Normal Strength Steel Fiber Reinforced Concrete Subjected to Explosive Loading

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ABSTRACT

This paper presents the results of an experimental investigation on the behavior of plain reinforced concrete and Normal strength steel fiber reinforced concrete panels (SFRC) subjected to explosive loading. The experiment were performed by the Blast Research Unit Faculty of Engineering, University Pertahanan Nasional Malaysia A total of 8 reinforced concrete panels of 600mm x 600mm x 100mm were tested. The steel fiber reinforced concrete panels incorporated three different volume fraction, 0.5%, 1.0%, and 1.5% of hooked end steel fibers. The panels were subjected to explosive loading generated by the detonation of 1kg of explosive charge located at a 0.6m standoff. This investigation indicates that the steel fiber reinforced concrete panel containing of 1.5% volume fraction gave the best performance under explosive loading.

Keyword: *Steel fiber concrete, explosive loading, steel fibers*

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1.0 INTRODUCTION

Terrorist attacks on building structure worldwide are the example of the fact that the destruction of the civil engineering structure are one of the target of the terrorist activities. The terrorist often target at hotel, restaurants, and on public transportation or places where civilian has gathered .The attack is highlighted by several recent terrorist attack such as on Moscow Metro Train (2010), Marriott Hotel in Jakarta (2009), and Mumbai (2008) which had shown that the destruction of the hotels and other facilities such as public transport and military base has become target of the terrorist [1-3]. As a result there is a need to increases the resistance of the building materials against explosive loading especially critical government, military and corporate buildings, strategic bridges, dams and also chemical or petroleum plants that are all at risk from terrorist attack. Most of the building materials is made of concrete which brittle and has low tensile strength [4]. As a result concrete members exposed to explosive could not support such loads and stresses that usually take place on concrete beams and slabs and will result in collapse of the structure, or severe cracking as well as fragmentation.

This disadvantage of concrete can be overcome by adding steel fibers to the concrete. Studies by Bayazi, 1989 [5] shows that by introducing randomly dispersed steel fibres into the mixture can increase tensile, shear and flexural properties of the concrete. There are several steel fiber shapes available such as straight, crimped, hooked single, hooked collated, and twisted. This is as shown in Figure 1.0.

Tadepalli, et.al [7] in his research on the effects of steel fiber reinforcement on the mechanical properties of reinforced concrete found that the most effective shape for energy absorption capacity is the hooked end type fibers. When steel fiber concrete (SFRC) beam or other structural element is loaded, steel fibers in the matrix will bridge the cracks, as shown in Figure 2. Such bridging action provides the SFRC specimen with higher ultimate tensile strength, toughness and also energy absorption capability [8].

Previous studied revealed that Steel fiber reinforced concrete can perform very well under dynamic loading such as explosive charge, drop weight and also projectile impact [9–11]. Shengrui et.al [12] had performed a series of explosive tests on the composite component which include steel fibre reinforced concrete slab, profile sheeting reinforced concrete slab and also conventional reinforced concrete slab. The specimens were tested with a charge weight ranging between 8 and 100 kg of bare explosive at a stand-off distance of 5m. The test results show that 1.0% of steel fibre volume in the concrete perfume is significant in resisting the blast loading. Magnusson et.al [13] reported the benefit of incorporating the steel fibre in the reinforced concrete to resist the blast load.. In another study by Wu et al [14] the researchers tested the behavior of Ultra-high performance steel fiber concrete against explosive loading and the study shows that Ultra-high performance steel fiber was the preferable concrete mixture for resisting blast loads.

Previous literature provides numerous definitions for the term explosion. NFPA 921 2008 [15] defines an explosion as “the sudden conversion of potential energy chemical or mechanical into kinetic energy with the production and release of gas under pressure. These high-pressure gases then do mechanical work such as moving, changing, or shattering nearby materials. A series of explosion event captured by high speed video movie showing the explosive detonation is shown in Figure 3.

Figure 3 shows pictures taken from high speed movie at the field blast testing site showing the sequence of explosion resulted from detonation of Plastic explosive (PE40) [16]. As the explosive detonated, it creates a creates a shock wave that travel at supersonic velocities then reflected, later in the explosive event, the shock wave create a powerful wind which drag pressure on all surfaces and also surrounding area. Finally the wind picks up and carries flying debris in the vicinity of the detonation. [17]. this explosion event will result in the fragments, debris, missiles ground shock, and cratering at the surrounding area. A typical overpressure history for a conventional explosive is shown in Figure 4.

Generally the failure modes on structure associates with the explosive loading can be flexure, direct shear or punching shear, bleaching and spalling which is depended on the explosive size and standoff distance between the blast source and the target as shown Figure 5.0.[17] The extend of the damaged on a structure can be classified as light, moderate and also severe. Light damaged is referring to the appearance of hair line crack with crack width of less than 1 mm on the exposed surface of the concrete. Moderate damaged refers to the situation when the bottom surface of the concrete is having cracks width of up to 1.5 mm and also having a minor spalling. Severe damage refers to the large cracks up to 4 mm wide together with large deflection and also heavy concrete spalling [18].

The objective of this study is to investigate the behaviour of normal strength steel fiber reinforced concrete subjected to explosive loading. In this study eight concrete panel were tested using charge weight of 1 kg of plastic explosive (PE4) at a standoff distance of 0.6 meter to determine their response against explosive loading. After each test, the failure mode of each type of specimen was recorded and examined. These details are presented in the paper.

2.0 EXPERIMENTAL PROGRAM

A total eight numbers of concrete panel were fabricated which consist of was Normal Reinforced Concrete (NRC) as a control panel and also Steel Fiber Reinforced Concrete Panel (SFRC) containing different volume of hooked-end steel fibres, 0.5%, 1.0% and also 1.5% volume shown in Figure 6. The specimens was reinforced on both tension and compression face with 12mm diameter steel reinforcement at 200mm centre-to-centre in both ways. The entire specimen was measuring 600mm × 600mm at a thickness of 100mm with 20mm cover.

The size, thickness for both the NRC and SFRC panels were the same. The only difference was the SFRC panel was incorporated with two different lengths of hooked-end steel fibres, 0.5%, 1.0% and also 1.5% volume of hooked-end steel fibers which is made of mild carbon steel as shown in Figure 7.

The fibers have an average length of 60mm, nominal diameter of 0.75mm, aspect ratio of 80 and tensile strength of 1100Mpa. The mix proportion of cement : water : aggregate : sand was 357:160: 997:534: kg/m^3. In the production of concrete, firstly the aggregate and sand was put into the mixer and mixed for a few minutes and then cement and water were added into the mix. Finally the fibres were added in small amounts to avoid fibre balling and to produce the concrete with uniform material consistency and good workability. The freshly mix steel fibre reinforced concrete was placed in two equal layers into mould to cast a standard 150mm × 150mm × 150mm cube and 150mm × 300mm cylinder concrete specimen for a compressive strength test and a split tensile test and also into a 100mm ×100mm ×500mm beam mould for a flexure strength test. Each layer was consolidated using a vibrating table. At the end of 24 hours after consolidating, the specimen was removed from the mould and cured in water for 28 days.

Finally the NRC and SFRC were poured separately into the panel mould of 600mm × 600mm × 100mm. The NRC and SFRC panels were later removed from the mould after consolidation and cured with wet gunny sacks for 28 days before the field blast test. Table 1 shows the results of the average compressive strength tests, flexural strength tests and split tensile strength tests for both the NRC and SFRC specimens.

3.0 FIELD BLAST TESTING PROGRAM

The field blast test was conducted by a blast research unit of faculty of Engineering; University Pertahanan Nasional Malaysia.The field blast test involves tedious preparation of test specimen, prediction of blast load, usage of high end instrumentation such high speed camera, sensors and also validation of the experiment. Figure 8 shows the various components involved in the field blast testing. Due to the limitation of cost and also possible blast charge weight to be used for the research, the charge weight was limited to a maximum of 1kg of explosive. In the test two steel I beam support of a length 800mm each was fabricated at the Fabrication Laboratory of the Engineering Faculty of Engineering Universiti Pertahanan Nasional Malaysia The support was fixed to the existing heavy reinforced concrete structure located at the blasting site. The concrete panel was then fixed to the steel support frame as shown in Figure 9.0 and Figure 10.0.

4.0 RESULTS AND DISCUSSION

At the end of each test, the failure patterns of each specimen were recorded. A set of photographs of specimens is presented in Figure 11 which illustrates the damage pattern of the specimen. Detailed observations on each specimen are summarised as follows in Table 2.

Specimen NRC: This specimen failed as in flexural shear mode. Two large shear cracks with more than 4mm wide were developed on the back face of the specimen at mid-span. A number of smaller cracks were also observed on both the front and rear faces. This is because the normal reinforced concrete has a very low resistance against flexural strength and also low ductility [20].

Specimen SFRC: The concrete containing 0.5 % volume fraction of fibers shows similar failure mode of normal concrete .This because the percentage volume of fiber added into the mix is insufficient to provide adequate resistance against blast loading which resulted in pullout of the fiber due to higher force applied by the detonation on the concrete structure . The fiber pullout behaviour is shown in Figure 12.

On the other hand the concrete containing 1% of the fibers shows significant resistance effect to resist the blast loading and steel fiber concrete panel consist of 1.5% shows the best performance against explosive loading as there is no significant damaged on both front and back face of the specimen and only two hair line cracks were developed at the back face of the specimen. This is because by incorporating the fibres into concrete can significantly restrain the initiation and propagation of crack by the bridging effect and subsequently change the failure mode from brittle manner to a pseudo- plastic manner [21].The bridging effect is observed in the panel is shown in Figure 13

5.0 CONCLUSIONS

The experimental results indicate that increasing the volume of steel fibers leads to increase in blast resistance of a concrete structure. The best performance under explosive loading has been given by steel fiber concrete containing 1.5% volume of fibers, followed by concrete containing 1.0% fibers. However it can be seen that concrete containing fiber volume of 0.5% and normal reinforced concrete is not effective in resistance the explosive loading.

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7.0 REFERENCES

[1] Peters A.Train Bombing in Moscow Kill Dosen, Available from http://www.wsws.org/articles/2010/mar2010/russ-m30.shtml (Accessed on 30 March 2010).
[2]Moestafa B.Marriot Hotels in Jakarta Hit by Bombing, Available from http://www.bloomberg.com/apps/news?pid=newsarchive&sid=a_SusXvRLY.0 (Accessed on 17 July 2009).
[3] Milli A.Taj hotel attack in Mumbai. Available from http://www.nowpublic.com/world/taj-hotel-attack-mumbai-puts-nowpublic-worldwidespotlight (Accessed on 26 November 2008)
[4]Magnusson J.Steel Fiber Reinforced Concrete subjected to Air Blast Loading. Report F01- R-2045-SE, Stockholm, 2006.
[5] Bayasi, Z. "Development and Mechanical Characterization of Carbon Fiber Reinforced Cement Composites & Mechanical Properties and Structural Applications of Steel Fiber Reinforced Concrete." Dissertation for the Degree of Ph.D., Michigan State University, 1989, V.1, pp. 1-199.
[6]Bentur A. and Mindess S., 1990, *Fibre Reinforced Cementitious Composites*, Elsevier Science Publishing Ltd., New York, United State of America.
[7]Tadepalli, P., Mo, Y., Hsu, T., & Vogel, J. (2009). Mechanical Properties of Steel Fiber Reinforced Concrete Beams. *2009 Structures Congress* (pp. 1039-1048). Austin, TX: ASCE.
[8]Michael Gebman Application of steel fiber reinforced concrete in seismic beam – column joint. Msc Civil Engineering Thesis, San Deigo University, 2001.
[9] Williamson,G.R, 1965, The use of fibrous reinforced concrete in structure exposed to explosive hazars, Miscellaneous Paper No. 5-5, U.S.Army Ohio River Diversion Laboratories.
[10] Robin, P.J, and Calderwood , R.W., 1978" Explosive testing of Fiber Reinforced Concrete". Concrete (London), V.12, No 1, pp. 26- 28.
[11] Suaris, W, and Shah, S.P., 1984, The test method for Impact Resistance of Fiber Reinforced Concrete". Fiber reinforced concrete – International symposium, SP -81, American Concrete Institute , Detroit, pp. 247 -260.
[12] Shengrui L, Lok T, Heng L. Composites Structural Panels Subjected to Explosive Loading. Journal of Construction and Building Materials, 19, (2005), 387 -395
[13] Magnusson, J., Hallgren, H., "High Performance Concrete Beams Subjected to Shock Waves from Air Blast, Part 2", FOI- R--1116--SE, Tumba, 2003
[14] Wu C, Oehlers D J., Leach J, Whittaker A S. Blast Testing of Ultra High Performance Fibre and FRP Retrofitted Concrete Slabs. Journal of Engineering Structures (2009).
[15] NFPA 921. 2008 *Guide to fire and explosion investigations*, National Fire Protection Association, Quincy, Mass

[16] Alias, Norazman, Arifin, Ng Choy Peng, Fauzi and Risby . Response of steel fiber reinforced concrete subjected to air blast loading .Jurnal Asia Pertahanan dan Keselamatan (1), 2010.
[17] Ngo, T.and Mendis, P. (2007). Blast Loading and Effect on Structures. EJSE Specials issue. Loading on structure.
[18]Ghani R. Blast Loading Response of Reinforced Concrete Panels with Externally Bonded CFRP Laminates. Journal of Composites: Part B: 38 (2007), 535-546.
[19] Alias, M.Y., Norazman, M.N. Ariffin, I, Ahmad.M, Ng, C.P. and Fauzi, M.Z., M.S Risby 2009. "An Overview of Field Blast Test on Concrete Structures Subjected to Blast Loading". Asia Pacific Conference on Defence and Security Kuala Lumpur, 6-7 October 2009.
[20] Karihaloo, B.L. (1995). Fracture Mechanics and Structural Concrete. Longman, London, United Kingdom.
[21] Sierakowski, R.L. (1997). Dynamic Loading of Fibre Reinforced Composites. Wiley. New York.

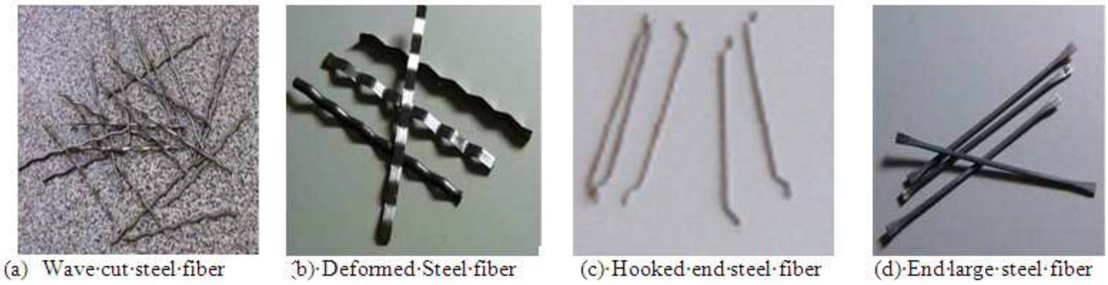

Figure 1. Types of steel fibres. [6]

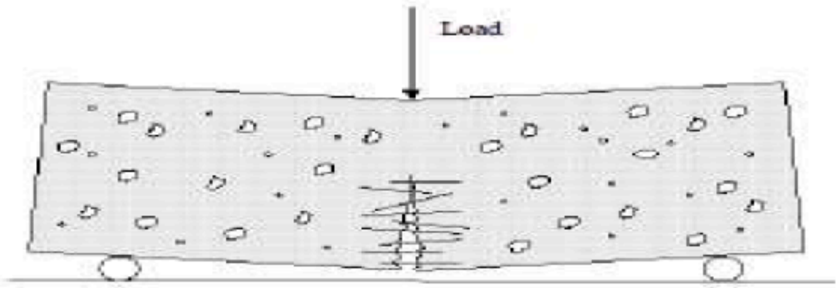

Figure 2.Bridging Action of steel fiber [8]

Figure 3. Sequence of an explosion event resulted from a detonation capture by high speed movie [16]

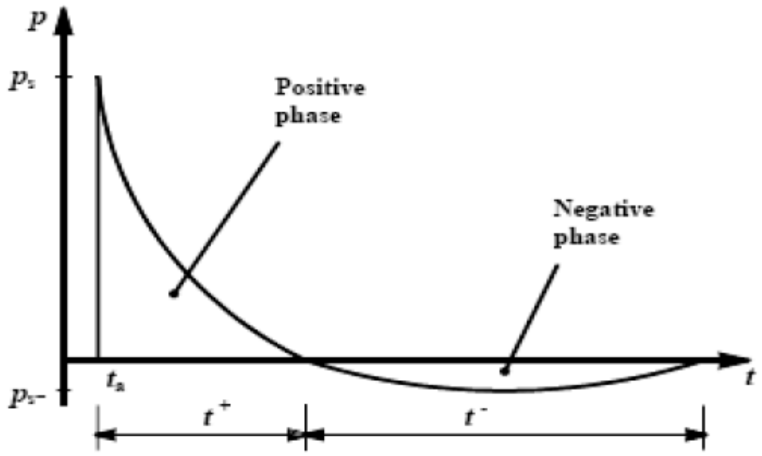

Figure 4.Typical pressure history profile for a conventional explosive [17].

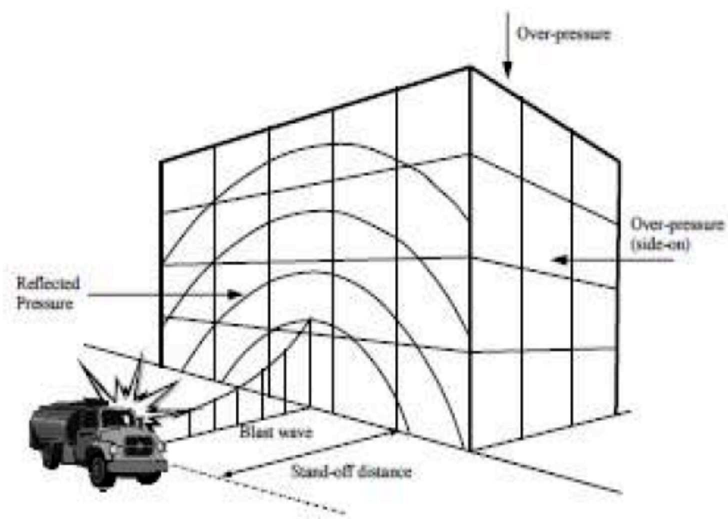

Figure 5. Blast load on building [17].

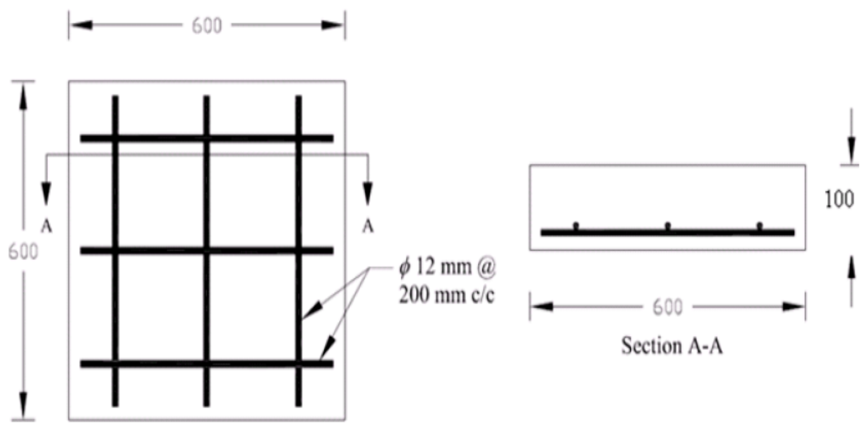

Figure 6: Typical plan and section of the concrete panels.

Figure 7: Photos of hooked end steel fibers

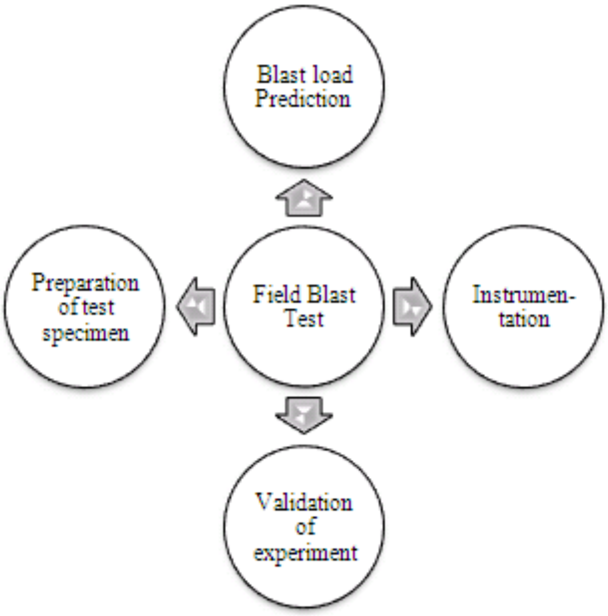

Figure 8. Field blast testing component [19]

Figure 9. Support Frame

Figure 10.Test set up

Fiber volume	V_f = 0.0%	V_f = 0.5%	V_f = 1.0%	V_f = 1.5%
(a) Back face of concrete panel				
(b) Side face of concrete panel				

Figure 11: Damage pattern of concrete test panels after the blast.

Figure 12: Fiber pullout from the concrete due to explosive loading.

Figure 13: Bridging action of steel fiber on concrete panel

Table 1. Test Results for NRC and SFRC

Fiber Volume fraction	**Compressive Strength, (MPa)**	**Splitting tensile strength (Mpa)**	**Modulus of rupture (Mpa)**
0	31.0	3.0	3.5
0.5	33.0	3.4	4.0
1.0	37.0	4.0	5.3
1.5	38.5	4.5	6.0

Table 2. Observation of the panel after the explosion test

Specimen	Fiber Volume (%)	Main Observation	Damage Classification
Specimen NRC	0	Shear failure, two large cracks more than 4mm wide at rear and back face and fragmentation.	Severe damage
Specimen SFRC	0.5	Shear failure, one large crack at rear and back face more than 4mm wide.	Severe damage
	1.0	No crack at rear and only one large crack at back face upto 2mm wide	Moderate damage
	1.5	Undamaged, No major cracks, only minor cracks at back face width less than 1mm	Light damage