

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

**Lecture - 59**  
**Blast - resistant design - 2**

(Refer Slide Time: 00:15)

The slide contains handwritten notes in green ink on a white background with a blue grid. The text is as follows:

Lecture 59

- Blast resistant design - II

design philosophy of blast-resistant design,

- 1<sup>st</sup> step - to choose/design the layout of the building units and the arrangements of plants & equipments in the units

objectives are

- 1) to decide, what needs protection
- 2) to imagine how damage or injury will be caused
- 3) to consider how the units of the structure can be arranged (both v/h)

In the bottom right corner of the slide, there is a small inset video of a man in a pink shirt speaking.

Friends, welcome to the 59th lecture on Advanced Steel Design course. In this lecture, we are going to learn about Blast Resistant Design, let us say 2 because in the earlier lecture we discussed about Blast Loads.

So, when you talk about the design philosophy of blast resistant design, the starting point for the design of a structure of blast test and design is to consider the layout and arrangements. So, the first step is to choose or to design the layout of the building units and the arrangements of plants and equipment's in the unit. That is a first step.

So, there is a specific objective which you have to keep in mind when you choose the layout of the building which you want to design for blast resistance. The objectives are, one need to design what needs protection. One need also imagine how damage or injury will be caused. One need to also consider how the structure can be arranged or I should say how the units of the structure can be arranged both vertically and horizontally to get the best blast resistant protection.

(Refer Slide Time: 03:29)

Blast loading

- An explosion is a very rapid chemical process producing transient air pressure waves - called as blast waves
- parameters that govern these blast waves are
  - 1) peak over pressure
  - 2) duration of the over pressure

Both these parameters may vary with the distance of the unit from the source of explosion

- In blast load computations, it is necessary to recognize the scenarios that could have severe outcome

The slide also features the NPTEL logo in the top right corner and a small inset image of a man in a pink shirt speaking into a microphone in the bottom right corner.

Having said this, when we talk about blast loading, let us define what is a blast load. Blast loading actually is caused by an explosion. An explosion is a very rapid chemical process producing transient air pressure waves. These transient air pressure waves are called as blast waves.

Now, these blast waves are governed by various parameters, parameters that govern these blast waves are, one, peak over pressure; two, duration of the over pressure. Now, both these parameters may vary with respect to the distance of the unit from the source of explosion. Therefore, in blast load computation, it is important to recognize the scenarios that could have severe outcome and take into account of these in the design. Therefore, friends, the blast pressure waves will also be reflected and refracted by the buildings.

(Refer Slide Time: 06:46)

- Blast pressure waves will also get

- reflected and
- refracted by the buildings

all the 4 sides of the structure can be subjected to over pressure

- As the blast wave progresses in the forward direction, the peak over pressure intensity decreases

- If the unit is located far away from the blast source, effect of peak over pressure on the unit will be min

Blast waves are very intrusive and all sides of the structure can be subjected to over pressure. So, if we have a structure, all the 4 sides can be subjected to over pressure. The peak over pressure decreases as the wave moves further. So, as the blast wave progresses in the forward direction, the peak over pressure decreases. Therefore, in simple terms, if the unit is located far away from the blast source effect of peak over pressure on the unit will be minimum.

(Refer Slide Time: 09:08)

- Reflected waves from the buildings generate multiple wave fronts which can also cause further damage

blast wave

reflected blast wave

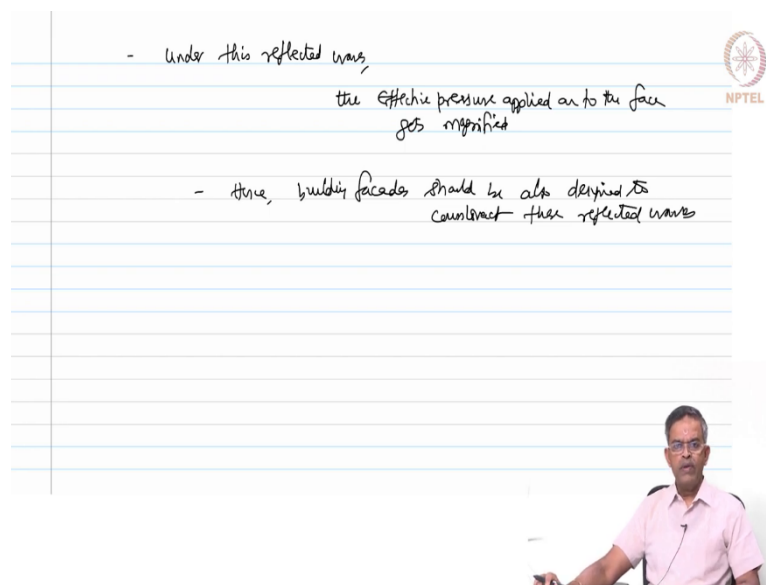
- when the blast wave impinges directly onto the face of the bldg, it is reflected - these reflected waves also cause damage

Further, reflection or let us say reflected waves, from the building generates multiple wave fronts which can also cause further damage. So, let us say I have a building, there is a blast

wave source, so the fore is affected and there is a reflected wave. Even these waves can also severe effect on the structures.

Further, when the blast wave impinges directly onto the face of the building it is reflected from it. And these reflected waves will also have consequences and they can also cause damage.

(Refer Slide Time: 11:12)



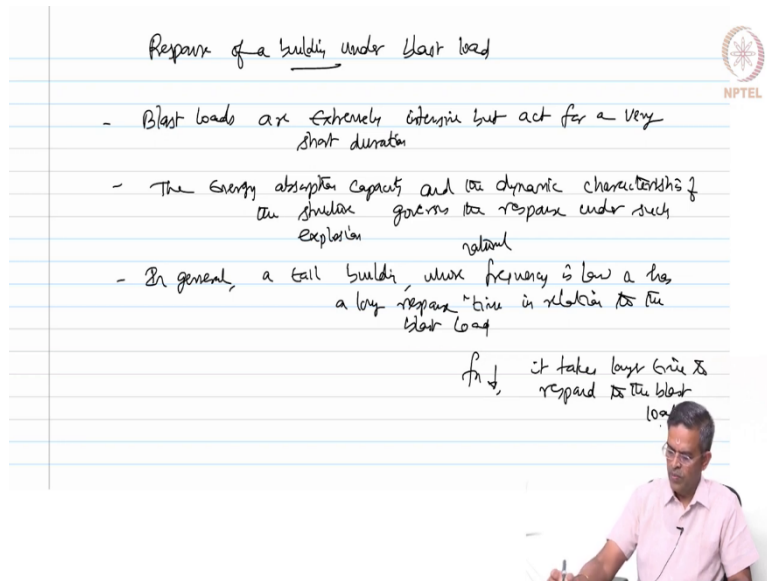
The effective pressure applied on to the face of the building is magnified when this occurs. Under this reflected wave, the effective pressure applied on to the surface gets magnified. If the facade is to survive without breaching, it must be designed to resist this pressure. So, therefore, building facades should be also designed to counteract these reflected waves.

(Refer Slide Time: 12:44)

Response of a building under blast load

- Blast loads are extremely intense but act for a very short duration
- The energy absorption capacity and the dynamic characteristics of the structure governs the response under such explosion
- In general, a tall building, whose frequency is low has a long response time in relation to the blast load

$f_n \downarrow$ , it takes longer time to respond to the blast load



Let us quickly see qualitatively how to estimate the response of a building to a blast load. So, blast loads are extremely intense, but act for a very short duration. The energy absorption capacity and the dynamic characteristics of the structure governs the response of the structure under such explosions.

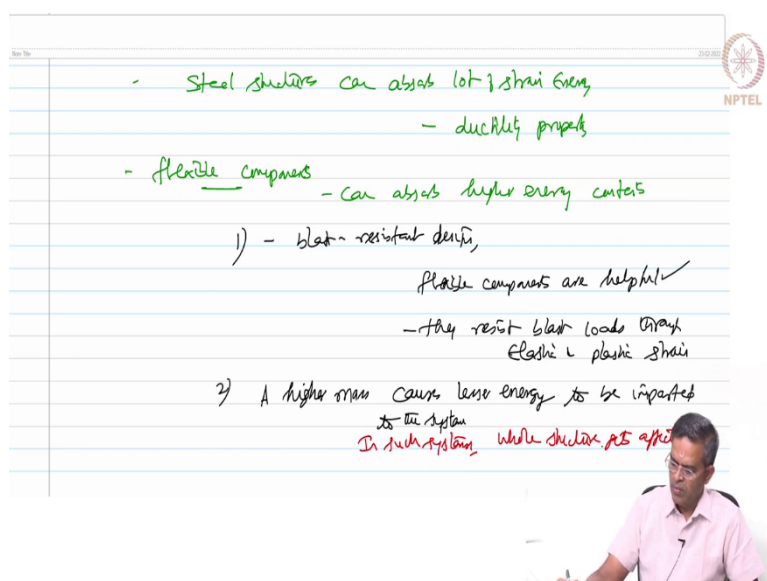
In general, a tall building, whose frequency or let us say natural frequency is low and has a long response time in relation to the load. So, if the frequency is low as in the case of tall buildings, it takes longer time to respond to the blast load.

(Refer Slide Time: 15:29)

- Steel structures can absorb lot of strain energy
  - ductility property
- Flexible components
  - can absorb higher energy content

1) - blast-resistant design,  
flexible components are helpful  
- they resist blast loads through elastic & plastic strain

2) A higher mass causes less energy to be imparted to the system  
In such systems, where ductility is applicable



Especially, steel structures can absorb lot of strain energy. This is because of its ductility property. Further, flexible components can absorb higher energy contents. So, friends, in blast resistant design, flexible components are helpful because they resist blast loads through elastic and plastic strain. Further, this is the first point we have. The second point, a higher mass causes less energy to be imparted to the system.

In case of larger explosions, the structure as a whole becomes affected by the blast waves. So, in such systems, the whole structure gets affected by the blast waves. In blast resistant design, we have a concept called protected space. Let us see what is that.

(Refer Slide Time: 18:13)

The slide features handwritten text in green and black ink on a lined background. The title 'Protected space' is written in green. The main text explains that these are spaces within a building, strengthened to withstand external explosions, with examples like control rooms and units of critical functions. It also notes that these spaces should be located based on building geometry and structural characteristics, and that their blast capacity is highly limited and confined to that specific space. An NPTEL logo is visible in the top right corner. A small inset image of a man in a pink shirt is visible in the bottom right corner of the slide area.

Protected space

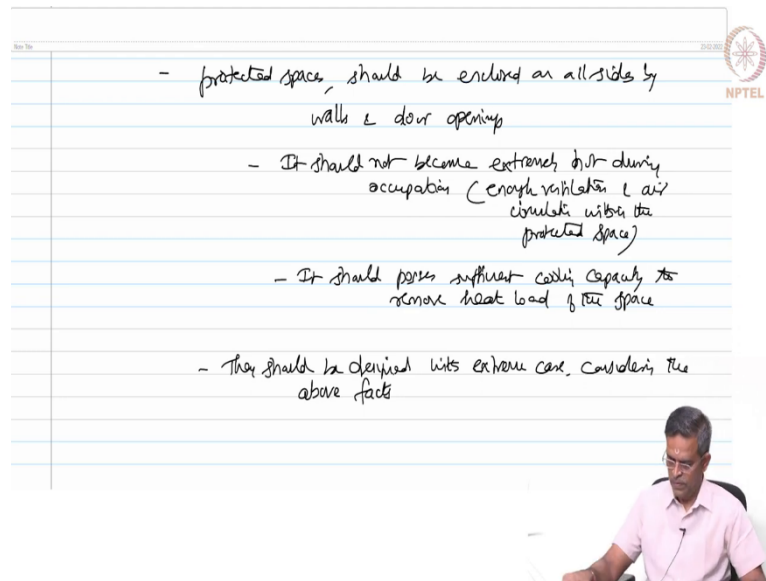
These are spaces within the building, which are strengthened to withstand the building unit from external explosions (for example, control rooms, units of critical functions etc)

- protected space should be located by taking the advantage of the building geometry & structural characteristics of the building
- In the design of protected spaces, one need to quantify the blast capacity (highly limited & confined only to that space)

What do we understand by protected space? Protected spaces or areas within the structure which are hardened to protect the occupants and equipment's against the effect of external explosion. So, these are spaces within the building which are strengthened to withstand the building unit from external explosions. For example, protected spaces could be control rooms, units of critical functioning, etcetera.

Protected spaces should be located utilize the benefit offered by the offer with geometry. So, protected spaces should be located by taking care or taking the advantage of the building geometry and structural characteristics of the building. Having said this, in the design of protected spaces, one need to quantify the blast capacity. But please note, the blast capacity of protected spaces is highly limited and confined only to that space, not for the entire building. That is important to remember.

(Refer Slide Time: 21:28)



- protected space, should be enclosed on all sides by walls & door openings

- It should not become extremely hot during occupation (enough ventilation & air circulation within the protected space)

- It should possess sufficient cooling capacity to remove heat load of the space

- They should be designed with extreme care, considering the above facts

So, protected spaces therefore, should be enclosed on all sides by walls and door openings. It should not become extensively hot during occupation. So, there should be enough ventilation and air circulation within the space.

It should possess sufficient cooling capacity to remove the heat loads of the space. So, one should be able to maintain both the temperature and the humidity conditions of this protected space. So, protected spaces should be designed by the extreme care considering the whole facts. Having said this, let us see what are the principal parameters which will govern the blast resistant design.

(Refer Slide Time: 24:18)

Principal parameters

- 1) peak side-on positive over pressure ( $P_{so}$ )  
positive phase-duration ( $t_d$ )  
corresponds positive impulse ( $I_o$ )
- 2) peak side-on negative pressure (suction) ( $P_{so}$ )  
negative phase-duration ( $t_d$ )  
associated impulse ( $I_o$ )

The principal parameters to be defined for blast resistant design are as follows. One is peak side-on positive over pressure, indicated as  $P_{so}$ . So, the second is positive phase-duration indicated as  $t_d$  and the corresponding positive impulse indicated as  $I_o$ . This is one set of data.

The second set of data is peak side-on negative pressure, which is suction pressure which is called as again  $P_{so}$  with a negative sign. Negative phase duration is also the  $t_d$  and the associated impulse which is also  $I_o$ . In addition, other parameters also important.

(Refer Slide Time: 26:36)

secondary parameters

- 3) peak reflected pressure,  $P_r$  ✓  
✓ peak dynamic pressure,  $q_o$   
shock front velocity,  $u$   
Blast wave length,  $L_w$

peak reflected pressure ( $P_r$ )

- When the blast opposes pressure of the blast wave it is reflected
- Effect is that the surface will experience or pressure max than the incident side-on value



The third set of parameters is peak reflected pressure called as  $p_r$ , then peak dynamic pressure called as  $q_o$ , shock front velocity which is  $u$ , and blast wave length which is  $L_w$ . The secondary parameters can be always derived from the primary blast wave parameter. So, these are called as secondary parameters.

Let us talk about peak reflected pressure, indicated as  $p_r$ . When the blast wave hits the surface, it is reflected back because the building is causing obstruction for progress of the blast wave. So, when the building opposes progress of the blast wave, it is reflected.

The effect of this reflection is that the surface will experience a pressure more than the incident side-on value. So, the pressure will now increase. The pressure intensity will be more.

(Refer Slide Time: 29:23)

- therefore, the magnitude of reflected pressure is amplified using a ratio

$$p_r = C_r p_{so} \quad (1)$$

where  $p_r$  - reflected pressure wave  
 $C_r$  - reflection coeff

which depends on

- 1) peak over pressure
- 2) angle of incidence of the wave front relative to reflecting surface
- 3) type of the blast wave

The slide also features the NPTEL logo in the top right corner and a small video inset of a presenter in the bottom right corner.

So, therefore, the magnitude of reflected pressure is amplified using a ratio. So, we should say the reflected pressure is given by reflection coefficient of  $p_{so}$ . Let us say equation 2.

$$p_r = C_r p_{so}$$

Let us say equation 1, no problem, equation 1. Where,  $p_r$  is reflected pressure wave,  $C_r$  is the reflection coefficient.

Which depends on, which depends on the peak over pressure and angle of incidence of the wave front related to the reflecting surface. It also depends on the type of the blast wave.

(Refer Slide Time: 31:41)

for peak over-pressure upto 138 kPa, following eqn (Newmark) helps to compute the reflection coeff

$$C_r = \frac{p_r}{p_{so}} \quad (2)$$

$$\approx 2 + 0.0073 p_{so} \quad (2a)$$

Alternatively, blast waves type,  $C_r$  can be also obtained from the TNO Green Book

duration of reflected pressure wave

- 1) depends on the dimensions of the reflecting surface
- 2) surface roughness

*(Lecturer's video inset shows a man in a pink shirt speaking.)*

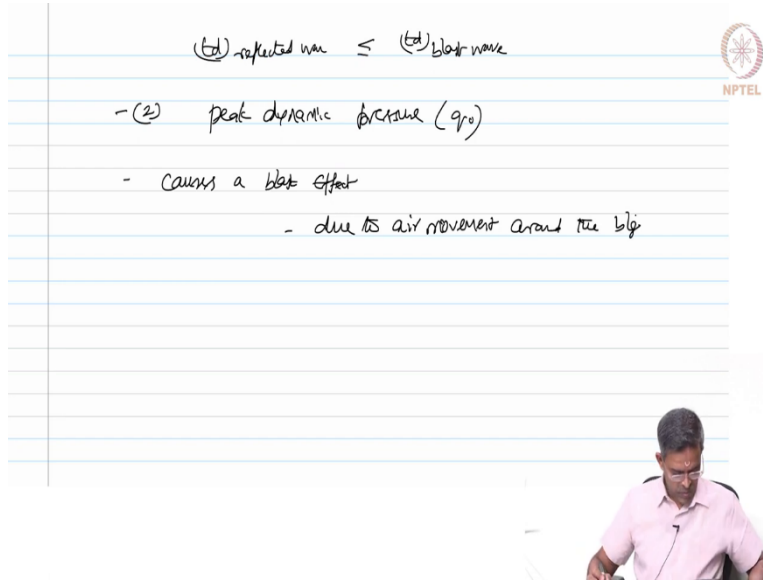
$$C_r \cong \frac{p_r}{p_{so}}$$

Having said this, let us say for peak over pressure up to 138 kilopascal following equation provided by Newmark helps to compute the reflection coefficient. So,  $C_r$  is given by  $p_r$  by  $p_{so}$ , is approximately equal to, you can see from this equation, will call say equation number 2, which is equation 2 (a).

$$C_r \cong 2 + 0.0073 p_{so}$$

Alternatively, for different type of blast waves  $C_r$  can be also obtained from the TNO Green Book. The duration of the reflected pressure depends on, the dimensions of the reflecting surface, surface roughness, up to a maximum time approximately equal to the positive phase duration of the wave.

(Refer Slide Time: 34:30)



$(t_d)_{\text{reflected wave}} \leq (t_d)_{\text{blast wave}}$

- (2) peak dynamic pressure ( $q_0$ )

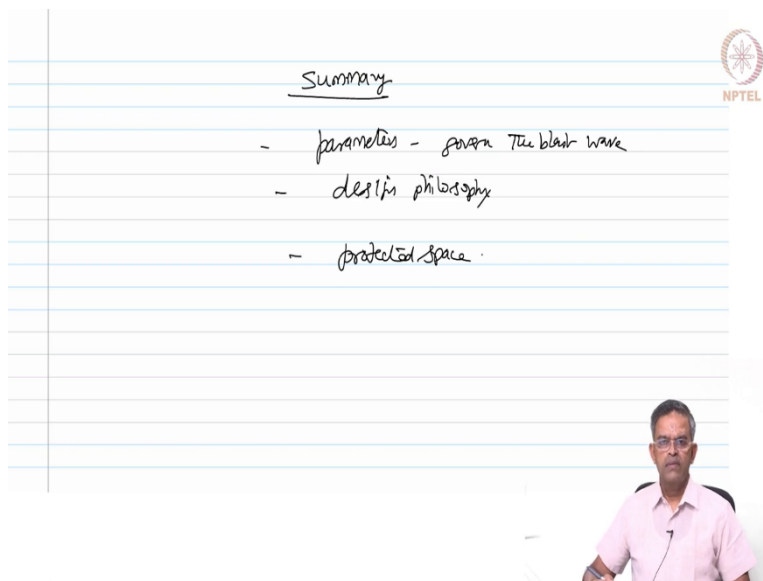
- causes a blast effect

- due to air movement around the bldg

So, therefore, we can say time duration of the reflected wave is less than equal to time duration of the blast wave, and depends on the O parameters. Upper limit of this corresponds to total reflection of the entire blast wave without any diffraction.

Let us talk about the next parameter which is peak dynamic pressure, talk about this parameter peak dynamic pressure which is given as  $q_0$ . The peak dynamic pressure causes a blast effect, and it is caused due to the air movement around the building.

(Refer Slide Time: 35:51)



Summary

- parameters - govern the blast wave

- design philosophy

- protected space

Friends, in this lecture, we learned about various parameters that govern the blast wave characteristics. We also learned about the design philosophy of blast resistant design and how the flexible units are better. We have also learnt something called protected space, and where and how a protected space should be used in a blast resistant design structure.

We will see further details in the next lecture about the Blast Resistant Design.

Thank you very much. And have a good day.