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Numerical Investigation of Steel Reinforcement Arrangement in Reinforced Concrete Wall Subjected to Blast

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Abstract. Three-dimensional (3D) numerical modelling of inverted-T shape reinforced concrete (RC) wall subjected to blast load is study in this paper. The walls have the same moment resistance with different steel reinforcement arrangements. It is subjected to 13.61 kg Trinitrotoluene (TNT) explosive at 1.21 m standoff distance from the centre. The Arbitrary Lagrange Euler (ALE) solvers coupling approach is employed for the interface analysis between air and structure to simulate the damage mechanism in AUTODYN numerical commercial software. The numerical damage indicator indicated, with mesh dependency assessment, the damage pattern vs experimental appeared precisely on the steel reinforcement grid due to the smaller element size compared to the coarse element used.

Keywords: Reinforced concrete; Structure; Blast; Simulation; AUTODYN

1. Introduction

Study on the structure with the capability of withstanding blast load in the construction industry around the world became necessary since the last decade due to the September 11, 2001 attacks in New York. Besides, since then series of aggressor attacks occurred over the world targeted the civilian buildings. This phenomenal lead for a series of blast experimental and numerical studies related to structure and its materials. However, blast test is an expensive test to conduct by civilian due to equipment for data acquisition, and explosive materials also need permission from the military. Thus, constrain for the researcher to use a small panel to ensure that the blast post impact is enough for further investigation to develop suitable materials, retrofit methods, new material to protect the existing structure and to understand the behaviour of RC subjected to blast load [1-5]. However, there still lacks research published regarding the appropriate steel reinforcement arrangement in a complete RC wall structure with its base. As published academically are inverted T-shaped RC Wall, L-shaped RC wall, RC column-beam connection and RC column for different objective such as performance of varying steel reinforcement materials used in RC structure, effectiveness high-strength steel fibres and high compressive strength aggregate concrete, dynamic response and damage characteristic and influence of width and height of column respectively [6-9]. Besides, from the construction record retrieved, although two RC walls subjected to the possibility of blast load from electrical transformer explosion, there are variations to place the horizontal steel reinforcement tied-outside same to RC shear wall or tied-inside on the vertical steel reinforcement identical to RC retaining wall [10-11].

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2. Numerical blast

The rapid development of the digital computer, with the capacity of performing the complex arithmetical operation, has come to rescue, allowing the use of numerical formulations to the process of analysis. Here lies the importance of the Finite Element Method (FEM) where expensive experimental models, often used in the design of critical structures, are rapidly becoming replaced by more parametric studies through computations. With one validated numerical solution against experimental work, a parametric study can conduct without another expensive experimental. Currently, numerical simulation is an alternative method to replace a costly blast test. For example, AUTODYN simulation package can model non-linear dynamic problems that use finite elements (FE), finite volume (CFD) and mesh-free particle (SPH) to solve nonlinear dynamic problems of solid, fluids, gas and the interaction between them.

With the capability of current 3D numerical modelling together input from series of experimental and numerical studies conducted on the RC subjected to blast load such as small rectangular or square RC panel shape [1-5,12-13] and complete RC structure with its base [6-9] the detail 3D numerical study is possible. Usually, with one blast impact experimental data available, the numerical research conducted for the validation with commercial 3D finite element (FE) numerical simulation packages such as ANSYS AUTODYN and ANSYS LS-DYNA. In AUTODYN, a well-developed material subjected to blast load such as CONC35MPA and STEEL 4340 assigned for concrete and steel respectively. Different erosion limit introduced to approximate the experimental result numerically. Then, with a validated numerical model, further numerical parametric studies are considered mainly on the effects of charge weight, standoff distance, panel thickness and reinforcement size for further assessment such as failure, response and behaviour characteristic [1-2,14-17].

3. Numerical blast impact on RC wall

In the present study, the experimental result of the RC wall structure subjected to a blast load by Yan was appraised based on the blast pressure parameter [6]. Figure 1 shows the geometry and section detail of the wall. The walls have a cross-sectional dimension of 1829 mm x 1219 mm with a wall thickness of 152 mm and 305 mm thickness of footing. Three numerical displacement gauges located on the RC wall and the fixed end boundary condition is assigned to the wall base surface, which is in accordance with Yan [6]. The modification of the vertical flexural reinforcement placement into the wall base from the hooked-out direction on RC-WA to the hooked-in direction is made to get RC-WB. On the other hand, the horizontal flexural reinforcement is changed from tied-outside to tied-inside on the vertical flexural reinforcement for the RC-WC, as shown in Figure 2. Although the arrangements are different, the design moment resistance for each is the same with 167 kNm.

In the numerical modelling, the RC structure is modelled as Langrange solver. To describe the concrete behaviour under blast load, the material model developed by Riedel, Hiermayer and Thoma (RHT) adopted [18]. The RHT concrete model is an advanced plasticity model for brittle materials. Notably, it is useful for modelling the dynamic loading of concrete. The model includes pressure hardening, strain hardening, strain rate hardening, third invariant dependence for compressive and tensile meridian as well as damage model for strain softening. This model also employs the p-a equation of state to represent the concrete thermodynamic behaviour at high stress. It provides a reasonably detailed description of the compaction behaviour at low-stress ranges [19]. While, for steel reinforcement, Johnson-Cook (JC) material model was used [20]. This model represents the strength behaviour of material subjected to a large strain, high strain rates and high temperature, typically metal.

Three meshed sizes are considered to investigate the mesh dependency and further investigate the failure of the RC wall due to blast loading. The RC wall meshed with hexahedral coarse, medium and fine mesh respectively. Table 1 shows the mesh size and element detail used for the meshed RC wall. In the AUTODYN, the initial detonation of the explosive and blast wave propagation is modelled with an axially symmetric wedge shape. The 1 m wedge filled with the calculated charge circle for 13.61 kg (30 lbs.) of TNT material model and the remaining region outside the circle is filled with the air material. The wedge consists of blast pressure history is created before the application remap function in AUTODYN, as it is used to apply the effect of the explosion in 3D model [21].

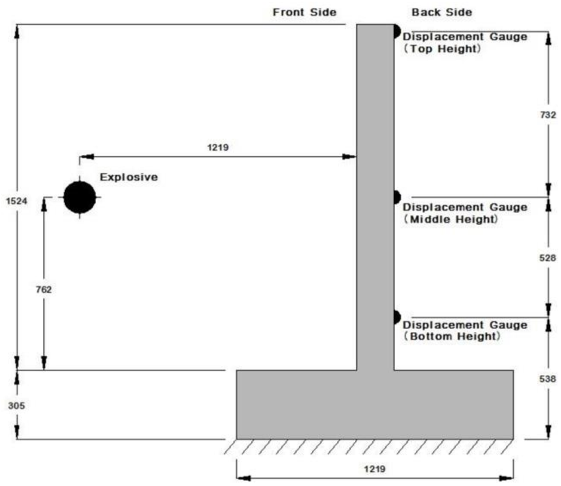
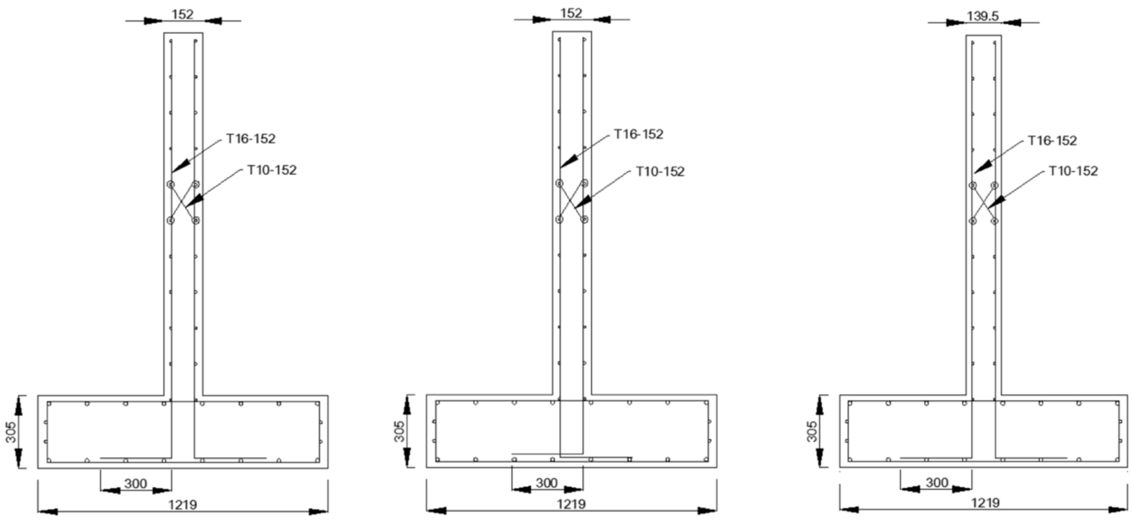


Figure 1. Setup for the blast in simulation (in mm)



(a) RC-WA (b) RC-WB (c) RC-WC

Figure 2. Steel arrangement of reinforced concrete wall (unit in mm)

Table 1. Mesh sizes

Mesh type	Mesh size (mm)	No. of element
Coarse	35	24,073
Medium	20	160,407
Fine	10	1,205,524

4. Blast impact assessment on RC wall

Figure 3, 4 and 5 show the RC wall after imposed with the blast load. It is found that the back face of the wall experienced more visible cracks compared to the front face of the wall as the shock front is engaged with a concrete wall and generates compressive stress on the concrete in contact. The concrete on the front face of the wall and the shock front is locally subjected to bending as the stiffness of the front reinforcement grid suddenly change, potentially causing a concrete crack. It is clearly indicated the cracks follow the pattern of the steel reinforcement grid in the reinforced concrete wall. A few more cracks also appear at the lower part of the wall and fewer cracks, particularly at the upper part of the wall [6].

The effect of different steel reinforcement arrangements in RC-WB and RC-WC was assessed by comparing the results with the RC-WA. The hooked-out direction of vertical flexural reinforcement placement into the wall base was changed to the hooked- in direction for RC-WB wall. Furthermore, the tied-outside of horizontal flexural reinforcement was changed to tied-inside for the RC-WC wall. Both of the RC walls were subjected to an equal blast loading of 13.61 kg (30 lbs.) TNT. The TNT charge weight used for the case studies was similar to the weight applied on the RC-WA wall as reported by Seman [21] the other hand, illustrate the damage indicator for RC-WB and RC-WC wall, respectively. It is noticeable that the damage indicator for RC-WB is almost identical to the RC-WA in Figure 3 and Figure 4, respectively. Conversely, for the RC-WC in Figure 5, on the front side, the vertical damage indicator pattern is rather visible, this indicates the effect of the vertical flexural reinforcement placement in the wall tied-outside the horizontal flexural reinforcement. In addition, with the steel reinforcement arrangement changed for RC-WC wall, the maximum displacement is higher than the RC-WA wall, as shown in Figure 6. However, the resistance is improved for the RC-WB wall when the direction of vertical flexural reinforcement into the wall base is changed to hooked-in direction. It is apparent that the maximum displacement for RC-WB is the lowest as compared to RC-WA and RC-WC walls, respectively. Figure 7 shows the displacement propagation for RC-WA. Therefore, the best arrangement is hooked-in and tied-inside of vertical steel and horizontal steel respectively for the RC wall subjected to blast load.

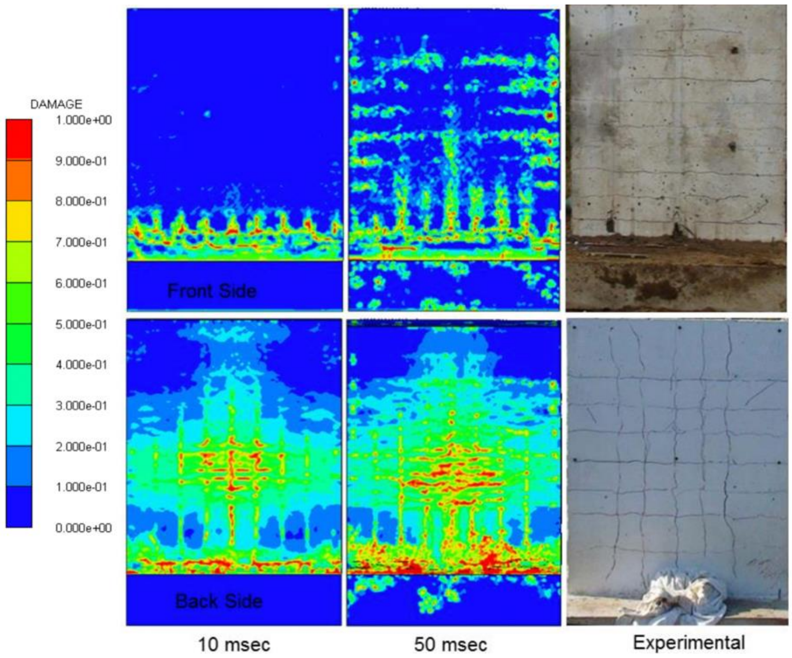


Figure 3. Damage indicator for RC-WA

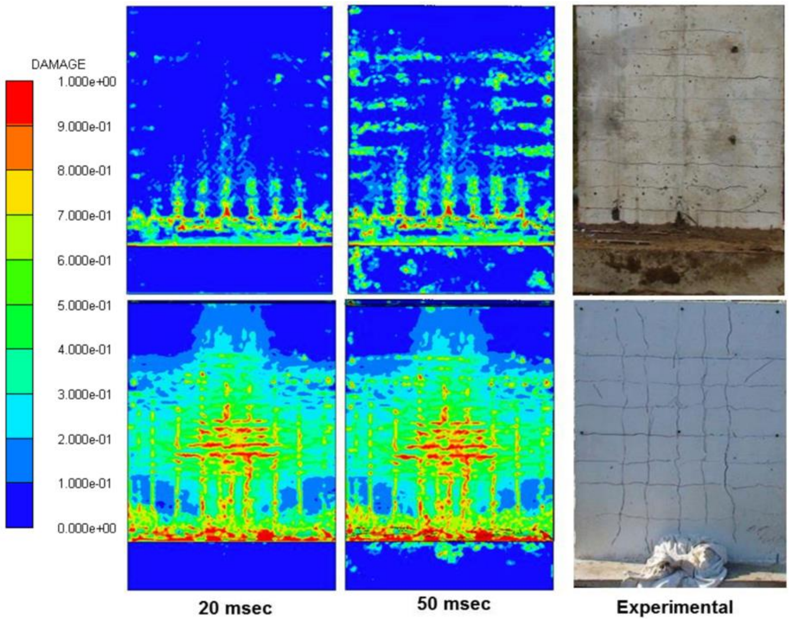


Figure 4. Damage indicator for RC-WB

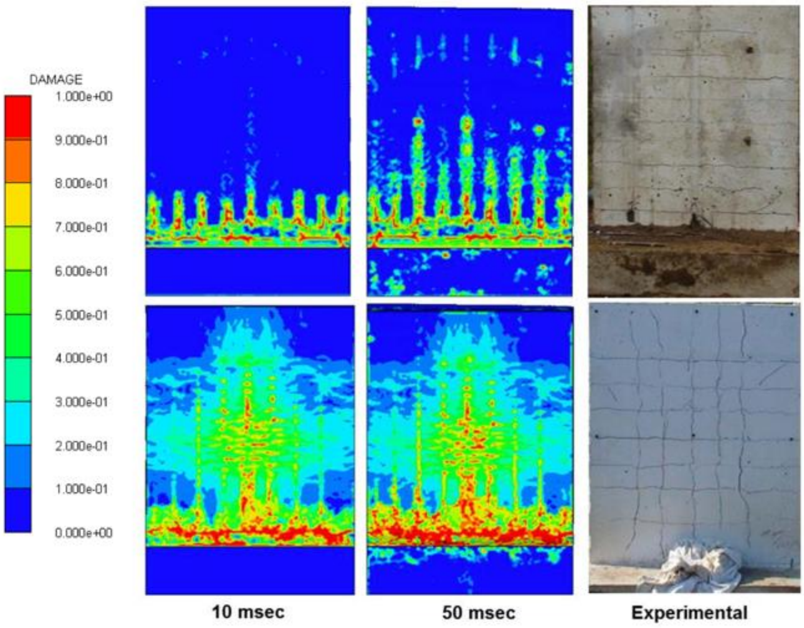


Figure 5. Damage indicator for RC-WC

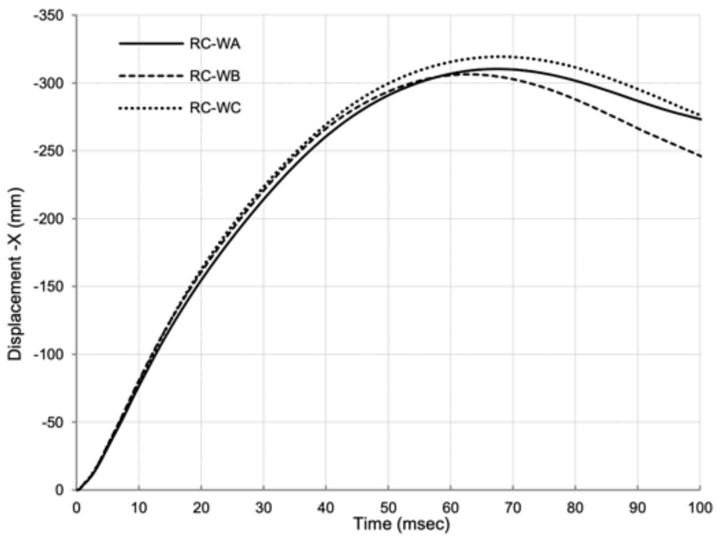


Figure 6. Displacement time-history at top height displacement gauge

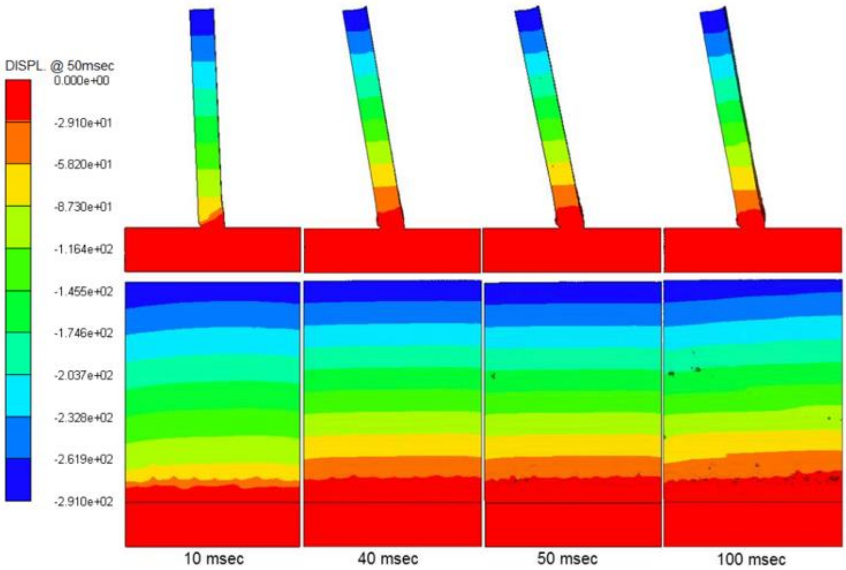


Figure 7. Displacement propagation for RC-WA.

5. Conclusion

The numerical simulation with a coarser element size of 35 mm used to approximate the blast impact on the RC wall indicated an acceptable result for the preliminary assessment. The mesh dependency assessment indicated the most suitable element size to approximate the crack pattern on the RC wall is the fine element size of 10 mm. The damage indicator appeared precisely on the steel reinforcement grid due to the smaller element size compared to the coarse element of 35 mm. The numerical simulation also implies that the best arrangement is hooked-in and tied-outside of vertical steel and horizontal steel, respectively for the RC wall to be subjected to blast loading. However actual blast test required to prove this preliminary numerical modelling result.

6. References

[1] Castedo R, Segarra P, Alanon A, Lopez L M, Santos A P and Sanchidrian J A 2015 *Int. J. of Impact Engineering* **86** 1419

IOP Conf. Series: Earth and Environmental Science **682** (2021) 012039 doi:10.1088/1755-1315/682/1/012039

[2] Thiagarajan G, Kadambi A V, Robert S and Johnson C F 2015 *Int. J. of Impact Engineering* **75** 162
[3] Alengaram U J, Mohottige N H W, Wu C, Jumaat M Z, Poh Y S and Wang Z 2016 Construction and Building Materials **116** 391
[4] Jian L, Chengqing W, Chunguang L, Wenxue D, Yu S, Jun L, Ning C, Fan Z, Lan D, Qingfei M and Jiabao P 2019 *Construction and Building Materials* **197** 533
[5] Fei Y, Wanhui F, Lin J, Bing Y and De C 2019 *Construction and Building Materials* **198** 423
[6] Yan D, Chen G, Baird J, Yin H and Koenigstein M 2011 *Proc. of the Structure Congress (Nevada)* p1538
[7] Radek H, Marek F and Josef F 2016 *Construction and Building Material* **120** 54
[8] Chao L S, Dan L and Bo Y 2019 *Int. J. of Impact Engineering* **132**
[9] Dua A, Braimah A and Kumar M *Engineering Structures* **205**
[10] TNB 2006 *Contract No. TNB 342/2006 Supply, erect & commissioning of 132 kV and 33 kV switchgear and ancillary equipment and associated civil works for PMU Teluk Kalong (Kuala Lumpur)*
[11] TNB 2005 *Contract No. TNB 586/2005 Supply, erect & commissioning of 132 kV and 11 kV switchgear and ancillary equipment complete with associated civil works at transmission main intake substation in eastern region (Kuala Lumpur)*
[12] Demetris N, Antonis K, Pericles S and Micheal P 2015 *Construction and Building Materials* **95** 566
[13] Li J, Wu C, Hao H, Su Y and Li X Z 2017 *Int. J. of Impact Engineering* **110** 242
[14] Kong X, Qi X, Gu Y, Lawan I A and Qu Y 2018 *Construction and Building Materials* **178** 244
[15] Jin M, Hao Y and Hao H 2019 *Int. J. of Impact Engineering* **131** 238
[16] Zhao C, Wang Q, Lu X, Huang X and Mo Y L 2019 *Engineering Structures* **199**
[17] Kumar V, Kartik K V and Iqbal M A 2020 *Engineering Structures* **206**
[18] Riedel W, Thoma K and Hiermaier S 1999 *Proc. of the Int. Symp. on Interaction of the Effect of Munitions with Structures (Strausberg)* p 315
[19] Herrman W 1969 *J. Appl. Phys.* **40** 2490
[20] Johnson G R and Cook W H 1983 *Proc. of the 7th Int. Symp. on Ballistic (The Hague)* p 541
[21] Seman M A, Syed Mohsin S M and Jaini Z M 2019 *Int. J. of Recent Technology and Engineering* **8** 524