Experimental characterization of interstitial pore pressure in concrete under high confinement

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Résumé :

Le but de cette étude est de mesurer la pression interstitielle du béton sous haut niveau de confinement. Lorsque les structures de béton sont soumises à un chargement de type impact ou explosion, le matériau subit de très fortes contraintes triaxiales qui sont fortement influencées par le taux de saturation. Afin de mesurer la pression interstitielle d'eau à l'intérieur du béton sous fort chargement triaxial, un nouveau dispositif expérimental a été développé. Des éprouvettes de 14 cm de longueur et 7 cm de diamètre sont testées à l'aide de la presse GIGA. Dans le nouveau concept, la longueur de l'échantillon est réduite à 8 cm et une enclume de mesure de la pression interstitielle de longueur 6 cm a est incorporée. Des micro-trous sont percés sur sa face supérieure de sorte que la pression de l'eau libre dans l'échantillon puisse ainsi être transmise dans la cavité durant l'essai. Un capteur cylindrique équipé d'une jauge est placé dans la cavité permet de mesurer cette pression. Les résultats préliminaires d'un essai hydrostatique effectué sur un béton saturé indiquent que la pression interstitielle a augmenté jusqu'à 200 MPa pour 300 MPa de confinement.

Abstract :

This study focuses on measuring the pore pressure of concrete under high confinement. When concrete structures are subjected to an impact loading, material exhibits high triaxial compressive stresses which are highly influenced by the saturation ratio. In order to measure the interstitial water pore pressure inside the concrete under mechanical loading, a new experimental device was developed. Usually, specimens of 14cm in length and 7cm in diameter are tested using the GIGA press. In the new concept, the specimen length is reduced to 8cm and a pore pressure measurement cell of 6 cm in length is incorporated. The cell has micro-holes on its upper face, so that, when the specimen is loaded water pressure is transmitted from concrete to the cell where a cylindrical sensor equipped with a gage is placed. Preliminary results indicate that concrete pore pressure increases up to 200 MPa during an hydrostatic test at 300 MPa of confinement.

Mots clefs : concrete, confinement pressure, pore pressure, experiment

1 INTRODUCTION

During their lifetime, massive concrete structures may be subjected to impact or blast loadings. Under such circumstances, concrete undergoes very high-intensity triaxial stress states [1]. Besides the saturation ratio of such massive concrete structures changes from almost saturated state in its core to almost dry near its skin yet, behavior of concrete is highly influenced by the state of water saturation. Many static and dynamic tests have been developed aiming to study the behavior of dry or wet concrete under confined conditions. Vu et al.[2] conducted static triaxial tests at high confining pressure on dry and wet ordinary concrete and showed that as the degree of saturation increases, a decrease in the volumetric strain and shear strength is observed. Forquin et al. [3] studied the influence of free water presence in a micro-concrete passively confined tested under dynamic loading. At high or intermediate strain rates, the author observed a continuous increase of strength with pressure in dried specimens and a quasi-nil strength enhancement in water-saturated specimens. The main reason behind this differential behavior is probably the contribution of pore pressure.

To validate this hypothesis and to quantify the interstitial pore pressure 'PP' into concrete, an experimental device was developed. The pressure sensor is designed and integrated into a collect water cell placed under a fully saturated concrete sample. The whole system is subjected to high confining pressure 'CP' using a high capacity hydraulic triaxial press, the GIGA press.
In this paper, the procedure used to perform the experimental campaign are presented, then some results of hydrostatic tests conducted on ordinary concrete will be discussed.

2 EXPERIMENTAL PROCEDURE

2.1 Experimental set-up

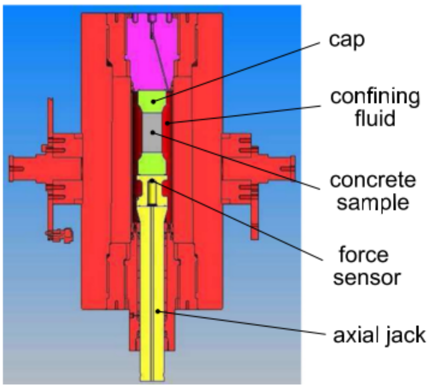

FIGURE 1 – Cross section view of the confining cell.

A large capacity triaxial press called GIGA was used to accomplish the experimental research. Numerous studies have been performed on this press since 10 years aiming to understand the triaxial behavior of geo-materials such as concretes and rocks under high confinement pressure, [4-5]. Figure 1 shows a cross section view of the press which is able to generate a confining pressure up to 0.85 GPa and an axial stress reaching 2.3 GPa on cylindrical concrete specimens 7 cm in diameter.

2.2 Instrumentation and measurement

To measure the pore pressure into the concrete sample while subjected to high hydrostatic confinement pressure generated by the GIGA press, a new experimental technique was developed as shown in Figure 2. Usually, specimens of 14cm length and 7 cm diameter are tested within the press, (Fig 2-a). Using this technique, we reduced the specimen length to 8 cm, therefore a water collect steel cell could be incorporated in the remained length, (Fig 2-b). The cell has micro-holes of 1mm in diameter on its upper face, so that, when the specimen is loaded the water pore pressure is transmitted from concrete to deform a cylindrical sensor equipped with gages, (Fig 2-c). The system is also equipped with two o-joints to keep sealing during tests, (Fig 2-d).

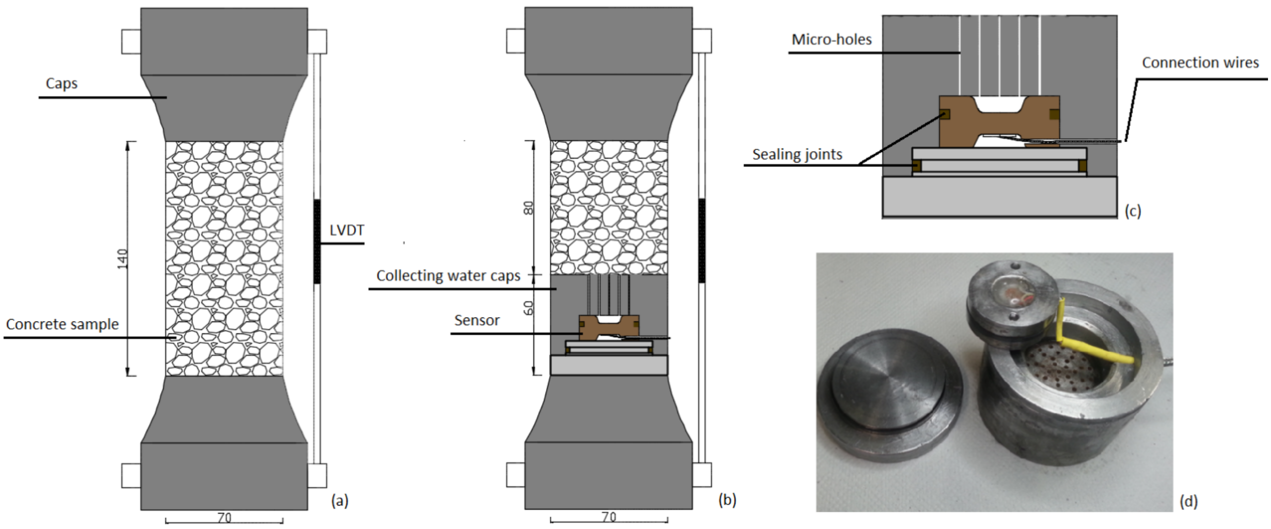

Figure 2 – Schematic diagram of the measurement system. (a)-(b) : general view before and after modification; (c)-(d) : the water collect cap with a sensor imbedded inside

2.3 Concrete properties

This study is part of a larger project that aims to characterize the behavior of a reference ordinary concrete sample called R30A7 which was used before. Its composition and mechanical properties are summarized in Table 1[4]. The concrete is casted, removed from the mold after 24 h then conserved for 28 days in a saturated environment within plastic bags immersed in water in order to insulate the concrete both physically and thermally. The block is cored, cut at 8 cm of length. Finally, concrete samples are held again in water for about 4-6 months in accordance with a conservation procedure, after that, samples could be considered fully saturated.

3 EXPERIMENTAL RESULTS

3.1 Sensor Calibration

To be able to measure the pore pressure in concrete, a relationship has to be established between sensor deformations and the applied pressure. Therefore, calibration test has to be performed. It consists in

Concrete mix properties	***Kg/m^3***
Water	169
Sand 'D' 1.8mm	838
Gravel 'D' 0.5-8 mm	1007
Cement CEM I 52.5N	263
Mechanical properties	
Average compression strength after 28 day (MPa)	30
Average slumps (cm)	7
Porosity accessible to water	11.8
W/C ratio	0.64

TABLE 1 – Compositions and mechanical properties of R30A7

applying a well-known confining pressure generated by the confining fluid on the sensor. A cylindrical aluminum sample comes to replace the concrete specimen. In order to allow fluid pressure to be transmitted to the sensor via cell micro-holes, transversal and longitudinal holes of 4 mm in diameter were made through the aluminum sample as shown in Figure 3. The equipment is then protected by mean of latex and neoprene membranes, Figure 3-b.

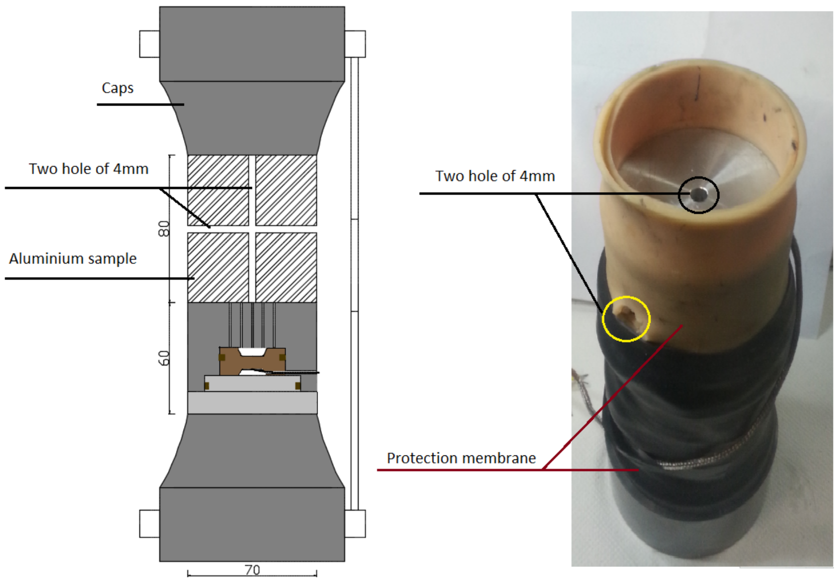

FIGURE 3 – Schematic diagram of the calibration system. (a) : general view of the aluminum sample with fluid passage holes ; (b) : final phase of preparation, application of protective membrane

A hydrostatic test at 200MPa of confining pressure has been carried out on the prescribed configuration. A graph of the gage readings and applied pressure is then drawn as shown in Figure 4. Sensor response is quasi-linear, therefore a relation between confining pressure and gage deformation could be set by calculating the slope k of the curve. A value of k = -626 MPa/% was adopted.

3.2 Pore Pressure results

In order to validate the experimental set-up showed in (Fig2), a first experimental test has been conducted on a fully saturated ordinary concrete. Figure 5, presents the results of an hydrostatic test

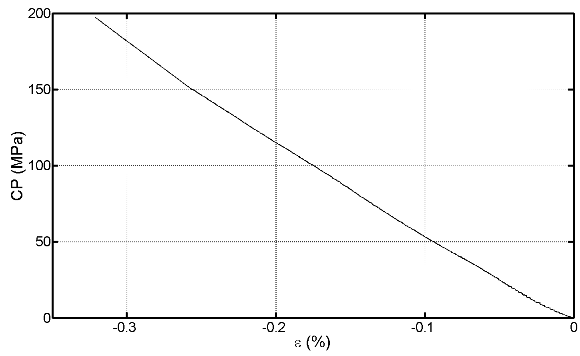

FIGURE 4 – Confining pressure versus gage deformation

at 300 MPa of confinement. It is observed that regardless the saturation state of the specimen, the pore pressure remains null up to a confining pressure of about 30-40 MPa. This phase corresponds to an elastic hydrostatic behavior of concrete during which the volumetric strain is very low.
Beyond this phase, and since pores inside concrete are filled by water, a gradual increase of pore pressure is observed. It could be attributed to a progressive damage and compaction of the cementitious matrix which acts on the saturated pores. The maximum pore pressure reached is 180 MPa for 300 MPa of confining pressure.

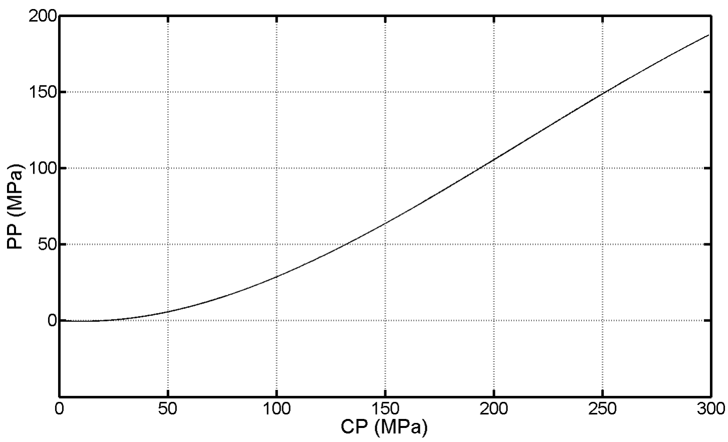

FIGURE 5 – Pore pressure vs confining pressure

4 CONCLUSION

This paper presented a new experimental technique to measure the interstitial pore pressure into concrete under high confinement. Giga Press has been used to apply high confining pressure, where a water collect cell equipped with a sensor was inserted. Two sets of tests were developed to accomplish the study. Preliminary tests have been conducted to calibrate the sensor then hydrostatic test on a fully saturated concrete specimen was performed. The first result shows an almost linear increase of the pore pressure with the confinement beyond the elastic behavior phase.

Références

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