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Behaviour of Steel Concrete Composite Wall Panel Under Blast Load

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Abstract

Composite wall panel (CWP) design involves a multidisciplinary approach involving material science, structural engineering and dynamic analysis, using advanced modelling techniques and empirical methods. This paper presents an experimental investigation and numerical analysis carried out to understand the component behaviour of Steel-Concrete composite wall panel using Basalt fibers under explosion test. The examination of plain cement concrete (PCC) and basalt fiber reinforced concrete (BFRC) walls with and without profiled steel sheets are casted as the experimental specimens. In this experiment, an explosive with a heat of detonation 1.59 (MJ/kg) is used at a standoff distance range of 1.0 meter and a varied charge weight is used. The Wall Panels experienced the different explosive load conditions, it is observed that minor cracking to moderate deformation is developed and under different charge weight displayed more noticeable deflection and localized damage, despite maintaining structural integrity without catastrophic failure. The experiments results are analyzed numerically; the simulated shock wave overpressure waveforms were compared with that tested. The result shows that the numerically simulated waveform is slightly different from the test waveform, it means that explosive test results achieved more strength than the analytical results. The Profiled sheet composite wall panel with PCC, it functions better and exhibit less spalling and cracking than PCC walls. Although the steel has good ductility properties and strength, it can sustain more significant damage from large explosions. BFRC walls perform better than PCC walls because of the basalt fibres increased tensile strength and ductility properties.

Keywords: *CWP, PCC, BFRC basalt fiber, Explosive load.*

1. Introduction

Over its lifetime, a civil engineering structure is subject to a variety of loads, with blast loads being one notable but infrequent loading scenario. Accidents can result in blast loads and explosions can cause dynamic waves. Blast loads are extremely high loading scenarios that have very little chance of happening to a structure over its lifetime. However, in recent decades, blast load analysis has become more crucial to ensuring the safety of the structure due to an increase in terrorist attacks. The findings suggest that such composite panels can be viable options for constructing blast-resistant structures. The study recommendations for optimizing material composition and panel design to improve performance under high-intensity blast conditions. A popular technique for strengthening diaphragms is composite construction, in which two distinct materials work together to produce a composite effect. The shear action between the profile steel sheeting and infilled concrete is what drives the composite action of the wall through shear connectors. In addition, that basalt fibers improved the ductility and tensile strength of the concrete, reducing crack propagation and spalling under blast loading. Some important studied referred journals are listed below:

A.P. Santos et.al [2023] This study looked at the behavior of three different polyurea coating systems for blast mitigation. Polyurea performance was evaluated through a combination of large-scale experimental testing and numerical modeling using a micro-modelling technique. Four concrete masonry walls were the subject of two experimental blast experiments at first; the experimental part involved a number of laboratory tests to determine the mechanical and physical properties of the polyurea used [1].

Lekshmi Priya A N et.al [2022] The study's main objective is to determine whether FRP composites may be used to improve and lengthen the life of RC beams from various structural angles. This study examines the dynamic behavior of reinforced concrete beams strengthened with fiber-reinforced polymer composites (such as CFRP, GFRP, and AFRP) using the traditional Finite Element Method using ANSYS [2].

Hao Zhou and et. al [2020] this paper reports on the compressive, tensile, and flexural tests that were conducted on concrete that varied in the amount of basalt fiber. The outcomes showed that basalt fiber considerably increased concrete's toughness and crack resistance. Concrete's tensile and flexural strengths are enhanced more by basalt fiber than by concrete's compressive strength. Furthermore, the highest improvement effect was observed at 0.3% and 0.4% basalt fiber content [3].

Zhifeng Xu et.al [2020] his study proposed a high-strength foamed concrete (HFC)-filled cold-formed thin-walled steel (CTS) composite wall that is close fitting in straw-fiber boards (HFCS composite wall). Under compression loading, six full-scale examples of CTS composite walls that were filled and voids with HFC underwent testing [4].

Asim Abbas, et.al [2019] The experimental study conducted to investigate the behavior of reinforced concrete sandwiched panels (RCSPs) under blast load is presented in this paper. An EPS (Expanded Polystyrene) foam core is the central component of an RCSP, and its sides are covered in spray-on reinforced concrete skins that resemble ferrocement overlay. The physical behavior of the RCSPs was examined using excellent visuals, and fragility curves were created. The relationship between damage intensity and scaled distance and charge size is interpreted by the fragility curve [5].

Zhan Li et.al [2017] in the study under consideration The performance of autoclaved aerated concrete (AAC) masonry walls reinforced with basalt fiber reinforced polymer (BFRP) strips under vented gas explosions was investigated through ten full-scale field tests. Autoclaved aerated concrete (AAC) has been used as a substitute for traditional normal-weight or lightweight concrete products as a "ultra-lightweight" concrete material. Three types of walls were ready for blast testing: unstrengthened, rear-face strengthened, and front-face strengthened wall specimens [6].

Subramani Pichandi et.al [2013] has carried out this experimental study, concrete's tensile, flexural, and compressive strengths using fiber-reinforced polymers (FRPs), as well as how these fibers are used in conventional construction. The performance of steel fiber-reinforced polymeric composites, GFRP, CFRP, aramid fiber, and polypropylene fiber is investigated experimentally in this work. Based on the experimental work, they came to the conclusion that further research should be done on creating fiber and composite materials that are suitable for blast protection in real-world scenarios. The most common materials for bomb blasts are secondary explosives like TNT and ANFO [7].

M A Seman1 et.al [2007] Based on the blast pressure parameter, the experimental result of the reinforced concrete (RC) wall structure subjected to blast load was evaluated in this study. Ten mm diameter transverse stirrups and sixteen mm diameter vertical reinforcement, spaced 152 mm apart, were used to reinforce the reinforced concrete wall. Every side of the walls has a 25 mm thick concrete cover. The concrete's modulus of elasticity is 31.5 GPa with a standard deviation of 827 MPa, and its cylinder compressive strength is 44 MPa with a standard deviation of 1.38 MPa. The reinforcement has a 200 GPa Young's modulus and a yield strength of 619 MPa [8].

G.K. Schleyera et.al [2007] has carried out this experimental study on 1/4-scale stainless-steel blast panels with connections subjected to shocked pulse pressure loading as part of a project to ascertain the impact of structural response on the air blast loading, Texas. The panel design, which featured welded angle connections at the top and bottom, was based on the deep trough trapezoidal profile. The sides of the panel were empty. The panels were approximately 880 mm wide and 1000 mm tall. The panels had a profile depth of 40 mm and a total depth of 195, 255, or 315 mm, including end connections. Experiments have demonstrated that the connection detail has a major impact on how the panel reacts to air blast loading [9].

1.1. Design and Detailing of Composite Wall Panel

To conduct an experimental program on composite wall panels, the cold formed steel sheet profiles are defined as per Euro code-IV. The profile sheet measuring 1200 mm length, 912 mm width and 1mm thickness. The sand-witch profiles are connected with shear connectors using 8mm bolts and nuts to maintain uniform wall thickness of 80mm throughout the profile section. The washers are used to create a high grip between the nut and bolt, also controls the leakage of concrete materials. This connection creates the shear bond between the steel and concrete. A dimensions of a cold formed profiled steel sheet is shown in Fig 1.

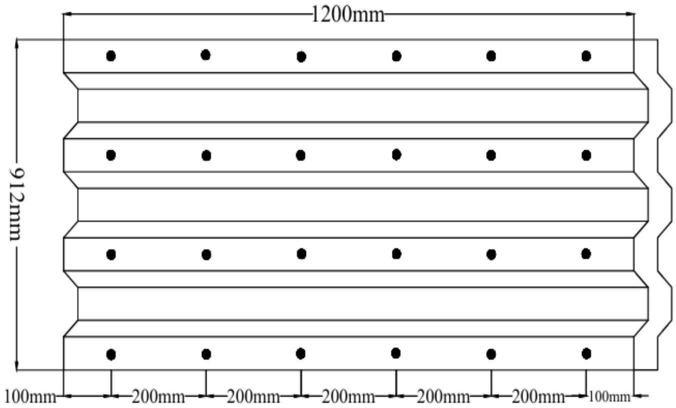

Figure 1 Profile of Cold Formed Steel Sheet

1.2. Material Properties

Plain cement concrete (PCC) and Basalt Fibre Reinforced Concrete (BFRC) has been casted to obtain the characteristic strength of M-25 grade concrete for the composite wall panel specimes. Ordinary Portland Cement (OPC-53 Grade), fly ash (30%), M-sand (used as fine aggregate), 20mm and 12mm downsized coarse aggregates are used in the concrete mixtures. In order to achieve the necessary workability, 0.6% Chryso optima KR77 super plasticizer (SP) is used. Additionally, 1% of basalt fibres are added to the concrete to improve its mechanical qualities. In this experiment, different charge weights of 250g and 500g blast materials are used.

2. Method

The techniques used to calculate the external blast loads on structures in this article are only applicable to rectangular structures that are raised above the ground and will experience a plane wave shock on their front walls. The test takes into account unconfined explosion scenarios, which allow for surface burst explosions. (from the UFC 3-340-02 code for the above-ground rectangular structure without openings).

2.1. Analytical Method

Applying analytical techniques entails resolving intricate equations that depict shock wave propagation, pressure distribution, and the dynamic behaviour of structures. Utilizing these formulae, determine the weight of the TNT equivalent (4.10-4.55 heat of detonation from code) for a distance of range 1 meter and the weight of 250 g and 500g ammonium nitrate (NH_4NO_3; the heat of detonation value is 1.59 by code) are calculated (Figure 2).

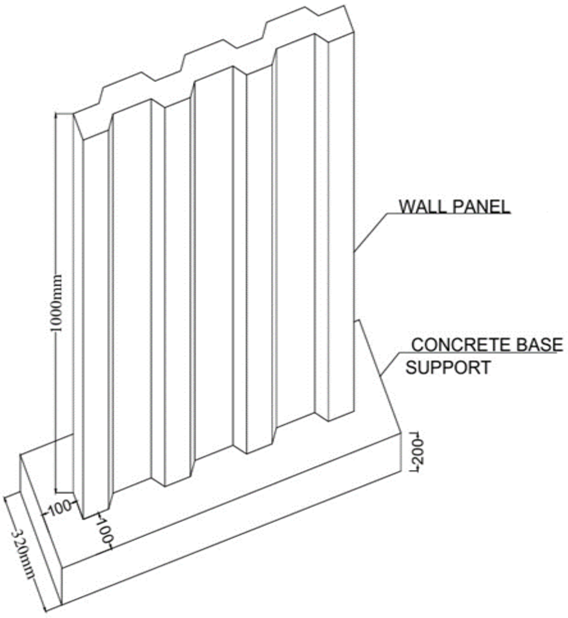

Figure 2 Schematic diagram of Experimental Setup

2.2. Practical Method

In practical investigation, the response of structures under blast loads are assessed through field observations and experimental testing (Figure 3). The useful empirical data from the practical analysis the behaviour of materials, structural deformation and failure mechanisms under conditions of explosive loads. These studies contribute the theoretical model validation and the creation of practical blast mitigation techniques. From Practical analysis, recorded data values of:

t_a = 0.75ms, t_o = 0.62 ms, t_c= 2.74 ms

Newmark has put forth another formulation for computing peak overpressure values [8-11] (Table 1 (a, b) and Table 2 (a, b)) for ground surface blast or hemispherical burst, based on the literature and code book:

$$P_{so} = 6784\left[\frac{W}{R^3}\right] + 93\sqrt{\frac{W}{R^3}} \text{ in bars}$$

Figure 3 **Experimental Set up of Composite Wall Panel**

Table 1 **Pressure and Time Values from The Above Analysis for 250gm Detonated Weight**

(A)Table of Positive Phase Pressure

SL No	Methods	P_{so} (kPa)	t_a (ms)	t_o (ms)	t_c (ms)
1	Theoretical	206.59	0.86	0.93	2.74
2	Practical	172	0.75	0.62	1.91

(B) Table of Negative Phase Pressure

Sl. No	Methods	P_{so}^- (kPa)	$P_{r\alpha}^-$ (kPa)	t_{rf} (ms)
1	Theoretical	10	40	5.5
2	Practical	16	30	6.38

Table 2 **Pressure and Time Values from The Above Analysis for 500gm Detonated Weight**

(a) Table of Positive Phase Pressure

SL No	Methods	P_{so} (kPa)	t_a (ms)	t_o (ms)	t_c (ms)
1	Theoretical	411.78	0.473	1.29	2.27
2	Practical	300	0.40	0.90	2.36

(b) Table of Negative Phase Pressure

SL No	Methods	P_{so}^- (kPa)	$P_{r\alpha}^-$ (kPa)	t_{rf} (ms)
1	Theoretical	33	76	4.85
2	Practical	18	90	5.6

3. Results and Discussion

3.1. Results

According to the results, the steel-concrete composite wall panels using basalt fiber reinforced concrete under blast load improves the greater resistance Under blast loading, the ductility and tensile strength of concrete are increased by using the basalt fibers, which also prevented crack propagation and spalling. According to the analytical and practical results, blast resistance to explosive loads can improved concrete strength parameters. In addition, the standoff distance gets closer to the structures, the explosion damage gets worse [12-15]. In terms of blast resistant against extreme loading, the BFRC specimens perform better than the PCC specimens. Analysis of the deformations and physical damages of wall panels with PCC and BFRC are caused by blast loads using damage scale analysis factors are listed in Table 3. Refer Figures 4, 5, 6 and 7 [16-19].

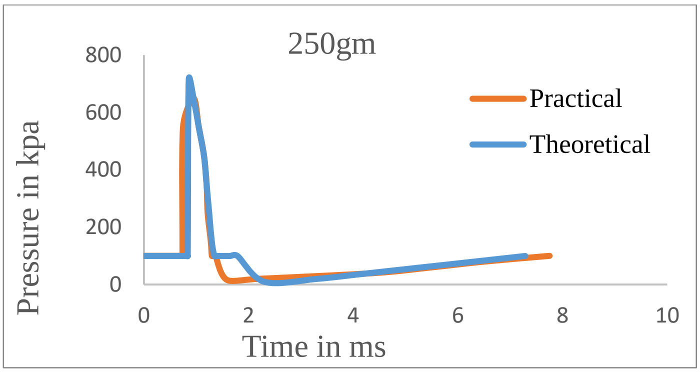

Figure 4 Measured Pressure-Time History of 250g Surface Explosion

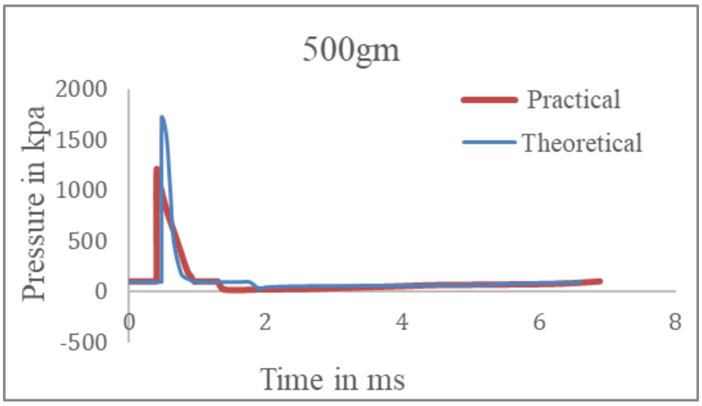

Figure 5 Measured Pressure-Time History of 500g Surface Explosion

A standard blast load damage scales which are adopted for the damage categorization are used in literature studies [20-24]. Using a judgment-based approach, the post-damage pattern and percentage of damages of BFRC walls with and without profiled sheet subjected to progressive blast loads are observed.

Table 3 Blast Load damages scales

Percentage damage	Damage Scale
0	No damage
0-20	Negligible damage
20-40	Slight damage
40-60	Moderate damage
60-80	Major damage
80-100	collapse

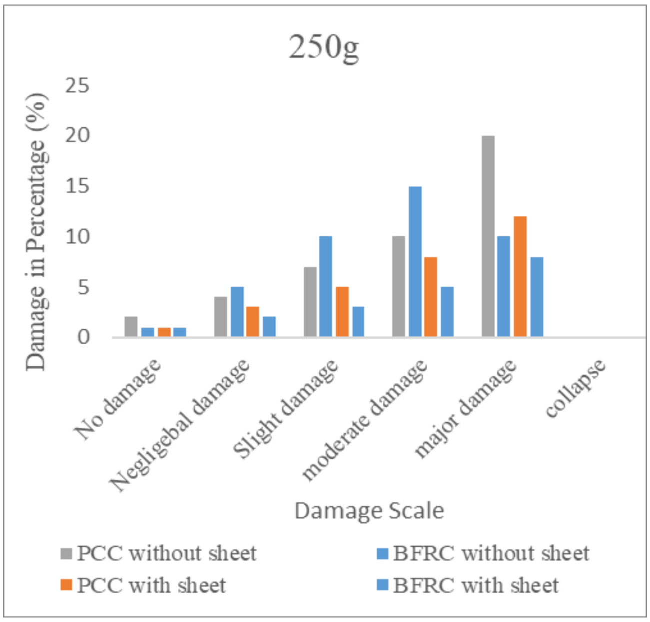

Figure 6 Relationship Between % Damages and Damages Scales for Different Charge Weights

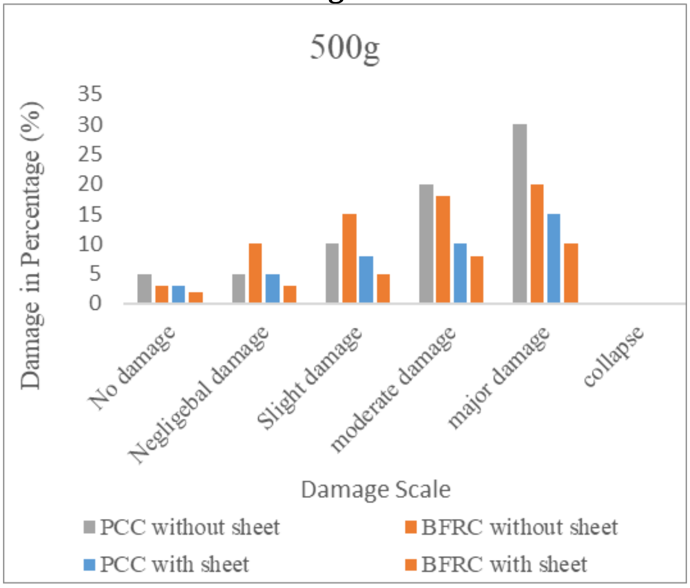

Figure 7 Relationship Between % Damages and Damages Scales for Different Charge Weights

3.2. Discussion

Adding the sand witch profiled steel sheet to PCC walls can improves their performance but not that much effectively than BFRC walls [25]. The integration of basalt fibers and steel sheets provides a considerable solution for blast-resistant construction [26-28]. The physical damage analysis indicates that BFRC walls with profiled steel sheets offer the highest resistance to blast loads, showing minimal damage and retaining structural integrity than the other wall panels. Refer Figures 8,9,10, and 11.

Figure 8 **BFRC CWP**

Figure 9 **PCC CWP**

Figure 10 **PCC Wall Panel**

Figure 11 **BFRC Wall Panel**

Conclusion

The mechanical properties of test results for concrete cubes, cylinders and prisms are calculated which are casted in wall panels for blast loads [29]. The results of the experimental investigation show that Composite wall panels made up of steel-concrete matrices using basalt fibres which are encased in composite structures and shows the more blast resistance behaviour. It effectively controls the propagation of cracks, absorb and dissipate blast energy and preserve structural integrity under high-pressure loads. The panels ductility and resilience are increased by the interaction between the steels and concrete through shear studs. In order to further enhance composite panels performance under blast loading conditions, this study offers recommendations for improving their design and material composition.

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