Risk Assessment due to Terrorist Actions: A Case Study in Lisbon

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Abstract: The occurrence of unanticipated extreme events in modern societies typically induces significant damage and losses to the built heritage and people, but also concern and fear in the population. The capacity of structures to resist to extreme events has been deserving the attention of researchers during the last decades. The occurrence of explosion-based terrorist attacks in the last two decades has caused a great concern among decision makers and had led to important investments towards the characterization of the structural response of buildings subjected to blast loads. The work presented in this paper was performed in collaboration with one of the largest Public Transportation Operators in Portugal and addresses the problem of risk assessment due to terrorist actions in the case of external explosions, and structural safety evaluation of buildings when subjected to different explosion scenarios.

Keywords: Risk assessment, blast loading, structural safety, transportation infrastructure

1. Introduction

Protection is not an absolute concept and there is a level of protection where the cost of the protection provided with respect to the cost of potential loss is in balance. On one hand, protection cannot offer full guarantee of safety and, on the other hand, too much protection is a waste of resources with regard to what is expected to be saved. The purpose of protective construction is to improve the probability of survival of people and other contents in a given facility for a given threat. In order to improve this probability, one must first understand the threat and accordingly analyse the facility.

Terrorism has been described as the deliberate use of violence to create a sense of shock, fear and outrage in the mind of the target population. One of the reasons that make this easy to achieve is that developed societies have become very dependent on complex and fragile systems (railways, airlines, gas pipelines, electricity infrastructure, large shopping areas and business centres, etc.) which are both vulnerable and critical to society's functions, and provide the terrorist with many suitable targets. Attackers can use various weapon systems in different combinations and such events cannot be predicted. However, reliable information and objective threat and risk assessment can produce effective estimates of such incidents.

There are a number of methods available to conduct an organization's risk assessment, and the steps can be accomplished in different sequences (FEMA 452, 2005; ISO 31000, 2009; DEMA, 2006; UFC 4-020-01, 2008). All these methodologies have one common objective: to apply a quantitative assessment process that identifies the assets at highest risk. One key factor that can lead to an effective risk assessment is the selection of the entities/people brought into the process. These assessments should have inputs from, but not limited to, police agencies, intelligence agencies, structural engineers and national emergency management agencies.

Modern society is heavily dependent on transportation networks. In the past 60 years, these networks have been seen as an appropriate target for terrorists (Muhlhausen and McNeil, 2011). They allow easy access and they provide suitable cover for escape. They also provide concentrations of civilians and their slaughter never fails to generate high levels of public interest, both national and international. The attacks on the Spanish railway network in Madrid in March 2004, the Metro and Bus strikes in London in July 2005, the Mumbai train attacks in July 2006 and the bombing in the international arrival hall of Moscow's busiest airport in January 2011, among many others, all point to public passenger transport networks as being suitable terrorist targets.

COUNTERACT (Cluster Of User Networks in Transport and Energy Relating to anti-terrorist ACTivities) was an European research project set up to improve security against terrorist attacks aimed at public passenger transport, intermodal freight transport and energy production and transmission infrastructure (COUNTERACT, 2006). The project focused on the protection of critical transport infrastructures, public transport passengers and goods. It reviewed the existing security policies, procedures, methodologies and technologies to identify the best practices, which in turn have been promoted throughout the relevant security community in the EU. One of the main objectives of the project was to develop generic guidelines for conducting risk assessment in public transport networks.

This paper presents a risk assessment performed on a large Public Transportation (PT) Operator in Portugal that allowed identifying the elements with the highest risk regarding each analysed threat. From the elements with the highest risk, one was selected for a structural safety assessment regarding possible explosion scenarios.

2. Risk Assessment

For confidentiality reasons, the Operator will be kept anonymous as it is not essential for the presented analysis. Performing a risk assessment analysis allows identifying the elements in the network with the highest risk regarding a specific threat and provides the decision makers with essential tools to prioritize possible interventions. The COUNTERACT methodology was chosen for its specific character regarding Public Transportation Operators.

The first step is to structure the whole PT (Public Transport) system in an operational diagram. This allows for proper knowledge of the entire network under study. A total of 73 elements were located in the selected part of the Operator's network. The types of elements located in the area under study were stations, administrative offices and operational centres. In order to focus the study on the elements with the highest relevance for the whole network, five criteria were considered on all elements. The selection of the criteria took into account the internal methodology for characterization of elements used by the Operator, being: a) C1 – passenger flow; b) C2 – service provided; c) C3 – mobility; d) C4 – significance; e) C5 – location. Different values for the sub-criteria and weights should be used for different Operators and conditions (Pereira and Lourenço, 2014). These five criteria were applied to all elements of the network and a ranking score was achieved. Table 1 shows the individual scores for selected examples of elements in this network. As a result of this first step, 14 elements with high scores were selected (in this case it was considered a high score above 0.60).

Table 1 – Selected examples of key infrastructures scores

#	Element	C1	C2	C3	C4	C5	C
10	AJ	0.78	0.23	0.20	0.00	0.30	**0.49**
15	AO	0.68	0.88	0.20	0.15	0.37	**0.54**
17	AQ	0.78	0.23	0.20	0.15	0.37	**0.51**
23	AX	0.18	0.23	0.12	0.04	1.00	**0.29**
30	BD	0.43	0.23	0.12	0.00	0.36	**0.32**
35	BI	0.75	0.65	0.2	0.15	0.24	**0.54**
43	BQ	0.01	0.10	0.12	0.15	0.68	**0.12**
46	BT	0.01	0.20	0.12	0.15	0.12	**0.08**
58	CF	1.00	0.23	0.60	1.00	1.00	**0.85**
62	CJ	0.89	0.23	0.20	0.60	0.31	**0.62**

The second step is to determine, for the elements identified previously, the probability of occurrence. In this step, each element is linked to the selected threats. For the purpose of this study, only threats involving external explosions were selected. Five levels were selected according to the capacity of the delivery system, namely: a) Suicide vest (9 kg TNT); b) Luggage (25 kg TNT); c) Car (500 kg TNT); d) Van (1

500 kg TNT); e) Truck (25 000 kg TNT). The calculation of the probability of occurrence for each threat and each element implies a research on previous and similar attacks and attempts. COUNTERACT defines the probability of occurrence as a 5 level scale according to the frequency that the threat has been executed in their own or in other public transport operations (COUNTERACT, 2006). After crossing the information of previous attacks on similar PT Operators and their delivery systems, a value of Probability of Occurrence is assigned to each threat and for each element. In this specific case study, no threat has been executed within the organization, but similar threats have been executed repeatedly within other PT Operators worldwide, including neighbouring countries, implying a maximum value of 3 (possible) according to this methodology (COUNTERACT, 2006).

The thirst step is to determine the severity of occurrence. Impact/Severity stands for the damage to an asset arising from the execution of a threat, which is measured in escalating categories. COUNTERACT suggests a 4-level scale (Table 2), where the criteria for differentiation between the different levels focus mainly on the consequences of the various threats for persons, property and PT operator (COUNTERACT, 2006). The final classification for the Impact would be the maximum of the three consequences. In the case of consequences for persons, the impact value was estimated according to previous attacks with similar delivery systems and the number of passengers at peak time for each element. The consequences for property were estimated studying the layout of the element. For each element, a minimum standoff distance was established regarding each threat. As an example, it might be possible that a car, van or truck cannot get closer than several meters from a given element, while an armed vest can get close to most elements. It is possible to estimate the maximum overpressure resulting from an explosion according to the standoff distance of its charge using simple empirical equations available (Bangash and Bangash, 2006; Cormie et al, 2009). Although the damage resulting from an explosion is dependent on the maximum pressure and its duration (impulse) it was considered enough, in order to simplify the analysis, to use the maximum pressure as a damage indicator. Later, when analysing the elements with the highest associated risk, a more detail analysis should be performed. Reference charts (FEMA 426, 2003; Elsayed and Atkins, 2008), where pressure thresholds are presented for different construction materials, were used to estimate the damage on each element for each threat. The consequences for the PT Operator were estimated according to previous attacks on similar size elements. Studying the time while the attacked PT Operators ceased functions on a similar size element due to similar threats, it is possible to have an estimation of the required time for this PT Operator.

Table 2 – Impact/Severity (COUNTERACT, 2006)

		Consequences for Persons	Consequences for Property/Environment	Consequences for PT Operator and Services
Disastrous	**4**	Several deaths and/or numerous severe injuries	Most severe damage to property and/or environment	Loss of vital functions and/or operation over a long period of time
Critical	**3**	Low number of deaths and/or severely injured	Severe damage to property and/or environment	Loss of vital functions and/or operation over a short period of time
Marginal	**2**	Light casualties	Notable damage to property and/or environment	Minor impact on functions and/or operation.
Uncritical	**1**	Possibility of few light casualties	Small damage to property and/or environment	No impact on functions and/or operation

Knowing the values for the Probability of Occurrence and the Severity of Occurrence, it is possible to plot the risk matrix for the elements under study and each selected threat, being Risk as the product of both previous values. COUNTERACT (2006) suggests four risk categories according to their score and the subsequent required action, ranging from Negligible (1-3) up to Intolerable (15-20). In our case study, because the Portuguese PT Operator has no previous occurrences of attacks, there is no combination with Intolerable classification. Some combinations scored a Precarious classification (8-12) due to similar attacks on neighbouring countries and the respectively delivery systems (9-25 kg TNT), with easy “infiltration” and possibility to achieve low standoff distances. This methodology is relatively easy to apply and provides the PT Operator with tools to quantify the relative risk for its elements. It must be kept in mind that this is a dynamic process and requires “real time” updates whenever there is a change in the network. Risk

Assessment in only one of the steps in the Risk Management model and the following step should be a detailed analysis of the highest risk elements, where prevention and mitigation measures would be studied. Comparing the risk values with and without those prevention and mitigation measures and the required investment costs, the PT Operator could make informed decisions on where and how to act. If a more detailed study on the structural behaviour of a specific element is required, a structural safety assessment should be performed.

Table 3 – Risk matrix for the PT Operator

#	Element	*Vest*	*Luggage*	*Car*	*Van*	*Truck*
1	AA	9	12	6	6	4
5	AE	6	9	6	6	4
19	AS	6	9	6	6	3
20	AT	9	9	6	6	4
21	AU	9	12	6	6	4
22	AV	6	9	6	6	3
25	AY	6	9	6	6	4
27	BA	9	9	6	8	4
58	CF	9	12	6	8	4
59	CG	6	9	6	6	4
62	CJ	9	12	6	6	4
66	CO	9	12	6	6	4
72	CU	3	3	3	4	4
73	CV	2	2	2	3	4

3. Structural Assessment for Selected Threats

A structural safety assessment was performed on one of the elements with the highest risk associated with the threats under study. This element is a three-story building constructed in limestone stonework. This "L" shaped building (Figure 1) is a high value element in the PT Operator, not only because of its effect on public opinion but due to its high passenger flow. Several different scenarios were studied in this analysis, however only two scenarios are presented here (Pereira and Lourenço, 2014):

a) Scenario B – corresponds to an explosion at the East façade of the building (at 5 m from the centre of the façade). The van size IED (1500 kg TNT) was the selected delivery system for this scenario.
b) Scenario B' – where the access to vehicles up until 25 m from the East façade was closed. The same delivery system would still be possible, but only at 25 m from the centre of the façade.

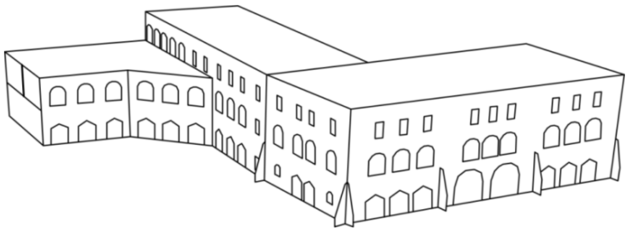


Figure 1 – Building schematics

The FEM model was built in the ABAQUS software, where the explicit solver was used. The definition of the geometric model was based on available drawings, but the quality of the connection of the walls to the pavements of the building could not be assessed. Due to lack of information regarding the condition of the pavements of the building, different models were prepared, neglecting and considering the contribution of pavements. The walls were modelled as shell elements and the columns were modelled as beam elements. Additional details on the FEM model can be found in Pereira and Lourenço (2014). It must be noted that this analysis focuses only on the structural response of the building. Non-structural parts of the building, door frames, glazing systems, or occupants were not taken into consideration in the present analysis. For this kind of analysis, it is necessary to define a damage criterion that can be applied to categorize the damage on the masonry panels. UFC 3-340-02 (2008) classifies the damage to unreinforced masonry walls according to the support rotation. This standard establishes two levels of damage, being reusable and non-reusable according to the yield pattern and the maximum rotation (varying between 0.5 and 2 degrees).

3.1 Scenario B

Scenario B corresponds to an explosion at the East façade of the building, at 5 m from the center of the façade. This explosion with 1500 kg TNT will create a reflected pressure of around 34.5 MPa with duration of 1.7 ms in the L1 region and around 2.5 MPa in the L2 region, see Figure 2. Due to the presence of large span masonry panels, both situations regarding the pavements (neglecting and considering its contribution) were considered and the results were compared. Figure 3 shows the evolution of deformation for this model. The global response of the structure changes if one neglects or considers the contribution of pavements. In the first case, the East facade panel behaves as one large masonry panel being supported at ground level and on its side edges. In the second case, considering the contribution of the pavements, the East façade behaves with intermediate supports along its height, similar to three "independent panels". Due to the dimensions of these panels (very long) it is almost as if they were only supported at the bottom and at the top.

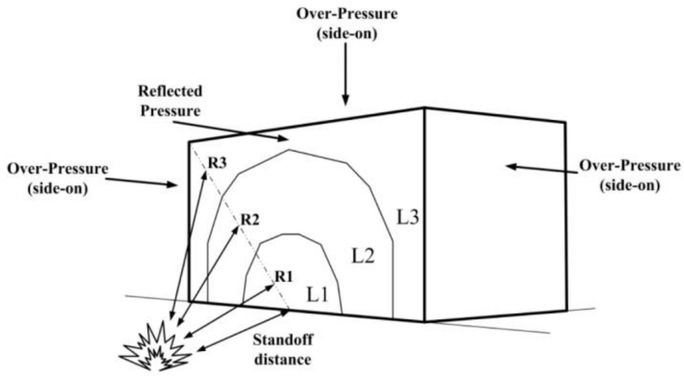


Figure 2 – Blast loading distribution

The load resulting from this explosion is quite high and the structure response is quite fast. In the first 30 ms the masonry reaches a velocity of around 10 m/s resulting in around 300 mm of maximum displacement in the L1 region after 30 ms. Analysing the support rotations (Figure 4) it is clear that, in both situations, the masonry panel rotates beyond the non-reusable state defined in UFC-3-340-02 (2008). At this point, it was considered that this part of the structure would have collapsed. The contribution of pavements in the model leads to lower values of rotations at ground level (Figure 4b). However, the behaviour of the panel in the first floor is closer to one-way yield pattern which lowers the limit to 1.0º. This scenario would have resulted in collapse of the structure due to the failure of the central supporting wall.

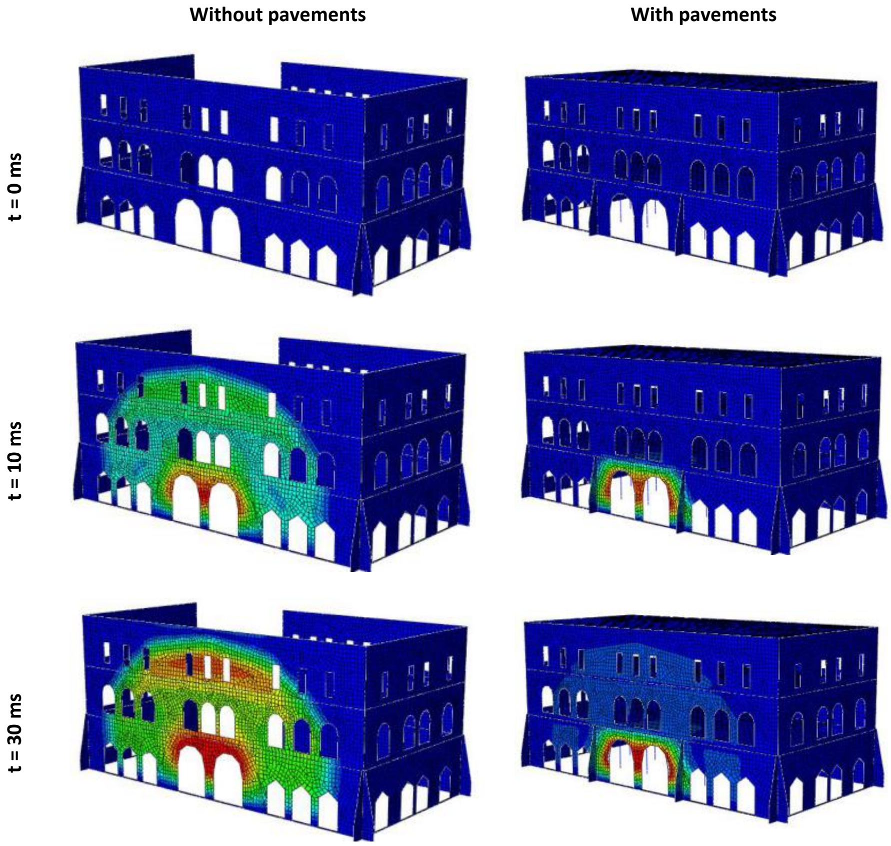


Figure 3 – Deformed mesh time history for scenario B: with and without pavements

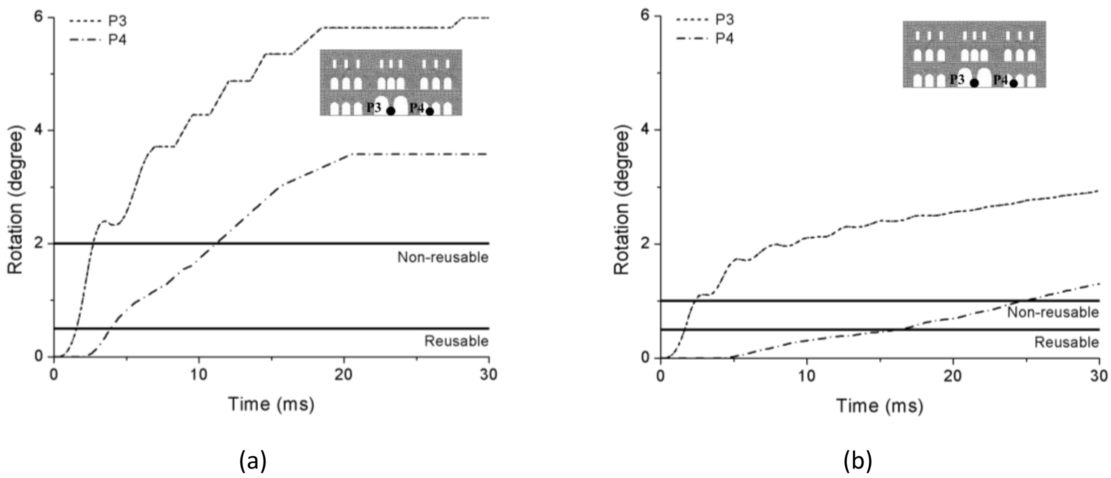


Figure 4 – Rotations time history for scenario B: a) neglecting pavements; b) considering pavements

3.2 Scenario B'

Scenario B' corresponds to an explosion at the East façade of the building, at 25 m from the centre of the façade. This simulates the possibility of closing to traffic the road right in front of this façade and the application of bollards preventing vehicles to get closer to the building. This explosion with 1500 kg TNT will create a reflected pressure of around 0.45 MPa with duration of 9.5 ms in the L1 region (Pereira and Lourenço, 2014). The behaviour of the masonry panels is similar to the one observed in Scenario B. Without pavements, the east façade behaves as one large masonry panel supported at ground level and on its sides. With pavements, it is clear the "independent panel" behaviour at the 3rd floor (Figure 5b). In both models the support rotations (Figure 6) are kept under the Reusable limit established by UFC-3-340-02 (2008). Although it is not shown here, the rotations at the side edges of the East façade were also analysed and its value are also under safe levels.

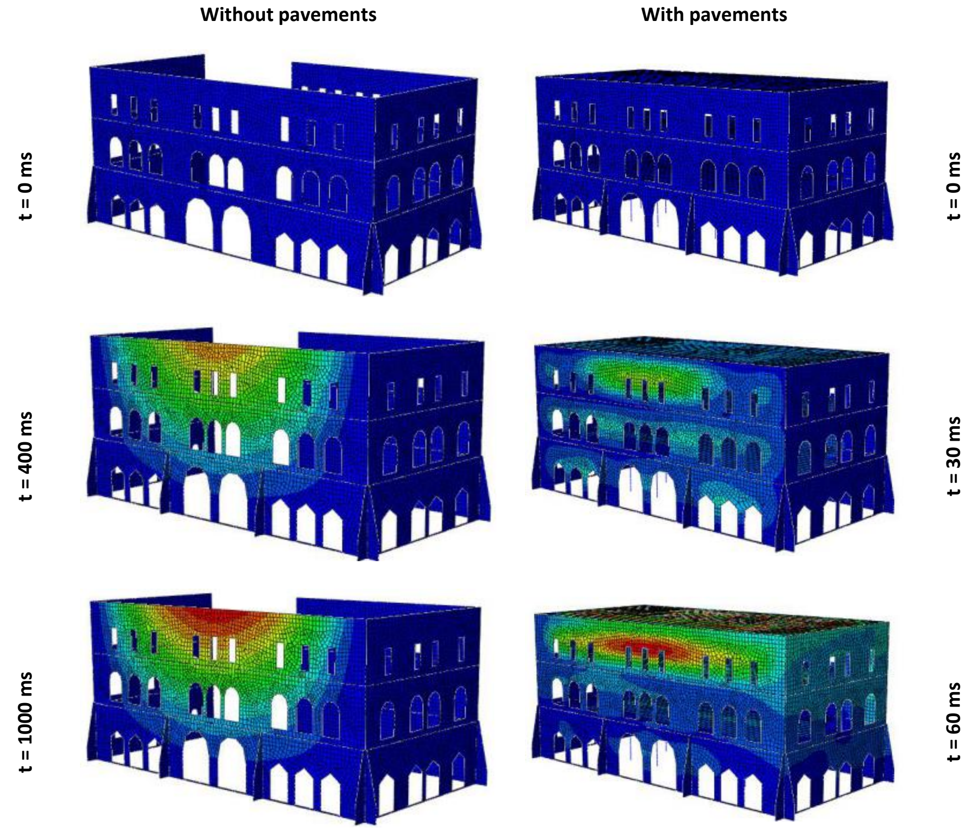
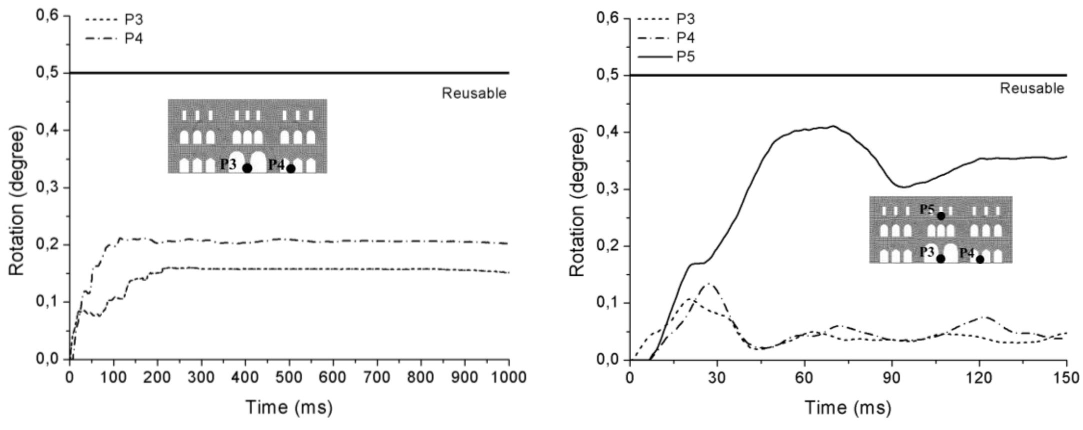


Figure 5 – Deformed mesh time history for scenario B': with and without pavements



(a) (b)

Figure 6 – Rotations time history for scenario B': a) neglecting pavements; b) considering pavements

4. Concluding remarks

A blast risk assessment model for public transport networks was applied to a case study in a Portuguese region and the elements with the highest risk due to external explosions were identified. The COUNTERACT methodology, due to the dynamic nature of transportation networks, require “real time” monitoring as any changes in the network could lead to a different risk matrix. From the risk assessment, one element was selected for a detailed structural safety analysis. This structure was modelled using explicit non-linear dynamics and the results were presented for different explosion scenarios. It was shown that a large package explosion would lead to the collapse of the structure. Increasing the standoff distance, as a measure for mitigating the impact of the explosion, was analysed and proven to be an effective measure, according to the obtained results. This measure is especially important when dealing with historical masonry construction where structural strengthening is difficult generally due to the historical and cultural value of the structure.

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