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Case study

Structural behavior for rehabilitation ferrocement plates previously damaged by impact loads

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ABSTRACT

The main objective of this research is to investigate the possibility of using ferrocement concrete to rehabilitee the damaged plates which failed under impact load. The current work presents the comparison between the results of the first crack loads, the ultimate loads and the deflections in the cases of the impact and static loads. Seventeen plates were damaged under impact load [1], which having the dimensions of 500 × 500 and 25 mm thick. The plates were subjected to impact load by 1.15 kg spherical steel ball under its height 1.12 m at the center of the tested plates. The ferrocement plates were reinforced with skeletal steel bars welded galvanized meshes and expanded steel meshes with skeletal steel bars. *The plates* were tested up to failure. The damaged plates were repaired by employing concrete mortar and two layers of galvanized steel mesh (300 * 300 mm) at both the top and bottom faces of the damaged plate and tied with one layer (500 * 500 mm) by means of shear connectors at both top and bottom of the damaged plate by using L screw bolts with imbedded fisher. The rehabilitation plates (500 * 500 * 50 mm) were tested simply supports along its four sides and subjected to central flexural loadings until failure. The obtained results reached emphasized good deformation characteristics, high first crack and ultimate load, high ductility, energy absorption properties, and cracking pattern without spilling of concrete cover that is predominant.

1. Introduction

Ferrocement as a construction technique is defined by ACI committee 549 [2] Ferrocement is type of reinforcement concrete. It commonly composed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. It is lightweight, low cost, durable, weather-resistance, and particularly its versatility comparing to the reinforced concrete [3].

Ferrocement is an excellent material for housing construction. Also Al-Kubaisy and Jumaat [4] studied the possibility of using ferrocement cover in the tension zone of reinforced concrete slabs.

This material is also used in rehabilitation the reinforcement elements such as beams, slabs or walls (Fahmy et al., 1997; [5,6].

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Mourad and Shang [7] used ferrocement jacket in repairing reinforced concrete columns, their test results indicated that using the ferrecement jacket increases the axial load capacity and the axial stiffness of rehabilitation reinforced concrete columns compared to the control columns. Many researches were carried out to study ferrocement elements (beams, slabs and columns) to investigate its behavior under applied loads up to failure.

Ferrocement has been used for many years as a rehabilitation material for reinforced concrete and masonry elements as an alternative to other expensive ones. It allows rapid construction with no heavy machineries or high-level skilled workers, imposes small additional weight and the cost of construction is low. These unique qualities make the ferrocement as an ideal material for rehabilitation. However, one layer of square welded galvanized steel mesh, 300 mm tied with another square layer, 500 mm which were applied at both top and bottom of the failed plate through shear connectors as a developed method of rehabilitation.

The main objective of this paper is to investigate the structural behavior of rehabilitation plates by using ferrocement concrete layers of 10 mm thick at both top and bottom faces. The main objective is to investigate the flexural behavior of rehabilitation plates. This research comprises extensive comprehensive statistical analysis and the comparisons.

2. Experimental study

The experimental program consists of rehabilitation of seventeen Ferro cement plates having the dimensions of 500×500 and 25 mm thick which were previously tested under impact loadings until failure. The failed plates were designed and cast with dimensions of $500 \times 500 \times 25$ m. Plates were designed, mixing and curing according to Egyptian Code of Practices (E.C.P. 203/2007). All damaged plates were repaired by employing two layers of welded galvanized steel meshes with dimensions of 300×300 at both top and bottom of the central region of the plate tying together with another welded galvanized welded mesh of dimensions of 500×500 mm. Tying the top and bottom reinforcing material together by using shear connectors into a rigid cage while failed plate into between. The total dimensions of the repaired plates after rehabilitation 500 mm $\times$ 500 mm and 50 mm thick. All repaired plates were tested under central concentrated flexural loadings along platen of dimensions 100 mm $\times$ 100 mm and 20 mm thick located at the center of all plates until failure. In case of plate FW22 which was reinforced with four layers of welded galvanized steel mesh, additional layer of galvanized welded steel mesh of dimensions 50×50 mm was used as result of separation of the test specimen into two pieces. The main objective of the experimental program is to compare the structural behavior of plates subjected to impact loadings and that rehabilitation by using ferrocement layers and subjected to flexural loadings until failure.

3. Materials, mortar matrix, preparation and casting of test specimens

3.1. Materials

Ordinary Portland cement was used, produced by the Suez cement factory. Its chemical and physical characteristics satisfied the Egyptian Standard Specification (E.S.S. 4657-1/2009).

The fine aggregate used in the experimental program was natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007), (E.S.S. 1109/2008) and (ASTM C 33, 2003). It was clean and nearly free from impurities with a specific gravity 2.6 t/m^3 and modulus of fineness 2.7.

Super Plasticizer was used with high rang water reducer HRWR. It was used to improve the workability of the mix. The admixture used was produced by Sika Group under the commercial name of ASTM (Sika viscocrete 20), it meets the requirements of ASTM (Sikaviscocrete20), It meets the requirements of ASTM C494 (type A and F). The admixture is brown liquid having a density of 1.18 kg/l at room temperature. The amount of HRWR was 2.0% of the cement weight.

Polypropylene Fibers PP 300-e3 was used. It was available in the Egyptian markets. It was used in concrete mixes to produced fibrous concrete jacket to improve the concrete characteristics. The percentage of addition was chosen as 900 g/m^3 based on the recommendations of manufacture. The chemical and physical characteristics of Polypropylene Fibers 300-e3 is given in Table 2.

Water used was clean drinking fresh water free from impurities is used for mixing and curing the plates tested according Egyptian Code Practices (E.C.P. 203/2007).

The reinforcing, Welded Metal Mesh: Galvanized welded metal mesh used was obtained from China. We used welded metal mesh as reinforcement to rehabilitee the ferrocement plates. Its chemical and physical characteristics satisfy the

Table 1
Technical Specification and Mechanical properties of Welded Metal Mesh.

Dimensions (mm)	12.5×12.5 mm
Weight (gm/m^2)	430
Proof Stress (N/mm^2)	400
Ultimate Strength (N/mm^2)	600
Ultimate Strain $\times$ 10-3	1.25×1.5 mm
Proof Strain $\times$ 10-3	1.17

Table 2
Constituents of mortar used per $m^{3.}$

Mix Design	Mix. Weight (kg/m^3)
Cement	681.82
Sand	1363.64
Water	238.64
S.P.	6.82
Fibers	0.9

Fig. 1. Welded Metal Mesh.

Egyptian Standard Specification (E.S.S. 262/2011). See Table 1.which explain the technical specification and mechanical properties of welded metal mesh and its shape in (Fig. 1).

3.2. Mortar matrix

The concrete mortar used for casting plates was designed to get an ultimate compressive strength at 28-days age of (350 kg/cm^2), 35 MPa. The mixes properties for mortar matrix were chosen based on the ACI committee 549 report [2] and Egyptian Code Practices (E.C.P. 203/2007). For all mixes, mechanical mixer in the laboratory used mechanical mixing. In the laboratory used mechanical mixing. The constituent materials were first dry mixed; the mix water was added and the whole patch was re-mixed again in the mixer. The mechanical compaction was applied for all specimens. Mix properties by weight for the different groups are given in Table 2.

3.3. Preparation and casting of test specimens

A space cubic steel frame box used to be a freely supported frame for four sides of plates during the experimental program Fig. 3. Showing The load cell testing machine, LVDT (data show) (Fig. 4). Table 3 includes the description of the reinforcing ferrocement plates used and their reinforcement details to the actual reinforcing plates before failure under impact load and the additional reinforcing for the rehabilitation plates. Fig. 5 shows 3D shape and the details of additional reinforcing for rehabilitation the plates. Fig. 6 shows the AutoCAD comparison between the reinforcing details of the original plates and rehabilitation plates. Fig. 7 shows the details of reinforcing for tension and compression faces of seventeen plates, which damaged under impact loads and their additional reinforcement for rehabilitation. Fig. 2 show the wooden form of plates coated with thin oil film before casting concrete mortar. The layers of welded meshes was then placed and fixed in the two tension and compression sides by means of shear connectors. The concrete mortar was then placed inside, top and bottom of plates and compacted by using the vibrating table to ensure full compaction. After the surface and the center of plates of concrete in molds was leveled, plates were lifted in the forms and covered with polythene sheets for 24 h in laboratory conditions until the sides of the forms were stripped away. After plates were remolded, then plates were immersed in water for 28 days curing before testing. Then the plates were left for 4 h in the laboratory conditions before testing. Its average weight = 31 kg.

Table 3
Reinforcing details of all series of plates before impact load and rehabilitation layers.

The plat NO.	Type of reinforcement Before rehabilitation		Rehabilitation reinforcement
	No. of Steel bars	No. of mesh layers before repairing	
S_3	Steel bars (3Φ6) in two directions	0.0	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
S_4	Steel bars (4Φ6) in two directions	0.0	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
S_5	Steel bars (5Φ6) in two directions	0.0	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
S_6	Steel bars (6Φ6) in two directions	0.0	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
FW_{22}	Welded steel mesh	2 layers top &bottom	2 layers 30 * 30 at the center + two layers 50 * 50 welded meshes top &bottom
FW_{33}	Welded steel mesh	3 layers top &bottom	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
FW_{44}	Welded steel mesh	4 layers top &bottom	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FW_{22}S_2$	Welded steel mesh &steel bar	2 layers welded. mesh top &bottom & (2Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FW_{33}S_2$	Welded steel mesh &steel bar	3 layers top &bottom & (2Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FW_{33}S_3$	Welded steel mesh &steel bar	3 layers top &bottom & (3Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FW_{44}S_3$	Welded steel mesh &steel bar	4 layers top &bottom & (3Φ6)	2 layers 30 * 30 cm at the center + one layer 50*50 cm welded mesh top &bottom
FE_{22}	Expanded steel mesh	2 layers	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
FE_{33}	Expanded steel mesh	3 layers	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FE22S_2$	Expanded steel mesh & steel bars	2 layers top &bottom & (2Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FE_{22}S_3$	Expanded steel mesh & steel bars	2 layers top &bottom & (3Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FE_{33}S_3$	Expanded steel mesh & steel bars	3 layers top &bottom & (3Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom
$FE_{22}S_4$	Expanded steel mesh & steel bars	2 layers top &bottom & (4Φ6)	2 layers 30 * 30 at the center + one layer 50 * 50 welded meshes top &bottom

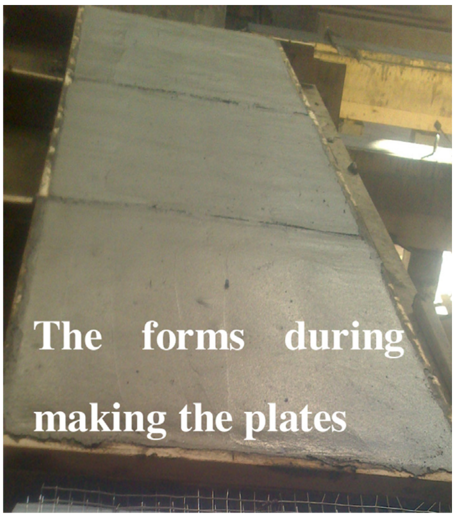


Fig. 2. The wooden forms for the casting plates.

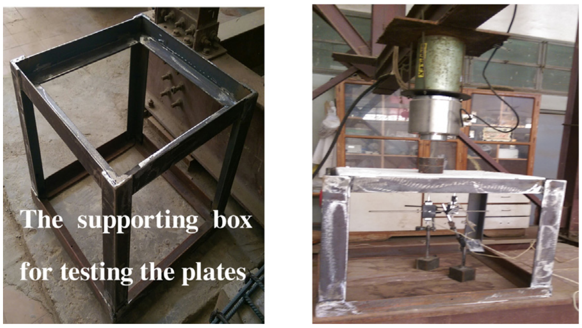


Fig. 3. The cubic steel box and the Test rig.

Fig. 4. LVDT (Data show) and load cell.

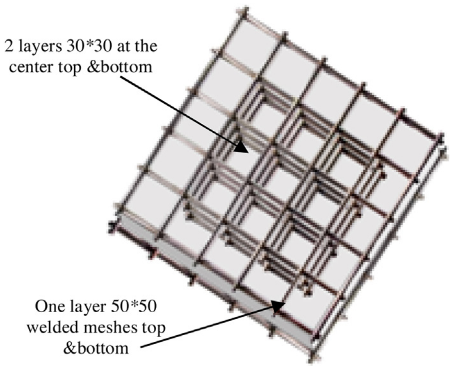


Fig. 5. 3D shape for the welded mesh layers which used to repairing the plates.

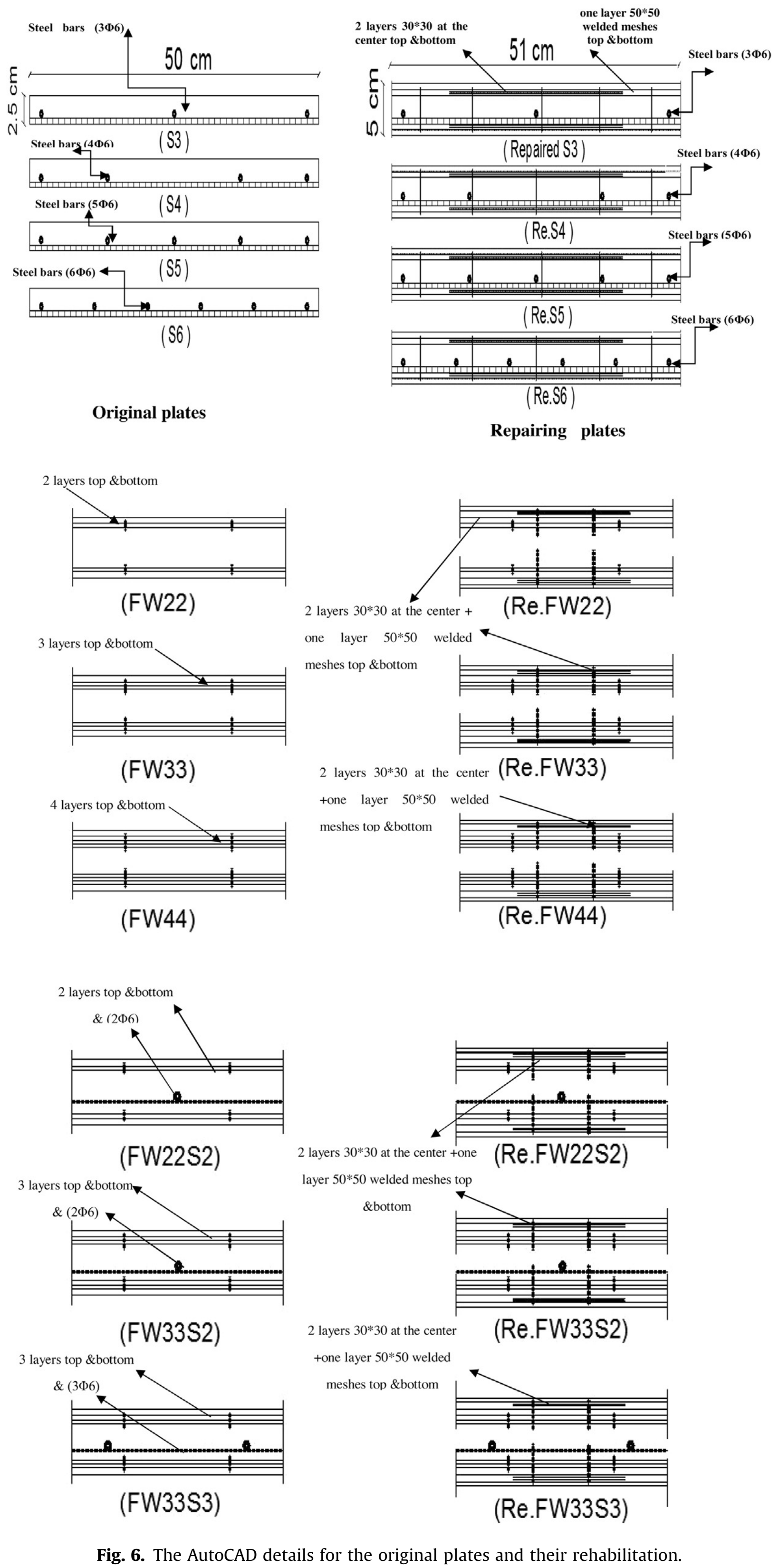


Fig. 6. The AutoCAD details for the original plates and their rehabilitation.

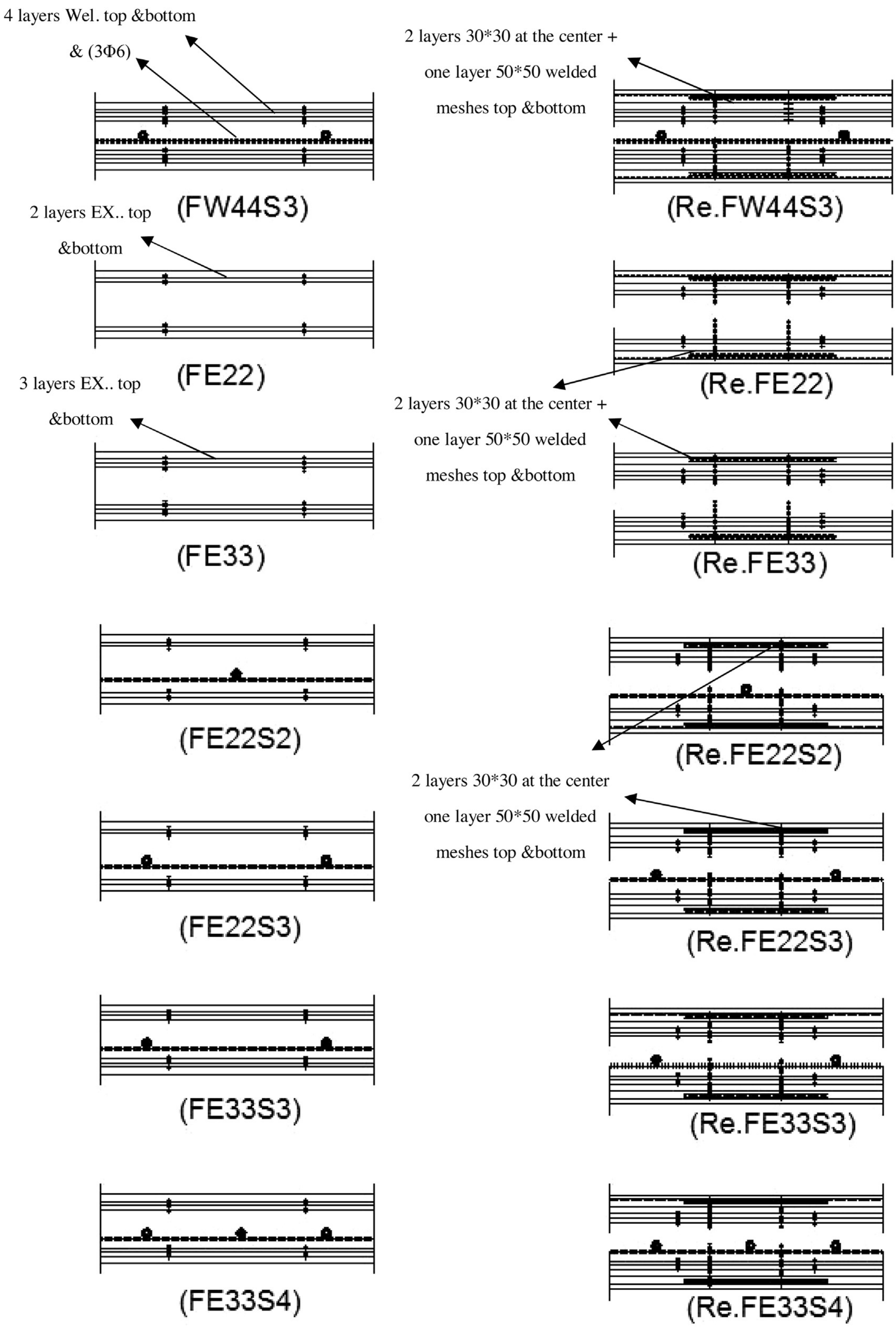


Fig. 6. (Continued)

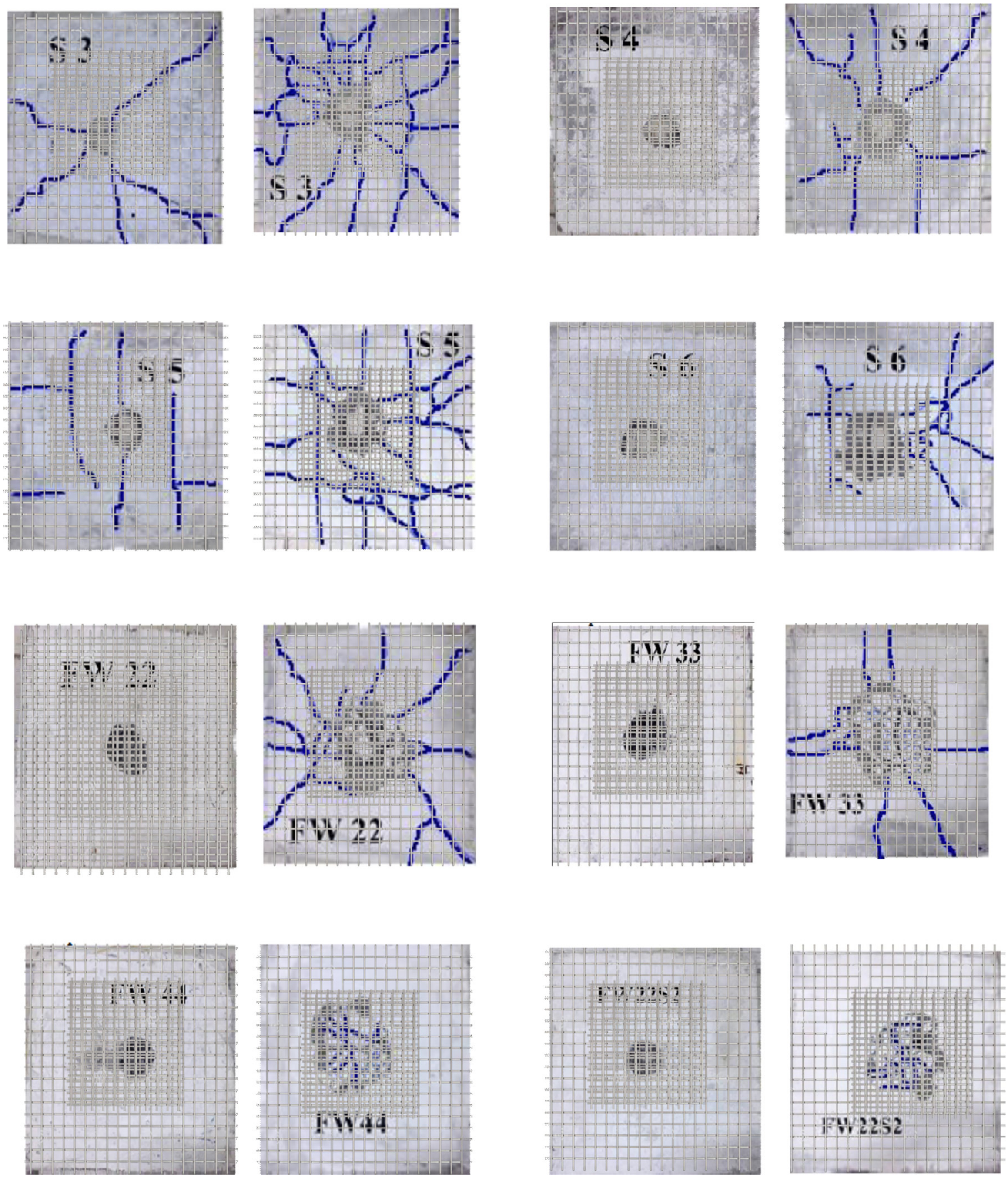


Fig. 7. The tension and compression faces for the rehabilitation of the seventeen plates.

4. Experimental results and discussions

4.1. Initial cracking load and ultimate loads

Chart 1 shows comparison between the first crack load and ultimate load under static case where the first crack load is defined as the load which causes the first crack of tested plates, where the ultimate load (Final load) is defined as the load which causes failure for the plates, there were measured and obtained by the device of LVDT system at the laboratory. It is interesting to note that the ratio between final & 1st cracking loads is about (4, 4, 2.9,2.7) for plates S3, S4, S5, S6 respectively

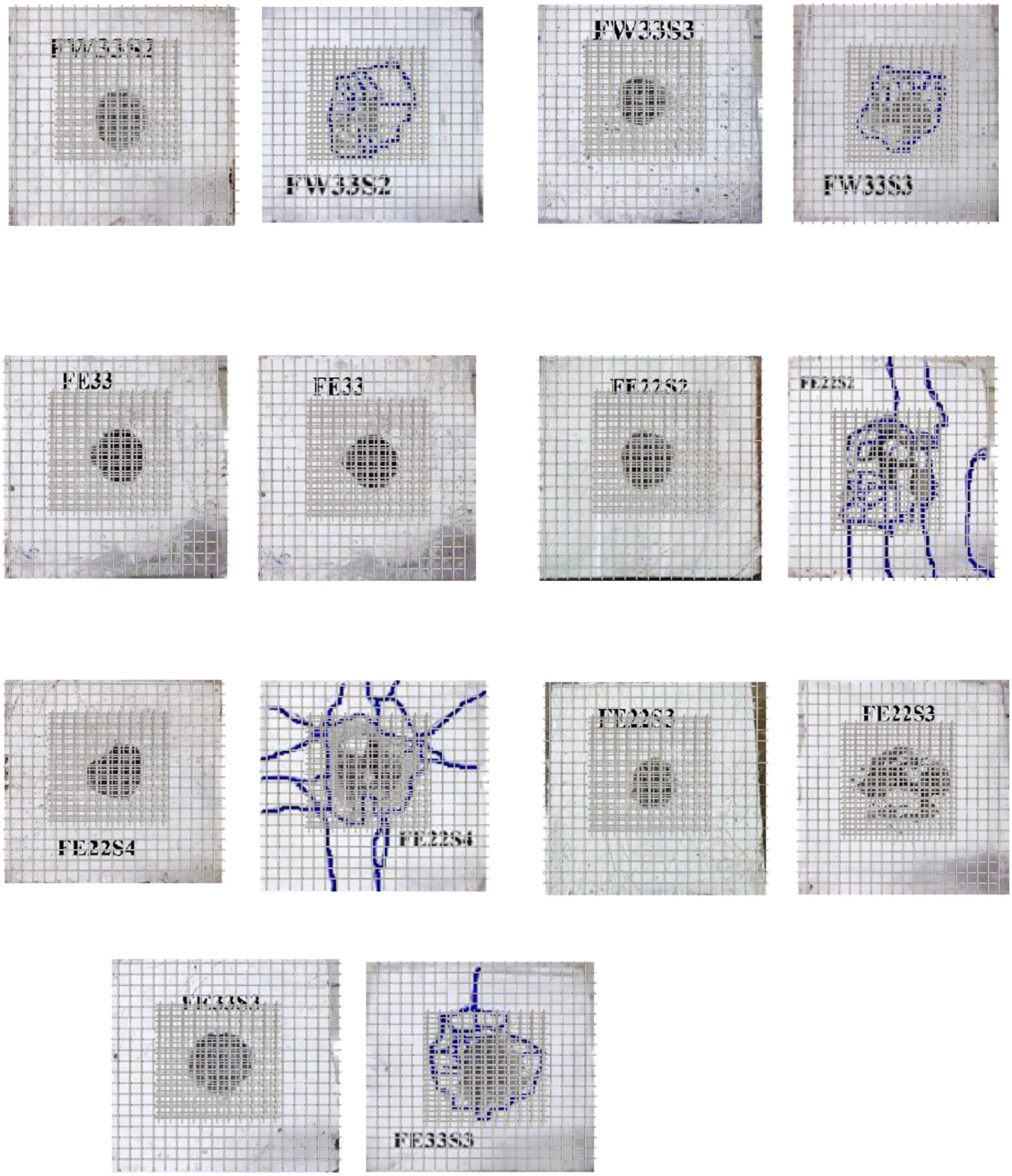


Fig. 7. (Continued)

under static load but it was (2.7, 2.8, 3.33, 3.5) for them under impact loads. For plates FW22, FW33, FW44 under static loads it was (3.75, 2.5, 2.4) but it was (2.5, 3.33, 1.8) under impact loads. For FW22S2, FW33S3, FW33S2, FW44S3 under static case the ratio was (4.2, 4.6, 3.4, 3) and it was (2.4, 4, 2.7, 4) under impact case. The ratio was (4.7, 3.5, 3.4, 3.7, 5.25, 4.4) under static case for FE22, FE33, FE22S2, FE22S3, FE33S3, FE22S4 respectively and it was (4.4, 4.2, 7, 2, 3.5) for dynamic loads. It is interesting to note that the ratio is biggest in case of static load by about (1.3%–1.5%), which indicated the high energy absorption and high ductility. Chart 2 shows that there are a large difference between 1st cracking loads in the two cases with ratio (12.5–25%) in static case after repairing, and Chart 3 emphasized that there is a large difference between the ultimate load ranging from 6.3% to 25%.

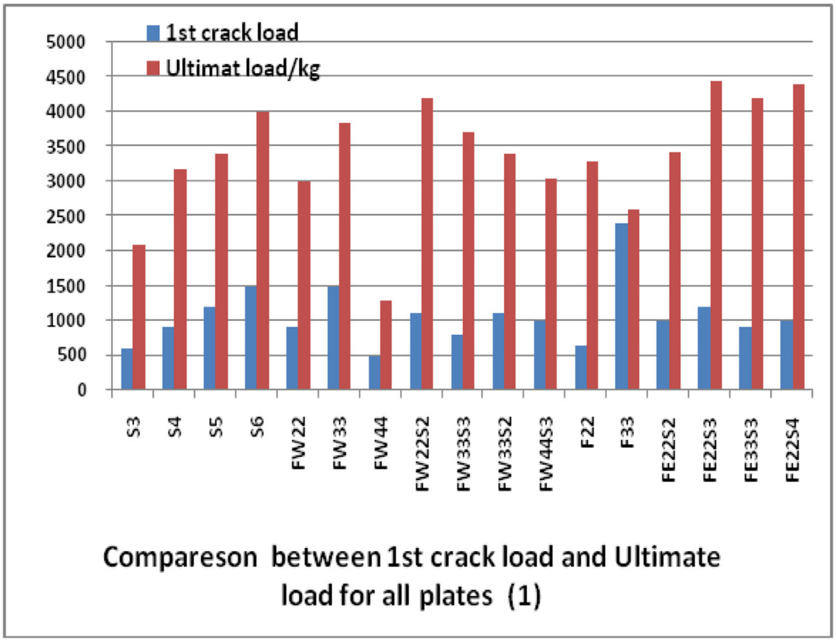


Chart 1.

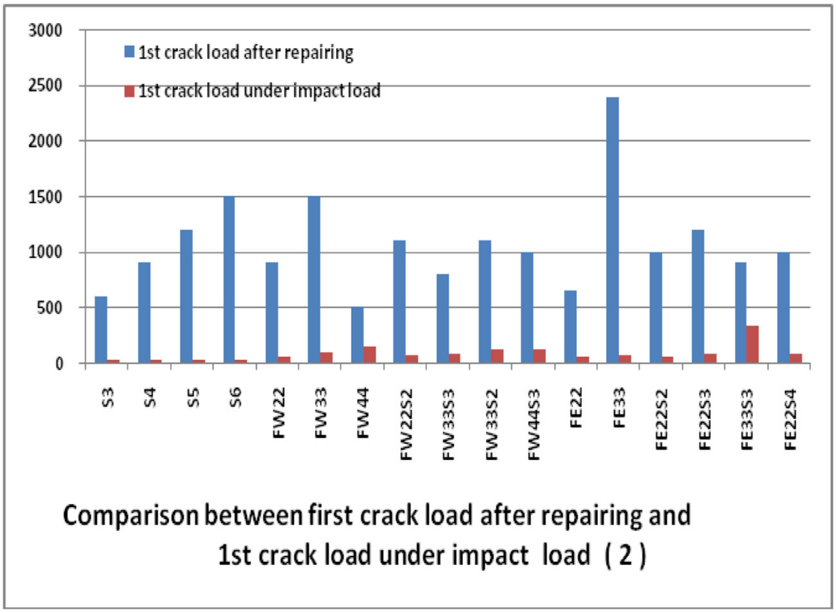


Chart 2.

4.2. Discussions of deflection and ductility ratio

Chart 4 shows comparison between deflections at the center of the repairing plates at 1st cracking loads, the ultimate loads and maximum deflections after the failure. It is interesting to note that the deflections at the first cracking loads are about (2–4 mm) but at the final loads are about (3–18 mm). The maximum deflections at the center of the repairing plates which damaged under impact loads and repaired by one layer welded steel mesh with thickness of 50 mm, are about (14–

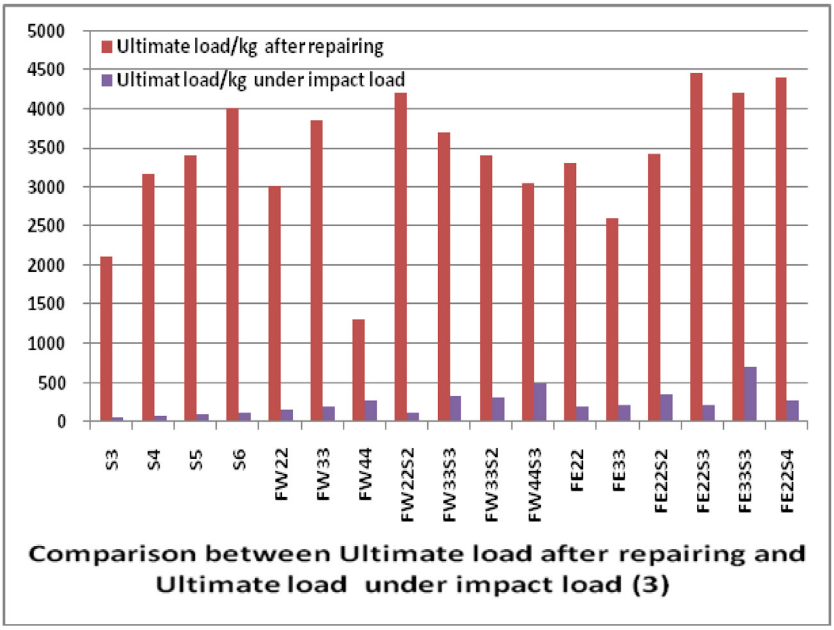


Chart 3.

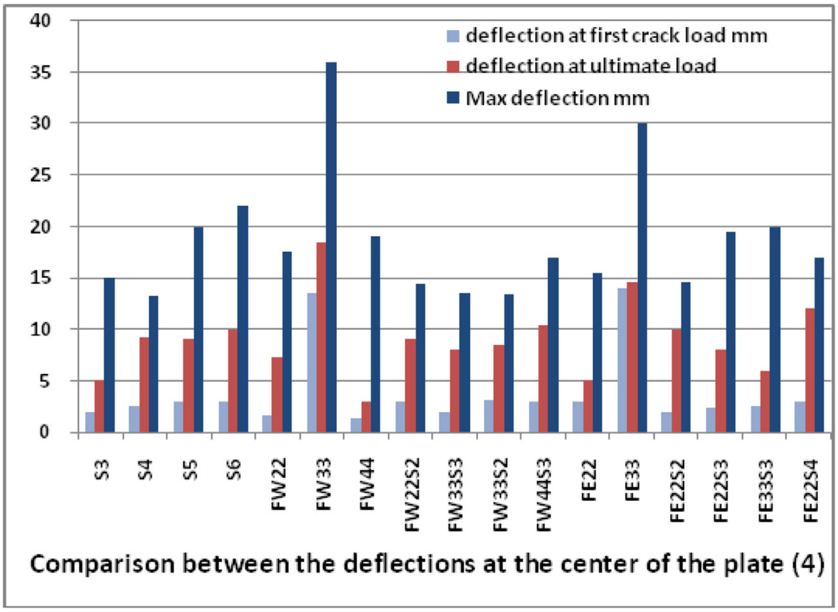


Chart 4.

37 mm) without damaged concrete. The maximum deflections are increased by (2.1–4.7) more than the ultimate load deflections and by (7–9.25) more than 1st cracking load. Behavior of plates is defined by large increase in deformation with little increase in applied load. All repaired plates exhibited large deflection at ultimate loading, which is an indication of high ductility. Chart 5 showing ductility ratio of the repairing plates, which is the ratio between maximum deflection at the ultimate load and that at the initial crack load.

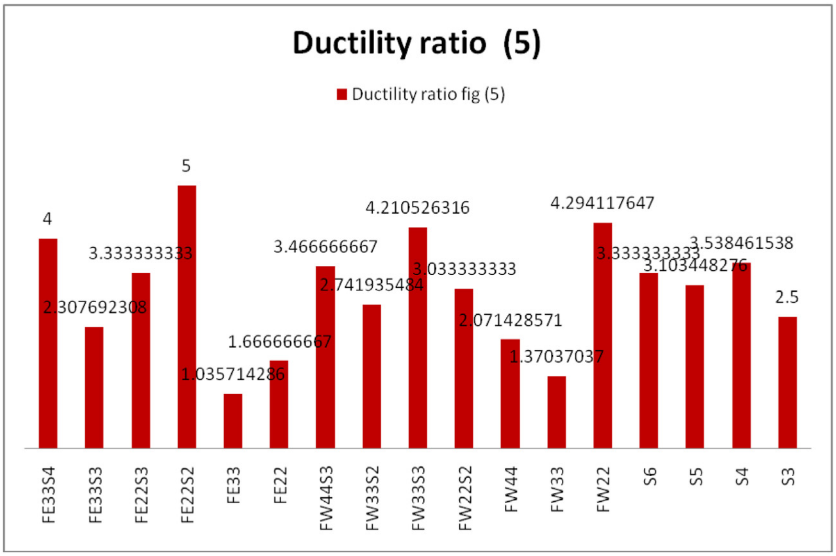


Chart 5.

4.3. The crack pattern at tensile faces

Fig. 8 emphasizes cracking patterns in the tension faces for all repaired plates after the statically compression test and the origin plates which damaged under impact load. It is interesting to note that from comparison that there is good innovation concerning behavior of ferrocement repaired plates under static loads without palling of concrete cover that is predominant. It is obvious that there is a good control of fine cracking widths as result of higher surface area of layers of metal meshes resulting in higher bond of employed reinforcing materials, the smaller: the opening of steel mesh; the better the results. The volume fraction of steel mesh used is 0.596% while its specific surface area equal to 0.341 cm^{-1}. Welded steel mesh is uniformly distributed along both sides resulted in achieving well cracking pattern.

4.4. Deflection – load curves

Fig. 9 explains the Load – Deflection curves for the rehabilitation plates and showing the comparison between them of the energy observed for all plates under static load.

Table 5 explains comparisons between the values of serviceability load, first crack load, deflection at the first crack load and the ultimate load, the ductility ratio and energy absorption for all the repairing plates which have the same ferrocement jacket in rehabilitation but different types of original reinforcing materials.

4.5. The first crack load and ultimate load before and after rehabilitation

Table 4 emphasizes comparison between first crack loads and the ultimate loads after and before rehabilitation and their corresponding percentages. However, there are a huge percentages values and increasing in loads after rehabilitation (in statically case).

5. Conclusions

1. Irrespective of the type of welded steel mesh employed in rehabilitation ferrcement plates leads to improve ductility ratio and energy absorption and consequently increases ultimate load also good cracking pattern reached without spalling of concrete cover that is predominant.
2. The existence of the synthetic fibers resulted in retarding the occurrence of the first crack and better crack distribution in the ferrocement composites.
3. Using ferrocement concrete in repairing is helpful because it is cheaper, easier in casting and lightweight materials in repairing.
4. Welded meshes have a higher modulus and hence higher stiffness which leads to smaller crack widths in initial portion of the load – deformation curve. This leads to a higher stiffness of the tested specimen.

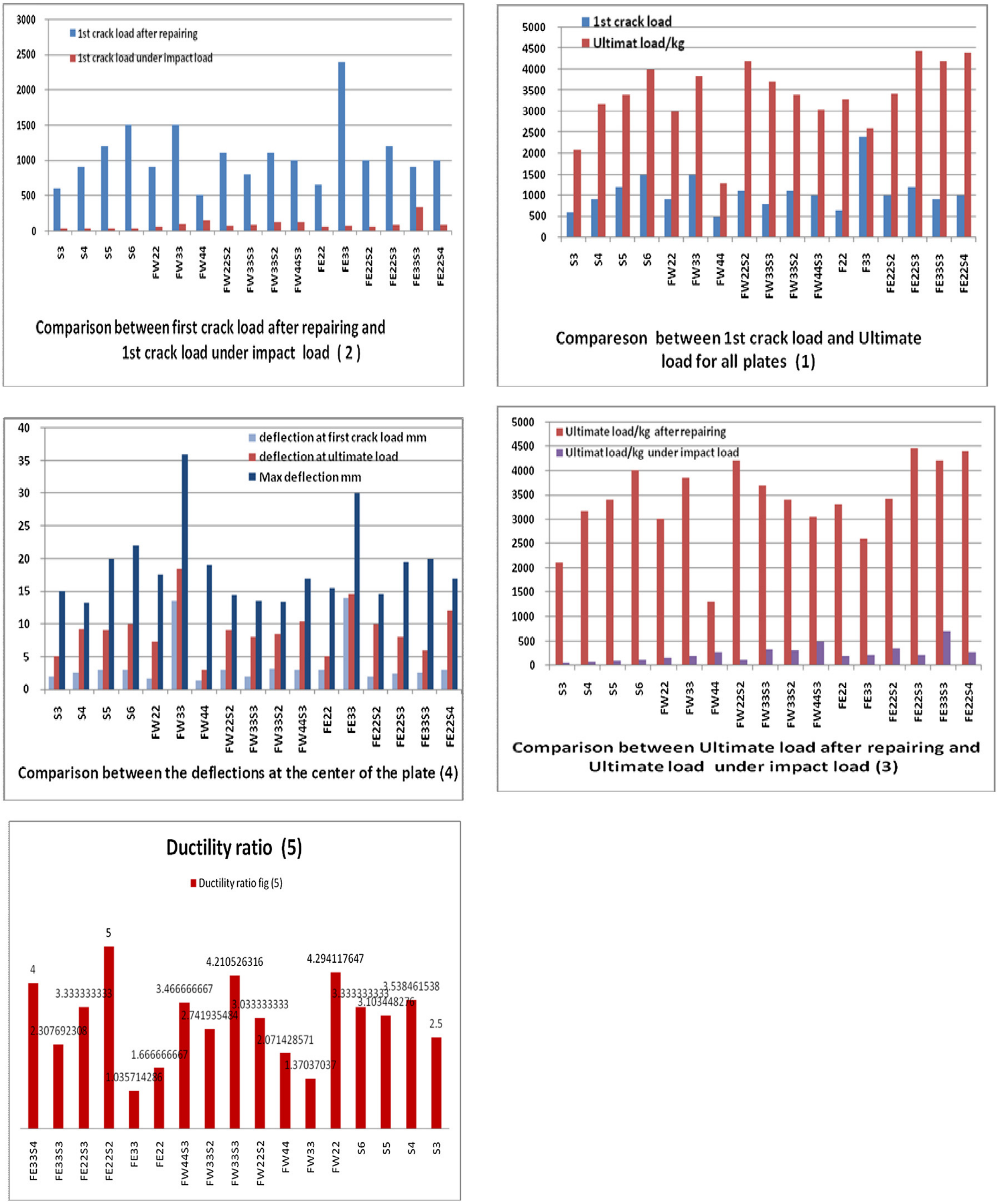


Fig. 8. The comparison between cracking patterns of rehabilitation plates (Re.) And original plates at tension face.

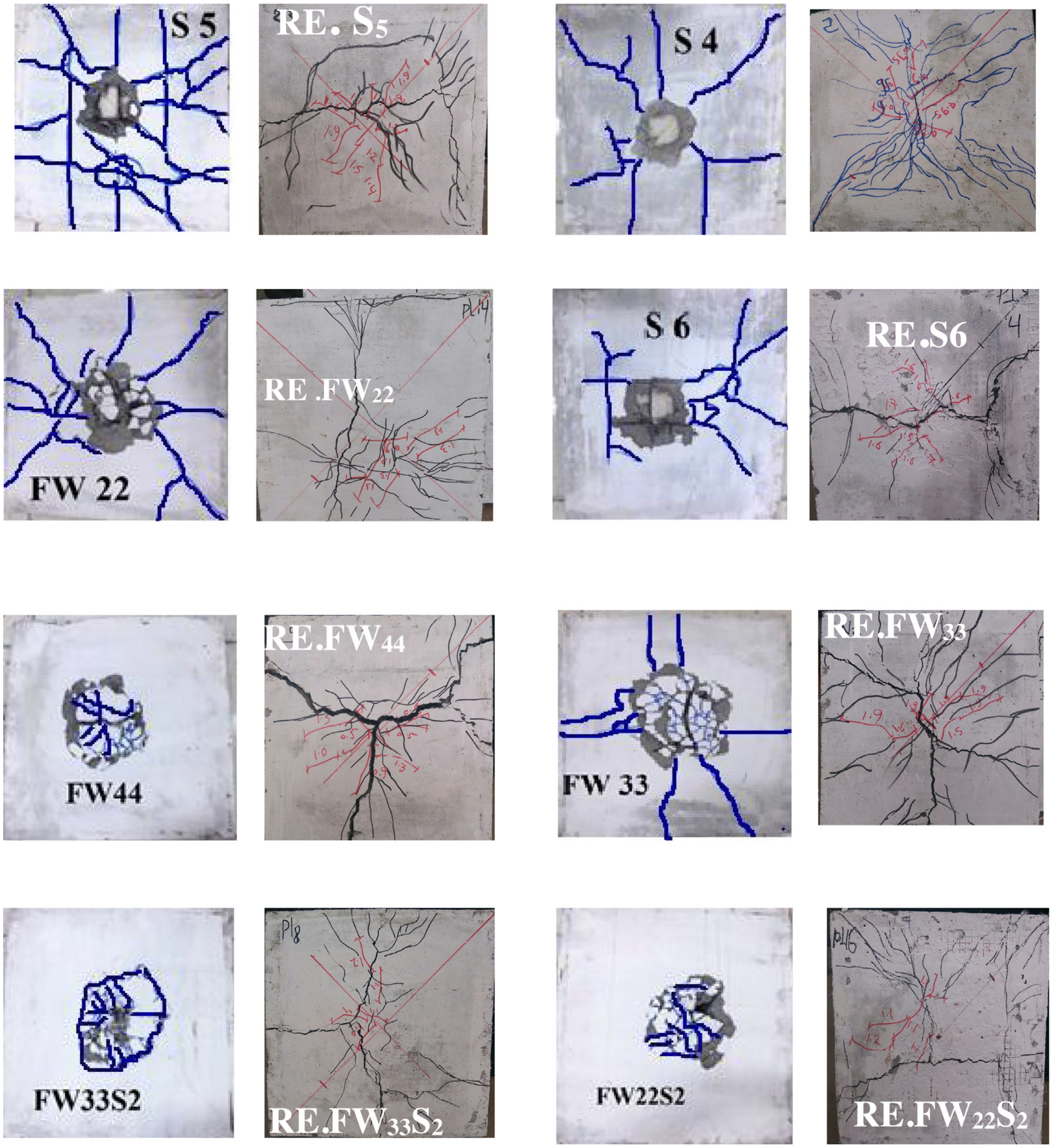


Fig. 8. (Continued)

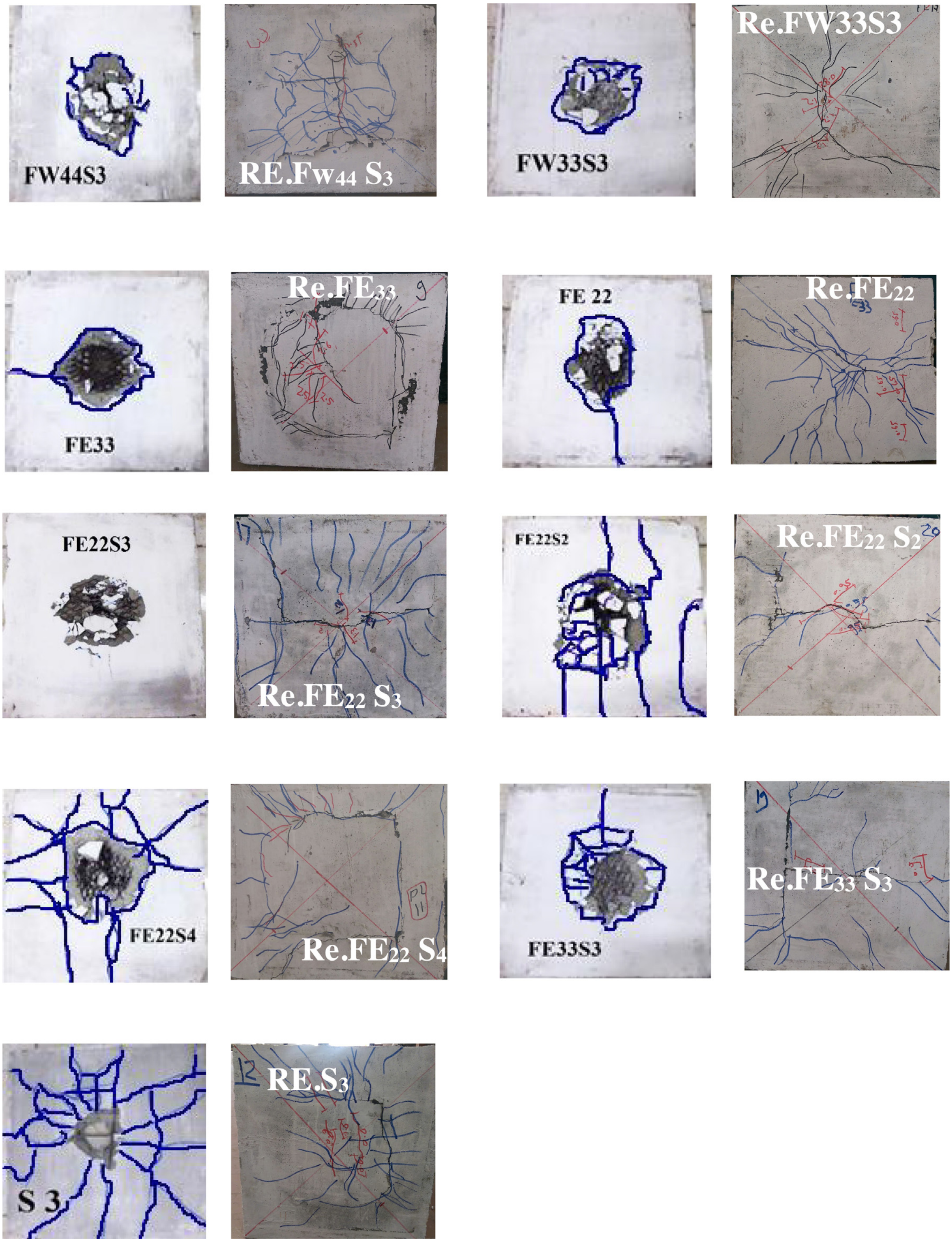


Fig. 8. (Continued)

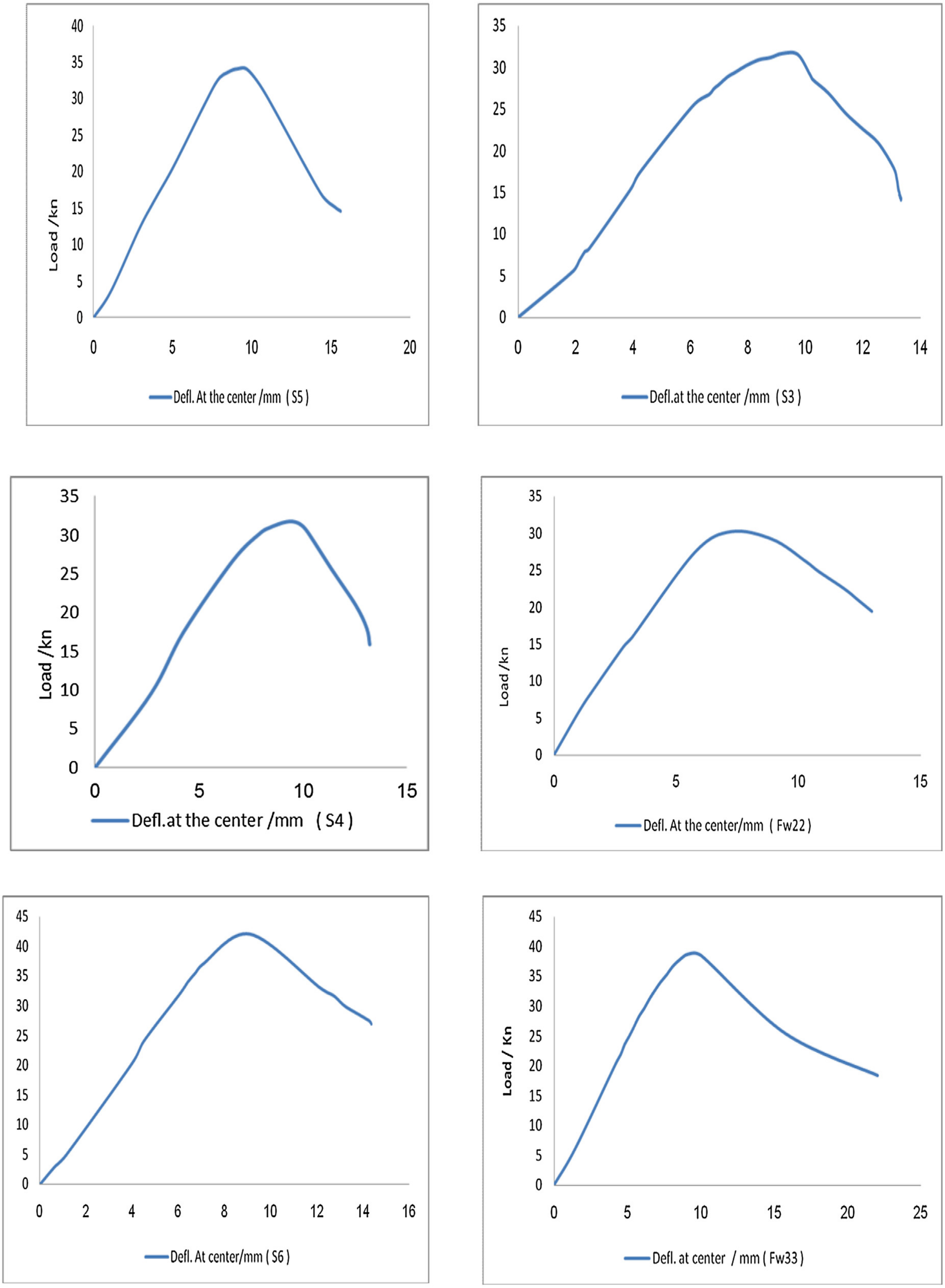


Fig. 9. Load – Deflection Curves.

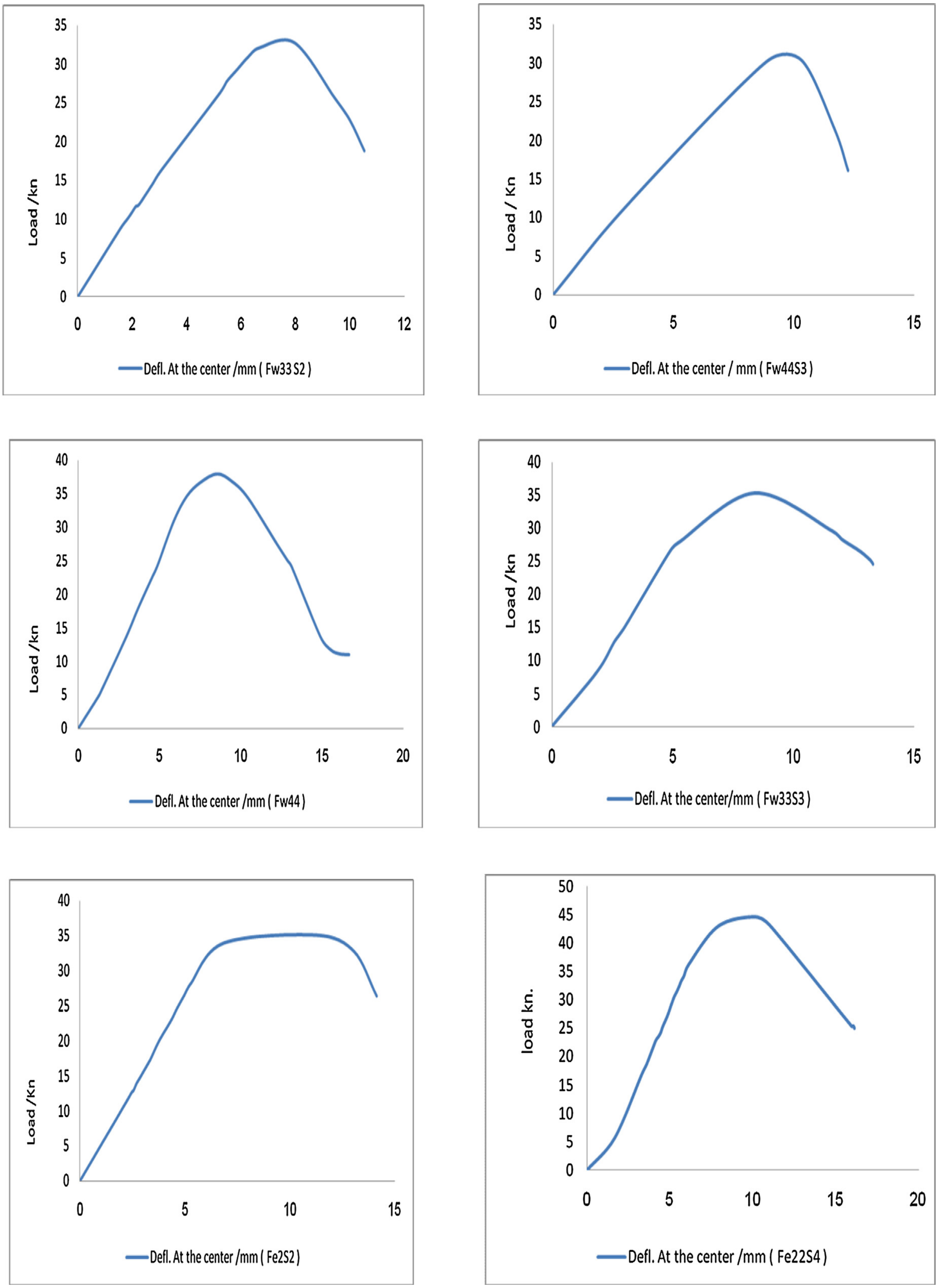
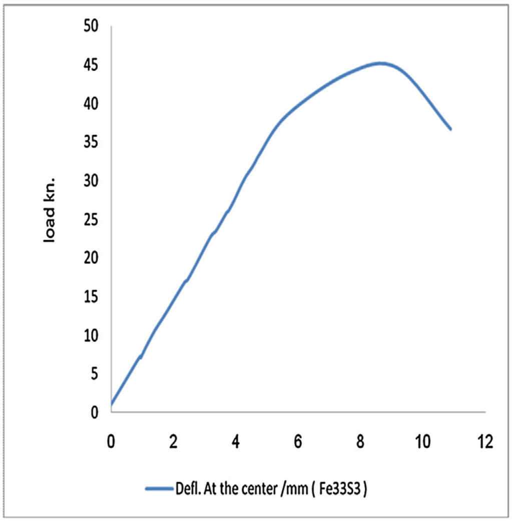
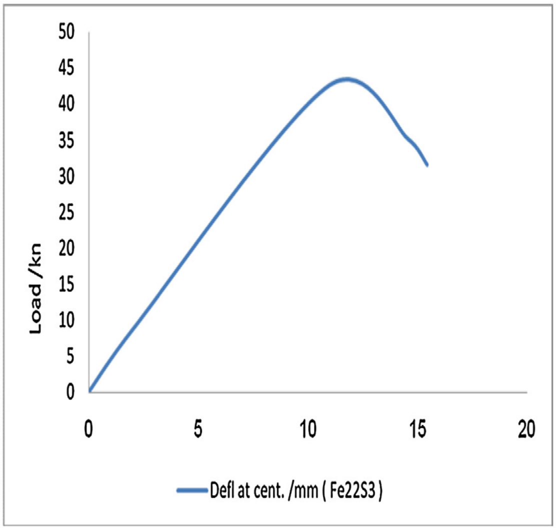
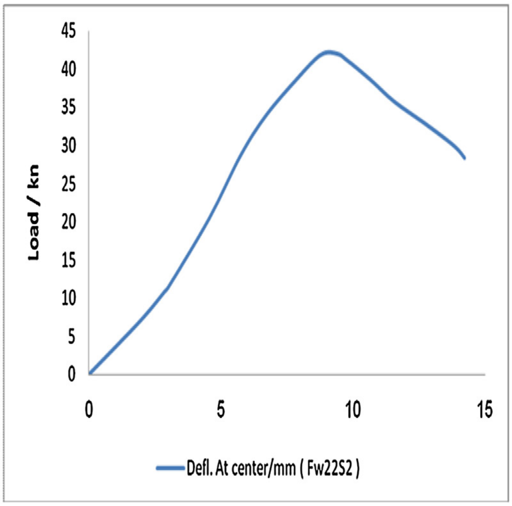
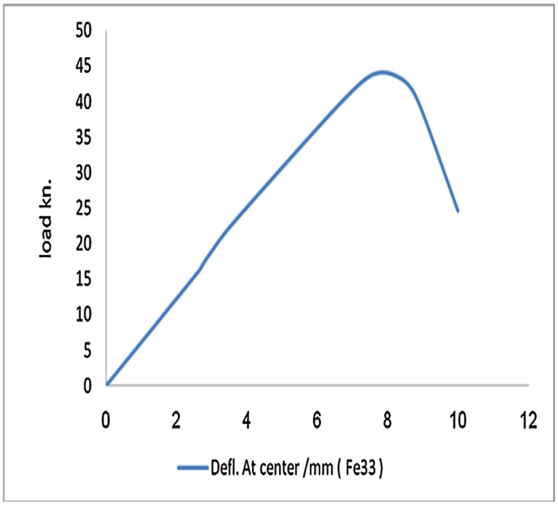


Fig. 9. (Continued)









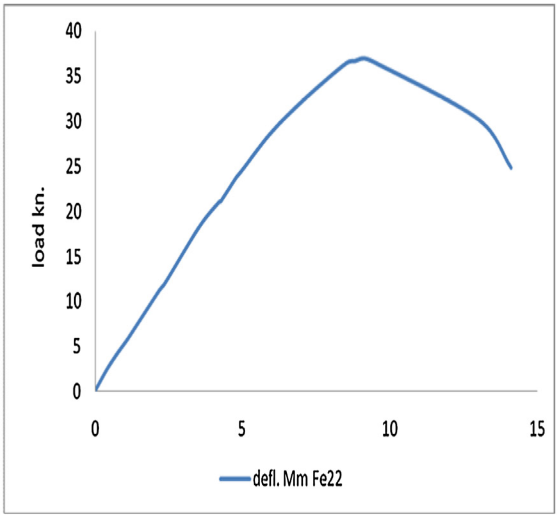


Fig. 9. (Continued)

Table 4
comparison between the first crack load and the ultimate load in cases of original and rehabilitation plates.

% of Pu of rehabilitation and original plates	Ultimate load,KN of rehabilitation plates	Ultimate load, KN for the original plates	% of first crack rehabilitation and original plates	The first crack load, KN of rehabilitation plates	The first crack load, KN of original plates	PL. NO.
20.56%	37.04	1.8	5.1%	2.55	0.5	Fe22
10.6%	35.03	3.3	13.33%	10	0.75	Fe2s2
21.19%	44.5	2.1	15%	12	0.8	Fe22s3
15.93%	44.6	2.8	5.56%	5	0.9	Fe22s4
21.15	44.42	2.1	3.71%	2.6	0.7	Fe33
32.29%	41.98	1.3	8.3%	5	0.6	Fw2s2
10.74%	34.37	3.2	5.83%	7	1.2	Fw3s2
11.2%	36.96	3.3	10%	8	0.8	Fw33s3
9.73%	37.96	3.9	3.26%	5.55	1.7	Fw44
6.34%	30.41	4.8	4.54%	5	1.1	Fw44s3
23.23%	30.2	1.3	12.86%	9	0.7	Fw22
18.45%	38.74	2.1	13.63%	15	1.1	Fw33
37.32%	31.72	0.85	16.67%	5	0.3	S4
35.9%	34.1	0.95	12.33%	3.7	0.3	S5
6.37%	44.58	7	3.36%	11.1	3.3	Fe3s3
26.38%	21.1	0.8	34.1%	6.82	0.2	S3
33.33%	40	1.2	25.71%	9	0.35	S6

Table 5
Serviceability load, Ductility ratio, and Energy absorption.

Energy absorption, KN. mm	Ductility ratio Def.at P_u/Def.at P_{first}	Defl. at first crack load, mm	Defl. at Pu, mm	Ultimate load, KN	Serviceability load[a],KN	First crack load, KN	Plate No.
355	33.33	0.64	9.11	37.04	9	2.55	Fe22
362	3.5	4	11.3	35.03	11	10	Fe2s2
471	2.5	2	8.12	44.5	6	12	Fe22s3
390	10	2.3	10.13	44.6	7	5	Fe22s4
261.5	11.25	0.8	8.12	44.42	10	2.6	Fe33
392	7.67	3	9.4	41.98	7	5	Fw2s2
253.5	9	1	9	34.37	10	7	Fw3s2
321.75	5.9	2	7.57	36.96	9	8	Fw33s3
364.5	7.67	1.3	8.5	37.96	8	5.55	Fw44
233.5	10	3.1	10.3	30.41	8	5	Fw44s3
272	6.67	1.7	7.3	30.2	10	9	Fw22
539	4.1	2.8	9.1	38.74	20	15	Fw33
259	7.2	1.6	9.2	31.72	7	5	S4
329.5	10.7	1.1	9.1	34.1	7	3.7	S5
427.5	4.74	2.3	7.9	44.58	13	11.1	Fe3s3
229	3.1	2.1	5	21.1	7	6.82	S3
372	4.71	3.7	10	40	10	9	S6

[a] The load corresponding to deflection equal to span/250.

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