

BLAST RESISTANT DESIGN PARAMETERS AGAINST AN UNCONTROLLED DEMOLITION (IMPLOSION) IN AUSTRALIA

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ABSTRACT: Because of the uncertainty that presently exists within the Australian community of a possible improvised explosive device (IED) or vehicle improvised explosive device (VIED) detonating at some time in the not too distant future there is uncertainty as to what would happen if an Australian engineer was approached by a civilian developer to either design a new commercial structure or design a retrofit an existing commercial structure what explosive charge weights are to be designed for and what type of explosives will be used? With no Australian Standard or Design Code yet available the engineer could look for overseas examples for design parameters. Three events were considered in this paper using CONWEP software. A 5kg IED detonated on a top deck of a London bus with zero detonation distance amongst travelers generating a peak pressure of 32.69MPa, a 1020kg VIED was detonated 3m from a club generating a peak pressure of 10.29MPa and a massive 2990kg VIED was detonated 6m from a multi-storey RC building generating a peak pressure of 5.83 MPa. Peak pressures in all three events meant all were well above lethality for people and that destruction of assets they were detonated in or next to was inevitable. As explosive charge weights can't be controlled the only parameter a designer can dictate is range. So, any design must be such that it forces a terrorist to detonate as far away from the intended target as possible thus reducing blast overpressures that impact people or assets.

Keywords: charge weight (kg), damage, collapse, pressure, impulse

1. INTRODUCTION

When a structural engineer is commissioned to design for blast loadings subjected to a new building or to retrofit an existing building because of a potential IED or VIED attack the two things that must be actioned before the engineer even commences the design process is to determine the likely explosive that could be used by a bomber [1] and the charge weight of explosive that could be detonated against or near the building. This is a particularly onerous process as presently Australia has no standard for blast loadings and the availability of such information sought is limited. The Australian Security and Intelligence Organization (ASIO) and the Australian Federal Police (AFP) may be able to provide information sought but not necessarily in the operational time frame required. That puts the structural engineer at a disadvantage which would inevitably lead to drawing on information of past terrorist style attacks in Australia and probably the Asian region to highlight the type of explosive and charge weight [2] most likely to be used. With no Australian standard available one would be forced to use overseas codes and standards that give guidance in such matters to develop a suitable design capable of carrying the blast loadings with minimal

damage to the structure occurring and minimal death or injury for those unfortunate enough to be caught inside or near the building.

1.1 Past Australian Bombing Attacks

In regards to several mainland Australian bombings [3] that have occurred over the years many Australians are unfortunately completely unaware that such events ever took place. Seven terrorist attacks have been carried out in Australia stretching since 1972 that include the Sydney Yugoslav Travel Agency bombing (1972), the Sydney Hilton bombing (1978), the Sydney Israeli Consulate and Hakoah Club bombing (1982) and the Family Court building in Parramatta NSW plus the family home of one of the courts judges (1984). All saw severe to minor damage being sustained to buildings and deaths and injuries [4] resulted. The explosive used in the Yugoslav Travel Agency and the Hilton Hotel bombings was gelignite and in the case of the Israeli Consulate an improvised explosive device (IED) [5] made of several gas cylinders and placed in the boot of a stolen sedan was used. So, blast loadings because of bombings are not new to Australia but the authors by increasing impact factor of the journal.

type and size of explosive charges [6] deployed against targets have been limited and small to date with the closest to Australian shores being a 1ton vehicle improvised explosive device (VIED) detonated in Bali in 2002.

1.1 Building Damage Standards

The United States provides standard guidance [7] in regards to the level of protection necessary for any design process to mitigate against structural damage and the death or injury to individuals. Table 1 [8] provides suitable guidance, but two additional pieces of information are required by any structural engineer to design for blast loadings. In addition to this information the engineer needs to know the pressures from the specific blast loading that dictates the type of damage that inevitably occurs in structures and the pressure that causes death and injuries. Tables 1 and 2 from DoD Minimum Antiterrorism Standards for Buildings (UFC 4.010.01 dated 31 July 2002) below provide that specific type of information. Hardened or polymer coated glazing stops or reduces shattering of glazing and restricts the primary fire entering the building at best or delay it at worst.

1.2 Primary Injury Thresholds for Individuals

Table 2 shows that pressures impacting on individuals from blast loadings exceeding 700 kPa will kill or injure [9] so the designer must do the utmost to bear this in mind during the design process. No amount of design can overcome the pressures detailed in sub-para 2.6 below and such pressures applied will inevitably cause death.

1.3 Structural Damage Overpressures

Table 3 stipulates those pressures that will result from the severity of the damage from blast. These United States figures clearly show that for the American structural designer pressures more than 82 kPa will probably cause destruction and collapse of buildings. Of course, with pressures of 5.85 MPa being applied to the building during the Oklahoma bombing destruction and collapse was catastrophic. The 82 kPa figure provided to American designers again gives guidance regarding structures likely to be impacted by this level of pressure or above and the opportunity to employ design criteria such as provide increased structural ductility, inbuilt redundancies and the implementation of alternate

path design methods. This is design information which is lacking in Australia.

2. TYPICAL REGIONAL AND INTERNATIONAL BOMBINGS

The following are examples of three bombing attacks [10] two of which are at the far ends of the earth from Australia but one which occurred on our doorstep in Indonesia. The three use totally different explosives and charge weights and although the first two were for political reasons the last was carried out for domestic reasons. So, attacks occur for a variety of unrelated reasons. If a structural engineer is looking to choose the type of explosive and the charge weight to be used it may not only be the result of the type of bombing itself but the motivation of those behind the attack coupled with the availability of materials. The Americans and the British have now experienced so many attacks [11] over the years they are acutely aware of what type of detonations will probably be involved and what exactly to design for. The situation currently presents a major problem for a designer to arrive at an explosive type and charge weight to use to design against blast loadings within the Australian environment.

2.1 London 2 July 2005

These were a series of attacks in London [12] by four British nationals on the London underground and on a city bus. The attacks caused maximum chaos during the rush hour in tube stations. The bombing was possibly a politically motivated attack, but no definite explanation has been forthcoming to this day.

2.1.1 Type of Explosive Used

The explosive used produced by heating acetone and peroxide together to form an explosive called "Tri- acetone Tri- peroxide "but known simply known as TATP [13]. It has a velocity of detonation of 5300 m/s which means a high capacity to cause severe structural damage and death or injuries to those nearby. It is a very unstable explosive that is sensitive to both heat and pressure changes and can detonate without warning. Acetone is solvent and peroxide hair bleach with both being readily available and at low cost over the counter in the United Kingdom. The ingredients of the explosive are sold over the counter in the United Kingdom.

The explosive has never been used (detonated) in Australia but a person was arrested by police in late 2013 in Bunbury Western Australia after manufacturing the explosive. He was aware of its inherent instability and so stored it in the Swan River in plastic bags and underwater. Both ingredients to make TATP are also available and at low cost over the counter anywhere in Australia.

Table 1 Primary injury thresholds

CRITICAL EFFECT	LIKELIHOOD OF EFFECT	PEAK OVERPRESSURE (kPa)
Ear Drum Rupture	Threshold	34
	50%	103
Lung Damage	Threshold	207
	50%	552
Lethality	Threshold	689
	50%	896
	100%	1379

Table 2 Damage typical overpressure

DAMAGE	INCIDENT OVERPRESSURE (kPa)
Typical Glass Window Damage	1.03-1.52
Minor Damage to Some Buildings	3.45-7.60
Panels of Sheet Metal Buckled	7.58-12.41
Failure of Concrete Blockwork	12.41-19.99
Collapse of Wood Framed Buildings	OVER 34.47
Serious Damage to Steel Framed Buildings	27.58-48.26
Severe Damage to Reinforced Concrete Structures	41.37-62.05
Probable Total Destruction of Most Buildings	68.95-82.74

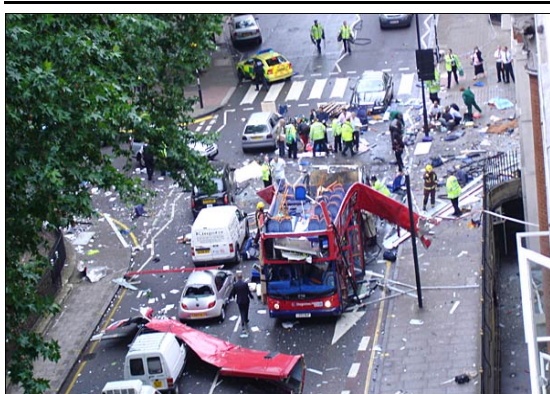


Fig.1 Roof of bus blown off central London



Fig.2 Total collapse of half of the reinforced concrete 9 storey Oklahoma building

2.1.2 Method of Carriage of the Explosive

The bomb carriers involved carried the explosives in 10 kg full backpacks which were quite capable of carrying the bomb, the detonator and the detonation device. Because of the sensitivity of the explosive both to vibration and rise in temperature this presented a very risky way of carrying the explosive device for the bombers that could have resulted in an unplanned detonation.

2.1.3 Where the Attack Took Place

Subways and buses could have been targets where such explosive devices could have been detonated. The targeted areas were suitable for the detonation of small (5 kg) explosive charges weights with the ultimate view in causing maximum damage to structures and people.

2.1.4 Level of Damage to Assets

Table 1 dictates that the damage sustained was certainly “below antiterrorism standard” thus causing severe damage and death and injury to travelers. Figure 1 below clearly bears out this assessment.

2.1.5 Casualties

Because of the bombings the four assumed attackers and 52 civilians were killed and over 700 Suffered injuries.

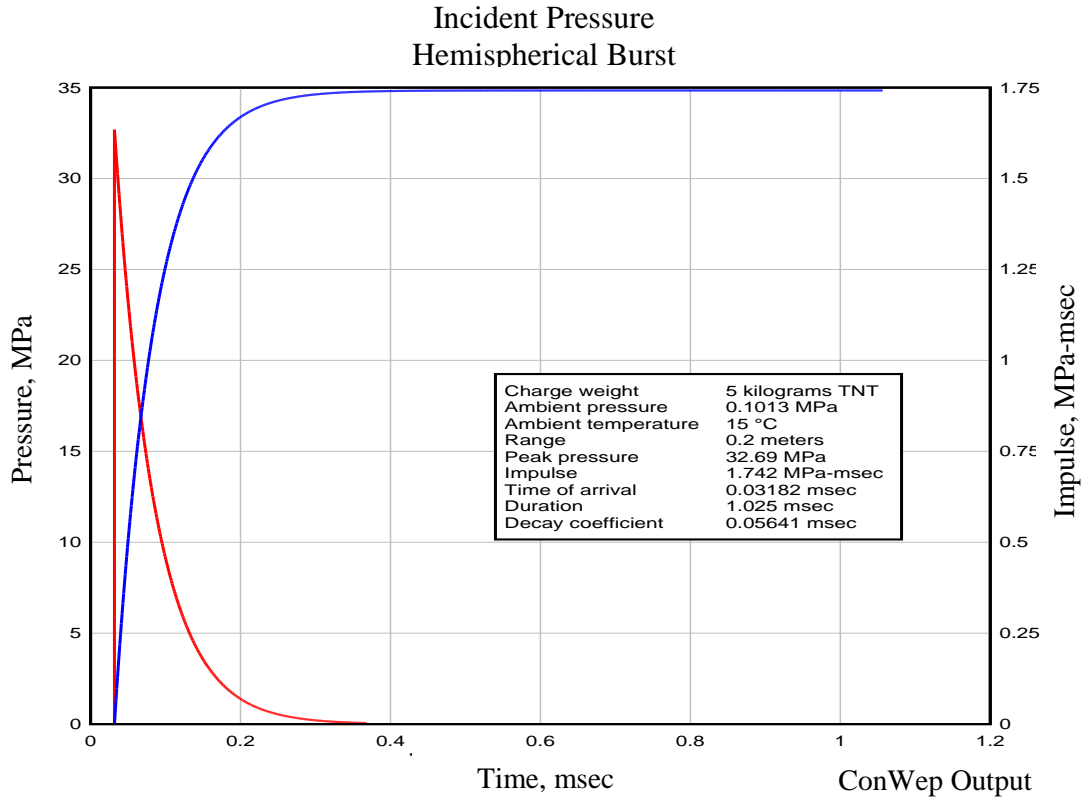


Fig.3 Pressure V's Time graph for 5kg explosive

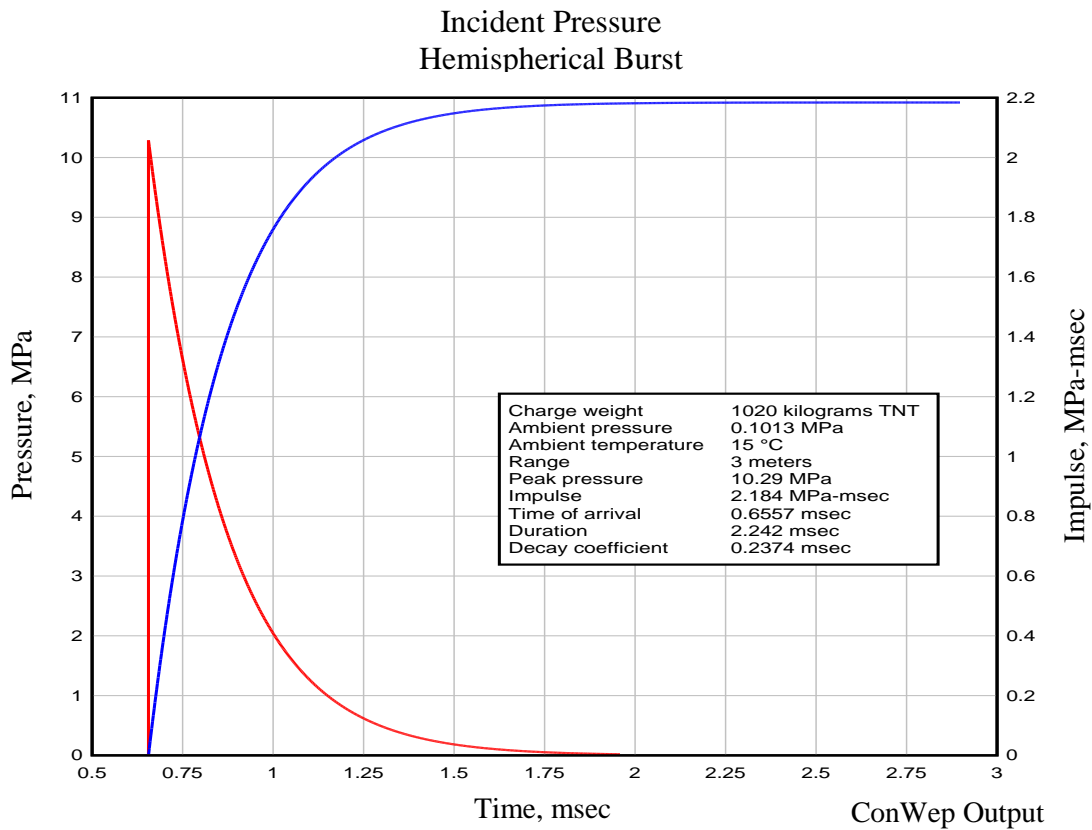


Fig.4 Pressure V's Time graph for 1020kg explosive

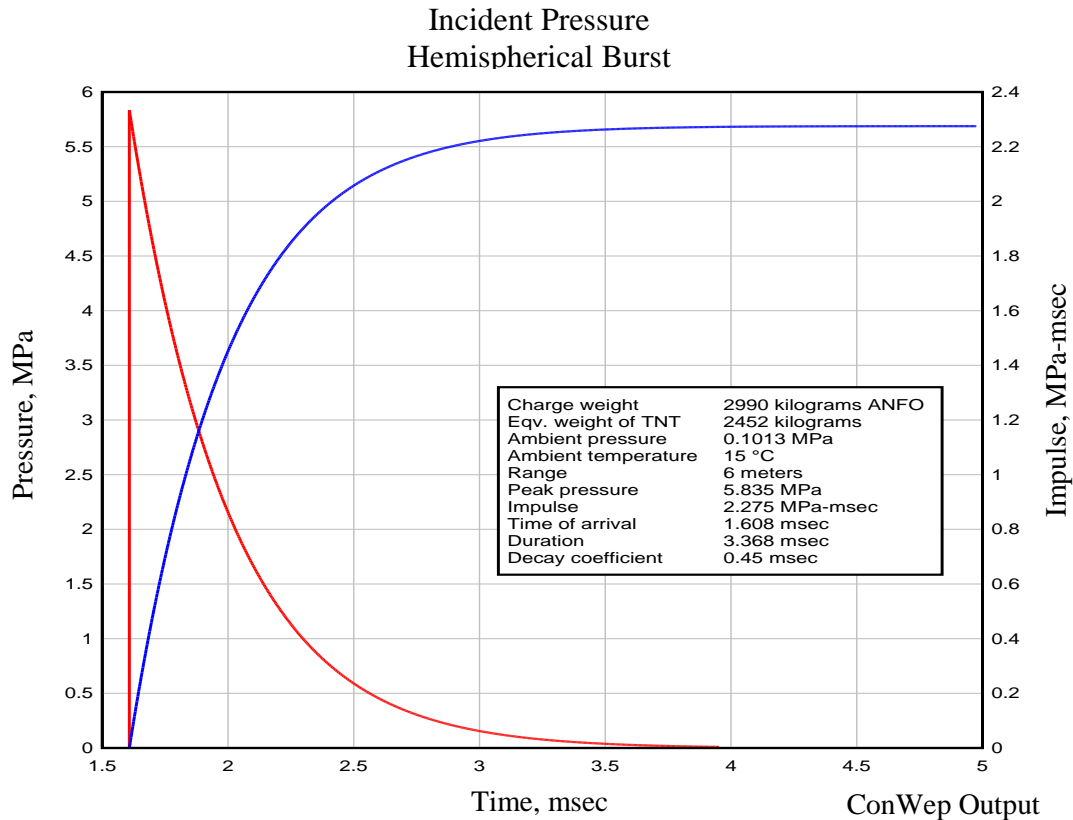


Fig.5 Pressure V's Time graph for 2990 kg explosive

2.2 Bali Bombing 12 October 2002

The bombings occurred in the tourist district of Kuta on the Indonesian island of Bali [14]. There were three IED's detonated one being a backpack device, the other a 1-ton van car bomb and the last a small device outside the United States consulate in Denpasar. Both the backpack and the van were detonated outside and inside the Sari night club. The bombings were politically motivated attacks.

2.2.1 Type of Explosive Used

All the products necessary to make the bomb were readily available in Kuta. The potassium chlorate is in effect a fertilizer regularly used in Indonesia by farmers and both the aluminium powder and sulphur are used in numerous commercial processes in the country. Sulphur is collected from the craters of the many active volcanoes found throughout Indonesia. The high temperature blast damage produced by this mixture is like that produced by a thermobaric explosive used in military ordnance. This type of explosive feeds off the surrounding oxygen which does not happen with a normal nitrate explosive.

2.2.2 Method of Carriage of the Explosive

One IED was carried in a 10 kg backpack within the Sari club whilst outside a 1-ton van capably carried the larger VIED that was detonated causing much structural damage and many casualties. Many people outside of the club were caught and killed by this blast.

2.2.3 Where the Attack Took Place

The attack took place in an Indonesian tourist center designed to cause maximum damage, casualties and chaos. The 1020 kg of explosives caused massive damage [15] to the building outside of which it was parked and to surrounding structures. The cost to design against this type of damage would be large. In this case the van was parked some 3 m from the target and the backpack bomber detonated THE explosive inside the club.

2.2.4 Level of Damage to Assets

Table 1 dictates that the damage sustained was certainly "below antiterrorism standard" thus causing severe damage and death and injury to holiday makers.

2.2.5 Casualties

The attack killed 202 people (including 88 Australians, 38 Indonesians, 27 Britons,

7 Americans, 6 Swedes and 4 Danes). A further 209 people were injured.

2.3 Oklahoma City Bombing 19 April 1995

The bombing was a domestic bombing attack [16] in that it was carried out by Americans against Americans and was carried out against a large government occupied building. The attack was carried out by two white supremacists. The blast not only virtually demolished one half of the Alfred P. Murrah building (Figure 2) but it also destroyed or damaged 324 buildings within a 16 block radius, destroyed or burned 86 cars and did minor damage to adjacent buildings such as shattering glass and causing cracking in masonry [17] and concrete walls. This attack has been very closely investigated by other government agencies and many of the structural details that have been adopted to mitigate against structural damage and so save lives has resulted from such an investigation and many recommendations made can now be found in both civilian and military American codes, standards and manuals designing for blast loadings.

2.3.1 Type of Explosive Used

The attackers in this case chose to use a prilled ammonium nitrate [18] mixed with nitromethane and diesel to form ANFO (ammonium nitrate fuel oil mix). This is a standard mix with the exception in this case the terrorists chose to spice up part of the mix by using nitromethane [19] which is a sports drag racing car fuel designed to give instant acceleration and vast power to the engine. The velocity of detonation of normal ANFO is 3200 m/s [20] but with the addition of the nitromethane the capacity of the mix to cause maximum damage was present as the nitromethane has a higher laminar combustion velocity of approximately 0.5 m/s than diesel fuel plus a higher flame temperature of about 2,400°C.

2.3.2 Method of Carriage of the Explosive

The two attackers hired a three ton truck to carry the explosives [21] and bought a small car as a getaway vehicle. Thirteen plastic barrels were placed in the back of the truck each containing 230 kg of the explosives.

2.3.3 Where the Attack Took Place

The attack took place on the Alfred P. Murrah Federal Building, Oklahoma City, Oklahoma, and United States. The motivation for the attack on the government building was apparently as a result of the bombers anger at the federal government's handling of the Federal Bureau of Investigation (FBI) standoff at Ruby Ridge [22] and Waco [23] where the sieges lead to deaths and injury of civilians. The vehicle was placed 6 m from the left-

hand side of the building and detonated from a distance inside the building. Most of those killed were as a result of the [24] collapse of the building.

2.3.4 Level of Damage to Assets

Table 1 dictates that the damage sustained was certainly "below antiterrorism standard" thus causing severe damage and death and injury to those caught.

2.3.5 Casualties

Because of the bombing casualties amounted to 168 people killed and more than 680 injured.

2.4 Availability of Compounds in Australia

All compounds specified in the previous paragraphs are readily available in Australia and there are no restrictions on their sale or limits on the quantity that can be purchased over the counter. For large amounts such as 1Ton and 3 Ton bombs suppliers may not be able to provide the total amount sought by the would-be bombers, but they would simply be compelled to travel to other suppliers until the quantity required is obtained. An example would mean for an ANFO bomb of 2990kg in weight means some 120 bags of prilled ammonium nitrate fertilizer would be required. 10 suppliers would therefore be required to provide 12 bags each which probably would not be a problem.

2.5 Bombing Access to Targets in Australia

In the present uncertain climate of possible attacks within Australia targets are not in short supply. In the United Kingdom and the United States many new and existing structures have been designed to withstand blast loadings with this process starting in the late 1970's because of terrorist attacks. Initially Government and Military buildings worldwide were designed for blast loadings as these were the structures primarily targeted by bombers but today with the constant reporting of worldwide attacks in many countries on civilian targets such as churches (primarily Muslim countries), markets, night clubs and carparks not only have the targeting changed but also the tempo of attacks. This creates a dilemma as the question arises as to which buildings should be designed or retrofitted to take blast loadings and the loadings. A prominent structure designed and built to withstand blast loadings has been the new ASIO headquarters in Canberra [25].

2.6 Pressure and Impulse Outputs form the 2 Attacks

Inputting charge weights (kg), distance from target (m) and type of explosive incident pressures

[26] shown in Fig.3,4&5 were generated by CONWEP [27] for hemispherical surface blasts. It is also The Figures also show that as both the charge weight and distance to target increases the peak overpressure experienced reduces but the time of arrival and duration of the blast load increases. In the case of the 5 kg TATP explosive IED detonated on the top floor of the London bus it was detonated amongst seated fellow travelers. So, the distance to target was a minimum and the full impact of an incident pressure of 32.69 MPa was felt by the bus structure and the people. The incident pressure is well above the 82 kPa damage levels detailed in Table 2 so maximum damage to the bus structure would have been expected and with loss of life the incident pressure experienced meant that the 1379 kPa threshold for lethality was far exceeded. In Fig.1 the bus roof can be seen peeled back by the blast. The blasts time of arrival to target was 0.031 msec and the blast duration was only 1.025 msec. For the 1020 kg explosive VIED detonated in Fig.5 only 3 m from the entrance from the Sari club in Bali the 10.29 MPa incident pressure experienced produced the exact same result as that in sub-para a above with massive damage to the structure occurring and a large loss of life resulting. In Oklahoma City as has been discussed in para 2.3 above the 2990 kg VIED charge weight in Fig.5 was massive and placed only some 6 m from the structure. The incident pressure of 5.83 MPa is still large when compared to the other two charge weights above but in this case death and injury to those caught in the building was primarily due to the collapse of the structure.

3. THE STRUCTURAL ENGINEERS' CHOICE OF EXPLOSIVE AND CHARGE WEIGHT (kg)

Based on the information to hand the structural engineer would base the choice of explosive and charge weight to commence a design on the several points. If the commercial premises both new and old were provided with car parks a bombing from within the car park would be dictated by the ability of the would-be attacker to drive into the car park. In other words, the size of the vehicle that could be driven into and parked within the car park. Large 3-ton vehicles cannot access commercial car parks, but 1-ton vehicles can so a design blast loading charge weight of 1 metric ton would no doubt be an acceptable choice. This blast loading would also accommodate smaller vehicles laden with explosives entering the car park with explosives and detonating the explosives. The type of explosive the would-be terrorist may use Prilled Ammonium Nitrate that is readily available in 25 kg bags from any hardware store or explosive supplier in Australia as is the diesel fuel to mix with it to create

“ANFO”. It is not expensive, and it is now marketed in bags (@ \$57.00 per bag) with the fuel oil already added which makes a terrorist’s job exceptionally easier. ANFO has a reasonable velocity of detonation so its detonation depending on the size of the charge would cause considerable damage to any structure and injure or death to those caught nearby. For the 5 kg of explosive carried in a backpack by the attacker as can be seen from Fig.4 with an incident pressure of 32.69 MPa the blast is deadly as evidenced by the death toll in London and Bali. With this knowledge, the structural engineer can begin to incorporate security measures into the design such as checkpoints for security checks of people and vehicles trying to enter the building and vehicle barriers to forestall terrorists from getting close to the building before detonating the explosive. CCTV monitoring may also be incorporated into any design to monitor terrorist activity in advance. After choosing the explosive and charge weight the structural engineer will be aware of the complexity and effort that must be put into the design process to mitigate against structural damage and possible collapse of the building. The greater the charge weight and the velocity of detonation of the explosive the more sophisticated and precise the design has to be remembering that the overriding duty is to mitigate against damage and delay collapse.

4. CONCLUSIONS

If both new and retrofitted structures were designed to cater for the 2990 kg charge weight, there is no doubt that the structures would see minimum damage and injury or loss of life from any bombing, but the cost may well be prohibitive. A compromise could no doubt be reached such as to design against a blast load emanating from say a 1000 kg charge weight of explosive placed in a 1-tonne vehicle. The design of a new building is a far easier design proposition than having to design the retrofit of an existing structure. If short stubby columns spaced close together with a beam on top is considered a more suitable structural configuration to accommodate blast loadings and so avoid structural damage it may be impossible to retrofit a building with long slender columns already in a position spaced wide apart. Whatever explosive type and charge weight is chosen by the structural engineer based on experience, it would be prudent to keep in mind all legal and insurance implications if a greater charge weight is applied to the structure than was designed for. Did the engineer choose the right code or standard at the start of the design process and is the engineer prepared to argue and justify the design choices if such an unfortunate situation arose? Fig.6 is the

diagrammatic design process that any structural engineer would have to follow.

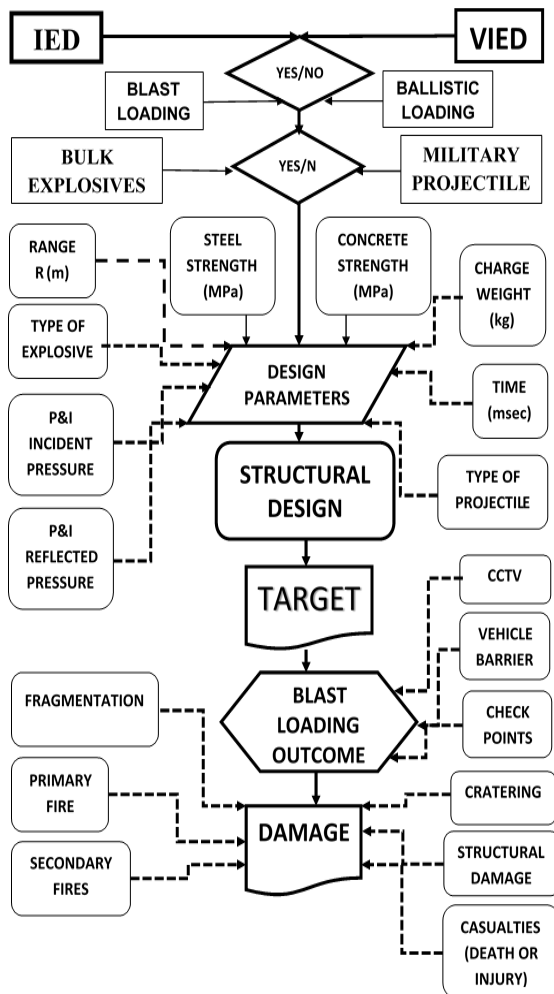


Fig.6 Uncontrolled demolition design process flowchart

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