DOI: http://dx.doi.org/10.12989/sem.2010.34.3.391
Structural Engineering and Mechanics, Vol. 34, No. 3 (2010) 391-394

Technical Note

Constitutive law of grouted concrete block masonry in plain stress state

Liu Lipeng† and Wang Zonglin‡

School of Transportation Science and Technology, Harbin Institute of Technology, Harbin 150090, China

Zhai Changhai‡† and Zhai Ximei‡‡

School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China

(Received February 27, 2009, Accepted September 9, 2009)

1. Introduction

Grouted concrete block masonry (GCBM) exhibits distinct directional characteristics on account of the different properties of the anisotropic of the block, its component materials and the regular layout pattern. Owing to the lateral actions (e.g., earthquake or wind, etc.), most masonry walls are in a state of biaxial stress, for example, shear walls, infill walls in framed constructions, walls supported on beams, etc. To predict the behavior of the walls, knowledge of the deformation and constitutive law of GCBM under plain stress state is required. The behavior of GCBM under uniaxial and biaxial loading for monotonic conditions was investigated by numerous researchers. The failure modes, strength and constitutive model were also established. Besides many stress-strain modes were achieved in which GCBM were considered as an isotropic material (Priestley 1983, Dhanasekar 1985, Romano 1993, Madan 1997, Baqi 1999, Alshebani 2000). It is the purpose of this study to provide more complete understanding of the anisotropic stress-strain response to develop practically useful constitutive relationships for GCBM subjected to all combinations of biaxial loading.

2. Experimental program

The experimental program consisted of monotonic uniaxial compression, uniaxial tension, biaxial compression and biaxial tension-compression tests in which the angel θ between the principal stresses and the bed joint was limited to 0°, 22.5°, 45°, 67.5° and 90°. And the anisotropic parameter

† Lecturer, Corresponding author, E-mail: liulipeng@hit.edu.cn
‡ Professor, E-mail: wangzonglin@vip.163.com
‡† Vice Professor, E-mail: zch-hit@hit.edu.cn
‡‡ Vice Professor, E-mail: xmzhai@hit.edu.cn

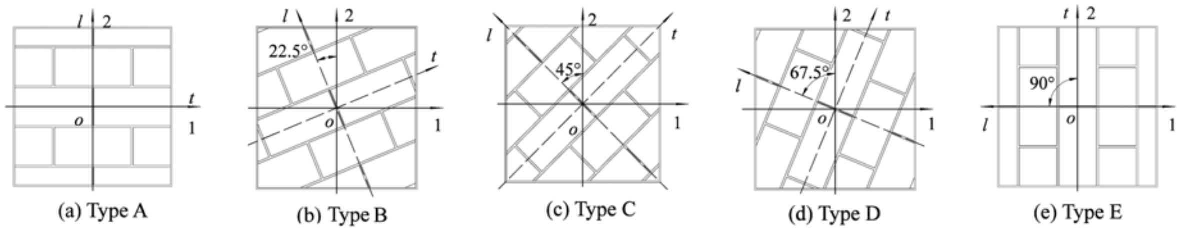

Fig. 1 Types of specimen

γ was defined by dividing θ by 90°. The investigation was carried out for the following five principal stress ratios: $\alpha = \sigma_1/\sigma_2 = -0.1$, 0, 0.25, 0.5, 1.0, where α is principal stress ratio, σ_1 and σ_2 represents stress applied in horizontal and vertical direction, respectively.

2.1 Test specimens

The test specimens were of dimensions 800 mm × 800 mm × 190 mm (Fig. 1) constructed from concrete block units of size 390 mm × 190 mm × 190 mm and 10-mm-thick bed joint mortar. The mean nominal compressive strength of the blocks was 19.6 N/mm^2. And the block was of 58% solid volume. The mean compressive strength of mortar from 81 cubes was 6.0 N/mm^2 with a standard deviation of 1.6 N/mm^2. The mean cubic compressive strength of grouted concrete was 25.5 N/mm^2 with a standard deviation of 3.4 N/mm^2 based on a sample of 54 cubes.

2.2 Loading arrangement

As shown in Fig. 2, the loading arrangement was devised to provide uniform stresses by four steel beams of 350 mm in depth. A biaxial stress state was achieved by applying vertical load with a hydraulic testing machine of 5,000 kN and horizontal load with a specially devised setup. The compressive state was realized by setting the jack(s) and load cell(s) inside the setup, adjacent to the steel beam, as shown in Fig. 2(a). While the tension could be realized by setting them outside the setup, the load from the jack was transferred to the beam via a tie rod (Fig. 2(b)).

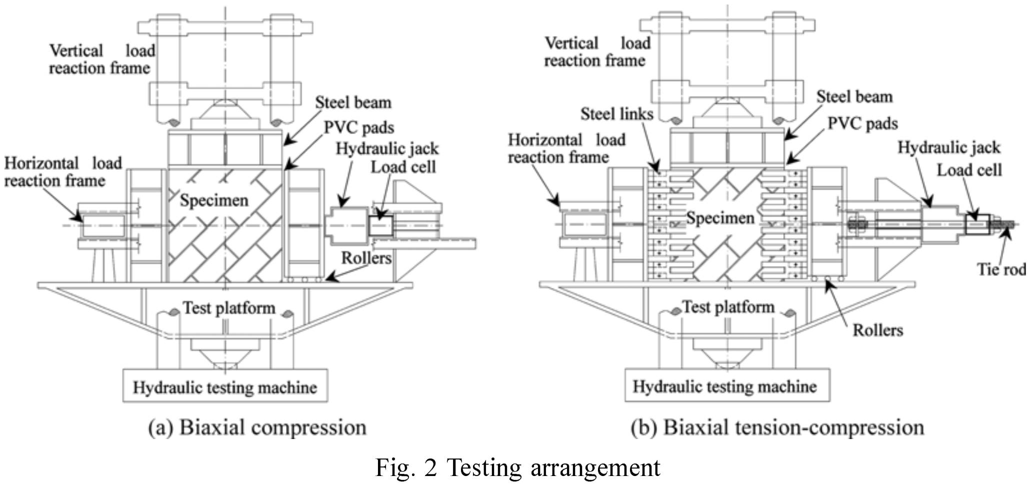

Fig. 2 Testing arrangement

3. Equivalent uniaxial stress-strain relation

3.1 The equivalent uniaxial stress-strain relationship of GCBM

The incremental equivalent uniaxial strains may be expressed in the simple from (Liu 2005)

$$d\varepsilon_{iu} = \frac{d\sigma_i}{E_i} \quad (i = x, y) \tag{1}$$

Writing the Sargin (1971) relationship in terms of equivalent uniaxial strain, we have

$$\frac{\sigma_i}{\sigma_{ic}} = \frac{A\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right) + (D-1)\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right)^2}{1 + (A-2)\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right) + D\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right)^2} \tag{2}$$

in which σ_i = stress in direction i; σ_{ic} = the peak strength in direction i; ε_{ic} = equivalent uniaxial peak strain corresponding to σ_{ic}; $A = E_{i0}/E_{ic}$; E_{i0} = the tangent modulus of elasticity at zero stress in direction i; $E_{ic} = \sigma_{ic}/\varepsilon_{ic}$ = the secant modulus at the peak stress in direction i. Parameter D is an adjustive coefficient, which influences the curve shape of falling branch.

As mentioned in Liu (2005), we get

$$D = 1.19 - 0.25A \tag{3}$$

3.2 Peak strength σ_{ic} and equivalent uniaxial peak strain ε_{ic}

According to the test results, the surface of peak strength σ_{ic} in terms of stress ratio (α), anisotropic parameter (γ) and uniaxial compressive peak strength of specimen A (σ_{0c}) is of the form

$$\sigma_{ic}(a, \gamma) = ((1.31\gamma^2 - 1.47\gamma - 3.21)(1-a) - 2.97a^{1.5} + 4.21)\sigma_{0c} \tag{4}$$

The regression function of equivalent uniaxial peak strain ε_{ic} in terms of stress ratio (α), anisotropic parameter (γ) and uniaxial compressive peak strain of specimen A (ε_{0c}) is of the form

$$\varepsilon_{ic} = ((1 + 0.35\alpha\gamma)((1-a)(2.08\gamma^2 - 2.02\gamma - 1.72) - 2.15a^{1.5} + 2.72))\varepsilon_{0c} \tag{5}$$

where ε_{0c} = uniaxial compressive peak strain of specimen A corresponding to σ_{0c}.

3.3 Parameter A

Parameter A ($= E_{i0}/E_{ic}$) accounts for the variability of elastic modulus and influences on the shape of the ascend branch of stress-strain curve. It is of the form (Liu 2005)

$$A = \frac{E_{i0}}{E_{ic}} = (1 + 0.37(\exp(-6.29a) - 1))(-6.51\gamma^3 + 6.67\gamma^2 - 0.40\gamma + 3.11) \tag{6}$$

4. Theoretical and experimental curves

To uniaxial compression series specimen, stress ratio α is equal to 0. According to each

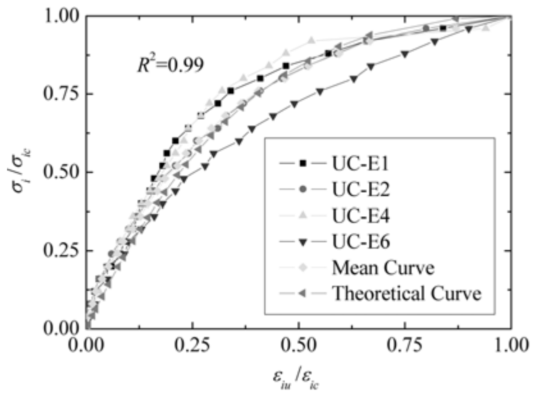

Fig. 3 Stress-strain curves for UC-E series

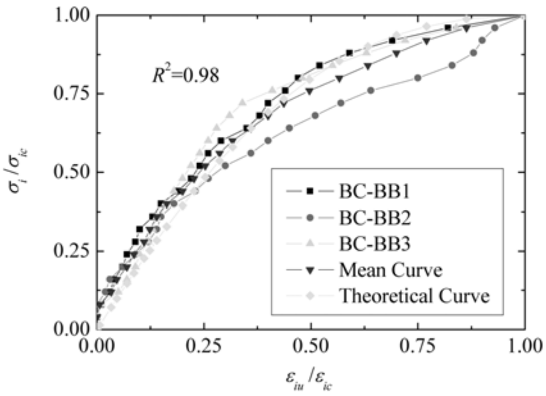

Fig. 4 Stress-strain curves for BC-BB series

anisotropic parameters γ, the value of parameter A can be got from the Eq. (6). Fig. 3 is the uniaxial compressive theoretical and experimental curves of series E (UC-E).

By the same way, the value of parameter A of biaxial compressive specimen can be got from the Eq. (6). Fig. 4 is the theoretical and experimental curves of series BC-BB.

The compressive constitutive mode can be generalized and used to describe both uniaxial tension and biaxial tension-compression response (Liu 2005).

Acknowledgements

The project was supported by the NSFC (No. 90815014, 50608024) and the Innovation and Development Foundation of School of Transportation Science and Technology in HIT. The supports are greatly appreciated.

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