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Missile Effect on Penetration Resistance of Ferrocement slabs

By

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Abstract:

This paper presents results of an experimental investigation to enhance the protective layer material .A special concrete mixture with high reliability to resist the penetration of missiles was designed. Ferrocement technique is used to enhance the concrete panels' penetration resistance. An experimental investigation was performed for three specimens of plain concrete and eight reinforced concrete panels in which steel blunt-nose projectile with a diameter of 23 mm and a mass of 175 g is fired with striking velocity about 980 m/s.

The main findings show that the penetration depth, the cracks and damage in the front ' rear face exhibit an overall reduction, The fragments weight in the front face of target specimens showed the same response when dividing the specimen to layers and also with using expanded steel meshes as reinforcement. The penetration depth and the cracks pattern were clearly enhanced.

Keywords:

Reinforced concrete; Ferrocement; Penetration; Missile effect.

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1. Introduction:

Concrete has been used extensively as a construction material for buildings, bridges, tunnels and nuclear reactor containments. In defense applications, concrete is used as a structural material for runways, command bunkers and hardened shelters. Concrete which encounter in all aspects of our everyday life is a mixture of cement grout, water, air and quartz aggregates. Variation of any of these components will lead to a change in the mechanical properties [2], it has been claimed, that concrete not an environmentally friendly material due to its destructive resource-consumption nature and severe environmental impact after its use. Nevertheless, it will remain one of the major construction materials being utilized worldwide. [3]

The end of the 19th century shaw the discovery of a range of military explosives of great importance known as TNT. This became the standard explosive of the First World War. TNT can be manufactured with relative safety and economy, and because of its universal use it has become customary to class all types of explosive (conventional or nuclear) in terms of TNT as a standard.

The next major shift in the balance of attack and defense developed between 1918 &1930with the introduction of aerial warfare, widely used in World War II 1939:1945.

The "1991, 2003" Gulf War (I, II), and second Lebanon War "2006" emphasized the structural damage that can result from modern missiles which have a great accuracy and small volume (compound B) [1].

The penetration of high-velocity objects into soils, stone, metals, and concrete has historically been a subject of interest for military engineers.

In the last decades, rapid improvement has been occurring in the explosives and the ammunition; its way of transport has a heavy impact on the design and construction of the fortified structures. The improvement not only concerns the capacity but also the ability to penetrate the aimed targets. A level of protection against its response is often specified in new civil works and structures.

The missiles impact, bombs, explosive shell, aircraft crashes, mountainous rock falls, and accidental explosions became the major attacking events against the fortified structures and military targets, wherever it is, above or underground. To obtain protection against mechanical effects of weapons, it is important to build shelters entirely underground or at least soil-covered. Establishing buried structure with protective layers above it can reduce, or better vanish, the effect of the developed weapons on the main structure. Consequently, static and dynamic loads affect only a limited part of the main structure.

Much of the experimental work has been aimed at reinforced concrete structures, because, from the beginning of the present century, many of the protective structures that are built to withstand the effect of missiles, conventional bombs, or shells have been constructed with this material. It is not surprising that the research expenditure on studying the response of different types of concrete (plain concrete and ferrocement) to dynamic impact generated from the missiles impact get the attention of many researchers.

Ferrocement is a type of thin-wall reinforced concrete commonly constructed of cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The typically range of diameter from about 0.4 mm up to about 2.5 mm, which usually spaced between wire centers ranges from about 10 mm up to about 30 mm. The mesh may be constructed from metallic or other suitable materials. The fineness of the mortar matrix and its composition should be compatible with the used mesh [4, 5, 6].

2. Experimental program:

Comparative penetration tests were conducted on varies square plain concrete and ferrocement specimens. The projectile used was API, blunt-nose steel penetrator 23 mm diameter and 64 mm length as shown in Fig.(1) , the material properties of the penetrator shown in Table(1). The impact velocity was measured and reported for every shot with electro-optical velocity measurement device, which had connected with computer as shown in Fig.(2) and turn to be 980 m/sec.

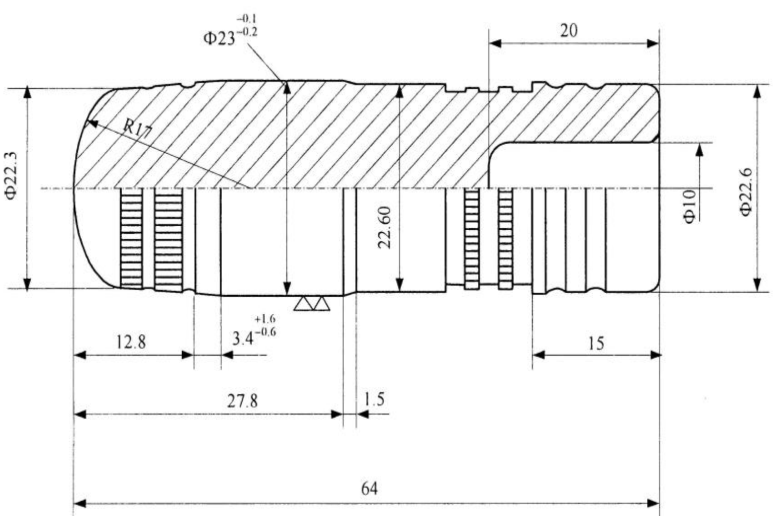


Figure (1): *Dimensions of 23 mm API missile*

Figure (2): *Velocity measurement device*

Table (1) *Mechanical properties of the projectile materials*

Brinell hardness number,	**Yield strength [MPa]**	**Ultimate strength, [MPa]**	**Strain to fracture, [%]**
475	1726	1900	**7**

2.1. <u>Materials used:</u>

Concrete panels with Portland cement, sand and coarse aggregate of 19 mm maximum aggregate size were casted. The mix proportions by weight for 1 m^3 of concrete are given in table (2). The ratios of water, sand and coarse aggregate, to cement by weight were 0.5, 2, and 4, respectively. 500 x 500 mm Expanded steel meshes were employed to reinforce the concrete panels. Data sheet of steel meshes used are given in table (3)

Table (2): *Mix proportions of concrete*

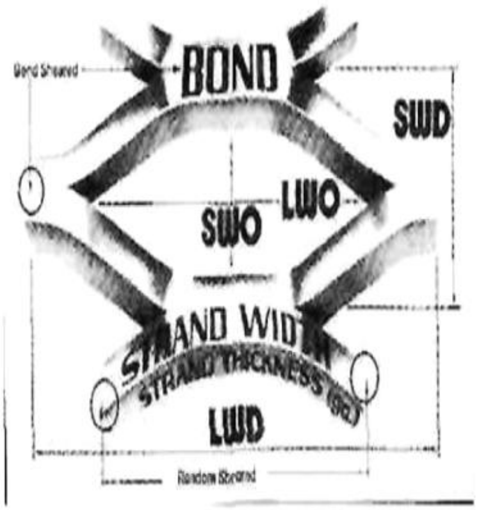
Material	Portland cement	Fine aggr. (Sand)	Coarse aggr. (Dolomite)	Water
Kg/m^3	350	700	1400	175

Table (3): *Data sheet of expanded steel mesh used*

MULTI M GROUP

METAL-X- SECTOR

SWD SHORT WAY OF DIAMOND OR DESIGN DIMENSION
LWD : LONG WAY OF DIAMOND OR DESIGN DIMENSION
SWO : SHORT WAY OF OPENING DIMENSION, USED TO INDICATE CLEAR OPENIN IN THE SHORT DIRECTION.
LWO : LONG WAY OF OPENING DIMENSION, USED TO INDICATE CLEAR OPENIN IN THE LONG DIRECTION
STRAND THICKNESS: EQUAL TO THE THICKNESS OF METAL USED IN MM
STRAND WIDTH: AMOUNT OF METAL FED UNDER THE DIE TO PRODUCE ONE STAND
BOND SHEARD: WHERE TWO STRANDS INTERSECT ELIMINATES PRONGS OR JAGGED EDGES
RANDOM SHEARED: THIS TYPE OF SHEARING LEAVES PRONGS OR JAGGED EDGES.



DIM. EXPENDED METAL (MM)

SHEET SIZE	MATRIAL DESCRIPTION	SHEET WEIGHT KGS	SHEETS QTY/TON	STYLE	THICKN	LWO	LWD	SWO	SWD	SW
100X800CMS		14.00 KG		1038	1 MM	30MM	38MM	12MM	14.5MM	1.7MM
100X700CMS		22.00 KG		1538	1.5 MM	30MM	38MM	11.7MM	15.5MM	1.9MM
100X600CMS		30.00 KG		2038	2 MM	26.5MM	38MM	10.8MM	16MM	2.4MM
100X600CMS		45.00 KG		3038	3MM	26.5MM	38MM	10MM	16MM	2.6MM
100X400CMS		60.00 KG		4042	4 MM	25.00MM	42MM	7.3MM	18MM	3.5MM
100X500CMS		60.00 KG		4050	4 MM	36MM	50MM	15MM	26MM	4.4MM
100X500CMS		75.00 KG		5090	5 MM	67MM	90MM	23.5MM	40MM	4.1MM
100X500CMS		91.00 KG		60110	6 MM	82MM	110MM	43MM	48MM	7.7MM

2.2 Material characterization:

Characterizations of the concrete material were investigated. This include the mass density ρ_c and compressive strength f_{cu} of 150 x 150 x 150 mm cubes in uniaxial stress, The tensile strength f_t via split testing of cylinders Φ100 x 200 mm, The results are given in Table (4).

***Table (4)**: The mechanical properties of concrete*

Properties	Density (kg/cm²)	Compressive strength (MPa)	Tensile strength (MPa)
value	2.36	35	3.1

2.2. Specimens:

Two classes of target were considered unreinforced (plain) and reinforced concrete (ferrocement) the specimen dimensions were 550 x 550 mm with thickness of 600 and 400 mm. The total numbers of specimens were eleven. The details of them are listed in Table (5). Fig. (3&4) show the dimensions and details of the specimen and Preparation of slabs.

***Table (5)**: Specimens detail*

NO.	Code	Specimens description	Thick. (cm)	No. of mesh	
				front	rear
1	SC 1	60 cm plain concrete	60	-	-
2	SC 2	(3x20cm) plain concrete	60	-	-
3	SC 3	(2x20cm) plain concrete	40	-	-
4	SE 1-1	(2x20cm) ferrocement panel with 2 meshes (style 60110)	40	1	1
5	SE 2-1	(2x20cm) ferrocement panel with 2 meshes (style 5090)	40	1	1
6	SE 3-1	(2x20cm) ferrocement panel with 2 meshes (style 4050)	40	1	1
7	SE 4-1	(2x20cm) ferrocement panel with 2 meshes (style 4042)	40	1	1

Table (5)*: Specimens detail (cont.)*

NO.	Code	Specimens description	Thick. (cm)	No. of mesh	
				front	rear
8	SE 5-1	(2x20cm) ferrocement panel with 2 meshes (style 3038)	40	1	1
9	SE 6-1	(2x20cm) ferrocement panel with 2 meshes (style 2038)	40	1	1
10	SE 7-1	(2x20cm) ferrocement panel with 2 meshes (style 1538)	40	1	1
11	SE 8-1	(2x20cm) ferrocement panel with 2 meshes (style 1038)	40	1	1

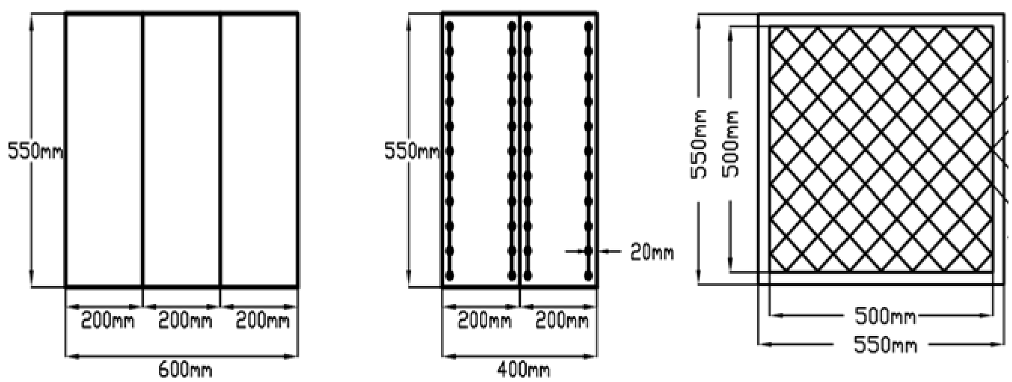


Figure (3)*: Dimensions and details of the specimen*

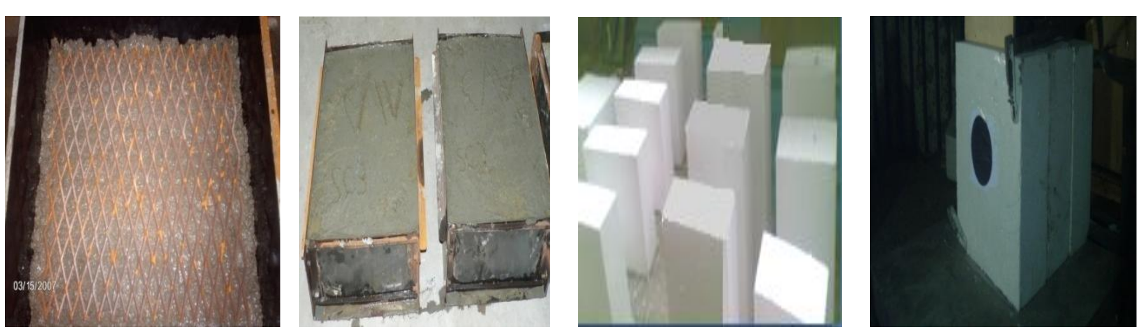


Figure (4): *Preparation of specimens*

3. Test results:

The response of the experimental program specimens was examined and recorded. The concrete parameters were :

(a) The penetration depth.
(b) The front face crack pattern.
(c) The rear face crack pattern.
(d) The front face damaged areas.
(e) The rear face damaged areas.
(f) The front face fragments weight.

Table (6) and Figure (5) show The results of the penetration test

***Table (6)**: Results of penetration Test*

NO	Name	Velocity (m/sec)	Pentration depth (X)		Crack diameter (front face)		Crack diameter (rear face)		Diam. of damage (front face)		Diam.of damage (rear face)		Frag wt (*kg*)
			cm	%	cm	%	cm	%	cm	%	cm	%	
1	SC 1	974	60	100	Full	100	Full	100	Full	100	Full	100	Full
2	SC 2	976	40	66.7	Full	100	0	0	Full	100	0	0	Full
3	SC 3	978	40	100	Full	100	Full	100	Full	100	Full	100	Full
4	SE 1-1	976	28.5	71.2	54	77.1	0	0	25	44.6	0	0	3.04
5	SE 2-1	996	28.5	71.2	65	92.8	0	0	30	53.6	0	0	2.78
6	SE 3-1	994	28.5	71.2	65	92.8	0	0	32	57.1	0	0	2.60
7	SE 4-1	979	28	70	68	97.1	37	52.8	28	50	5	8.9	2.47
8	SE 5-1	982	28	70	70	100	56	80	34	60.7	0	0	2.44
9	SE 6-1	990	28	70	70	100	56	80	40	71.4	10	17.8	2.28
10	SE 7-1	996	27.5	68.7	70	100	56	80	43	76.8	14	25	1.66
11	SE 8-1	987	28.5	71.2	70	100	56	80	45	80.4	19	33.9	1.45

Damage in Front Face of plain concrete slab Damage in rear Face of plain concrete slab

Damage in Front Face of ferrocement slab   Damage in rear Face of ferrocement slab   projectile stopped inside the panel

Figure (5): *The results of the penetration test*

Discussion:

In case of high velocity (about 980 m/sec), the effect of using ferrocement technology on the penetration resistance of concrete panels had been studied. From previous results in Table (6), and as shown in Fig.(5) the following findings are obtained:-

3.1 Penetration depth

Effect of dividing the panel into layers on penetration depth:

In plain concrete specimen [SC1 (60 cm thickness as one panel)], the penetration depth was 60 cm, but the penetration depth in specimens [SC2 (60 cm thickness as three panels 20 cm for each one) & SC3 (40 cm thickness as two panels 20 cm for each one)] was 40 cm. This means dividing the panel into layers leads to reduction in the penetration depth by about 33.3 %, see Fig. (6).

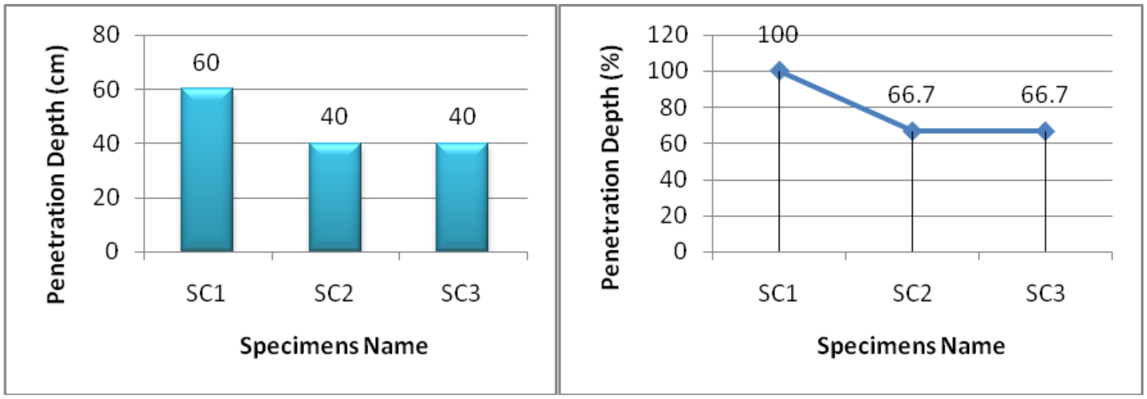


Figure (6): *Effect of dividing the panel into layers on penetration depth*

Effect of using ferrocement on penetration depth:

In comparison with plain concrete specimen [SC3] in which the penetration depth was 40 cm, the penetration depths in Ferrocement specimens(SE8-1,SE7-1,SE6-1, SE5-1, SE4-1, SE3-1, SE2-1and SE1-1)were (28.5 , 27.5 , 28, 28, 28, 28.5, 28.5and 28.5cm) respectively. That's means using Ferrocement in these specimens' leads to reduction in the penetration depth by about 31.25 %, see Fig. (7).

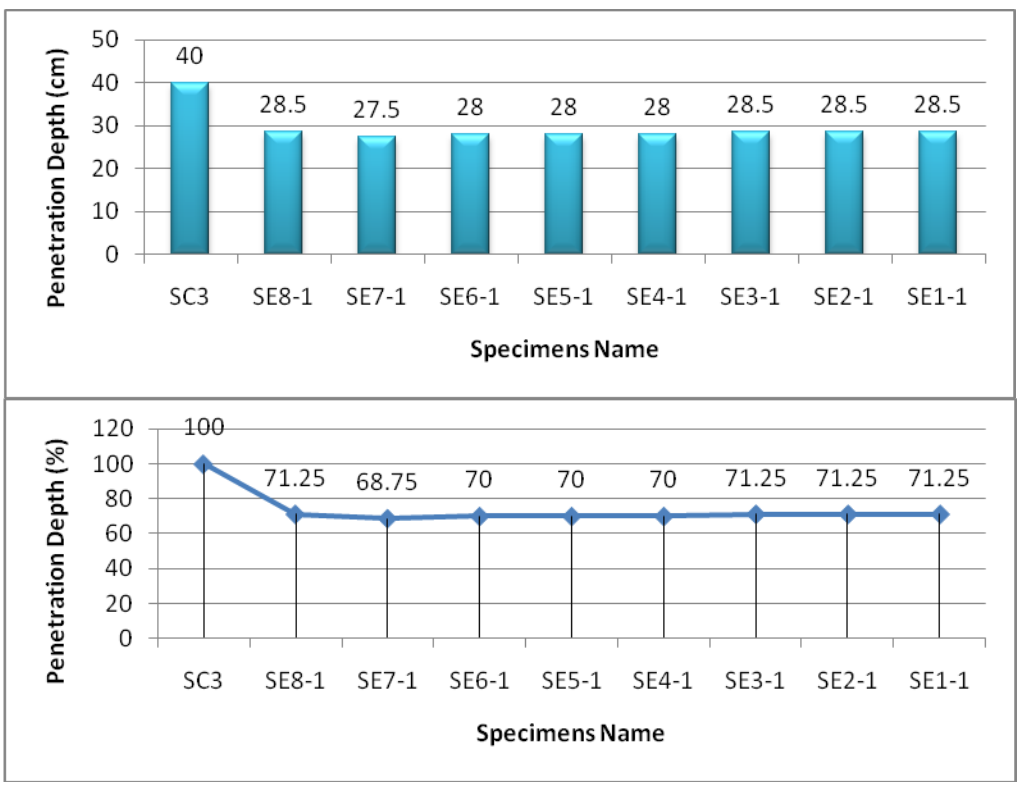
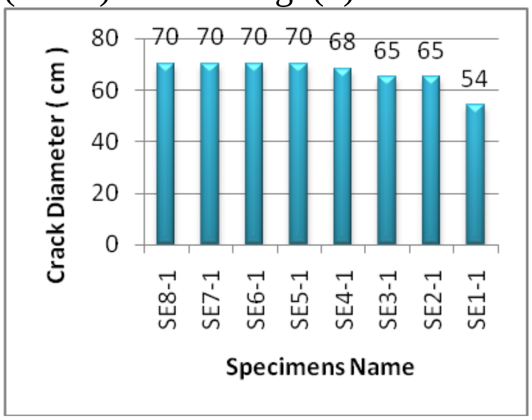


Figure (7): *Effect of using ferrocement on penetration depth*

3.2 Front face crack pattern

Effect of using ferrocement on cracks in front face:

In comparison with plain concrete specimen (SC3), in which the damage in front face was full damage, the crack diameter in front faces in Ferrocement specimens (SE8-1, SE7-1, SE6-1, SE5-1, SE4-1, SE3-1, SE2-1and SE1-1)were (70 , 70 , 70 , 70 , 68, 65, 65and 54cm) respectively. That’s means using Ferrocement in these specimens' leads to reduction in cracks in front face about (22.86) % . See Fig. (8).



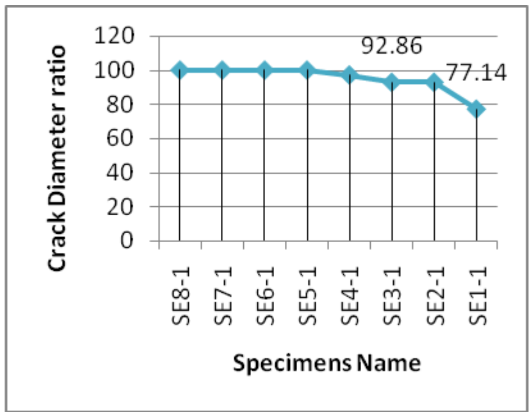
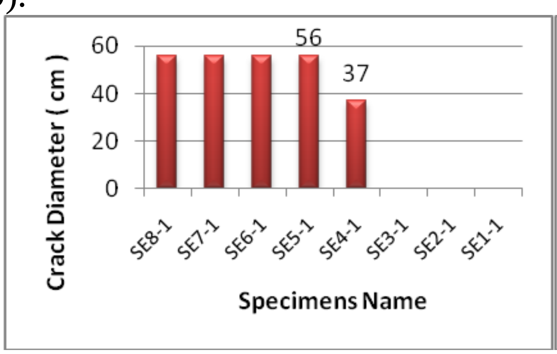


Figure (8): *Effect of using ferrocement on cracks in front face*

3.3 Rear face crack pattern

Effect of using ferrocement on cracks in rear face:

In comparison with plain concrete specimen (SC3), in which the damage in rear face was full damage, the crack diameter in rear faces in Ferrocement specimens (SE8-1, SE7-1, SE6-1, SE5-1, SE4-1, SE3-1, SE2-1and SE1-1)were (56 ,56 ,56 ,56 ,37,0 ,0 and0 cm)respectively. This lead to conclude that using Ferrocement in these specimens' leads to reduction in cracks in rear face between (20-100) % . See Fig (9).



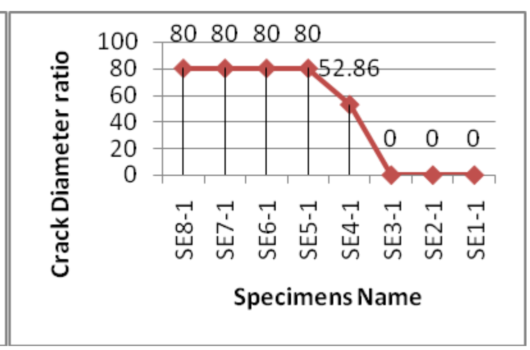


Figure (9): *Effect of using ferrocement on cracks in rear face*

3.4 Front face damage

Effect of using ferrocement on damage in front face:

In comparison with plain concrete specimen (SC3), in which the damage in front faces was full damage, the damage in front faces in Ferrocement specimens (SE8-1, SE7-1, SE6-1, SE5-1, SE4-1, SE3-1, SE2-1and SE1-1)were (45 , 43 , 40 , 34 , 28 , 32, 30and 25cm) respectively. It is clear that using Ferrocement in these specimens' leads to reduction in the damage in front face between (19.65 – 56.4) %. See Fig. (10).

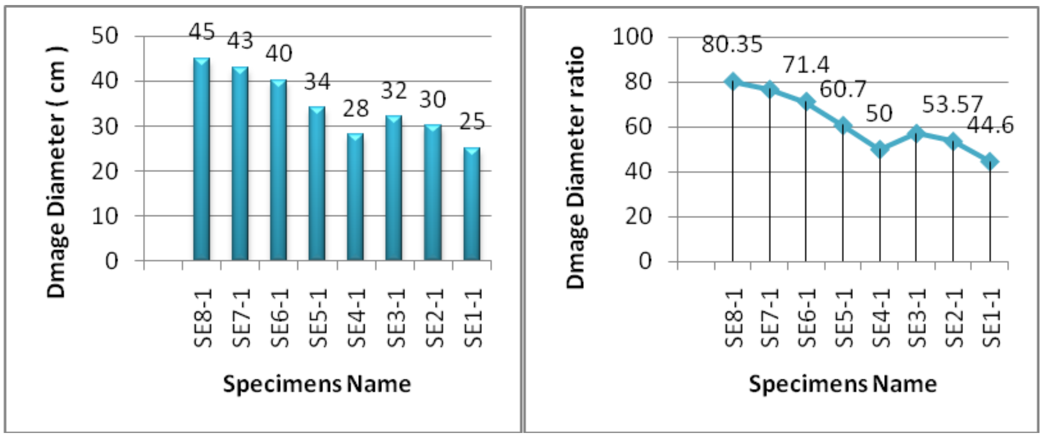


Figure (10): *Effect of using ferrocement on damage in front face*

3.5 Rear face damage

Effect of using ferrocement on damage in rear face:

In comparison with plain concrete specimen (SC3), in which the damage in rear face was full damage, the damage in rear faces in Ferrocement specimens (SE8-1, SE7-1, SE6-1, SE5-1, SE4-1, SE3-1, SE2-1and SE1-1)were(19 , 14 , 10 , 0 , 5 , 0 , 0 and 0cm) respectively. This analysis show that using Ferrocement in these specimens' leads to reduction in the damage in rear face between (66.1 – 100) %. See Fig. (11).

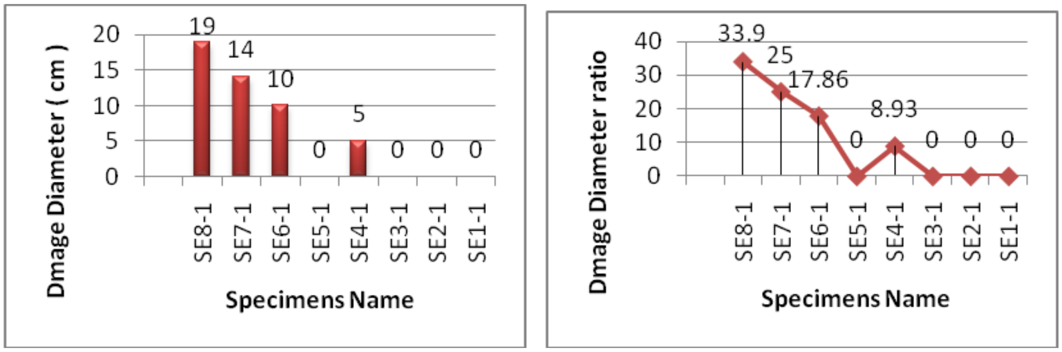
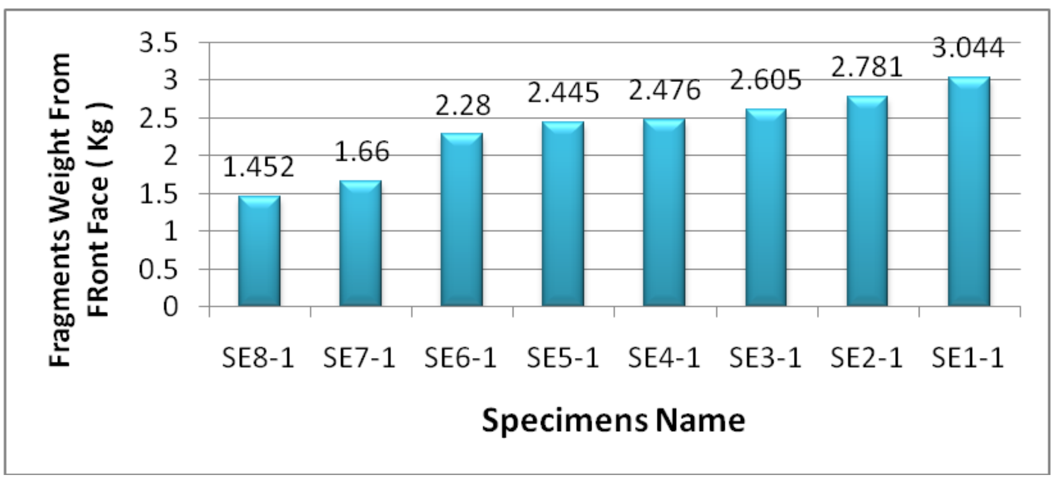


Figure (11): *Effect of using ferrocement on damage in rear face*

3.6 fragments weight in front face

Effect of using ferrocement on fragments weight in front face:

In comparison with plain concrete specimen (SC3), in which the damage in front face was full damage, the fragments weight in front faces in Ferrocement specimens (SE8-1, SE7-1, SE6-1, SE5-1, SE4-1, SE3-1, SE2-1and SE1-1)were(1.452 , 1.66 , 2.28 , 2.445 , 2.476 , 2.605 , 2.781 and 3.044kg) respectively. It is clear that using Ferrocement in these specimens' leads to reduction in the damage in front face between (83.77 – 92.26) %. See Fig. (12).



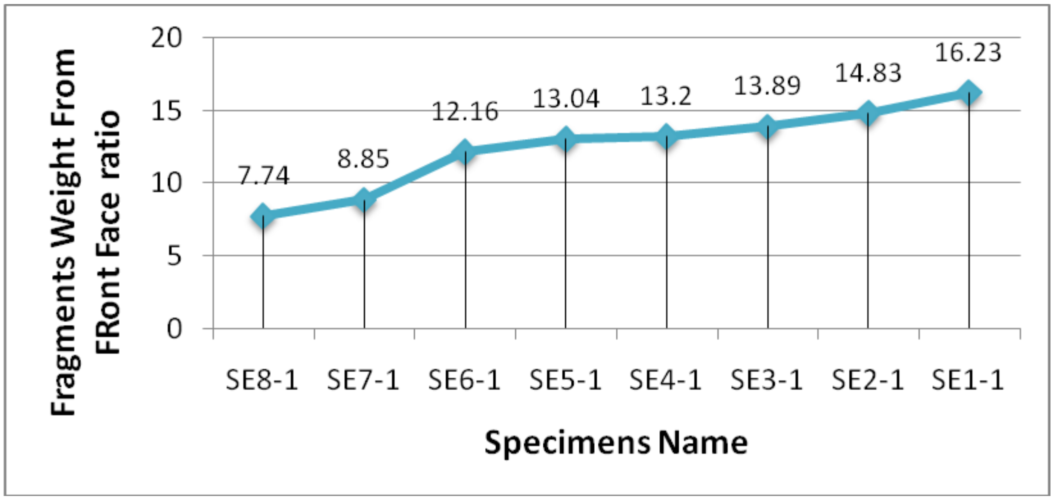


Figure (12): *Effect of using ferrocement on fragments weight in front face*

4.Conclusions:

The following general conclusions could be derived Based on the carried out experimental studies and the performed analysis:

- Dividing the panel of plain concrete into layers enhances the penetration resistance of concrete panel. That is through reducing the penetration depth by about 33.3%.
- Using Ferrocement enhances the penetration resistance of concrete panels. That is through reducing the penetration depth by about 31.25%.
- Using Ferrocement reducing the front and rear face cracks by about (22.86%) and (20-100%) respectively.
- Using Ferrocement reducing the front and rear face damage by about (19.65 – 56.4%) and (66.1 – 100%) respectively.
- Using Ferrocement reducing the fragments weight in front face by about (83.77 – 92.26 %).

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