Reliability Analysis of P-I Diagram Formula for RC Column Subjected to Blast Load

Masoud Abedini, Azrul A. Mutalib, Shahrizan Baharom, and Hong Hao

***Abstract*—**This study was conducted published to investigate there liability of the equation pressure-impulse (PI) reinforced concrete column in previous studies. Equation involves three different levels of damage criteria known as D =0.2, D =0.5 and D =0.8. The damage criteria known as a minor when 0-0.2, 0.2-0.5 is known as moderate damage, high damage known as 0.5-0.8, and 0.8-1 of the structure is considered a failure. In this study, two types of reliability analyzes conducted. First, using pressure-impulse equation with different parameters; the parameters involved are the concrete strength, depth, width, and height column, the ratio of longitudinal reinforcement and transverse reinforcement ratio. In the first analysis of the reliability of this new equation is derived to improve the previous equations. The second reliability analysis involves three types of columns used to derive the PI curve diagram using the derived equation to compare with the equation derived from other researchers and graph minimum standoff versus weapon yield Federal Emergency Management Agency (FEMA). The results showed that the derived equation is more accurate with FEMA standards than previous researchers.

***Keywords*—**Blast load, RC column, P-I curve, Analytical formulae, Standard FEMA.

I. Introduction

An easy way to illustrate structure response when subjected to blast load is the pressure-impulse diagram form (PI). This P-I diagram combines the two magnitudes with periods of blast load of linking the blast loads and the level of damage, where it can readily be used for rapid damage assessment of structures subjected to different blast scenarios. Shi et al. [6] have carried out numerical simulations to develop the PI diagram for concrete under blast load. Damage index is defined based on the residual axial load capacity borne because the main function of the column is to carry the vertical load. Numerical study of FRP strengthened RC column response to blast load is still limited. No general relation between explosive damage of RC columns with various FRP strengthening measures and blast loading conditions is available for a reliable and quick assessment of column performance under blast loadings. Most of the previous studies concentrate on the level of blast load that can be sustained by a particular FRP strengthened RC column [1]-[3], [7]-[10].

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Concrete structures subjected extreme dynamic loads such as blast and impact are important as a consideration in producing the analysis and design to enhance the safety of a structure. There are two studies done before about the blast load to produce P-I diagrams. The first study is done by Shi et al. [6], while the second study by Mutalib & Hao [9]. The study was published formula to be applied in drawing a P-I diagram. In this study, there reliability analysis should be performed using both the formulas produced from previous studies to obtain a value that is more accurate. If needed, derive a new formula to be used to generate P-I diagram.

II. P-I Equation for RC Column

To construct P-I diagrams of RC columns of different parameters with or without FRP strengthening, the above numerical results are used to derive empirical formulae to predict P_0 and I_0 as functions of column parameters. The empirical formulae are derived using multivariate non-linear regression (curve fitting) method. The regression model consists of nine independent variables that are columns width b, depth d, height H and FRP wrap thickness twrap, all in mm, concrete fcu, FRP strip strength fstrip and FRP wrap fwrap strength, all in MPa, and longitudinal and transverse reinforcement ratio ρ and ρ_s. The empirical formulae were derived by the authors and had been published [9].

III. Damage Criteria

Deterioration of the axial load-bearing capacity is appropriate to assess the damage of shear RC columns and flexural damage. It is also a parameter that directly relates the overall nature and functions of the RC columns, and easily obtained from numerical simulation or experimental studies. Damage index is defined as follows:

$$D = 1 - \frac{Presidual}{Pdesign} \quad (1)$$

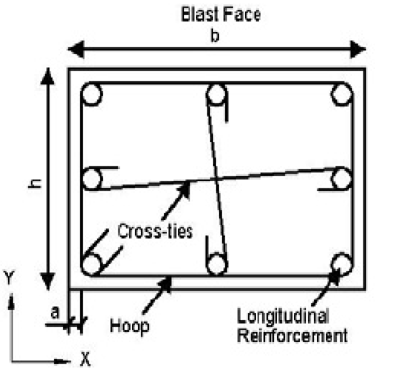
where $p_{residual}$ is the residual axial load-carrying capacity of the damaged RC column and P design is the maximum axial load carrying capacity of RC column.

The damages can be classified as follows:

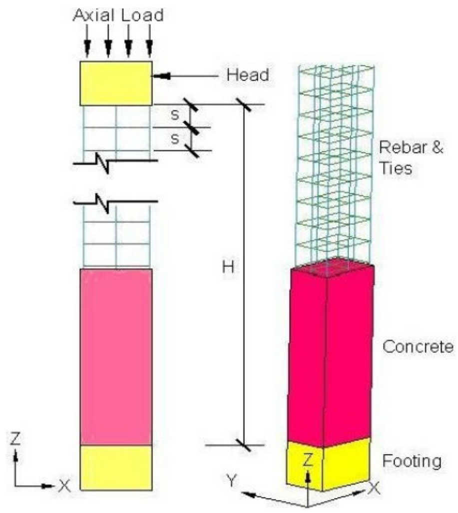
D =(0-0.2)minor damage
D =(0.2-0.5)medium damage
D =(0.5-0.8) high damage
D =(0.8-1)collapse

IV. The RC Column Configuration

In this study, rectangular RC columns normally designed for low to medium rise building are analyzed. The unstrengthened RC column is designated as C1. The details of the column are shown in Fig. 1 where H, b, h, s and a respectively represent the height, width, depth, spacing and cover depth of the RC column.



(a)Cross sectional of column



(b) Details of column

Fig. 1 RC column C1

Equations of Mutalib & Hao [9]:

$$P_0(0.2)=7.25f_{cu}+2.37d-0.147H-0.414b+7342.47\rho+10073.44\rho_s+\alpha_1 \quad (2)$$

$$I_0(0.2)=25f_{cu}+7.289d-0.158H-0.168b+19261.3\rho+44864.881\rho_s-2398.62+\alpha_2 \quad (3)$$

$$P_0(0.5)=2f_{cu}+3.174d-0.217H-0.445b+15786.72\rho+18137.95\rho_s+210+\alpha_3 \quad (4)$$

$$I_0(0.5)=27.5f_{cu}+9.75d-0.168H-1.776b+13121.77\rho+29433.94\rho_s-1848.178+\alpha_4 \quad (5)$$

$$P_0(0.8)=11f_{cu}+3.456d-0.268H-1.552b+14753.44\rho+8924.068\rho_s+851.90+\alpha_5 \quad (6)$$

$$I_0(0.8)=59f_{cu}+13.16d-0.43H\ 0.26b+1091.78\rho+489.97\rho_s\ 3302.33+\alpha_6 \quad (7)$$

V. Procedure Reliability Analysis

Reliability analysis is divided into two analyses: First, using different parameters on the equation pressure-impulse asymptote by 62 different parameters of the equation Mutalib & Hao [9]. From the results obtained from numerical analysis, researchers Mutalib & Hao [9], corrections and improvements were carried out on the equation. This analysis was conducted using 62 different parameters to the equations that have been made for improvement.

Secondly, the new equation will be used for three different types of column. Each column has a different parameter of size (450x450) mmmarked as C1, sized (550x550) mmmarked as C2 and sized (650x650) mmmarked as C3. Based on the equations derived in this study and the equations published by Shi et al. [6], three types of selected columns will be used both equations to determine the asymptotic values of pressure and impulse of the column. From the data obtained, the asymptotic value is used to form a PI curve diagram. Figure a minimum stand off against the weight of explosive charge designed to use the PI curve diagram on the extent of damage D =0.8 to compare with standard FEMA.

VI. Results and Discussion

A. Analysis of Different Parameter

Different parameters are used in this study. This parameter used in equation of pressure and impulse asymptote developed by Mutalib & Hao [9]. Then, result error occurs in the equation being compared with result error occur in the new equation. If new equation can provide less error occur in equation provided by Mutalib & Hao [9], then this equation can be used as improve of equation of Mutalib & Hao [9].

By getting data from researcher, new equations are derived using Multivariate linear regression being used to get which one is more less error occurs. This is new equations:

$$P_0(0.2)=5.75f_{cu}+2.096h-0.182H-0.6b+6992.365\rho+8203.56\rho_s+461.19 \quad (8)$$

$$I_0(0.2)=25f_{cu}+6.775h-0.188H-0.5b+15937.82\rho+37922.543\rho_s-1759.12 \quad (9)$$

$$P_0(0.5)=9.42f_{cu}+2.79h-0.227H-0.675b+13510.54\rho+12840.65\rho_s+329.15 \quad (10)$$

$$I_0(0.5)=27.5f_{cu}+9.44h-0.287H-2b+11223.667\rho+29813.035\rho_s-1010.112 \quad (11)$$

$$P_0(0.8)=3.37f_{cu}+3.112h-0.27H-1.694b-12962.314\rho+4523.527\rho_s+1452.97 \quad (12)$$

$$I_0(0.8)=38f_{cu}+14.875h-0.5H-0.125b+7142.857\rho+27777.78\rho_s-3249.762 \quad (13)$$

TABLE I
RESULT ERROR OCCURS USING A DIFFERENT FORMULA BEING DERIVE

Parameter	Concrete Strength, f_{cu}		Depth, d		Height, H		Width, b		Longitudinal Reinforcement Ratio, ρ		Transverse Reinforcement Ratio, ρ_s	
Researcher	M*	I**	M	I	M	I	M	I	M	I	M	I
Total analysis	6		14		6		14		11		11	
Total Error	2	0	8	5	13	4	5	3	11	0	11	0

*M-Mutalib & Hao [9]; **I- Improve Equation

B. Verification with Standard FEMA and Comparison with Shi et al. [6]

Table II shows three examples of concrete column have been chosen for analysis to get the P-I curve. Based on a new formula derived, P-I curve for C1, C2 and C3 has been developed and compared with Shi et al. [6].

Using a variety of parameters is to show the equations used can be trusted. In addition, be used to compare the new equation and Shi et al. [6] and FEMA standards [4], [5]. This comparison is made to show that the equation is more accurate and more suitable for use at the present time.

TABLE II
THREE TYPES OF COLUMNS

Column	Width b (mm)	Height H (mm)	Depth h (mm)	Concrete strength f_{cu} (MPa)	Longitudinal Reinforcement ratio, ρ	Transverse Reinforcement ratio, ρ_s
C1	450	3000	450	25	0.020	0.010
C2	550	3500	550	35	0.025	0.015
C3	650	4000	650	45	0.030	0.020

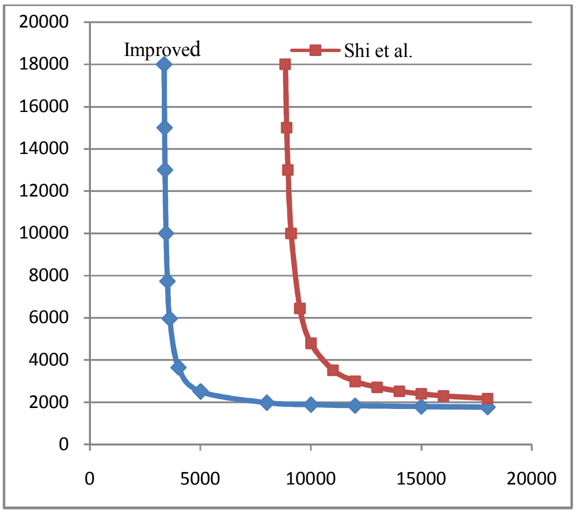


Fig. 2 P-I curve of column C1

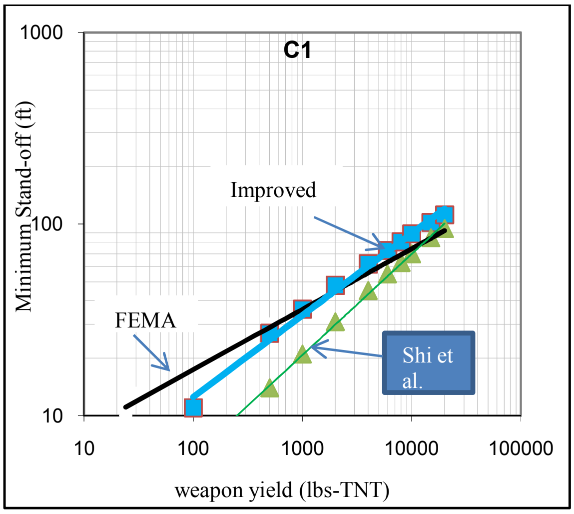


Fig. 3 Minimum standoff due to weapon yield for column C1

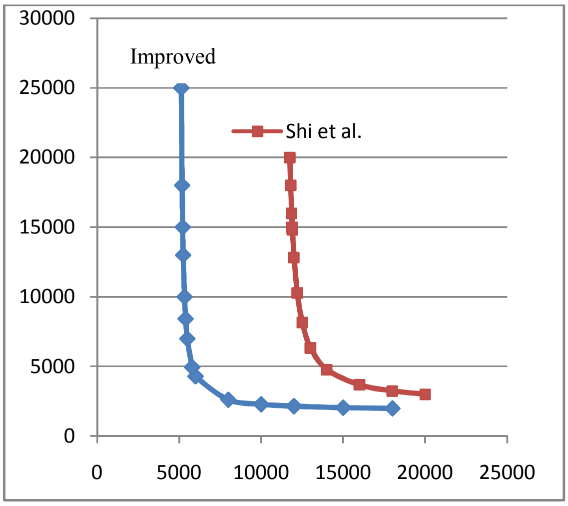


Fig. 4 P-I curve of column C2

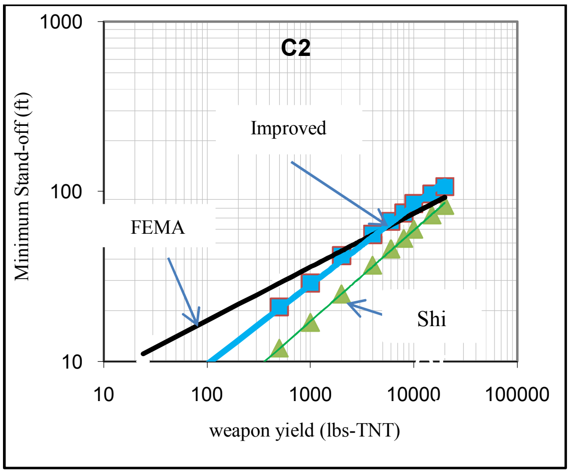


Fig. 5 Minimum standoff due to weapon yield for column C2

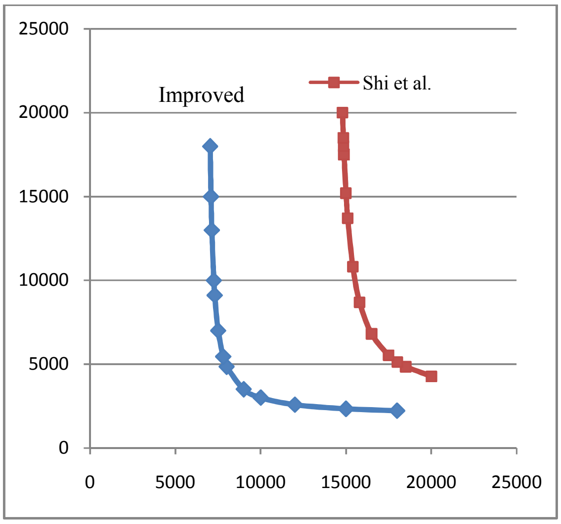


Fig. 6 P-I curve of column C3

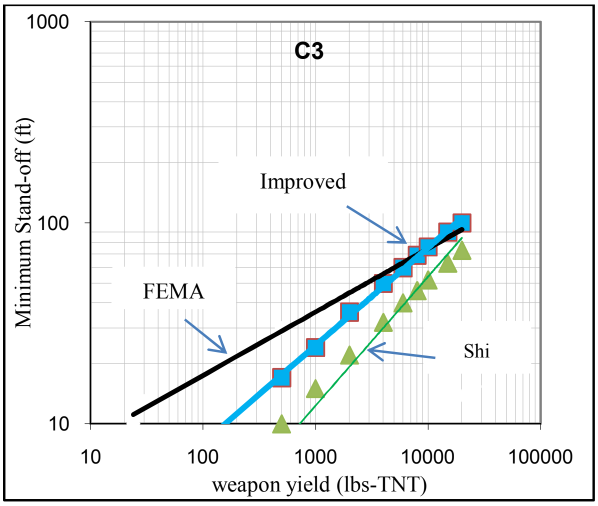


Fig. 7 Minimum standoff due to weapon yield for column C3

Figs. 2, 4, and 6 show the PI curves generated using the equation of Shi et al. [6] and improved equation of pressure and impulse asymptotic value for all three types of columns at the level of damages D =0. 8. The findings showed that the equation of Shi et al. [6] has a sumptuous value the three types of columns are higher than using an improved equation. The highest difference is the asymptotic pressure value using the equation of Shi et al. [6] compared using a modified equation. While the asymptotic value of the impulse for both equations is very close.

Figs. 3, 5, and 7 show the analysis of concrete damage threshold C1, C2 and C3 compare values between FEMA, the improved formula and formula Shi et al. [6]. Damage threshold of the two formulas is a lower damage threshold than the threshold set by FEMA damage on impulsive load. But it is different in the quasi-static load conditions, where the threshold of degradation is higher than the threshold value of damage to FEMA.

VII. Conclusion

Selection of appropriate parameters for column structure is important to ensure maximum safety when dealing with any risk explosive which is likely to occur. Therefore, the equation derived from previous researchers with respect to pressure and impulsive asymptotes to get the pressure that can be borne by the structural column before failure. PI curve diagram formed at the level of damages D =0.8 was chosen because of concrete with a pressure and impulse more than in of PI curve D=0.8 is considered a failure. While the pressure and impulse values lower than the curve calculated PI are damaged but still no failure. The new equation derived shown that there is a reduction of the error terms. Derived equation, the tested reliability and found to comply with FEMA standards. When a comparison is made using PI diagram equation of Shi et al. [6] and a new equation, shows that causing a new equation is more accurate with FEMA standards.

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REFERENCES

[1] Crawford J. E., Malvar L. J., Morrill K. B., Ferritto J. M, "Composite retrofits to increase the blast resistance of reinforced concrete buildings,"*In: Proceedings of the 10th international symposium on interaction of the effects of munitions with structures. San Diego, USA*. hlm. 1–13,2001.

[2] Crawford JE, Malvar LJ, Kenneth BM, "Reinforced concrete column retrofit methods for seismic and blast protection,"In: Proceeding of the SAME National Symposium on Comprehensive Force Protection, Charleston, SC, 2001.

[3] Crawford JE, Malvar LJ, Wesevich JW, Valancius J, Reynolds AD, "Retrofit of reinforced concrete structures to resist blast effects,"ACI Structural Journal;94(4):371e7,1997.

[4] FEMA-427, "Risk Management Series: Primer for Design of Commercial Building to Mitigate Terrorist Attacks,"Applied Technology Council (ATC) and Eve Hinman, Hinman Consulting Engineers,2003.

[5] FEMA-428, "Risk Management Series: Primer for Design of Commercial Building to Mitigate Terrorist Attacks,"Applied Technology Council (ATC) and Eve Hinman, Hinman Consulting Engineers, 2003.

[6] Shi Y, Hao H, Li ZX, "Numerical derivation of pressure-impulse diagrams for prediction of RC column damage to blast loads,"International Journal of Impact Engineering;35:1213e27, 2008.

[7] Malvar L.J., Crawford J.E., Wesevich J.W., Simons D, "A plasticity concrete material model for DYNA3D," *InternationalJournal of Impact Engineering* 19: 847-873,1997.

[8] Muszynski LC, Purcel MR, Sierakowski R, "Strengthening concrete structures by using externally applied composite reinforcing material," In: Proccedings of the seventh international symposium on interaction of the effects of munitions with structures, Germany,1995.

[9] Mutalib A. A. and Hao H, "Development of P-I diagram for FRP strengthened RC columns,"*International Journal of Impact Engineering* 10(38): 290-304,2011.

[10] Wood BH, "Experimental validation of an integrated FRP and visco-elastic hardening, damping and wave-modulation system for blast resistance enhancement of RC columns,"Rolla, Missouri, US: Missouri University of Science and Technology,2008.