Making public transport safer

Following the 7/7 bombs in London, Dr Philip Esper (Director, EBI Engineering Ltd), Bill Keane (Director, Clarke Bond Group), and Robert Ince (Explosive Effects consultant), discuss ways of improving the safety of public transport against terrorist attack.

On Thursday 7 July, London experienced a more terrifying type of terrorist attack from those previously perpetrated on mainland UK. There was no hint of advance warning to allow evacuation of the public from the areas under attack and all four attackers, most probably deliberately blew themselves up by manually detonating the device on site. This resulted in the loss of over 50 lives and in damage to both property and infrastructure.

This is similar to the attacks executed in the Madrid train bombs in March 2004, with possibly one chilling exception. All of these attacks were undertaken by suicide bombers previously unknown to the security forces whilst the Madrid bombs were remotely detonated by a group of extremists, most of whom blew themselves up when located by the authorities some days later.

Ever since the 9/11 attacks in the United States the UK has been warned by security experts that it was not a question of if but when such an attack would take place in mainland UK. The Madrid train bombings were a reminder of this very real threat and the horrendous consequences, 191 fatalities and over 1500 injured.

The increase in indiscriminate bombing as a method of attack on modern societies in the last decade or so, and particularly in the last few years, means that engineers, architects, building owners, government officials and anti-terrorists groups need to rethink the way our societies and our transport systems operate. They need to consider this risk in the design and safety measures utilised in order to protect our societies from such attacks.

It is important that organisations have a clear policy setting out plans for dealing with a major terrorist incident. The foundation of such a plan must be based on risk assessment.

The UK experience

Since the first major bombing incidents which took place in mainland UK in 1992 (St Mary's Axe bomb), and those that followed (1993 Bishopsgate, the 1996 Docklands and Manchester bombs and the 2001 Ealing Broadway bomb), we have been involved in the investiga-
When the pressure wave moves radially away from the centre of an explosion and comes into contact with a surface, the pressures and impulses of the initial (undisturbed) wave are reinforced on the reflection. When the shock wave impinges on a surface that is normal to the direction of the propagation of the shock wave, then the initial point of contact will be subjected to the maximum reflected pressure and impulse. This is different from the incident values as shown in Figs 1 and 2. The variation of the pressure and impulse patterns on a reflecting surface is a function of the angle of incidence and the magnitude of the incident pressure $P_i$ as shown in Fig 3.

As the blast wave radiates away from the fireball, the peak pressure decreases and the wave duration increases until it falls, eventually, to ambient pressure (Fig 2). There also negative pressure associated with the over-expansion of the gas, caused by momentum, the result of which is a reversal of flow towards the source (i.e. suction). This negative phase has a longer duration than that of the positive phase but has a much lower peak value.

If the explosion is close to, or on the ground surface, a proportion of the energy will be transmitted through the ground as seismic waves, and some of the energy will be absorbed by the ground surface displacing it and forming a crater. For instance, a detonating device with an energy equivalent to that of a 10lb device (as reported in the 7/7 attacks) is capable of producing a crater with a diameter of around 2ft in reinforced concrete and breaching a 6in concrete wall by cratering alone.

The detonation of the devices used in the 7/7 bombing attacks would also have generated shock pressures local to the device of several hundred psi and gasblast pressures of between 5-6 psi (35-42kN/m²) in the confined spaces. Unlike previous bombs in London, which were detonated above ground in well ventilated spaces, i.e. open streets, the blast pressures generated from the 7/7 underground bombs had only the tunnels to vent through, with hard, reflecting surfaces to act on and be redirected by, so (depending on the exact location where they exploded) would have taken longer to dissipate, resulting in the increased damage as demonstrated in the news coverage.

This can be explained by looking at a schematic of the pressure/time histories to be expected for explosions in confined spaces as shown below in Fig 4.

In this way, even though each of the shocks and its reflections are of very short duration, the overall loading is more of a quasi-static nature – of longer overall duration than the period of vibration of the structure (or structural element) and hence, much more likely to cause damage to the structure.

Of course the position of the device and the geometry of the structure will all heavily affect the strength and time of arrival of the reflected shock waves, the local blast environment would be complex and more like shown in the attached representation of Fig 5.

Finally, as the tunnel walls confine the shock waves, the expansion route is primarily in the axis of the tunnel. This will mean that the shock waves will no longer decrease as a spherical expansion (a 3-dimensional bubble) but more nearly a linear decay with the distance down the tunnel being the main factor. In this way, damage could be expected much farther from the charge than would be expected in above ground cases.

**The threat and level of risk**

In the more stable democracies of the world the events of 9/11 changed our comprehension of the World and people's perception of safety and security within their hitherto relatively safe environment. These concerns were further reinforced following the Bali, Madrid and London bombings.

Following the 7/7 London bombings, people, although defiant in the sense that they are not allowing the terrorist to win, are nonetheless apprehensive about using a public transport system that is clearly a soft target for attack. The London Underground network has on average 2.67M passenger journeys a day and peak time trains have capacities of up to 900 people. A potential terrorist can easily access the network on any of its 275 stations and travel unhindered to the desired target anywhere in the system. Clearly in the light of the threat posed by today's terrorists – mass murder and casualties with a willingness to kill themselves in the process – consideration now needs to be given to detecting their entry to the network at ticket barriers in a manner similar to the aviation industry.

Clearly, because of the large numbers of people that the network transports daily, a detection procedure has to be such that it does not greatly disrupt the intended function of this mass transit service and bring London to a standstill, but nevertheless capable of deterring the opportunist and minimising the risk of the more hardened/determined individual from causing mass death and destruction. Such technology does exist but at a cost.

This cost may be a small price to pay for gaining the confidence of the public to continue to use the public transport system. The same technology could also be implemented within bus entry and mainline train stations. The time has come to consider all reasonable/practicable options to thwart terrorist activities.

**The issues**

For many years the aviation industry has been the target of terrorists attacks worldwide, and two of the most notable attacks on civilians were the blowing up of Pan American Airways flight 103 over Lockerbie in 1989 in Scotland, which killed all of its 207 occupants and the 9/11 suicide attacks in the United States, which killed nearly 3000 people.

The Lockerbie attack highlighted shortcomings in airport security whilst the 9/11 attack highlighted both shortcomings in airport security on internal flights and a failure of counter intelligence to anticipate such an attack. The aviation industry response worldwide was to address these shortcomings, in light of the new threat and the publicity such attacks invoke. It also forced a detailed review of the evacuation procedures for tall buildings and the accepted industry standards prior to 9/11 were shown to have shortcomings that needed addressing.

Similarly repeated bombings in London initiated target hardening measures such as the ‘ring of steel’ around the City of London following the Bishopsgate bombing and attacks on individual buildings nationwide. In Colombo, Sri Lanka, subjected to repeated attacks from Tamil Tiger suicide bombings, part of the city centre has been fenced off and access is only through checkpoints.

Following the recent London bombings the security forces are now advising businesses to update their security measures in the wake of this threat. We will now see a more visible presence in the mitigation procedures put in place to deal with terrorism if we are to ensure that business maintain their ability to operate normally and with minimum disruption. The public will also need reassuring that it is safe for them to go about their daily business.
A measured response is required to these recent events, but it should also be borne in mind that if the network remains a soft target it will continue to attract attack. Clearly the challenges are great and to discount this happening again on a public transport network would be foolhardy. In the past 12 months the US has reported 3200 terrorist attacks worldwide.

Some options
Clearly the challenges are great and our first line of defence will always be the security forces to thwart such attacks and put the public on notice. However should terrorists manage to evade this net then we need to be prepared. This can take the form of mitigation – strengthening pre-identified weaknesses to improve structural integrity, detection and, most effective of all, prevention.

The recommendations outlined below are not exhaustive. Action can be taken as and when it is deemed appropriate, being mindful that public confidence and perception will be primary drivers, particularly as London is host city for the 2012 Olympics. Suggestions include:

- risk assessment of the most vulnerable lines, tunnels, and tube stations;
- bomb detection devices to be installed at ticket barriers at stations with high levels of risk;
- stop and search suspicious people carrying packages in stations;
- enhance CCTV cameras operating system in all stations;
- more visible security personnel on trains and stations;
- use of sniffer dogs;
- enhance and maintain close links between national security agents in the government intelligence structure;
- structural integrity assessment of the older tunnelling techniques i.e. brick tunnels etc, should be carried out, and strengthening measures should be implemented where necessary (such as replacing the old brick arches in some of these tunnels with concrete arches);
- identify soft targets such as where tunnels are at shallow depths from building foundations, as in the case with the earlier cut and fill tunnels;
- computer modelling of the response of tunnels under different detonation devices/sizes should be investigated in order to predict the risk levels involved for various attacks scenarios;
- back-to-back seats with gaps/spaces in between should not be utilised any more in British Rail or London Underground trains, as they form ideal places for terrorists to conceal parcel bombs;
- removable seats should be designed out as they can easily conceal a small device; currently these seats have easily removable seat security tags;
- possible consideration of ‘black boxes’ to enable real-time monitoring of the network including more secure communication between the driver and central control;
- more secure tube/train driver cabs to prevent unauthorised entry;
- possibly two drivers, located at opposite ends of the train, to assist with evacuation in the event of an emergency or global communication between the passengers and central control anywhere within the network.

FURTHER READING

2. Esper, P., ‘Non-linear transient and quasi-static analyses of the dynamic response of buildings to blast loading’, ANSYS 7th Int. Conf. and Exhibition on Finite Element Modelling and Analysis, Pittsburgh, USA, May 1996
3. Esper, P., ‘Dynamic response of steel building frames and connections to bomb blast loading’, 1st Int. Conf. on Impulsive Analysis, Osaka, Japan, November 1996
4. Keane, W., & Esper, P., Technical report on major incident and disaster management (MIM), April 2005 following the South Asian Tsunami, London (www.ebi-engineering.com) and (www.clarkebond.co.uk)
5. Keane, W., and Esper, P., ‘Major Incident and disaster management’, The Structural Engineer, 7 June 2005