Advanced Design of Steel Structures
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Lecture - 61
Blast-resistant design - 4

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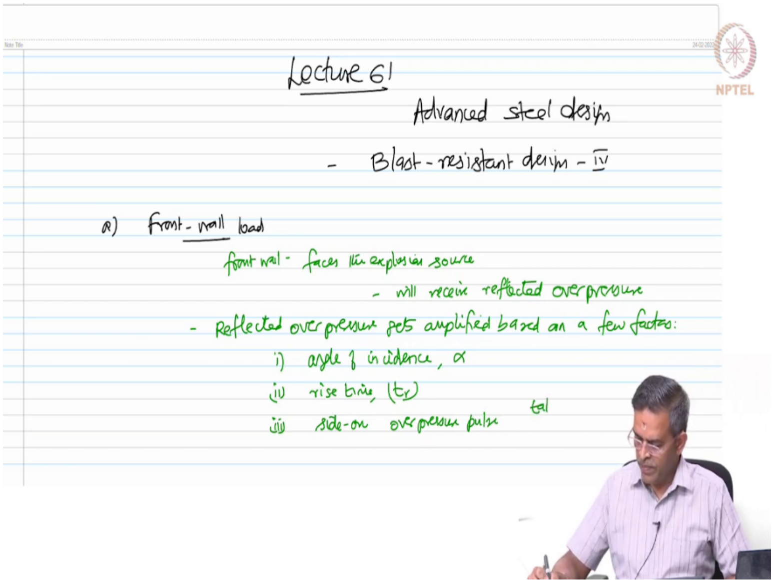

Friends, welcome to lecture 61 on Advanced Steel Design course. We will continue discuss Blast resistant design. I will say this is IV. In the last lecture, we discussed that the blast loading general arrangements of rectangular building. And we understood that the blast wave travels horizontally from left to right. And when it travels it starts imposing reflected and back phase over pressure waves all around the circumference of the building.

Having said this, depending upon the location of the potential explosion hazards related to the building site, the blast load strikes the building from any direction. It cannot necessarily be horizontal it can be inclined to the building major axis. It all depends upon the source of explosion. Therefore, an ideal assumption could be the blast wave travels horizontally, but not necessarily all the time.

So, in this specific discussion, we are assuming that the blast wave hitting the surface of the building is normal to its surface and it propagates horizontally along the axis of the building. If it is so, it creates a variety of loading. Let us see one by one, how a front wall loading is created. Front wall in sense is the wall which faces the explosion source. Therefore, the wall facing this explosion source will receive reflected over pressure. The reflected over pressure gets amplified and that depends on various factors.

Let us see, what are these factors. It depends on angle of incidence of the blast wave which is indicated as alpha. It also depends on what is called as the rise time which is t r. It also depends on the side on over pressure pulse. For design purposes, the normal shock refraction can be considered by considering or by taking.

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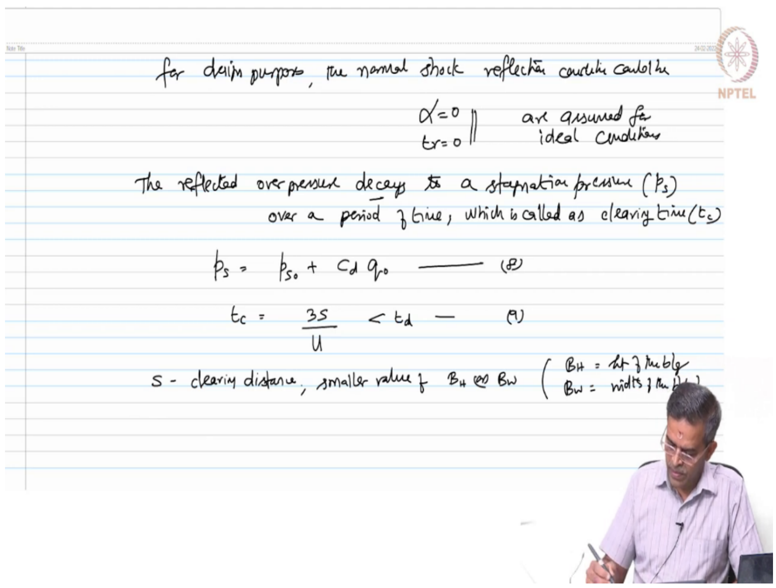

We will write it here. So, for design purposes, the normal shock reflection condition could be alpha 0 and t r 0 ok, they are generally assumed. However, in some cases when there is an oblique reflection which can become critical to overall building, then the reflective pressure from two adjacent sides should be considered after resolving it into the respective components.

Now, the reflected over pressure decays to a stagnation level, we call this stagnation pressure as p s over a period of time. And this time is called clearing time indicated as t c. So, p s is given by p so + C d of q naught. We call this equation number 8.

We are continuing the equation number from the previous derivation. And the clearance time t c is given by 3S by u which is always less than t d ok, where S is the clearing distance. It should be smaller value of B H or B W where B H is the height of the building, B W is the width of the building.

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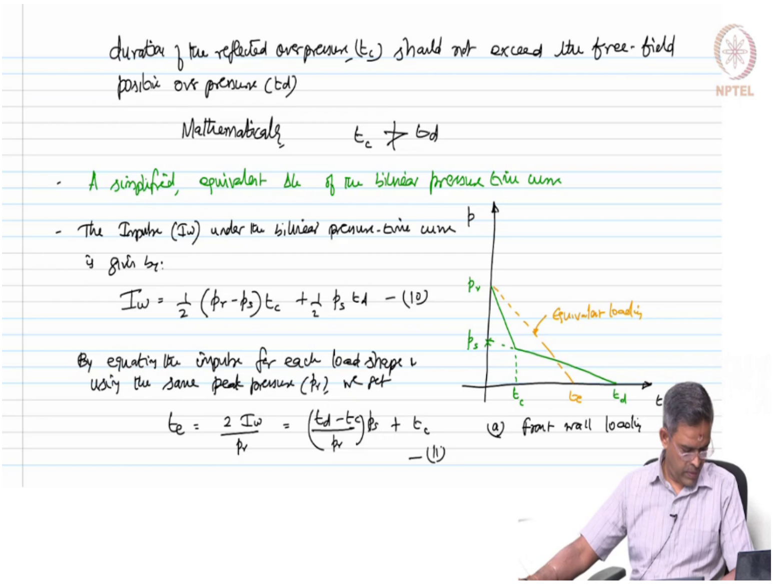

The duration of the reflected over pressure t c should not exceed the free field positive over pressure t d. So, mathematically t c cannot be greater than t d. Having said this, let us see the simplified equivalent triangle of a bilinear pressure time curve. So, now, I am looking for a simplified equivalent triangle of the bilinear pressure time curve, which I am drawing here. So, the horizontal axis is indicated as time and the vertical axis is the pressure. We are now talking about the loading over the front wall. So, ideally speaking, the pressure variation.

So, this is what I call as t d. And this particular time is called the clearing time. Let us project this and this is what we call as p s, and this is p r . Now, I am looking for an equivalent loading. Equivalent loading starts from there and I get a time equivalent, and I call this as an equivalent loading of blast wave for the front wall. This equivalent load is computed by equating the impulse for each load shape and the same peak pressure p r.

The impulse I w under the bilinear pressure time curve is given by the following relationship. Half of p r - p s into t c + half of p s into t d, let me call this equation number 10. Now, by equating the impulse for each load shape and use the same peak pressure p r, I can find we get t equivalent time should be twice I w by p r, which is t d - t c by t r by p r of p s + t c, call this equation number 11.

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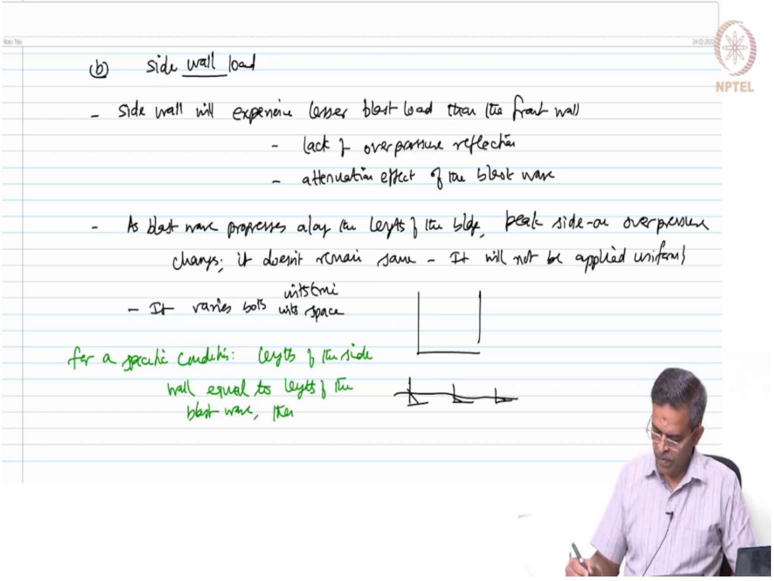

Now, let us talk about the side wall loading due to the blast load. The side walls will experience less blast load than the front wall. This is due to lack of over pressure reflection and attenuation effect of the blast wave. You know friends, attenuation is a property of variation of any subject with respect to distance. So, attenuation effect is decay of the blast wave with distance propagated by the blast wave from the explosion source.

As the blast wave travels along the length of the structural member, the peak over side on pressure will not be applied uniformly ok as blast wave progresses along the length of the building peak side on over pressure changes. It does not remain same. We have seen that yesterday if I have a building with respect to time it changes. So, it is not applied uniformly. It varies both with time and with space in fact, it gets reduced.

If the length of the sidewall is equal to the length of the blast wave for a specific condition, length of the sidewall equal to length of the blast wave.

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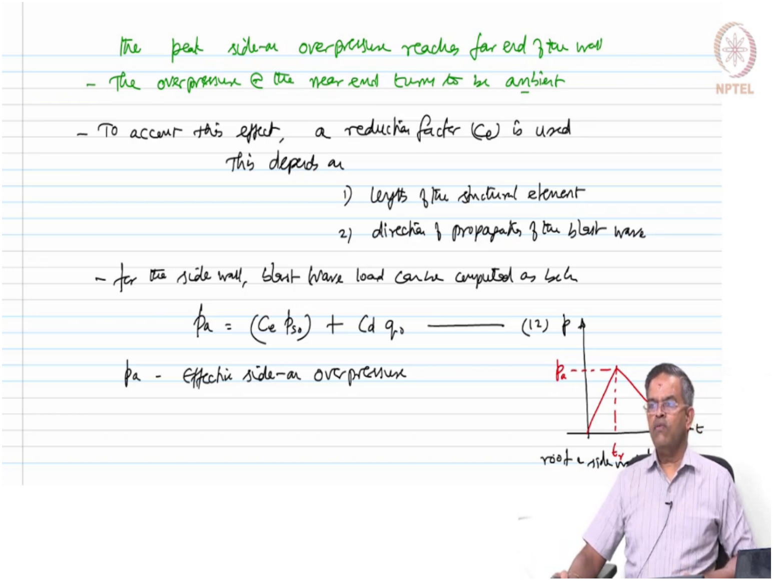

Then the peak side on over pressure reaches the far end of the wall. In that case the over pressure at the near end turns to be ambient. So, now, this behaviour should be accounted the decay of the side on over pressure with respect to the attenuation should be accounted.

So, to account this effect a reduction factor is used. A reduction factor is being used which we call as C d is used. Now, this depends on the length of the structural element and the direction of propagation of the blast wave. So, for the side walls, blast wave load can be computed as below; p a will be equal to ok this is not C d, this is C e. We can say ok C e of p so, reduction factor + C d of q naught. We call this equation number 12. We know p a is effective side on over pressure.

Let us plot this if this is time versus pressure. This is indicated as t r this is what we say as p a. And this is called as t o. This is the figure for roof and side wall load. Having said this, the sidewall load has a rise time equal to the top, as shown in the figure.

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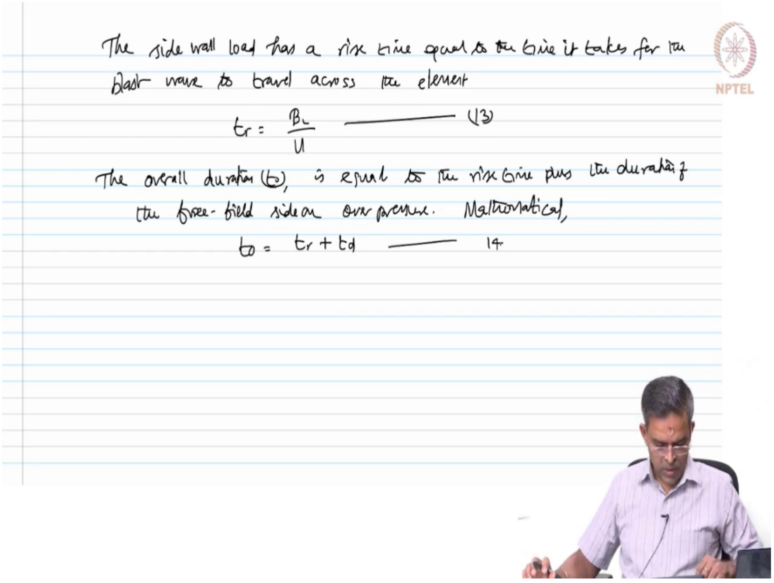

The sidewall load has a rise time equal to the top, as shown in the figure. Equal to the time it takes for the blast wave to travel across the element. So, t r is given by B L by u equation 13. Now, the overall duration t o is equal to the rise time of the duration + the duration of the free field side on over pressure. Mathematically, t o will be t r + t d, equation 14. This is for the sidewall loading.

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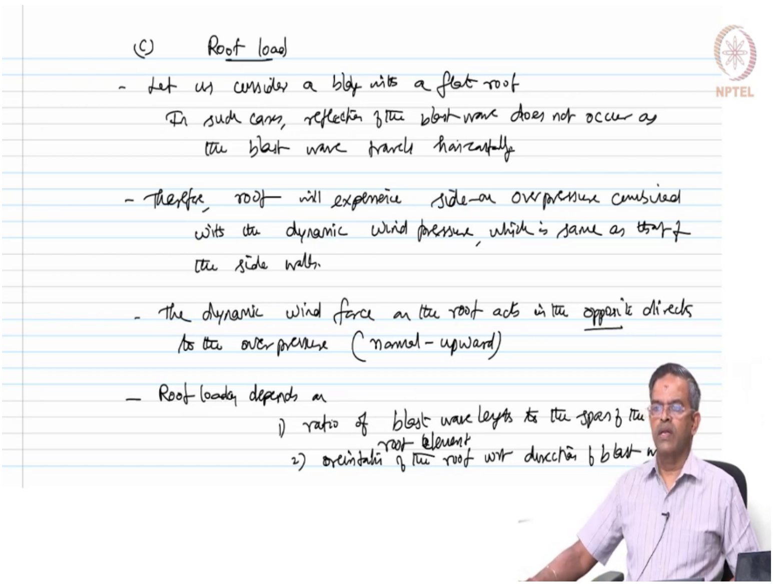

Let us look for roof load for a building with blast roof flat roof. Let us say let us consider a building with a flat roof. So, in such cases reflection of the blast wave does not occur as the blast wave travels horizontally. This horizontal travel was an assumption made by us.

Therefore, roof will experience side on over pressure combined with the dynamic wind pressure which is same as that of the sidewalls. The dynamic wind force on the roof acts in the opposite direction to the over pressure that is it is going to be acting normal upward. The roof loading depends on ratio of blast wavelength to the span of the roof element that is the first factor. The second factor orientation of the roof with respect to the direction of the blast wave. Ideally speaking, we assume it is horizontal, but not necessarily, it needs to be horizontal.

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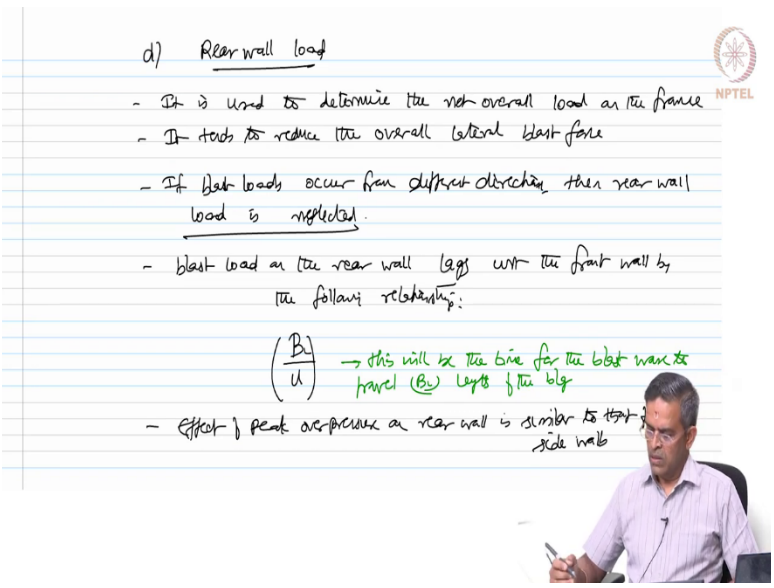

Let us now talk about rear wall load. Friends, we have seen the front wall, side wall, the roof; now the rear wall. The rear wall load is used only to determine the net overall loading on the frame on the frame. It tends to reduce the overall lateral blast force. The rear wall effects are neglected for buildings where the blast loads could not occur from any direction. If blast loads occur from different directions, then rear wall load is neglected. The rear wall blast load lags that of the front wall.

So, the blast load on the rear wall lags with respect to the front wall by the following relationship which is equal to B L by u. Time for the blast wave to travel the length of B L of the building. Essentially this will be the time for the blast wave travel, the length of the building, is it not? Because distance by speed will give you the lag. The effect of peak over pressure is similar to that of side walls, on rear walls is similar to that of side walls.

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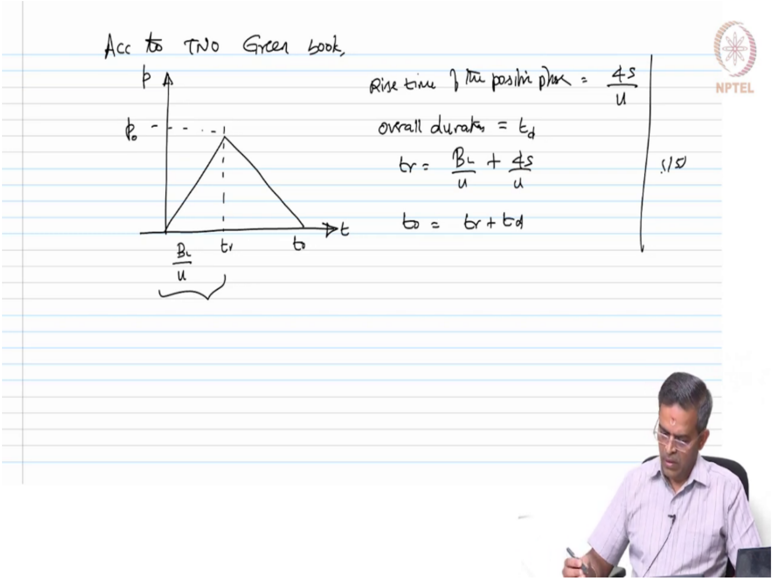

Now, according to TNO Green book, we have this figure is t r and this is B L by u and this is p o . Now, the rise time of the positive phase that is this, is it not? The rise time is given by 4S by u. This is t naught, the overall duration is t d and t r is given by B L by u + 4S by u further to is t r + t d equation 15.

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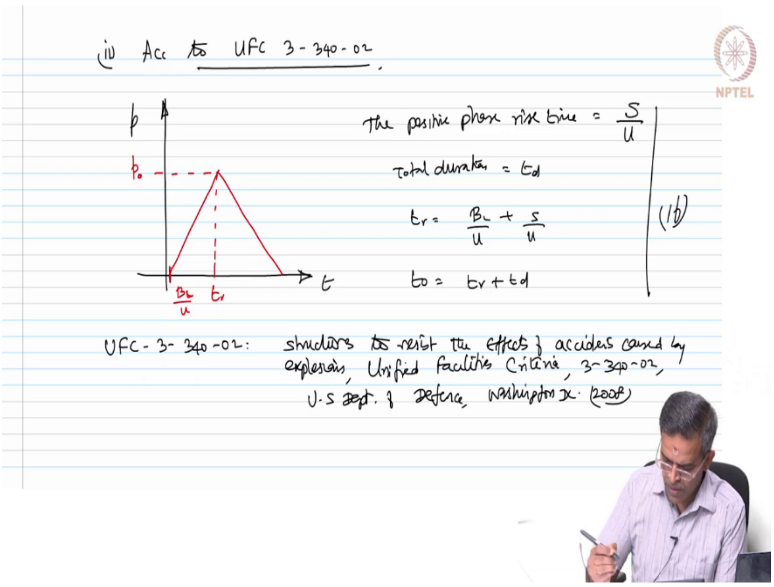

So, now according to UFC, 3- 340 - 02 quo. This is t r this is still B L by u. And this is p o, the positive phase rise time is S by u. Total duration is td and tr are B L by u + S by u. And overall time is t r + t d equation 16. This got very interesting reference friends. UFC- 3- 340 - 02 is the quo for structures to resist the effects of accidents caused by explosions.

Unified facilities criteria 3 – 340 - 02 US, Department of Defense, Washington D.C 2008.

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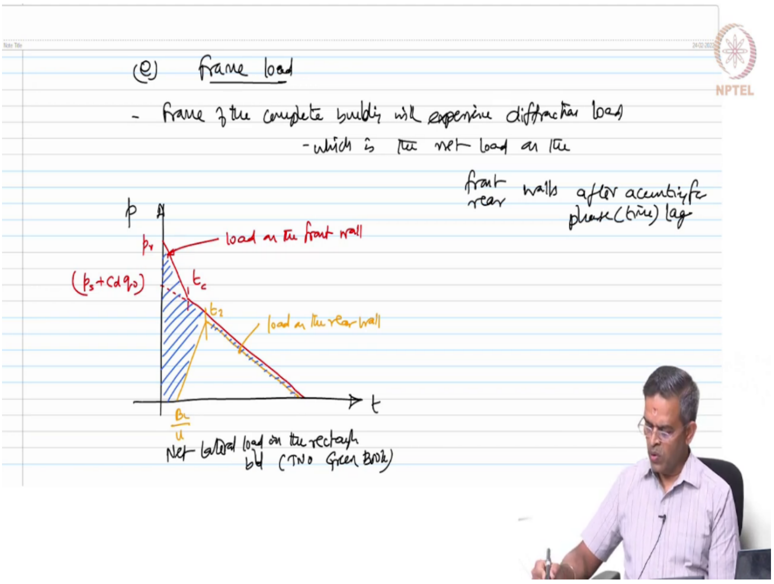

Then, let us talk about the overall frame loading under the blast wave. Frame of the entire building will be experiencing diffraction load, which is the net load on the front, rear walls after accounting for the time lag.

During the time lag, when the blast wave travels from the front to the back side of the building, the structural frame will be subject to logged horizontal imbalance pressure on the front wall. After this passes away the front wall loading is partially offset by the rear wall loading. So, this can be experimentally I mean represented by a figure ok let us see how. So, this is time is p.

Let us say, we have a loading for a specific time. We call this as p r and this as t c. Let us extend this slope and call this as p s + C d of q naught. So, now, I can say this represents load on the front wall. This is what we have discussed. When we talk about the load on the rear wall, this was the rear wall loading.

So, friends, in the rear wall loading this curve does not start from 0. Please be very careful this starts from B L by u. Let me change this it starts from B L by u. So, we call this as time t 2, there is load on the rear wall. And we know very well this is going to be B L by u. So, now, the net force is going to be.

So, I can say, this is the net lateral load on the rectangular building as per TNO Green book. There will be in addition negative and rebound loading as well, let us see what that is.

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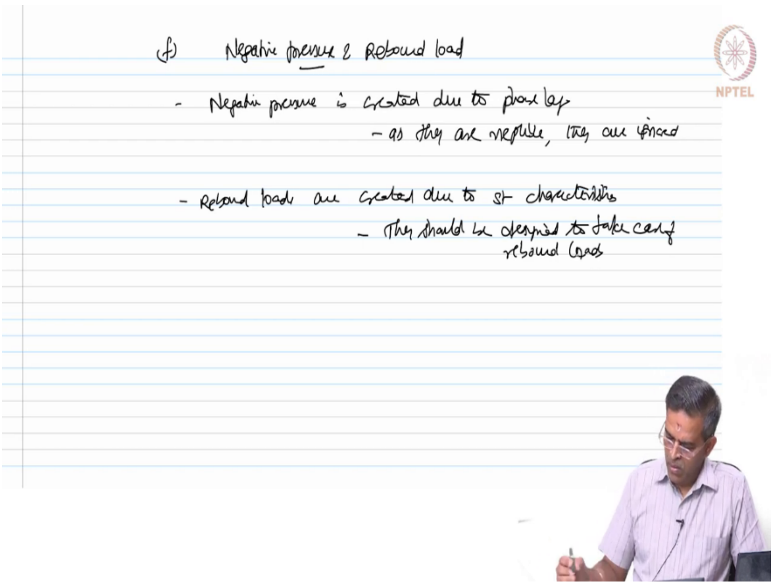

Due to the negative phase, the building components will experience blast load effects opposite to the direction of primary load. It also occurs due to the rebound of the structural members and its components from the inertial effects.

So, negative pressure forces are generally ignored since they are negligible; however, the structural component should be adequately detailed to perform satisfactorily for the rebound effects. So, the negative effects, negative pressure is created due to phase lag as they are negligible. They are ignored. Rebound effects ok, rebound loads are created due to the structural characteristics. And they should be designed to take care of these rebound loads.

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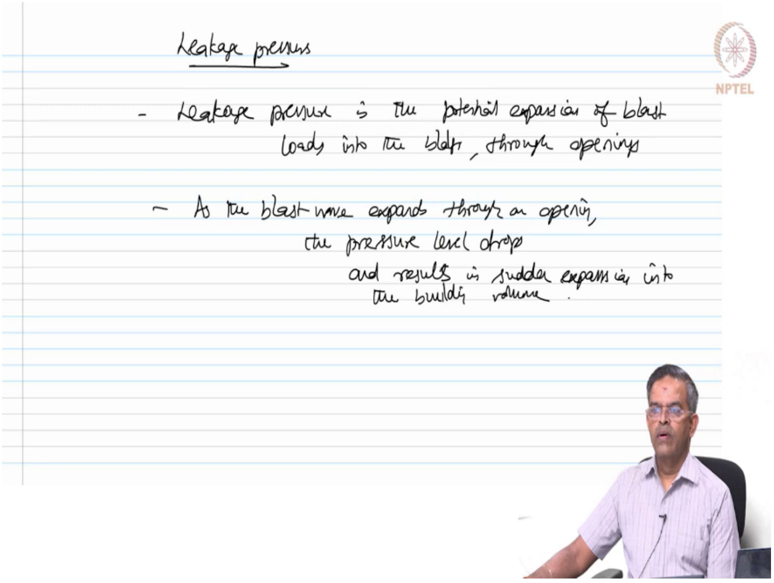

There is something called leakage pressure. The potential expansion of blast loads into the building through the opening is called as leakage pressure. As the blast wave expands through an opening, the pressure level drops and sudden expansion into the building volume.

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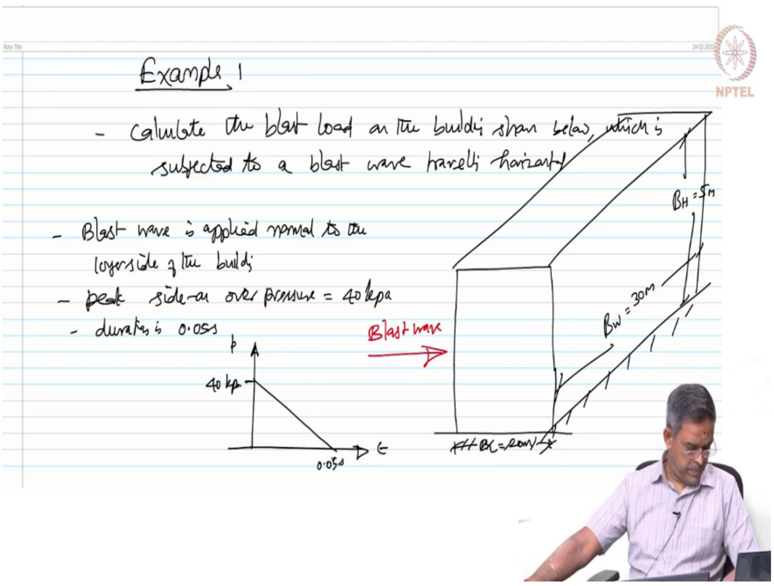

Let us take an example and illustrate this load estimates for a design. So, we say calculate the blast load on the building shown below which is subjected to a blast wave travelling horizontally. Let us say this is the building block. This is B L which is 20 meters, this is B W which is taken as 30 meters and this B H which is taken as 5 meters. The blast wave is hitting the building like this assumed to travel horizontally.

Now, you know in this example, the blast wave is applied normal to the longer side of the building, am I right. Peak side on over pressure is taken as 40 kilo pascal and the duration is 0.05 seconds. So, that is the loading wave we have. This is t and this is p and this value is 40 kilo pascal and this time is 0.05 seconds.

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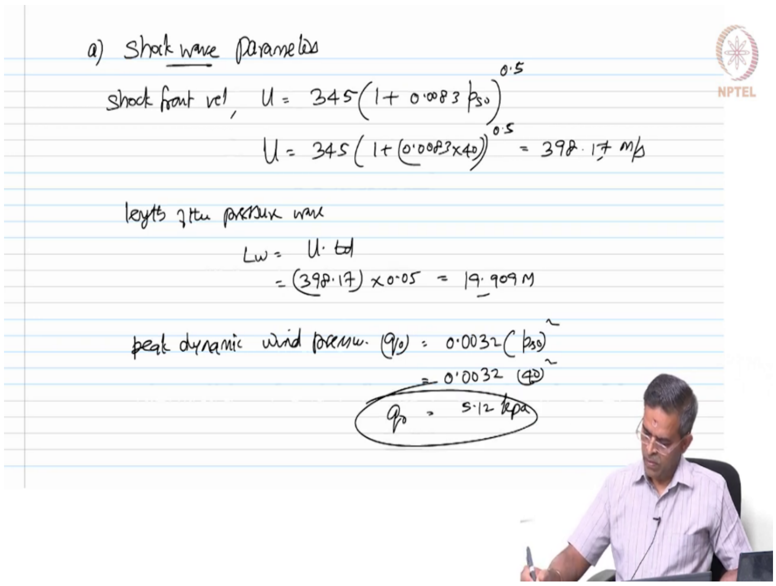

Let us work out the shock wave parameter. Shock front velocity which is u is given by 345 1 + 0.083 of p so to the power 0.5. So, u in our case is going to be 345 1 + point zero sorry 0083 into 40 to the power 0.5 which comes to 398.17 meter per second. Let us work out the length of the pressure wave.

So, the length of pressure wave is u into t d which is 398.17 into 0.05 which comes to 19.909 meters peak dynamic wind pressure; q naught is given by 0.0032 times of p so square 0032 into 40 square which is 5.12 kilo pascals.

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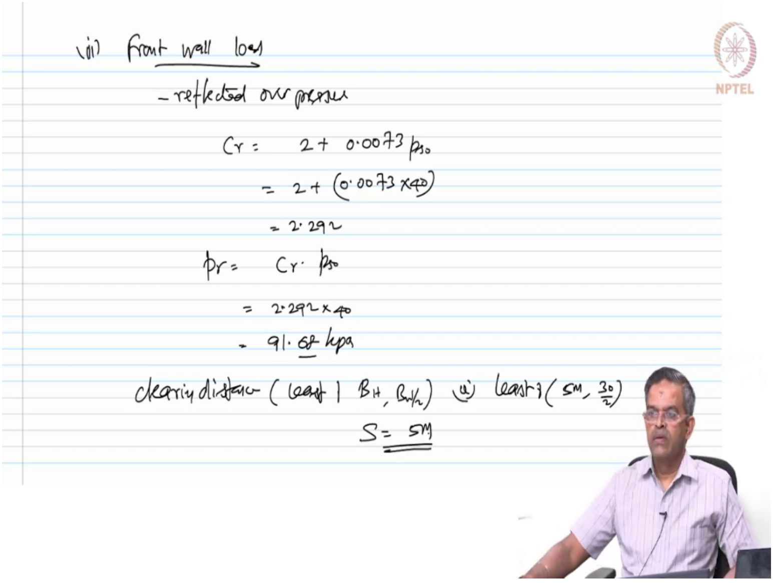

Now, let us do the front wall loading. Let us calculate the reflected over pressure which is given by C r is equal to 2 + 0.0073 of p so which is 2 + 0073 of 40 which comes to 2 point 292 and reflected over pressure is C r times of p so which is 2.292 into 40 which is 91.68 kilo pascal. Let us calculate the clearing distance.

This should be the least of B H and B W by 2 that is least of 5 meters comma 15 by 2 sorry. So, B, B W is 30, is it not? That is 15 meters. So, therefore, S is 5 meters the minimum of this two.

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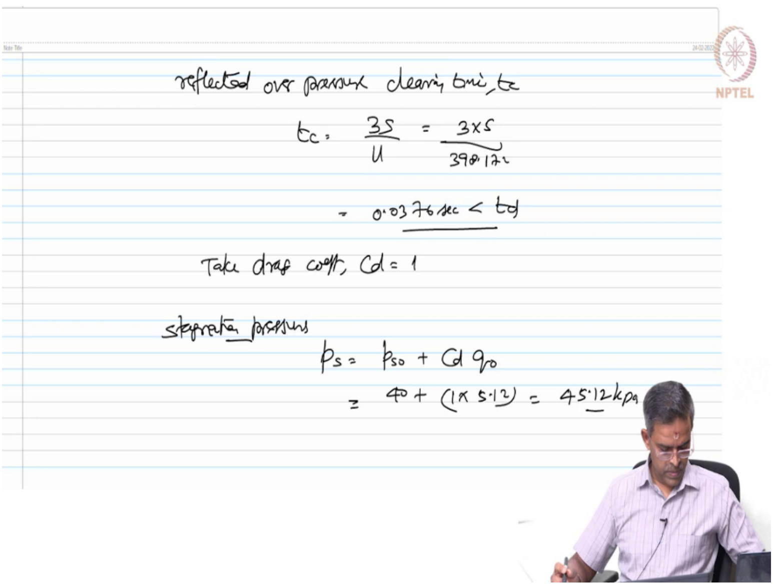

Therefore, reflected over pressure clearing time t c is given by 3S by u which is 3 into 5 by 398.172 which comes to be 0.0376S which is less than t d which is seconds.

It has got to be less than t d that is a condition, is it not? Take the drag coefficient C d as unity. So, now, let us calculate the stagnation pressure. The stagnation pressure p s is p so + C d of q naught which is 40 + 1 into 5.12. That is not q naught we calculated, is it not? That is the q naught we have right. Yeah, ok 5.12 which comes to be 45.12 kilo pascal.

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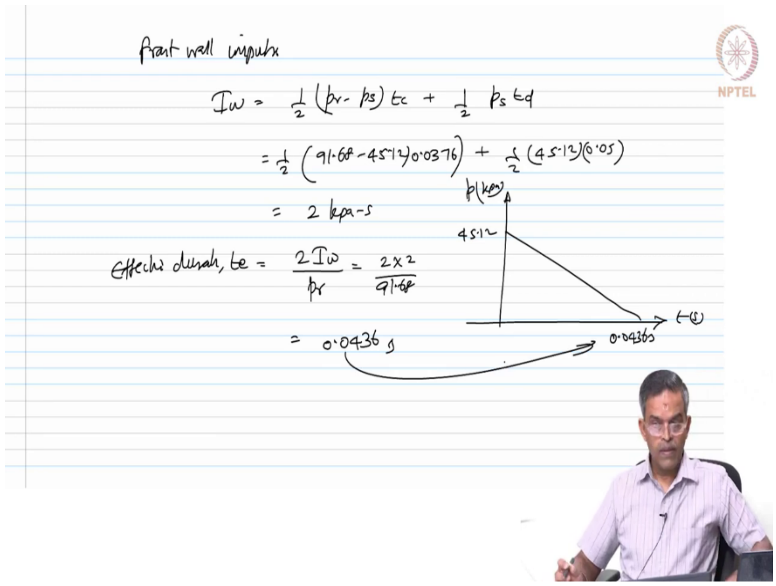

Front wall impulse, I_w will be ½ $(p_r - p_s)$* t_c + ½ of p_s * td. Let us substitute them ½ of (91.68 - 45.12) of 0.0376 + ½ of 45.12 * 0.05 which gives me 2 kilo pascal seconds. So, if I try to plot this, this is time in seconds and this is p in kilo pascal.

So, I get this as 45.12 for 0.043 seconds that is the effective duration; t e is given by 2 a I w by p r, 2 into 2 by 91.68 which comes to 0.0436 seconds which is here.

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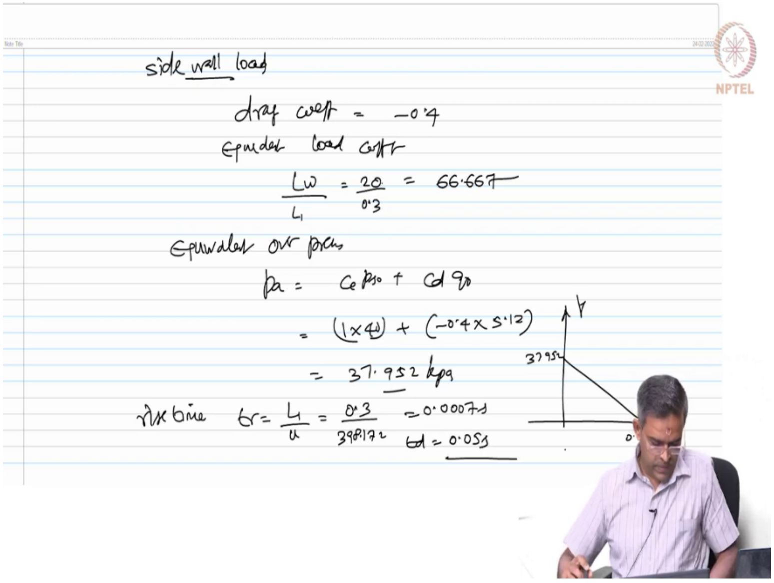

Let us do the sidewall loading. The drag coefficient for the sidewall is - 0.4. The equivalent load coefficient is going to be L_w / L_1 which is 20 / 0.3 which is 66.667.

So, equivalent over pressure is given by Ce * Pso + Cd*q_o which is 1 * 40 + (-0.4* 5.12) which comes to 37.952 kilo pascal. The rise time is calculated as L 1 by u which is 0.3 by 398.172 which comes to 0.0007 seconds, we can plot this.

So, t and p this value is 0.05 and this is 37.952. The total duration td will be now 0.05 seconds.

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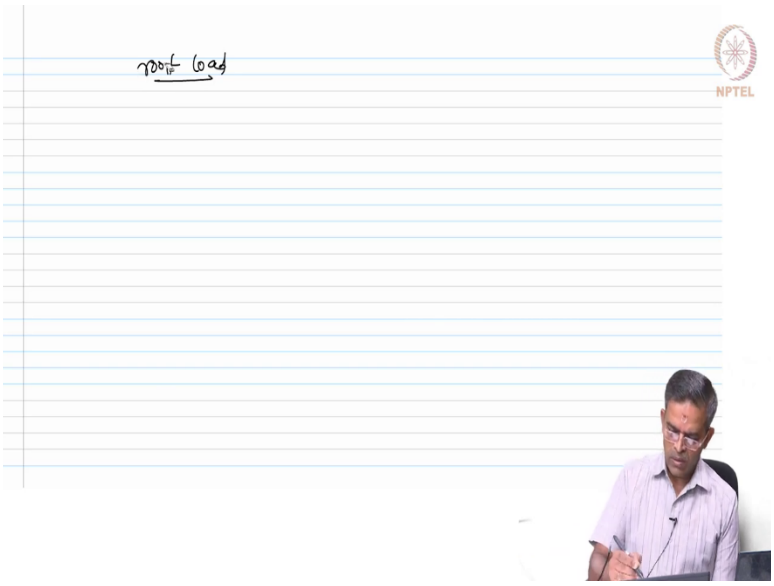

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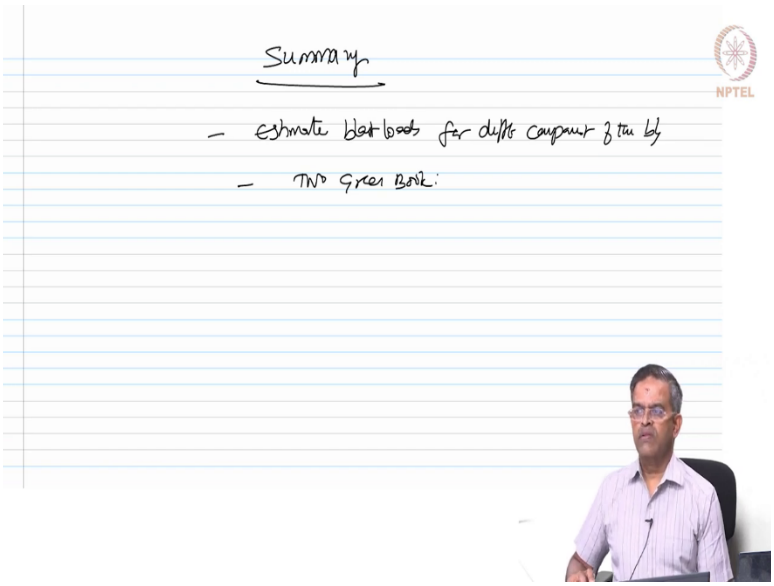

Let us calculate the roof load. So, we will continue this problem in the next lecture. So, we want to make this understand for all the components. So, let us do this. So, I will not do this here we look at the summary. So, friends in this lecture, we learnt how to estimate blast loads for different components of the building.

We have learnt how this TNO Green book is helpful to estimate these (Refer Slide Time: 56:59) and we have learnt diagrammatically how the reflected side over pressure creates additional loading on the surface of the building and as well as in the rear side of the building. In the whole derivation, we assume that the blast wave is travelling horizontally.

Thank you very much and have a good day.