IMPROVING CONCRETE INFRASTRUCTURE PROTECTION USING DIFFERENT GRID TYPES AGAINST IMPACT LOADS

***M. Majeed, *A. O. Abd El Halim, and *E. Contestable**

ABSTRACT

Protection of existing reinforced concrete structures against impact loads caused by blast has become a major concern of designers, engineers and security authorities. The release of high speed loads such as explosives can generate high pressures on the structures resulting in fragmentation that can lead to serious damage to the asset and injuries and death to people.

The main objective of this paper is to report the results of a comprehensive experimental investigation performed on reinforced concrete panels of 600 x 600 x 100 mm, retrofitted with different grids including poly-propylene, poly-ethylene and steel meshes. The testing program includes applying impact tests utilizing a falling weight test facility and fragmentation simulation using special air gun test facility.

Tests results and information including deflections, penetration measurements were gathered in addition to taking pictures and videos which were used to calculate applied and absorbed kinetic energy, penetration depth after each loading step and the weight and speed of concrete fragmentations during the tests. The results and analysis of the data and observations showed that the concrete panels retrofitted with combination of steel mesh and poly-ethylene grid provided the most promising retrofitting protection when compared with other options.

The results provide an economic and effective technique for improving the protection of existing governmental and buildings of critical importance.

KEYWORDS: **Concrete Structure, Impact, Penetration, Retrofitting,, Steel Mesh And Non- Metallic Grids.**

1- INTRODUCTION

The behavior of structures during projectile and missiles fragments attack have demonstrated that a significant damage can be imposed on structures that are designed prior to the enhancement of the modern design provisions of current building codes. These structures constitute the majority of governments and public buildings in the world, increasing the impact resistance vulnerability of our infrastructure by different retrofitting technique have gained importance in recent years as a viable terrorist risk mitigation strategy. The usual approach to protect sensitive structures is generally in the form of establishing a secure perimeter (e.g. concrete walls or other types of barriers, including security guards) at a stand-off from the structure. Although this approach can be quite effective, it still does not address the problems associated with long-range projectiles and other stand-off weapons that can be launched to directly strike the structure.

Among the options considered for structures retrofitting, a new approach has been emerging as a new technique for retrofitting existing structures. The technique involves external protection techniques that employed different type of metallic and non-metallic grids embedded in mortar and attached to the exterior side of the structures.

This paper provides information regarding this retrofitting/protection technique, the combined system (cement mortar and mesh layers) is

***Carleton University, Department of Civil and Environmental Engineering, Ottawa, Canada**

considered as a composite material, and it consists of cement mortar reinforced with layer(s) of mesh with small openings.

The experimental part of the research includes the following activities:

The development of an impact test on a series of reinforced concrete slabs with different retrofitting materials to identify the materials with highest energy absorption capacity;

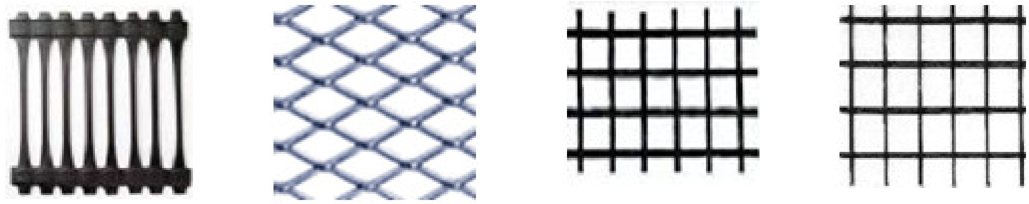
Establishing a penetration test using different bullet sizes and energy by using a shot guns and air guns;

This paper discusses: (1) Specimen preparation; (2) Impact testing of the specimens.

2- Specimens Preparation

76 reinforced concrete slabs (35Mpa) were cast as specified in the drawing in Figure (2). Table (1) provides a summary of the specimens prepared and tested in the experimental program. Specimens were square shaped with the following dimensions: 600 mm x 600 mm x 100 mm. The slabs were reinforced with 10 mm (3/8 inch) diameter hot rolled deformed steel bars in two perpendicular directions with spacing of 200 mm between the bars. Concrete cylinders were taken during the casting for compressive strength; Figure (3) illustrates the average stress-strain relationship for the concrete cylinders test. Specimens were left on the site for 28 days for hardening and curing after the full curing of the reinforced concrete slabs, the metal mesh on one face of the slabs installed as the following steps.

Expanded metal mesh (Figure 1) with mortar layer (40 Mpa) were added at different thicknesses on top of the specimens after they were fully cured (Figure 4). Different mesh reinforcements have been used to retrofit the panels. The details of the reinforcement are also provided in Table (1). Only control specimens (simple reinforced concrete panels with no protective layer) did not have any metal mesh. An expanded metal sheet were cut with dimension of 600 mm x 600 mm (style ½ "–No 16), and fixed to the slab surface by a concrete screws and steel washers. Following this, a mortar layer with different thicknesses (depending on the mesh layers) were placed on top of the expanded metal mesh (see Figures 4 and 5); again specimens were left for 28 days to allow the mortar to cure and gain its required strength before the specimens were shipped to testing area.



Expanded steel mesh Glass fiber grids Polypropylene grids Polyethylene grids

Fig. 1: Different types of wire meshes used in Ferro-Cement Reinforcement

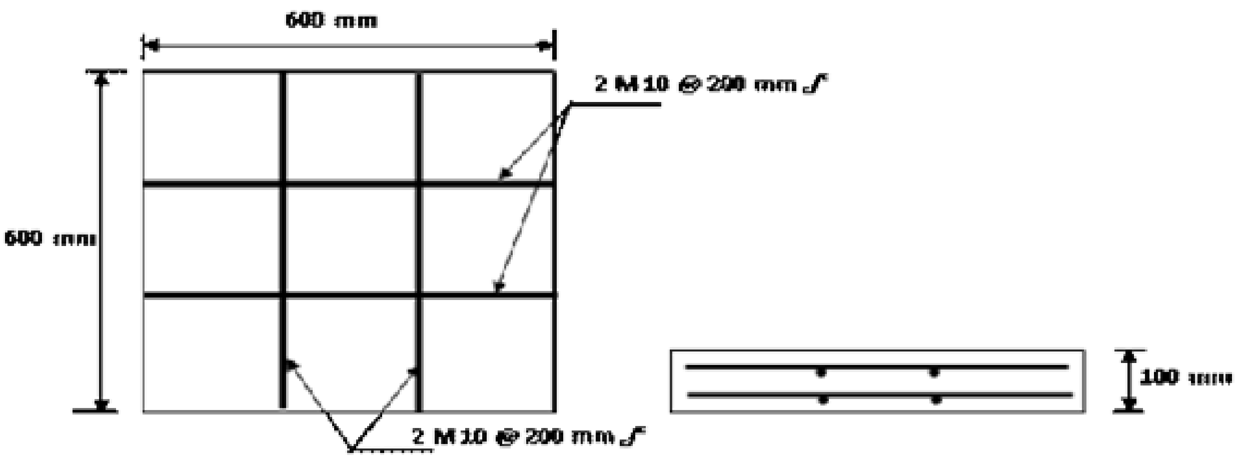


Fig. 2: Detailing of the specimens

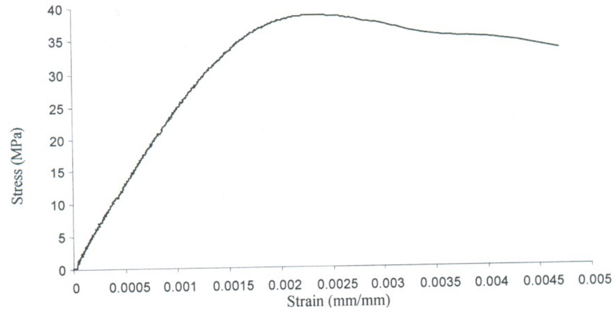


Fig. 3: Concrete cylinders average stress-strain

Fig. 4: Steel mesh installation

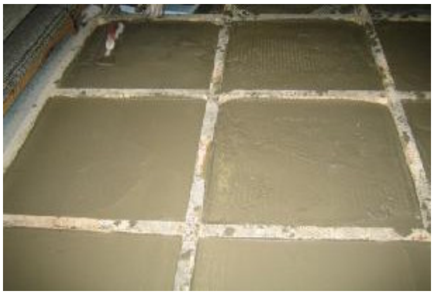


Fig. 5: Pouring of the mortar layer

Table 1- The Specimens Tested in Drop Weight Test

Specimen No.	Specimen ID	Retrofit Layer	Quantity
1	CR(1,2)	Regular reinforced concrete	2
2	SMP(1,2,3)	1 layer of steel mesh	3
3	SMPEEP(1,2,3)	Steel Mesh+Poly Eth Expando	3
4	2SMP(1,2,3)	Steel Mesh 2 Layer	3
5	SMSP(1,2,3)	Steel Mesh +Slag Mix	3
6	SMPPEP(1,2,3)	Steel Mesh +Poly Pro Expando	3
7	2SMGEP(1,2,3)	2 Steel Mesh + Glass Expando	3
8	2SMEP(1,2,3)	Steel Mesh +2 layer Expando+ Expando	3

3- IMPACT TESTING (FALLING WEIGHT)

Among the 76 reinforced concrete slabs that were delivered to Carleton University, three specimens from each type have been tested under impact load (Falling Weight). The mass of the falling weight (shaft) used in the tests was 268 kg, falling from a height of 40 cm. The depth of the shaft penetration measured after each hit by LVDT's (linear variable displacement transducer) which have been placed in six locations: five around the center point and the sixth under the slab at the center point. Table (2) showing samples of the tests results. Table (3) summarises the comparison between the two test sets. Figure (6) shows the Energy–Penetration curves, to demonstrate the tests; a number of cases are presented in this paper Figures (7) and (8) illustrate the damage caused by the impact loading on the control specimen, RC1. The test results show that RC 1 (un-retrofitted control slab) failed after 2 hits. Following the first hit, flexural cracks initiated along the edges and severe damage occurred after the second hit as shown in Figure (8). It can be seen in Figures (9), which shows the behaviour of the SMP (steel mesh protection) specimen, that addition of the Ferro-Cement retrofit improves the resistance of the slabs significantly.For this specimen, a single steel mesh and mortar were added on top of the regular slab (RC). Test results show a significant enhancement in the response in terms of more energy absorption is observed when compared with the regular control slab. Full penetration occurs after four hits (the same mass and drop height has been used), double the hits of the control specimen.

Table 2- Energy – Penetration Data (Slabs 1-8)

Specimen ID	No. of hits	Energy (k N .m)	Penetration depth (mm)
RC	1	1.05	7.00
	2	2.10	F.P
SMP1	1	1.05	6.35
	2	2.10	10.16
	3	3.15	38.10
	4	4.20	F.P
SMPEEP3	1	1.05	7.62
	2	2.10	12.70
	3	3.15	50.80
	4	4.20	91.44
	5	5.25	111.76
	6	6.30	127.00
	7	7.36	F.P
2SMP3	1	1.05	3.81
	2	2.10	7.62
	3	3.15	20.32
	4	4.20	F.P
SMSP2	1	1.05	5.08
	2	2.10	16.51
	3	3.15	F.P

Table 3- Comparison of the Results of the Two Sets of Testing

Specimen (ID)	Overall thickness (mm)	No. of hits caused full penetration (0.40 m height)	Area under Energy-Penetration Curve (N.m)
CR1	100	2	3.68
SMP1	131	4	37.39
SMP3	124	3	39.90
SMPEEP3	131	7	355.26
SMPEEP2	132	7	321.33
2SMP3	132	4	22.70
2SMP2	130	4	23.44
SMSP2	124	3	14.02
SMSP3	124	3	11.25
SMPPEP2	133	5	64.90
SMPPEP3	130	5	61.33
2SMGEP3	130	5	106.06
2SMGEP2	130	5	83.41
2SMEP1	130	5	95.45
2SMEP2	132	5	88.55

From Figure (6) it can be observed from the data that the addition of the non-metallic grids have a direct contribution to the impact resistance of the retrofitted slabs. In general, the slabs reinforced with Steel mesh and + polyethylene combinations have yielded superior results than the others, yielding almost 3-10 times larger energy absorption compared to other types.

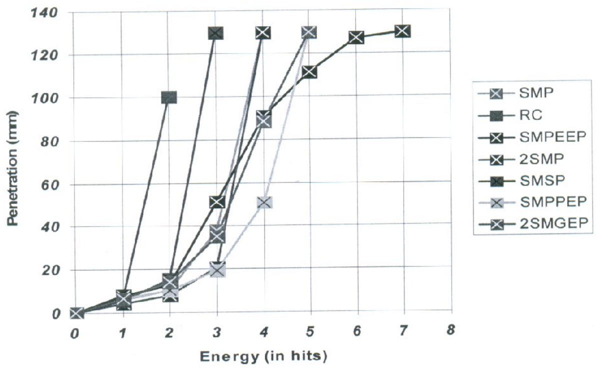


Figure 6- Penetration Curves For the First Set of Tests

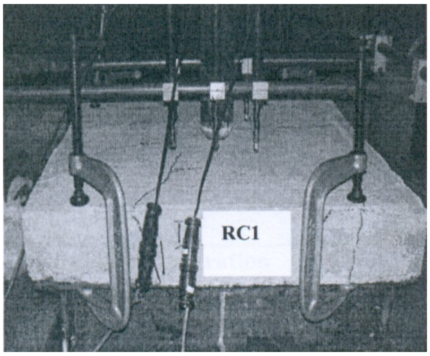


Fig. 7: Specimen RC1 before test

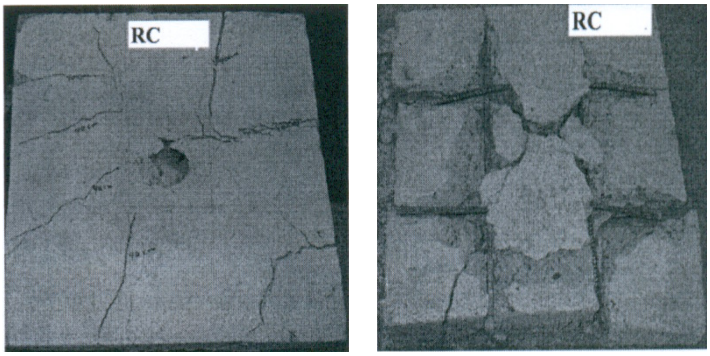
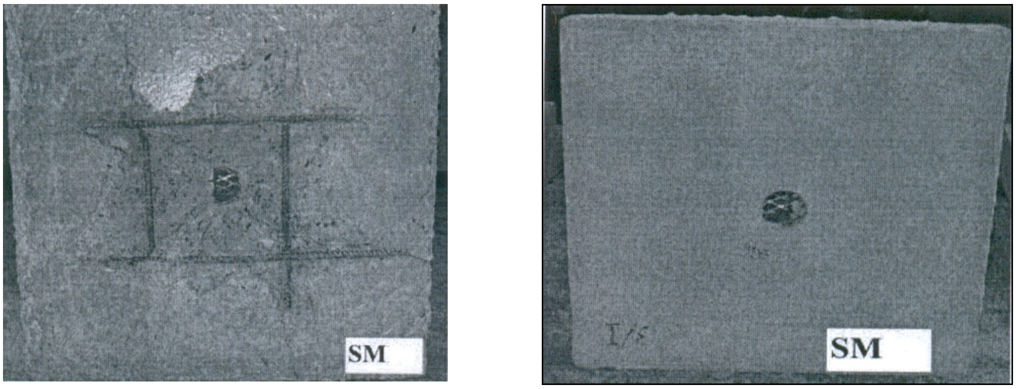


Fig. 8: Specimen RC1 after 2nd hit



SMP Back Side **SMP Front Sid**

Fig. 9- SMP after Penetration

4-RANKING AND RATING OF THE RETROFIT SYSTEMS

The laboratory testing program has provided large amount of data and results. These results were used to devise a method for ranking the retrofit systems which included experimental and simulation penetrations, drop weight indices, residual load bearing capacities, and amounts of scabbing as shown in Table (4). Accordingly, the retrofit systems, 2SMGEP and SMPPEP rate highest with SMPEEP being third best.

Table 4- Specimen Ratings from Various Tests and Simulations

Ranking (Best- to- Worst)	Drop Weight		Air Cannon		Indices(Drop Weight		Residual Capacity	Bullet Scabbing
1	SMPEEP	2SMGEP	2SMGEP	2SMGEP	SMPEEP	SMPEEP	SMPPEP	SMPPEP
2	SMPPEP	SMPPEP	SMPPEP	SMPPEP	SMPPEP	2SMGEP	2SMGEP	2SMP
3	2SMGEP	SMPEEP	SMPEEP	SMPEEP	2SMGEP	SMPPEP	SMPEEP	2SMGEP
4	2SMP	2SMP	2SMP	2SMP	2SMP	SMP	2SMP	SMPEEP
5	SMP	SMP	SMP	SMP	SMP	2SMP	SMP	SMP
6	RC	RC	RC	RC	RC	RC	RC	RC

A rating technique of the different retrofit systems was established using the criteria for kinetic energy levels for fragment-related injuries and fatalities (Tables 5 and 6).

Table 5- Kinetic Energy Levels of Fragment Injuries (J)

Injury Type	Head	Abdome	Limbs
Under Skin Penetration (USP)	2	**2**	**2**
Soft Tissue (ST)	**30**	**18**	**18**
Bone Tissue (BT)	**48**	**48**	**48**

Table 6- Kinetic Energy Levels of Fragment Injuries (J)

Injury Level	Energy(J)
Threshold	14.91
90% Injury (10% Fatal)	54.23
50% Injury (50% Fatal)	78.6
10 Injury (90 % Fatal)	115.24

Table (7) shows the ranking based on the degree of protection against the three applied energies as measured by the amount of reduction of the imparted energy until failure. The ranking method followed herein showed that the three retrofit systems utilizing non-metallic grids ranked first, second and third when compared to the other steel retrofitted systems. The results of this method agree with the ranking obtained from Table (4). The ranking obtained from the application of the method in Table (7) showed that the retrofit utilizing the 2 steel mesh-glass grid layers was the best. When the injury/fatality level criterion was applied the results shown in Table (7) indicated that the same system which ranked first provided 157% better protection than the control slabs. Also, the 2SMPGEP retrofit system is shown to be the only system that passes all applied criteria as given in Table (7). This conclusion is a significant contribution to the field of enhancing the resistance of concrete structures to impacts with an emphasis on the protection of human lives since it reduces the probabilities of injury and fatality.

Table 7: Ranking and Rating of Retrofit Systems (Injuries and Fatalities Criteria)

Type	CR			SMP			2SMP			SMPPEP			SMPEEP			2SMPGEP		
Drop Mass Test																		
	3.2						3.1			9.77			0.51			0.6		
Injury Type	H	A	L	H	A	L	H	A	L	H	A	L	H	A	L	H	A	L
USP				N/A														
ST																		
BT																		
Threshold																		
Bullet Test																		
	21.8						2.88			11.1			2.37			1.55		
USP																		
ST																		
BT																		
Threshold																		
Air Cannon																		
	3.2			4.3			2.2			2.1			2.2			2.0		
USP																		
ST																		
BT																		
Threshold																		
BT	5	6	6	2	2	2	6	6	6	6	6	6	7	7	7	9	9	9
	2			1			3			3			3			3		
Rating	19			7			21			21			24			30		
Ranking	5			N/A			3			3			2			1		
Rating Scale	100			N/A			110			110			126			158		

5- CONCLUSION

In summary, the use of the non-metallic grids improved the performance of the protective layer in terms of absorption of applied impact energy, control of fragments hazards and scab volume, and reducing the amount of damage inflicted on the structure. A number of mechanisms explaining how a selected retrofit will operate to protect the concrete slab against a specific attack were suggested and the results of both the laboratory tests and simulations were utilized to develop procedures for ranking and rating different retrofit systems.

The results from this research can be used to formulate a preliminary guideline for assessing materials as candidates for retrofitting reinforced concrete structures against hazards arising from projectile and fragment threats. Generally, a design method must include a theory describing the material response under the applied forces or energies, material properties, and a failure criterion. The procedure is as follows:

* Perform drop weight tests. Such equipment is commonly availability in most structural labs. Use these test results, penetration and deflection, to rate the new products among themselves and to those tested in this thesis.

* Determine the kinetic energy of the fragments produced. Again this can be used for rating and comparing. In addition, the fragment energy must be compared to injury and fatality criteria to ensure that the correct protection level is achieved.

* Perform projectile and fragment tests as per requirements. Use specimen penetration, flexture, fragment energy and number of dangerous fragments, and volume of scabbing to obtain additional rating data.

* Use numerical modeling to support and extrapolate the experimental data to tune the retrofit system to the design threat hazards.

* Finally, consider the economic and environmental factors to make a final decision.

It should be noted that this preliminary guideline is a “work in progress” but a step in the right direction to develop complete design guidelines for retrofit systems.

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