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# An Investigation to Optimize the Layout of Protective Blast Barriers Using Finite Element Modelling

**V Lawrence[1], C Ngamkhanong[1,2] and S Kaewunruen[1,2]**

[1]Department of Civil Engineering, School of Engineering, The University of Birmingham, Birmingham, B15 2TT, United Kingdom
[2]Birmingham Centre for Railway Research and Education, The University of Birmingham, Birmingham, B15 2TT, United Kingdom

CXN649@student.bham.ac.uk

**Abstract.** The past has shown that the risk of terrorism is on the rise as can be seen in many events. Terrorist attacks such as the 2004 Madrid bombings, the 2005 London bombings, the 2013 Boston bombing and the 2017 Manchester bombings have shown the impact acts of terrorism has on the public. Nowadays, terrorist attack is likely to increase in the wider area in the future together with a higher density in train passengers. Previous researches into protective measures have been focused on the structure. However, the impacts of terrorist attack on human have not been fully investigated. The needs for protective measures for the public have never been greater. This research aims to investigate the optimum layout for protective blast barriers situated on a train station platform using finite element analysis. The 3-dimensional structure is modelled and analysed using LS-DYNA.The focus is placed on an island platform at Birmingham New Street Station, which is one deemed to be at high risk of terrorist threats. Two shapes of barriers were tested, straight and angled. A total of six models were created and tested against two scenarios. Scenario one is a bomb placed on the ground, scenario two is a bomb being carried. The results focus on the impact the pressure created from the blast has on a person's lungs and head. Both can cause the most fatalities due to bombings. The results demonstrated that the shape of the barriers had no effect on the pressure. However, it can be concluded that an increase in the number of barriers, reduced the pressure below the critical amount for lung damage. Increasing the number of intervening objects between the bomb and target has a positive effect on the reduction of blast pressure. The insight into this study will help railway and structural engineers to establish strategic preventing methods to minimise catastrophic damage to and potential losses of the public.

## 1. Introduction

In the past fifty years the risk of terrorist bombings in public places has increased. The Madrid train bombings in 2004, London bombings in 2005 and Manchester bombings in 2017 demonstrated the impact terrorism can have on the public. Many governments are introducing various protective measures to important structures within their country. Much research has already been performed on the protection of structures. However, it is clear from recent terrorist attacks that the public is the target. Though research is being done into protection for the public, there is very little implementation in the real world. Railway stations are a highly congested and crowded place many hours of the day. Making railway stations a target for terrorism. The finite element modelling was used to determine the effects of an explosion within a railway station [1-3]. Considering the results only small amounts of research have been done on protective blast barriers for the public. The concrete blast barrier was tested considering barrier shapes and layouts [4-5]. The blast barrier was investigated by changing the material of the barrier to glass fibre reinforced polymer [6], but the results showed that concrete has a higher resistance. With such little research done on this subject, it is unclear on the effectiveness and benefits of protective blast barriers.

This paper will investigate the optimal layout of protective blast barriers, to reduce the blast wave pressure of an explosion at railway stations. A finite element model of a Birmingham New Street Station platform will be created. Each blast barrier arrangement will be subjected to an explosion from the surface and free air. Both scenarios are similar to terrorism tactics. The blast wave pressure will be recorded to determine the effects of each arrangement.

## 2. Methodology

A blast wave is in the "form of a shock wave composed of a high-intensity shock front which expands outward from the surface of the explosion into the surrounding air" [7]. The pressure exerted from a standard blast wave is shown below (Figure 1). The sudden increase in pressure from the detonation of the explosion to the peak pressure is defined as the overpressure. In Figure 1, the pressure plotted is the incident pressure. The incident pressure is the pressure on the structure from the incident wave.

This report will not focus on incident pressure due to the reflected pressure being much greater.

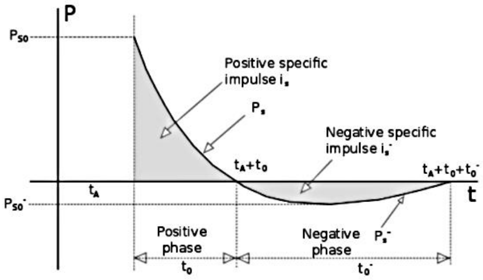


**Figure 1**. Blast wave pressure plot [8]

LS-DYNA software was used to simulate the air blast created from TNT. LS-DYNA has an empirical function LOAD_BLAST_ENHANCED which computes to a high degree of calibration, the pressure exerted on a Lagrangian structure from an air blast. LS-DYNA calculates pressure by measuring the distance from segment to charge, and the angle of incidence from the segments normal. To identify the blast load criticality, the document Unified Facilities Criteria (UFC), Structures to Resist the Effects of Accidental Explosions [7] has been reviewed.

$$Z = \frac{R}{\sqrt[3]{W}} \quad (1)$$

where R is the distance between the point of the detonation and the structure, W is the weight of the charge.

The scaled distance is computed. LOAD_BLAST_ENHANCED uses both of these variables at every cycle to calculate the pressure. The pressure can also be calculated by hand using this formula to validate the pressure computed by LS-DYNA. LOAD_BLAST_ENHANCED enables the blast to be located at any point throughout the model. The function can allows for four different types of blast shape. This research uses the hemispherical blast with reflected waves, as well as a free air blast with reflective waves. The model was created through LS-DYNA Prepost and is based on Birmingham New Street Station. The floor slab and roof slab were made completely rigid to simulate a blast underground.

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The platform is an island platform with a width of 16 metres. Columns are situated 12 metres apart. The columns are 3 metres long and 1 metre wide. The epicentre of the air blast was situated in the middle of the platform. Two scenarios were tested, both using 15kg of TNT.

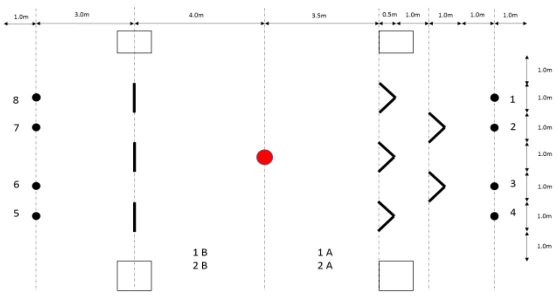
- Case 1: The bomb is placed in a bag and left on the floor of the platform (0m above G.L)
- Case 2: The bomb is carried by a person in a rucksack. (1.6m above G.L)

The barrier design and orientations from the previous study were used [4], as shown in Figure 2.

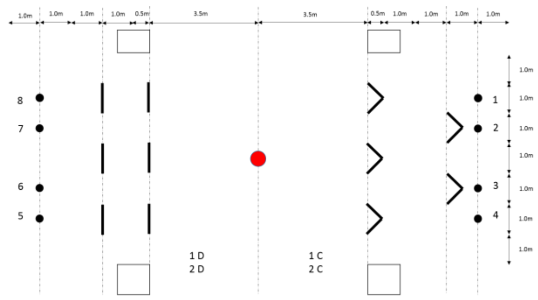

a) b)

**Figure 2.** Dimensions of barrier designs a) corner b) straight

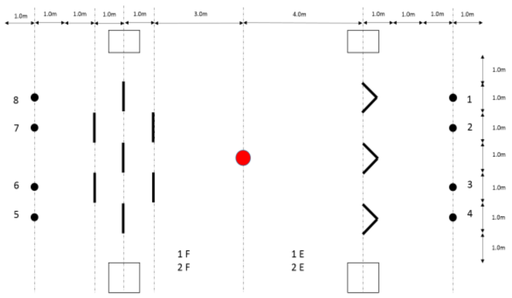
The internal holes in the barriers were designed to increase the porosity of the barrier such that they did not fail. The holes aided the diffusion of the total blast pressure. The internal holes in the barriers were designed to increase the porosity of the barrier such that they did not fail. The holes aided the diffusion of the total blast pressure. Figure 3 represent the barrier arrangements. The sensors were placed such that to model pedestrians waiting for a train. To calculate a valid air blast pressure at a targets lungs and head, the sensor were positioned 1.4 metres above G.L. Three finite element models were created, each model contained two different arrangements as can be seen in Figure 3.




a)




b)




c)

**Figure 3.** Barrier arrangement
a) A – Five Corner Barriers in close arrangement and B – Three Straight Barriers
b) C – Five Corner Barriers with larger separation and D – Six Straight Barriers
c) E – Three Corner Barriers and F– Seven Straight Barriers in tight arrangement

The platform and columns are to be modelled as reinforced concrete. The function CONSTRAINED_LAGRANGE_IN_SOLID is a validated solution to model the rebar within the concrete mesh. The concrete material uses the function MAT_CSCM_CONCRETE. Through which C32/40 concrete properties are imputed. The rebar and steel barriers are both defined to be MAT_PLASTIC_KINEMATIC. Transverse rebar is 16 millimetres diameter, longitudinal rebar is 10 millimetres diameter. The steel properties of the barrier are shown in Table 1.

**Table 1**. Steel Properties

| | |
|---|---|
| Mass Density | 7850 kg/m$^3$ |
| Young's Modulus | 2.1 x 10$^5$ MPa |
| Poisson's Ratio | 0.3 |
| Yield Stress | 400 MPa |

## 3. Results and discussions

### *3.1. Case 1: Near Surface Blast*

Table 2 shows the pressure on the sensors due to near surface blast. When comparing the control sensor values with arrangements 1B and 1E the two central sensors have an increased pressure. The increased pressure is caused by the blast pressure reflecting and intensifying as it is transmitted through the barriers. It is noted that the flow of a shock wave expands directly after the barrier gap, resulting in the velocity of the wave intensifying [9]. The two external sensors of both arrangements were predicted to act the same due to the findings of recent study [4]. Concluding that the shape of the barriers placed in identical orientation has minimal effect on mitigating the blast wave. It is also concluded that a blast wave travels over a barrier, reforming a reduced pressure wave on the other side.

**Table 2.** Near Surface blast pressure (KPa)

| Sensor Number | 1A | 1B | 1C | 1D | 1E | 1F |
|---|---|---|---|---|---|---|
| 1 & 8 | 254 | 289 | 238 | 248 | 289 | 211 |
| 2 & 7 | 279 | 339 | 276 | 315 | 339 | 237 |
| 3 & 6 | 279 | 339 | 276 | 315 | 339 | 237 |
| 4 & 5 | 266 | 305 | 250 | 261 | 305 | 221 |

Note: Sensors 1-4 for 1A, 1C, 1E. Sensors 5-8 for 1B, 1D, 1F

Arrangement 1A and 1C were created to investigate this conclusion. Arrangement 1C is the same orientation as 1A but the barriers have a greater distance between them. From the results 1C reduced the overall pressure of the blast wave. The two external sensors of 1C both have a decreased pressure of 16 KPa than 1A. As found by [9], the reformed blast wave travels a longer distance until reaching the second row of barriers. Within this distance the wave is dissipating, thus reducing in force. However, the two central sensors show a very minimal decrease in pressure. The cause of both outcomes are as a result of the shape of the transmitted shock wave. As demonstrated in [9] the peak of a transmitted shock wave is created at the centre point between two barriers. The remaining transmitted wave travels in a 'close to' hemispherical shape (Figure 4), depending on the angular degree of barrier shape.

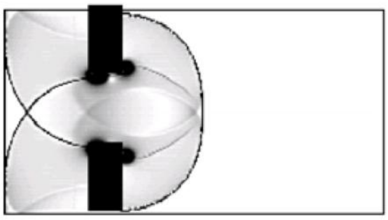


**Figure 4.** Mapping of a shock wave travelling through a barrier [10]

1C allows for the transmitted blast wave to dissipate and reduce more, before impacting the external sensors. The peak transmitted blast wave travels identically in both 1A and 1C resulting in minimal reduction at the central sensors. Arrangement 1F insured the two most vulnerable sensors (central) were protected from the peak transmitted blast wave. 1F increased the number and density of the barriers. Comparing the results with the other arrangements, 1F has significantly decreased the pressure over all sensors.

*3.2 Case 2: Free Air Blast*

Table 3 shows the pressure on the sensors due to free air blast. The free air blast results all have decreased pressure when compared with the identical arrangement subjected to a surface blast. As explained in [11], compared with a surface blast, free air blast waves amplify less from the ground due to the distance they must first travel.

**Table 3.** Free Air blast pressure (KPa)

| Sensor Number | 1A | 1B | 1C | 1D | 1E | 1F |
|---|---|---|---|---|---|---|
| 1 & 8 | 218 | 271 | 227 | 233 | 271 | 174 |
| 2 & 7 | 278 | 309 | 255 | 299 | 309 | 193 |
| 3 & 6 | 278 | 309 | 255 | 299 | 309 | 193 |
| 4 & 5 | 229 | 284 | 233 | 245 | 284 | 182 |

Note: Sensors 1-4 for 1A, 1C, 1E. Sensors 5-8 for 1B, 1D, 1F

Comparing 1A, 1C, 2A and 2C, a larger gap between the barrier rows has increased the overall pressure on the sensors subject to a free air blast. The opposite occurred in a surface explosion. The free air blast waves travel at a steeper angle over the barrier due to the height of the epicentre. Resulting in the reflection point behind the barrier being nearer. 2C’s larger gap allows for the wave to be reflected and reformed into a Mach front before the second row of barriers. However, the two central sensor of 2C are recorded to have a decreased pressure than 2A. The blast wave projection has changed [9,12]. With a larger gap between rows the central sensors are protected due to being located directly behind the barriers. The external sensors however, are positioned far enough for the reflected wave to impact them. With a reduced gap between rows the central sensor are subjected to the full Mach front. The external sensors are protected due to the dissipation angle of the blast wave. In case of B and E, the layout arrangements are identical, with only the shape of the barrier changing. The results showed very minimal difference between the corner and straight barrier shapes.

## 4. Conclusion

This research can conclude that the layout of blast barriers does have an impact on the reduction of blast pressure. Increasing the amount of barriers between the explosion and target, increases the chance of survival. The results show that layouts 1F and 2F both had very successful effects compared with other layouts. The positive effects of increasing the distance between barrier rows is subject to the height of the bomb. Moreover, it can be concluded that the shape of the barrier provides minimal effect on the mitigation of blast pressure. Due to similar effects seen in both experiments. The omnidirectional nature of a blast wave causes the pressure to travel over the barrier as well as through them. In addition, the gap between barriers row also plays a role in pressure reduction. Further research is need on whether full optimization of the entire space available for blast protection is a viable option. Increasing the height, thickness and amount of barriers could all aid in the reduction of blast pressure. This research only accounted for the blast pressure cause from an explosion. The heat and fragmentation of explosions must also be tested. The psychology of reducing the space of an already highly congested area is important. Though people may want to be protected from bombings, limiting space could be putting people in more danger. The insight into these blast behaviours will help railway and structural engineers to establish strategic retrofitting methods to minimise catastrophic damage to and potential losses of train passengers, the public and railway assets.

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