

Design Of Structural Components Against Blast Load

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Abstract— Bombing and explosion severely cause human, infrastructural and economic loss. Also irresponsible elements in the society can cause damage to the infrastructure which can result in human as well as economic loss. To mitigate the effect of blasts on the structures the need of structural resistance against blast load has gained tremendous importance and for this purpose the calculation of ultimate intensity of the blast load on the structure along with its analysis is must so that, the structure can be designed to resist and mitigate the effects of the blast. Data related to blasts that took place in the history were assimilated and a set range of weight of charges and their particular standoff were statistically tabulated. A model of G+12 RCC structure was designed on Staad Pro these set ranges of weight of charges and their stand off distances were applied on the structure with an aim to study the behavior of the structure under its application. Time history theory was found convenient for analyzing the structure against blast load and then it was designed using Staad Pro. The structure was also estimated for getting an idea about cost comparison of such structure against the normal structure.

Index Terms— Bombing , Explosion, Human loss, Infrastructural loss, Economic loss, Mitigate the effect of blast, Structural Resistance against Blast load, Weight of Charge, Stand off Distance, Staad Pro, Time History Theory, Cost Comparison

1 INTRODUCTION

1.1 INTRODUCTION TO THE RESEARCH WORK

Recent incidents of the attacks on places of public interests by some groups belonging to the terror fraternity have created a feeling of distress among people. The explosives such as trinitrotoluene (TNT), Ammonium nitrate fuel oil (ANFO), etc had been repeatedly used for the sole purpose of damaging the structural components, ultimately damaging the entire structure and creating structural, economical as well as human loss. Explosions can also occur due to human error. Hence, designing efficient blast resistant building components account to be of immense importance. As the blasts are uncertain, one has no idea about the standoff distance, weight of the charge, type of explosive material, etc. Hence different weights of charge at different standoff distances which would damage the structural elements are considered. Different codes and research papers had been under constant reference for calculating the blast load acting on the structure, and will also be used further for analysis of the forces due to impacts caused by the blasts, behavior of the structure due to blast and for designing a blast resistant structure.

1.2 OBJECTIVES

The objectives of the research were as follows :

1. To analyze the structural component and understand its behavior when blast load is applied.
2. To design the component in such a way that the blast forces get mitigated and there is reduction of damage coming to the structure.
3. To prevent structural, economical and human loss.

1.3 SCOPE

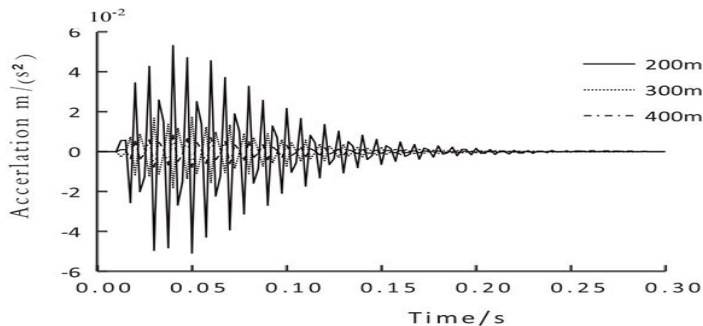
1. The structural components susceptible to damage under blast will now be designed efficiently to resist the blast load .
2. We can understand the impact and effect of different charge of explosives at different standoff distances .
3. Enabling us to calculate to pressure due to a blast and its effect on the structure and even design the structure to prevent failure under blast load .
4. We will be able to design blast resistant structure economically maintaining the aesthetics of the structure

2 RESEARCH METHODOLOGY

Various past events of blast, their factors and blast parameters were studied. A series of weights of charge (TNT kg) and their standoff distances were considered by researching the previous events which caused a major damage to the structure. The parameters of blast pressure and blast wave were calculated. A model was prepared on StaadPro. General load combination was assigned to the model along with time history analysis. Time history analysis was done based on the computed parameters of blast wave and the structure as whole was analyzed. To mitigate the effect of blast, various remedial measures were studied. Results were calculated and the project was concluded.

3 BLAST WAVE- TIME HISTORY CURVE

As the blast wave after its encounter with structure releases energy, that is transferred through available creation of a blast wave. The time needed for pressure to reach its Peak Value (**Pso**) is initially considered equal to zero, ie before the occurrence of blast, the pressure acting on the structure is equal to the atmospheric pressure denoted by (**Po**). At the instance of blast at ground level away at a specified distance from the structure, huge amount of energy is released from the point of blast. Under ideal conditions, the pressure at a point is considered to rise instantly to its peak value, it then promptly decays with an exponential rate to reach the ambient pressure, it goes below it, and it finally rises again to the ambient level. The blast waves are generated in all the directions in form energy spheres. They release pressure in both horizontal as well as vertical components but, since horizontal components dominate vertical components, the structure is to be designed to mitigate majorly horizontal structural displacements. A tangent drawn from the energy globe approaching the structure depicts the total blast pressure acting on the face of the structure. The time required by the blast wave to enforce itself on the structure is known as approach time (**tA**). The instance at which the blast wave enforces itself on the structure gives rise to Peak Pressure (**Pso**). The Peak Pressure decreases with an exponential rate and reaches ambient pressure creating a positive specific impulse region and its duration is known as positive time duration (**td**). The soon as it reaches ambient pressure, the pressure gets dissipated creating a negative pressure is formed on the face of the structure. The duration required for the negative pressure to dissipate itself is known as negative time duration (**td-**). The summation of approach time (**tA**), positive time duration (**td**) and negative time duration (**td-**) is known as total pressure dissipation time or over pressure dissipation time. Under ideal conditions, the pressure at a point is considered to rise instantly to its peak value, it then promptly decays with an exponential rate to reach the ambient pressure, it goes below it, and it finally rises again to the ambient level.



4 ANALYSIS AND DESIGN

4.1 CALCULATION OF BLAST PRESSURE PARAMETERS

An explosion)blast(is defined as a large-scale, rapid and sudden release of energy. The effects of explosion generate impulsive high stresses on the structure and also damage the structural components resulting catastrophic failure of the structure. Hence, to prevent economical and human loss the structure is designed to resist the blast load. For calculation of blast load two parameters are considered of immense importance. They are **STANDOFF DISTANCE & WEIGHT OF CHARGE**. As blasts are sudden and their effects are unpredictable, we considered a range of standoff distances and weights of charge which would ultimately damage the structure. Using TM5-1300 and studying various research papers, we calculated the various parameters of the blast pressure their summation of all the pressure parameters with a certain case of standoff distance and particular weight of charge gave us maximum blast pressure

The pressure parameters are defined as follows:

1. Standoff distance (**R**) : The distance of the explosive from the external face of the structure is known as standoff distance. We considered three standoff four standoff distances at 2.5 & 5 m from the structure
2. Weight of charge (**W**) : The weight of the explosive is known as weight of charge. We considered three charges of 850 kg, 1000kg & 1500 kg respectively for each standoff distance.
3. Scaled distance (**Z**) : It is nothing but co-relation between standoff distance and weight of charge. #

$$Z = \frac{R^{\frac{1}{3}}}{W} \tag{I}$$

4. Peak pressure (**Pso**) : It is the pressure exerted exactly at the instance when the blast occurs. #

$$P_{so} = \left(\frac{1772}{Z^3}\right) - \left(\frac{114}{Z^2}\right) + \left(\frac{108}{Z}\right) \tag{II}$$

5. Pressure exerted by air behind shock front:

$$Q_s = \left(\frac{5(P_{so}^2)}{2(P_{so} + 7P_o)}\right) \tag{III}$$

6. Reflected pressure (**Pr**) : The pressure reflected after being confronted by an solid object.*

$$Pr = 2P_{so} \left(\frac{7P_o + 4P_{so}}{7P_o + P_{so}}\right) \tag{IV}$$

7. Over pressure dissipation time (**td**) : Duration **td** is related directly to the time taken for the overpressure to be dissipated. Overpressure arising from wave reflection dissipates as the blast waves propagate to the edges of the obstacle at a velocity related to the **speed of sound(Us)** in wave front. Denoting the maximum distance from an edge as **S** (stand off distance) the additional pressure is calculated in time **5S/Us**. Conservatively, (**Us**) can be taken as the normal speed of

sound, which is about **340 m/s**, and the additional impulse to the structure evaluated on the assumption of a decay.

4. Hence, peak pressures at 2.5m and 5m standoff distances with 850 kg TNT, 1000 kg TNT & 1500 kg TNT are considered as their scaled distance is between 0.1 m/kg^{1/3} and 0.2 m/kg

Standoff distance R	Weights of charge W	Scaled distance Z	Peak pressure P_{so}	Pressure exerted by air behind shock front Q_s	Reflected pressure Pr	Over pressure dissipation time Td	Reflected impulse Ir
2.5	850	0.145	577.06	897.99	2718.64	0.036	48.93
	1000	0.135	715.33	1200.79	3601.2	0.036	64.82
	1500	0.118	1070.22	1619.66	6029.63	0.036	108.53
5	850	0.181	298.42	222.98	1132	0.073	41.31
	1000	0.171	315.17	293.21	1405.96	0.073	51.31
	1500	0.150	520.577	555.06	2373.31	0.073	86.62

Table 1 : Blast Pressure Parameters

Here, at a stand off distance of 2.5 mand with a charge of 1500 kg the structure is severely damaged. Hence, the structure should be so designed that it sustains the blast load from 1500kg charge with an stand off distance of 2.5m from the structure.

4.2 CALCULATION OF BLAST WAVE PARAMETERS

1. Scaled Distance (**Z**) plays an important role in calculation of various blast wave parameters.
2. If the scaled distance accounts (0.1 < Z < 0.2) greater than 0.1 m/kg^{1/3}, then the blast wave generated will have disastrous effects on the structure and even causes failure of its structural elements.
3. As the structure is designed as efficient blast resistant structure, only those parameters can be calculated for calculation of the blast pressure parameters which will have the tendency to critically damage the structure so it is of utmost importance to mitigate these pressures.

5. Blast wave coefficients (**λ**)
It is used to find arrival time (tA) of blast wave. #
$$\lambda = \frac{Z}{1.1m} \quad (v)$$
6. Arrival Time (**tA**): The time in which wave front encounters the surface of structure. #
$$tA = \lambda * Ot \quad (VI)$$
7. Decay Coefficient (**b**) : The coefficient rearding experiential decrease of wave front to reach the ambient pressure.
$$b = 1.5 * (Z^{-0.38}) \quad (VII)$$
8. Using Kinney Graham equation to calculate positive time duration*

$$P_{so}(T_a) = P_{so} \left(1 - \frac{t_A}{t_0}\right) * e^{(-b * \frac{t_A}{t_0})} \quad (VIII)$$

9. Positive impulse (**Is**) : Impulse created at the arrival time of the blast wave is called as positive impulse.
10. Negative Impulse (**Is'**): Impulse created after the positive impulse gets disseminated is known as negative impulse*
$$Is' = Is \left(1 - \frac{1}{22}\right) \quad (IX)$$
11. Negative duration time (**to'**): Time taken by negative impulse tto dissipate.Using Henrych equation to calculate negative dissipation time#
$$to' = 10.4(W)^{1/3} \quad (X)$$

#: Referred from Euro Code
*:Referred From TMS 1300

Stand off distance	Weight of Charge	Scale Distance	Peak Pressure	Over pressure dissipation time	Blast wave coefficient	Arrival Time	Decay Coefficient	Positive duration time	Negative impulse	Positive impulse	Negative duration time
R	W	Z	P _{so}	O _t	λ	t _A	B	t _o	I _s ⁻	I _s	t _o ⁻
2.5	850	0.145	577.06	0.036	0.26	0.00936	3.12	0.0107	10767.80	26362.54	0.985
	1000	0.135	713.33	0.036	0.25	0.009	3.21	0.0104	12000	32444.24	1.04
	1500	0.118	1070.22	0.036	0.21	0.00756	3.37	0.0087	15724.42	50904.41	1.19
5	850	0.181	298.42	0.073	0.527	0.038	2.87	0.053	5383.90	9488.75	0.985
	1000	0.171	315.17	0.073	0.5	0.036	2.93	0.057	6000	11543.83	1.04
	1500	0.150	520.57	0.073	0.436	0.031	3.08	0.044	7862.24	18345.21	1.19

Table 2 : Blast wave parameters

5 PREVENTIVE MEASURES

The increase in the number of terrorist attacks especially in last few years have shown that the effect of blast loads on the building is a serious matter as they create structural, economical and human loss. Thus, there arises a need to design a blast resistant structure which would mitigate the effect of blast. Designing and execution of such blast resistant structure needs an expert team and of designers, architects, construction managers & project managers. The cost of such a specialized structures is way more as compared to any ordinary structure and hence those structures having national or international importance are designed as blast resistant structures. There are less chances of an ordinary structure having threat due to blast. But being on the safer side, if certain preventive measures are taken then even the ordinary structures stand safe and mitigate the effect of blast.

Following are the preventive measures which should be adopted.

A) Architectural Aspect of Blast Resistant Building Design.

1. Planning and Layout
2. Structural form & Internal Layouts
3. Bomb Shelter Areas
4. Ventilation

B) Analysis Methods used in Blast Resistant Design.

C) Structural Aspect of Blast resistant Building Design.

5.1 Architectural Aspect of Blast Resistant Building Design.

A primary requirement in the prevention of catastrophic failure of the entire portion or a large portion of it. It is necessary to minimise the effect of blast wave transmitted to the building through the opening to minimise the effects of the projectiles on the inhabitants of the building. Hence, designing a blast resistant structure and maintaining the aesthetics of structure is a challenge.

5.1.1 Planning and Layout

Much can be done at planning and designing stage of a new building to reduce the potential threats and the associated risks of injury and damage. The risk of a terrorist attack, necessity of blast protection for structural and non-structural members, adequate placing of shelter areas within a building should be considered for instance. In relationship to an external threat, the priority should be to create as much as standoff distance between the external bomb and the building as possible. On congested city centres there may be little or no scope for repositioning the building, but what standoff there is should be secure where possible. This can be achieved by strategic location of obstructions such as bollards, trees & street furniture.

5.1.2 Structural form & Internal Layouts

Structural form is parameter that greatly affects the blast loads on the buildings. Arches and domes are the type of structural forms that reduce the blast effect on the building compared with a cubicle form. The plan shape of a building also has a significant influence on the magnitude of blast load it is likely to experience. Complex shapes that cause multiple reflections of the blast should be discouraged. Projecting roofs or floors, and buildings that are U-shaped on plans are undesirable for this reason. It should be noted that single storey buildings are

more blast resistant compared to multi-storey buildings of applicable. Partially of fully embed buildings are quiet blast resistant. These kind of structures take the advantage of shock absorbing property of the soil covered by. The soil provides protection in case of a nuclear explosion as well. The internal layout of building is another parameter of the building that should be undertaken with the aim of isolating the value from the threat and should be arranged so that the highest exterior threat is separated by the greatest distance from the highest value asset. Foyer areas should be protected with reinforced concrete walls & double door opening should be used and the doors should be arranged eccentrically within a corridor to prevent the blast pressure entering the internal of the building. Entrance to the building should be controlled and be separated from other parts of the building by robust construction for greater physical protection. An underpass beneath or a car parking below or within the building should be avoided unless access to it can be effectively controlled. A possible fire that can occur within structure after an explosion may increase the damage catastrophically. Therefore the internal members should be designed to resist the fire.

5.1.3 Bomb Shelter Areas

The bomb shelter areas are specially designated with the building where vulnerability from the effect of explosion is at minimum and where personnel can retire in the event of a bomb threat warning. These areas must offer reasonable protection against explosion & ideally be large enough to accommodate the personnel involved and be located so as to facilitate continual access. For modern framed buildings, shelter areas should be located away from the window, external doors, external walls and top floors if the roof is weak.

Areas surrounded by full height concrete walls should be selected and underground car parks, gas storage tanks, areas of light weight partition walls, eg. Internal corridors, toilet areas, conferences should be avoided while locating the shelter areas. Basements can sometimes be useful shelter areas, but it is important to ensure that the buildings does not collapse on top of them. The functional aspect of bomb shelter areas should accommodate all the occupants of the building, provide adequate communication with the outside, provide sufficient ventilation and sanitation, limit the blast pressure to less than the ear drum rupture pressure and provide alternative means of escape.

5.1.4 Ventilation

When an explosion occurs within a building, the pressures associated with the initial shock front will be high and therefore will be amplified by their reflections within the building. This type of explosion is called as confined explosion. In addition and depending on the degree of confinement, the product produced by chemical reaction involved in the explosion will cause additional pressures and increase the load duration

within the structure. Depending on the extent of ventilating, types of confined explosions are possible.

5.2 Analysis Methods used in Blast Resistant Design.

Most structures are complex in behaviour even under static loads and their responses to dynamic loads might include additional complications from combinations of elastic and inelastic vibrations modes. A common approach to determine the dynamic response of a structure to some specific loading in to model the structure as a system of infinite structural elements and masses connected together at a discrete number of nodal points. If the force displacement relationships are known for the individual elements, structural analysis can be used to study the behaviour of the assembled structures. It is prudent for practical design purposes to adopt approximate methods that permit rapid analysis of complex structures with reasonable accuracy. These methods usually require that both the structures and the loading be idealized to some degree.

5.3 Structural Aspect of Blast resistant Building Design.

The front face of the building experiences peak over pressure due to reflection of the external blast wave.

Once the initial blast wave has passed the reflected surface of the building, the over pressure decays to zero. As the sides and the top faces of the buildings are exposed to overpressure (which has no reflection and are lower than the reflected over pressure is on the front face), a relieving effect of the blast over pressure is experienced on the front face. The rear of the structure experiences no pressures until the blast wave has travelled the length of the structure and a compression wave has been to move towards the centre of the rear face. Therefore, the pressure built up is not instantaneous. On the other hand, there will be time lag in the development of the pressure and loads on the front and back faces. This time lag causes translational forces to act on the building in the direction of the blast wave. Blasts loading are extra ordinary load cases however, during structural design this effect should be taken into account with other loads by an adequate ratio. Similar to the static loaded design techniques which are collapse limit design and functionally limit design. In collapse limit design the target is to provide enough ductility to the building so that the explosion energy is distributed to the structure without overall collapse. For collapse limit design the behaviour of the structural member connection is crucial. In case of an explosion, significant transitional movement and moment occurs and the loads involved should be transferred from the beams to columns. The structure does not collapse after the explosion, however it cannot function anymore. Functionally, limit design however, requires the building to continue functionality after a possible explosion occurred. Only non-structural members like windows or claddings may need maintenance after an explosion so that they should be designed ductile enough.

When the positive phase of the shock wave is shorter than the natural vibration period of the structure, the explosion effect vanishes before the structure responds. This kind of blast loading is defined as 'impulsive loading'. If the positive phase is longer than the natural vibration of the structure, the load can be assumed constant when the structure has maximum deformation. This maximum deformation is a function of blast loading and the structural rigidity. This kind of blast loading is defined as 'quasi-static loading'. Finally, if the positive phase duration is similar to the natural vibration period of the structure, the behaviour of the structure becomes quite complicated. This case can be defined as 'dynamic loading'. Frame buildings designed to resist gravity, wind loads and earthquake loads in the normal way have frequently been found to be deficient in two respects. When subjected to blast loading, the failure of beam-to-column connections and the inability of the structure to tolerate load reversal. Beam-to-column connections can be subjected to very high forces as the result of an explosion. The forces will have a horizontal component arising from the walls of the buildings and a vertical component from the differential loading on the upper and lower surface of floors. Providing additional robustness to these connections can be a significant enhancement. In the connections, normal details for the static loading have been found to be inadequate for blast loading. Especially, for the steelwork beam-to-column connections, it is essential for the connections to bear inelastic deformation so that the moment frames could still operate after an instantaneous explosion. The main feature to note in reinforced concrete connections are the use of extra links and the location of these starter bars in the connection. These enhancements are intended to reduce the risk of collapse or the connection be damaged, possibly as a result of a load reversal on the beam. It is vital that in critical areas, full moment resisting connections are made in order to ensure that the load capacity of the structural members after the explosion. Beams acting primarily in the bending may also carry significant axial load caused by the blast loading. On the contrary, columns are predominantly loaded with axial forces under normal loading conditions, however under blast loading they may be subjected to bending. Such forces can lead to loss of load carrying capacity of a section. In the case of an explosion, columns of a reinforced concrete structure are the most important members that should be protected. Two types of warping can be applied to provide this, Warping with steel belts or warping with carbon fibre-reinforced polymers (CFRP). Cast-in-situ reinforced concrete floor slab are the preferred option for blast resistant buildings, but it may be necessary to consider the use of precast floor in some circumstances. Precast floor units are not recommended for use at first floor where the risk from an internal explosion is greatest. Light weight roofs are more particularly, glass roof should be avoid-

ed and reinforces concrete or precast concrete slab is to be preferred

6 COST COMPARISON

A blast resistant structure and a normal structure of same dimension was designed for the sole purpose of studying, interpreting and comparing. After comparing both the structures, it was observed that the structure designed to resist blast required more quantity of concrete and steel than the normal structure. The requirement of concrete by blast resistant structure was 5% more than normal structure. The requirement of steel by blast resistant structure was 37% more than the normal structure. Hence, such structures prove to be uneconomical in construction as their cost is sums up way more than the normal structures. But, after studying the results, it was also observed that the moment generated at the supports of blast resistant structure are found less than that of the normal structure. Hence, such structure is more likely to resist heavy loads by mitigating the effect of blast rather than a normal structure which is more susceptible to damage and ultimately collapse under heavy loads. It is also proved that blast resistant structures can resist accidental loads (in form of blast loads) while the same case may not be in the structures not designed as blast resistant structures. Blast resistant structures are uneconomical in construction but after studying the results of both the structures in detail, it is understood that blast resistant design should only be implemented in case of those structures which have national or international importance. Blast resistant design should not be adopted for ordinary structures.

7 RESULTS

Maximum reactions, bending moments maximum displacements at the nodes of these columns were generated through running a design programme on staad pro. The requirement of concrete for blast resistant structure was 5% more and the requirement of steel was 37% more than normal structure.

8 CONCLUSION

A blast resistant structure was successfully designed on Staad Pro using time history theory. The applied blast loads were successfully mitigated. As blast load is not predefined on the structure a series of weight of charges and their potential standoff distances have to be generated and without generating a series, the structure cannot be designed as blast resistant structure. No structure can be made purely blast proof. If the blast occurs with an intensity way more than the considered blast or design blast, then the structure is surely going to fail. Blast resistant structure needs more quantity of concrete

and steel than normal structure. The requirement of concrete by blast resistant structure was 5% more than normal structure. The requirement of steel by blast resistant structure was 37% more than the normal structure. Blast resistant structures are uneconomical in construction and hence they should only be used to designed structures having national or international importance. Moments generated at the end of columns are less than that of natural structure, hence it can mitigate the effect of blast in a calculated extent. But the structure cannot be designed as blast proof structure because the action on the blast wave on each component of the structure is unpredictable and it is a heinous task to calculate the blast pressure and also one cannot firmly quote about the intensity of blast which would act on the components as it is a dynamic load.

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