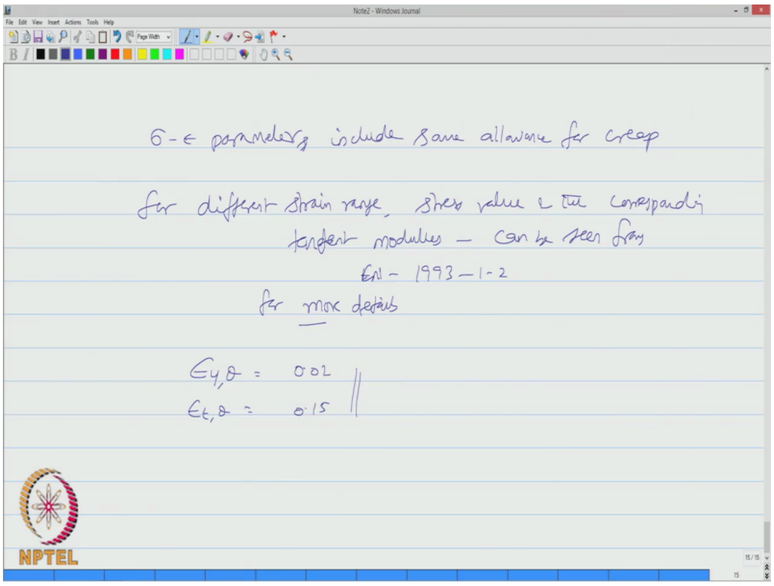

Now, the strain parameters including the stress strain parameters, includes some allowance for creap and for different strain ranges the stress value and the corresponding tangent modulus can be seen from the euro code for more details, for understanding epsilon y theta is limited to 0.02 and epsilon t theta is limited to 0.15, these are the upper limits which are bounding the design for steel or material strain at elevated temperatures.

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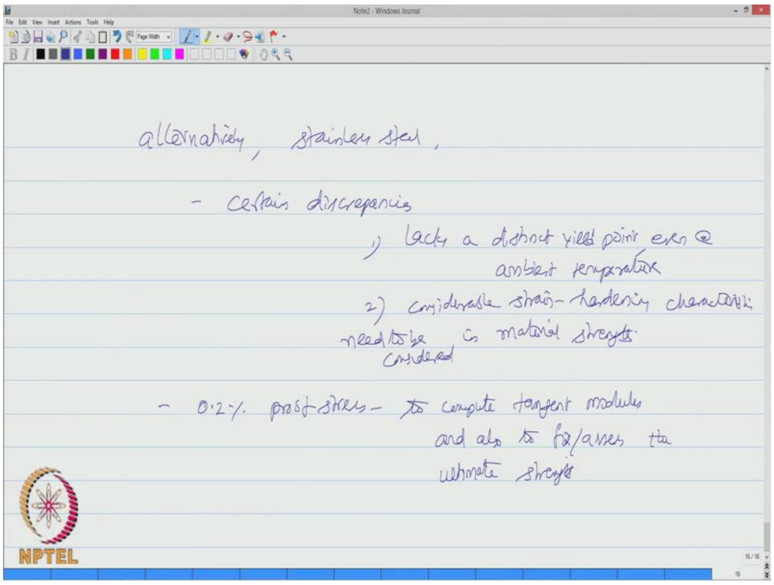

Alternatively people have used stainless steel also as a material for fire resistance, but stainless steel has certain discrepancies: one it lacks a distinct yield point even at room mean temperature, two it has of course, considerable strain hardening characteristics which need to be accounted for in the material characteristics in the material strength. So, in such cases as we all know 0.2 percent proof stress is used to compute the tangent modulus and also to fix or asses the ultimate strengths.

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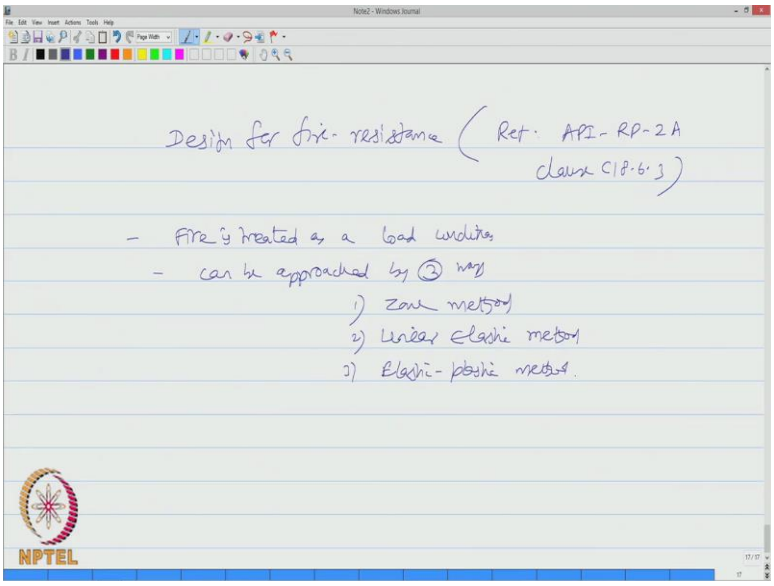

Finally if you talk about the design approach specifically for fire resistance, one can also refer to API-RP-2A to a specific clause 18.6.3 C 18.6.3. In this class fire is treated as a load condition and can be approached by 3 ways: one a zone method, two linear elastic methods and three elastic plastic methods.

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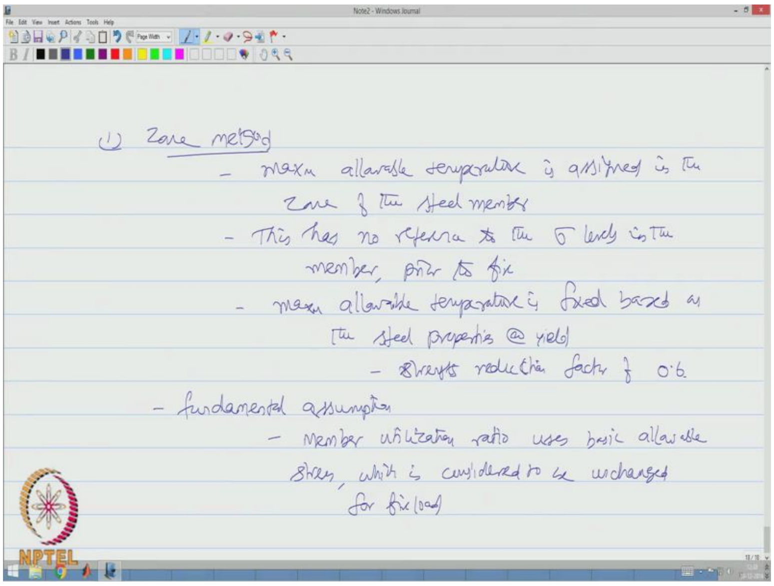

In zone method maximum allowable temperature is assigned in the zone of the steel member, this has no reference to the stress levels in the member prior to fire. So, the maximum allowable temperature is fixed based on the steel properties at yield, with a strength reduction factor of 0.6. This method has a fundamental assumption; the fundamental assumption is that member utilization ratio uses the basis allowable stress, which is considered to be unchanged for fire.

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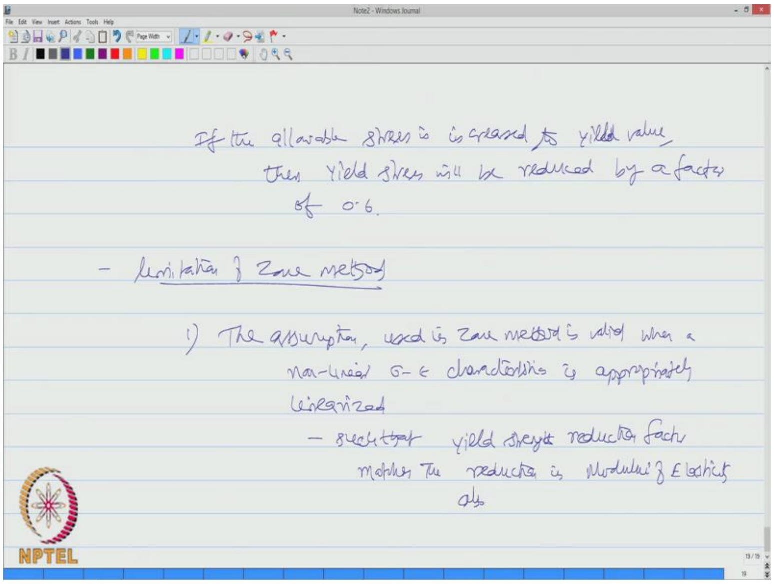

Therefore if the allowable stress is increased to the yield value, then yield stress will be reduced by a factor of 0.6, there are some limitations of zone method: one the assumption used in zone method is valid when a non liner stress strain characteristic is appropriately linearized such that the yield strength reduction factor matches the reduction in modulus of elasticity also.

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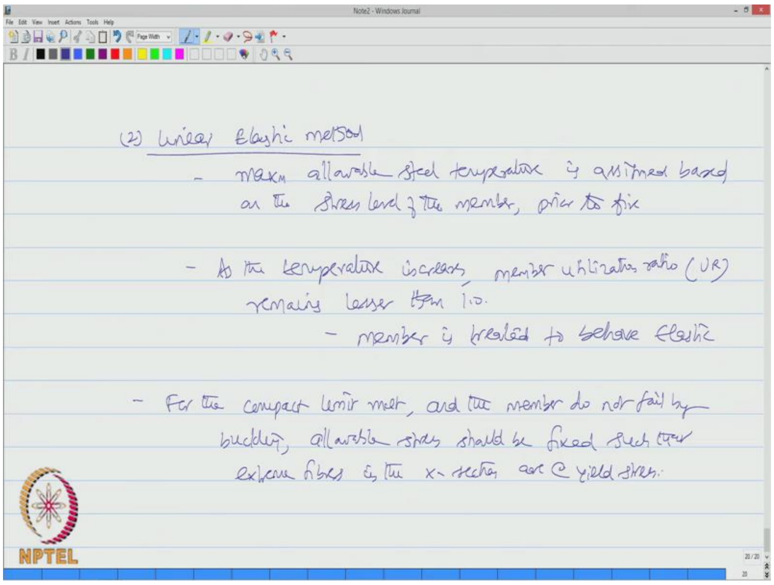

The second method is linear elastic method; in this method maximum allowable steel temperature is assigned based on the stress level of the member prior to fire therefore, as the temperature increases, member utilization ratio which is UR remains lesser than 1; that is the member is treated to behave elastic. For the compact limit met and the members do not fail by buckling, the allowable stress should be fixed such that extreme fibers in the cross section are at yield stress.

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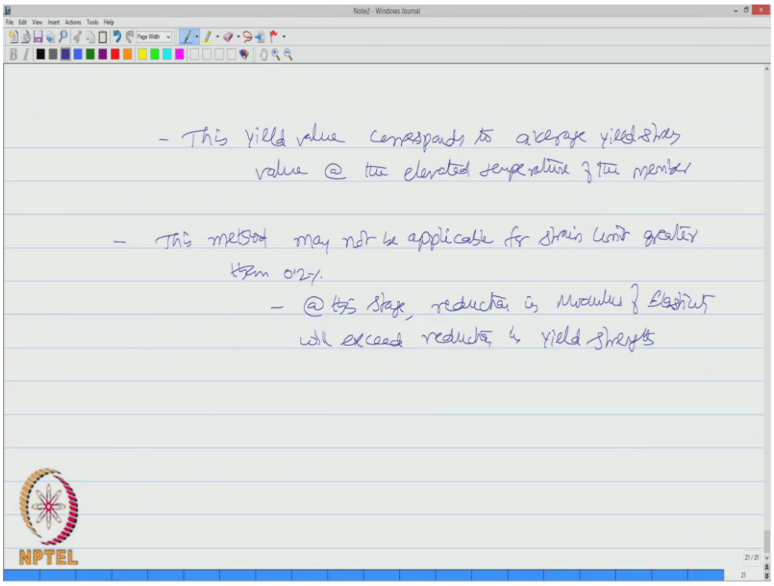

Now, this yield stress value corresponds to the average yield stress value at the elevated temperature of the member. This method may not be applicable for strain limit greater than 0.2 percent. Because at this stage reduction in modulus of elasticity will exceed reduction in yield strength and there will be no one to one correspondence, the correspondences need to be there because this is an elastic design.

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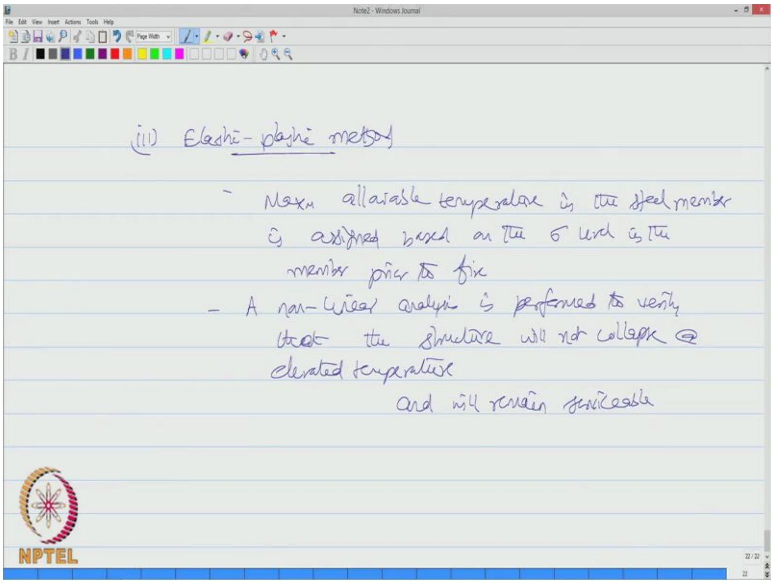

The third case is elastic plastic design; in this method maximum allowable temperature in the steel member is assigned; based on the stress level in the member prior to fire, but a non liner analysis is performed to verify that the structure will not collapse at elevated temperature and will remain serviceable.

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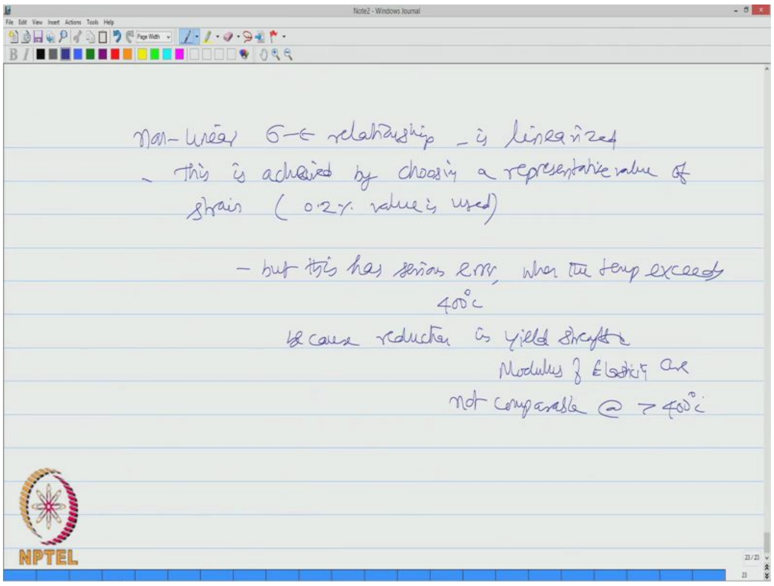

So, interestingly a non-linear stress strain relationship is linearized, this is achieved by choosing a representative value of strain typically 0.2 percent value is used, but this has serious error when the temperature exceeds 400 degree celsius because reduction in the yield strength and modulus of elasticity are not comparable at temperature exceeding 400 degree.

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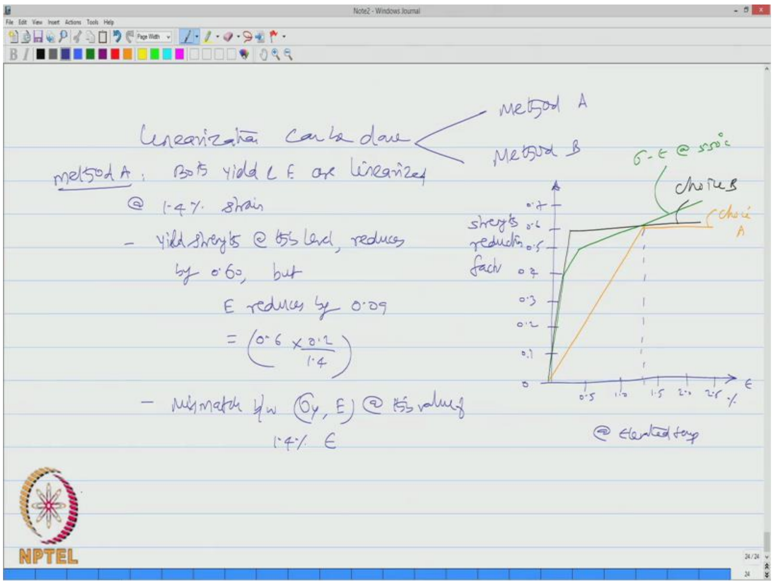

So, linearization can be done by two ways: let say method A and method B. So, the typical stress strain curve looks like this, this is test and curve at elevated temperature. So, this is percentage strain and this is the strength reduction factor starting from 0.1, 0.2 0.3, 0.4, 0.5, 0.6, 0.7.

Typically choice b the value is here, 0.5, 1.0, 1.5, 2.0 and 2.5; typically choice B goes till 0.6 and then remains horizontal whereas, choice A goes to 1.3 and then goes horizontal whereas, the real behavior follows up to 0.4 the same modulus, then deviated till 0.5 then goes ahead and then crosses, this is the stress strain relationship at 550 degree celsius. Let us quickly see what is the choice A or method A of seven both yield value and modulus of elasticity are linearized at 1.4 percent strain. So, this value is close to about 1.4, but yield strength at this level reduces by factor of 0.6, but Young’s modulus reduces by 0.09 that is 0.6, 0.2 by 1.4 therefore, there is a mismatch between Young’s modulus and yield strength, but at this value of 1.4 percent strength.

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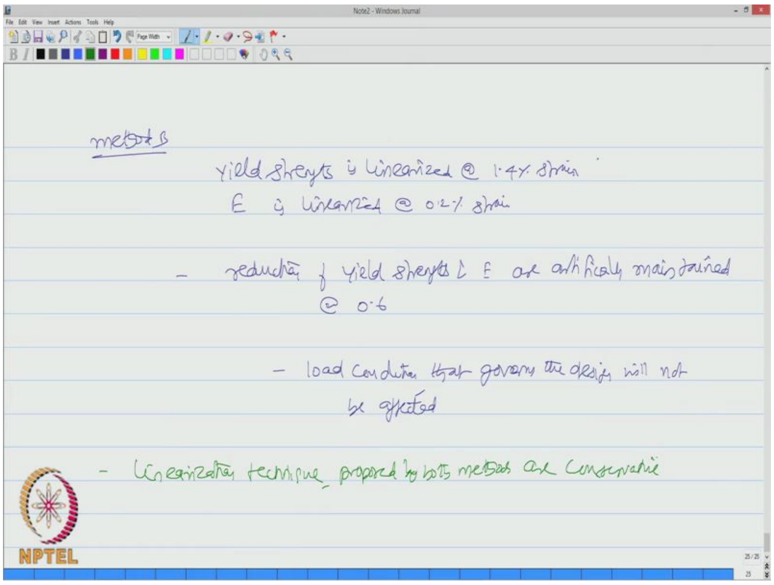

If you look at method B, yield strength is linearized at 1.4 percent strain and Young's modulus is linearized at 0.2 percent strain. So, reduction of yield strength and Young's modulus are artificially maintained at 0.6. So, that will load condition that governs the design will not be affected, but there is a common note between both the methods linearization technique proposed by both methods are conservative, this you can easily see when you compare it with the actual system behavior shown in green color in the curve.

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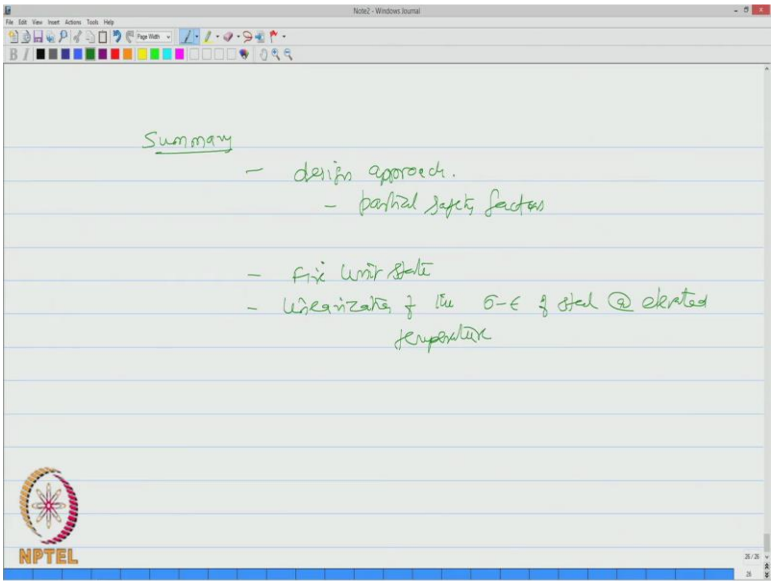

So, friends in this lecture we discussed about the design approach. We discussed about the partial safety factors that account for uncertainties, we also discussed about the fire limit state, we discussed about the linearization of the stress strain behavior of steel at elevated temperature and we realized that the governing equations used in compromising the Young's modulus reduction and yield strength reduction by appropriating choosing either method A or method B, give you conservative statements when you compare this with the real stress strain behavior relationship of steel at 550 degree centigrade. So, the partial safety factors account for these kinds of uncertainties of material characteristics of elevated temperatures, which is used and recommended in fire limit state design procedure in Euro codes.

Thank you very much.