Engineering Structures 125 (2016) 39–53

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Seismic performance of steel and concrete composite shear walls with embedded steel truss for use in high-rise buildings

Yun-tian Wu *, Dao-yang Kang, Yeong-Bin Yang

School of Civil Engineering, Chongqing University, Chongqing 400045, China

ARTICLE INFO

Article history:
Received 9 November 2015
Revised 25 June 2016
Accepted 28 June 2016

Keywords:
Composite wall
Static test
Earthquake
Parametric analysis
Shear wall
Steel truss

ABSTRACT

This paper studies the seismic behavior of steel and concrete composite shear walls with embedded steel truss, a crucial structural element for use in high-rise buildings. Three one-fourth scaled composite wall specimens with an aspect ratio of 1.0 were tested until to failure under reversed cyclic lateral load and constant axial load. The test parameters were the amounts of embedded truss chord and web brace. The behavior of the test specimens, including the damage formation, failure mode, hysteretic curve, stiffness and strength degradation, energy dissipation and ductility, were examined. Test results indicated that the embedded truss web braces affect significantly the hysteretic behavior of the composite walls in terms of lateral load capacity, energy dissipation and ductility, while the embedded truss chords can enhance the lateral load capacity. To further broaden the test results obtained, while searching for the optimal design, finite element (FE) models were validated against all the test results. Then 27 FE models that cover the practical ranges of axial load ratio, amount of embedded steel truss chord and web braces were adopted in a parametric analysis to investigate their effects on the wall performance. The results indicate that high axial load ratio is beneficial to initial stiffness and lateral load capacity, while adverse to energy dissipation capacity. Although increasing the volumetric ratio of embedded truss web brace can most effectively increase the lateral load capacity, a medium level about 1.59% is its optimum value for ensuring the critical seismic performance in terms of energy dissipation and ductility. In order to avoid the adverse effect on ductility behavior, the axial load ratio should be limited to the medium level, about 0.13 for the nominal value or about 0.30 for the design value.

1. Introduction

In recent years, a large number of high-rise reinforced concrete (RC) buildings have been constructed in regions of high seismicity. If conventional RC shear walls are used as the lateral force resisting system, the thickness of wall may need to be significantly increased in order to satisfy the stringent seismic design provisions of current building codes, resulting in reduced usable floor area and increased seismic structural weight. The difficulty and cost of the construction will also be increased. Therefore, the steel and concrete composite wall has been introduced, where shaped steel is incorporated into RC wall, to obtain high strength, high stiffness and excellent post-yield deformation characteristics by combining the advantages of concrete and steel materials.

Various types of steel and concrete composite walls have been developed and used in seismic zones. Zhao and Abolhassan [1] attached RC panels to the steel plate walls using bolts, resulting in highly ductile behavior and stable cyclic post-yielding performance. Dan et al. [2] encased vertical steel profiles into RC walls and demonstrated the effectiveness of the steel profiles in improving the seismic performance of RC shear walls. Qian et al. [3] embedded steel tubes at the wall boundaries and fully anchored into the foundation of RC walls and proved such composite details can ensure good seismic performance under high axial load and cyclic lateral loading. Nie et al. [4] investigated the seismic behavior of high-strength composite walls composed of concrete filled steel tubular (CFT) columns at the two boundaries and high-strength concrete filled double-steel-plate wall body. Rafiei et al. [5] and Hossain et al. [6] investigated the behavior of composite shear walls consisting of two skins of profiled steel sheeting and an infill of concrete under in-plane monotonic and cyclic loading respectively, demonstrating more ductile behavior and higher energy absorbing capacity. Chen et al. [7] studied the double steel plate-high strength concrete composite walls with concrete filled steel tube boundary elements, showing high strength and excellent deformation capacity.

* Corresponding author.
E-mail address: yuntianw@cqu.edu.cn (Y.-t. Wu).

http://dx.doi.org/10.1016/j.engstruct.2016.06.050
0141-0296/

Nomenclature

V_n	the ideal lateral load capacity of the composite wall
V_{RC}	the shear capacity of concrete encasement
V_{st}	the shear capacity of steel truss
u	the displacement ductility coefficient
Δ_u	the corresponding horizontal displacement when the tests were terminated
Δ_y	the lateral displacement at yield
h_w	the height of shear wall
l_w	the width of shear wall
α	the axial load ratio.
ρ_c	the steel ratio of the embedded truss chord
ρ_{vb}	the volumetric ratio of the embedded truss web braces
$\varepsilon_{c/3}$	the strain at which one-third of the maximum compressive strength is reached
ε_c	the strain at which the maximum compressive strength is reached
ε_u	the ultimate strain at which the material is completely softened in compression
f_c	compressive strength of concrete
f_t	tensile strength of concrete
E	Young's modulus
G_c	the total compressive fracture energy
G_F	the total tensile fracture energy
h	the characteristic element length
τ_{max}	the bond strength
τ_f	the residual bond stress
s	the relative slip between steel and concrete
β	the empirical coefficient.

In this study, an alternative type of steel and concrete composite shear wall has been developed as shown in Fig. 1. The steel truss embedded in the concrete wall is composed of channel steel chords at boundary elements and equal-leg double angle web braces at the wall web. By embedding a steel truss instead of steel plate in the RC wall, considerable saving in steel material and improvement in constructability can be achieved. Previously, Sittipunt et al. [8] and Shaingchin et al. [9] have proved the effectiveness of diagonal web reinforcement in improving the seismic performance of the RC walls. Replacing the diagonal web reinforcing bars by shaped steel members such as equal-leg double angle can surely improve the constructability. In order to further investigate the seismic behavior of steel and concrete composite walls embedded with steel truss, a series of three one-fourth scaled wall specimens with a small aspect ratio of 1.0 were tested under constant axial load and reversed cyclic lateral loads. To broaden the results obtained, while searching for the optimal design, finite element models were established and validated via comparison of the simulation results with the experimental ones for the three specimens. Then 27 FE models that cover the practical ranges of axial load ratio, steel ratio of embedded truss chord members, and volumetric ratio of embedded truss web braces were adopted in the parametric study to investigate their influences on the overall performance of the composite shear walls.

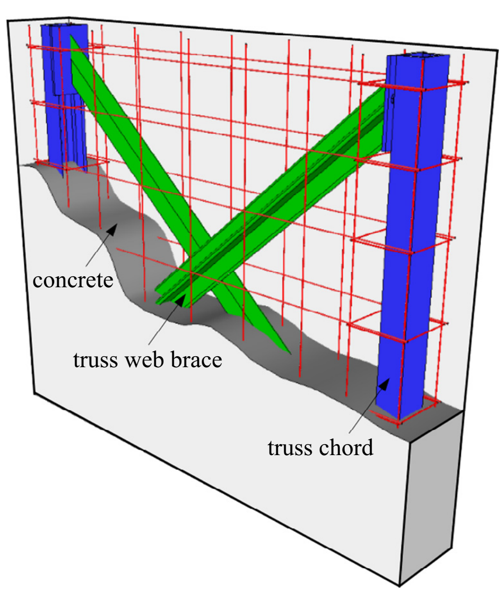

Fig. 1. Proposed type of composite wall.

2. Experimental program

2.1. Details of test specimens

Three one-fourth scaled specimens embedded with steel truss identified by S-1, S-2 and S-3 were constructed and tested under constant axial load and reversed cyclic lateral load. All the specimens were designed according to the Chinese Code for Seismic Design of Buildings (GB50011-2010) [10], having identical overall geometric dimensions, as shown in Fig. 2. The aspect ratio of the wall height l_w to wall width h_w was approximately 1.0. The chord members of the embedded truss were channel steel for specimens S-1 and S-3 and I section steel for specimen S-2. The web brace member of the embedded truss was equal-leg double steel angles ∟25 × 2 for specimens S-1 and S-2 and ∟30 × 4 for S-3. The shop welded 180 mm × 68 mm × 6 mm endplate connection was introduced to join the chord and web brace of the embedded truss. Detailed dimensions of the truss members are also shown in Fig. 2.

The main design results of the specimens are listed in Table 1. The key parameters of the specimens are listed in Table 2, where the steel ratio ρ_c of the embedded truss chord is defined as the ratio of the cross sectional area of the chord members to the total wall cross sectional area, and the volumetric steel ratio ρ_{vb} of the embedded truss web brace is defined as the ratio of the web braces volume to that of the wall. The steel ratios of the embedded truss chord members were 1.73% for S-1 and S-3 and 3.59% for specimen S-2. The volumetric steel ratios of the embedded truss web braces were 0.70% for specimens S-1 and S-2 and 1.59% for specimen S-3. The influences of ρ_c and ρ_{vb} on the overall behavior of the composite wall can be evaluated by the comparison of the test results of the specimens. The axial load ratio α, defined as the ratio of the applied axial load to the total axial load carrying capacity of the wall cross section, was 0.2 for all three specimens. It was approximately maintained constant and vertical during testing.

2.2. Test setup and instrumentation

The axial load and lateral cyclic load were applied to the specimens using the test setup shown in Fig. 3. It is noted that there was a roller track between the vertical hydraulic jack and the reaction girder that allowed the jack to horizontally slide so as to maintain the vertical direction of the axial load. The reversed cyclic horizontal load was applied to the specimen by a servo-controlled