DYNAMIC BEHAVIOUR OF STRUCTURES SUBJECTED TO BLAST LOADS

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Abstract: These days throughout world terrorist attacks are occurring. These are unpredictable and also depend upon the blast material used and place of explosion occurred. Presently the explosive devices become the weapon of choice for the majority of the terrorist attacks which is a result of Property damage, Injuries and loss of lives. To protect property, lives and society is primary target of an Engineer and Architect.
This Paper contains how to resist blasting effects on the structures, loads due to blasts and guidelines to improve the resistance while designing the structures. It also consists of how to improve blast resistance to the existed structures and temporary structures. This paper contains mainly how to calculate blast load on the structures. This paper is a new one in the structural Engineering design to provide design guidance for engineers to design structures to resist against several types to blast loadings.

Keywords: Blast, explosion, terrorist, design, structure, resistance.

Introduction: Presently the explosive devices become the weapon of choice for the majority of the terrorist attacks. Property damage, Injuries and loss of lives are the result of these attacks. To protect property, lives and society is primary target of a civil Engineer. Now a day all over world these types of terrorist attacks are occurring. These are unpredictable and also depend upon the blast material used and place of explosion occurred. Though it unpredictable we can secure property and lives somewhat.
The attack of the World Trade Centre in New York City in February 1993, Federal Building in Oklahoma City in April 1995, and the recent collapses of both WTC Towers have underscored the attractiveness and vulnerability of civilian Buildings as terrorist targets. These attacks have also demonstrated that modern terrorism should not be regarded as something that could happen elsewhere. Any nation can no Longer believe themselves immune to terrorist violence within their own borders. The fact is that the majority of government and civilian buildings continue to be vulnerable to terrorist attacks. Structural engineers today need guidance on how to design structures to withstand various terrorist acts. A very limited body of design documentation currently exists which can provide engineers with the technical data necessary to design civil structures for enhanced physical security. The professional skills required to provide blast resistant consulting services include structural dynamics, knowledge of the physical properties of explosive detonations and general knowledge of physical security practices.
Purpose: This project, which is a new one in the structural engineering design to provide design guidance for structures of various types to resist blast loadings. Information in this project is the Result of extensive literature and data search, supplemented by some Original studies on various aspects of blast design.

Design Philosophy:
In the design of facilities for the manufacture or storage of explosive materials, the designer is concerned with maintaining a cost effective design and at the same time, directing his efforts towards reducing the risk of injury to people and damage to property from accidental explosions. The trade-off between risk reduction and safety costs can be balanced reasonably by enforcing the minimum design requirements provided in the design manuals. The design engineer needs a working knowledge of these manuals to design and construct safe economical facilities which comply with explosives safety standards.
For the blast resistance design main consideration is the loads are assumed 10% more than the general loading of the structure. Which gives minimum factor of safety and also grade of concrete is not less than M60. This grade of concrete is recommended here.
There are several methods to predict dynamic response of the structure. Some of Numerical methods, physical methods, empirical methods and semi-empirical methods etc.
Methods for Predicting Dynamic Response:
In the report, Structures to Resist the Effects of Accidental Explosions - Class Notes by Keenan(hereafter referred to as Class Notes), several methods are presented for predicting the dynamic behaviour of a single degree-of-freedom system subjected to a dynamic load; namely,
1. Phase Plane Method
2. Moment Area Method
3. Response Charts.

(1) Phase Plane Solution: This is a graphical method of solution in which it is assumed that the structural system can be represented by a single degree-of-freedom system. It is very useful in predicting maximum deflections, velocities, and times to maxima for response in the elastic or elasto-plastic range. However, it can be very cumbersome for predicting response in the plastic range. For a complete description of this method, the designer is referred to the report by Keenan.

2. **Moment Area method:**

This solution is easier to follow than the previous method; the governing relationship for the motion of a simple spring-mass system is:

EQUATION: $p - r = ma$ or:

EQUATION: $p/m - r/m = a$

Where,

p = applied pressure

r = resistance of system

m = mass of system

a = acceleration of system.

Effects Of Explosions : Generally effects will be

1. Loss of lives
2. Property damage
3. Pollution

We have to know that how will be the damage occur during the blast. For example take nuclear explosion.

Thermal radiation and prompt nuclear radiation are the first effects to threaten areas relatively close to a nuclear explosion. When thermal radiation strikes an object, much of the energy is absorbed. The amount absorbed determines whether combustible materials will be ignited or whether people will be burned. Thin, highly combustible materials such as paper, window curtains, leaves and dry grass can easily be ignited. They act as kindling for heavier combustible building materials, which fuel major fires.

The effects of the shock wave which travels away from the explosion faster than the speed of sound, poses the next hazard at close-in locations. The shock front is similar to a moving wall of highly compressed air and is accompanied by blast winds. When it arrives at a location, it causes a sudden rise in the ambient pressure. The increase in atmospheric pressure over normal values is referred to as overpressure, and the simultaneous pressures created by the blast winds are called dynamic pressures. Both decay rapidly with time from their peak values to ambient pressure and overpressure actually sinks below ambient before equalizing back to normal atmospheric pressure.

Blast pressures can create loads on buildings that are many times greater than normal design loads, and blast winds can be much more severe than hurricanes. Buildings with relatively weak curtain walls and interior partitions would probably be gutted very early during the blast phase, even at low overpressures. Dynamic pressures would then continue to cause drag loads on the structural frame that is left standing. Slabs over closed basements would experience the downward thrust of the over-pressure, which would be transmitted to supporting beams, girders and columns. Foundations would experience blast-induced vertical and overturning forces. Failure would occur unless the structural system was designed to resist these large, quickly applied loads.

Thermal Radiation:

Thermal radiation travels in a straight line from its source-the nuclear fireball-until it interacts with matter. Any solid, opaque materials will shield against thermal energy. Combustible materials will ignite when the thermal energy they absorb reaches the ignition threshold. Light colours and shiny surfaces will reflect a great deal of thermal radiation; dark, dull surfaces will absorb most of the thermal radiation that strikes them. A thin material is more likely to ignite than a thick material, since there is little opportunity for heat to be conducted away from surface layers. Protection against primary ignitions can be achieved by limiting the radiant heat energy that can penetrate the building. Metallic blinds or glass fibre draperies over windows will shield combustible furnishings from the thermal pulse. Blinds painted in light colours and having non combustible tapes will afford protection even though the paint may char. Although transparent materials cannot provide a complete shield against thermal radiation, solar glass will reduce the thermal energy reaching the interior of the room more than ordinary window glass and will have performed this function efficiently before the blast. Avoid combustible draperies and window shades.

Blast Pressure Output: Blast Phenomena: The blast effects of an explosion are in the form of a shock wave composed of a high-pressure shock front which expands outward from the centre of the detonation, with intensity of the pressure decaying with distance and as a function of time. The magnitude and other characteristics of the blast loads associated with the explosion are a function of:

1. Explosive properties.
2. Location of the explosive relative to the structure.
3. Amplification of the pressure by its interaction with the ground, barrier etc.

Short And Long Duration Blast Loads: The response of a structure to blast loads depends on its location relative to the source of the explosions. This response is expressed in terms of pressure ranges; namely, high, intermediate, and low pressure ranges.

a. Impulse Design. When the initial pressures acting on a structure are high and the durations short, compared to the response time of the structure, then it has to be designed for the impulse (area under curve)rather than for the peak pressure. The design of structures that respond to impulse loads is presented in detail in

Design manual.

b. Pressure Design. Durations of blast loads acting on structures Designed for a low pressure range are extremely long in comparison to impulse (short duration) loads. Here, the structure responds to the peak pressure.

c. Pressure and Duration Design. Structures subjected to pressures in the intermediate range are designed to respond to the combined effects of both the pressure and impulse associated with the blast output. To resist impulse and pressure earthen beams will play major roll.

Pressure Increase Within A Structure: Leakage of pressures through any openings in a structure occurs when such a structure is engulfed by a blast wave. The interior of the structure experiences an increase in its ambient pressure in a time that is a function of the structure's volume, area of openings, and applied exterior pressure and duration.

External Blast Loads On Structures: Forces Acting on Structures: The blast wave generated by an explosion in air is characterized by its transmission velocity, U; by a peak incident pressure, by a positive phase duration, and by a specific impulse, For each pressure range, there is a particle or wind velocity associated with the blast wave that causes a dynamic pressure on objects in the path of the wave. The values of the peak dynamic pressure, vs. peak incident pressure are shown above.

Calculating Durations of Positive and Negative Pressure Phases:

For design purposes, it is necessary to establish the variation or decay of both the incident and dynamic pressures with time, since the effects on a structure subjected to a blast loading depend upon the intensity-time history of the loading as well as on the peak intensity. Equations are provided in Design manual to be used in calculating the durations of the positive and negative pressure phases. However, the rise time for the negative pressure should be taken as one-third of its duration.

Structural Analysis And Design: Design and analysis of a structure for blast loads is a dynamics problem. A structural-dynamic problem differs from its static-loading counterpart in two important respects. The first difference to be noted is the time-varying nature of the dynamic problem. Because the load and the response vary with time, it is evident that a dynamic problem does not have a single solution, as a static problem does.

A succession of solutions corresponding to all times of interest in the response history can be established. If a single degree-of-freedom system (such as a mass, M, connected to a spring having a stiffness, K) is subjected to a static load, P the deflected shape depends directly on the applied load and can be calculated from P. On the other hand, if a load P(t) is applied dynamically, the resulting displacements of the system are associated with accelerations which produce inertia forces resisting the accelerations. In general, if the inertia forces represent a significant portion of the total load equilibrated by the internal elastic forces of a system, then the dynamic character of the problem must be accounted for in its solutions.

Procedure for blast load calculation:

Step1. Determine the explosive charge weight, w. Assume a hemispherical surface burst model. Select point of interest on the exterior vertical wall of a building at height h above ground.

Step2.For the point of interest, calculate standoff distance at height h, Rh scaled standoff distance, Z and angle of incidence α.

$Rh = (R^2+h^2)^{1/2}$

$Z = (Rh/w^{1/3})$

$\tan \alpha = h/R$

step3.From graph, read peak reflected pressure and scaled positive reflected impulse. Multiply scaled impulse by w to obtain absolute values.

Step4.Calculate the load and impulse load from the parameters of Z which are obtained from graph. Add this load to the analysis and design of the structure.

Example Problems:

For Single Room Design:

Take a ten square meters area room and calculate the strength of the wall, column, beam and slab. Consider blast occurred at the mid of the room. That is source of distance is 5 m. and charge weight is 100kg of TNT

$Z= Rh/W^{1/3}$

$Rh=R/w^{1/3}$

$\tan \alpha =h/R$

Rh=5.9=6m

$z=1.3\ m/kg^{1/3} > Z_{min}=1.2$

angle a=32.6<45 deg

Determining the blast wave parameters for $Z=1.3 m/kg^{1/3}$ reading from graph are:

Peak reflected pressure Pr= 178 kpa

Positive incident impulse $Ir/w^{1/3}$= 189 kpa-msec/$kg^{1/3}$

+phase duration $to/w^{1/3}$ = 3.05 msec/$kg^{1/3}$

Ir=877.3 kpa-msec

to= 14.2 msec

The penal load is calculated:

Load= Pr*area= 5696 KN

Impulse= Ir*area= 28073 KN-msec

Strength of the wall:

Tensile strength and crushing strength of a brick is 2000 KN/m2 and 60000 KN/m^2 Therefore here the tensile strength not enough to withstand so need not to go for shear wall construction with minimum M60 grade of concrete. The crushing strength of a brick is 60000Kn/m2. For the above calculated impulse load and load due to reflected pressure structure will withstand but damage will take place. Here the crushing value of the brick is grater that the impulse loads on the wall so the wall is not going to collapse but it cracks. More well as the beams, columns and slab are also crack but safe because it has higher strength than brick. The panel load calculated above should take in to the account of design and then only we can prevent damage.

In the procedure the calculation of blast loads and impulse load will be calculated and the structure is designed for this impulse load and load calculated load. This load is addition load to the general load considered in the design process.

Table of various blast materials are given in terms of TNT equivalent weight at the end. Based on this material property the weight of the explosive material is selected from the table given.

Air-burst example:

Let us take 20,000 lb of charge weight, ground distance be 300ft. And height of burst 90ft.

Sol:

W=20,000

By applying 20% of safety factor,

W=1.2(20000)

W=25000

Rg=300ft

Hc=90ft

Scaled height of burst is $Hc/w^{1/3}$ = 3.08 ft/$lb^{1/3}$.

Tanα = $Hc/w^{1/3}$

α= 73.3

Reflected pressure:

$Hc/w^{1/3}$= 3.08 ft/$lb^{1/3}$ and α=73.3

Prα=10.1(from graph)

Irα/$w^{1/3}$=9.2 psi-m/$lb^{1/3}$

Irα= 269 psi-ms

From scaled distance Z=7.8ft/$lb^{1/3}$.through graph 2-7 from manual.

U=1.33ft/ms

ta/$w^{1/3}$=300ms/$lb^{1/3}$

ta=8772.05ms

ls/$w^{1/3}$=9.2psi-ms/$lb^{1/3}$

to/$w^{1/3}$=155ms/$lb^{1/3}$

to=4532.23ms.

Free-air burst:

Let us take 290 lb of charge weight, and height of burst 60ft.

Sol:

W=290lb

By applying 20% of safety factor,

W=1.2(290)

W=350

Hc=60ft

At the point of interest R=[h^2+b^2]

R=54.1ft.

From scaled distance Z=7.67ft/$lb^{1/3}$. through graph 2-7 from manual.

Pso=11.2psi

U=1.34ft/ms

ls/$w^{1/3}$=7psi-ms/$lb^{1/3}$

ls=49.3psi-ms

to/$w^{1/3}$=2.05ms/$lb^{1/3}$

to=14.5ms.

ta/$w^{1/3}$=3.15ms/$lb^{1/3}$

ta=22.2ms

Surface burst example:

Let us take 20,000 lb of charge weight, ground distance be 530ft.

Sol:

W=20,000

By applying 20% of safety factor,

W=1.2(20000)

W=25000

Rg=300ft

From scaled distance Z=18.1ft/$lb^{1/3}$. through graph 2-15from manual.

Pso=3.45 psi

U=1.22ft/ms

is/$w^{1/3}$=4.7psi-ms/$lb^{1/3}$

is=137.4psi-ms.

to/$w^{1/3}$=3.3ms/$lb^{1/3}$

to=96.5ms.

ta/$w^{1/3}$=10.6ms/$lb^{1/3}$

ta=310 ms

Computer Programs: Currently a large number of structural mechanics programs are available, most of which utilize finite element methods, finite difference methods or a combination of the two.

a.Finite Element Computer Programs: Four widely used finite element computer programs that have provisions for both static and dynamic structural behaviour. Additional features of these programs, ADINA, ANSYS, NASTRAN, and STARDYNE are described in their respective manuals.

b. Additional Computer Programs: There are eight additional programs now available to the Navy, which are not as well known as the four described above. These programs offer unique capabilities for blast resistant design and were developed specifically to analyze structures encountered in this area. The programs are stored in the NAVFACENGCOM Library and the user can operate the programs via a time-share or batch terminal by addressing the Control Data Corporation CYBERNET Computer System.

Blast - Blast Loading In Blast Cells: BLAST is a computer program capable of generating characteristic blast loading parameters associated with confined explosions, such as determining the internal blast environment in a rectangular cell.

POLYMERS: Polymers are various types. Some of the polymers we can use to improve the strength and blast resistance to the existing structure. Polymer coatings can increase blast resistance of the

Temporary and existing structures. One of the greatest threats during a bombing attack comes from fragmentation – pieces of walls, windows, equipment, and vehicle debris flying at high speeds can result in extensive injury and death. A key tactic to defeating this threat is to ensure that the exterior wall of a building can survive the bomb blast without contributing to the fragmentation problem. While this is typically accomplished in existing buildings by adding strength and mass to the wall (usually with concrete and steel),this is often difficult to implement, time-consuming, heavy, and expensive. Polymer retrofit solutions are to introduce ductility and resilience Into walls. The premise of the retrofit technique is to apply an elastomeric coating that bonds to the wall forming a tough elastic membrane. Although fracture of the wall may occur, the polymer membrane will not rupture and can effectively contain the debris.

Application of Elastometric Retrofit. In the fall of 1999, AFRL began evaluating spray on polymer coatings as an expedient retrofit technique for non-load bearing CMU walls. The material that was used is an elastomer that is ductile, tough, and has modest strength . The material is sprayed directly onto the interior surface of the wall and cures almost instantly, as shown. The thickness of application is relatively easy to control, and the polymer bonds to a wide variety of surfaces. This retrofit technique takes advantage of the toughness and resiliency of modern elastomers to effectively deform and dissipate the blast energy, while containing shattered wall fragments. Although the retrofitted walls may shatter in a blast event , the elastomer does not rupture and effectively contains the debris .

The resilience and large strain capacity of elastomers can be exploited to absorb blast energy and contain building debris. Elastomers are composed of long polymer chains, usually cross-linked or connected by chemical bonds. Cross-linking

makes elastomers reversibly stretchable within a significant range of deformations. In the outstretched state, the polymer chains are oriented in random directions. When stretched, the

polymer chains become elongated and ordered along the deformation direction.

When no longer stretched, the cross -links guide the elastomer back to its original shape as the chains once again randomize.

Polymer Characteristics used in the blast resistance coating:

Property	Value	Test Standard
Secant modulus 1	24,000 psi	ASTM D638
Elongation at Rupture	90%	ASTM D638
Maximum tensile strength	2000 psi	ASTM D638
Flammability	Flame resistant; 2-hr fire rating	ASTM E11 ASTM E84
Toxicity	Non-toxic after curing	Review MSDS

Table 1 polymer characteristics

The polymers was much stiffer than many other candidate materials. This initial stiffness helps to reduce wall deflections in response to a lateral load such as air blast. The high elongation at rupture provides the toughness and ductility to contain the debris and fragmentation, even if large deformations occur. Based on the engineering properties determined from uniaxial tensile tests, dynamic models of the wall system can be used to predict response to air blast loads.

Conclusion: Blast is unpredictable like earthquake. We can not predict completely but we can calculate and estimate the effect by it material and quantity used. Engineers should have proper guidelines towards blast resistance design and should have skill to execute design during the construction. For the existing structures polymer coatings are applied to improve blast resistance to the structure.

Although it is not practical to design buildings to withstand any Conceivable terrorist attack, it is possible to improve the performance of structures should one occur in the form of an external explosion. By maximizing standoff distances and hardening key elements, designers can give building occupants a reasonable chance of escaping death and serious injury during such an event. Building owners need to understand the factors that contribute to a structure's blast resistance and provide input throughout the design process to ensure that appropriate threat conditions and levels of protection are being incorporated.

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