Composite Structures 134 (2015) 493–505

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Optimization of protective panel for critical supporting elements

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ARTICLE INFO

Article history:
Available online 31 August 2015

Keywords:
Structural optimization
Sandwich blast panel
Infrastructure safety
Dynamic analyses with FSI

ABSTRACT

The improvement of blast resistance of supporting elements by application of protective cover is the main goal of this paper. Developed sandwich panel is very effective in blast protection, however, such solutions are sensitive to the design parameters including thickness of components, stiffness and strength of materials and panel lay-up. Therefore, a numerical optimization based on computational mechanics was implemented to reduce deformations of protected supporting structure caused by blast loading. Optimization was based on the simplified FE model which consisted of laminate parts, metallic foam, steel external cover and I-beam pillar. The model was automatically generated depending on the optimization variables using a developed pre-processor script. The delamination process was also taken into consideration. Dynamic response of structural components subjected to the blast wave in different cases was analysed. Obtained results clearly showed that application of the optimized blast panel reduces the plastic deformation of the structure and significantly increases the blast resistance. Moreover, the obtained parameters were verified using fully 3D FE model of protective panel with pillar with FSI interface.

1. Introduction

Terrorist attacks with high explosives carried on public facilities cause many serious injuries of people inside. Unfortunately this injuries are often fatal. Direct shock wave loading is not the only reason, damage of attacked object can be much more deathly. Blast loading of critical supporting elements can cause considerable reduction of its carrying capacities and partial or global collapse of building. This kind of situation took place during Oklahoma City bombing where 87% of death was caused not by direct blast interaction but contact of structural elements with human body [1,2]. It indicates that supporting elements require special explosion protection. Reduction of it damage should significantly improve the blast resistance and minimize a loss of carrying capacity which finally reduce the risk of building collapse. Highly exposed for explosive attacks are public buildings, in particular: airports/railway stations, shopping centers/offices, financial/government institutions, water and fuel supply facilities, hospitals and schools.

Nowadays, due to increased number of terrorist attacks [3,4] the problem of buildings protection is very common. The following methods of life and property protection against explosion can be distinguish: access control and prevention, passive structural protection and fire alarms systems. The passive mechanical protection such as shield or reinforcements are critical where access control and prevention fail. The improvement of blast resistance of supporting elements by application of protective cover will be the main goal of this paper.

Two main types of protective shield which take advantage of two mechanism are used to improve the blast resistance of various objects. First type use specific shape of panel to reduce the reflected pressure of the shock wave, while the second absorb the blast wave energy due to plastic deformations or structure failure. If the direction of blast incidence can be quite accurately predicted than fist type of shields – wave deflectors are used. The most common are V-type shields protecting the armoured vehicles against mine explosions [5]. The effectiveness of this type of protection were presented in several papers [6–8].

Absorption of blast wave energy is the second mechanism used to improve objects blast resistance. Due to high stiffness and plasticity various types of alloys are used is panes designs, such as cold formed profiled steel plates [9,10]. Some guidelines for designing this covers contains standard UFC 3-340-02 [11]. Today, very often polymer matrix composites, especially fiber or mats reinforced, are also used. In this case the absorption mechanism is reinforcement and matrix failure [12]. In order to improve effectiveness of the composite or steel panels a multilayer, multi-material panels are

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http://dx.doi.org/10.1016/j.compstruct.2015.08.069
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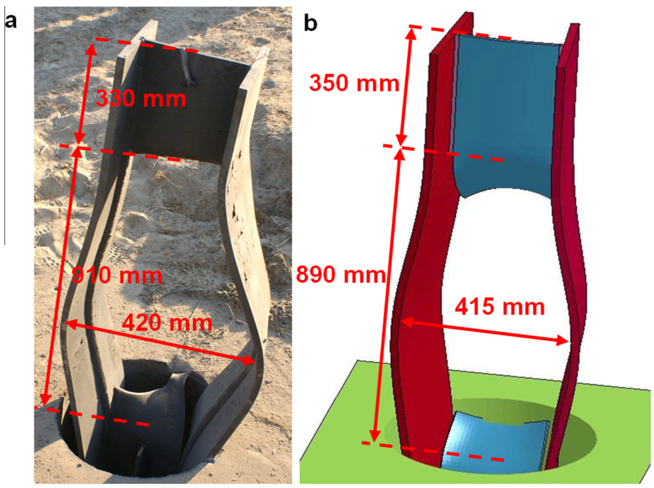

Fig. 1. Destruction unprotected of the pillar – (a) experimental and (b) numerical tests results [40].

used which take advantage of different energy absorption mechanisms [13–17].

Another group of shields use spatial structures for enhancing the energy absorption by progressive deformation and damage of panel structure. In literature panels based on: metal foam [18–20], polymer foam [21,22], honeycomb structures [18,23], lattice structure (pyramidal [24,25], the octahedral [26]), cylinders crush transversely [27] or longitudinally [28] and other spatial structures [29,30]. The most common of protective panels consist of metal foam structure together with composite materials. This sandwich panels are very effective in blast protection. High strength of laminate sheets and high energy of foam progressive crushing results in high consumption of blast wave energy [31–34]. However, this types of panels are sensitive on design parameters such as thickness of the components, stiffness and strength of materials used and panel lay-up.

In this paper a method of sandwich protective panel optimization based on computational mechanics is presented. The objective is reduction of deformations of protected supporting structure caused by blast loading. Optimized design of panel should prevent from critical loss of supporting elements carrying capacity and improve whole object safety.

The parametric study of structures response to blast loads was also carried out by several authors [35–38]. In paper [35] authors studied the longitudinal and shear reinforcement ratios and concrete strength influence of the RC column blast resistance. The parametric study of laminated glass window response was investigated in [36]. Also the different lay-ups of sandwich panel with balsawood core, crushable foam and polyurea was considered in [37]. In [38] authors studied sandwich structures with composite face sheets and polymer foam cores with different densities. Mentioned optimization studies based on stiffness, strength and thickness parameters and the geometry changes were not taken into consideration, thus mechanisms such as delamination were not introduced in numerical models. In presented research the parameters change affect the model geometry as well as the number of composite layers. Additionally this approach allows to consider the laminate failure between layers.

2. Analysed problem

In the performed studies the problem of pillar protection against a blast wave generated by detonation of explosives in "abandon briefcase" was considered. The mass of the charge placed near the pillar was 6 kg. The protected object is critical supporting element of chosen infrastructure facility. It is I-beam pillar of HKS-

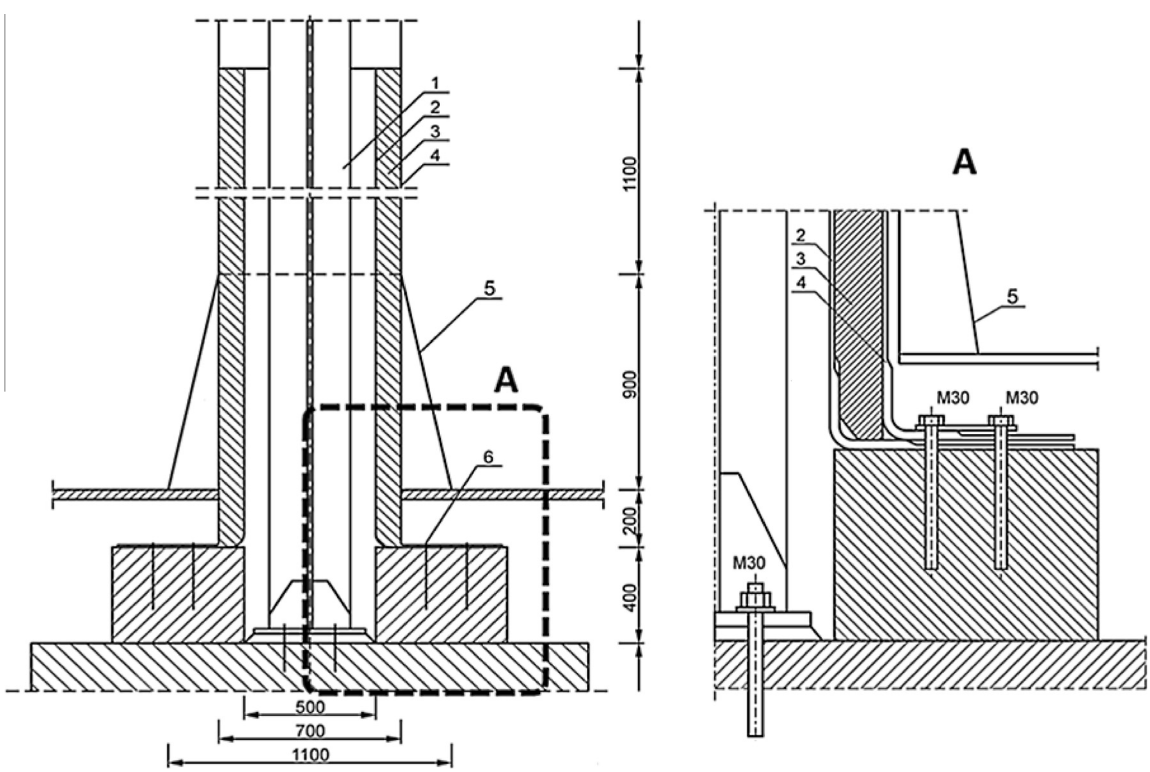

Fig. 2. Protective panel design (1) protected pillar, (2) FR carbon/epoxy and kevlar/epoxy composite, (3) aluminum foam core, (4) FR carbon/epoxy composite and (5) external aluminum sheet [40].