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Mitigation of Blast Load and Protective Design of Vulnerable Buildings with Concrete Facades

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Attention to design secure buildings against blast loading has become more important as the number of terrorist attacks are increasing daily. Protection of the vulnerable structures against blast loading is a prerequisite to safeguard the occupants' lives. In this background, designing structures with concrete facades to transfer blast induced substantial lateral loads to a moment carrying frame system, and allowing it to behave in the predetermined manner is paramount. A property of designed facade restricts blast waves to propagate into the building and thereby prevents damages to key elements. Further it would avoid the entering of exploded fragments which could injure occupants of the building. Failure of critical/key structural elements will lead to the progressive collapse of the structure. This paper discusses the behaviour of the concrete facades under blast loads; enhancement of load carrying capacity & effective load distribution of facades by introduction of concrete fins and reinforcement design. Procedures to be followed in calculating blast loads, recognition of material nonlinearity for economising the designs and material strength enhancement at straining are also discussed in the paper. In addition, behaviour of structures for different occupancy levels based on performance-based designs are elaborated with relevant to the blast load actions

Keywords: Blast pressure loads, Concrete Facades, Material nonlinearity, Progressive collapse

1. Introduction

The importance of design structures against blast loads is increasing globally due to the ever-growing terrorist threats. It is a known fact that blast generates very high pressure loads in a very short period of time. Therefore, designing structures against any blast load is not always feasible. Even though it becomes possible for a specific event, such design would not be an absolute measure to the issue as it may incur huge cost for construction. In this context, interest of different defensive systems to minimize the pressure load applied on structures and thereby achieving desired security goals economically, is noticeably increasing.

The central bank of Sri Lanka was attacked by terrorists on 31st January 1996 and it is believed to be the largest bomb attack targeted to a building in the country. There were about 85 deaths and more than 1500 people injured. Though the building did not collapse, it was severely damaged due to the blast pressure generated and subsequent fire erupted. There were no significant defensive systems in the designed building to diminish the blast pressure loading or to minimize its severity.

Blast pressure increases with the reduction of the scaled distance which is proportionate to the standoff distance. Higher the standoff distance, lesser the blast pressure on the structure. Increasing the standoff distance, i.e. distance to the target from the blast point, and avoiding the reach of heavy explosives closer to the objective, blast load can be reduced. These aspects which have to be planned at conceptual design stage, are considered as initial defensive methods. Different initial defensive methods such as design landscape with different ground levels, planting trees as obstacles, accommodating physical barriers as design features, limiting the vehicle access and allocate dedicated parking spaces away from the structure by proper layout arrangements, etc. are few examples for initial defensive planning that could be adopted to increase at scale distance and reduce design explosive charge. These initial defensive measures allow structure to be designed for lower blast loads.

Facades are constructed as a physical defensive system to enhance the blast resisting capacity of a building. Pressure waves and blast fragments generated at an event of explosion will enter into the building at a blistering speed. This pressure may destroy load carrying structural elements leading to its failures, in addition to the casualties triggered by blast waves & fragments themself. Failure of an internal or a perimeter axial load carrying element, columns or wall, could open a way for the progressive collapse of part or whole structure, giving rise to a large number of casualties. Facades when properly designed will act as the defensive system, preventing blast pressure waves and fragment entering into the building. It will protect brittle & sudden structural system failures when designed to behave as a load distribution shield to shear lateral loads exerted on it.

Mostly, facades are constructed from reinforced concrete, brick, and glass. Brick walls may be constructed by introducing cross walls, increasing the width and by adding steel plates when required to be adopted against high lateral loads. Laminated glass made as a glass sandwich with two or more plies of glass with one or several vinyl interlayers are used in blast resisting facades and windows. Vertical fins are introduced in glass facades to enhance their loads carrying capacity, but the ability of glass to withstand high loads heavily depends on its aspect ratio. In this context, concrete is usually selected as preferred material over others due to its comparatively high flexural strength, availability for using in mass scale, flexibility in usage and economy.

2. Principles of Blast Loading

A blast is a sudden explosion that generates huge energy. This energy is released to the atmosphere as pressure

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waves with fragments moving away from the point of blast. Pressure waves expand away from the point of blast and decay with the distance. Structural damages are mainly caused by the pressure and moving fragments do less damage to the structures comparatively. Figure 01 indicates the pressure variation with time at a fixed location away from point of detonation.

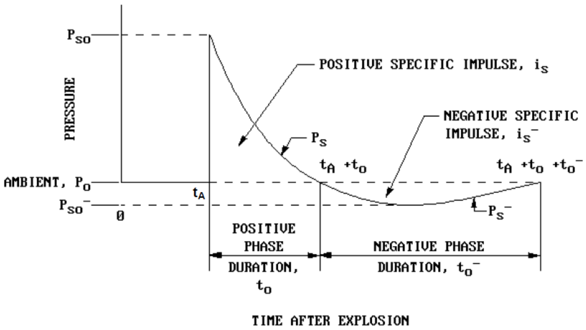


Figure 1- Variation of Blast Pressure with Time [1]

Variation of the blast pressure at a given point has two phases; positive phase and negative phase. Pressure waves will be reached to the point of concern at a time called arrival time, with a magnitude much greater than atmospheric pressure and indicated symbolically as positive.

After a steep rise at the wave reach, pressure quickly falls to atmospheric pressure ending the positive phase which typically would last only for a few milliseconds. The pressure further falls lower than atmospheric pressure due to the suction created by the momentum of expanding gases, reflecting negative phase as indicated graphically in figure 1. After the end of the negative phase, pressure returns to the ambient value. Duration of negative pressure phase is longer than positive phase, but value is less and insignificant for designs. Variation of the blast pressure at a point can be expressed from the following equation.

$$P(t) = P_{so}(1-t/t_0)\exp(-bt/t_0) \qquad (1)$$

Where P(t) is the pressure at time t, P_{so} is incidental pressure.

When a blast wave encounters an obstacle in its path, a reflected wave will generate with its partial reflection. This phenomenon happens when blast occurs near the ground level as well. The amplitude of the reflected wave is significantly higher than the incidental pressure and the same shall be used for the structural design if building interacts with it. Meeting of the incidental wave and reflected wave is called Mach reflection. It creates a Mach stem as shown in figure 2, forming uniform pressure over the building face. The point where the incidental wave, reflected wave and Mach stem met is defined as the Triple Point. Studies have shown that Triple point usually forms at the point when an incidental wave touched the ground at an angle around 40^0 [2].

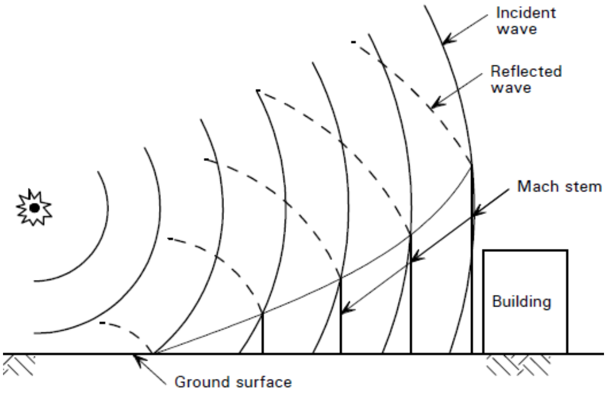


Figure 2 – Wave Pattern of Mach Stem [2]

2.1 Scale Distance

The blast pressure is evaluated based on the scale distance (Z) which is a function of the standoff distance (R) and the weight of the blasting materials (W). A relationship between the standoff distance and weight of the blast materials had been derived by Hopkinson [3] and Cranz [4] and it is the most common formula used to evaluate the parameters related to the blast loading.

$$Z = R / W^{1/3} \qquad (2)$$

Estimation of the blast pressure at the point of the blast and where it exerts the pressure is a very difficult task due to the inclusion of many variables and uncertainties in the weight of the explosive materials. The study done by Manmohan, et al [5] on the comparison of blast wave parameters had found that there is a significant variation in the peak positive overpressure when $Z<1$ m/kg$^{1/3}$. The widely used method for evaluating blast loading is presented in Unified Facilities Criterion (UFC) UFC 3-340-2, (2008) [1], published by the Department of Defence, United States of America.

2.2 Blast Load Assessment

Simplified distribution of pressure is considered in structural design due to the difficulty in dealing with the nonlinear time history load variation. Parameters required to calculate the blast pressure could be evaluated from the graphs given in the UFC 03-340-02 (2008) [1].

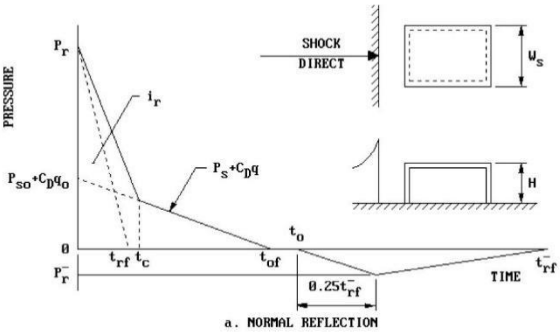


Figure 3- Simplified Variation of Pressure [1]

Figure 3 indicates the distribution of pressure over the front façade. Similarly, separate distribution charts could be found for different faces of façades. The parameters related to the positive phase Pressure variations may be evaluated from Figure 4.

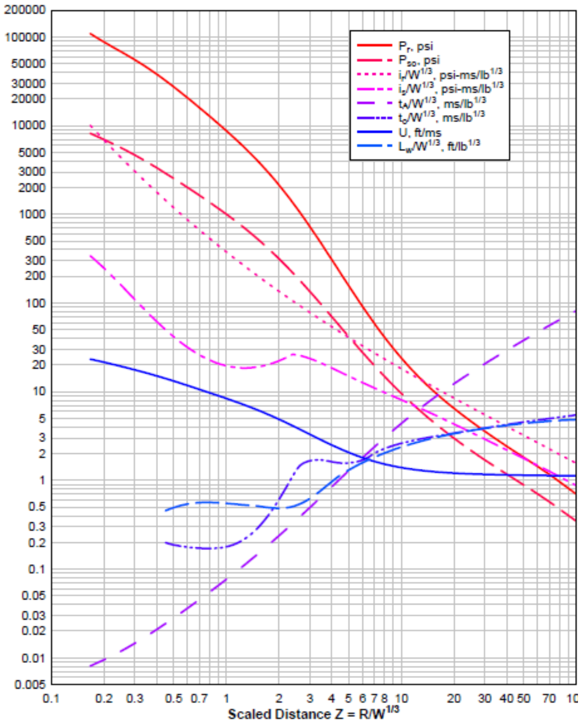


Figure 4 – Positive Shock Wave Parameters for Hemispherical TNT Explosions on the Surface at the Sea Level [1]

Pressure variation with time can be calculated once the parameters were obtained from the above figure 4 and following below steps

1. A factor of 1.2 could be considered to encounter the uncertainty of estimating the weight of blasting materials
2. Calculate the scaled distance by; $Z = \frac{R}{W^{1/3}}$
3. Obtain the parameters from Figure 4 and calculate time and pressure variation from Figure 3.

2.3 Material Behaviour

Strength of the materials plays a major role in structural analysis, design of structural systems and in the determination of overall stability of structures.

2.3.1 Material Nonlinearity and ductility

In a conventional design, linear stress - strain relationship of material is mostly considered. However, linear analysis approach is not economical in design structures for extreme loads initiated by earthquakes, blast, etc. which may sometimes not occur throughout their design life span.

Confined concrete can maintain higher stress for a prolonged period with considerable increase in strain. Figure 5 indicates the stress-strain diagram proposed by Kent and Park [6] for confined and unconfined concrete under the compression. Confinement of reinforced concrete could be improved by providing additional links. The improved material ductility contributes to the performance based designs to a great extent.

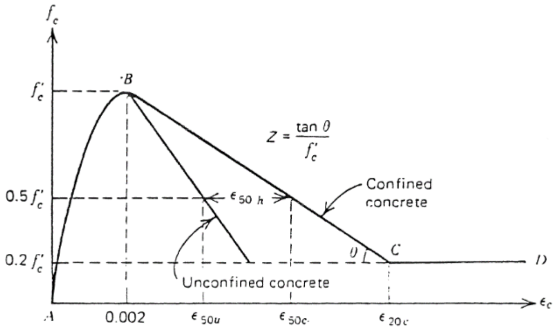
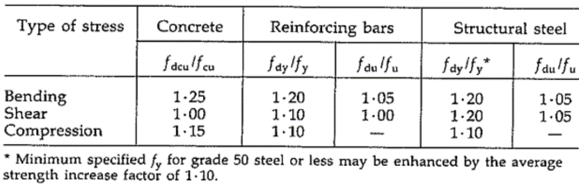


Figure 5. Stress-Strain Curve for Concrete Confined by Rectangular Hoops (Kent and Park, 1971)

2.3.2 Material Strength Enhancement

Characteristic strengths of the materials are enhanced by high strain rate. Though different researchers have proposed different modification factors for straining effect, the guidelines of General Services Administration (GSA Manual) for Progressive Collapse [8] stipulates agreeable values for many scholars. Table 1 indicates the material enhancement factors recommended in GSA manual.

Table 1 – Material Strength Enhancement Factors at Straining



Type of stress	Concrete	Reinforcing bars		Structural steel	
	f_{dcu}/f_{cu}	f_{dy}/f_y	f_{du}/f_u	f_{dy}/f_y*	f_{du}/f_u
Bending	1·25	1·20	1·05	1·20	1·05
Shear	1·00	1·10	1·00	1·20	1·05
Compression	1·15	1·10	—	1·10	—

* Minimum specified f_y for grade 50 steel or less may be enhanced by the average strength increase factor of 1·10.

More recent studies have found that these values can be increased further, and could be used for designs as and when applicable.

2.4 Performance Based Design

Performance of the structure when subjected to a defined load condition is considered in the performance based design. In contrast to the code based design, performance goals of a structure are predefined in this approach, based on its function and importance. This methodology is commonly used in designing new structures and evaluation of existing structures for extreme load cases such as blast and earthquake loads. The deformations of building structure are evaluated in terms of its floor drift for monitoring structural, non-structural elements responses. Recommended drift limits for elements such as concrete walls, columns, etc. are given in the Federal Emergency Management Agency (FEMA 273) [9].

Evaluation of overall structural performance with respect to different load conditions may be examined based on the criteria specified in FEMA 356 [10]. The behaviour of plastic hinges formed at beams, near the column-beam joints under lateral load condition is modelled to predict overall performance of the structure. As indicated in figure 06, different occupancy levels; Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) are specified in the FEMA guidelines. If a structure's global displacement was reached only to "IO level" under a specified load condition, its structural capability is deemed to be satisfied for immediate occupancy after an event that induced a similar load. Similarly, other performance levels too have meanings expressed by their terms itself.

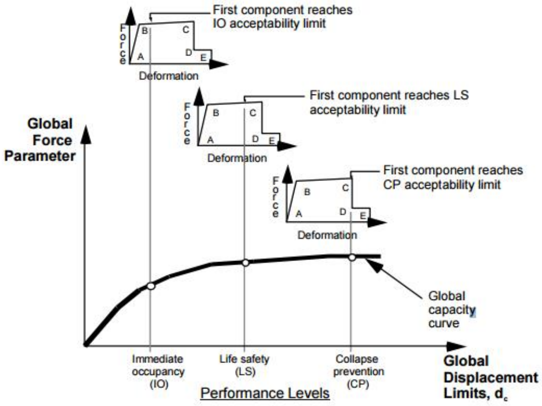


Figure 6: Performance Levels [12]

Many commercially available software today facilitate designers to use a simplified force- displacement curve that represents different occupancy levels. Figure 7 shows a simplified linear model.

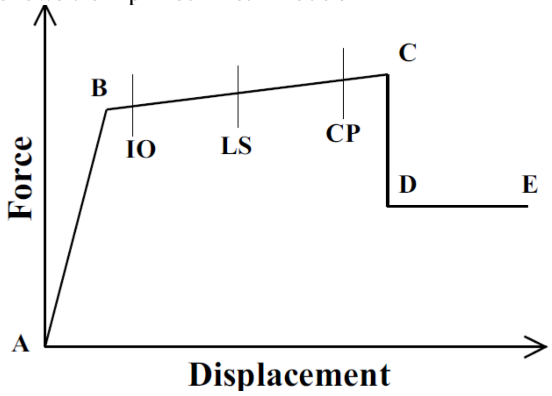


Figure 7: Occupancy Levels (Computers and Structures INC, 2009)

3.0 Practical Design Approach and Methodology

A building complex designed to satisfy blast resistant design criterions specified by stakeholders are discussed here. The foremost concern for blast resistant design is human casualties due to the structural collapse. Designing a new building to resist failure due to blast loading shall commence at planning stage with the intention of mitigating the effect as much as possible rather than confronting with it, to achieve financial feasibility of the project. Protective design approach for a new building can be treated in three stages.

- Selecting site location and layout planning
- Architectural Design
- Structural Design

3.1 Selecting Site Location and Layout Planning

As standoff distance plays a dominant role in deciding blast pressure on a structure, selection of appropriate site and building layout planning are deciding factors for design of economically feasible, yet very effective blast resistant building. Once the decision was made on the standoff distance, focus shall be laid on the threat of reaching explosives to the concerned building or the vulnerable section of a building. Vehicle access control methodologies and internal road layout shall be planned according to the vehicle type, their use and threat assessment to the building. Stakeholders' concerns on security measures and surveillance which would be implemented after occupying & functioning the building should also be evaluated at this stage.

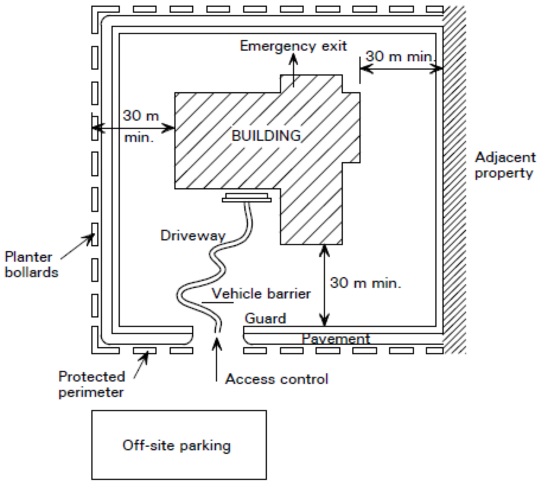


Figure 8: External Layout Planning (Yandzio and Gough, 1999) [2]

Locating structures at the correct position is crucial in protecting most invulnerable areas from blast effects. Figure 8 indicates an example for a planned layout which indicates different defensive levels for different parts of the building. In addition, landscape could also make use to reduce the exposure of the structures to a blast.

The layout plan shown below Figure 9 indicates how standoff distances were maintained for the designed building complex from boundaries of the land.

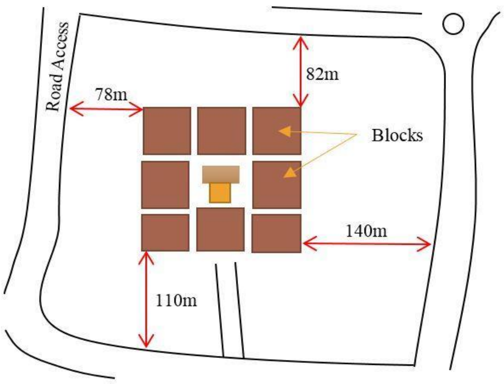


Figure 9: Layout Planning

A separate car park building for authorised vehicles was planned away from the building complex and manned access controls to be provided at gates when functioning the complex which will ensure that no other vehicle may enter. This allows designers to exclude high blast load occurrence within the premises. Further, a landscape with different ground levels, physical barriers such as ramps & retaining walls integrated as a part of the layout planning and other vehicle barriers adopted in the layout establish that standoff distance considered for the design blast surcharge remain intact even at forced entry condition.

3.2 Architectural Design

Architectural design of a building is a decisive factor on its performance against blast load. Buildings having irregular shapes and complex exterior details will develop reflective waves to a greater extent than regular shaped buildings and therefore would be more vulnerable under the blast load. For example, multiple reflective waves generated by U-shaped buildings and projections of exterior will increase the blast pressure. More openings in external walls and large glass façade will also reduce the blast resistant capability of a building.

Building floor layouts too shall be developed in parallel to the structural output obtained by preliminary analysis performed for specified load conditions and subsequent performance outcomes. Schematic architectural designs of a building may need to be modified if performance level could not meet stakeholders' requirements. Alternatively desired performance level may be achieved by modifying standoff distances to the building.

Avoiding irregularities of external walls, limiting aspect ratios for opening and preliminary structural assessments on schematic architectural drawings were prerequisites in the design development process of protective buildings. Developing several structurally independent buildings with wide gaps was chosen against designing a single building, to confine any damages which may cause not only by blast but also from other unexpected extreme load conditions. One such risk assumed was the fire, which anyway could erupt at a bomb attack. Therefore the building finally laid down as several blocks as shown in figure 9. This arrangement was further benefited to invent more secure areas in the building, as spaces faced to the centre core were safe against the external pressures and hindered the line of sight to the exterior.

Introduction of podiums for tower buildings as shown in figure 10, was also a measure to increase standoff distance to the towers which are to be utilized by stakeholders for high security purposes.

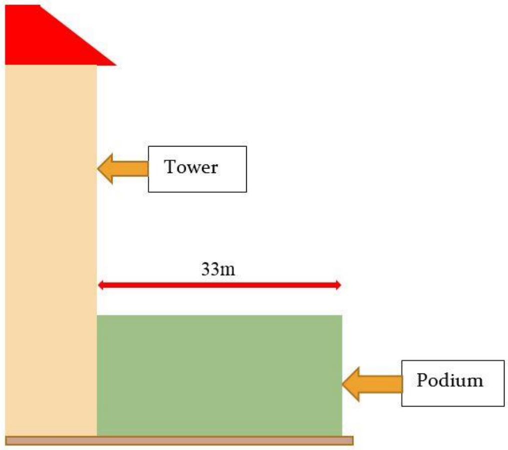


Figure 10: Building Having a Podium

3.3 Structural Design

Once the designing and planning steps were completed, design of security buildings to be started off with load evaluation, structural analysis and shall be completed by reinforcement detailing and producing drawings. As discussed earlier, providing structural inputs in parallel to the Architectural concept development is necessary to design a feasible protective building which satisfies stakeholders' requirements. In this context, wide beams satisfying long spans requirements and the strong column - weak beam concept which enables the formation of beam plastic hinges before in columns was introduced. Shear wall and column positioning was suggested to achieve effective moment resisting frame arrangement to encounter lateral loads.

The concept of structural facade remarkably helped to disperse high lateral forces throughout the frame structure and improve overall ductility of building. Blast waves when generated at controlled standoff distance, would reach to the building as a uniform pressure forming a Mach stem. Façade system will transfer this pressure to the lateral load resisting system of the building, while absorbing the blast load energy to reduce the impact on the internal structural elements. Further, it could be used as an external shield or sacrificial structural element which protects external columns being exposed to the blast pressures. This aspect prevents peripheral column failure and subsequent progressive collapse; the most common scenario in massive damages caused due to bomb attacks.

3.3.1 Reinforced Concrete Façade Design

Though facades could be constructed by concrete, glass, brick in common, reinforced concrete is widely selected for designs of blast resisting facades due to the availability of material, flexibility, strength and most importantly, easy accessibility to literature on the subject.

Major practical challenge in adopting reinforced concrete external walls as a structural element of a building is tackling its behaviours in thermal & shrinkage effects and creep. Wall could crack if these issues were not technically handled. The most appropriate methodology to overcome these effects is to provide suitable joints on external walls at appropriate intervals and locations.

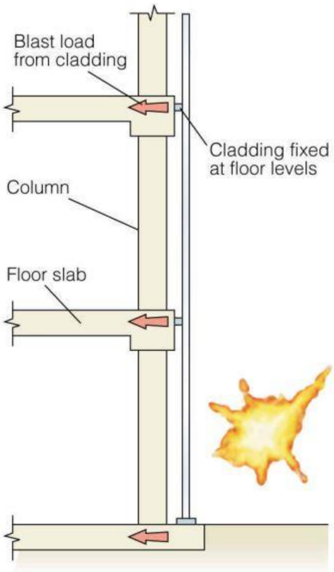


Figure 11: Typical Cladding Arrangement

In the building project construction, vertical movement joints were provided to avoid the likelihood of unwanted thermal or shrinkage stress concentrations in immature concrete that could generate due to the restrained conditions taken place in continuous construction. Figure 12 below indicates the joint pattern adopted in the design. Deciding aspects for joints positioning were;

- Providing horizontal expansion joints at near two-third floor height, just above the window lintel to minimize vertical cantilever action of wall against lateral load.
- Providing vertical expansion joints at the column grid, at regular intervals or systemically to the elevational views satisfying architectural / aesthetical requirements.
- Delaying of façade construction until the completion of superstructure works to minimize the danger of applying comprehensive force to the facade with elastic shortening of peripheral columns; and to avoid probability of cracking due the creep.

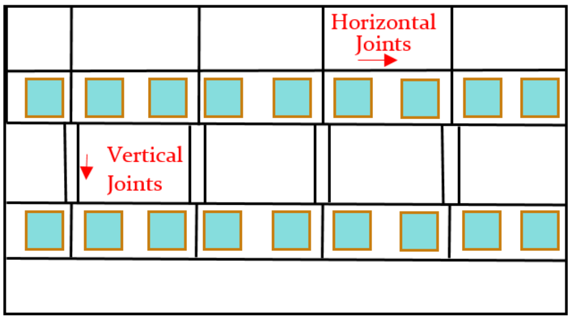


Figure 12: Vertical and Horizontal Expansion Joints

Once the joint arrangements were finalized, the next task was the minimising of facades acting in cantilever action of which load carrying capacity was enormously decided. Concept of adding vertical fins to facades for featuring those as vertical sides of embossed windows was emerged at this point. Figure 13 shows a typical detail of vertical fins, construction joints detailed for the delayed facade and movement joints positioned at the window lintel level.

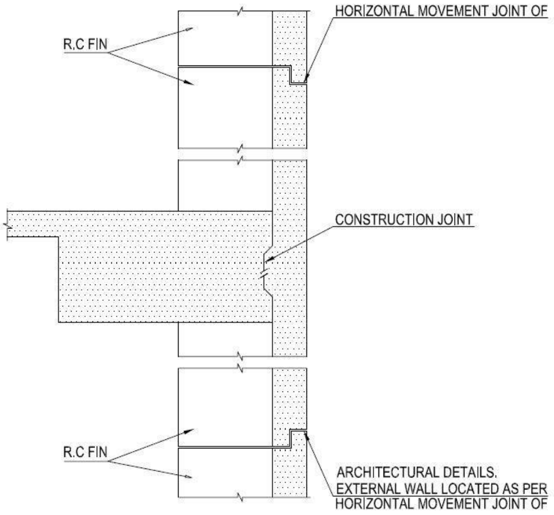


Figure 13: Arrangement of the Façade and Vertical Fins

In addition to vertical fins located at sides of windows, additional fins were introduced at facade to warrant two-way or three-way load distribution to optimize the design.

3.3.2 Blast Load Calculation

Mainly there are two methods available for load evaluation.

- Obtaining blast load from stakeholder's blast load experts
- Evaluation of blast pressure by following standard procedures as previously discussed.

If design blast loads are provided, structural designers' scope for blast design would be limited only to the analysis and obtaining relevant outputs for applicable load combinations.

However, the blast pressure could be calculated as discussed earlier when the standoff distance and design explosive weight are provided. Usually explosive weight is expressed as TNT equivalent value, which is a relative measure to describe the weight of explosives needed to release a similar amount of energy by exploding Tri-Nitro-Toluene (TNT). For example C-4, one of the frequently heard explosive materials by Sri Lankans in past decades, has 1.3 TNT equivalent value. Accordingly, 100kg of C4 could generate energy equivalent to the energy dissipated by exploding 130kg of TNT. There are many guidelines including UFC 3-320-2, for estimating the blast pressure based on TNT equivalent explosive weight and standoff distance.

Stakeholders intended procedures for vehicle access had been specified for the designed building. Furthermore, their suggestion for TNT equivalent blast load and standoff distance had been outlined in the Terms of References given for the design, making the load evaluation process straightforward. Blast load estimation could be performed for different standoff distances and explosive weights as shown in Tables 2 below to determine the best building positioning and most viable design load for economical design, satisfying stakeholders' space requirements but without sacrificing their security considerations.

Table 2 Design Loads

LC	R	W	Z	P_r	P_{so}	T_{of}	T_o	P_{r-}	t_{rf-}
1	10	10	5	117	50	6	8	17	31
2		25	3	236	89	5	9	23	41
3		50	3	436	144	5	9	29	49
4		100	2	845	239	5	10	38	58
5		200	2	1695	407	4	12	51	68
6	25	25	9	40	18	11	13	9	47
7		50	7	58	26	13	16	11	58
8		100	5	87	38	14	18	14	69
9		200	4	140	58	14	21	18	84
10		300	4	189	74	14	22	21	94
11		400	3	241	90	14	23	23	102
12	50	100	11	28	13	20	23	8	75
13		200	9	40	18	23	27	9	93
14		300	7	49	23	24	29	11	107
15		400	7	58	26	25	31	12	115

In Table 2, LC- Load case, R-Standoff Distance (m), W- weight of blasting material (kg) TNT equivalent, Z-scaled distance(m/kg$^{1/3}$), P_r-peak reflected pressure(kN/m^2), P_{so}- incidental pressure(kN/m^2), T_{of} –end of positive phase(ms), T_o-start of the negative phase(ms), P_{r-} -negative pressure(kN/m^2) and t_{rf-} - end of the negative phase(ms) are indicated. There are 15 load cases considered by varying the standoff distance as 10m, 25m, 50m and weight of blasting materials as 10kg, 25kg, 50kg, 100kg and 200kg.

3.3.3 Structural Arrangement

Structural arrangement for building complex was finalized after several preliminary analysis by assuring its action in agreement with both code based load combinations and performance based criterion. Concrete Facade was primarily used as defensive and load shearing structural element against the design blast load. It's positioning was arranged keeping a gap to the peripheral columns so that lateral loads could directly be transferred to the slab plates at each floor level. The isolation of peripheral columns, avoiding them being subjected to lateral loads between slab levels ensured ductile response of the structure.

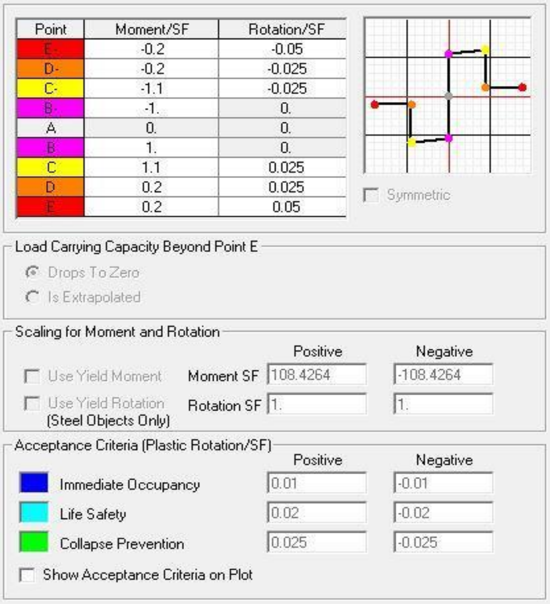
Peripheral columns and frames further checked for the intended performance level and for the redundancy of ground floor level columns which had not been shaded by previously mentioned podium structures. A consideration was laid on sizing peripheral beams, which meant to originate alternative load paths at external frame column redundancy. Guidelines in GSA Manual were used for element sizing, and thereby to eliminate the chance of initiating progressive collapse even at higher blast load than specified was curtailed. A special care was taken on structural robustness, adopting proper reinforcement details.

3.3.4 Structural Analysis

Structural Analysis for a building subjected to blast load may be performed in two-folds. Conventional elastic analysis for static loads is demanded for the structure at the first stage, and the same structure could secondly be checked against blast load with elasto-plastic analysis.

Blast load is time dependent and load varies with the time. The load variation with time could be established as discussed earlier. Though there are inbuilt facilities in modern software to perform nonlinear time history analysis, such approaches have been found as impractical for real time applications. Nonlinear property and plastic moment capacity of a structural element subjected to a blast load could be confined to a plastic hinge location where critical bending moments are generated for a blast load case. Blast load, which mainly acts as a lateral uniform force to a building, creates critical bending moments near the column-beam joints at frame action. Simplified moment-resisting frame structure with elasto-plastic elements having lumped plastic hinges near column-beam connection would provide sufficiently accurate information to judge its structural ductility and performance level.

Example for a user defined moment-curvature diagram used to model elasto-plastic elements is shown in figure 14. The elastic moment capability My and plastic moment capacity Mu for moment-curvature may be based on sectional properties of the structural element.



Point	Moment/SF	Rotation/SF
E-	-0.2	-0.05
D-	-0.2	-0.025
C-	-1.1	-0.025
B-	-1.	0.
A	0.	0.
B	1.	0.
C	1.1	0.025
D	0.2	0.025
E	0.2	0.05

☐ Symmetric

Load Carrying Capacity Beyond Point E
● Drops To Zero
○ Is Extrapolated

Scaling for Moment and Rotation

		Positive	Negative
☐ Use Yield Moment	Moment SF	108.4264	-108.4264
☐ Use Yield Rotation (Steel Objects Only)	Rotation SF	1.	1.

Acceptance Criteria (Plastic Rotation/SF)

	Positive	Negative
Immediate Occupancy	0.01	-0.01
Life Safety	0.02	-0.02
Collapse Prevention	0.025	-0.025

☐ Show Acceptance Criteria on Plot

Figure 14: Simplified Moment-Rotation Curve

The concept of elevator-plastic element is valid in the analysis of the performance of facade too. Designed facade walls were always discontinued at window lintel by the horizontal joint provided. For the upper wall segment hung at the upper floor acting as a cantilever with a small span, plastic hinges may be modelled at slab level. Since the bottom wall segment had a larger span giving rise to lower load resisting capacity when behaved in cantilever action, fins were needed. These fins too were terminated at horizontal moment joints provided at window lintel level, and act in cantilever. The plastic hinges placed at fin bottom, at the connection with the slab represented their action at loads that exceeded its elastic capacity. Typical reinforcement details provided for fins to satisfy their performance level at blast load and reinforcement links arranged to increase confinement are shown in figure 15 below.

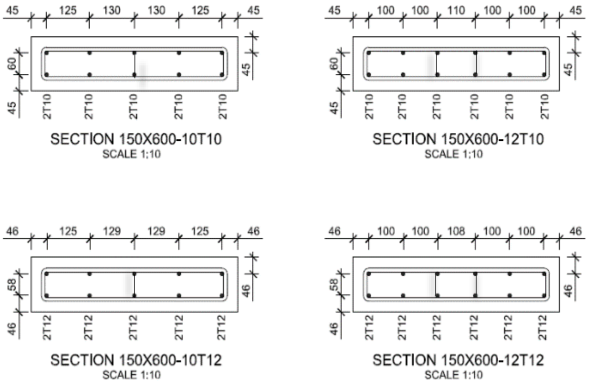


Figure: 15: Typical Fin Reinforcements and Dimensions

3.3.5 Results and Modifications to Structural System

Modification to the element design and detailing to enhance blast resisting capacity of the elements were made based on the outputs of analysis. Deformation pattern, drift, total lateral deflections were checked against the specified performance criterions. Plastic hinge formation patterns, ductility of frames and vulnerable areas of building under different blast load directions were observed to adopt necessary modification to the structural system. Based on hinge formation and their level of deformations, reinforcements were modified at recognized structural elements when occupancy level was not upto the requirement.

Figure 16 below illustrates the variations of bending moment variation with time at a elastic-plastic hinge of a concrete fin under different time history loading arrangements.

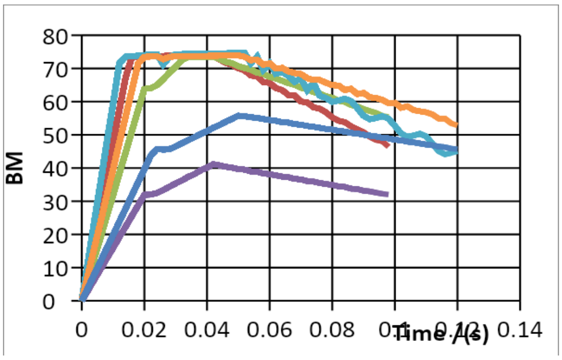


Figure 16: Bending moment vs Time

As mentioned earlier, time history analysis for the whole structure is not practical, but may be used to check a performance of a crucial structural element in detail. Accordingly, a facade supporting fins were modelled with different reinforcement arrangements and subjected to various load cases that would generate based standoff distance (R), explosive weight(W) and fin spacing. Outcomes of a fin for a selected reinforcement arrangement is shown in Table 3 below.

Table 3 Damage Assessment for Fins of facade (150x600)

Fin	Load Case	Fin Spacing	Performance the Hinge
150x600 10T10	R10W10.3m	3	IO
	R10W25.2m	2	LS
	R10W25.3m	3	CP
	R10W50.1m	1	LS
	R10W50.2m	2	>CP
	R10W50.3m	3	>CP
	R10W100.1m	1	>CP
	R10W100.2m	2	>CP
	R10W100.3m	3	>CP
	R10W200.1m	1	>CP
	R10W200.2m	2	>CP
	R10W200.3m	3	>CP
	R25W100.3m	3	IO
	R25W200.2m	2	IO
	R25W200.3m	3	LS
	R25W300.2m	2	IO
	R25W300.3m	3	LS
	R25W400.2m	2	LS
	R25W400.3m	3	CP

In naming Load cases, a national system was selected to identify its variables. R10W10.3m load case has the meaning of pressures variation applicable to the fin (In this case 150x600 mm fin with 10T10 main reinforcements) having 10m standoff distance; under 10kg of TNT equivalent explosives; paced 3m intervals at facade. The action of the hing and performance level could then be assessed to judge most suitable spacing, sizing & reinforcements of fins to design for an effective facade system.

4.0 Conclusion and Discussion

The study showed that a building could be economically and effectively designed as a blast resisting structure if relevant mitigation measures are adopted at the planning stage. Involvement of professionals of all Engineering and Architectural disciplines at the initial design phase is paramount. Design concepts for a preventive building shall be clearly laid down and agreed by all parties; including stakeholders.

Façade could play a prominent role in protecting a building against design blast load and controlling its action to a predefined performance level. It could further be utilized as a load shearing element and distribute load for frame action, allowing structure to behave in the ductile manner.

Though there are not well established code specified procedures for blast resistant design, UFC documents, FEMA Guidelines and GSA manuals of the United States and many other literature published on the subject facilitate sufficient information for designs. Few basic procedures that could be followed in calculating the blast loads, deciding element sizes, material properties under blast loads and structural modelling / analysis methods have been outlined with reference to an application for an actual project.

Having experienced terrorist attacks for decades, the importance of designing vulnerable buildings for blast loads is not something to be rationalized. However, the code based elastic analysis will not be feasible for blast design, and therefore the approach of performance based analysis with appropriate elasto-plastic structural model could be used.

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