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Research paper

Structural Behavior of Continuous Steel-Reactive Powder Concrete Composiate Beams Under Repeated Loads

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Abstract

A study for the continuous composite steel-reactive powder concrete beams under repeated loads were executed experimentally and analytically. In the experimental part, six continuous composite sections were constructed as test beams. The decks slab concretes was connected tos steel I-beams by headed steel studs welded to the top flanges ofs thes steel I-beams. T,he dimensions of the deck slab is (2200×250×80mm), while the type of I-beam is (IPE 140) with length of (2200mm). For the present work, the experimental work includes also examining the shear in the links by creating two models (push out) and tested to determine the properties and behavior of the studs. The behavior of the studs were conducted by getting load-slip curves. In the part of the,oretical, tested beams.was numericallysmodeled then analyzed using thesfinite element method. Thes numerical models were carried out in three dimensionss bys the software package (ANSYS 16.1). Verifi,cationsof thesnumericalsresults was donesbyscompari,ngs thems with the experimentals results. "Thesresultssof thesfiniteselementsanalysissshowed good agreements with the results ofsthe experimental tests. The maximumsandsminimum difference in ultimate loa,ds for beams were (5.85% and 1.33%) respectively. The results show that stiffenerssof beamssandsstrengthening with CFRP shall increase the ultimate load capacity and affects on mode of failure of theses beams.

Keywords: *Continuous composite member, Reactive Powder Concrete ,repeated loads and CFRP.*

1. Introduction

Continuous composite construction as one of the common methods of construction in bridges and buildings. Composite member is connecting different materials together inorder to build a composite structural member with desirable properties of the materials. The reason behind that is to make full advantage of the construction materials since there is no material that can provide all the structural requirements. Continuous composite steel-concrete beams have been widely used because of the satisfactory utilization.of the two materials, steel and concrete. Reducing ors preventing thesrelative displacement of concrete and steel section guaranteessthe composite action. Shear connectors are useds tos provides this composite action. Composite action is the degree of the connection (or bond) between thesconcrete deck slabsandssteelsI-beasm. Thesdegree ofscomposite action is mainly affected by mechanical and geometrical properties of shear connectors. The degreesof the composite action is ranging between thescase of zero bond when there is no shear connectors between the integrated material and case of full bond when there is enough number of shear connectors. In case of full bond, one can assume there will be no relative slip occurred between concrete slab and steel beam and the two components will act as one unit. Non-deformable connectors may cause excessive bearing stresses which may cause crushing in concrete, due that complete connection is not preferable in the composite sectionAl-Thebhawi (2005). Shear connectors are used to resist longitudinal slip along the contact surface and consequently resist shear forces, in addition to that resist the vertical splitting forces which try to separate the composite materials.

when used CFRP, thes ultimates loads capacitys was enhanced by 6% ands thesload-deformation curve was enhanced by about 75% whens compareds withs unstrengtheneds specimenss..Alis(2014).

2. Reactive Powder Concrete

Onesof thesachievementssof thesrecent revolutionsof concrete is Ultra-high performance concretes(UHPC)"like reactivespowder concrete RPC sChandra (2014). Reactives powdersconcreteis an ultra-high strengths and highsductility compositesmaterials with advancedsmechanical propertiesswhichsis developeds in 1990's by French companysBouygues. The disadvantages of RPC are that its ingredients are expensive and require special attention in preparing, mixing, handling, casting and curing, therefore using RPC in a structural application requires special analysis to use smaller section size to reduce the overall cost. "

Thes producers expect thatsas RPC becomes more common inpractice, the cost of useswillsdecrease and they suggeststhat savings will be achievedsoversthe lifescycle whenscomparedsto conventional solutions.

- Itss superiors strengthscombineds withs high shears capacity results in significantsdead loadsreductionsand less limitedsshapes of structsuralmesmbers O'Neil and Dowd(1995).
- RPC hassthesabilitysto restrictsthe directstensilesstressess so rebar shear indispensable.
- "RPCs providessimproveds seismic performancesby reducing inertiasloads with lightersmembers, allowingslarger deflections withsreduced

crosssections, and providingshigher energys absorption Collerpardi(1999).

- The finess of the product allows high – quality surface finish Dauriac (1997).
- Superior strength can lead to more slender structures resulting in a significant dead load reduction Warnock(2005).

3. Beams Details

Experimental investigation implemented construction and testing six beams, each beam isconsisting from the concrete deck slab and steel I-beams connected together by steel headed studs. Figure 1 shows. thes dimensionssof thesbeam. Dimensions of concrete deck slab are (1m length from center to center (two span), 0.25m width and 0.08m depth). Thes slabsreinforcementswas followingsthe ACI buildingscodesrequirements. Steelsratiossdesigned depending on requirementssfor"temperatures andsshrinkagesfor longitudinal and transversesdirectionss"ACI 318M-08. Figure 2 showss thes cross (positive and negative) sections of thes beam.
A headedsstud techniques was useds tos connect thes concrete slab tosa steels beam. Thes shearsconnectorss.weresweldedsto the topsflangesofsI-steel beamsandsembeddeds to concretesslab. Thes length and diameter were same for all headed studs were used for the test beams. Shear connectors were used to avoid slip failure. Despite that the number of shear connectors was selected according to the standard specifications, but still there was a little slip values recorded through the testing process. The reactive powder concrete beams contain 36shear connectors, distributed by two. Distributed along the longitudinal axis spaces are shown as Figure 3. Pattern of fixing stiffeners and CFRP (sheets and bars) for the test beams (BC3, BC4, BC5, BC6) in Figure 4.

4. Instruments and Test Procedure

Allsbeams.were testedsunderstwossymmetric concentratedsloads appliedsat the midpoints of each span. and were continuously supported at the ends as shown in Figure5. Put the beam inside the testing machine the beam was labeled and the demec discs and dial gauges were fixed at the required positions shown in Figure 6. At each load stage, all readings of load, deflections and slips readings were recorded. Repeated load was applied to the four beams was loaded gradually until (70%), and then unloading is followed, Thus a cycle of loading was applied. Each applied cycle is loaded and unloaded step by step and at each step readings of deflection, slip and strain were recorded. The number of the applied cycles was 2. Finally, thes beamswassloaded gradually up to failure."Thes totalstimesduringsthe examinations of the beam undersstaticsloads was 4 minutes, and in thescasesof repeated loads was 5 hourss.

5. Experimental Results

Thes obtained resultss froms thes experimental testings. of thes presents studys are:
1. Deflections at the center of each span for all beams. The symbols of these deflections are (D1) and (D2).
2. Slip on the ends between concrete slab and steel beams. The symbols of these slips are (S1) and (S2).
The value of the load was obtained from analog reader of the test machine. The experimental data were obtained by using a dial gauge for deflection and slip.Table 2"showss thesultimates loads recordedsfor eachsbeamsand the loads of firstscracksformedsin concretesslabsand thesratiosbetweens the twosloads. Beams (BC1) iss the controls beam, it wsass faileds unders ultimates load of (Pu=445 kN). The first crack appeared under load (218kN), In addition to the appearance of cracks on the surface of the concrete above the internal support tensile result. The beam (BC2) was tested under repeated load, a reduction in the value of the ultimate load by a ratio (9.2%), (Pu= 404kN), Also the number of cracks increased due to repeated of load. The beams (BC3, BC4, BC5 and BC6) were stiffened in I-steel section and strengthened with CFRP sheets and bars in the surface of concrete and there is an increase of ultimate load from (445kN) to (493, 504, 498 and 483kN) respectively.
The response of each test beam is presented through load-deflection curves shown in Figure (7) to (13).
Deflection of repeated beams indicatessthatsthere is an increase in deflectionsat the samespoint and thessamesincrementsof load with the increasesof thes numbers of cycles. Thiss causes nots to return the beam to thesoriginalsshapeswhen thesloads decreasedstoszero levelsat thesend of eachscyclesofsloading. Strengthen beams with three pairs of stiffeners in steel beams (BC3, BC4, BC5 and BC6) provide a greater increasing percentage of ultimate load with the clear decrease of maximum deflection, maximum deflection this beams (7.33, 7.3, 7 and 7.4 mm) while increasing of corresponding ultimate load (1.8, 13.3, 11.9 and 8.54%)) Respectively.
End slip readings are denoted as (S1) and (S2). Figure (14) shows the load versus average slip of (S1 and S2) for all tested beams. The beams of repeated load record slip values greater than control beams at the zone of repeated loading 7%Pu. This is may be caused by initial slip stored in the beam due to repeated loading.

6. Finite Element Modeling

FinitesElementsmodelingsand analysis were carriedoutsto simulate
the behaviorsof theseightstestedscompositessteel-concrete girders from linears thrsoughs nosnlinears ressponses ands ups to failure, usingsthe (ANSYS 16.1) ACI program ANSYS help. Thes choices of thesproperselementstypesisverysimportantsin thesfinite element ansalysis. The chosens elementstype dependssupson the geometry of the structure and thes numbers of independents space coordinates.
In thespresentsstudy, threesdimensionalsmodel wasusedsto analyze composite girders consistingsfrom concretes decksslabsands I-steelsbeamss integratseds by steels studss shear connectors."The concretes slab wass divideds in its length, width, andsdepth into brickselement"(SOLID65). Elements types (SOLID185) was used to model steel I-beam. Reinforcement of concrete and stud connectors were modeled by element type (LINK180). Element (COMBIN39) was used, in this study, tos simulate the behavior ofsthesshearsconnectorssinsresisting the tangential forces between thes concretesslabsand thes I-steels beams.The contact between concretes slabsand steel beams produce normal forces and tangential forces acting on the plane of contact. This action modeled by using a 3-D point-to-point contact element called (CONTAC52). If the bond between concrete slab and steel beams is full bonded (which can be achieved by using an excessive number of studs) this difficulty will be solved by connecting directly the neighboring concrete elements and steel beams elements through concerted nodes. Thus, a need for using more types of elements is appear to represent the bond action between concrete slab and steel beams. Figure 15 shows the overall finite element meshing of the test beams.

7. Finite Element Analysis Results

Thesnumericalsresultssof ultimates loads, vert,icals deflection, and horizontals slips aresconcernedsto comparesthemswithsthoses of experimentalswork. Thisscomparisonswassconductedsto verify the numericalsmodel.

Table3 showssa comparison between experimentalsand numerical ultimatesloads forsthe studysbeams. In general, the ultimate loads whichspredictedsbysthe numerical analysessare rathersgreater than those of experimental testing.

The "percentages of differences between experimentals testss and numericalsanalysessfor thesultimatesloadssis betweens(1.33-5.85) % for all thes beams. Thes deflectionsin numericalsmodels is, in general, smallersthansthatsin experimentalsbeamssandsthe percent -agessofsvariationsaresbetweens(4.6-9.7)% at thesultimates load. The exceptionsis that, numericalsdeflectionsof thesbeams(BC1) is littlesgreatersthansthatsin thesexperimental beam.

The percentagesvariation for beams(BC1) is (4.6%) at the ultimate load. Thespercentagesof variations in deflections for beams (BC1) is veryssmall. Hence, In generalsthesnumericalsmodels are stiffer. ThesfollowingsFiguress16-21showsa comparison between experimental and numericalsresults for deflection.

Thes previousstablessand figuresspresentsa comparison between experimental, numerical resultssrelatedsto load, deflection, and slip for all thes beamss of the present study. "This comparison shows in generalsthats thesnumericalsmodelssaresstiffer, and the numerical analysessgivesa smaller result forsthesdeflectionsand greaters for ultimates load. Theses differencess may bes due to the followings reasons:

1. "The concrete of experimental beams is not perfectly homo geneous as assumed in the numerical models.
2. The compressive strength of the tested concrete cubes may not represent exactly the actual compressive strength.
3. The Perfects bonds.betweens concretes and steels or CFRP reinforcementss.is assumedsin the finiteselements analyses, but in thesexperimentalsbeamssthis bonds is nots perfects and theres is a slip which causess a losts in composite actions.
4. Numerical integration on element volume based Gauss-Techinqe means surveying the plastic behavior at (Gauss) points which is not so efficient to cover all important points in each element.

8. Conclusions

The general behavior during test process is similar for all tested beams. The first cracks are formed at about (49%-67%) of the ultimate load level of testing beams. This percentage is change by varying the cases of the present study. The mode of failure of RPC with steel fibers exhibited ductile behavior. Steel fibers resulted in more closely spaced cracks, reduction in the crack width and improvement in the resistance to deformation. "

Repeated loading producess a residual deflections which increases withs thes increases of the level of the repeated load".

The ultimate load value decreases with the increasing the repeated loading level. Strengthen beams by stiffeners provide a greater increasing percentage of ultimate load (1.8%), with the clear decrease of maximum deflection and the end slips reach to (22.2%) and (12.6%) respectively. CFRP provided had an insignificant effect on the behavior of loads deflections and loads-slipcurves of composite beam. The adopted finite element modeling in general overestimates the ultimate load in comparison with the experimental results.

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Table 1: Details of tested beams in the present study

Name of beam	Type of loading	Type of strengthening
BC1 (control beam)	Static	---------------
BC2	Repeated 70%Pu	---------------
BC3	Static	Stiffeners
BC4	Repeated 70%Pu	Stiffeners and CFRP sheet
BC5	Repeated 70%Pu	Stiffeners and CFRP bars
BC6	Repeated 70%Pu	Stiffeners

Table 2: First Crack Load, Ultimate Load and mid span deflection at ultimate load

Beams	First Crack Load Pcr (kN)	Ultimate Load Pu (kN)	Pcr / Pu (%)	Mid span deflection at ultimate load (mm)	
				D1	D2
BC1	218	445	49	9.4	9.3
BC2	215	404	53.2	9.72	9.8
BC3	314	493	63.69	7.33	7.2
BC4	319	504	63.3	7.3	7
BC5	322	498	64.66	7	6.8
BC6	320	483	66.25	7.4	7.2

Table 3: Comparison of Load and Deflection at Ultimate Stages for the Tested Beams

Beam	Ultimate Load Pu (kN)		Max. Deflection	
	Experimental	Numerical	Experimental	Numerical
BC1	445	451	9.4	9.834
BC2	404	412	9.72	8.955
BC3	493	518	7.33	6.94
BC4	504	529	7.3	6.88
BC5	498	527	7	6.32
BC6	483	513	7.4	7.3

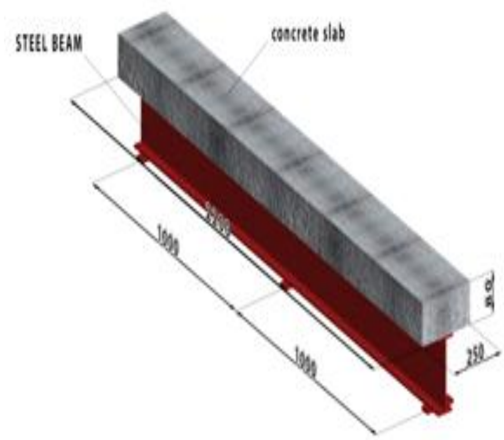

Fig. 1: Composite steel-concrete beam (Dimensions in mm)

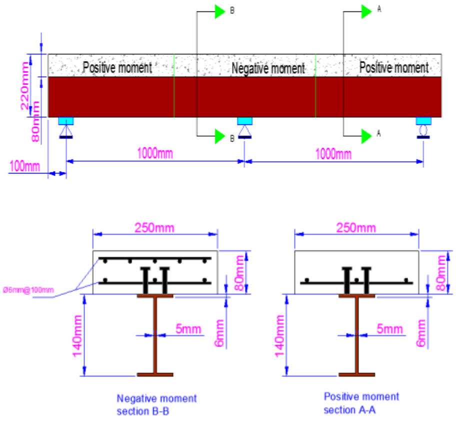

Fig. 2: Details of section specimens

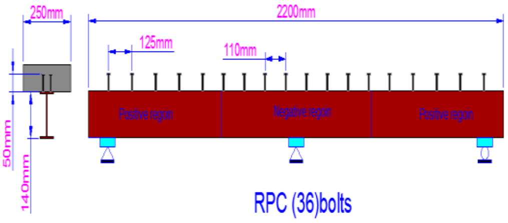

Fig. 3: Distribution of shear connectors used in the present work

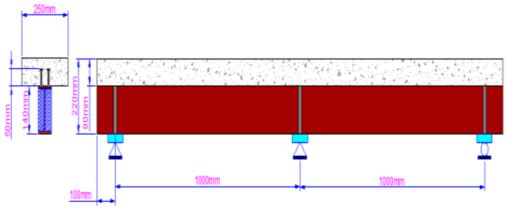

Fig. 4: Distribution of stiffeners

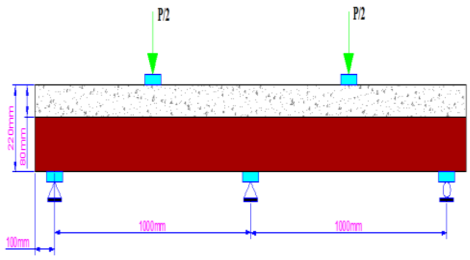

Fig. 5: Loading and supporting conditions of test beams

Fig. 6: Specimens during Casting

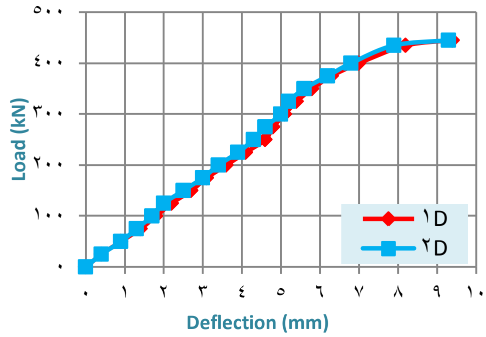

Fig. 7: Load-deflection curve of the beam (BC1)

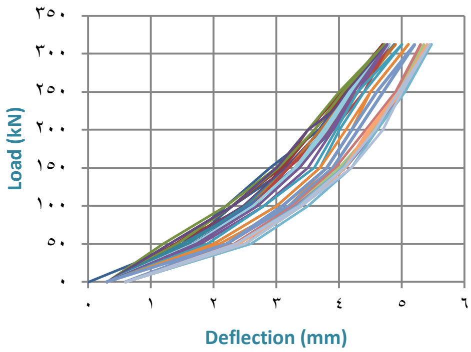

Fig. 8: Load-deflection curve average(D1and D2) of repeated load (BC2)

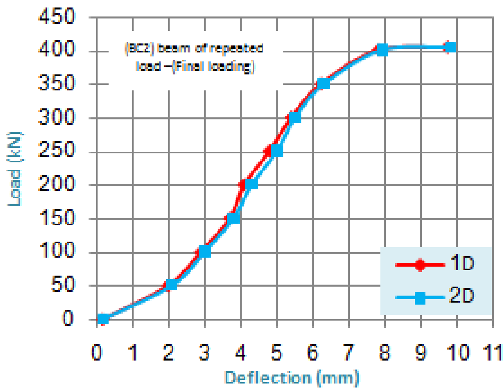

Fig. 9: Load-deflection curve of the beam (BC2)

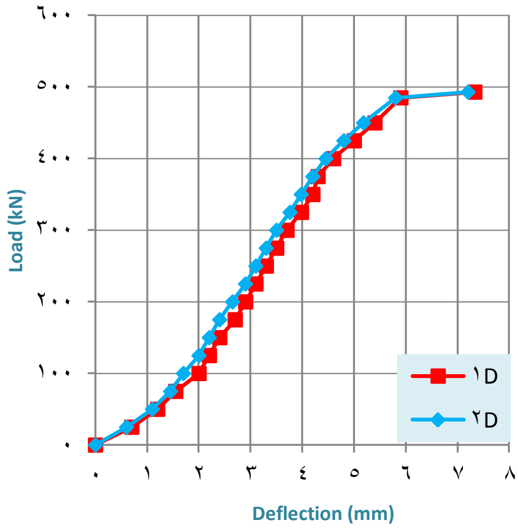

Fig. 10: Load-deflection curve of the beam (BC3)

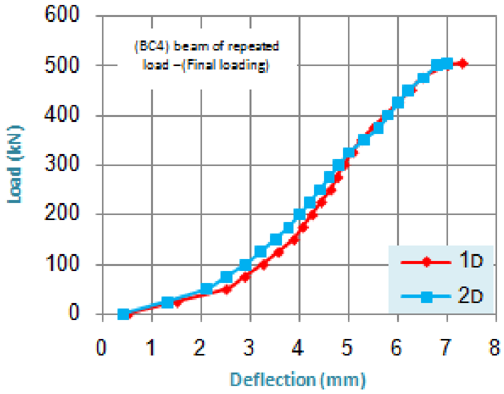

Fig. 11: Load-deflection curve of the beam (BC4)

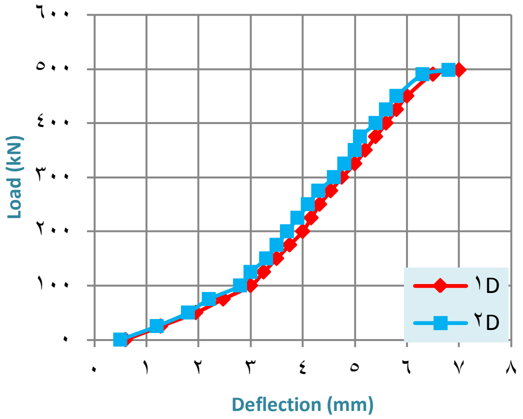

Fig. 12: Load-deflection curve of the beam (BC5)

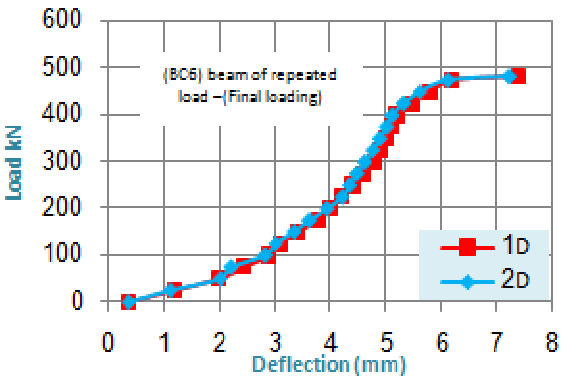

Fig. 13: Load-deflection curve of the beam (BC6)

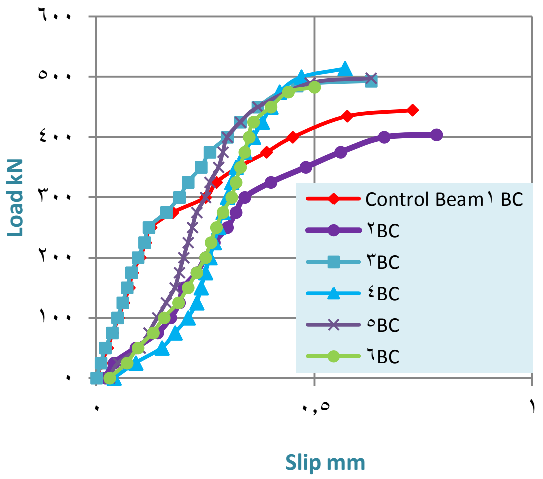

Fig. 14: Load-Slip (ave. slip of S1 & S2) Curve of Test Beams

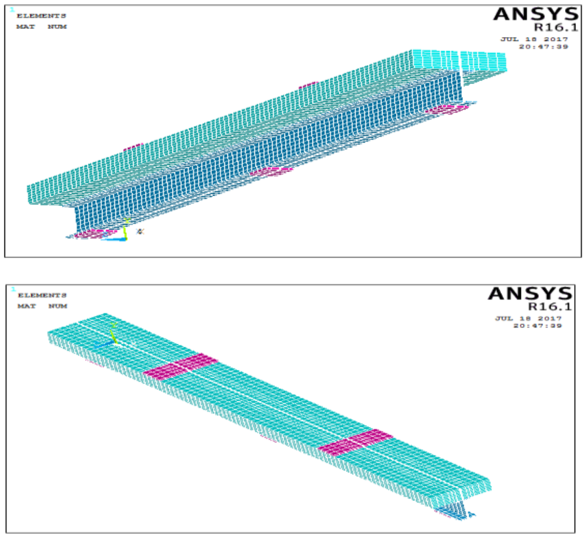

Fig. 15: Geometry of the numerical model

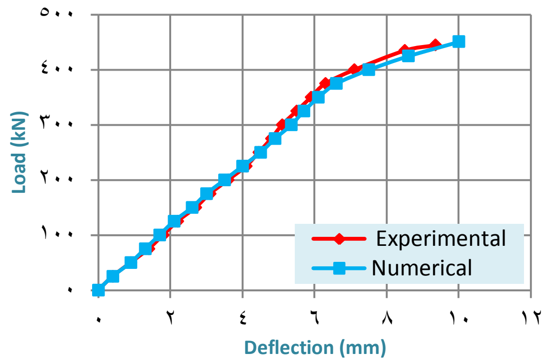

Fig. 16: Load-deflection relationship of the beam (BC1)

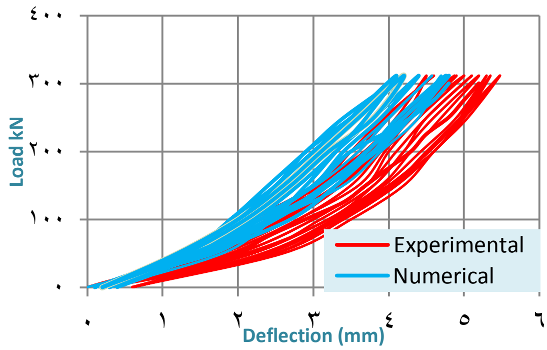

Fig. 17: Load-deflection relationship of the repeated load beam (BC2)

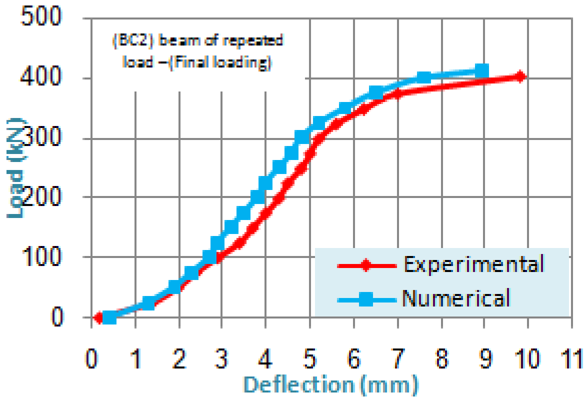

Fig. 18: Load-deflection relationship of the beam (BC2)

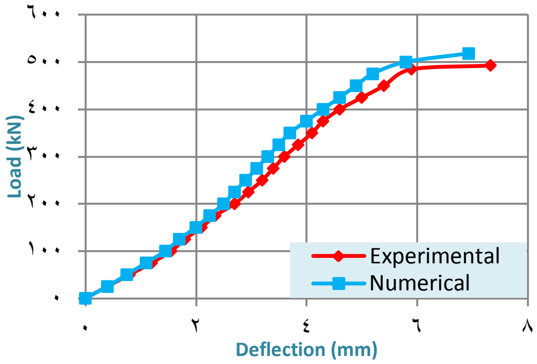

Fig. 19: Load-deflection relationship of the beam (BC3)

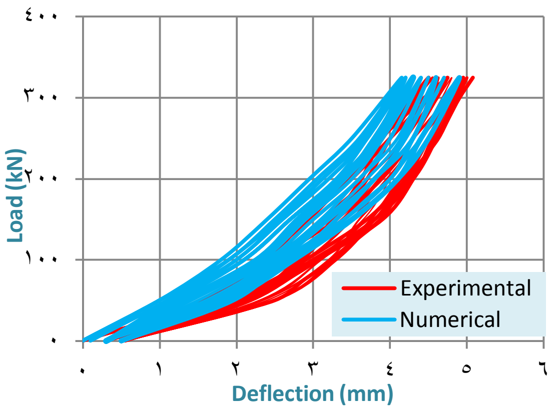

Fig. 20: Load-deflection relationship of the repeated load beam (BC4)

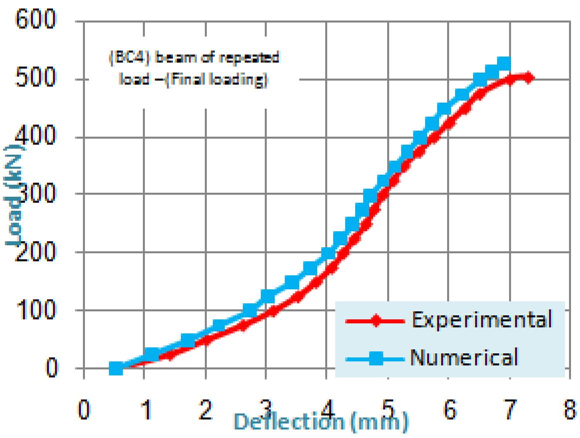

Fig. 21: Load-deflection relationship of the beam (BC4)