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New architectural forms to reduce the effects of blast waves and fragments on structures

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Abstract

Important structures such as embassies, government buildings, office buildings ... etc. form a category of civilian buildings that can be considered as a potential terrorist target. This fact leads to the need of offering them an adequate degree of protection against blast waves and fragments. This may convert them to a type of fort or casemate which will psychologically influence users of that building.

An approach for designing these sorts of buildings can be by using new materials like laminated glass, ceramic cladding, ... etc. Alternatively, protection can be offered by increasing the dimensions of the structural elements (columns, beams, lintels, walls, ... etc.). These approaches, despite their advantages, may oppose the aspiration of the architect as well as incurring high construction costs.

From here, a new concept of design may give a better solution to these problems, by using the effect of different architectural vocabularies (architectural forms, landscape, cantilevers, louvres, ... etc.) in the form of design criteria, to reduce the effect of blast waves and fragments on these types of structures.

This paper examines by analysis, the concept of using specific architectural general forms to reduce the effect of blast waves and fragments on structures, and simulating this process by using the Autodyn simulation package.

1 Introduction.

The design process of protected structures has to be a joint responsibility, in which several specialists have to take part. Each specialist has his own role and ideas in reducing the effect of the threat on the structure to a certain limit. By combining all these design approaches together, the effect of the threat will be reduced to reach its minimum value.

From here, the process of designing a protected structure can be organized in the form of steps of a procedure. At each step the design will be influenced by a new design criterion in a way to reduce the threat effect, a simple example for that procedure can be in this form :

- First step : The landscape design.
- Second step : The overall architectural concept of design.
- Third step : Civil engineering analysis and design.
- Fourth step : Cladding systems design.

In a previous conference, the authors presented a paper (Barakat[1]) describing the role and the shielding effect of the landscape design (Ground Profile Technique) in reducing the effects of blast waves and fragments on structures (Figure 1). This technique reduced both impulse and pressure values to a certain degree. However the overall architectural design concept can increase protection levels further.

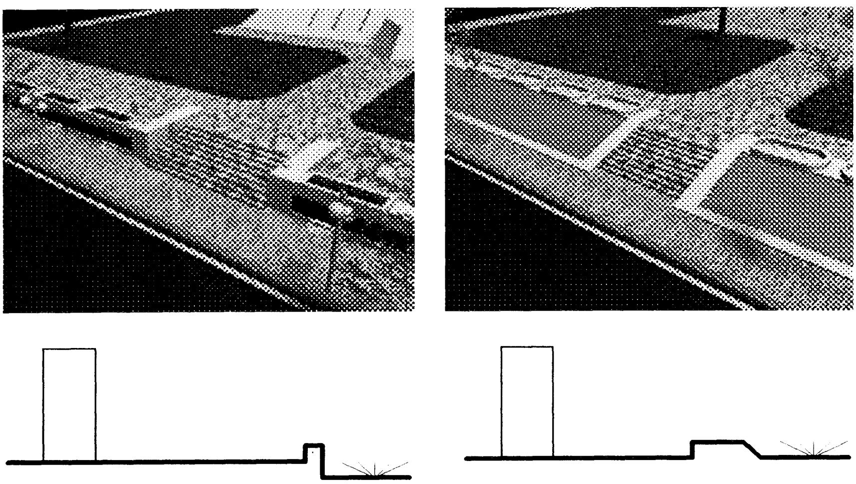

Figure 1 : Examples for the ground profiles architectural design.

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This paper spotlights the second step in the design procedure. It describes the role of the architect in the design process of protected structures. It presents the technique of using the overall architectural design concept (Form and Orientation) to reduce the impulse and pressure values on the structure.

2 Measurements and evaluation.

Architects usually use subjective scales (harmony, contrast, unity, variety, beauty,...etc.) to measure the effectiveness of their design. In the case of protection, however, the issue is different as an objective scale is obviously needed.

In the evaluation of the effectiveness of these new design techniques, the Autodyn simulation package V3.0.07 was used to evaluate the impulse and pressure values on a target structure that have different forms and orientations.

2.1 The reference scenario.

The reference scenario, with which all simulation outputs (for different forms and orientations of structures) will be compared, is the simple case of an explosion in front of a normal cubic structure (Figure 2). All the results will then be tabulated in a group of comparative tables.

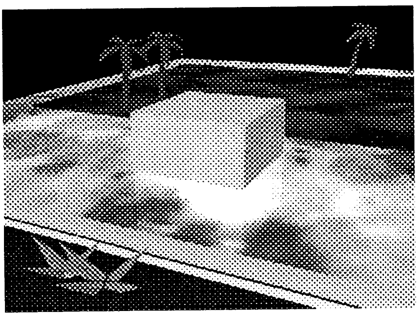

Figure 2 : The Reference Scenario.

3 Simulations organization.

3.1 Structural forms.

Several scenarios were prepared to simulate a comprehensive range of structural forms. These forms were based on the following criteria :

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1) Structures with straight or inclined flat surfaces (Figure 3-Structures A,B,C,D&E).
2) Structures with one-dimensional curvature surfaces (Figure 4-Structures F&G).
3) Structures with two-dimensional curvature surfaces (Figure 4-Structure H).

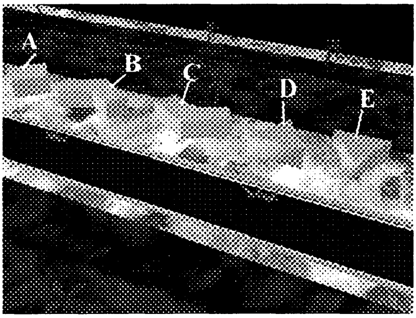

Figure 3

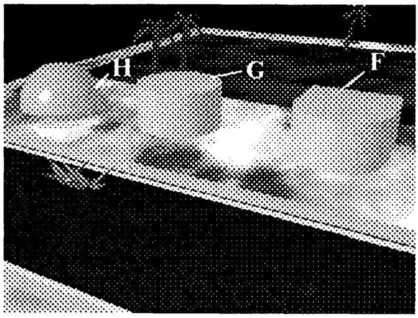

Figure 4

3.2 Structural dimensions.

To aid comparison between simulations, all structures were given the same dimensions i.e. 15m in both height and width.

3.3 Threat criteria.

The group of simulations were set up based on a threat due to a car bomb situated at 15 m from the blast (as structures situated at distances more than 20 m can be protected using different protection methods or the distance itself is enough to protect the structure from the blast waves). The impulse values due to the blast waves will then be measured for different forms of structures.

4 Simulation results.

After executing the whole group of simulations, tabulating and comparing the output impulse values, a group of results were deduced.

From the traced curves of the change in Impulse (%) Vs Height (m) for different scenarios, the decrease in the values of impulse when compared with the values of the reference scenario varied according to the form and orientation of the structure as follows :

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4.1 Values at the middle of the structure (Figure 5).

i) For square plan structures, the impulse values were found to be lower in case when the structure is rotated by 45° (the corner of the structure is facing the explosion) (Figure 3-Structure A).
ii) For Triangular plan structures, the impulse values were found to be lower in case when the structure is rotated by 60° (the apex of the structure is facing the explosion)(Figure 3-Structures D&E).
iii) For wing-form-plan structures, the impulse values were found to be lower when the angle between the two wings facing the explosion is obtuse (Figure 3-Structure C). In the case of acute angles (Figure 3-Structure B) the impulse values are higher than the values of the reference scenario as the wings form a collector to the blast waves.
iv) From the above results, it is clear that the decrease in impulse values depends upon the value of the angle facing the explosion. The larger the angle (more obtuse) the higher the reduction in impulse values.
v) For cylindrical and semi-cylindrical plan structures, the decrease in impulse values is very low. The impulse values depend on the radius of the structure and the distance of the structure from the explosion (Figure 4-Structures F&G).
vi) For hemi-spherical structures, the decrease in impulse values is quite significant. At high elevations this reduction is particularly marked (Figure 4-Structure H).

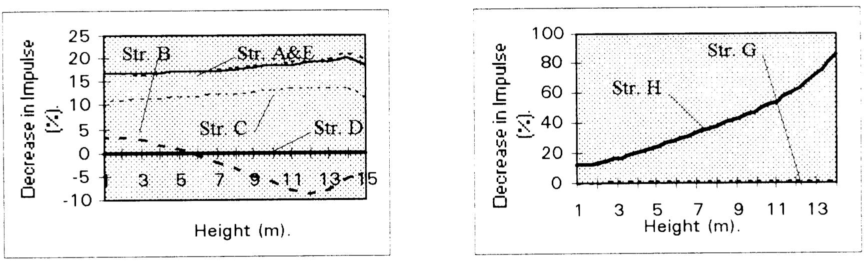

Figure 5 : The decrease in impulse (%) Vs height (m) at the middle of the structures.

4.2 Values at the structures' edges (front corners)(Figure 6).

i) For square plan structures and for the case when the structure is rotated by 45° (the corner of the structure is facing the explosion), the impulse values were reduced by more than 70% of the reference scenario impulse values (Figure 3-Structure A).

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ii) For triangular plan structures and for the case when the structure is rotated by 60° (the apex of the structure is facing the explosion) the impulse values were reduced by more than 60% of the reference scenario impulse values (Figure 3-Structures D&E).
iii) For wing-form-plan structures, the impulse values were reduced by a percentage depending on the angle between the two wings facing the explosion. For the case when the angle is obtuse (Figure 3-Structure C) the decrease in the impulse values is higher than in the acute angle case (Figure 3-Structure B).
iv) From the above results, it is clear that the decrease in impulse values depends upon the value of the angle facing the explosion. The larger the angle (more obtuse) the higher the reduction in impulse values.
v) For cylindrical and semi-cylindrical plan structures, the impulse values were reduced to more than 70% of the reference scenario impulse values. The impulse values depend on the radius of the structure and the distance of the structure from the explosion (Figure 4-Structures F&G)..
vi) For hemi-spherical structures, the impulse values were reduced to more than 65% of the reference scenario impulse values (Figure 4-Structure H).

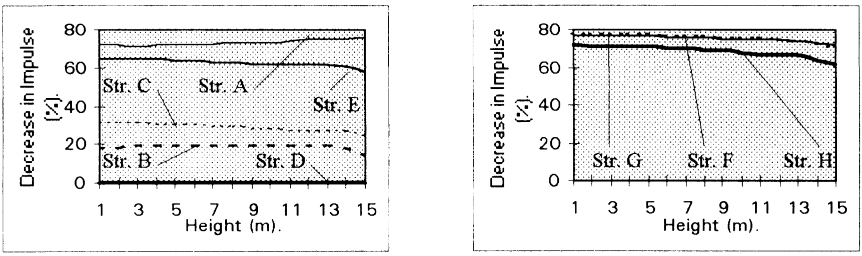


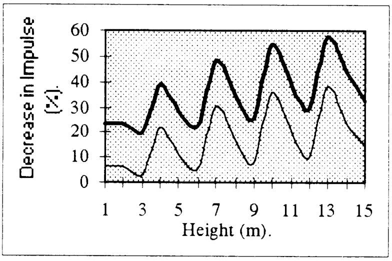
Figure 6 : The decrease in impulse (%) Vs height (m) at the structures edges.

5 Further protection.

Further protection could be offered to the structure by applying two methods of enhancements to its form :

5.1 Method 1 - The stepped form.

By dividing the elevation of the structure to several layers of steps, further protection can be offered to some parts of the structure in which glass (windows) and fragile construction materials can be placed. Figure 7 shows the prominent decrease in impulse values on the stepped elevation when compared with the reference scenario.



—— Structure's facade parallel to the threat (the road).
—— Structure's corner facing the threat (structure is rotated by 45 °).

Figure 7 : The decrease in impulse (%) Vs height (m) due to the stepped form.

This decrease will help in protecting the glazing, the fragile construction materials and the human beings from being affected by either the blast waves or fragments, due to the mutual shielding effect of the steps on each other (Figure 8). Figures 9,10,11&12 show some examples for the architectural designs based on the stepped form.

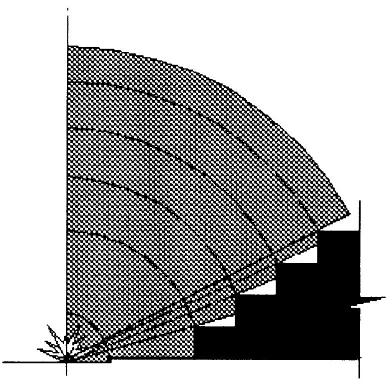


Figure 8

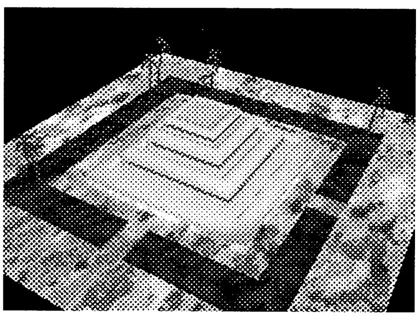


Figure 9

Figure 8 : The mutual shielding effect of the steps on each other.
Figure 9 : A Perspective declaring the stepped form concept.

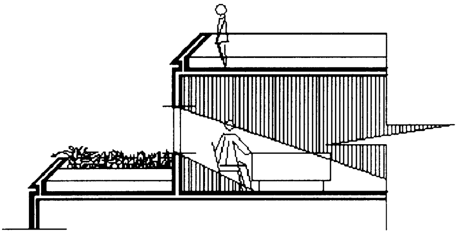


Figure 10 :
Using the steps as a roof garden.

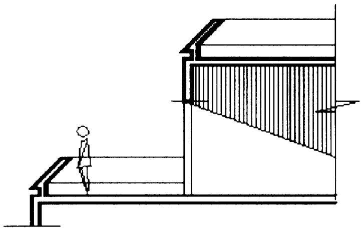


Figure 11 :
Using the steps as a terrace.

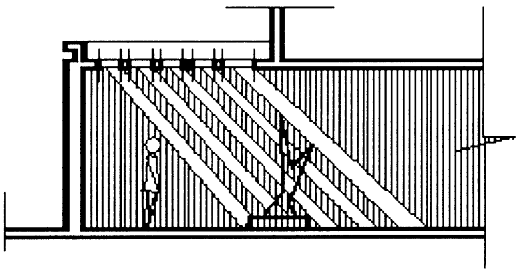
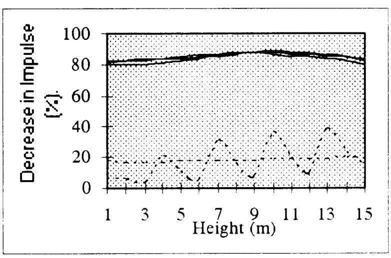


Figure 12 : Roof light slots, ideal for exhibitions and museums.

5.2 Method 2 - The introvert design.

Further protection can be offered to the structures by applying the introvert method. In this method the overall design concept of the structure will be inverted so as the elevations of the structure will face an internal atrium while the outer elevations will be kept solid or with minimum openings (windows). Figure 13 shows the huge decrease in the impulse values on the internal facades that will guarantee a high percentage of protection.



.... External facades. —— Internal facades (atrium).

Figure 13 : The decrease in impulse (%) Vs height (m) due to the introvert form.

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The aesthetic values of the structure can be enhanced by applying some architectural and artistic ideas, an example of those ideas is shown in (Figure 14).

The internal atrium can be in either closed or open space. In the case of an open atrium, the kind of threat that may affect the structure is the attack from mortars. In this case protection can be achieved by using a simple metallic mesh as a roof for the atrium to prevent projectiles from falling inside (Figure 15).

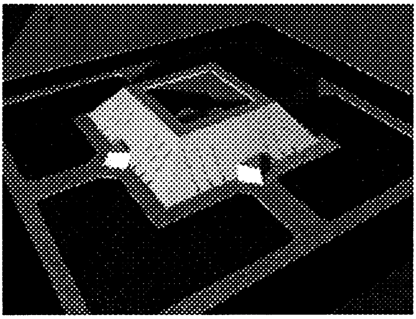

Figure 14.
The introvert design.

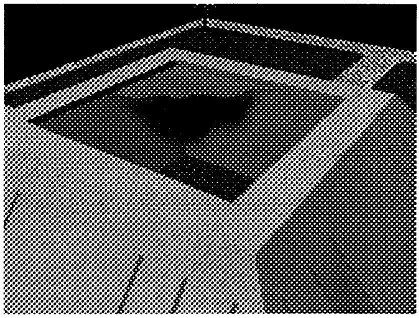

Figure 15.
Protection against mortar attack.

6 Conclusions.

From the previous simulations, the following conclusions can be deduced :

a) The architectural concept of the structure and its orientation have a prominent effect in reducing the effects of blast waves on it.
b) The architectural concept of the structure and its orientation are an excellent solution to reduce the effect of the explosion on structures even when the explosion is very near to the structures or in situations where no extra land is available to set the structure far enough from the expected threat.
c) The technique of using the architectural concept and orientation to reduce the effects of blast waves, can be used without affecting the structure's functions, it's aesthetic values and it's users psychology.
d) The technique of using the architectural concept and orientation to reduce the effects of blast waves, will assist in the optimization process of designing the architectural features of the structure facades.

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e) The stepped form and the introvert design concepts are excellent forms that assist the process of protecting the structure and the occupants from being affected by the blast waves and fragments.
f) The Autodyn simulation package was found to be a convenient tool for measuring the effectiveness of the overall architectural concept of the structure and its orientation in reducing the effects of the explosion.

7 References.

[1] Barakat, M.A., An architectural approach toward reducing the effects of blast waves and fragments on structures, *Proc. of the 2nd Asia-Pacific Conf. on Shock and Impact Loads on Structures*, eds. J.G. Hetherington, Melbourne, Australia, pp. 41-51, 1997.