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Retrofit of the Concrete Structures by CFRP Sheets against Explosion

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Abstract

This paper first offers information on blast wave and blast loading. Then, the dynamic analysis of a single concrete slab against blast loading was conducted by the ABAQUS software program. Maximum stress in CFRP plates in the center of the reinforced concrete slab was observed in all loading phases, since this area was in the maximum stress zone. It is also an efficient method of retrofitting the slabs against blast loading using externally fiber-reinforced polymer attached to the tensile side of the slab.

Keywords: Blast load, reinforced concrete slab, CFRP, retrofitting;

1. Introduction

Sufficient displacement and resistance must be provided using high-performance construction materials such as fiber-reinforced polymer, to retrofit the construction against explosion. For the modified construction materials to be effective, the design must be carefully evaluated based on the materials' dynamic responses under the blast loads. Concrete is generally considered a construction material with high blast loading resistance as opposed to other materials. However, concrete structures are designed for operating loads with normal strain which require special modification to enhance the resistance of the structure to explosion. The method retrofitting the construction by attaching multiple structural components or using multiple abutments to improve explosion resistance is undesirable due to increased expense and waste of available space. Choosing the right FRP type is critical for the modification of concrete structures against explosion resistance. The selected FRP should increase the rigidity, strength, and ductility of the modified structures to provide durable explosion resistance and absorb the explosion energy, which deforms the structural rupture mode rather than breaking it.

Explosion Performance

An explosion creates a shock wave which contains extremely dense air that radiates at the supersonic speed from the source of the explosion. When the shock wave expands, the pressure decreases swiftly (proportional to the power three of distance), and after colliding on a surface, it is reflected and can increase its value up to 13 times. The reflection coefficient is a function of the proximity of the explosive and the wave collision's angle[1]. A negative shock wave is produced at the end of the explosion phenomenon which generates suction (Figure 1), and in displacement where a vacuum has been created, a strong wind or traction force is exerted to the construction surfaces.

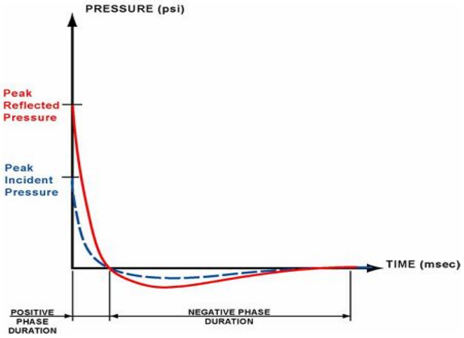

Figure 1. Blast pressure-time history

The maximum pressure depends on the amount of the explosives and the power three of distance. For an explosion hazard explained in terms of explosive's weight and size, the maximum collision and the reflected pressure of the shock wave and other parameters such as the amount of impact and reflected impact, impact speed and wave arrival time can be extracted from charts in several sources such as TM5-1300[2].

1. Blast Loading

The explosions emit an airwave called a shock wave. It is a dense stream of air that spirals at a very high-speed outwards from the source of the explosion. In an explosion, there are two crucial independent parameters, namely the portion of explosives that equals TNT (W) and the distance of explosives from the structure (R). The product of these two quantities is introduced as Z (scale distance) parameter[3].

$$Z=\frac{R}{W^{\frac{1}{3}}}$$

Where W is the amount of explosive and R is the distance between the structure and the explosives.

The observed characteristics of blast waves are affected by the physical parameters of the source. Figure 2 illustrates an explosion pressure profile. At the time of t_A input, the pressure level instantly increases to the full P_{s0} level. At the t_d time, this pressure is then reduced to the ambient pressure level, then to the negative pressure (which creates a slight vacuum) and eventually, it returns to the ambient pressure in the td + td time again. The quantity of P_{s0} is commonly regarded as the peak pressure.

2. Sample Modeling

Based on the article by Wu et al.[4], next we will examine and model the sample in the software. The dimensions of the laboratory sample slap are 1000.2000 mm in plan and 100 mm in thickness. Based on figure 3, this sample is retrofitted above and below the slab with a reinforcement network with a 12 mm diameter at 100 mm horizontal and 200 mm vertical distances with a thickness of 10 mm concrete cover.

The retaining clamps are used for the blast load which includes 3 tubular profiles as shown in figure 4. The horizontal profile is hanged with a light cord, with 4 horizontal beam conductors collecting the load at a point. The distance from the bottom of the explosion to the top of the slab was 3m and the weight of the used TNT was one kilogram.

The damaged concrete plastic model has been used to model the behavior of concrete in the software. The concrete's behavioral specifications in stress and strain are as per figure 5. Also, Yang's concrete modulus equals 28.3MPa. Using Truss elements, the rebars are modeled and buried in concrete. Their tensile strength is 600MPa, and Yang's modulus is 200GPa.

The compound material used in this study is for examining the retrofit of CFRP. The resin used is epoxy and carbon fiber (T300) [3]. The applied CFRPs have linear-elastic behavior, and their mechanical characteristics are described in Table 1.

3. Retrofitting by using CFRP sheets

The models were examined in order to investigate the impact of CFRP sheets on the deformation of slab 45, and their arrangement is as follows:

3.1. Retrofit of the slab by vertical CFRP sheets only on the front side of the blast load

For this purpose, 5 slabs with a distance of 3m from the center of the slab under the blast load and a volume of 3kg TNT were modeled with a configuration based on the figure (4-71). The abbreviation S refers to the word "Slab" and the abbreviation T refers the word "Top" due to the fact that slab is only retrofitted at its top by the CFRP sheets.

3.2. Retrofit of the slab by horizontal CFRP sheets only on the front side of the blast load

3.3. **Retrofit of the slab by vertical and horizontal** *CFRP sheets only on the front side of the blast load*

3.4. Retrofit of the slab by vertical CFRP sheets only on the back side of the blast load

The arrangement of CFRP sheets in these slabs is as shown in figure 5 and the percentage of their coverage is as shown in table 2. These slabs are labeled as SB1, SB2, SB3, SB4 and SB5. The abbreviation S stands for "Slab," and the abbreviation B stands for Bottom, indicating that the slab is only retrofitted by CFRP sheets at the bottom.

3.5. Retrofit of the slab by horizontal CFRP sheets only on the back side of the blast load

The arrangement of CFRP sheets in these slabs is in accordance with figure 6 and the percentage of their coverage is in accordance with table 3. They are labeled as SB6, SB7, SB8, SB9 and SB10.

3.6. Retrofit of the slab by vertical and horizontal CFRP sheets only on the back side of the blast load

The arrangement of CFRP sheets in these slabs is in accordance with figure 7 and the percentage of its coverage is in accordance with table 4. These slabs are labeled as SB11, SB12, SB13, SB14, and SB15.

3.7. Retrofit of the slab by vertical CFRP sheets only on both sides of the slab

The arrangement of CFRP sheets in these slabs is in accordance with figure 5 and the percentage of their coverage is in accordance with table 2. These slabs are labeled as SBT1, SBT2, SBT3, SBT4, and SBT5. In labeling these slabs, S stands for Slab, and BT means the slabs is retrofitted on only two sides by CFRP sheets.

3.8. Retrofit of the slab by horizontal CFRP sheets only on both sides of the slab

The arrangement of CFRP sheets in these slabs is in accordance with figure 6 and the percentage of their coverage is in accordance with table 3. The labels of these slabs are SBT6, SBT7, SBT8, SBT9 and SBT10.

3.9. Retrofit of the slab by vertical and horizontal CFRP sheets on both sides of the slab

The arrangement of CFRP sheets in these slabs is in accordance with Figure 7 and the percentage of their coverage is in accordance with table 4. These are labeled as SBT11, SBT12, SBT13, SBT14, and SBT15.

4. Examining the accuracy of the modeling

Several analyses were performed in order to obtain an analytical model which has a decent accuracy with the sample in the study. The model used for modeling and validation in the paper is NRC-1. At a distance of 3m from the center of the slab, the slab is subjected to an explosive charge of 3kg TNT against the loading details previously mentioned.

As can be seen in figure 8, the path of the time-displacement curve for the laboratory sample and the software designed model is almost the same, indicating that the performed software test has a very high precision. Also, less displacement than the model in the ABAQUS software was observed, that is to say, the laboratory sample demonstrated more rigidity than the analytical sample.

5. Examining the CFRP sheets arrangement

It should be noted that to retrofit the slab only on one side of its top or bottom where the sheets are positioned vertically, the side facing the blast load is under compressive stress in the positive phase of the blast. The opposite side is under compressive stress and the explosion stretches to the other leg. The positive process is the determinant stage in the slab's deformation. The face side of the explosion is under tensile stress, which is the determining phase in the deformation of the positive phase slab. Though its occurrence time is less than the negative period, the force applied to the slab is maximum at this point. It is also known that concrete has a really good behavior regarding compressive stress, but this is not the case with tensile stress.

According to the above discussion, and as seen in table 5 and figure 9, retrofitting of the slab on the back side of the blast load tends to have a better effect than retrofitting the front side of the blast.

We will subsequently analyze the horizontally retrofitted models at the top or bottom. By comparing these horizontally retrofitted models with the same model that was vertically retrofitted, as we can see in Table 6, we can infer that the models in vertical directions or, in other words, retrofitted in the direction of the larger side of the slab have been able to control their deformation.

We retrofitted the slab in both directions and in one dimension only to further explore and find the ideal pattern. For instance, the maximum slab deformation for model SB13 is 2.17mm, for model SB8, it is 2.21mm and for model SB3, it is 2.19mm. Although the percentage of CFRP sheet coverage for SB3 model has increased from 60% to 84%, the slab deformation has decreased by just 0.02mm. It can be concluded that while it has had a positive impact, it is not economic at all.

The combination of CFRP sheets and slab retrofitting at the top and bottom on both sides has shown interesting results. For models in which the CFRP sheet was positioned on a larger side, the retrofitting at the top and bottom was able to minimize the deformation by around 2mm. For the SBT15 slab with a 97.50% coverage, the deformation of the slab's middle point is 2.01mm, which is the same for the SBT5 slab with a 90% coverage and only on the larger side.

6. Conclusion and recommendations

Maximum stress was noted in the center of the slab on CFRP sheets at all loading stages, since this area was in the maximum stress zone. The segregation phenomenon happens when the sheets hit their maximum stress in retrofitting implementation in which case segregation will occur in the center of the slab. CFRP sheets' excellent strength for dealing with the effects of external explosions suggests the need for using these materials to design structures against explosion and impact loads. The best arrangement for dealing with the impact of an explosion is to retrofit the slabs in the form of sheets on their larger side and under compressive stress in the explosion's positive phase or, in other words, in the opposite direction of the blast loads. An efficient way to protect the slabs against blast loading is by using externally attached fiber-reinforced polymer on the tensile side of the slab. This method's efficiency has been proved for flat slab systems exposed to blast loads. The use of strip arrangements is more effective for the efficiency of the structure and reduces maximum displacement against explosion compared to the full coverage of the wall. Also, the absence of sharp corners and beams and columns corners helps with the integration function in design.

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