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Triaxial test for concrete under non-uniform passive confinement

Mohsen Mohammadi [a], Yu-Fei Wu [b,*]

[a] Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Hong Kong Special Administrative Region
[b] School of Engineering, RMIT University, Melbourne, Australia; Formerly, Department of Architecture and Civil Engineering, City University of Hong Kong

HIGHLIGHTS

- New test method for passively confined concrete.
- Design of test facility for passively confined concrete.
- Method for design of friction reduction pad.
- Method for calibration of triaxial concrete cube test.

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ABSTRACT

Concrete in structures cannot be reliably simulated by computer under nonlinear triaxial stress state due to the lack of an appropriate constitutive relationship of concrete. When a continuum mechanics based constitutive model is adopted, users need to "adjust" its parameters to suit benchmark experimental results. Triaxial tests of concrete cubes are used to evaluate model parameters. As concrete is load path sensitive, model parameters are different under different stress conditions. Most existing triaxial tests of concrete are for active stress condition. This type of test is not suitable for passively confined concrete, such as fiber reinforced polymer (FRP) confined concrete. This problem is resolved by a unique and yet simple test method reported in this paper for conducting monotonic and cyclic compression tests. Detailed considerations for designing the test assembly are reported, particularly when considering factors that significantly affect test results such as friction from loading plates and measurement of three dimensional deformations.

1. Introduction

Fiber reinforced polymers (FRP) and steel are used to enhance ductility and strength of conventional and high performance concrete in structural engineering [1–7] by providing passive confinement. For developing constitutive material models suitable for concrete under confinement or multiaxial stress state, triaxial or biaxial tests are required [8–10]. Existing material models for passively confined concrete structures are classified as design oriented models [11–20] and analysis oriented models [21–26]. The latter are more analytical and dependent on lateral strain-axial strain relationship of concrete, suitable for modeling confined concrete with finite element method (FEM).

Finite element analysis along with plasticity based models has shown promising results in capturing the strength and deformation behaviour of conventional and high performance concrete structures [27–30]. However, the accuracy of FEM results is dependent on proper calibration of material parameters. In a plasticity model, the lateral strain-axial strain relationship i.e. the dilation property of concrete plays a vital rule. Such a relationship has been established for passively confined concrete under uniform confinement where the confinement pressures in the two lateral directions are equal or by using an "effective" value of non-uniformly confinement as equivalent uniform confinement [31–38]. However, in case of non-uniform confinement e.g. the confinement field in rectangular columns with a FRP jacket [39–41], no experimental result is available for calibration of material parameters.

To solve the problem, people use the results of multi-axial concrete cube tests where the lateral or confinement stresses are actively applied on a concrete cube during a test [42–44]. However, it has been found recently that in actively confined concrete the stress-strain behaviour is different from that in passively confined concrete [44–46]. Therefore, stress-strain properties obtained from traditional multi-axial cube compression tests cannot be used to characterize the behaviour of concrete under passive confinement.

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* Corresponding author.
E-mail address: yufei.wu@rmit.edu.au (Y.-F. Wu).

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Also existing triaxial concrete cube tests can hardly capture the strength and dilation properties of concrete after peak stress. This type of experimental data is essential for evaluating the parameters included in constitutive material models of concrete under non-uniform passive confinement.

To address the above issues, a three dimensional test method and the associated facilities are developed to conduct triaxial compression test of concrete under passive confinement in this work. This facility can apply independent lateral passive confinement pressures to a concrete cube under axial loading. The levels of passive confinement in each lateral direction and the ratio of confinement between the two lateral directions is adjustable. Details of design principles for the facility such as geometrical design, material selection and consideration of factors that significantly affect test results are reported in the paper so that this test method can be adopted by others for testing of passively confined concrete.

2. Conceptual design

The conceptual design of multi-axial compression test for concrete cube under non-uniform passive confinement was initially proposed by the second author in [35], as shown in Fig. 1(a). According to the concept, the first test assembly was designed and fabricated in Tongji University [47] as shown in Fig. 1(b). Based on the experience gained from the first implementation of the test setup, the second attempt was made at City University of Hong Kong which is reported in this paper.

As illustrated in Fig. 1(a), a concrete cube is placed inside four confining plates. When the concrete cube is loaded in axial direction at top and bottom faces, it expands in two lateral directions. Elastic bars are used to restrain dilation of the concrete cube, causing passive confinement pressure on the cube. When the restraining bars deform (within their elastic range), the stress condition of concrete confined by FRP is imitated. By using bars with different rigidities in the two lateral directions, the stress-condition of concrete under non-uniform passive confinement is simulated.

In a typical circular column under uniform FRP confinement, the degree of restraint against lateral dilation of concrete is controlled by the thickness and stiffness of FRP jacket as well as the diameter of the column, which can be reflected by one parameter, the lateral confinement stiffness ratio ρ [34,35], defined as:

$$\rho = \frac{2E_{FRP}t_{FRP}}{Df'_{co}} \qquad (1)$$

in which E_{FRP} and t_{FRP} are stiffness and thickness of restraining material, respectively; and D and f'_{co} are diameter of column and unconfined strength of concrete, respectively. With the test assembly depicted in Fig. 1(a), the stiffness, cross sectional area as well as the length of the bars determine the confinement stiffness ratio in each direction.

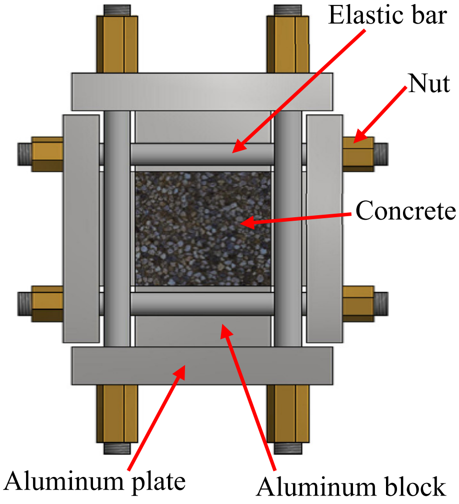
Based on the cylindrical coordinate system shown in Fig. 2, the confinement modulus C_j is defined as the ratio of the incremental lateral stress Δf_r to the incremental lateral strain $\Delta\varepsilon_r$ as follows:

$$C_j = -\frac{\Delta f_r}{\Delta \varepsilon_r} \qquad (2)$$

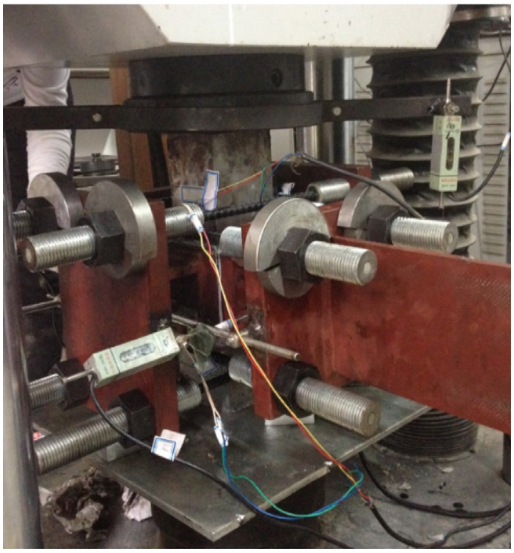
where the negative sign represents passive confinement, which does a negative work upon lateral expansive deformation. Using the equilibrium condition and the deformation compatibility condition in the cross section, the following two equations can be established:

$$f_r = -\frac{2t_{FRP}}{D}f_{j\theta} \qquad (3)$$

$$\varepsilon_r = \varepsilon_{j\theta} \qquad (4)$$



(a) Conceptual design



(b) First test assembly

Fig. 1. Three dimensional test assembly for passively confined concrete.

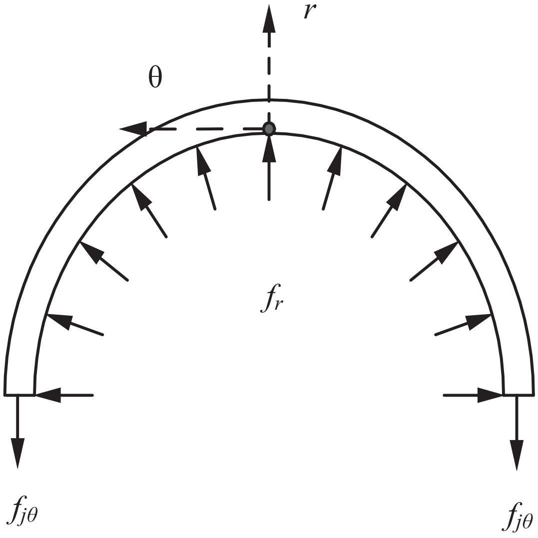


Fig. 2. Cylindrical coordinate system for FRP confined cylinder.