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Behavior of confined concrete beam by induced compression process

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Abstract

In order to provide higher mechanical effectiveness of confined concrete beam, the new technique proposed in this work consists to design at the ends of the steel reinforcements two opposing half cylindrical plates, creating an induced compression applied in the tended zone of the concrete beam element, when the steel reinforcement is subjected to tensile forces developed by the bending load. This technique ensures the concrete rigidity within the structure, avoids the problem of cracking and ruptures of the element and allows the transformation of the tensile force of the steel reinforcements into compressive force of the tended concrete inside the two half cylindrical plates. The confinement is induced by the displacement of the tended steel reinforcement, on all the transverse surface of the half-cylinder plates. This design avoids the penetration of the steel reinforcement in the concrete which generates a shear force of the section. Thus, the concrete of tended zone of the beam finds in position to take part in the resumption of the flexural efforts. The nonlinear finite element modeling shows that the proposed technique of confinement increases the strength and ductility of reinforced concrete beam. The numerical modelling analysis is completed by preliminary experimental work in order to allow for a better understanding of the behavior of this new confinement proposed technology.

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Keywords:Concrete, Confinement, Design, Induced compression, Experiments, Modeling

1. Introduction

In the Civil Engineering, the starting point of any failure of a structure subjected to various requests is caused by the initial cracks thus appearance of permanent deformations and imposition of a reduction in the rigidity of materials.

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In the traditional reinforced concrete the participation in mechanical term of the concrete uses only one very low capacity of this material. The remainder is taken again by the reinforcements of reinforcement out of steel.

Collapse and damage experienced by a large number of existing reinforced concrete structures, such as buildings and bridges, in recent earthquakes has given rise to an ever more urgent need to repair and strengthen these old structures [1]. The repair technologies of concrete structures knew important progresses in the last years and the composite materials, by their non-corrodibility, high stiffness and strength-to-weight ratios, have quickly appeared as innovative solutions adapted to the strengthening and the repair of civil engineering structures.

Several approaches for concrete confined by composite have been developed. Although that many studies have been carried out on confined concrete cylinders [2,3], different technologies can be applied for repairing, such as steel tubes and fiber reinforced polymers (FRP), tube encased concrete columns [2], concrete columns reinforced by non-adhesive filament wound hybrid composite [3] and polypropylene fiber reinforced concrete (FRC) [2]. A technique based on composite Jackets (FRP) glued on external area of RC members [5]; increases the rigidity and the bearing capacity of the confined concrete in a considerable way and modifies the behavior in large deformations. The enhancement in terms of mechanical performances of strengthened and confined structures with fiber reinforced polymers (FRP) was experimentally demonstrated by several researchers [4-7].

In addition to the need to improve the ultimate strength, this kind of failure underlines the necessity to avoid brittle failures, in 1927, a new process of active compression was proposed by E. Freyssinet. This process is very largely used nowadays even if it requires an implementation technologically pointed and expensive. It is certainly the reasons for which this technology occupies a market share which remains limited almost a century later. All these reinforcement technologies aim to prevent more or less the sudden failure as well as the risk of partial or total collapse. The choice of the best technology depends on mechanical and commercial benefits [2].

In order to provide higher mechanical effectiveness of confined concrete beam, the new technique proposed in this work consists to design at the ends of the steel reinforcements two opposing half cylindrical plates, creating an induced compressive force applied in the tended zone of the concrete beam element, when the steel reinforcement are subjected to tensile forces developed by the bending load.

The present study is focused on preliminary experimental investigation of structural behavior when the confined beams are subjected to flexural load. In order to assess the flexural performances of the proposal design confined beam, experiments were completed by numerical simulation based on finite element analysis. The average test and theoretical results are confronted to highlight the improvement of the proposed beam technology in terms of strength, and flexural stiffness.

2. Design and operating process

The design of the proposed technique is shown in Fig. 1This technique consists to design at the ends of the steel reinforcements two opposing half cylindrical plates, creating an induced compression applied in the tended zone of the concrete beam element, when the steel reinforcement are subjected to tensile force developed by the bending load.

The use of metal plates is justified by the need to distribute the compressive force obtained by confinement effect over the entire width of the cross section; this allows completely confining the cross section of the beam and avoids cracking of the concrete crushing at the contact point's reinforcements- concrete matrix. This phenomenon is widely observed in the early preliminary conducted experimental investigation.

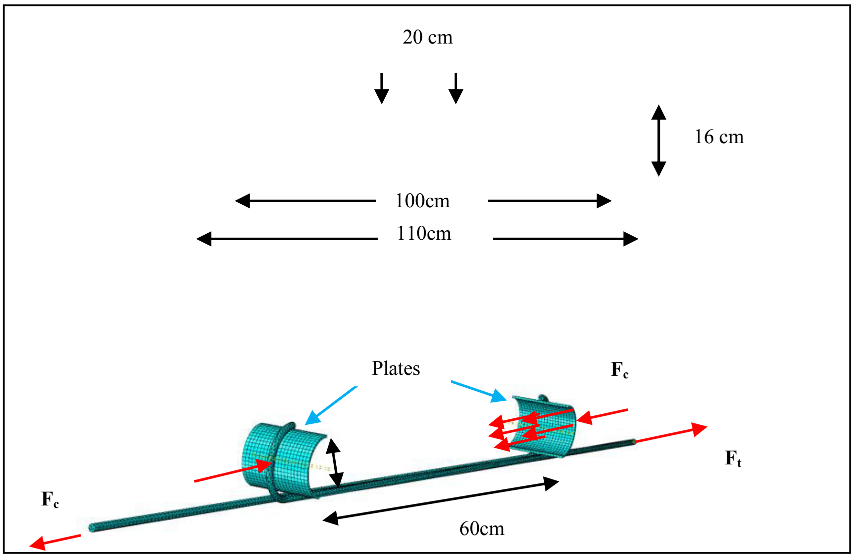

Fig. 1. Confined beam design propose and geometrical dimensions of the metallic plates used.

The Fig.1 shows the typical operating process of the technique proposed. It is clearly seen, that the operating process of the induced compression is obtained by plates reinforcement which it is used to provide lateral pressure to the concrete. Under flexural loading, tensile stress developed in the reinforcement and displacements of the reinforcement which results in compressing of concrete which is inside the metallic plates. In fact, the plates will confine the concrete, and as well as improving its strength, it will enhance its ductility and prevent brittle failure.

This construction technology aims to increase the member rigidity and strength, to allow for ductile failure and to prevent sudden failure under excessive loading. It avoids also the problems due to tensile strength of concrete. This study showed that the confinement level is proportional to the flexural loading.

3. Nonlinear Modeling

3.1. Simulated Models

Nonlinear analysis, carried out on reinforced concrete beams with the proposed new design, which consists of arranging two half opposed plates inside hooks longitudinal strength reinforcement, allows to evaluate the bearing capacity and the mode of rupture under flexural load, and to optimize the shape and layout as well as the geometric dimensions of the metallic plates.

The beams are meshed thinly in the susceptible zones to failure, in particular at the beam mid span where the helical steel reinforcement is embedded. Tetrahedral and hexahedral solid finite element models, with full 3D Lagrangian formulation were used respectively to mesh the concrete beam and the steel reinforcement.

The concrete damaged plasticity is used for modelling the concrete and the elastic-plastic behavior is used for the steel reinforcement. The nonlinearity of steel and concrete materials is used to determine the mode of failure and the level of corresponding load. Two types of reinforcement were considered; in this study: a classic reinforcement with 2 Ø6, these beams will be considered as a reference beam and a new reinforcement with 02 Ø6 bars length each 100 cm with two (02) opposing half cylindrical flat. The geometrical characteristics, boundary conditions and loading are illustrated in Figure 3. The longitudinal reinforcement and the metallic plates are integrated into the continuous concrete matrix, as shown in Figure 2b. Finally, steel / concrete adhesion is assumed to be perfect. In this simulation, the loss of adhesion between the steel reinforcement and concrete matrix is not taken into account explicitly.

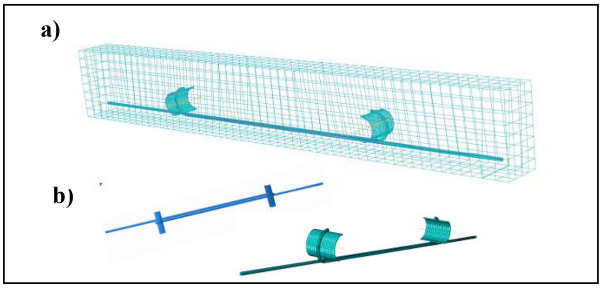

Fig. 2. Finite element models: (a) geometrical and boundary conditions (b) Steel reinforcement.

The beams are finely meshed in the places likely to the rupture. Finite elements hexahedral solid linear elements (3D) with 4 nodes with 12 degrees of freedom with a dimension of 2cm in the three directions are used to mesh the concrete beams. The solid elements have a dimension of approximately 2cm in all three directions. The steel reinforcement is meshed with 3D beam elements (element, consisting of two nodes, each with six degrees of freedom).

3.2 Materials modelling

The concrete material is modeled along the (Concrete Damaged Plasticity) embedded in finite element analysis code, to take account of the asymmetry of the behavior of the concrete in compression and tension, as well as coupling with damage to represent the primer and crack propagation. The concrete parameters are shown in Table 1

Table1: Concrete model parameters [8]

Properties			**Values**
	Uni axial loading		
Maximum compressive stress	fc	[Mpa]	25
Compressive Yield stress	fce	[Mpa]	10
Ultimate tensile stress	ft	[Mpa]	2,1
Young Modulus	Ec	[Mpa]	3216,5
	Multi-axial loading		
Poisson's ratio ν			0,2
Dilatation angle ϕ			32
Ratio of biaxial to uniaxial compressive strength			1,16
Parameter of the flow potential a_f			0,1

According to the experimental behavior of concrete, the tensile and compressive stress–strain values, strength and failure parameters are input point by point, in the used Software.

The constitutive behavior of steel is modeled using an elastic plastic model. The parameters used to define this model are elastic modulus, yield stress, plastic stress, and Poisson’s ratio, the values of these parameters are: E = 210GPa, υ = 0.3, σy = 348Mpa.

3.3. Results and discussion

The results of numerical simulation in terms of damaged and stiffness degradation and the evolution of Von Mises stresses are presented respectively in Fig 4and Fig 5. The evolution until the rupture of the applied external loading, according to the mid-span deflection of the beam under a four-point bending load is shown in Fig 3. The values of the ultimate applied load, deflection at peak, and the load corresponding to the first crack are given in Table 2. The comparison clearly shows the improvement in terms of bearing capacity.

Table 2 Numerical Results

Beam	Load 1stCrack (kN)	Deflection 1st Crack (mm)	Ultimate load (kN)	Deflection at peak (mm)
CRCB	7.303	0.604	16.48	6.5
RCB-2T6	5.09	0.611	13.12	8.21

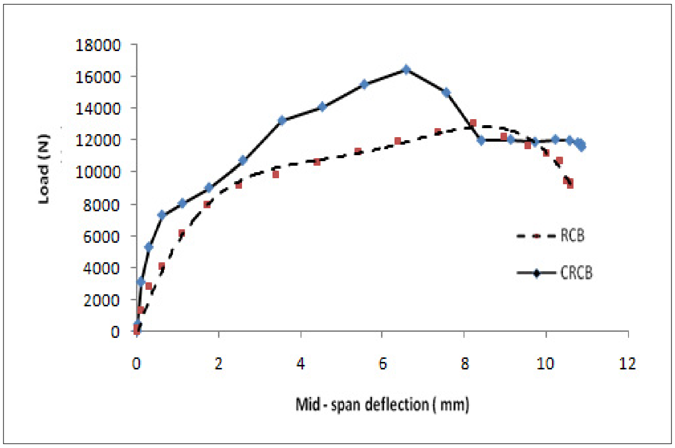

Fig. 3. Load-mid span deflection curves confrontation.

Analysis of the forces-mid-span deflections curves shows the positive contribution in terms of bearing capacity of around of 35% compared with the control beam. The proposed new design has a load capacity of 16.48KN and a vertical displacement at peak corresponding to 6.5 mm. The ordinary concrete beam specimen has a lower carrying capacity of approximately 13.12 KN and a corresponding arrow of 8.21 mm. These curves can be broken down into three phases: The first phase corresponds to small deformations, the vertical displacement increases linearly with the applied load, the beam element is in non-cracked state, this phase behavior is common with that of the reference beam. The second stage corresponds to the appearance and propagation of cracks. The cracks spread very quickly in the concrete matrix of the control specimen. The mobilization of the lateral confining pressure increases the value of the load that creates the first crack, and decreases the speed of propagation of cracks in the bending beam element. The last phase is the lamination of reinforcement, which ensure the recovery of the flexure cracks density up bending strength.

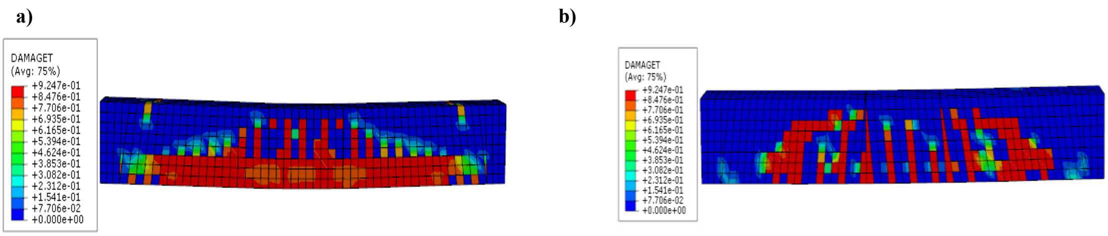

Fig. 4 Damaged cartography at failure: a) Unconfined beam, b) Confined beam by induced compression.

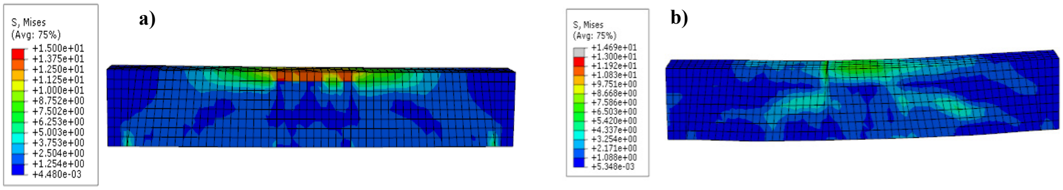

Fig. 5 Evolution of Von Mises stresses: a) Unconfined beam, b) Confined beam by induced compression.

The compressive and tensile damages variables take values from zero, in which the beams are in a state of non-cracked state to the final failure of the beams which corresponds to ultimate damages parameters. The beam has been deformed in the transverse direction, but the nature of the steel reinforcement remains relatively permanent. In other words, the cracked tensile concrete fragments have been confined inside the beam. The ultimate strength of the confined concrete beam by compression load (a new concept) compared to the control beam with a traditional design increase in the order of 30%. The mass gain of steel reinforcement is 20%.

4. Experiment

4.1. Material used and loading procedure

The preliminary experimental program was conducted according to Euro code 2, by mixing Portland cement, gravel, natural sand, water and super plasticizer. 06 standard cylinders with a diameter of 16 cm and a height of 32 cm and 06 beams with a width of 8 cm, a height of 16 cm and a length of 110 cm, were casted to prepare respectively the compressive and the flexural test specimens. Two groups of beams are considered, 03 reference reinforced concrete beams (RCB) and 03 reinforced concrete beams by induced compression (CRCB).

The steel reinforcement used is Ø 6 Fe240. The quantities of ingredients used in the concrete mix are shown in Table 1. RCB are reinforced with 2Ø6 and CRCB are reinforced by Two half bars steel reinforcement 2(1/2) Ø6. The specified average compressive strength of the concrete at 28 days is 25 MPa.

Table 3. Proportions of ingredients used for concrete mix

Ingredient	Quantity
Cement	400 kg/m^3
Water	198 kg/m^3
Crushed gravel	-
Ø 8/15	355 kg/m^3
Ø 15/25	806 kg/m^3
Career sand Ø 0/5	688 kg/m^3
High-range water reducing and super-plasticizing admixture	325 ml
Air content	2.4 %
w/c	0.49

The compression test was conducted according to NFP18-406 standards for cylindrical concrete specimens using a digital testing machine of 3000kN capacity with a loading rate of 20kN/s. During the test, each specimen was firstly preload at 20kN. Fig. 2 shows the typical flexural mode of loading of beams specimens. The flexion test was conducted according to NFP18-405 standards for prismatic concrete specimens. The tests were carried out by using a digital testing machine of 200kN capacity with a loading rate of 0.5kN/s. Each beam specimen was firstly preload at 0,5kNand then the load is increased until failure is detected by the testing machine.

4.2. Preliminary test results and discussion

The average strength for the control cylinders tested in displacement control mode, was 25.2 MPa. Under flexural load, the central area of the beam located inside the plates is subjected to a confining pressure obtained by linear displacement due to the tensile efforts in the metallic reinforcement. The force compressive transmitted by the steel reinforcement to the metallic plates is thus distributed over all the width of the beam thus creating a compressive force which comes to be opposed to the opening cracks. For some tested beams, we obtain the value of strength of rupture13.50 KN for RCB beams and 15.97KN for CRCB beams. For others confined concrete beam we observe cracks and rupture by shear force without densification of bending cracks in the central zone of the beam element. As we realized a few number of beams, since at this stage of study and to better understand the behavior of these beams confined by induced compression, tests are planned and will be implemented to support the effect of shear and optimization of the length between the two half cylindrical plates.

5. Conclusion

The numerical modeling allows us to observe the failure mode of the confined concrete beam and to evaluate the contribution of the induced compression effort in strength, stiffness and confinement level. It enables us to observe the differences in strengths between the reference concrete beam (RCB) and the confined concrete Beam by induced compression process (CCBP) and to draw the preliminary conclusions. The proposed design technology allows reducing 20 % of the mass of steel reinforcement and increasing the flexural stiffness and strength and preventing a sudden failure under excessive loading. The ultimate strength increased by ≈25-30%. Preliminary test results show clearly the improvement compared to the ordinary unconfined concrete beam. Future works should validate the different results obtained by numerical modeling based on the finite element method, also author believes that only experimental study very thrust can confirm or deny all the positive aspects observed in this numerical analysis and will understand the problems of rupture by shear force instead by bending moment, seen in a few beams tested. The first results of a numerical simulation with introduction of transverse frames show greater improvement in the resistance of beams confined by induced compression. In this respect, it is thus necessary to continue the study by more experiments to identified the mechanical behavior,

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