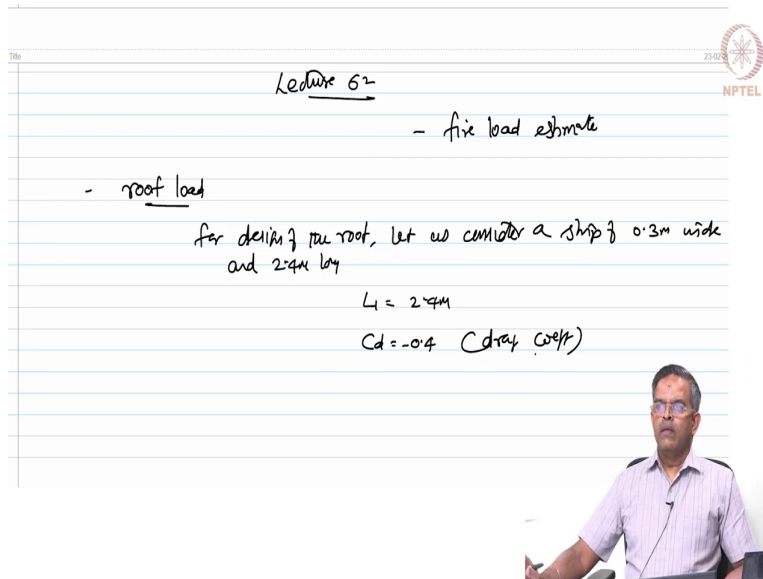


**Advanced Design of Steel Structures**  
**Dr. Srinivasan Chandrasekaran**  
**Department of Ocean Engineering**  
**Indian Institute of Technology, Madras**

**Lecture - 62**  
**Fire - resistant design - 1**

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The slide contains handwritten notes on a lined background. At the top right, there is a small circular logo with the text 'NPTEL' below it. The main text is written in blue ink and reads:

Lecture 62  
- fire load estimate

- roof load

for design of the roof, let us consider a strip of 0.3m wide and 2.4m long

$L_1 = 2.4\text{m}$   
 $C_d = -0.4$  (drag coefft)

In the bottom right corner of the slide, there is a small video inset showing a man with glasses and a light-colored shirt, likely the lecturer, speaking.

Friends, welcome to lecture 62, where we are going to talk about Fire Load Estimate. Before that, we will complete the numerical problem of blast load estimate on a rectangular building. We will continue with that.

So, we worked out previously the sidewall load, now let us work out the roof load for the problem. For design of roof, let us consider a strip of 0.3 meter wide and 2.4 meter long. So, let us take  $L_1$  as 2.4 meter, and let the drag coefficient be 0.4 negative for the roof.

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Equivalent load coefft,  $\frac{L_w}{L_1} = \frac{20}{2.4} = 8.333$

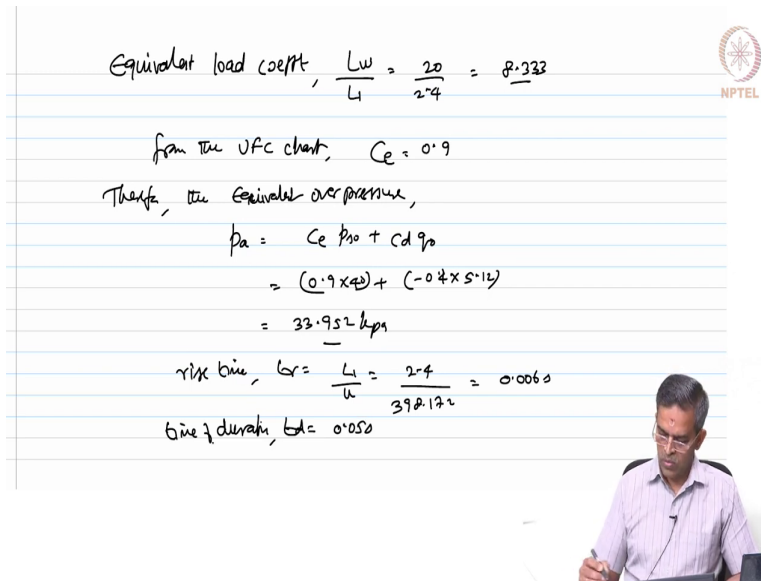
from the UFC chart,  $C_e = 0.9$

Therefore, the equivalent over pressure,

$$p_a = C_e p_{s0} + C_d q_0$$
$$= (0.9 \times 40) + (-0.4 \times 5.12)$$
$$= 33.952 \text{ kpa}$$

rise time,  $t_r = \frac{L_1}{u} = \frac{2.4}{398.172} = 0.006 \text{ s}$

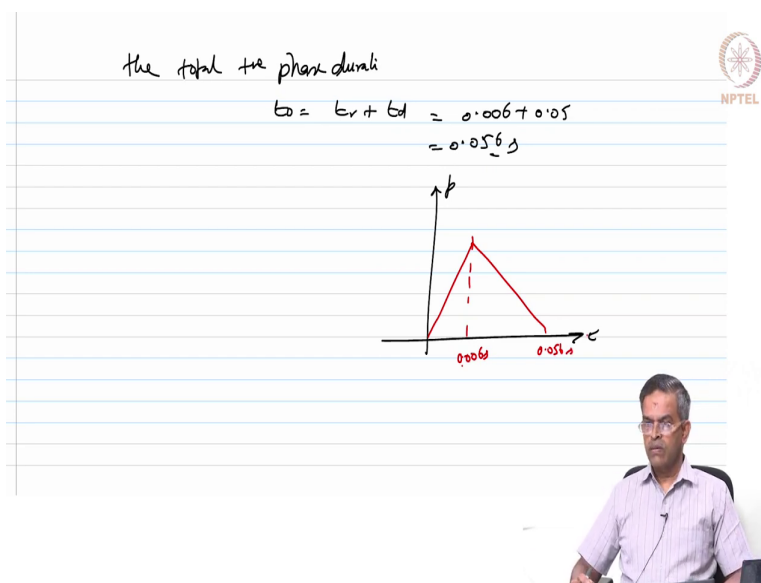
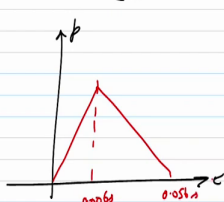
time of duration,  $t_d = 0.05 \text{ s}$



Equivalent load coefficient will be now equal to  $L_w/L_1$  which is  $20/2.4$  which is  $8.333$ . From the UFC chart, one can calculate  $C_e$  as  $0.9$ . Therefore, the equivalent over pressure is given by  $p_a = C_e p_{s0} + C_d q_0$  which is  $(0.9 \times 40) + (-0.4 \times 5.12)$ , that is what we had as  $q_0$ , which comes to be  $33.952 \text{ kpa}$ . The rise time for this,  $t_r$  will be  $L_1/u$  which is  $2.4$  by  $398.172$  which comes to  $0.006$  seconds. So, let us plot this. Further time of duration  $t_d$  is  $0.05$ .

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the total the phase duration

$$t_0 = t_r + t_d = 0.006 + 0.05$$
$$= 0.056 \text{ s}$$


So, the total positive phase duration will be equal to  $t_r$  plus  $t_d$  which is 0.006 plus 0.05, 0.056 seconds. Let us plot this. So, this is 0.006 seconds, is the positive rise phase. This is 0.056 seconds.

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rear wall load

let us consider the drag coef  $C_d = -0.4$

Eq load coeff,  $\frac{L_w}{s} = \frac{20}{5} = 4m$

from UFC chart,  $C_e = 0.88$

Eqn over load pressure

$$p_b = (C_e p_{so}) + C_d q_o$$

$$= (0.88 \times 40) + (-0.4 \times 5.12)$$

$$= 33.152 \text{ kpa}$$

Let us look at the rear wall loading. Let us consider the drag coefficient  $C_d$  as -0.4. So, the equivalent load coefficient will be actually given by  $L_w/s$  which is 20 / 5 which is 4 meters. And from the UFC chart, one can find  $C_e$  as 0.88. So, the equivalent overload pressure is given by  $p_a = C_e p_{so} + C_d q_o$  which will be  $(0.88 \times 40) + (-0.4 \times 5.12)$  which will be 33.152 kilopascal.

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time of arrival,  $t_a = \frac{B_L}{u} = \frac{20}{398.172} = 0.0502s$

rise time  $t_r = \frac{S}{u} = \frac{5}{398.172} = 0.0125s$

duration  $t_d = 0.05s$

total positive phase duration  $= t_n = t_r + t_d$

$= 0.0125 + 0.05$

$= 0.0625s$

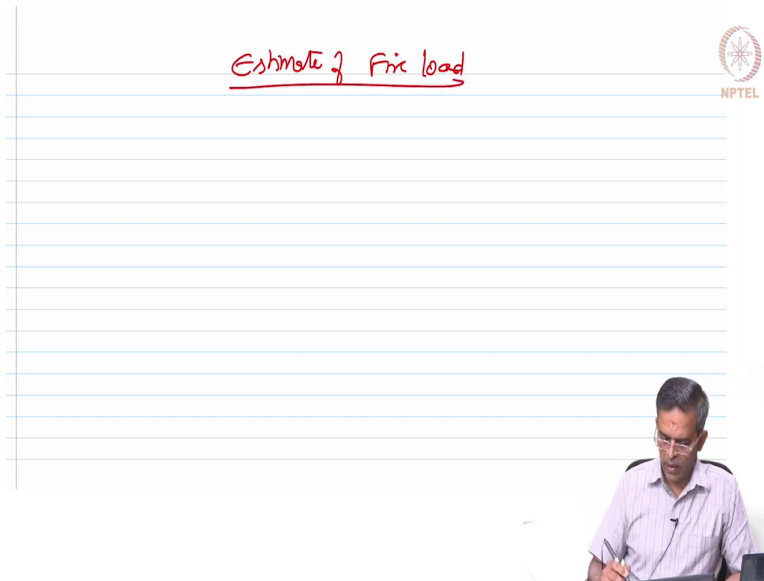
Graph showing pressure  $p_a$  (kPa) vs time  $t$  (s). The peak pressure is  $33.125 \text{ kPa}$ . The rise time is  $0.0125 \text{ s}$  and the duration is  $0.05 \text{ s}$ .

Time of arrival is  $t_a$  which is  $B_L/u$  which is  $20/398.172$  which is  $0.0502$  seconds. Now, the rise time of the positive phase  $t_r$  is given by  $S/u$  which is  $5/398.172$ , which is  $0.0125$  seconds. Duration,  $t_d$  is  $0.05$  seconds.

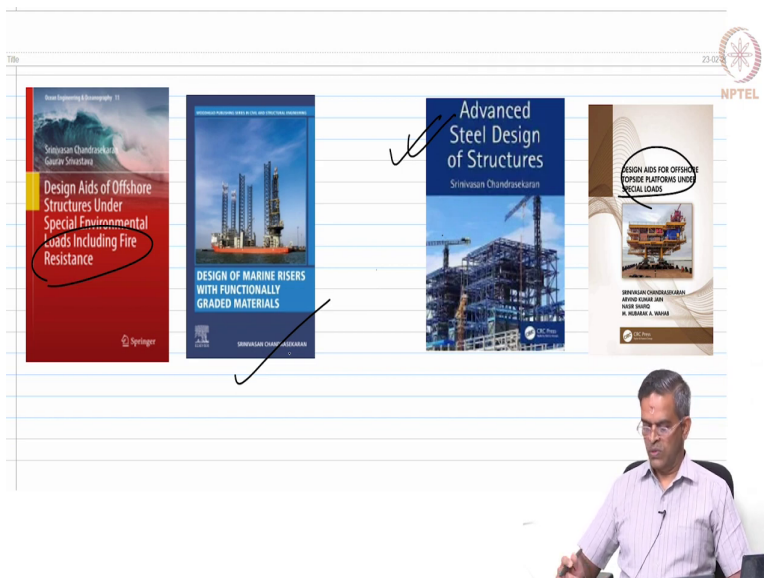
Therefore, the total positive phase duration will equal to  $t_n$  which is  $t_r$  plus  $t_d$  which is  $0.0125$  plus  $0.05$  which is  $0.0625$  seconds, which can be plotted as  $t$  and  $p_a$   $0.0125$ , this is  $0.0625$ , and this value is  $33.125$  kilopascal. So, friends, this example illustrated how to compute the blast loads on different segments of a rectangular building taken for the study using UFC code.

Now, let us discuss about estimate of fire loads on buildings.

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So, friends, now we will talk about fire loads. These are some interesting references which you would like to see back when you use fire load computation on structures. Design Aids of Offshore Structures Including Fire Resistance, this book covers concepts of fire-resistant design as well as the special loads. Please have a look at these textbooks, which are recommended for this course.

In addition, if you want to know about the properties of functionally graded material compared to steel, this is a very nice reference book which is recommended for this course.

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steel - most favourite material  
- design procedure is well established  
for conventional loads such as

live load	codes	IS 456
dead load		IS 800
wind load		IS 1893
wave load		
current		

Et load

fire load  
blast load  
impact load

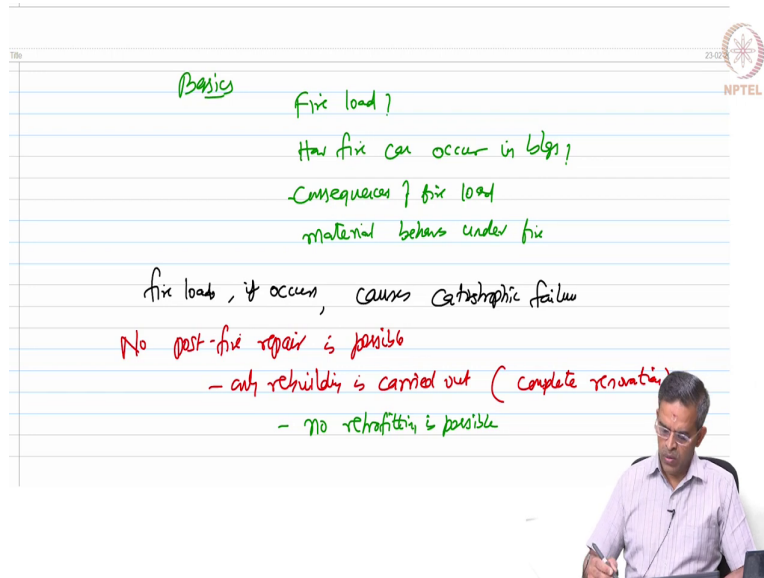
need special attention

NPTEL

Now, let us say steel is the most favorite material for construction. The design procedure for steel structures is well laid and well established. For conventional loads such as live load, dead load, wind load, wave load, current and earthquake loads, we have recommendations given by the codes. But when you talk about fire load, blast load, impact load, etcetera, they need a special attention, and the analysis methods are different for them.

For example, there are varieties of Indian codes which discuss about the design procedures. For example, let us say, IS 456 this is for concrete structures, IS 800 for steel structures, IS 1893 for earthquake loads. But there are no explicit design procedures available and recommended by the codes for fire loads.

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Basis fire load?

How fire can occur in bldg?

Consequences of fire load

material behaves under fire

fire load, if occurs, causes catastrophic failure

No post-fire repair is possible

- only rebuilding is carried out (complete renovation)
- no retrofitting is possible

So, let us see what are the basics of fire load. So, we would like to learn, what is a fire load? How fire can occur in buildings? What are consequences of fire load? And how material behaves under fire? Because there are no special design and repair procedures of structures under post fire accidents. And the steel that we generally use for construction is a high carbon steel. So, there are issues related to these two concerns, so we need to address that.

But, one thing we need to realize is that, if fire loads occur, causes catastrophic damage, very importantly no post-fire repair is possible, only rebuilding is done, no repair, it is amounting to a complete renovation because fire causes a total devastation. Very importantly no retrofitting is possible for structures subjected to severe fire loads.

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Which structures are exposed to fire load!

- Heavy Industrial structures
- Process Industries
- Nuclear reactors
- Offshore structures
- Chemical process plants
- Electric substations

Having said this, let us ask a question which structures are exposed to fire loads? Do we have to design every building for a fire load? The answer is no. Heavy industrial structures, process industries, nuclear reactor power plants, offshore structures, chemical process plants, can cause fire. We can also include electric substations, because electric fire is an important aspect for design.

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fire-resistant design

- structures can be only designed to withstand fire for a specific duration - fire rating
- No fire-proof buildings
- No fire-resistant buildings
- public safety
- fire safety buildings (specific duration)
- st design members

Now, let us talk about what do you understand by fire resistant design. Structures can be only designed to withstand fire for the specific duration. This is called fire rating. So, please



understand friends, there is no fire proof building, there is no fire-resistant building, but there are fire safety buildings for a specific duration only.

Then, in that case, what is important in fire resistant design? Structural design of members for fire load is only secondary. The primary is public safety. The primary is public safety. Structural design of members for fire is necessary, but that is only a secondary case.

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Factors that govern geometric design of fire safety bldgs


- Fire-fighting system to access the bldg (Circulation space)
- Assembly point - meeting point
- Evacuation facilities - public safety under fire-accidents
- Escape routes - follow fire-evacuation procedure
- All critical items such as fire hydrants, control room, fire water tank - should be in working condition

Now, let us see what are the factors that govern the geometric design of fire-resistant buildings. The first one is the firefighting system to access the building. That is the building should have enough circulation space around the building. The building should have something called a common assembly point, which is also otherwise called as meeting point which should be known to all the occupants of the building.

The building should have a very good evacuation facility. It should follow public safety under fire accidents. It should have well-lit escape routes; it should follow fire evacuation procedure as instructed by the course. Moreover, and most importantly, all critical items such as fire hydrants, control rooms, fire water tank, should be in proper working condition. It should be frequently inspected and certified for its proper working.

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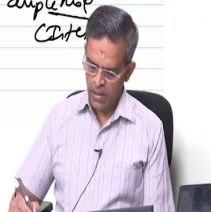
Basics of fire



Rapid, exothermal oxidation of ignition fuel  $\leftarrow$   $\begin{matrix} \text{solid} \\ \text{liquid} \\ \text{gas} \end{matrix}$

Fire releases Energy - Exothermal reaction


- within short time, released energy reaches its peak amplitude  
intensity



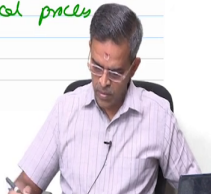
Let us quickly see some basics of fire. Friends, fire is a rapid exothermal oxidation of ignition fuel. The fuel can be in the form of solid, liquid or gas. Fire releases energy which is an exothermal reaction. Now, within short time, the released energy reaches its peak amplitude or peak intensity. That is the most serious concern as far as fire is concerned.

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fire can also result from explosion



- Explosion is rapid expansion of gases caused by pressure waves or shock waves
- These waves propagate very fast
  - Cause adiabatic expansion
- Explosion resulting from fire causes a mechanical process, chemical process



Fire can also result from explosion. Explosion is rapid expansion of gases caused by pressure waves or shockwaves. In the previous set of lectures, we understood how to calculate the

shockwave and overpressure waves. A rapid expansion of gases caused by these waves can result in explosion.

The interesting part is these waves propagate very fast. In the numerical example you see that they were only in milliseconds. What is the concern of this? It can cause adiabatic expansion.

Explosion resulting from fire can be a mechanical process or a chemical process.

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The slide shows handwritten notes on a lined background. The title is "Categories of fire (DNV code)". There are four entries:

- No fire risk - building has no energy resources (House)
- Low fire risk - building with stores non-flammable materials (Acad blocks, Apartments)
- Medium fire risk - building has low electric & major testing equipment (Workshop)
- High fire risk - building that stores flammable liquid & high power mech eq (Process industries, offshore platforms, Electric substation)

In the bottom right corner, there is a small video inset showing a man in a light blue shirt sitting at a desk with a microphone, likely the presenter.

Let us see what are categories of fire as per DNV code. So, DNV code classifies fire as follows. No fire risk, so the building in that case has no energy resources to catch fire. The example could be home or house.

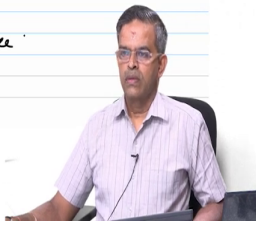

The next is low fire risk, this will occur in buildings which stores non-flammable materials. Examples of academic blocks, schools, colleges, apartments, which stores non-flammable materials.

Next could be medium fire risk, which is classified as buildings that has or that have electric and major testing equipment. For example, it can be workshop. Lastly, high fire risk, these can be buildings that stores flammable liquid. Example could be process industries, offshore platforms, as well as it also classifies and high-power mechanical equipment. So, in that case, I can also include electric substation.

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How can we avoid fire accidents

- fluid used in such industries should be above the flash point
  - above the fire point temperature
  - not be above the Auto-ignition temp
- fluid can be used upto the max<sup>m</sup> bulk temp
  - (max<sup>m</sup> bulk temp) fluid  $\gg$  flash point temperature
- No confined space near the ignition source

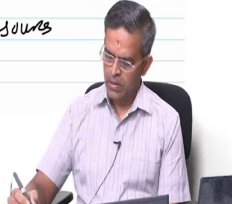



Let us ask a question how can we avoid fire accidents. The fluid used in such industries which are prone to fire should be above the flash point. It should be above the fire point temperature. It should not be above the auto ignition temperature.

Next, fluid can be used up to the maximum bulk temperature. So, the maximum bulk temperature of any fluid is always much higher than the flash point temperature. It is a common characteristic of a fluid. Finally, no confined space near the ignition source, it should be open from all sides.

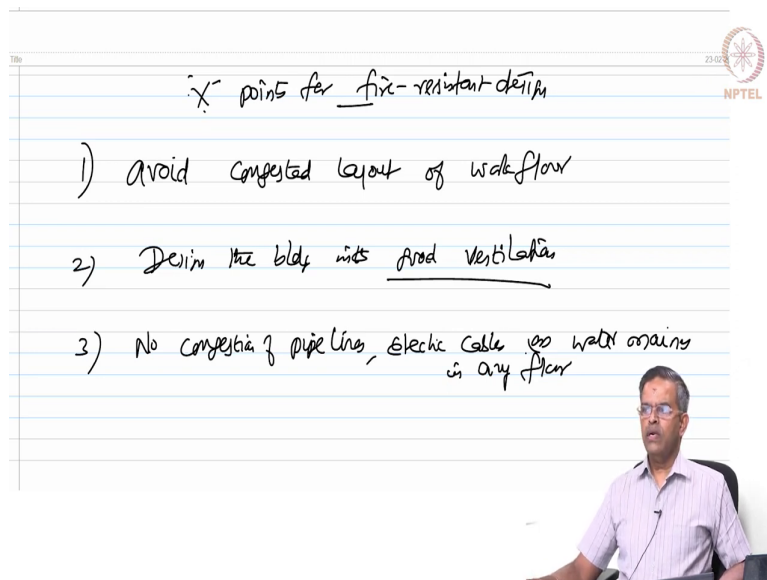
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- one should ensure good O<sub>2</sub> supply for the space should be well-ventilated
  - No oxygen supply near the heat source
    - electric heater
    - Heat Exchanger
    - Ditch Control etc
- fluid should be contained within the system
- No direct contact with the external ignition sources



Further, one should ensure good oxygen supply or the space should be well-ventilated. But importantly no oxygen supply near the heat source, electric heater, the heat exchanger, the drilling controller. Further, fluid should be contained within the system. There should be no direct contact with the external ignition sources.

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30:18

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3 points for fire-resistant design

- 1) Avoid congested layout of workflow
- 2) Design the bldg with good ventilation
- 3) No congestion of pipe lines, electric cable or water mains in any floor

So, let us see some of the important points for fire resistant design.

Avoid congested layout of workflow.

Design the building with good ventilation.

There should be no congestion of pipelines, electric cables, or water mains in any floor.

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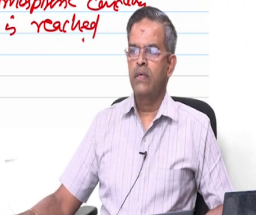

Characteristics of fire

1) Auto Ignition temperature (AIT)

- Kindling point of materials

It is the lowest temp above which the material may not require any external source for combustion

Ignition takes place @ normal atmospheric conditions when AIT is reached



Now, let us see what are important characteristics of fire.

First one, Auto ignition temperature, AIT. It is also called as kindling point of materials. It is the lowest temperature above which the material may not require any external source for combustion. So, ignition takes place at normal atmospheric conditions when AIT of a fluid is reached.

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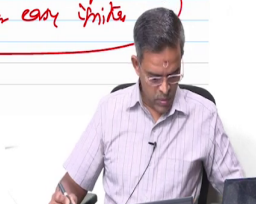

AIT - is also called as self-ignition temperature

- It is also the min temperature required to supply activation energy required for combustion

Diesel	210°C	flash point
Methane	516°C	- This is the lowest temperature @ which the liquid gives enough vapour to maintain a continuous flame
Gasoline	247-250°C	
Butane	405°C	

at flash point, fluid will not burn

- It is the temp @ which vapours are produced for easy ignition

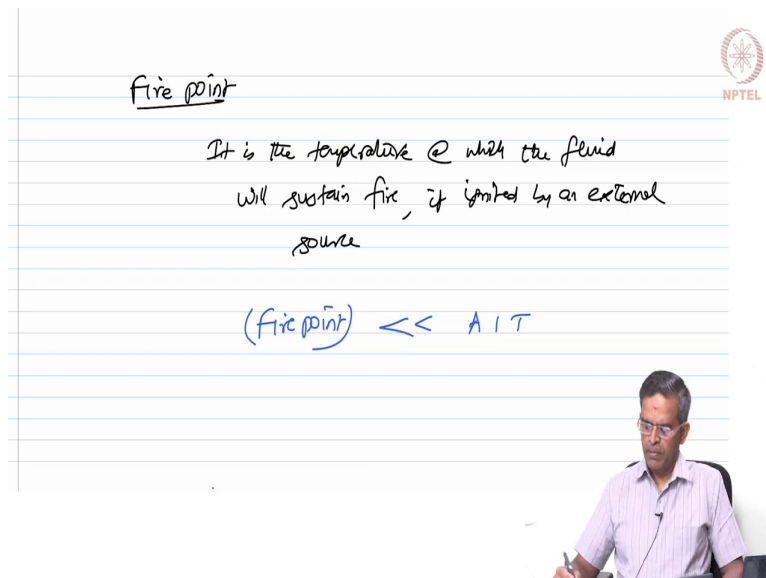


AIT is called also called as self-ignition temperature. It is also the minimum temperature require to supply activation energy required for combustion. Let us say for example, diesel has got 200 degrees Celsius, methane is 580 degrees Celsius, gasoline is in the range of 247 to 280, butane is about 405 degree Celsius.

Let us also look at something called a flashpoint. This is the lowest temperature at which the liquid gives enough vapour to maintain a continuous flame. It is not the temperature at which vapours are produced, for easy ignition. It is the temperature at which vapours are produced for easy ignition.

So, friends, an important point here is at flashpoint, fluid will not burn. That is important.

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fire point

It is the temperature @ which the fluid will sustain fire, if ignited by an external source


(fire point)  $\ll$  AIT

The image shows a man in a purple shirt sitting in front of a whiteboard. The whiteboard has the handwritten text above. In the top right corner of the whiteboard, there is a circular logo with a star and the text 'NPTEL' below it.

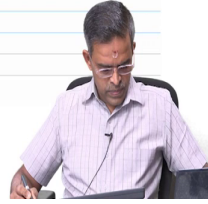
The next one is called as a fire point. It is a temperature at which the fluid will sustain fire, if ignited by an external source. But interestingly, fire point of a fluid is always much lesser than the auto ignition temperature. Since, we are writing about the fire-resistant design, let us talk quickly about fire protection systems as well for our understanding.

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fire-protection system



- 1) Flame arrester - passive device - prevents propagation of fire through pipe lines
- 2) fire barriers, fire insulators, water shower, foams, water spray lines
- 3) Spark preventers - or help to prevent spark  
- higher priority in fire-protection systems
- 4) fire-extinguishers




There are many fire protection systems available. One is called as the flame arrester. Flame arrester, it is a passive device which prevents propagation of fire through pipelines.

The second one is called fire barriers, fire insulators, water shower, foams, water spray lines etc. The third set of fire protection system involves spark preventers. It helps to prevent spark. This is one of the highest priorities in firefighting protection systems. Of course, the last one as we all know is fire extinguishers which are firefighting systems.

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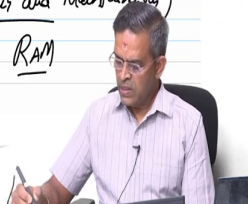
fire-fighting system



- simple in design
- easy to operate
- free from high-tech components
- should be maintained periodically
- should be available on demand (Reliability and Maintainability)

RAM

Conduct FIRE DRILLS

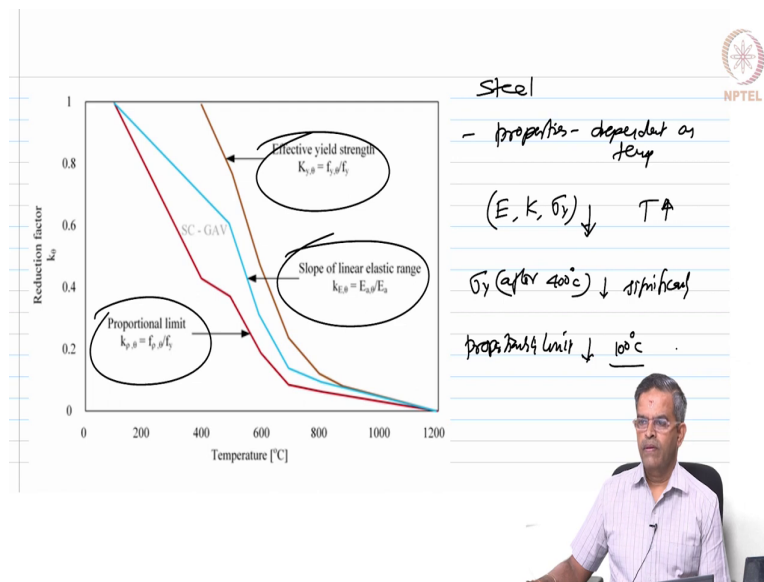




And let us have a brief look at the components of firefighting system. Firefighting system should be simple in design. It should be easy to operate. It should be free from high tech components. It should be maintained periodically. Most importantly, should be available on demand.

Friends, the recent research is now focusing on reliability and maintainability. So, you are looking for reliability and maintainability to check whether any specific system is reliable and available on demand. So, to ensure this, people conduct fire drills at periodic intervals in all industrial structural systems to ensure that the firefighting system is essentially works maintained in a proper manner.

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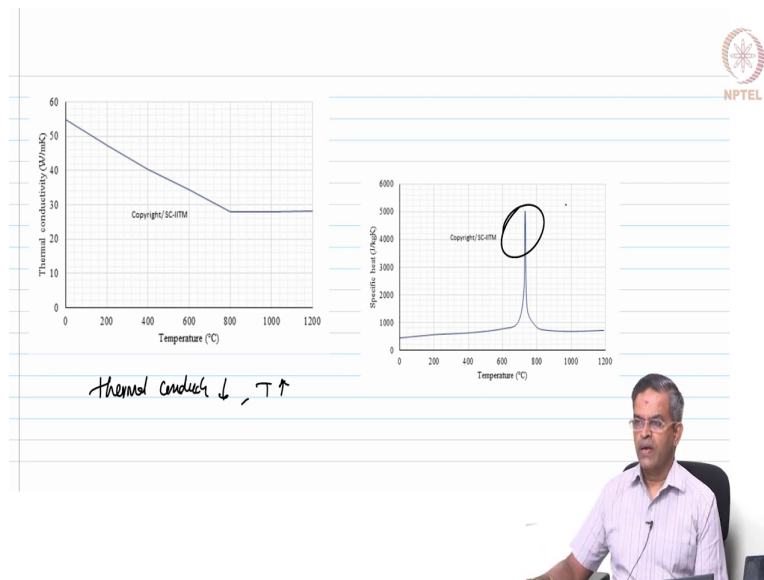


Now, friends as we understand, steel is seen as a very advantageous material. The curve on the screen shows the temperature is a reduction factor which is a strength reduction of steel. So, steel is the most preferred material, but steel has got properties which are dependent on temperature.

Look at the effective yield strength and proportional limit as well as the slope of linear elastic range. So, the yield strength, the stiffness, and modulus of elasticity, all decrease with increase in temperature. Especially, the yield strength after 400-degree Celsius decreases significantly.

The proportionality limit also decreases beyond 100 degree Celsius. So, the ductility characteristics, strength degradation, happens in steel as you proceed with the temperature.

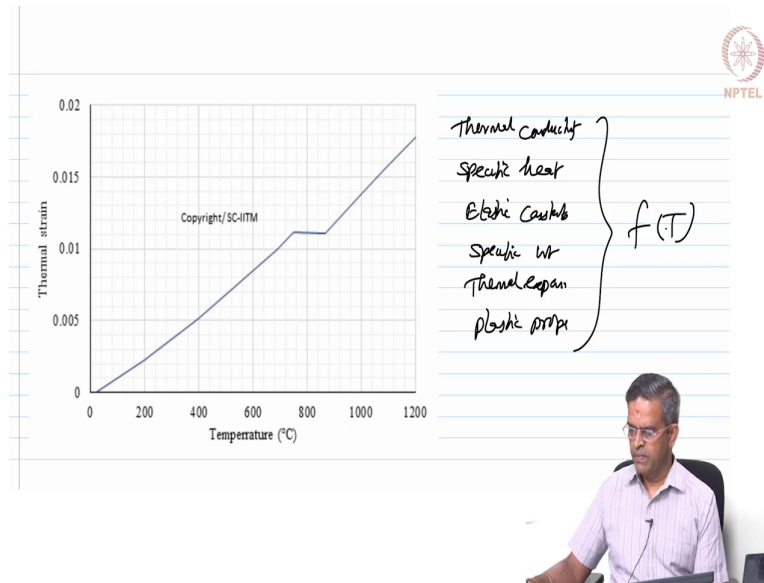
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Furthermore, if you look at thermal conductivity of steel, it also decreases with increase in temperature beyond 800 degrees Celsius. It remains constant. Furthermore, the specific heat capacity of steel remains almost constant except at about 700 degrees Celsius, it reaches a specific peak where the specific heat capacity touches about 5000 joules per kg kelvin close to range of about 750 degrees Celsius in the temperature.

So, these properties of steel which were discussed in the earlier lectures are only helping you to re-brush the constant characteristics of steel with respect to time and temperature.

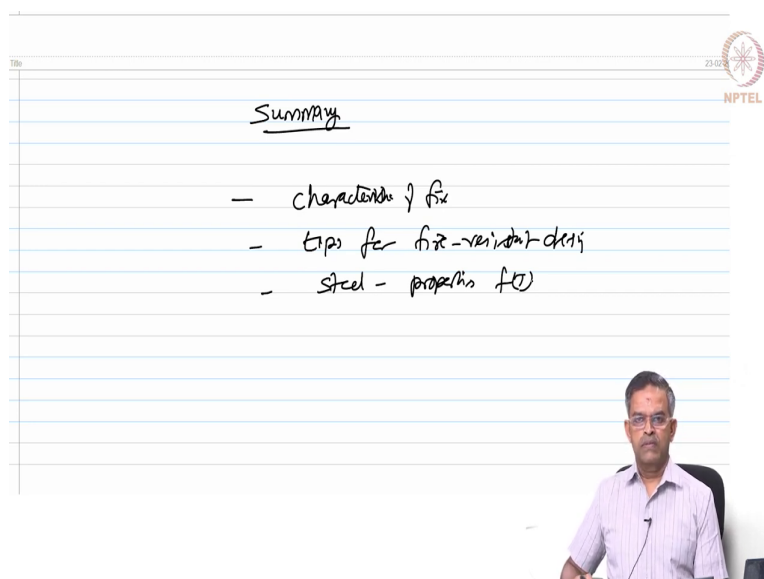
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Furthermore, if we look at the thermal strain, it keeps on increasing with increase in temperature. So, therefore, friends, thermal conductivity, specific heat, elastic constants, specific weight, thermal expansion, and plastic properties of steel all become function of temperature.

So, when you are using steel for a fire-resistant design, where the fire is going to happen at a higher temperature because of explosion or hydrocarbon fire et. You got to be very careful in understanding the properties of steel which is being used for fire resistant design.

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So, friends, in this lecture, we learnt about characteristics of fire. We learned briefly about tips for fire resistant design. We also completed a problem on blast loads analysis. And we learned that steel has got properties which are function of temperature. And one has got to be very careful, in using these properties appropriately in the design, if you are enabling fire resistant design of steel structures.

Thank you very much. And have a good day.