Offshore structures under special loads including Fire resistance
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Module - 03
Fire Resistance
Lecture - 49
Material Strength III

Friends, we will continue with the discussion on material strength and the characteristics variations of steel as a material under elevator temperatures in lecture 49, title material strength 3, under module 3; fire resistant.

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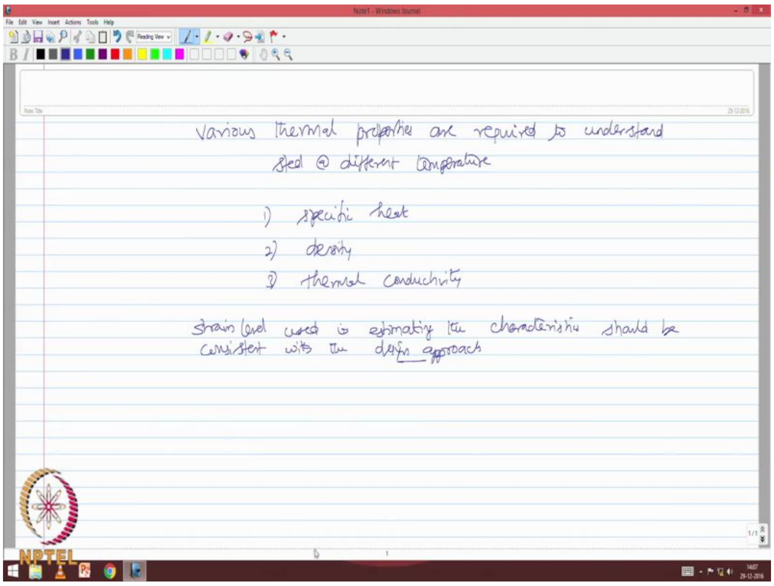

We already said that various thermal properties are required to understand steel at different temperature. For example, we should look at a specific heat, the density and thermal conductivity. We also said that the strain level used in estimating the characteristics should be consistent with the design approach.

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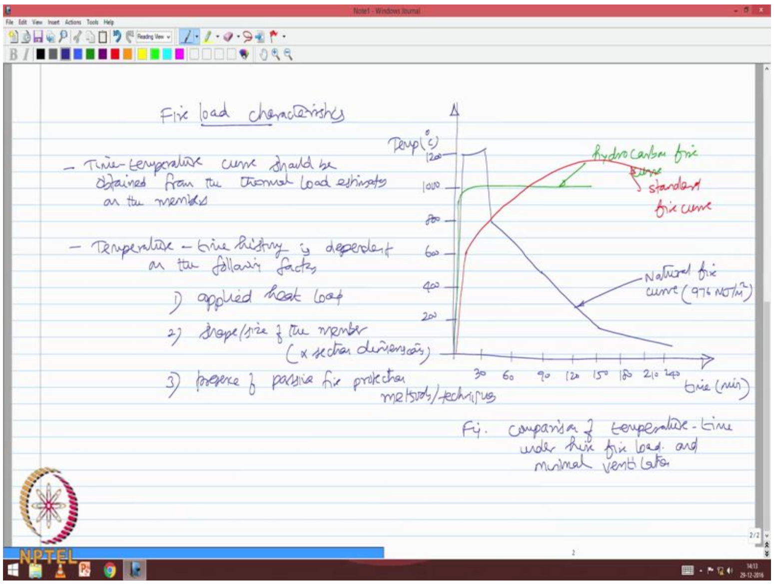

Let us try to look at the fire load characteristics to understand steel characteristics at elevated temperature, let us try to plot a variation of temperature in degree Celsius versus time in minutes for different fire curves, let us say a natural fire curve, let us try to mark these points 200, 400, 600, 800, 1000, 1200, let us say 30, 60, 90, 120, 180, 210, 240. So, the natural fire curve has a behavior similar to what I am marking here. So, this is actually natural fire curve which emits heat of 976 mega joules per square meter, let us see the how the hydro carbons curves vary, this affects the hydro carbon fire curve and of course, the standard fire curve takes a deviational 600 and goes non-linear, this is the standard fire curve. So, the time temperature curve should be obtained from the thermal loading estimates on the building.

One can see from here the temperature time history is dependent on the following factors, one it depends upon the applied heat load, two it also depends on the shape and size of the member including cross sectional dimensions, it also depends on the presence of passive fire protection techniques. So, this curve shows a comparison of temperature time under high fire load and minimal ventilation.

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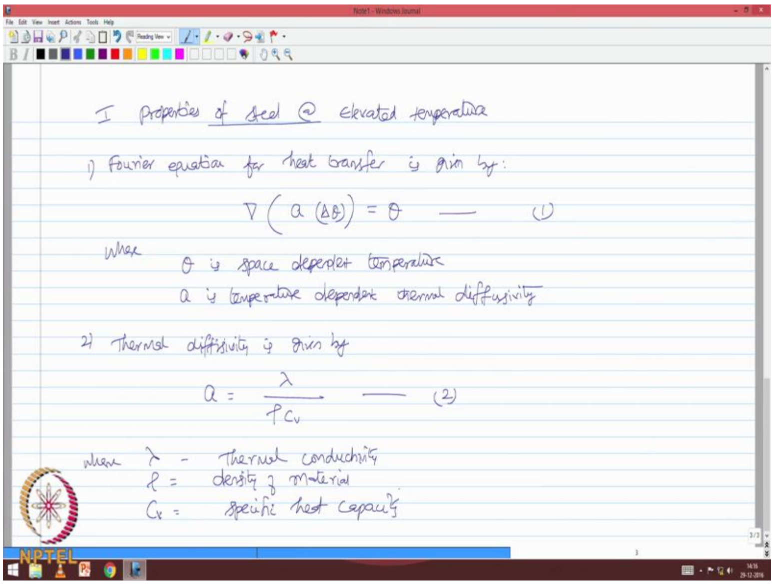

Where the idea of this, let us try to now understand properties of steel at elevated temperatures, the Fourier equation for heat transfer is given by this expression as seen in equation 1 where theta is space dependent temperature, a is temperature dependent, thermal diffusivity. Thermal diffusivity is given by this equation where lambda is thermal conductivity, rho is the density of the material and C v is specific heat capacity.

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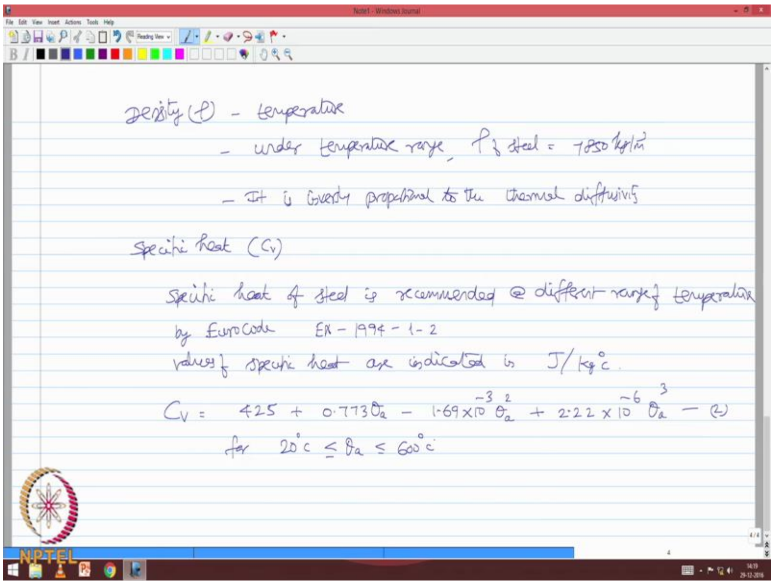

Let us see what is the role of density in elevated temperature, it is interesting that under normal temperature range density of steel is 7850 kg per cubic meter whereas, it is inversely proportional to the thermal diffusivity, let us talk about the next parameter which is specific heat which is indicated as C v, specific heat of steel is recommended at different temperature range by euro code E n 1994 1 2 values of specific heat are indicated in joules per kg degree Celsius. So, specific heat is given by a relationship as we are expressing this is true for theta a lying between the range 20 degree and 600 degree Celsius.

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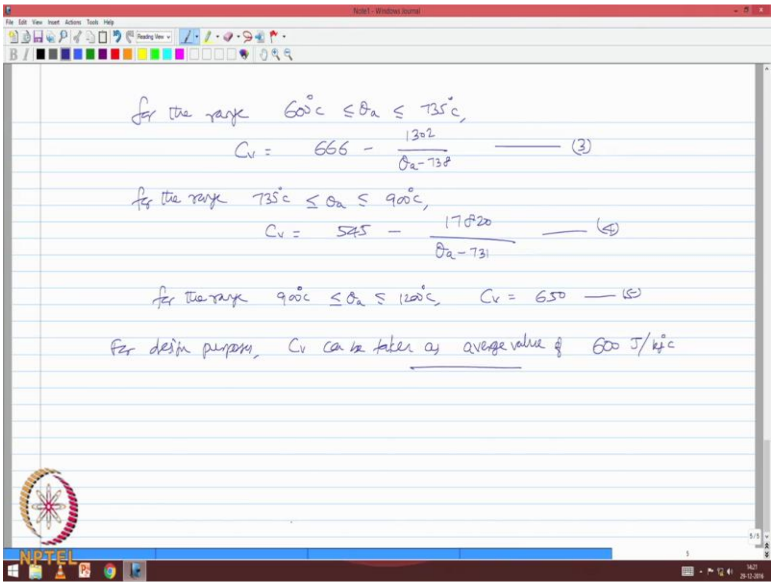

For the range 600 degree and 735 degree Celsius, C v is given by this equation and for the range 735 degrees and 900 degree Celsius, C v is given by this equation and for the range 900 and 1200 degree Celsius, C v is constant in the values 650; however, for design purposes C v can be taken as average value of 600 joules per kg degree Celsius.

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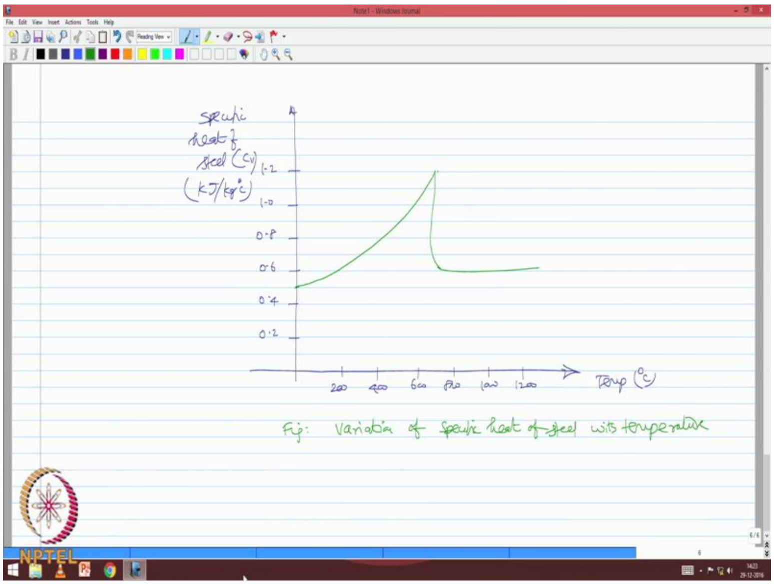

One can also look at the variation of specific heat with temperature. So, this is temperature in degree Celsius and this is specific heat of steel which is C v in kilo joules per kg per degree Celsius, the value touches 700 and 1.2 starting from 1.5 and it is (Refer Time: 16:14) variant and then at this point it drips off to 0.6 and stays horizontal. So, this is figure showing me a variation of specific heat of steel with temperature.

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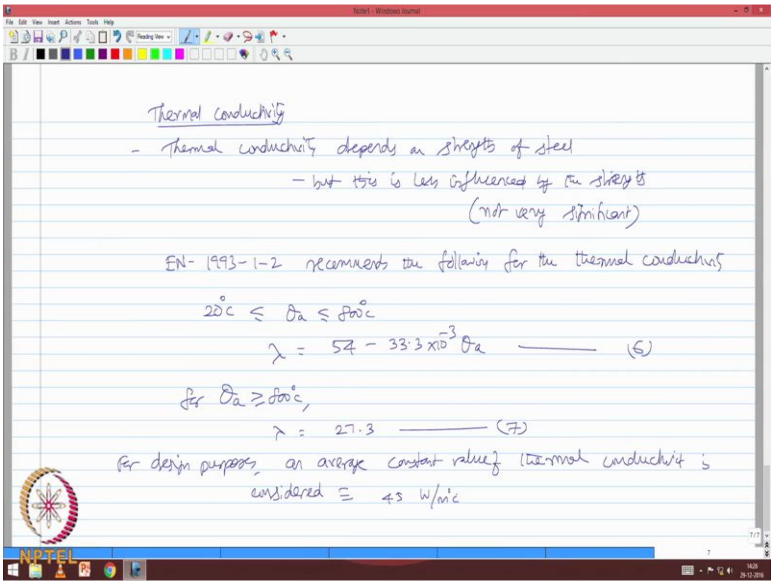

The next important property which effects the fire loading on steel is thermal conductivity; thermal conductivity depends on strength of steel, but this is less influenced by this strength, it is not very significant; however, euro code 1993 1 2 recommends the following for the thermal conductivity for temperature range between 20 degree to 800 degree Celsius, a thermal conductivity is given by 54 minus 33.3 into 10 power minus 3 theta, a for theta a greater than 800 degree Celsius, thermal conductivity is given as a constant value which is 27.3, for design purposes an average constant value of thermal conductivity is considered which is equal to 45 watts per meter second.

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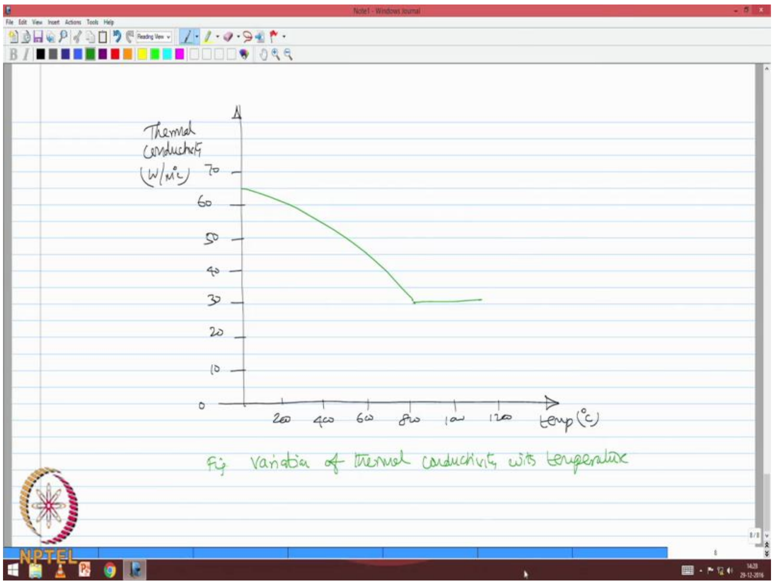

Let us try to look at the plot which shows a variation of thermal conductivity with temperature in degree Celsius and thermal conductivity of steel in watts per meter second degree Celsius, let say 0, 10, 20, 30, 40, 70 and temperature varies up to 1200 which shows that the variation is non-linear and then it becomes caste. So, this is variation of thermal conductivity with temperature.

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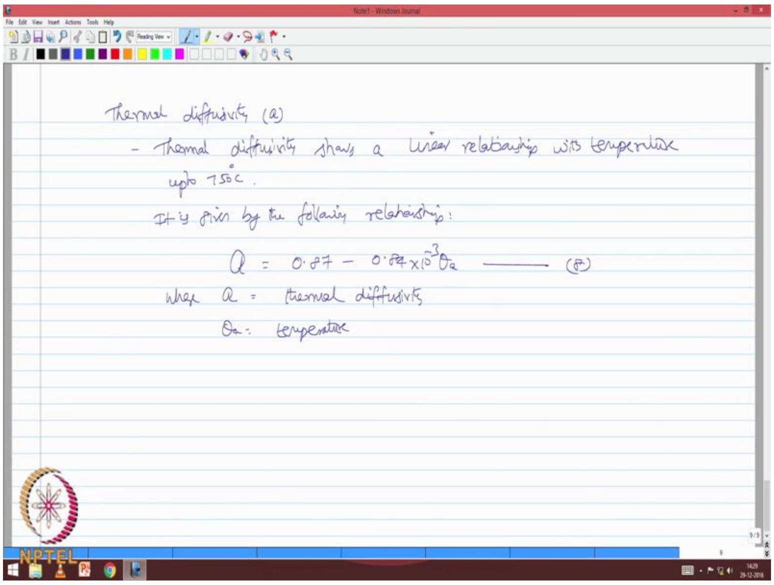

The next property is thermal diffusivity which is indicated as a, thermal diffusivity shows a linear relationship with temperature up to 75 Celsius, it is given by the following relationship 0.87 minus 0.84 into 10 power minus 3 of theta a, where a is thermal diffusivity and theta a is temperature equation number 8.

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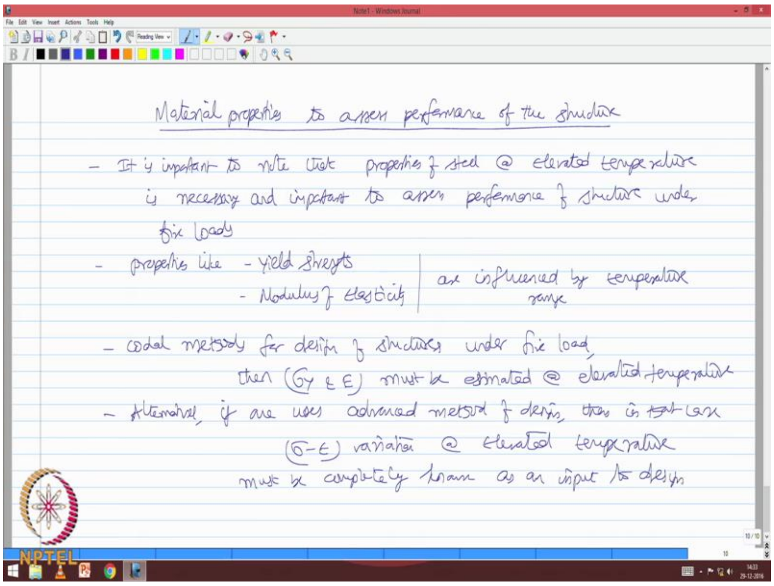

Let us try to look at the material property to assess performance of the material or the performance of the structure, it is important to note that properties of steel at elevated temperature is necessary and important to assess performance of structure under fire loads because properties like yield strength modulus of elasticity are influenced by temperature range. So, if we look at any codal methods for design of structures under fire load then yield strength and Young's modulus must be estimated at elevated temperatures alternatively, if one uses advanced method of design then in that case, a stress strain curve variation at elevated temperature must be completely known for the designer.

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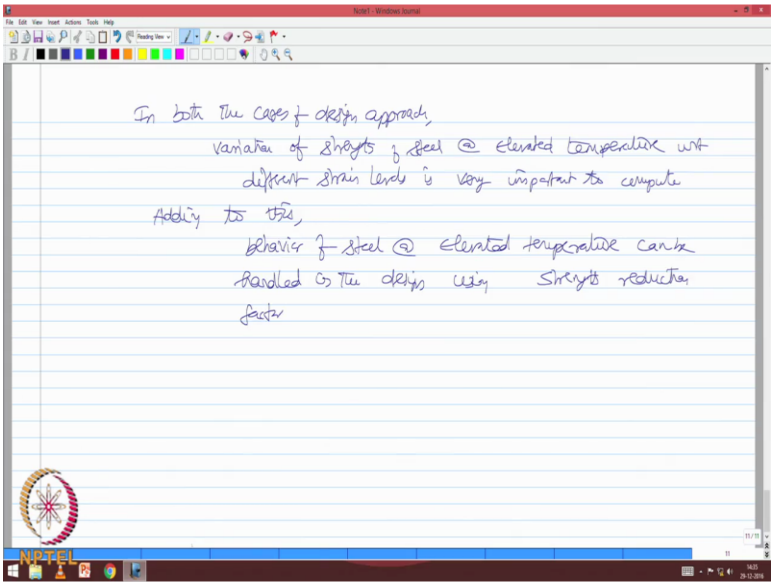

In both the cases of design approach, variation of strength of steel at elevated temperatures with respect to different strain levels is very important to compute add to this behavior of steel at elevated temperature can be handled in the design also using strength reduction factor.

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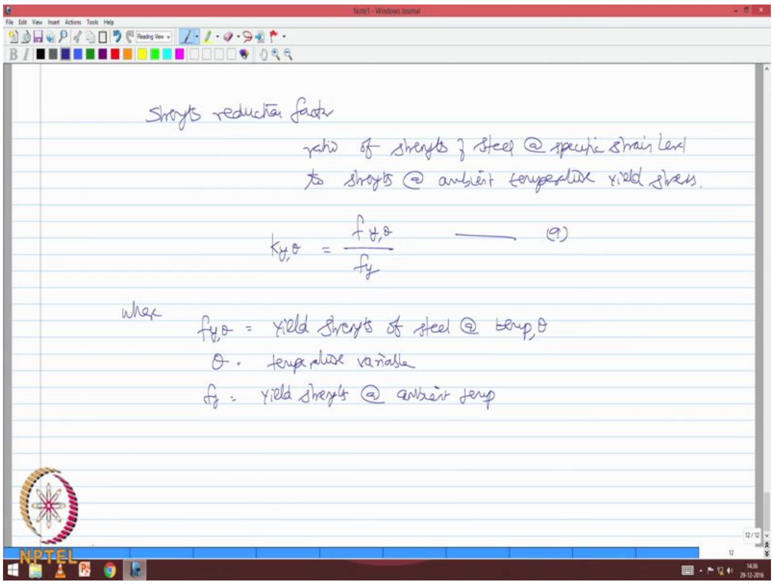

Then what is strength reduction factor? Strength reduction factor is actually the ratio of strength of steel at specific strain level to strength at ambient temperature yield stress. So, mathematically k y theta will be f y theta by f y where f y theta is the yield strength of steel at temperature theta, theta is the temperature index and f y is yield strength at ambient temperature.

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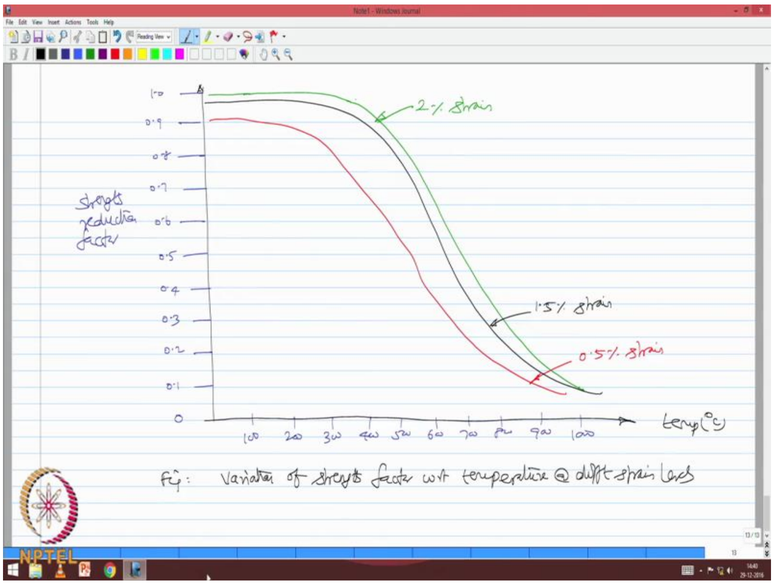

Let us try to look at this variation graphically, will try to plot a variation of strength reduction factor versus temperature let us say 0 to 0.1, 0.2 temperature variation is seen from 100 to 1000. So, let us try to plot this for different percentage strain level. So, to 401 and it drags down to 0.1 at 1000, this is for let us say 2 percent strain, I will try to plot it for 0.5 percent strain which shows a similar behavior for understanding, let us plot one more curve with 1.5 percent strain which is close to, now, this figure shows variation of strength factor with respect to temperature at different strain levels looking at this curve.

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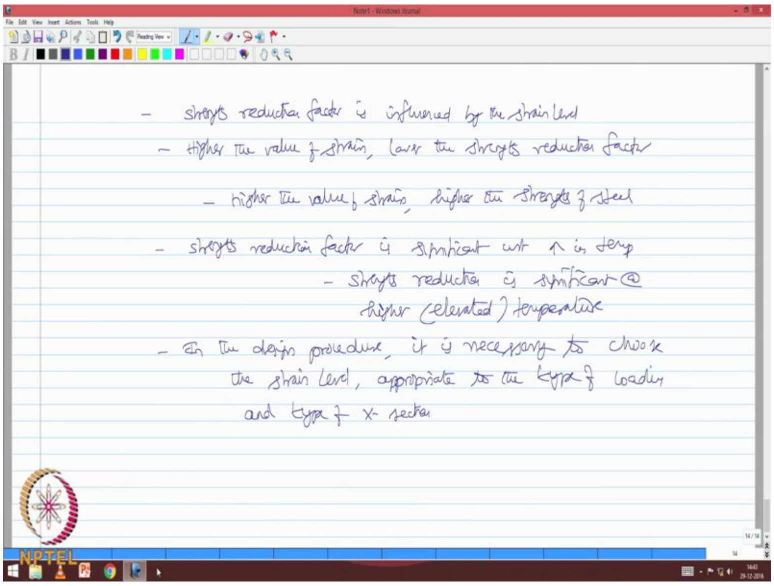

We can say that strength reduction factor is influenced by the strain level higher the value of strain lower is strength reduction factor that is higher the value of strain higher the strength, strength reduction factor is significant with respect to increase in temperature. So, strength reduction is significant at higher or let us say elevated temperatures. So, therefore, in the design procedure, it is necessary to choose the strain level which is appropriate to the type of loading and type of cross section.

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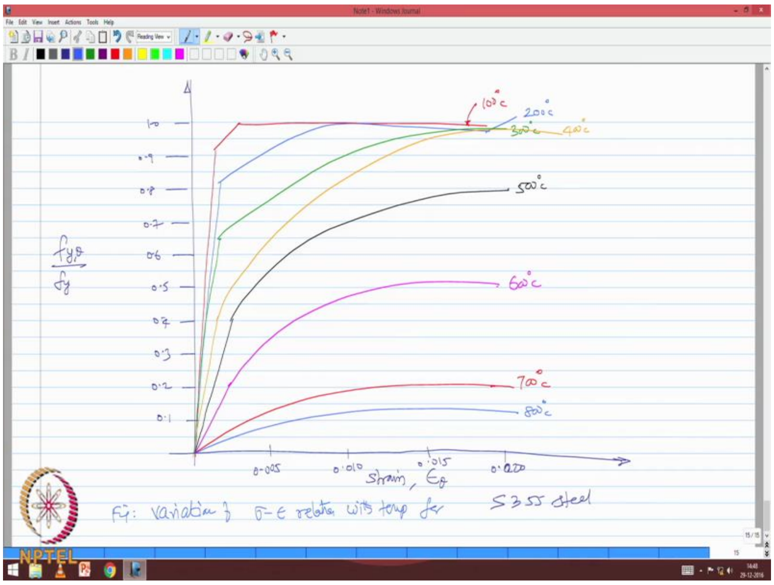

Let us take for example, the variation of let us try to plot a variation of f y theta by y that is strength reduction factor versus strain at various temperatures for s 355 steel, let us say 0.1 and the strain values of 0.005, 0.010, 0.015 and 0.020, will try to plot these for different temperature, let us say for 100 degree, the variation goes as close as shown in red mark in takes a tilt and becomes horizontal, if say this is for 100 degree Celsius, for 200 degree Celsius, the reduction stays at 0.8, starts from 0 and takes a bend and continue as this is for 200 degree Celsius, similarly for 300 degree Celsius, you start is 0.65, takes a curve, this is 300 degree Celsius and for 400 degree Celsius, it goes till 0.4, but the slope is different and then becomes non-linear and for 500, it stays at 0.4, but the value is reduced to 0.8, 0.2 then goes up, stays at 0.5 and at 700 degree Celsius, it stays at 0.2 and at 800 degree it stays at 0.1.

This could be the variation of stress strain relationship or strength reduction factor in sense with temperature for s 355 steel.

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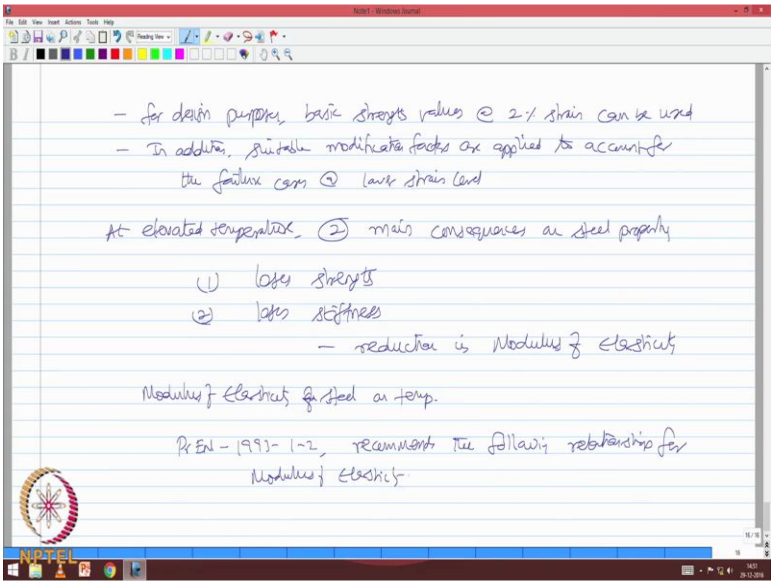

For design purposes, basic strength values at 2 percent strain can be used, in addition suitable modification factors are applied to account for the failure cases at lowest strain level.

At elevated temperature, there are 2 main consequences of steel on steel property, one it loses strength, two it also loses its stiffness which results in production in modulus of elasticity. So, let us now see the dependence of modulus of elasticity on temperature of steel on temperature. So, the draft version 1993-1-2, recommends the following relationship for modulus of elasticity.

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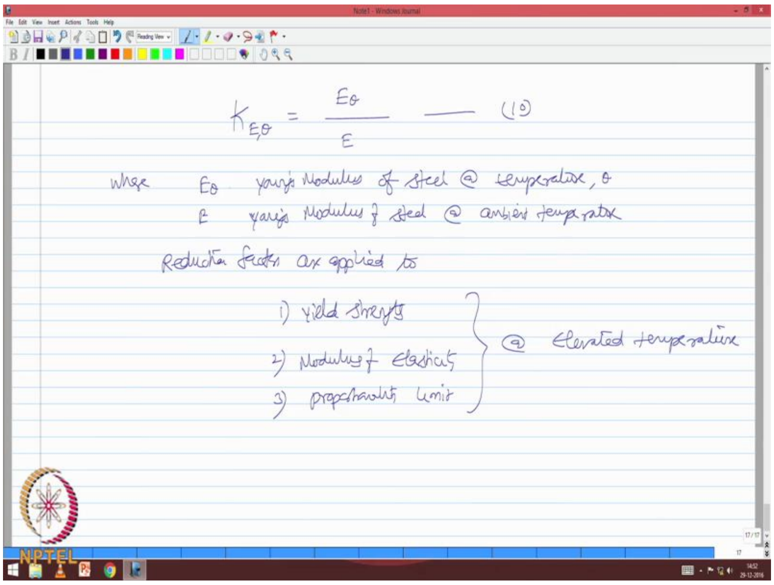

K E dependence theta is given by E theta by E where E theta is Young's modulus of steel at temperature theta at E is Young's modulus of steel at ambient temperature therefore, certain reduction factors are applied to yield strength modulus of elasticity and proportionality limit at elevated temperatures.

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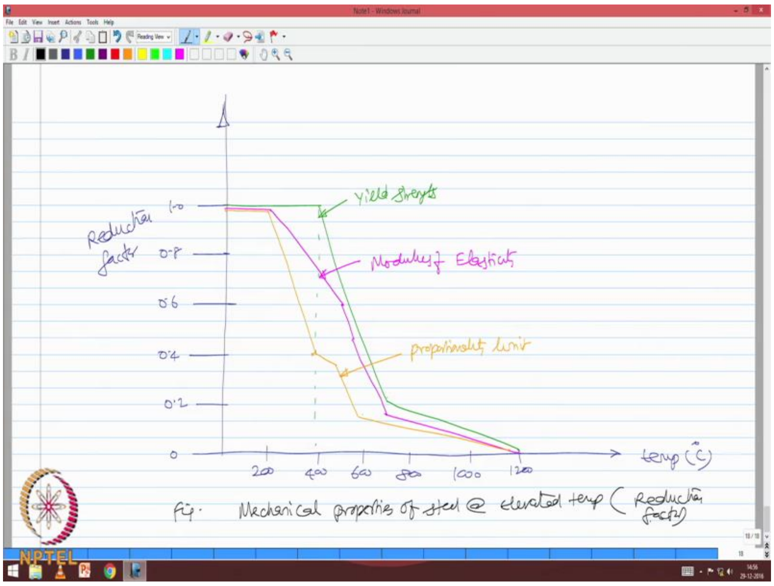

Let us graphically see how these variations influenced at elevated temperature for steel, let us try to plot the temperature dependence of these properties as a reduction factor which is temperature varies from 200 to 1200 yield strength, does not get reduced till

400 and then there is a linear drop at 2.2 then further drops 2000. So, that is my yield strength elastic modulus stays 0.6 and it is no variation till 200, then it drops, then it further drops at 600, then it further drops at 700, which comes to 0.1 and then goes to 0. So, this is my modulus of elasticity variation for steel at higher temperatures.

Proportionality limit has no change till 200 and drops to 0.4 at 400, further drops then further becomes steep at 0.1, at 600 then goes to 0. This is my proportionality limit. So, this curve shows important mechanical properties of steel at elevated temperature in the form of reduction factor as recommended by euro code.

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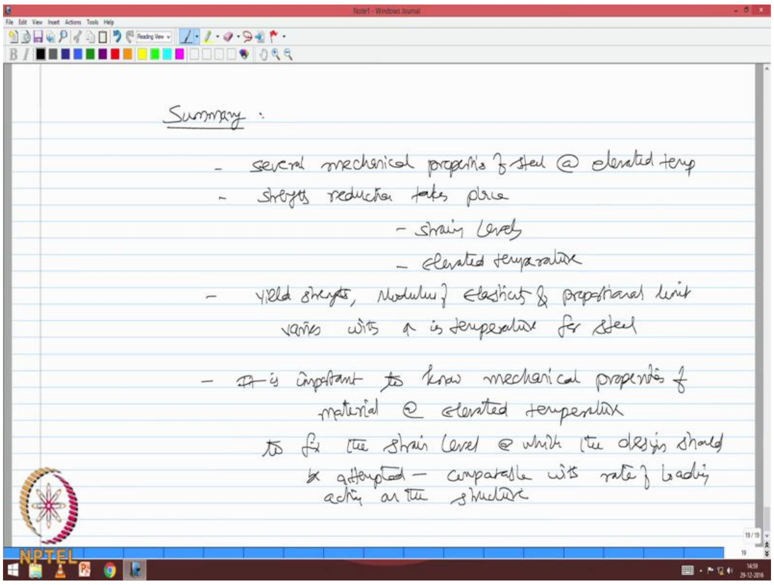

Friends, in this lecture we have understood several mechanical properties of steel at elevated temperature, we have also seen how strength reduction takes place with respect to different strain levels and elevated temperatures, we have also seen how yield strength modulus of elasticity and proportional limit varies with increase in temperature for steel. So, it is very important to understand to know mechanical properties of material at elevated temperature to fix the strain level at which the design should be attempted which should be also compatible with rate of loading acting on the structure.

Thank You.