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A restoring force model for steel fiber reinforced concrete shear walls

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ABSTRACT

A cyclic restoring force model is a useful tool for seismic analysis of reinforced concrete shear walls in high-rise building structures. In this paper, five steel fiber reinforced concrete shear walls were tested under horizontal reverse cyclic load with constant axial load. Crack load, ultimate load, lateral displacement, steel strain and concrete strain were measured and the skeleton curves and hysteretic loops were plotted. By analyzing the shape of the typical skeleton curve and hysteretic loop, the feature points which could represent the restoring force models of the curves were defined. After the determination of the feature points and the stiffness, the calculated skeleton curves and the hysteretic loops were obtained and found to agree closely with those of the experimental specimens.

1. Introduction

Because of the frequent occurrence of earthquakes and the extensive application of high-rise buildings, we have been giving greater and greater attention to seismic performance, especially on the restoring force capacity of shear wall structures [1,2]. Due to the high brittleness and low tensile strength of concretes, normal reinforced concretes have low crack resistance, low ultimate strength, and weak deformability and energy dissipative capacities, which indicate weak seismic capacity. Because of this, reinforced concrete shear walls are liable to crack and fail under reversed cyclic load, and need to be repaired or strengthened to improve the crack resistant and seismic performance [3–5]. A variety of methods have been used to resolve these defects such as slit concrete shear wall [6,7], shear wall with brace [8–10], steel and concrete composite shear wall [11–17], and shear wall with damper [18,19]. The purposes of the above technical measures are to improve the seismic performance of reinforced concrete shear walls. But among the above methods, some may reduce the crack resistances, the ultimate strengths or the initial stiffness of shear walls, others may result in complicated and high cost construction.

One effective approach to increase the ductility and tensile property of concrete is to add steel fibers into the concrete to obtain steel fiber reinforced concrete. Much research work has been done in recent years on the performance of steel fiber reinforced concrete and its structures. Short steel fibers dispersed uniformly in concrete can substantially improve the tensile strength, ductility, impact resistance and fatigue resistance of concrete. Therefore, flexural strength, shear strength, crack resistance, load bearing capacity after cracking and toughness of concrete structures can be improved [20–22]. Thus the closely spaced steel fibers throughout shear walls may help to control cracks and dissipate energies, which are expected to enhance the seismic performance of the members.

For the past few years, the authors have performed experimental research on shear walls with steel fibers, which showed that steel fibers can simultaneously improve the crack resistance, ultimate capacity, ductility and energy dissipation capacity of reinforced concrete shear walls [23,24]. In this paper, five steel fiber reinforced concrete shear walls are made to experimentally and theoretically research the restoring force performances. A simple restoring force model will be obtained based on the experimental skeleton curves and hysteretic loops of steel fiber reinforced concrete shear walls [25–32].

2. General test situation

Five steel fiber reinforced concrete shear walls with identification numbers BSWA-10-50, BSWA-15-50, BSWA-20-50, BSWA-10-30, and BSWA-10-70 were tested. The meanings of the identification numbers are as follows. The first number represents the volume fraction of steel fibers and the second number represents the concrete's strength grade. For example, BSWA-10-50 indicates a specimen with a volume fraction of 1.0% and a strength grade of C50.

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2.1. Specimen details

The specimens' height-to-width ratio was 2 and the sectional dimensions were $H \times L \times B$ = 1800 mm × 900 mm × 200 mm. In addition, the shear walls had a top beam and a base girder. The top beam was used to simulate the restricting effects from the floor and served as a load point. The base girder was used to simulate a rigid foundation and fix the shear wall on the floor of the laboratory. The detailed specimen dimensions and the layout of steel bars were displayed in Fig. 1 and Table 1. Shear-cut type steel fibers with length, diameter and aspect ratio of 32.4 mm, 0.56 mm and 57.4, respectively, were used.

2.2. Test scheme

The horizontal load was applied cyclically by the hydraulic servo load system on the longitudinal axis of the top beam as shown in Fig. 2. The vertical load applied by lifting jack reached design load and was kept constant. The ratio of axial compressive force to axial compressive ultimate capacity of section was 0.1. Rolling shafts between lifting jack and reaction beam assured smooth horizontal slipping of specimens Load control mode was adopted first. After the longitudinal steel bars yielded, the displacement control mode was used [33].

2.3. Test results

The compressive and tensile strengths of steel fiber reinforced concrete are listed in Table 1. The mechanical indexes of the steel bars are listed in Table 2. Through the above experiment, the crack load, ultimate load and lateral displacement were measured and the hysteretic loops and skeleton curves were plotted.

3. Feature points of skeleton curve

The typical skeleton curve of steel fiber reinforced concrete shear walls is shown in Fig. 3, which shows that the curve has a slight decline after the ultimate load. In this paper, a four linear skeleton curve is used to relatively coincide with the experimental skeleton curve. Thus, using the feature points, namely the crack point, yield point, ultimate load point and ultimate displacement point, we can transform the curvilinear skeleton curve of continuously changing stiffness into the multi-linear skeleton curve of constant slop in each line segment. To obtain skeleton curves that take the effects of steel fibers into account, the four feature points were determined based on the experimental data.

3.1. Crack point

The calculated models of steel fiber reinforced concrete shear walls were similar to that of normal concrete shear walls. For simplicity, the crack moments of steel fiber reinforced concrete shear walls under the combination of M and N can be calculated by Eqs. (1) and (2) based on the calculation formula of normal reinforced concrete shear walls in consideration of the effect of steel fibers. Comparisons of test and calculated crack moment values are listed in Table 3.

$$M_{fcr} = \left(\gamma f_t W_o + \frac{N}{A_{WO}} W_o\right)\beta_{fcr} = F_{fcr} H \tag{1}$$

$$\beta_{fcr} = 1 - 0.58\lambda_f + 0.717\lambda_f^2 \tag{2}$$

where λ_f is the steel fiber content characteristic parameters, $\lambda_f = l_f/d_f$, l_f the length of steel fiber, d_f is the equivalent diameter of steel fiber; F_{fcr} the horizontal cracking load on top of steel fiber reinforced concrete shear walls, namely the value of the applied load in the test; H the height of steel fiber reinforced concrete shear walls; γ the sectional plastic impact factor, according to the code for design of concrete structures in China (GB50010-2010), the value is $\gamma = (0.7 + 120/h)\gamma_m$, γ_m is 1.55 for the rectangular cross-section, here γ = 1.29; f_t the design values of tensile strength of ordinary concrete corresponding to the strength of steel fiber reinforced concrete; W_o the elastic resistance moment of the transformed section; N the applied axial force, with pressure taken as positive; A_{WO} the transformed sectional area of the shear walls; β_{fcr} is the comprehensive influence coefficient of steel fibers on the cross-sectional

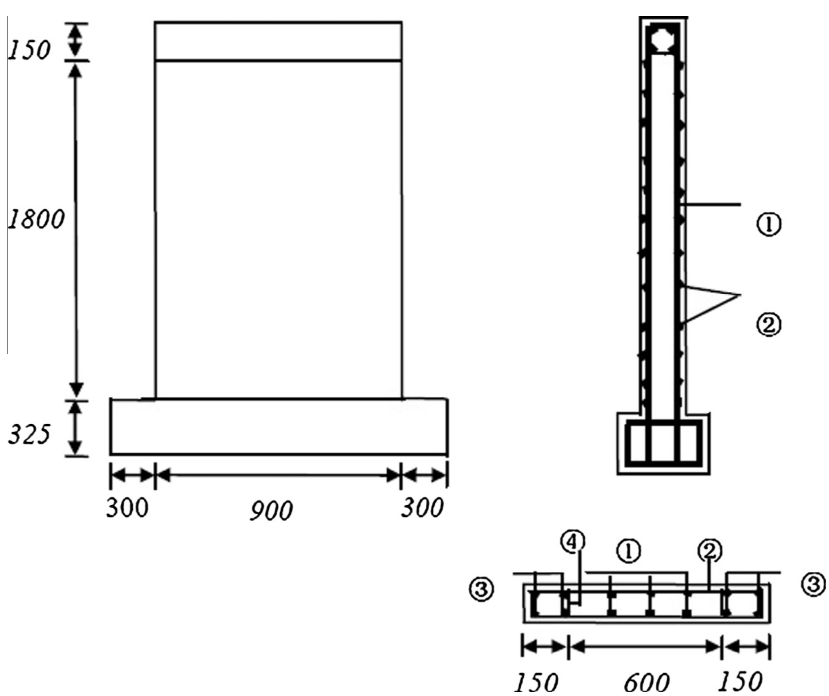

Fig. 1. Detailed specimen dimensions and layout of steel bars.