Empirical Formula Prediction on Critical Impact Energy for Scabbing Phenomena on Concrete Structures

Ismail Abdul Rahman
Faculty of Civil and Environmental Engineering,, Universiti Tun Hussein Onn Malaysia
86 400 Parit Raja, Johore, Malaysia
E-mail: ismailar@uthm.edu.my

Ahmad Mujahid Ahmad Zaidi (Corresponding author)
Faculty of Engineering, National Defense University of Malaysia
57 000 Kuala Lumpur, Malaysia
E-mail: mujahid80s@yahoo.com

Qadir Bux alias Imran Latif
Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia
86 400 Parit Raja, Johore, Malaysia
E-mail: imranqazi37@gmail.com

Muhammad Yusof Ismail
Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia,
86 400 Parit Raja, Johore, Malaysia
E-mail: yusofi@uthm.edu.my

Abstract

Concrete is basic construction material used for numerous sort of structure. However, in the mainstream crucial structures have to be designed as self-protective such as nuclear plants, Power plants, Weapon Industries, weapons storage places, water retaining structures like dams, & etc., which provides protection against any tragedy incident or intentionally produced horrible incidents such as dynamic loading, incident occurs in nuclear plants, terrorist attack, war, missile attack, and etc. This paper questioningly is paying concentration on judgment on minimum required kinetic energy for scabbing on the concrete structures generated by flat nosed hard missile using curve fitting empirical study. Argue overcome from this newly developed empirical formula can be used for making design recommendations and design procedures for determining the dynamic reaction of the target to frustrate scabbing.

Keywords: Scabbing, Concrete, Critical, Kinetic energy, Empirical, Flat nose, Hard missile

1. Introduction

Over the years, concrete is very commonly used construction material for the defensive and civil applications to protect structures from local and explosive impact loads. The effects of the local impact of hard missile on concrete structures have been studied since the mid of 17th century because of continuous military interest in designing high performance missiles and high performance protective barriers. Projectile exists in a long range with variation in sizes, shapes, velocity, weight, density, hardness, such as bullets, fragments, tornado, bomb, missile etc. The projectile may be classified as 'Hard' and 'Soft' depending upon deformability of projectile with respect to target's deformation. Deformation of hard missile is considerable smaller or negligible compared with target's deformation. Almost in all cases hard missiles are considered as non – deformable or rigid. However, 'Soft' missile deforms itself considerably well as compared to target's deformation. Interest is focused on scabbing of local damage of target caused by 'Hard' missiles. Local impact effect is briefly sub-divided in below explained processes:

<Figure 1>

Radial Cracking: When projectile colloids with concrete target with certain velocity, it results radial cracks originated from the point of impact within the target in every direction.

Spalling: The ejection of material of target from front face (impacted face) due to impact of hard projectile is called spalling. Spalling produces spall crater in the surrounding area of impact. Spall crater is the total damaged portion of peeling off material from target on impacted face.

Penetration: Penetration is defined as the digging of missile into the target body afar from the thickness of spall crater. The lengthwise measurement of dig is called penetration depth.

Cone cracking & Plugging: During penetration missile colloids with rear border of target and generates curved shear cracks in the shape of bell plug is called cone cracking. And than missile continues penetrating through target, it forces plug and shears-off the surrounding material of target is called plugging. This process generates rapid change into the behavior of target.

Scabbing: Ejection of target material from back face of target is called scabbing.

Perforation: Perforation means complete passage or complete crossing of projectile through the target. It causes missile to extend penetration hole through scabbing crater and exit from the rear face of target.

Nomenclature

d	(cylindrical) projectile shank diameter.
E	Young's Modulus of Elasticity.
E_k	Impact kinetic energy of the projectile.
E_c	Critical impact energy of projectile.
E_{cs}	Critical impact energy of the projectile for scabbing.
f_c	Quasi-static uni-axial compressive strength of concrete target.
f_t	Quasi-static uni-axial tensile strength of concrete target.
H	Concrete target thickness.
M	Mass of the projectile.

The local impact effect of hard missile on concrete structures can be studied by three ways, (i). Empirical Studies (predict empirical formula based on experimental data), (ii). Analytical Studies (create formula based on physical laws and compared with experimental data), and (iii), Numerical Simulation (based on computer based material model generate results and compared with experimental data). This study is based on empirical formula predicted by using curve fitting data method.

2. Critical Impact Energies and Non-dimensional Number Analysis

It is important to consider the mechanics of the impact processes and thus deduce the relevant non-dimensional numbers that could be involved in scabbing analyses.

When a non-deformable, flat-nosed projectile strikes a concrete target, scabbing could occur due to the reflection of the impact-induced compressive stress wave from the distal free surface of the target. This occurs in a much shorter time than complete perforation or the overall structural response. Therefore, the scabbing limit, i.e., the minimum target thickness to prevent scabbing, is generally defined by:

$$h_s = G\ (M,\ V_o,\ d,\ \rho,\ f_c,\ f_t, E) \tag{1}$$

Where ρ, E and f_c and f_t are the density, Young's modulus and unconfined compressive and tensile strengths (stresses) of the concrete target, respectively. M and V_o are the mass and the initial impact velocity of a projectile and d is the (cylindrical) projectile shank diameter. A dimensional analysis for scabbing of concrete targets based on Eq. (1) leads to:

$$\frac{h_s}{d} = G\left(\frac{E_k}{f_c d^3}, \frac{M}{\rho d^3}, \frac{f_t}{f_c}, \frac{E}{f_c}\right) \tag{2}$$

Where $E_k = (½)MV_o^2$ is the kinetic energy of the missile. Although the scabbing limit is normally selected as a design parameter in empirical formulae, the critical impact velocity to cause scabbing for given target thickness is another important parameter associated with scabbing. Some empirical formulae for critical impact energy are formulated for the onset of scabbing. When $h_s = H$ in Eq. (2), the critical impact energy can be expressed by:

$$\frac{E_c}{f_c d^3} = G\left(\frac{M}{\rho d^3}, \frac{H}{d}, \frac{f_t}{f_c}, \frac{E}{f_c}\right) \tag{3}$$

Where H is the thickness of the concrete target and $E_c = ½\ MV_c^2$. For a given target, f_t/f_c and E/f_c may be considered as constants.

2.1 New Empirical Formula

Empirical formulae based on experimental data are especially important in this field due to the complexity of the phenomena. These empirical formulae, e.g., for penetration depth, the scabbing and perforation limits, are often formulated by curve fitting test data, and thus, their validity is only guaranteed in their valid application range.

The new empirical formula for calculation of required critical energies for scabbing on concrete targets based on H/d is developed by using the linear equations. The formula is sub divided into three ranges. The basic equation for the derivation of formula, the equation of straight line is used on more than 75 experimental work data on scabbing.

The basic linear eq. for straight line is:

$$y = mx + b \tag{4}$$

Where y shows the value how far up in y – direction, x shows the value how far along x – direction, m is the slope or gradient of straight line, and b the y – intercept (where the line crosses y axis).

Where

$$m = \frac{y_2 - y_1}{x_2 - x_1} \tag{5}$$

Where $y_2 - y_1$ is change occurs in y direction, and $x_2 - x_1$ change occurs in x – direction respectively.

Based on eq. (4) the general equation for required energies to scab the concrete target is:

$$\frac{E_{cs}}{f_c d^3} = m\frac{H}{d} + b \tag{6}$$

Where E_{cs} is required kinetic energy of missile for scabbing of concrete target, f_c is unconfined compressive stress of concrete, d is (cylindrical) projectile shank diameter, and H is total thickness of concrete target.

Based on eq. (6) the critical impact kinetic energy required for scabbing of concrete target is:

$$\frac{E_{cs}}{f_c d^3} = 0.87\frac{H}{d} - 0.29 \quad \text{For } \left(0.69 \le \frac{H}{d} \le 3.0\right) \tag{7}$$

$$\frac{E_{cs}}{f_c d^3} = 3.31\frac{H}{d} - 7.58 \quad \text{For } \left(3.0 < \frac{H}{d} \le 6.0\right) \tag{8}$$

 ISSN 1916-9639 E-ISSN 1916-9647

$$\frac{E_{cs}}{f_c d^3} = 4279.18\frac{H}{d} - 25662.82 \quad \text{For } (6.0 < \frac{H}{d} \leq 14.86) \tag{9}$$

The above non – dimensional eqs. (7), (8), and (9) can be used within there applicable given range depend on (H/d) for the prediction of kinetic energy required for scabbing of concrete target.

3. Result and Discussion

The newly developed formulae examined for the prediction of minimum required critical kinetic energy of hard missile to scabb the concrete target. In all three cases (i) $0.69 \leq H/d \leq 3.0$, (ii) $3.0 < H/d \leq 6.0$, (iii) $6.0 < H/d \leq 14.86$, results obtained from newly developed formulae is relatively closer as compared to the experimental results. However the prediction obtained by using UMIST empirical formula, NDRC formula, and Semi Empirical Formula are less accurate as compared to the results obtained from newly developed formula.

The predictions based on these four formulae have been compared with the experimental data. The main results are summarized here. It is found that the UMIST formulae predict the lowest values of the impact energy for scabbing compared with other three groups of empirical formulae. The predicted results are consistently lower than the experimental results. Although overall predictions based on both NDRC and semi-empirical formulae are closer to experimental data than those based on UMIST formulae, also the NDRC and semi-empirical formulae sometimes overestimate the critical impact energy for the scabbing of concrete target.

Among all these four formulae the newly developed formula gives more relatively close results as compared to other formulae. The significant of this formula found in the third case when $6.0 < H/d \leq 14.86$, the huge difference found in comparison between the results obtained from newly developed formula and results obtained from UMIST, NDRC, and Semi empirical formula. However the newly developed formula predicts very close and relatively accurate results, as compared to other formulae.

Almost all empirical formulae for the prediction of local impact effects of hard missile concrete on concrete targets have their specific range of parameters, and the validity of empirical formulae are only guaranteed in their application range. Like other empirical formulae, this formula also can be used within the range of $0.69 \leq H/d \leq 14.86$, $24.15 \leq f_c \leq 50.20$ (MPa), $17.50 \leq d \leq 305.00$ (mm), $0.92 \leq M \leq 309.00$ (kg), $28.98 \leq Vo \leq 427.00$ (m/sec), $50.80 \leq H \leq 609.60$ (mm), for normal impact caused by flat nose hard missile on concrete targets.

4. Conclusion

The influence of the relative target thickness (H/d) on the critical impact energies, at which scabbing in concrete targets may be initiated by hard missile, has been investigated in this paper. A new empirical formula developed for critical impact energies for scabbing of concrete target, divided in three cases. The results obtained from new formula are also compared with other empirical formulae likes of UMIST, NDRC and Semi Empirical formula. Since UMIST formulae have been verified by a large collection of experimental data conducted by nuclear industries, and NDRC formulae have a long history and wide range of applications, they are recommended as the most appropriate formulae for the preliminary impact design of concrete targets in nuclear facilities. However the results obtained from newly developed formula shows significant difference and the results of newly developed formula are relatively closer to the experimental results as compared to the other formulae especially in the third case.

References

BNFL. (2003). Reinforced concrete slab local damage assessment. R3 impact assessment procedure, Appendix H, vol. 3. Magnox Electric plc & Nuclear Electric Limited.

Kennedy RP. (1976). A review of procedures for the analysis and design of concrete structures to resist missile impact effects. *Nucl. Eng. Des*, 37:183–203.

Li QM, Chen XW. (2003). Dimensionless formulae for penetration depth of concrete target impacted by a non-deformable projectile. *Int J Impact Eng*, 28(1):93–116.

Li QM, Reid SR, Ahmad-Zaidi AM. (2006). Critical impact energies for scabbing and perforation of concrete target. *Nucl Eng Des*, 236:1140–8.

Li QM, Reid SR. (2005). Wen HM, Telford AR. Local impact effects of hard missiles on concrete targets. *Int J Impact Eng*, 32(1–4): 224–84.

NDRC. (1946). *Effects of impact and explosion.* Summary Technical Report of Division 2, vol. 1, National Defence Research Committee, Washington, DC.

Riera JD. (1989). Penetration, scabbing and perforation of concrete structure hit by solid missile. *Nucl Eng Des,* 115:121–31.

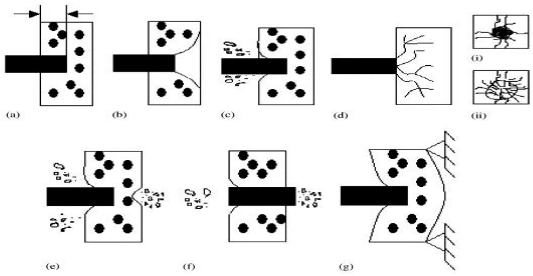

Figure 1. Explains the local impact phenomena caused by hard projectile. (a) Penetration, (b) Cone cracking and Plugging, (c) Spalling, (d) Radial cracking, (e) Scabbing, (f) Perforation, and (g) Global phenomena

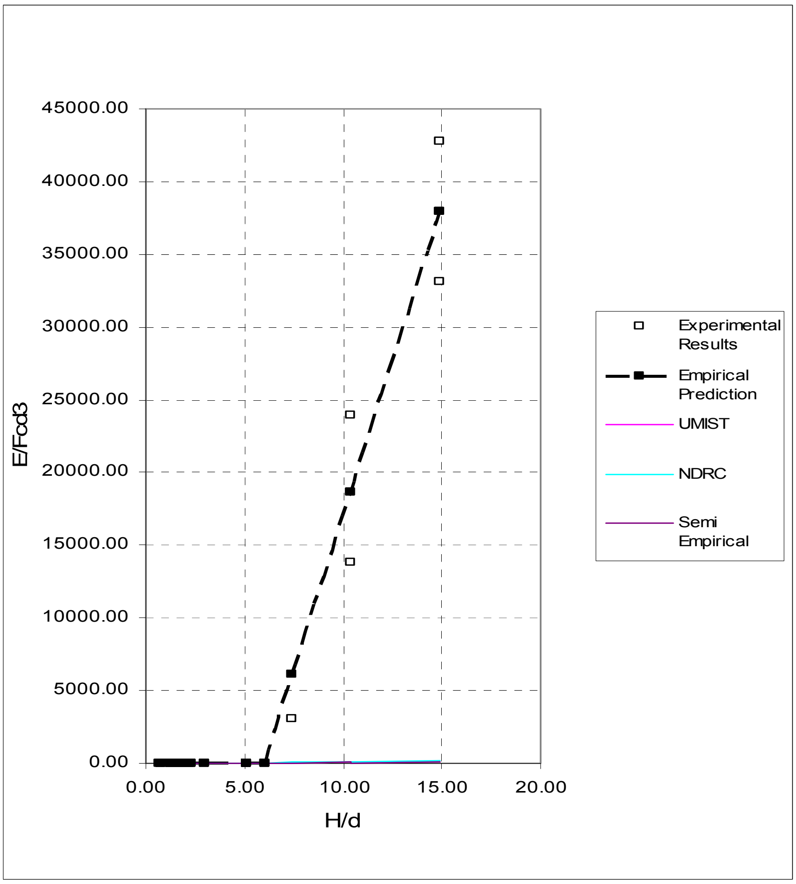

Figure 2. Shows the results of newly developed formula and comparison with prediction of other formulae

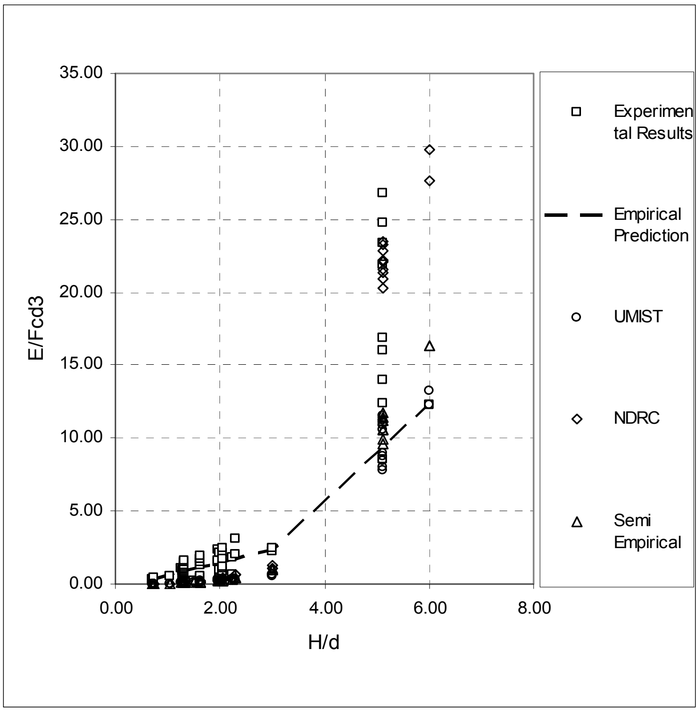

Figure 3. shows the results of newly developed formula and comparison with prediction of other formulae within the range of $0.69 \leq H/d \leq 6.0$

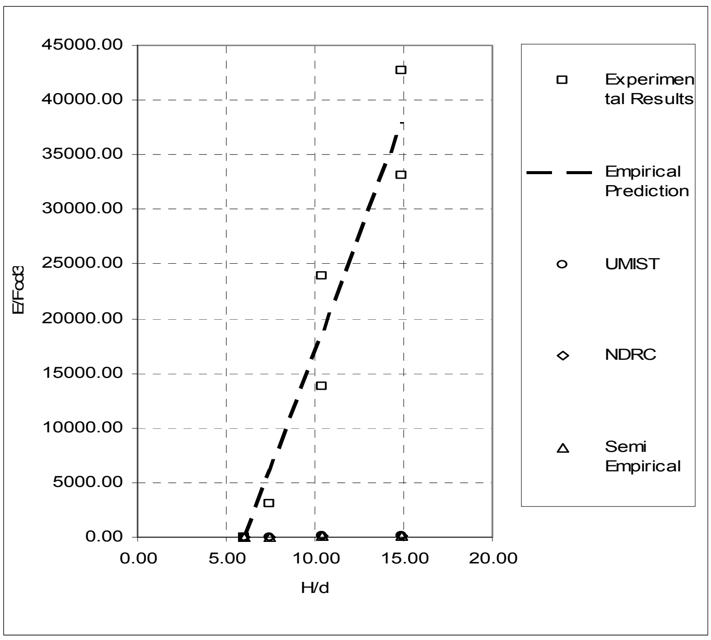

Figure 4. shows the results of newly developed formula and comparison with prediction of other formulae within the range of $6.0 < H/d \leq 14.86$