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CONCRETE UNDER HIGH COMPACTION: A NEW EXPERIMENTAL METHOD

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Abstract
The identification of compaction of concrete is classically obtained by dynamic tests. These experiments are, however, quite difficult to analyse directly. We have chosen here to perform an experimental testing in static's with the aim of obtaining compaction of concrete. This experimental investigation is based on two different tests. A first one, which is new, is a quasi-oedometric compression test adapted to concrete. A new cell has been designed and tests have been done on concrete and mortar. The second test is a pure hydrostatic compression test. We have used a high-pressure fluid cell initially developed for metallic materials. Experimental principles of the hydrostatic and oedometric tests are presented. We show several results obtained on mortar and concrete. We have compared the results of oedometric and hydrostatic compaction of mortar and shown that is not possible to separate in a constitutive model the hydrostatic behaviour from the deviatoric one.
Key words: Concrete compaction, experimental methods, oedometric test, hydrostatic test, triaxial compression

1 Introduction

Most models for concrete describe relatively well the material response in uniaxial and biaxial situations. Damage or plasticity models (see e.g. Mazars (1986), de Borst and Muhlhaus (1991), La Borderie (1991), Dragon and Mroz (1979)) are capable to describe correctly the behaviour of concrete if one of the principle strains is positive. However, they do not describe the material degradation under high hydrostatic compression. Those models cannot capture properly compaction, which is physically a collapse of the material voids. Under high triaxial compression, concrete has an elastic-plastic behaviour due to a decrease of porosity. The Young's modulus of the material increases, plastic strains develop. When the macro-porosity is totally closed, there is a stiffening of the behaviour of concrete which becomes elastic again. This type of behaviour plays a major role in the case of shocks and impacts, where the strain rate is about 10^3 s^{-1}. It is important to underline that prior cracking and shearing occur, e.g. in a perforation test, the material is first subjected to compaction near the impactor. This compaction modifies substantially the propagation of waves and the tensile failure process which results from it.

The goal of this study is to develop an experimental method in static's for the characterisation of cement based materials with a view to the modelling of concrete under high confinement pressures. The literature proposes some tests in triaxial compression presenting the disadvantages to be performed under moderate hydrostatic pressures (less than 100 MPa), Jamet et al. (1984), or on very small specimens (diameter and height lower to 20 mm), Bazant et al. (1986). Taking into consideration the different inconveniences of these tests, we have designed a new uniaxial confined compression test, Burlion (1997b), and we have used the adaptation of an existing experimentation to mortar specimen, which will be named hydrostatic confinement test, Burlion et al. (1997a).

We present here the results obtained on cementitious matrix materials following these two strategies. We examine first the principle of both tests. Second, experimental results on oedometric compaction (with the uniaxial confined compression test) and hydrostatic compaction (hydrostatic confinement test) are shown. Experimental results show that it is not possible to separate the deviatoric response from the hydrostatic response of the material.

2 Compaction on concrete: an uniaxial confined compression test

In our approach, the characterisation of the behaviour of concrete under high triaxial compression required the design of a test with several constraints: simplicity of manipulation, a sufficient specimen size in order to characterise a large range of materials and finally, the capability of reaching high compressive stresses (of the order of 400 to 600 MPa) in order to obtain the compaction of concrete.

It lead us to design an oedometric test, shown on Fig. 1, in which a proportional loading (in the elastic regime only) with $\sigma_2 = \sigma_3 = 0.2\ \sigma_1$ is applied on a concrete specimen. σ_1 is the axial applied stress to the specimen. The geometry of the specimen is a cylinder with a diameter of 50 mm and height 100 mm. The specimen of concrete or mortar is put in a cylindrical steel cell (outside diameter: 140 mm). The coefficient 0.2 corresponds to the Poisson ratio of the confinement cell.

With such a passive confinement method, it is necessary to develop confinement as soon as loading starts in order to avoid cracking to occur in the specimen. Furthermore, the possible cylindricity defects of the specimen which is moulded and not machined must not introduce local cracking and bias. These requirements lead us to use an interface product between the specimen and the confinement cell which is not adhesive to the steel. This product was characterised experimentally, and is supposed, by hypothesis and after an experimental study, to be incompressible for the exploitation of the tests.

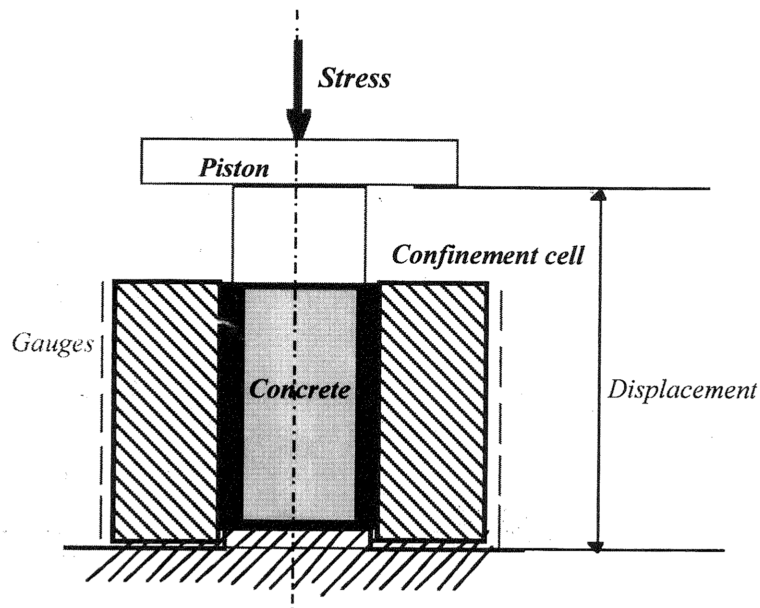

Fig. 1. Principles of the uniaxial confined compression test.

The cell shown on Fig. 2 is placed on a 2,500 kN MTS testing machine. The hydraulic jack loads the specimen axially. The axial maximal stress is about 1,275 MPa for a maximal confinement stress in the elastic regime of 260 MPa. During the test, the applied vertical force and the vertical relative displacement of the specimen are measured. The axial stress corresponds to the applied load divided by the initial cross section of the specimen. The axial strain is calculated by dividing the relative displacement with the initial length of the specimen.

The transverse strains and stresses are derived from the deformations measured on the cell: in order to interpret the data we assume that the friction between the specimen and the confinement cell is negligible. On the other hand, at the time of unloading, friction influences the behaviour of specimens and provokes some hysteretic loop between loading and unloading (Fig. 3). This phenomenon is not observed on the hydrostatic tests where the confinement is applied by a fluid under pressure (see Fig. 5). Besides, the strain gauges placed on the confinement cell inform us on the confinement applied to the concrete. After the analysis of the experimental data, we found that it is possible to consider that the confinement is almost homogeneous in the top part of the specimen of height two third the total height. Thus we calculate the applied hydrostatic pressure on the specimen by measuring the radial deformation of the cell and assuming that the cell has an elastic linear behaviour.

Figure 3 present the results obtained on mortars having different Water / Cement ratio, which is similar to having a different initial porosity. Table 1 gives the composition of the different mortars tested. The curves obtained for different mortars in terms of hydrostatic stress versus volumetric strain in percent are presented.

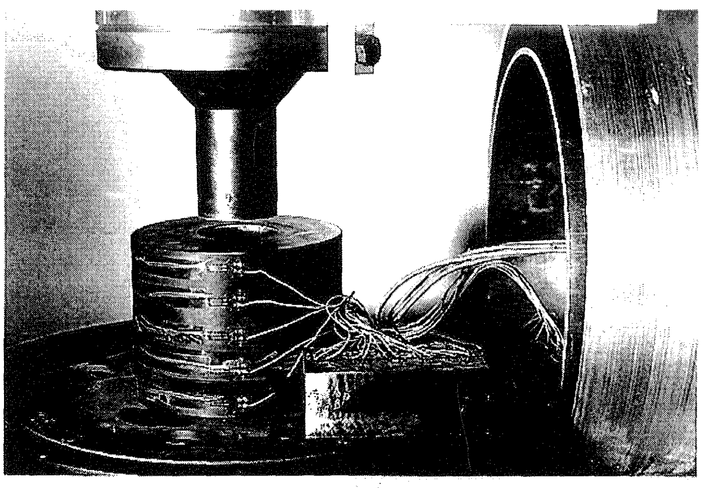

Fig. 2. Photograph of the uniaxial confined compression test.

Table 1. Composition of the tested mortars

	Mortar 1	Mortar 2	Mortar 3
Water/Cement Ratio	***0.3***	***0.5***	***0.8***
Cement CPJ/CEM IIb 42.5 [kg/m^3]	450	450	450
Water [kg/m^3]	135	225	360
Sand (Leucat 0/2 mm) [kg/m^3]	1350	1350	1350
Plasticizer [kg/m^3]	9	-	-

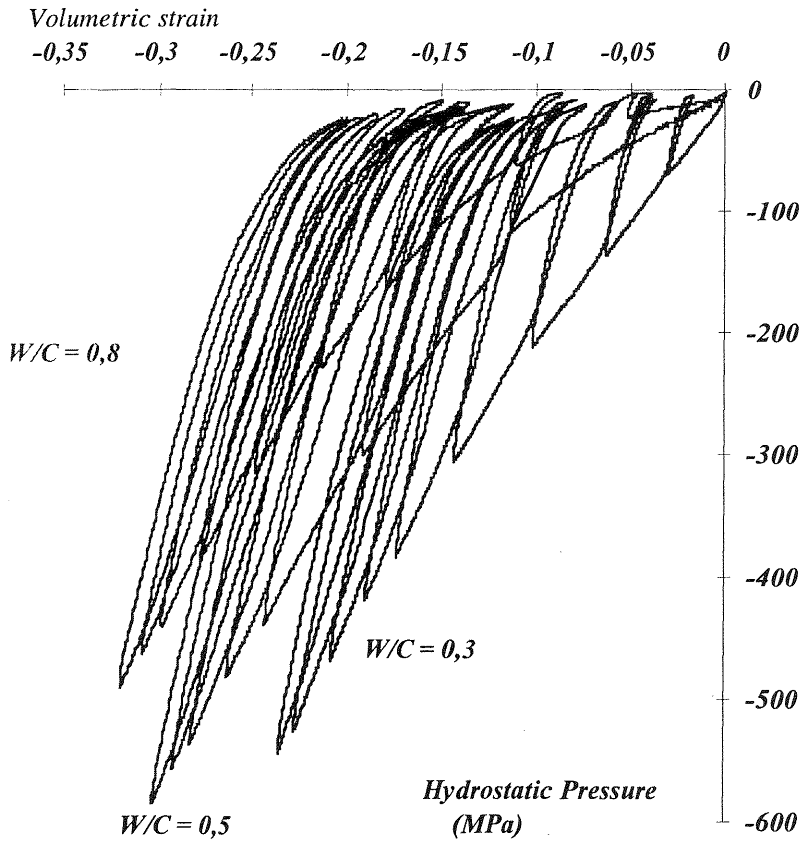

Fig. 3. Hydrostatic stress versus volumetric strain (percent) obtained on different mortars (W/C = 0.3 ,0.5, 0.8) .

As the volumetric strain evolves, the porosity of material decreases. At the same time, an increase of the stiffness of material is observed. During unloading, the material becomes almost elastic with irreversible strain (about 15% on mortar). This behaviour is elastic-plastic with hardening. Note that the elastic phase is very small initially.

The elastic plastic compacting behaviour of concrete is characterised by two types of hardening: an elastic hardening and a plastic hardening. The elastic hardening corresponds to the increase of the unloading stiffness of material with compaction. The plastic hardening is first linear and then non linear with an increasing modulus. Note that on figure 3, the elastic hardening is the same for the three materials, while the plastic hardening increases with the porosity of the material. The elastic threshold for these cementitious materials corresponds to about 30 MPa of axial stress. Different types of concrete and mortar were tested. The uniaxial confined compression test is very repetitive and the obtained confinements are almost entirely proportional to the axial applied stress. This type of test permits, however, only one type of loading in the three dimensional stress space.

Figure 4 presents different specimens of concrete and mortar after compaction by the uniaxial confined compression test. Deformation of the samples is uniaxial and this figure shows the influence of the initial porosity on the final irreversible strain of cement's matrix materials.

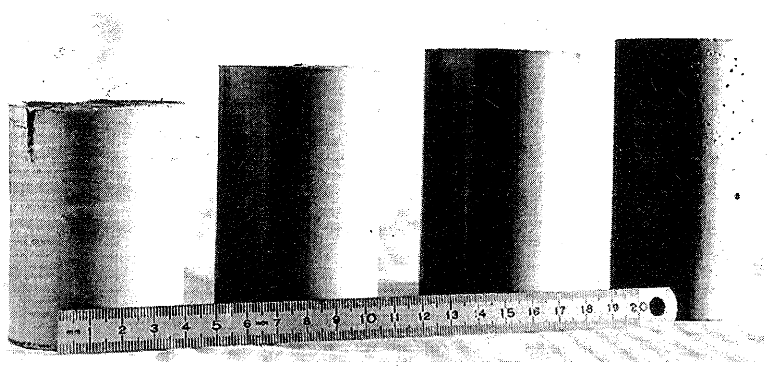

Fig. 4. Uniaxial confined compression test: samples after tests. The most deformed specimen corresponds to the higher W/C ratio.

3 Hydrostatic compaction on mortars

In order to apply another type of loading path to the material, a second type of test was considered. An existing cell had been designed in our laboratory for metallic tubes. The imposed loading was tension-torsion-internal pressure-external pressure. We adapted this test to porous materials. A fluid of which the pressure could reach 400 MPa (Fig. 5) applies the triaxial stress.

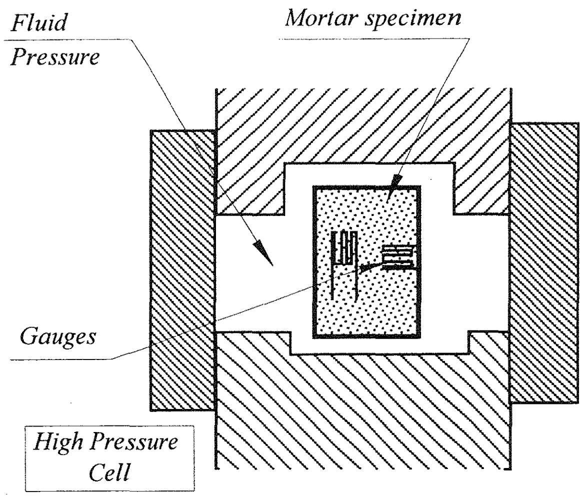

Fig. 5. Experimental hydrostatic test principles.

Given the size of the confinement cell, we had to use a cylindrical specimen of a smaller size (diameter: 17 mm, height: 18mm) equipped by two strain gauges (a longitudinal one and a transverse one). The specimen is covered with two disks in aluminium alloy (AU4G). A rubber membrane laterally protects this prepared sample. The role of this membrane is to stop the penetration of fluid in the material which is porous.

A test on mortar having a W/C ratio equal to 0.5 (Table 1) was done up to a pressure of 400 MPa. Figure 6 shows the evolution of the hydrostatic pressure as a function of the volumetric strain. The three curves on Fig. 6 were obtained with the same mortar. The behaviour of the material is first elastic-plastic until the pressure reaches 150 MPa. Then, there is a stiffening of the material combined with an increase of the compressibility modulus (of about 20% for the considered loading). At the end of the testing, the specimen does not present cracks and only its volume changed.

4 Comparisons between oedometric and hydrostatic results on mortar

The experimental data obtained on the same mortars from both types of tests, uniaxial confined compression (oedometric) test and hydrostatic compression test, are very different (Fig. 7). These data have been obtained after analyse of the stress state and the strain state in the both cases.

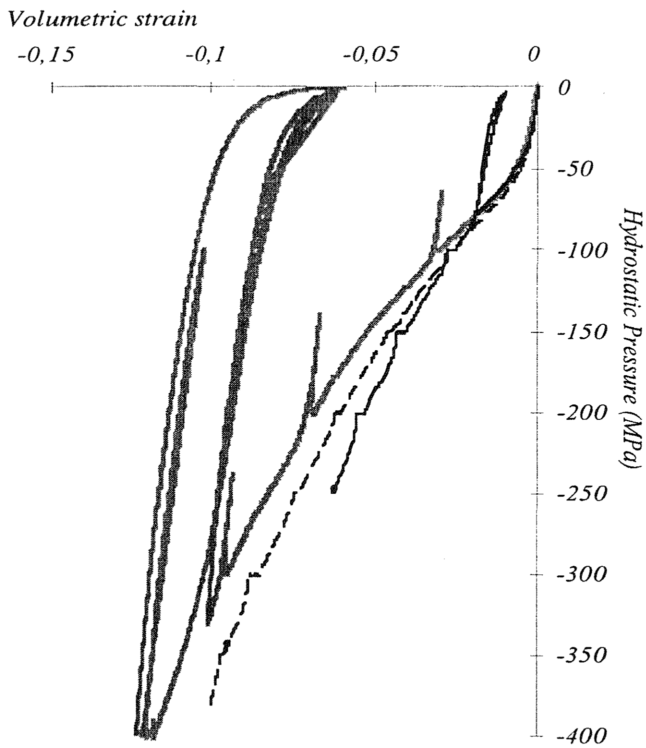

Fig. 6. Hydrostatic pressure versus volumetric strain (percent) curves for mortar.

The uniaxial confined test produces more compaction (stiffening and hardening) compared to the hydrostatic compression one. Besides, an analysis with an electronic scanning microscope showed substantial differences in the microstructure of the material after compaction. A reorganisation of the aggregate skeleton in the material is possible in the case of the uniaxial confined compression test. It provokes a steeper drop of porosity but also micro-cracks in the material. Micro-cracks are perpendicular to the axis of the maximal compression stress. This is the influence of the deviatoric stress on the development of plastic strains. The hydrostatic pressure, when applied solely, preserves the granular organisation of the material, without totally closing the initial porosity of the material. The differences of material behaviour (total volumetric strain, compressibility modulus, specimen state) between the two types of loading paths must be taken into account for modelling the behaviour of such cementitious matrix materials subjected to high triaxial compression.

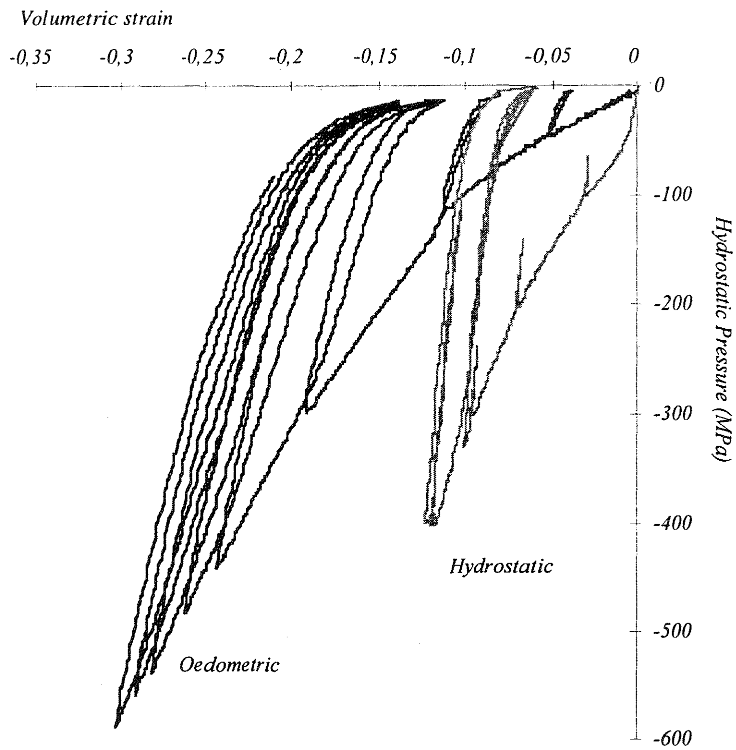

Fig. 7. Experimental hydrostatic and oedometric test results on mortar.

Figure 7 shows very clearly that it is not possible to separate the spherical behaviour from the deviatoric behaviour of the material. This separation, which is classically assumed for the constitutive models used in transient dynamics computations, would provide unrealistic variations of the compaction and, as a consequence of wave propagation, an incorrect response and failure process of the computed structure.

5 Conclusions

A new test was designed. Because of the high compression stresses applied and passive confinement, the concrete behaviour in compaction can be characterised experimentally. Results with loading and unloading cycles were obtained and used to characterise the evolution of the elastic stiffness and of the irreversible strains. In a second step, the adaptation to porous materials of a fluid confinement test was performed. The maximum hydrostatic pressure was 400 MPa. The use of the two tests allowed the investigation of the material response for two (at least) loading paths in the three dimensional stress space. The effect of the deviatoric stress and of the hydrostatic pressure was characterised on mortars. These data will be used to calibrate a concrete model, Burlion (1997b), based on damage mechanics and plasticity.

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