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HOW SAFE ARE ENGINEERING STRUCTURES AGAINST TERRORIST ATTACK? ¹

by John A. Hill

It was suggested that I address the question: *How safe are engineering structures against terrorist attack?* Let me state that structural Engineers consider safety to be at the centre of their profession. But the centre of that focus is the safety of people within and around structures.

I believe some basic distinctions can be made in the nature of terrorist attacks generally and on buildings. Is the intention to harm people without discrimination, or is the intention to maximise economic loss? In the numerous attacks in recent years against US targets overseas and on US home soil, it is the wanton disregard for any human life that adds a further dimension. This seems to remove a bar against any act as being too repulsive to contemplate by the probably well educated and sophisticated, but twisted minds, of the perpetrators.

I live in **Belfast**. Many of you may know that since Northern Ireland came into being in the early 1920's, the consequences of *riot and civil commotion* have been excluded from most insurance policies issued there. Thus it has fallen to Government there to compensate for loss of buildings and personal injury where it can be established that these resulted from the actions of terrorists. Now in Northern Ireland we are celebrating a new turn on the path towards peace where the terrorist Irish Republican Army (IRA), has decided to pursue the democratic process and begin to put its weaponry beyond use. There is some way to go in that democratic process to establish political stability and normality among a people who have grown accustomed to a certain level of violence during the past 30 or so years. Let us hope that this process proves to be an example to others groups who presently prefer the use of violent means to change society.

My experience of the security of buildings in the United Kingdom suggests that when new security measures are put in place, future attacks do indeed come in a different form. Once the measures you put in place are known, a way round them can be devised. I

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have been asked: how big a bomb should one design a structure to resist? I can give some guidance but once the enemy knows how thick your concrete is, the method of attack can be devised to destroy it. During the Gulf War Saddam Hussein found his multi-level, underground Command and Control Centres were not immune to attack and destruction from the air. Their design was known, so the nature of the weapon to destroy them could be determined. I shall have more to say about structural design in this context.

In 1968, in a suburb of London, there was a gas explosion during the night in one apartment on the 18th floor of a 22-storey apartment block called **Ronan Point**. The room where the explosion occurred was next to the gable end wall of the building. All of the rooms in that position on every floor collapsed as a result of the explosion. There was a Public Enquiry into the circumstances. There were several important findings from that Enquiry, some of which I would mention:

- Gas explosions in domestic dwellings were found to be surprisingly frequent when the incidence of explosions across the United Kingdom was examined. Most gas explosions occurred in one-family homes of at most two storeys in height. A similar gas explosion in a high rise apartment block would put at risk many families
- The risk of substantial loss of life from another gas explosion in a similar tall block of flats was unacceptably high if combined with a structure of limited robustness
- The fitters of gas appliances were not being formally trained and registered.
- Ronan Point, one of many tall apartment blocks of similar construction, was a proprietary system building formed from large precast concrete wall and floor panels, built rather like a 'house of cards', with quite limited physical connections of significant strength between panels. That form of construction and others like it were vulnerable to accidental loading.
- The structure of Ronan Point essentially depended on the force of gravity to hold it together

As the result of these findings it was necessary to have an extensive program of strengthening of all similar apartment blocks throughout the United Kingdom. The buildings were largely in public ownership so the government paid for the programme of strengthening. Gas for cooking and heating was removed from the buildings most at risk, and bottled gas was also banned from those buildings.

Thus **the concept of progressive collapse** entered the vocabulary of Structural Engineering and into the UK Building Regulations. Clearly what had been seen at Ronan Point was the collapse of one floor and all the floors above it, when the precast concrete gable wall of one room was blown out. The gable wall above, and the floors above, ceased to have support. A chain reaction ensued as the floors fell on the floor below leading to total progressive collapse of all floors of the end bay of the building. The rest of the building was undamaged.

The conclusion, in terms of the United Kingdom Building Regulations, has been that structures built since the early 1970's, higher than five storeys, including a basement storey, have complied with certain rules to limit disproportionate collapse in the event of an accident – to be sufficiently robust so that damage caused by an extreme event is not disproportionate to that event.

Using these rules, it is necessary to demonstrate that the building could survive the removal of any single member without damage affecting a significant floor area. This is achieved by accepting that the structure in a damaged state would bridge the gap by catenary action, perhaps with considerable distortion. This is not a serviceability consideration, but a situation close to the ultimate strength of the structure, with the

structure damaged and close to, but not at collapse. If the structure is unable to withstand the removal of a member in this way, that member, now defined as a *Key element*, has to be made strong enough to resist a very large force representing an arbitrary pressure. Most important: the structure must be tied together horizontally and vertically to enable the catenary action to take place.

In stages since early in 1970, British Standards and Codes of Practice dealing with structural materials and the design of structures have introduced these concepts. These Codes have defined the extent of lateral and vertical tying together of structure so that in the event of an accident, there will be the means to hold the building together without disproportionate damage. The aim is, and I quote from the current Building Regulations, that: *in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause*. I would emphasise the words not disproportionate to the cause.

However, growing concern in recent years has been expressed that these provisions should not only apply to tall buildings. It is possible to envisage that the failure of one member in a large single storey structure, perhaps occupied by many people, could lead to disproportionate collapse, and that must be prevented. For example, more people could be at risk in a sports stadium than might be the case in a tall building. The United Kingdom *Standing Committee on Structural Safety*, usually known as SCOSS, the watchdog on structural safety, has recommended change.

In the United Kingdom we are currently considering a consultation paper from Government on proposals for new Building Regulations; the paper was published last August. The paper introduces risk assessment concepts to identify if special measures to deter disproportionate collapse are required for the particular circumstances of a structure. For example the following factors might be considered:

- The building type and its usage – number of people at risk
- Construction materials to be used – brittle or ductile: masonry, steel or concrete?
- Height of the building in relation to its environment – consideration of its surroundings
- Where there is a high risk - such specific hazard as may be identified

The consultation document refers to *hazards likely to arise during normal use and that may occur in an accident*. The document proposes that the hazards considered: *should include both naturally occurring and man-made hazards*.

The actual risk factors are now being discussed. It is not known yet if the proposed new rules would have a significant effect on building design philosophy in general and cost of building. And in the light of the events of the 11th September, will these proposals go far enough?

At this point in my argument I would submit that *the factor of terrorism can indeed be calculated into engineering structures and buildings* where the kind of design rules I have described are applied. But again I would emphasise that the aim is to prevent *collapse to an extent that is not disproportionate to the cause*. We can design a building in a way that is plausible and reasonable in all the circumstances of the risk assessment, if the building owner so requires, but it is always possible that a more extreme event could arise in a deliberate attack. One is drawn to images of flattened cities from the Second World War. There is no practical limit to the extremity of the cause and effect.

I think that there is probably at present a considerable difference in approach to disproportionate collapse in buildings regulations around the world. In addition, the possibilities for retrofitting in the existing building stock will be limited. *'The disaster (of the 11th September) had changed the world, pointing up the low chance, high consequence risks'* (Prof. David Blockley, President of The Institution of Structural

Engineers).

Yet I would observe that there have been several examples in recent times of aircraft hitting buildings and destroying them; two come to mind: A 747 cargo plane ploughing into a block of flats near Amsterdam, and more recently the Scandinavian SAS aircraft destroying airport buildings after impact with another aircraft on the ground. There is some statistical probability of such events but they must be so rare as to be discounted in ordinary engineering design terms. What may be new in the terrorism context is the willful nature of the attacks on US buildings in recent years and the total disregard for human life.

I believe the main difficulty in engineering terms is to define the cause. Is it a bomb in a box, a bomb in a car, a bomb that fills a rubbish skip, is it a crashing vehicle or train or aeroplane, is it a nuclear explosion, is it a deliberate act of war? In the private sector, what range are we talking about? Is the threat inside or outside the building? Clearly the more protected a building, the more expensive it becomes and less friendly as a place to be. In the extreme, if some functions must take place in deep, secure, underground bunkers, so be it. Structural Engineers know how to design them. But that is not feasible for the generality of what we perceive today to be civilised life.

From my personal experience, concerned clients do make judgements on terrorist and other kinds of threats and do specify additional protective measures in discussion with their Structural Engineers. These measures may involve the robustness of floors, the strength of external walls and glazing, better standards of fire protection, evacuation policy in the event of threats and attack, and robust communication systems within the building. In addition, there will be measures to control access to buildings, and externally arrangements may be made to maximise the standoff distance for vehicles (potential bombs) near the building. A proposed new building or an existing building may have to be evaluated against such criteria.

We have witnessed the most extreme loading on three fine buildings. The impact of aircraft of more than 100 tonnes, at a velocity of several hundred miles per hour, with a fire load of thousands of gallons of kerosene are not things we contemplate for our clients on a day-to-day basis. In the limit our structures are designed to be demolished and a wilful terrorist will also find a way; there are wider [political] issues to address than the statics and dynamics of structural behaviour. Yet despite the extremity of the events, if there are lessons to learn, as structural engineers we shall learn them, and if there are things we can recommend within the bounds of probability to improve the integrity of our structures, we shall so recommend.

The structural engineering community has now had eight months to consider in forensic detail what happened to the World Trade Center on the 11th September 2001. The definitive report by Dr Gene Corley and his team in New York is expected to be published soon but the findings have not yet been made public.

The findings and recommendations will be important as a source of definitive performance analysis. The recommendations will be considered by the *Working Group on Safety in Tall Buildings*, a key internationally representative group with experts drawn from many disciplines. In the meantime the Group has accumulated a wealth of new material, particularly on the emergency evacuation of buildings and other issues. It has become clear from information in the public domain that the structural performance of both WTC towers, in resisting the impact of aircraft, achieved the objective of containing damage in the impact zone. The effect of a hydrocarbon fire as against a conventional fire load within an office environment is a comparative passive fire protection issue. Perhaps current standard fire tests on fire protection systems may need to be reviewed in the light of the evidence we have yet to see. And it was there for all to see that the WTC buildings stood for significant lengths of time to allow substantial evacuation. When we

specify, for example, one-hour fire resistance, we equate that in our minds broadly to the evacuation time available. Issues may also arise in the areas of active fire suppression measures and robust communications within buildings. Current evacuation policies have been reviewed and tests carried out in fully occupied major buildings in reasonably realistic circumstances.

Just as thinking was beginning to gel, we had the impact of a light aircraft with the Pirelli building in Milan. It was reported in NCE (25th April 2002) that some 300 to 500 terror-struck occupants were evacuated in seven minutes using a recently revised procedure. "We decided the most important thing is to get all the people out before the firefighters began ascending the building by the same staircases", an engineer for the owner, Regione Lombardia, is quoted as saying. The fire was contained by sprinklers and finally extinguished by firefighters who reached the 26th floor of the 30-storey, 42-year old building. The Pier Luigi Nervi designed building relies on concentrated strength and stiffness provided by major vertical concrete shear walls, massive in proportion. The damaged façade can be described as curtain walling which does not contribute to overall structural safety. Yet it has been reported that five 24m span prestressed concrete floor beams local to the impact area have been damaged and show permanent deflection of up to 250mm. The fact that they have not collapsed illustrates the ability to sustain damage, the kind of robustness that characterises structure that remains tied together after sustaining damage. In my view, this is an example of the kind of robustness that structural engineers seek to achieve. National building codes may need to describe that characteristic with greater rigour as recommendations emerge in due course from 11th September 2001.

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