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Structural and Dynamic Behavior of Concrete Beams reinforced with innovative Composite Materials

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ملخص البحث

يهدف البحث الى دراسة السلوك الانشائى والديناميكى للكمرات الخرسانية المسلحة من المواد المركبة والمبتكرة. والدراسة تجريبية ونظرية ، و يشمل البرنامج العملى على صب واختبار ثمانية عشر كمرة ذات أبعاد 300 مم × 60 مم ×60 مم مقسمة الى مجموعتين تسعة كمرات تم اختبارها استاتيكا و تسعة كمرات تم اختبارها ديناميكا ، وأظهرت نتائج الاختبار للبرنامج العملى أن الكمرة الفروسمنتية التي عززت مع مواد التسليح المبتكرة حققت خصائص تشوه أفضل، مقاومة للصدم، ليونة عالية وخصائص امتصاص الطاقة افضل من الخرسانة المسلحة ،زيادة طبقة الشبك المعدنى سواء ملحومة أو شبكة معدنية ممددة نظرا لامتصاص الطاقة أعلى من الكمرات التقليدية، تم استخدام تحليل العناصر المحددة للتنبؤ بسلوك الكمرات ، وتبين المقارنة بين التنبؤ التحليلي ونتائج اختبارتحليل العناصر المحددة ووجد توافق جيد بين الاسلوبين ، وتاثير الظروف الانشائية المحيطية من تاثير الترددات وتسليح الكمرات ووجود تغيرات كبيرة لذلك.

ABSTRACT

The main objective of this research is to study the structural behavior of concrete beams reinforced with advanced and innovative composite materials. The study is experimental and theoretical. The experimental work includes casting and testing eighteen reinforced concrete test beams having the dimensions of 300 mm long, 60 mm width and 60 mm depth will be tested as simply supported beams under central line loadings until failure. All deformation characteristics will be measured for beams subjected to static and dynamic loadings. The ductility ratio and energy absorption properties will be investigated. Comparisons between experimental and theoretical study using nonlinear finite element program and also calculations will be made. Economic investigation will be reached. Comparison of analytical prediction and test results shows good agreement of experimental work.

Keywords: Ferrocement, beams, ANSYS, Experimental, Ultimate_load, behavior, static

1. Introduction

Research to improve concrete durability, strength, and cost [6], largely carried out by partial replacement of the traditional constituents materials with cheaper alternatives have yielded some interesting outcomes. Considering however, the usual high volume of concrete used in buildings, the cost of producing concrete can still be said to be high.

Thus, further research dwelling on optimum utilization of concrete in buildings and other structures is essential and hence this study.

Designs of RC structural elements are mostly based on either national or international standards (codes), which are often put together to ensure provision of sections with adequate strength to resist both self and live loads during the expected service life of the structure.

Structural elements made of concrete can be subjected to a wide range of loading conditions during their service life, from very low strain rate up to severe dynamic events such as blast explosions, missiles, earthquakes, projectiles, and more. Due to the inherent brittleness and low tensile strength of most cement-based elements they do not always possess enough strength, toughness and ductility to maintain integrity without collapse under impact and other dynamic loads. As a result, ex- termer events can cause severe damage to the building [13]

2. Experimental program

The experimental program held in this study was performed in the laboratory of testing of building materials at the Faculty of Engineering, Menoufia University, Egypt. The experimental program was divided into two phases, the first phase regarding the reinforcement, in this program, eighteen specimens were cast and tested in order to study their behavior under flexural loadings ,dynamic work (see Table 1).There are designed according to Egyptian code of practice (E.C.P. 203/2007) . [5]

The main objective was to determine the mechanical properties of the used steel and wire meshes. The second phase, the main objective was studying the ultimate load, flexural behavior, ductility ratio, energy absorption and mode of failure at collapse of the control beams, which were reinforced with steel and to compare their behavior with those conventional reinforced ferrocement beams reinforced with expanded metal mesh, welded metal mesh.

2.1 Materials

1-The fine aggregate was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007), (E.S.S. 1109/2008). with a modulus of fineness 2.7.[5], [7]
2- The cement CEM I (42.5 N) was used during the study. The Type cement as in the Egyptian Standard Specification E.S.S. 4756-1/2009.[8]

3-The water used was the clean drinking water according to the (E.C.P. 203/2007) [5] .
4-Chemical admixture (super plasticizer) 1% by weight of powder .
4-Pozzolanic material (silica fume -. Fly ash) 10% , 20% of cement content respectively.
5-weight.,polypropylene fibers by volume (0.9 kg/m^3).
6- Reinforcement(Mild Steel 3mm diameter),(Galvanized welded steel mesh ,The mesh has a weight of 450 gm/m^2),Expanded metal wire mesh, The mesh has a weight of 1250 gm/m^2)

***Table (1): Mechanical properties of steel meshes*[21]**

Mesh type	Proof Stress (N/mm^2)	Proof Strain x 10^{-3}	Ultimate Strength (N/mm^2)	Ultimate Strain x 10^{-3}
Welded	400	1.3	600	60
Expanded	199	9.7	320	59.2

Table (2) Ferrocement mortar mix properties by weight /m3

Cement	Sand	Water	Fly ash	Super plasticizer	Silica fume	Fiber
479.14	1592	268	136.8	6.84	68.4	0.9

Table(1): Reinforcement of beams

Code	Vr%	Steel Bars	Stirrups	Meshes
BC6	1.071	2ø3 mm bottom 2ø3 mm Top	6ø2.2 mm /b	-
BC3	1.355		3ø2.2 mm /b	-
BC3E1	1.601			1 Layer Expanded mesh
BE1	0.530	-	-	
BE2	1.061	-	-	2 Layer Expanded mesh
BE3	2.120	-	-	3 Layer Expanded mesh
BW1	0.382	-	-	1 Layer welded mesh
BW2	0.764	-	-	2 Layer welded mesh
BW3	1.146	-	-	3 Layer welded mesh

3.Experimental work

Includes casting and testing eighteen reinforced concrete test beams having the dimensions of 300 mm long, 60 mm width and 60 mm depth, nine beams for static tests, and another nine beams for dynamic test

3.1 Flexural Test

All beams were painted with diluted white lime solution to facilitate observations of cracks during testing. One day before testing. The (nine beams) were tested under one line loadings by using flexural testing machine of maximum capacity of 100KN. The load was applied on successive increments. Dial gauges for measuring the beam deflection were fixed in position at the bottom face of the tension side. The strains, deflections and crack propagation were recorded after each load increment and up till failure. Fig. 1 shows test specimen on the flexural testing machine.

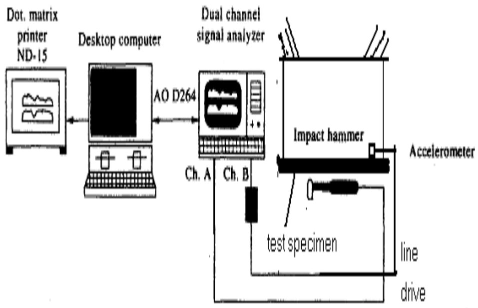


Fig. 1 Test specimen on the flexural testing **Fig. 2 Set up for dynamic testing** [20]

3.2 Dynamic test

Fig.2 shows a general view of test arrangement for structure with additional masses. The instrumentation used in the test includes an impact hammer, uni-axial accelerometers, a multi-channel data acquisition unit and a display unit (laptop computer).

4. Experimental Static Results and Discussions

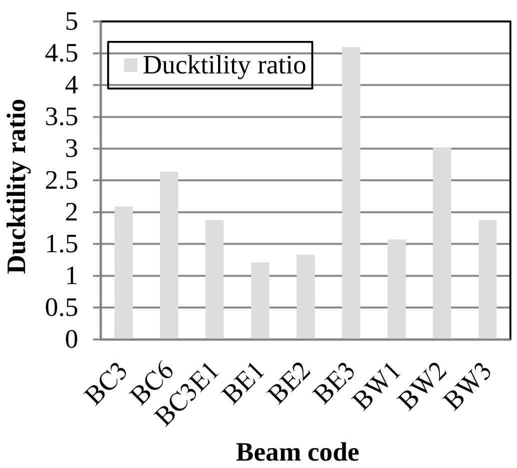
The experimental results of the static program and the discussions are presented. Comparisons are conducted between the results of the different test groups to examine the effect of the test parameters under investigation; existence of the permanent ferrocement forms, type of mesh reinforcement. The effects of these parameters on the structural responses of the proposed beams in terms of failure load, mode of failure, first crack load, ductility ratio, and energy absorption were studied extensively.

4.1 First crack load, Ultimate load of beams

The first crack load was determined from the load deflection curve at the point at which the load-deflection curve started to deviate from the linear relationship. Figure 4. shows the a comparison between beams in First crack load, Ultimate load.

4.2 Ductility Ratio

The ductility ratio was calculated as the mid span deflection at the ultimate load to that of the first cracking load.



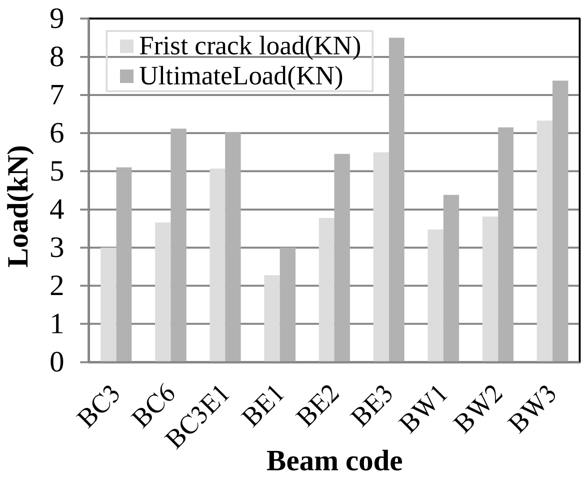


Fig. (3) The ductility ratio for beams **Fig. (4)ultimate load and first crack load**

4.3 Energy Absorption

The energy absorption was obtained by calculating the area under the load-deflection curve for each beam.

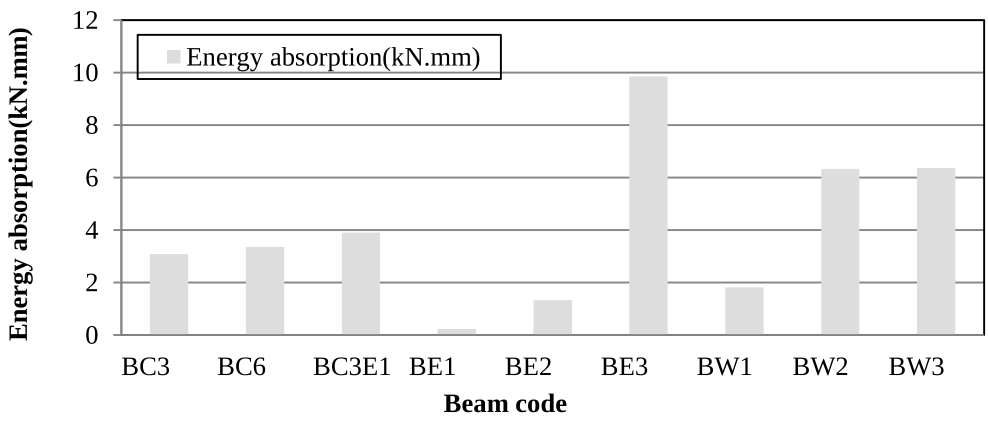
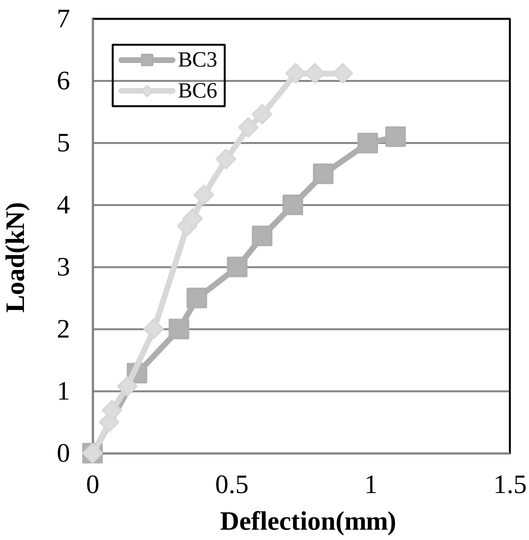


Fig. (5)The energy absorption for all test specimens

4.4 Load-Deflection Relationship



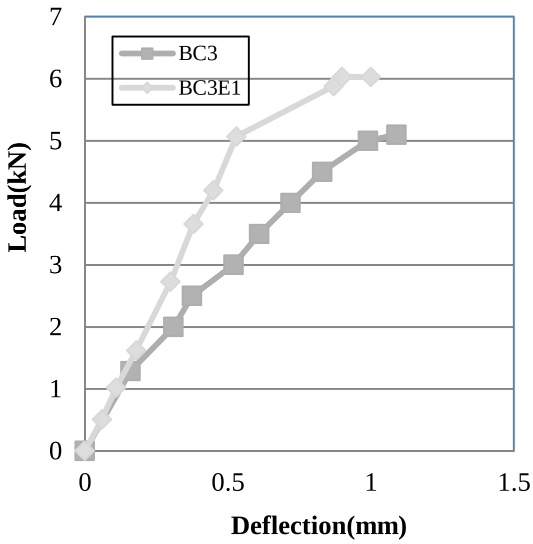


Fig. (6) Load- deflection curve of beams (BC3,BC6). Fig. (7) Load- deflection curve of beams (BC3,BC3E1).

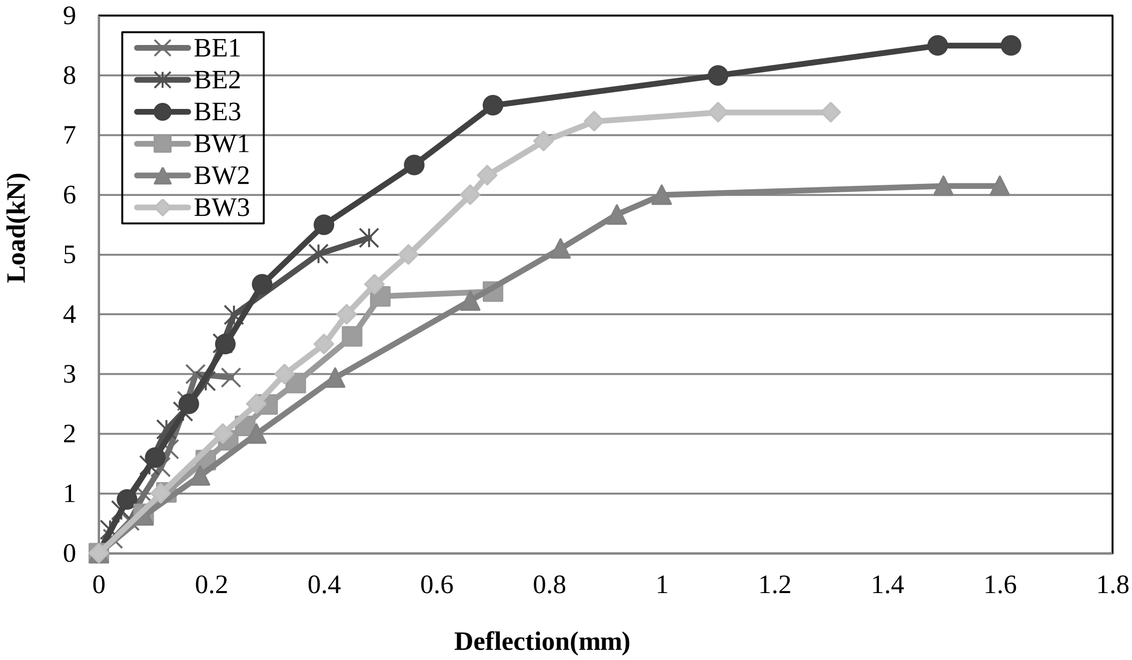


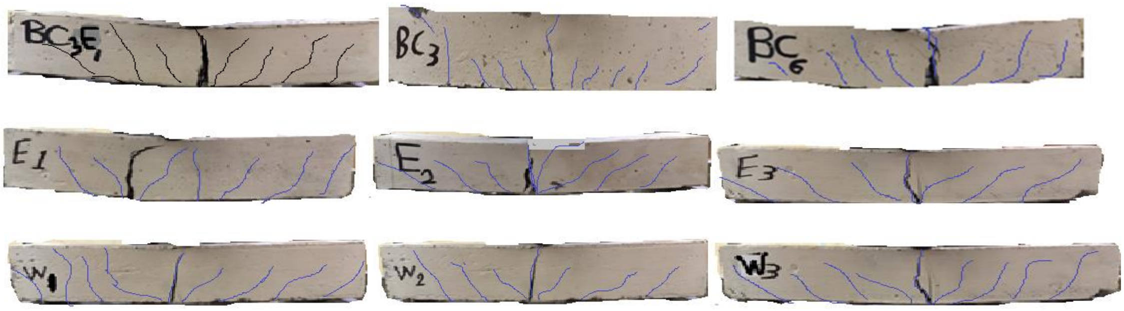
Fig. (8) Load- deflection curve of beams (BE1,BE2,BE3,BW1,BW2,BW3).

From fig(3,4,5,6) The first cracking load for BC3 and BC6 is 3kN and 3.66 kN respectively, The first cracking load for BC6 is more than BC3 by 22%., The ultimate load for BC3 and BC6 is 5.1k N and 6.12 k N. ,The ultimate load for BC6 is more than BC3 by 20 %., The ductility ratio for BC6 is more than BC3 by 26.3 %., The energy absorption for BC6 is more than BC3 by 11.3%.,That show effect of number of stirrups for control beams.

From fig(3,4,5,7) The first cracking load for BC3 and BC3E1 is 3kN and 5.07 kN respectively, The first cracking load for BC3E1 is more than BC3 by 69%. ,The ultimate load for BC3 and BC3E1 is 5.1kN and 6.03 kN ,The ultimate load for BC3E1 is more than BC3 by 18.2 %.,The energy absorption for BC6 is more than BC3 by 26.3%. ,That show effect of adding one expanded layer for control beam.

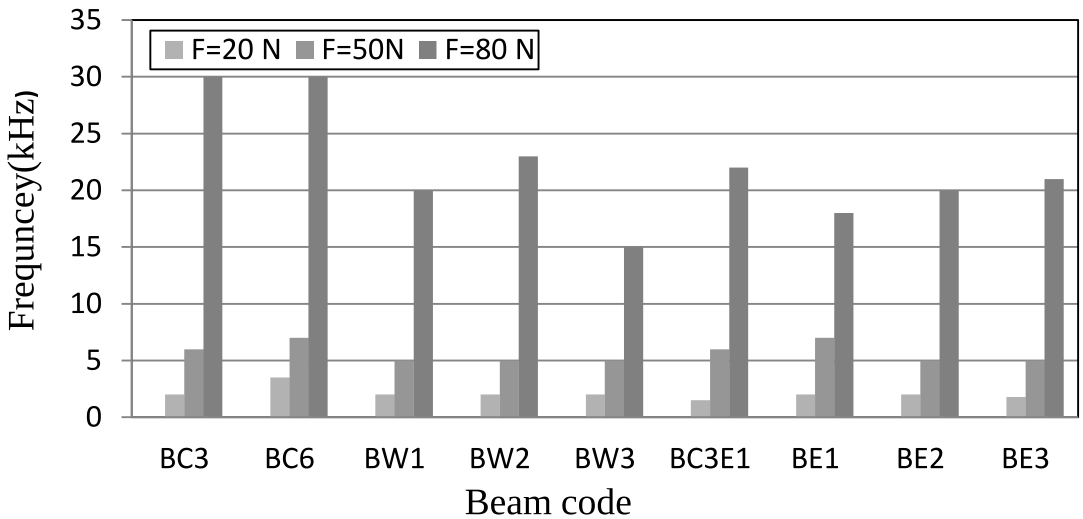
From fig (3,4,5,8) The first cracking load for BW1, BE1 is 3.48 kN ,2.28 kN respectively , The first cracking load for BW1 is more than BE1 by 52.63 % , The ultimate load for BW1, BE1 is 4.38 kN ,3 kN respectively , The ultimate load for BW1is more than BE1 by 46 % , The ductility ratio for BW1 is more than BE1 by 29.75 % , The energy absorption for BW1 is more than BE1 by 691.3% , The first cracking load for BW2, BE2 is 3.81 k N ,3 kN respectively , The first cracking load for BW1is more than BE1 by 7.93 % , The ultimate load for BW2, BE2 is 6.15 kN ,5.46 kN respectively , The ultimate load for BW2is more than BE2 by 12.64 % , The ductility ratio for BW2 is more than BE1 by 127.06 % , The energy absorption for BW2 is more than BE2 by 375.94 %. ,The first cracking load for BE3, BW3 is 5.5 k N , 6.33 kN respectively , The first cracking load for BW3 is more than BE3 by 15.09 % , The ultimate load for BW3, BE3 is 7.38 kN ,8.5 kN respectively , The ultimate load for BE3 is more than BW3 by 15.2 % , The ductility ratio for BE3 is more than BW3 by 67.78 % , The energy absorption for BW3 is more than BE3 by 6.32 %.

5.Cracking Patterns



6. Experimental Dynamic Results and Discussions

Frequency Response Force (FRF)



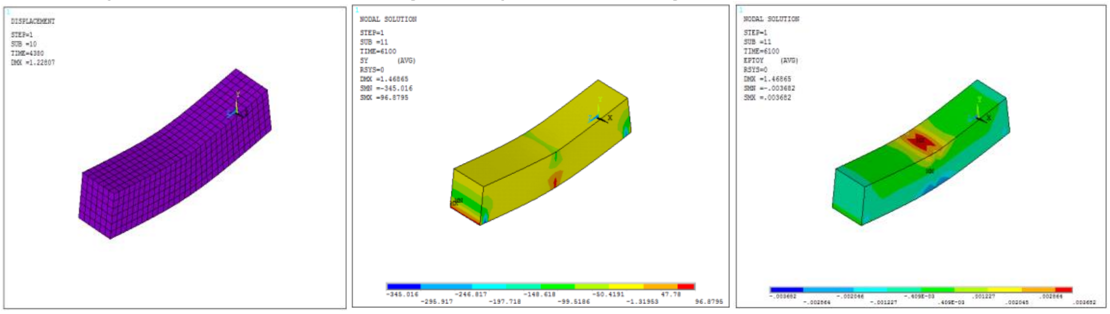
Fig(9) Frequency Response Force (FRF) for tested beams.

From fig(9) Beam (BC6) Achieve high frequency than other beams ,that belongs its weight (**2.587 KG)** ,The weight is directly proportional to the frequency as the weight increases the frequency increases and vice versa.

7. FINITE ELEMENT ANALYSES

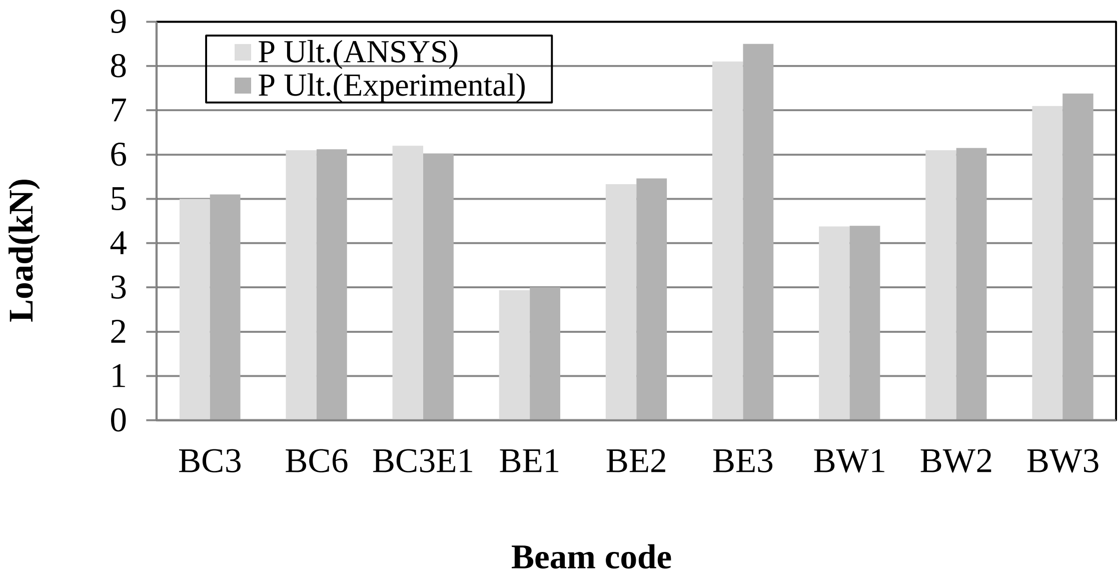
The following steps are involved in analyzing the trough element using the finite element software package ANSYS 15.

Element selection , Defining material properties, Model creation., Meshing., Applying boundary conditions and loading. Analysis., Viewing results.



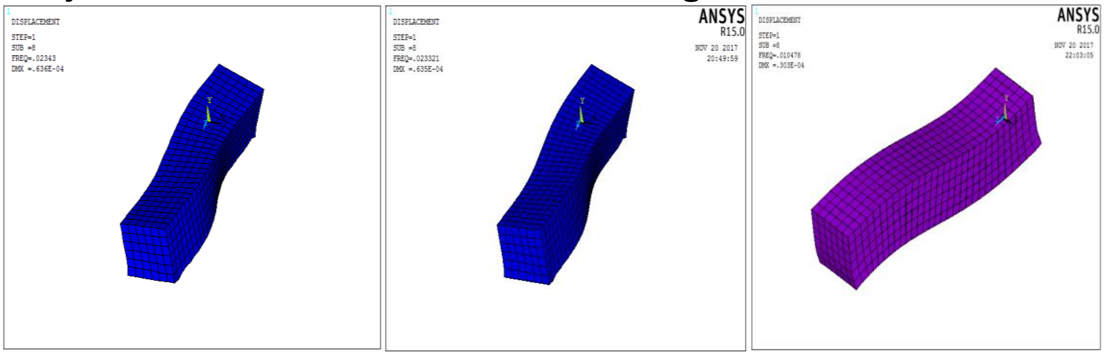
Fig(10) sample of deformed shape ,stresses and strain distributions .

8.Comparing between results by experimental and ANSYS.



Fig(11) Difference between ultimate load bY experimental and ANSYS.

9. Dynamic behaviour of tested beams using ANSYS.



Fig(12) Samples of mode shapes by (Modal Analysis).

10.Conclusions

The test results of the current experimental program showed that the developed ferrocement beams reinforced with innovative reinforcing materials achieved high strength, better deformation characteristics, crack resistance, high ductility and energy absorption properties. Irrespective of the type and number of steel mesh layers had better deformation behavior compared with conventional reinforced concrete beams. The results also demonstrated that ferrocement concrete beams showed fine crack widths at failure resulting of control of crack widths by employing steel mesh. The smaller the openings; the smaller crack widths.,Increasing numbers of stirrups reached high ultimate load for beam than the beam have all properties, Saving in the total reinforcing steel weight ranging could be achieved by utilizing welded galvanized steel mesh, expanded metal mesh for durability reason.,Increasing the box layer for welded metal mesh or expanded metal mesh achieved high energy absorption.The beams incorporating ferrocement forms and high strength mortar matrix achieved higher first crack load, ultimate load, and energy absorption compared to the control test specimen irrespective of the type of steel mesh and number of steel mesh layers.Experimental methods match with ANSYS methods for first crack and ultimate load calculations, also with dynamic modal analysis.,Finite Element Analysis is used to predict the structural behaviour of beams. Comparison of analytical prediction and test results emphasizes good agreement of modes (natural frequencies).

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