Paper No. 636. (quote when citing this article)
11 WCEE
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

EARTHQUAKE RESISTANT DESIGN CODE FOR COMPOSITE MASONRY WALL SYSTEM BUILDING IN SHENYANG METROPOLITAN AREA (1995)

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ABSTRACT

The brick / block masonry wall restrained by the reinforced concrete confined beams and columns, being acted as a part of the whole wall element, is taken as a composite wall to resist the vertical and horizontal loading actions. It was shown that the composite wall system buildings were of good aseismic behavior, a 15—25% of the cost would be cheaper than the frame structure building and about one-third of the construction period would be shortened.

Based on the systematic experimental and theoretical research works and on the probability and limit state strength design criteria the earthquak-resistant design code for composite buildings was published in 1995.

The quality control and constructional measures are to be introduced. When some provisions of constructing measures are conducted the needless of independent column footing is insured. The cheking of lateral displacement of storey or building might be omitted if the shear strength and some provisions for construction are satisfied. The working process of composite wall should particularly be made to guarantee for a solid performance of the confined beam, column and masonry together.

The height / width and height / length ratios for the building are limited in 2. 5 and 1. 5 respectively. The dynamic reliability index for seldom occurred earthquake is assigned for a value greater than 3 in this code. No calculation for reliability index is neccessary.

KEYWORDS

Reinforced concrete-brick / block composite wall; RC confined column; RC confined beam; Limit state criterion; Dynamic reliability; Construction measures.

INTRODUCTION

The so-called reinforced concrete-brick / block masonry composite wall is made of RC beam and columns around the perimenters and in the middle of brick masonry, they are so tightly combined to each other and would not break away until collapse. It is differed from either RC frame with infill walls or brick wall with the constructional RC columns on both ends. The RC beam and columns, as a part or members of the single wall structural element they are used not only to restrain the brick masonry, but would act as a part of the wall element to resist the vertical and horizontal loading actions. As well so the capabilites of RC masonry would be contributed to the fullest extent, the bending, shear and compression strength, as well as ductility of the wall are therefore increased.

Due to the restrain to the wall by the confined beams and columns and also confined columns at the intersections of the longitudinal and transverse walls on each storey, the integrity, as well as the aseismic behavior of the whole building are then greatly strengthened. The advantages of this type of masonry buildings include simple construction procedures and a 15—25% reduction of cost cheaper than the RC frame buildings.

Based on the experimental study and theoretical analysis on composite walls and on static and dynamic model buildings, the aseismic building design guide was issused and several millions square meters of 7—9 storey resident buildings had been built in the seismic zones where the earthquare intensity being assigned to be 7 and 8 since 1987. No cracks, even the temperature cracks, were not observed on these simulated built buildings. As a matter of accumulation in practice, the code entitled 《Earthquake-Resistant Design Code for Composite Masonry Wall System Building of Shenyang City (SYJB—94)》 had been published in 1995. Some prime provisions are briefly introduced in this paper.

DESIGN PRINCIPLES

The design principles of composite wall buildings are the same as those in the 《Chinese Aseismic Code of Building Structures (BGJ 11—89)》, in which the two-step of aseismic design was adopted. In the first step the strengths of bearing elements were checked by using of the seismic influence coefficient for mode intensity and in the second step the checking of lateral drift ratios are required for intensily of seldom occurred earthquake.

STRUCTURAL PLAN AND CONSTRUCTIONAL MEASURES

The height to width and height to length ratios of buildings should be limited respectively within 2. 5 and 1. 5 for both the shape of lateral displacement and the fundamental mode shape are predominately of shear deformations. The building height limits are of 21m. , 24m. and 27m. for intensities 8, 7 and 6 respectively. The lateral stiffness differences between adjacent storeys be not beyond 30% to avoid the concentration of deformation. The maximum storey height would be 4m.

The strength grades of brick, mortar and concrete could not be less than MU7. 5, M5 and C20 respectively. Should the requirements and some corresponding provisions be satisfied, the storey dirft ratios would be less than 1/1000 and 1/300 respectively for intensity 7 and 8 by the time history dynamic analysis. The value of reliability index greater than 3 would thus be guaranteed.

In case of tightly combined composite walls it is specially advised that brick walls should be constructed prior to the columns having poured and the convex and concave boundaries between masonry and columns have to be made, as shown in Fig. 1. The tying steels from column to masonry in the site of bed joint are also to strengthen the connection of them .

It is neccessary to have the confined beams laid on the top of the foundations and its cross section would not be less than 300×240mm. No individual foundation of the columns would be required, this has been proved by the analysis of the foundation reactions and settlements for a 8—storey building under various conditions of footings (Yang et al. , 1991) and also by practice.

As the code specified that the distance between the confined columns for the first three storeys should not be greater than the storey height and be not greater than 5m. for the other storeys for the transverse walls. If the corresponding provisions are fully met, the checking of overturning moment could be omitted.

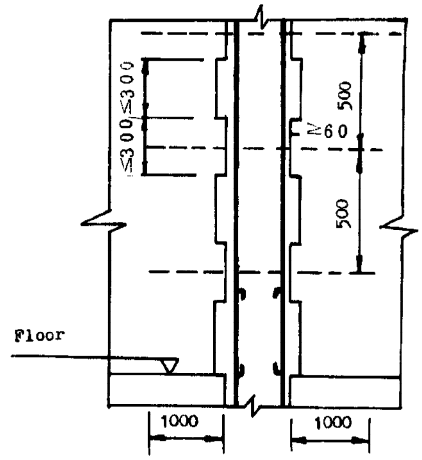

Fig. 1 Sketch of boundary between masonry and column. All in mm.

EARTHQUAKE RESISTANCE CHECKING OF COMPOSITE WALL BUILDINGS

The tests by pseudo-static method had been conducted by three groups all in 1 : 1 scale, seventeen groups in 1 : 2 scale for transverse walls and two groups in 1 : 1, three groups in 1 : 4 for longitudinal walls under various axial loading with different cross-sections and reinforcement ratios of columns to study the strength and deformability of the composite walls. It was shown that due to the restrain of confined beams and columns, the shear strength of masonry was increased and the ductility coefficients of walls reached to 3.5—5 (Zhang et al., 1991, 1994; Cui et al., 1991; Zhang et al., 1991). According to their stiffness, the vertical loads were basically distributed beteewn the columns and the masonry.

The 1 : 2 scale of 8-storeys model building was conducted by pseudo-static method and a 1 : 4 scale of 8-storeys model building by earthquake simulating shaking table test (Wei et al., 1991; Xia et al., 1994). It was shown that the two model buildings had good integration, higher resistance to shear and bending and sufficient strength to resist the earthquake action at an intensity of 8.

By dynamic testing in situ on 12 composite wall buildings of 8 to 9-storeys, the natural period were 0.33 to 0.39 sec. in transverse direction (average value was 0.36 sec.), and 0.27 to 0.37 sec. in longitudinal direction (average value was 0.32 sec.). All the first mode shape was predominately in shear deformations. That is why to use the base shear method for calculating the storey shear forces, for a rather conservation manner, the maximum value of seismic influencing coefficient α_{max} adopted.

The reliability index is calculated by using the First Order Second Moment Method with displacement as a criterion and 20 recorded earthquake ground accelerograms were collected to get the response sample data. The reliability index values obtained are greater than 3 for a typical 8-storey composite wall building (Huang et al., 1994).

LATERAL RESISTANCE CAPACITY OF COMPOSITE WALLS

By taking account of the composite wall as a structural element and the confined beam and columns are the members of the wall, more precise analytical method is that the wall is considered to be a plan stress problem by using the nonlinear FEM. Comparisons of FEM to the testing results were made and a good agreement of the ultmate lateral capacity between the testing results and FEM was obtained (Xi et al., 1995). By applying this nonlinear FEM to calculate a series of composite walls with different height to width ratios (0.23—0.92), different cross-section of columns (240×240—400×240mm), different vertical compressive stresses (0.2—0.9MPa), and various grades of concrete (C13—C20) and mortars (M5—M10), etc. was analyzed. Based on the systematic experimental and analytical works some simplified semi-empirical formulas of cracking, ultimate lateral strength and stiffness were obtained.

It may be seen that all of the testing and calculating walls were one storey only and the height to width ratio was limited up to 0.92, beyond this range the bending effect on the strength of the wall is increased with the increasing of height / width ratio. If a revised factor β (less than 1) in the formulas was considered, then the checking of bending strength of the wall could be omitted. The general form of checking the lateral bearing capacity formulas are shown as follows:

$$V \leqslant \frac{\beta}{\gamma_{RE}}[f_{VE}(k_1 A_{nm} + \sum \eta_c \frac{E_c}{E} A_c) + \sum \eta_y f_y \cdot A_{sc}]$$

where V—design shear force of the wall;

γ_{RE}—adjustment coefficient for the bearing capacity of wall;

f_{VE}—designed value of earthquake resistance shear strength

$$f_{VE} = f_V \sqrt{1 + 0.45 \frac{\sigma_0}{f_V}};$$

f_V—designed value of shear strength of masonry;

k_1—enhanced factor of masonry by confined effect of columns;

A_{nm}—net cross section area of masonry;

η_c—participation coefficient of confined columns according to the site of the columns;

A_c—cross section area of column;

A_{sc}—cross section area of the longitudinal steel bar, which should not be greater than 2% of A_c;

η_y—participation coefficient of reinforcement for shear resistance;

f_y—designed value of tension strength for steel;

E_c, E—elastic modulas of concrete and masonry.

An opening effect factor should be taken into account in the above formula if they are on the wall.

CONSTRUCTION REQUIREMENTS AND QUALITY CONTROL

The quality of construction should exercise great influence on the performance of the building structure. A series of construction requirements had been specified, such as the thickness of the bed joint, contact percentage of the brick with the mortar, the tolerances for placement of steel, the verticality of the columns, etc. The most important one is the construction procedure of the wall. It ought to be emphasized that the brick wall must be built in shape as shown in Fig. 1 and prior to the pouring of the columns to assure the tight combination between the masonry and columns. The height at which the pouring take place should be limited within 2m. and a cleanout for the column is necessary to remove the mortar droppings and other foreign materials. At least a sight face on each column should be provided for inspecting the qualtiy of the concrete.

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