Blast Effects inside a Partially-Enclosed Car Park

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Abstract

Modern buildings are commonly designed with densely populated offices or residential occupants above several storeys of car parks below. In case of an unforeseen explosive threat that occurred at the car parks, such buildings should protect the occupants from a catastrophic progressive collapse. Modelling and prediction of blast effects inside a partially-enclosed space due to such threats are therefore of interest to building designs. In this paper, the blast effect inside a partially-enclosed car park subject to a vehicle-borne improvised explosive device is modelled using a commercially available Computation Fluid Dynamics (CFD) code. The corresponding responses of the primary structural elements inside this enclosure due to the blast loads are analysed to confirm that the car park is able to withstand this blast load and protect the occupants above from such a threat.

Keywords: Partially-enclosed; Car park; Blast overpressure; Numerical simulations

1. Introduction

Singapore is a small city state with a highly urbanized population. Many of its buildings are high-rise and comprise offices or residential situated above several storeys of car parks. In the event of an unforeseen explosive threat such as vehicle-borne improvised explosive device (VBIED) occurring in the car parks, such buildings should protect the occupants from a catastrophic progressive collapse. This type of failure has not been adequately considered in conventional building design. Thus, designing buildings to withstand blast explosions is of great interests. The present study intends to make a contribution to the blast analysis in partially-enclosed car park.

Researchers have previously studied the structural response of reinforced concrete structures submitted to blast loading. The effect of blast action has been extensively analysed from both numerical and experimental point of view during past few years. Dimitrios Kakogiannis [1] analysed the blast bearing capacity of reinforced concrete hollow core slabs when they are subjected first to fire and then to a blast load using feasible experimental analysis and numerical modelling. Y.S. Tai [2] used non-linear finite element analysis software LS-DYNA to conduct a numerical simulation of a free-field explosion model. M. Bermejo [3] also proposed to evaluate blast loads on large concrete buildings using LS-DYNA. On the other hand, Denis Kelliher and Kenneth Sutton-Swaby [4] combined Monte Carlo method with a simplified but conservative progressive collapse structural model, to generate a dataset representing the percentage damage a ten storey reinforced concrete building sustains when subject to an explosive load in the ground floor car park. Paul J. Mullett [5] proposed the application of computational analysis to the design of a reinforced concrete structure subject to blast loading from a vehicle-borne improvised explosive device. They concluded that the performance of a reinforced concrete structural system can be cost-effectively assessed for blast loading using ProSAir and Finite Element (FE) tools.

2. Methodology

This paper builds on the work of Paul J. Mullett [5] and attempts to investigate the overpressure acting on the slabs and columns when explosion caused by different charge weight occurred in the car park. We would study the blast load on the elements using ProSAir. ProSAir is an advanced CFD code with the ability to model a wider range of blast-related phenomena. In general, ProSAir is used to model air-blasts in and around structures and estimating the resultant structural loading.

We modelled a generic car park in Singapore subjected it to a blast load caused by vehicle-borne improvised explosive device (VBIED). A model shown in Fig. 1 was modelled. In plan, the model was defined at centre of a typical car park – a distance of approximately 30m. All the columns are equally spaced at 9m centre-to-centre. To minimize the influence of modelled boundaries and to ensure all relevant structural elements were included, the model encompassed one floor above and below the levels of interest.

Detonations were investigated at 1.5m from the face of column. This standoff distance was selected as a reasonable value considering the likely position of a vehicle at the car park. Three different charge weights were modelled. The corresponding blast overpressure at several locations in the model (see Fig. 3) were read and presented in Fig. 4 to 7.

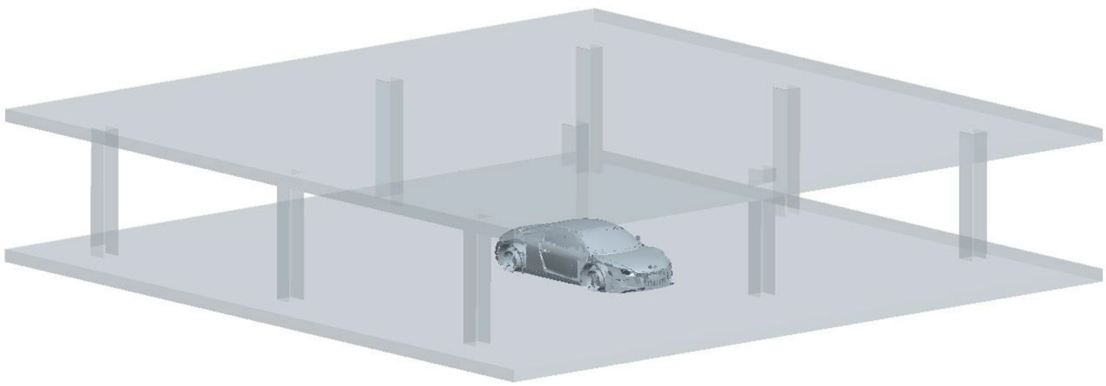


Fig. 1: Typical 3D car park layout in Singapore

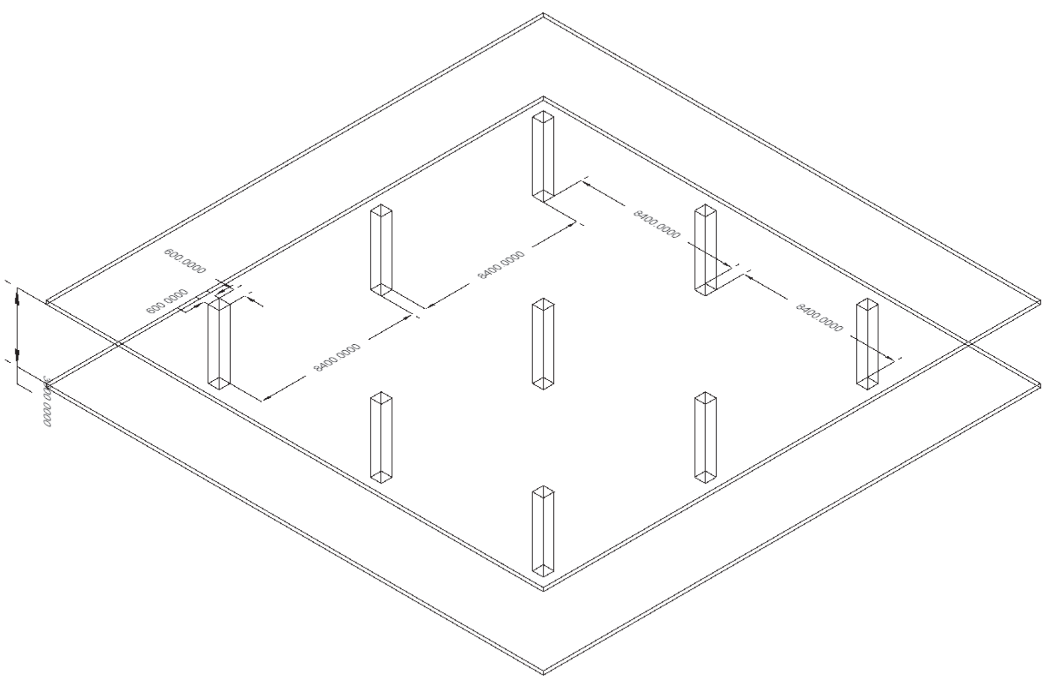


Fig. 2: All the dimensions are shown in wireframe view

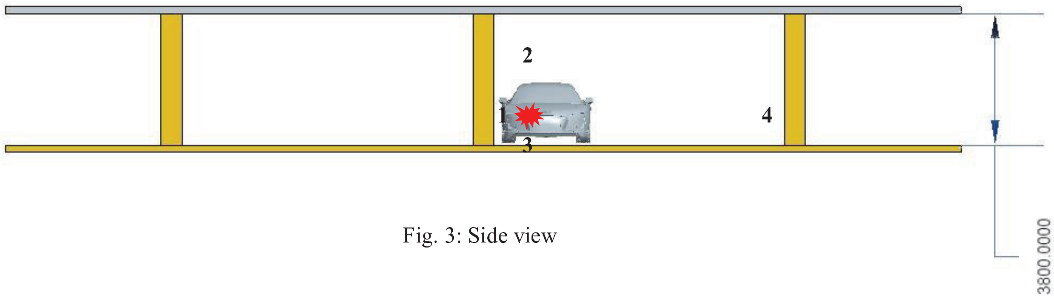


Fig. 3: Side view

3. Results

Pressure-time history data for the several locations in the model are shown in Fig. 4 to 7. Fig. 8 shows blast wave propagation for large charge weight.

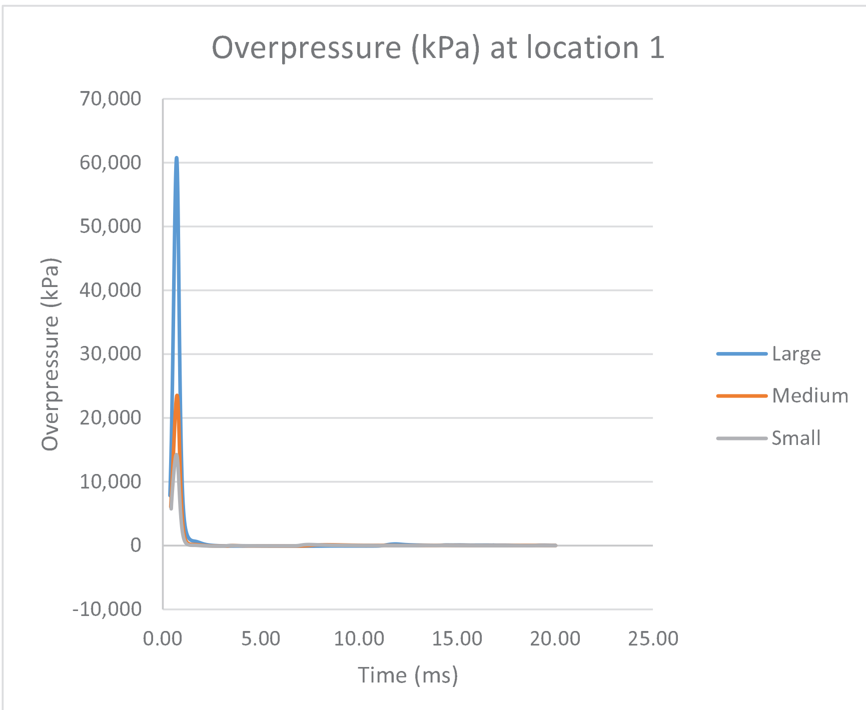


Fig. 4: Overpressure (kPa) at location 1

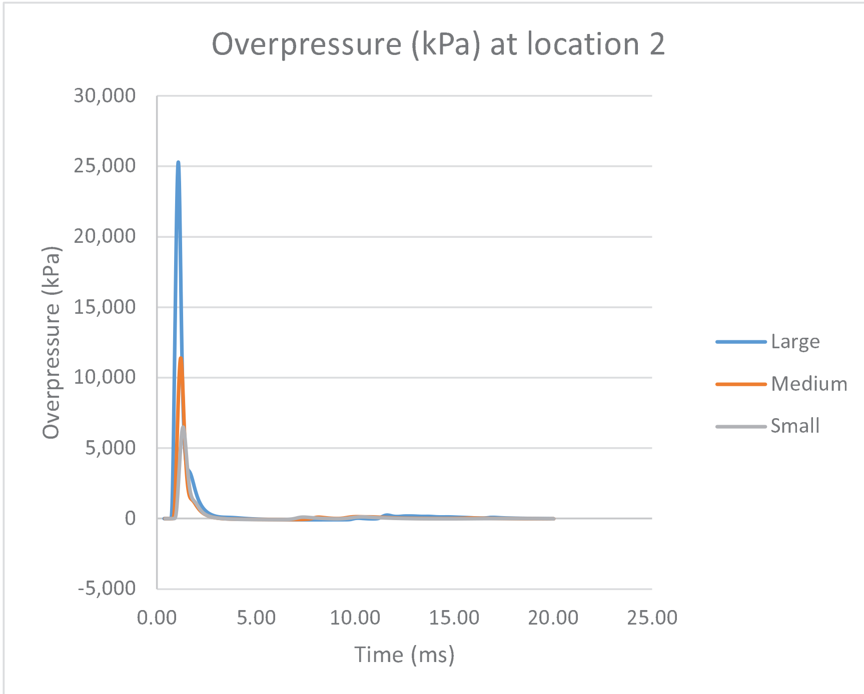


Fig. 5: Overpressure (kPa) at location 2

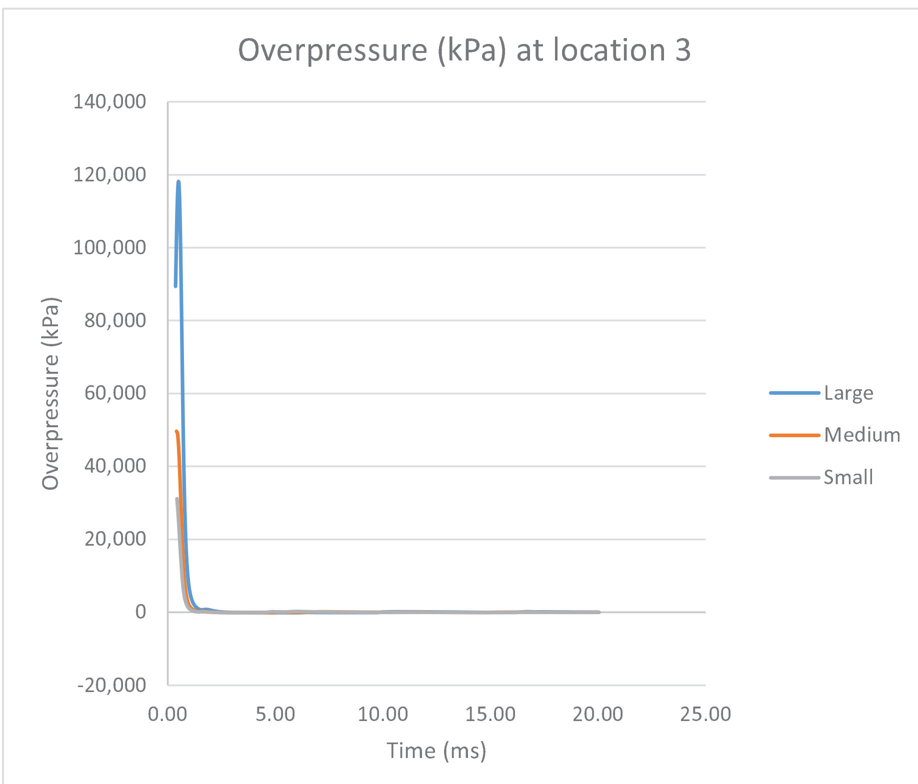


Fig. 6: Overpressure (kPa) at location 3

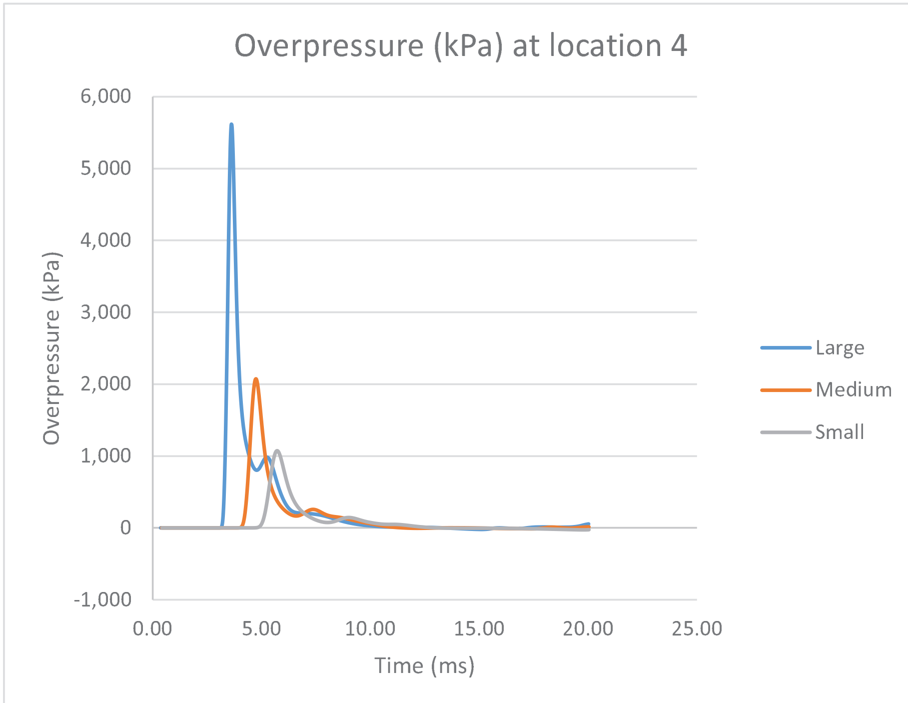
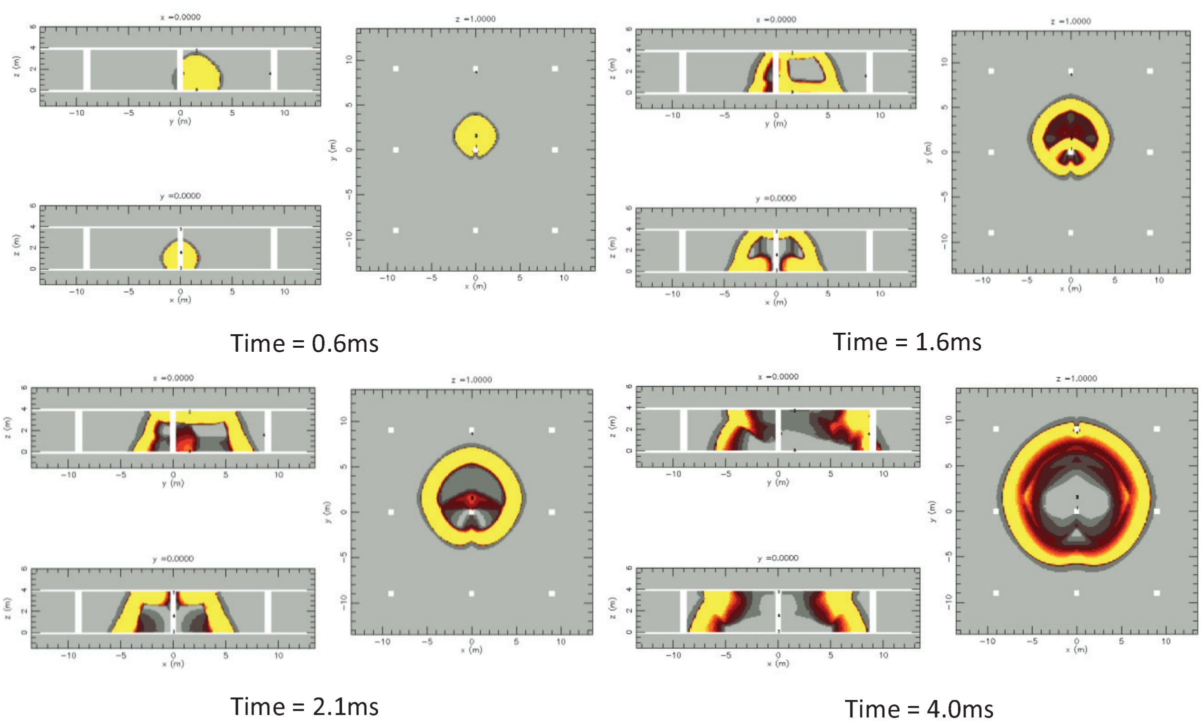


Fig. 7: Overpressure (kPa) at location 4



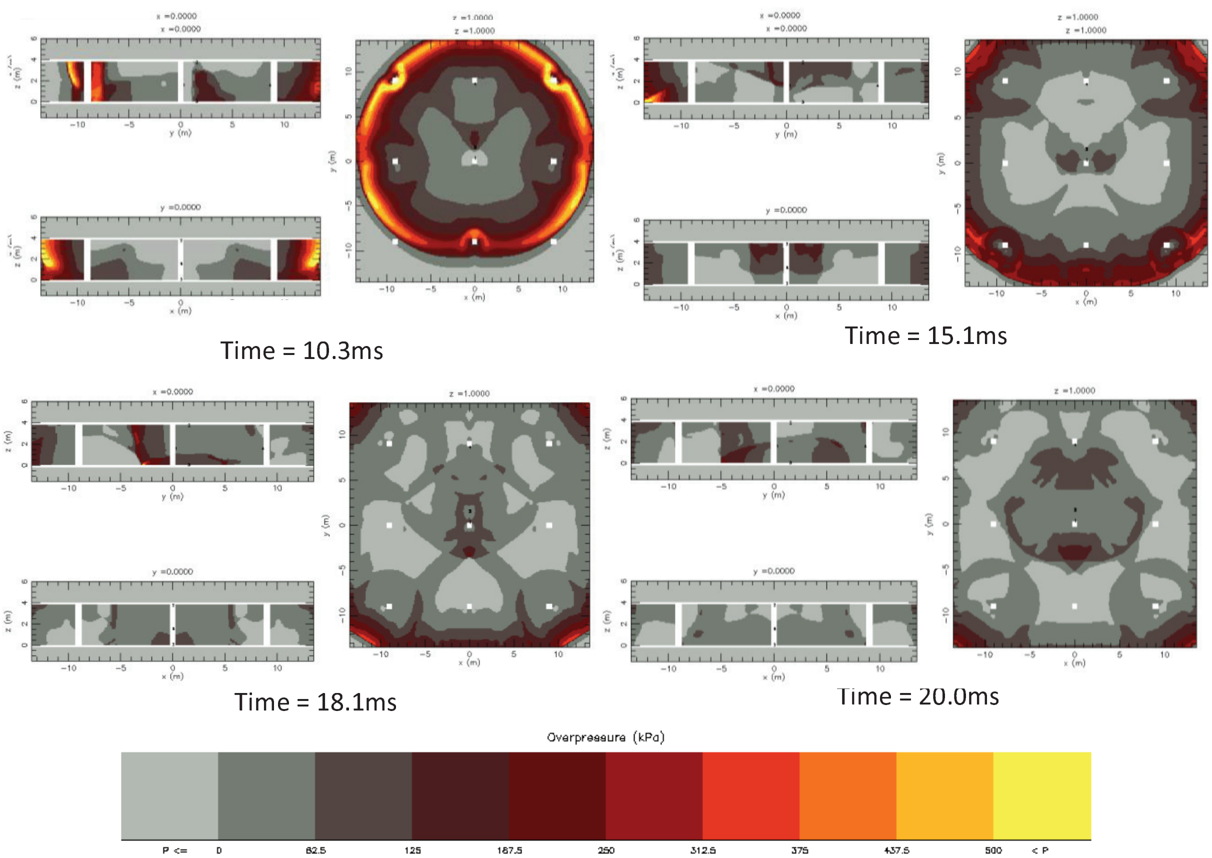


Fig. 8: Blast wave propagation for large charge weight

A summary of results for the slab and column is provided in Table 1. The summary includes maximum results from the geometry of the structure.

Table 1: Summary of peak overpressure and peak impulse for the slab and column

		CHARGE WEIGHT					
		small		medium		large	
LOCATION	**STRUCTURAL ELEMENTS**	Peak pressure (kPa)	Peak impulse (kPa-ms)	Peak pressure (kPa)	Peak impulse (kPa-ms)	Peak pressure (kPa)	Peak impulse (kPa-ms)
1	Column directly next to blast location	14246	5848	23543	9602	60791	23667
2	Slab directly above blast location	6495	3747	11393	5649	25299	12164
3	Slab directly below blast location	31171	6952	49655	13799	118142	43047
4	Column directly opposite blast location	1073	1563	2073	2429	5617	5035

4. Discussion

Pressure-time history data for the structural elements are shown in Figure 4-7 for detonation at 1.5m from the face of column. The blast wave propagation for detonation at 1.5m from the face of column is shown in Fig. 8.

The following key findings were apparent from the CFD analyses results.

a) As expected, peak pressures for slab directly below blast location was significantly higher, more than 110% compared to column directly next to blast location.
b) Peak pressures for column directly next to blast location also experienced high blast load, 10 times more than column directly opposite blast location.
c) From blast wave propagation, it was observed that the blast wave dissipated spherically symmetric, relatively with distance.
d) Blast wave caused localized effect on column and slab.
e) For large charge weight, the blast wave took roughly 20ms to dissipate from an area of 27m x 27m.

For car park deemed vulnerable to IED, the slabs and columns should be design to withstand blast load.

5. Conclusion

ProSAir was used to evaluate the performance of a reinforced concrete slab and column subject to a specific VBIED threat scenario. A ProSAir model of car park is created and validated with Paul J. Mullett [5].

The key findings pf the analyses are outlined below.

a) A generic car park in Singapore which subjected to small, medium and large charge weight is studied.
b) For car park deemed vulnerable to IED, the slabs and columns should be design to withstand blast load.

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