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Experimental investigation of the effect of coarse aggregate shape and composition on concrete triaxial behavior

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ABSTRACT

This article focuses on identifying concrete behavior under high triaxial loading. The study is carried out within a more general context of understanding the behavior of concrete under impact. The effect of coarse aggregate shape and composition on concrete under high triaxial compression is examined by means of a very high-capacity triaxial press. The shape effect is further investigated using rolled aggregates, crushed aggregates and glass balls. The influence of aggregate composition is determined on concretes mixed with siliceous aggregates, glass aggregates and limestone aggregates. These analyses specifically indicate that coarse aggregate shape exerts no influence on the concrete response at high confinement. Moreover, concrete behaves like a non-cohesive granular stacking that seems to be governed by the compacted cement matrix provided a sufficiently high aggregate strength. Otherwise, a lower aggregate strength serves to weaken this granular stacking. At an intermediate level of confinement, the shear strength of concrete is mainly controlled by aggregates strength; however, irregularly-shaped coarse aggregates slightly increase the overall strength of concrete.

1. Introduction

Concrete is the world's most widely used man-made material. More specifically, it is employed in the construction of complex infrastructure (high-rise buildings, dams, nuclear reactors, etc). A thorough understanding of the behavior of concrete under extreme loading situations, such as near-field detonations or ballistic impacts, is essential. In these situations, concrete undergoes very high-intensity triaxial stress states (Zukas, 1992). When a projectile strikes a concrete structure, various localized effects are generated: spalling on the front face of the structure can be associated with simple tension, while penetration of the projectile into the structural core constitutes the source of dynamic triaxial compression. If the target is thin enough, then both simple tension and shear stresses can be observed on the distal face of the concrete specimen during the final penetration phase. A validation of concrete behavior models, which simultaneously take into account the phenomena of brittle damage and irreversible strains, requires test results that enable reproducing these complex and intense loading paths.

The static characterization of a constitutive model to predict dynamic calculations represents a common practice in the study of geomaterials. The behavior of concrete in confined compression test slightly depends on the strain rate for dried or wet specimens (Forquin et al., 2010). Static triaxial compression is the loading type discussed in this article. Concrete behavior under such loading is now relatively well-known, especially at moderate levels of confining pressure (Pugh, 1970; Kupfer and Gerstle, 1973; Linhua et al., 1991; Imran and Pantazopoulou, 1996; Sfer et al., 2002). These studies have particularly revealed the transition from brittle to ductile behavior that characterizes

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cohesive materials. Some triaxial tests at high confinement levels have also been performed, on mortar (Bazant et al., 1986; Burlion et al., 2001; William et al., 2005) and concrete samples (Warren et al., 2004; Schmidt et al., 2009); their results have shown the evolution in material behavior and limit states in the presence of confinement.

The results presented in this article refer to triaxial compression tests conducted on concrete samples by means of a high-capacity hydraulic triaxial press, called GIGA. This experimental device allows testing specimens at stress levels in the order of 1 GPa with static, homogeneous and well-controlled loading paths. An extensive experimental study on an ordinary concrete was previously carried out with the GIGA press. Gabet et al. (2008) studied the influence of loading path on concrete behavior and revealed that under high confinement, the concrete limit state remains relatively independent of both the loading path and Lode's angle. To describe the overall behavior of concrete under high confinement in greater detail, Poinard et al. (2010) performed cyclic tests using several loading–unloading cycles on the same concrete. These results indicated that the evolution of elastic features (Young's modulus, Poisson's ratio) becomes less pronounced as confinement increases. Using the same baseline material, Vu examined the effect of the saturation ratio on concrete behavior under high confinement (Vu et al., 2009a). This ratio exerts a major influence on concrete behavior at high confinement: the deviatoric strength of concrete considerably increases with confining pressure for dried samples and remains constant over a given confining pressure range for either wet or saturated samples. Another study by Vu et al. (2009b) demonstrated that the water/cement ratio has no influence on concrete strength under high confinement. Concrete behaves like a non-cohesive granular stacking and shows no sensitivity to conventional compressive strength f_{c28}. A subsequent study of the effect of cement paste volume and coarse aggregate size (Vu et al., 2011) revealed that at very high confinement, both the paste volume and aggregate size only had a slight influence on concrete deviatoric behavior though aggregates size was significantly correlated with concrete strain limit states.

This study is specifically concerned with the influence of coarse aggregate type on concrete behavior at high stress levels. Many experimental studies have already examined this effect under uniaxial loading, in exposing that the influence of coarse aggregate type on concrete strength properties and failure mechanisms varies in magnitude and depends on the water/cement ratio of the mix (Kaplan, 1959; de Larrard and Belloc, 1997). To the best of the authors' knowledge, no results are available regarding the effects of coarse aggregate type on concrete behavior under high triaxial compression loading. This issue will be addressed in the present article, from the standpoint of both coarse aggregate shape and composition.

The results of these experiments are essential to mesoscopic modeling of concrete under high confinement. Indeed, the validation of predictive models for several kinds of concrete formulations requires experimental data. The GIGA press enabled identifying the behavior of mortar under high stress levels, as part of developing a mesoscopic model of concrete (Dupray et al., 2009; Malecot et al., 2014). The present study completes these research efforts with the knowledge of the effect of coarse aggregate on the concrete triaxial behavior.

The experimental device used in this study will be described in Section 2. Test results concerning the effects of coarse aggregate shape on concrete behavior will be presented in Section 3.1, followed by the effect of coarse aggregate composition (Section 3.2). Concluding remarks will be provided in Section 4.

2. Experimental set-up

2.1. The triaxial cell

Triaxial tests were performed by means of a high-capacity triaxial press, called GIGA. A full description of this testing procedure on concrete has been presented in detail in Vu et al. (2009c). The press, illustrated in Fig. 1, is able to generate a confining pressure of up to 0.85 GPa and an axial stress reaching 2.3 GPa on cylindrical concrete specimens 7 cm in diameter and 14 cm long. Fig. 2 shows a cross-sectional view of the confining cell, where the concrete sample is to be placed. The confining fluid, diethylhexyl azelate, a non-volatile organic, inert and slightly-compressible liquid, is injected into the cell through an upper opening; it is then pressurized by means of a pressure multiplying jack. The axial force is generated from a 13-MN jack located under the cell and then transmitted to the sample via a piston that passes through the lower plug of the confining cell.

2.2. Instrumentation and measurements

The press is equipped with various sensors that serve to supervise the tests and provide information on the state of the sample during loading. An axial displacement sensor is installed in order to control the axial jack displacement, while an axial force sensor and pressure sensor positioned inside the confining cell yield the stress state on the specimen.

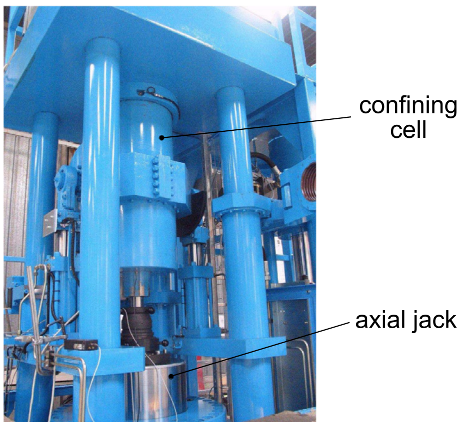

Fig. 1. Overview of the GIGA press.