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Penetration Depth Local Effect Of Impactors On Concrete Structures

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Abstract

Available formulae for predicting the penetration depth of concrete structures impacted by solid missile are summarized and reviewed. Based on statistical analysis of existing data, a new formula have been proposed for predicting the penetration depth of concrete structures due to impact by solid missiles.

The new equation for penetration depth of concrete structure impacted by solid missiles is applied for non-reinforced concrete structures, which give good result with experimental study and is compared with other research results to check its validity, this equation includes: missile parameters which are weight of missile(W), diameter of missile(d),Velocity of missile(V) and Target parameters which are concrete member thickness(t),and concrete member strength (fc').

الخلاصة:

الصيغ المتوفرة لايجاد عمق النفاذية للمنشأت الكونكريتية المتعرضة لقذيفة صلبة تم تلخيصها وعرضها. بالاعتماد على التحليل الاحصائي للمعلومات المتوفرة, تم ايجاد معادلات رياضية جديدة لعمق النفاذية للمنشات الخرسانية المتعرضة لقذائف صلبة.

المعادلة الجديدة تتضمن ايجاد عمق النفاذية للمنشأت الكونكريتية المتعرضة لقذيفة صلبة تطبق للمنشات الخرسانية الغير مسلحة, والتي اعطت نتائج جيدة مع نتائج الفحوصات المختبرية وايضا تمت مقارنتها مع بحوث أخرى لتدقيق صلاحيتها, هذه المعادلة تتضمن معاملات القذيفة والتي هي, وزن القذيفة, قطر القذيفة, سرعة القذيفة, ومعاملات الهدف هي سمك العضو الخرساني ومقاومة العضوالخرساني.

Introduction:

Normal concrete walls in certain types of structures need to be designed to withstand impact by accidently-generated flying objects referred to as missiles. For example, the missiles considered in nuclear facility design include tornado-borne debris and fragments from failed rotating machinery walls must be sufficiently thick to prevent an impacting missile from ejecting pieces of concrete from the back surface (scabbing), or completely perforating the wall. Such damage in the vicinity of the impact is called "local impact Response"[(1)].

Local impact response of normal Concrete is characterized by intense dynamic stresses that Produce crushing. Cratering, shear failure and tensile fractures in a highly nonhomogeneous material. Because of complex nature of this response, detailed analysis by means of computational mechanics are not yet developed enough for application in the design of nuclear power facilities and other structures for local impact effects, therefore design need to rely on empirical formulae. In general, the formula are derived from a single test program covering a limited range of Impact parameters.

The intention is to apprise designers of easy and accurate formulas available at present and to provide researches in this area with a ground work for developing more accurate design methods. Data had been generated exclusively in the field of military ballistics. The missile were solid circular cylinder with variously shaped noses and were underformable.

They had velocities less than 350m/s where nonrotating, and impacted with the longitudinal axis of symmetry along the line of flight. In nearly all the tests, the line of flight was normal to the target surface. Therefore, several empirical formula derived from these data are strictly applicable only for these impact parameters, among the most commonly used of these formula are the Ammann and Whitney formula, Army corps of Engineers formulas, and National Defense Research Committee (NDRC) formula.

Impact Effect:

Effect of Impact of solid missiles on concrete structure can be classified in to local effects and global dynamic response of the structure. If the kinetic energy transmitted through the zone of impact by the missile is considerably smaller than the strain energy capacity of the structure, the local effects will probably be the governing consideration. This paper is concerned with local effects of solid missile impact on concrete structure [(2)].

The local effect process is influence by many parameters. These parameters can be classified into two groups, missile parameters and target parameters.

Missile Parameters

- Weight of the missile (W).
- Size of the missile, e.g., the diameter if it is cylindrical (d)
- Velocity of the missile (V). Target Parameters
- Concrete compressive strength (fc').
- Target thickness (t).
- Steel reinforcement ratio (p). depending upon whether the missile def-ormablilty is small or large relative to the target deformability, the impacting missile can be classified as either "hard" or "soft". When the impacting missile is so stiff that its deformability is negligible to the target deformability, the missile is considered to be a hard missile when the missile deformability is moderate (e.g. pipe), or high (e.g. wooden poles) compared with the target deformability, the missile considered to be a soft missile. This paper is basically concerned with hard (solid) cylindrical missiles.

Available formula for local Concrete damage prediction [2,3,4,5]:

A- Ammann and Whitney formula the following formula has been developed to predict the penetration depth of small explosively generated concrete fragments traveling over 1000 ft/s.

$$X/D= (282\ KWV^{1.8})/(D*fc^{0.5}*(1000D)^{1.8} \text{ ......(1)}$$

B- Army Corps of Engineers Formula calculated In 1964, the following formula for Penetration was developed by the Army Corps of Engineers:

$$X/D=(282WV^{1.5} / D^{2.785}\ fc^{0.5} 1000^{1.5}+0.5) \text{ ......(2)}$$

Where;

D is the diameter of the missile in inches

W is the weight of the missile in pounds

fc' is the compressive strength of concrete in Psi V missile velocity in ft/sec^2.

C- Modified National Defense Research Committee (NDRC) Formula: In 1946, the National Defense Research Committee (NDRC) proposed the following formula for predicting the penetration depth:

$$X/D=(4KK_1WV^{1.8}/D(1000D)^{1.8})^{0.5} \text{ .....(3)} \quad \text{for } X/D \leq 2.0$$

$$X/D= 1.0 + (KK_1WV^{1.8})/(D(1000D)^{1.8} \text{ .....(4)} \quad \text{for } X/D >2.0$$

Where;

K_1 is the concrete penetration factor And is given as a function of concrete strength fc' as follows:

$$K_1 = 180 / \sqrt{fc'} \qquad (5)$$

K is the missile nose shape factor. 1.0 for average bullet nose (spherical end), 0.84 for blunt nosed bodies and 1.14 for very sharp nose. all the above empirical formula applied only for non-reinforced structures impacted by solid missile.

Table (l) shows the data of local effect (W, D, t, V, and fc') with experimental penetration depth result and proposal penetration depth from eq. (6) and comparisons between them is presented

Table (1): Data and proposal penetration depth local response for concrete members impacted by solid missile.

Ref.	Weight (W), N	Diameter(D),mm	Velocity (V)m/sec²	Thickness (t),mm	Concrete Strength (fc'),N/mm²	Penetration depth Experimental (X),mm	Penetration depth Proposal (X) , mm	% of Error Between Xpro, Xexp
EDF[1]	3365.04	109.982	28365	299.72	37.329	299.72	294.66	4.094
	3335.63	154.94	27145	299.72	39.9303	299.72	321.77	-5.64
EDF[1]	2225	304.8	110105	398.78	40.02	398.78	422.25	-7.32
	2225	304.8	106140	398.78	40.02	398.78	420.71	-6.89
	1566.4	304.8	132980	398.78	33.534	398.78	383.04	3.32
	1882.35	304.8	122915	398.78	33.534	398.78	391.91	1.21
	2225	304.8	126880	500.38	38.502	449.58	442.52	10.18
	1882.35	304.8	143960	500.38	38.502	500.38	435.77	11.41
	2941.45	304.8	143045	599.44	36.018	599.44	476.04	19.35
	2354.05	199.89	86010	398.78	36.018	398.78	367.80	7.95
	2354.05	199.89	71980	398.78	36.018	429.26	361.32	9.71
	2941.45	304.8	89060	398.78	36.018	398.78	418.56	-5.46
CEA[2]	294.14	199.89	112850	259.08	41.0205	259.08	255.42	1.28
	489.94	199.89	111935	259.08	41.0205	259.08	277.96	-7.39
	489.94	199.89	137860	259.08	44.505	259.08	291.43	-13.94
	294.14	249.93	186965	259.08	34.017	259.08	264.87	-2.46
	549.57	277.87	101870	208.28	41.538	208.28	289.14	-39.42
BEC[2]	246.08	249.93	308965	259.08	39.0195	248.92	282.65	-12.92
	952.3	203.2	65270	304.8	31.395	304.8	279.67	10.15
	947.85	203.2	103700	304.8	31.395	304.8	292.67	5.48

Where:

Weight (W) in N , Diameter (d) in mm, Velocity (V) in mm/s, Thickness (t) in mm, Concrete compressive strength (fc') in N/mm^2 and penetration depth (X) in mm.

Table (1) shows the database for missile parameters (W, d, and V) and Target Parameters (t, fc' and X) taken from researches, to make statistical analysis to it and then find new modeling for Penetration depth of unreinforced concrete member .

Statistical Analysis

Model Definition : After studying the effect of each factor on penetration depth separately the penetration depth local effect has the formula:

$$X= (W^{0.704} *D^{0.88} *V^{0.42} *t^{0.84} *fc'^{3.24})^{0.237} \quad \ldots\ldots\ldots (6)$$

And the statistical results for above formula are:

Number of observations = 20

Solver type: Nonlinear = 0.98

Nonlinear iteration limit = 250

Residual tolerance = 0.0001

Average Residual = 2.84E-12

Proportion of Variance Explained = 98.38%

Coefficient of Multiple Determination (R^2)= 0.98

Residual Sum of Squares = 7147.01

Coefficient of multiple determination (Ra^2) = 0.983

Durbin-Watson statistic = 2.37

The ratio between the penetration depth calculated from eqs.1 through 4, and present penetration depth through eq.(6) to experimental results are presented In table (2).

Table (2) shows the ratio of penetration depth for each formula to experimental results

Perty / Exp	COE / Exp	NDRC / Exp	Ammann /Exp	Pro / Exp
0.003813	0.692797	0.478454	0.244338	0.983118
0.003256	0.879731	0.686679	0.208902	1.073569
0.002964	0.685225	0.647856	0.215076	1.058855
0.002795	0.669003	0.626821	0.201336	1.054993
0.006685	1.908093	1.74168	0.485141	0.96053
0.002978	0.712528	0.687669	0.242323	0.982772
0.003276	0.678007	0.659221	0.251056	0.984296
0.00499	1.050191	1.05706	0.415757	0.870878
0.014593	2.565251	2.249469	0.982125	0.794141
0.004842	0.74612	0.648502	0.328597	0.922313
0.003293	0.58524	0.51324	0.221549	0.841728
0.00578	2.094189	1.736801	0.423354	1.049601
0.001458	0.519987	0.436135	0.096557	0.985873
0.002397	0.606607	0.558768	0.158491	1.072873
0.003292	0.675551	0.660396	0.221386	1.124865
0.001913	0.693275	0.658372	0.175981	1.022348
0.001488	0.814738	0.590951	0.102522	1.388227
0.00289	0.866333	0.951799	0.353377	1.135505
0.001522	0.513669	0.432838	0.110067	0.917552
0.003375	0.692788	0.655039	0.252082	0.960203

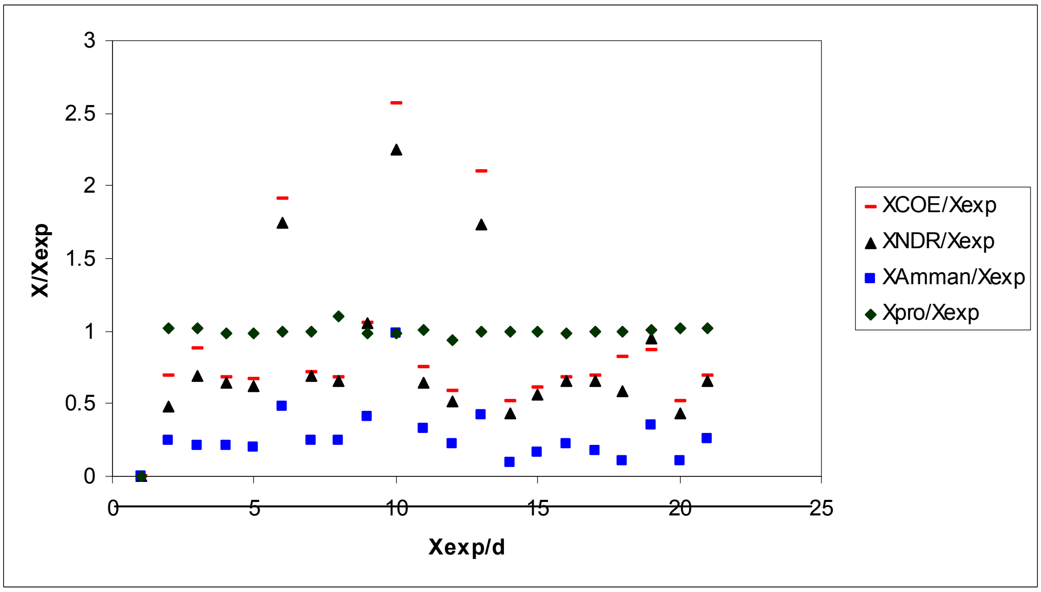

Figure1: Comparison between present proposal penetration depth and other results researches of non-reinforced concrete member for different missile diameter.

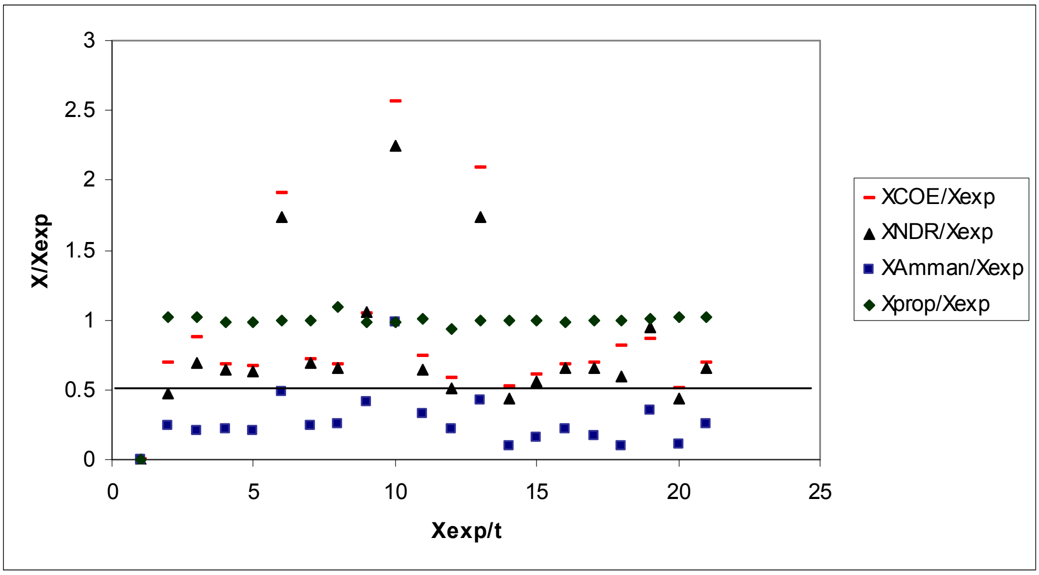

Figure2: Comparison between present proposal penetration depth and other results researches of nonreinforced concrete member for different thickness.

From table (2) and figures 2, 3 the following observation are made:

1- Perty and Ammann formulae are the a worst formula in predicting the penetration depth of concrete structure due to C.O.V about 99.6% and 71.5% respectively.

2- NDRC and COE formulae is better than perty and Ammann formulae in predicting the penetration depth due to C.O.V 16.1% and 6.7% respectively.

3- The proposed formula is more reiable than the others in predicting the penetration depth of concrete structures due to C.O.V is 0.46%

4- The ratio between the proposal to experimental penetration depth results is approaches to one.

Conclusion:

1- A new model of penetration depth for concrete member impacted by solid missile is presented.

2- The present model include the factors, missile parameter W, D, V and Target parameter t, and fc'.

$$X= (W^{0.704} * D^{0.88} * V^{0.42} * t^{0.84} * fc'^{3.24})^{0.237}$$

3- A comparison between the present penetration depth formula and others researches are presented.

4- A C.O.V between present penetration depth formula and other researches are presented.

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