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INNER FORCE REDISTRIBUTION AMONG DIFFERENT LATERAL STRUCTURES IN A MULTISTORY FLEXIBLE DWELLING WITH SEVERAL SHAFTS AND R.C.- MASONRY WALLS

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ABSTRACT

A new structural system was widely used in many residential buildings, during the renovation of former city of Beijing, China. It came from its flexibility in architectural layout and low cost. The system consists of R.C. tubes (shafts) and composed masonry walls(C.masonry walls), which have different antiseismic characteristics. Model test of the system at Tsing Hua University indicated that the inner force redistribution had influence on the maximum inner force of each lateral structure, which appeared at different working stage. It is important for structural design to get the inner force.

To measure shear redistribution in nonlinear stage between R.C. tubes and C.masonry walls is difficult in this kind of composed system, which is generally analyzed with various nonlinear models. However, the key points of nonlinear models are determined by independent specimen tests. This paper presents the inner forces' redistribution according to the test. The shear redistribution process was gotten through measuring the strain of steel bars and concrete, tested constitutive function and finite element technique. The results are very close to the test.

Considering the redistribution, a simplified method for design is given, in which, a stiffness degradation factor is studied theoretically and combined with test results.

KEY WORDS:

Model test, Nonlinear analysis, Force redistribution, Seismic research

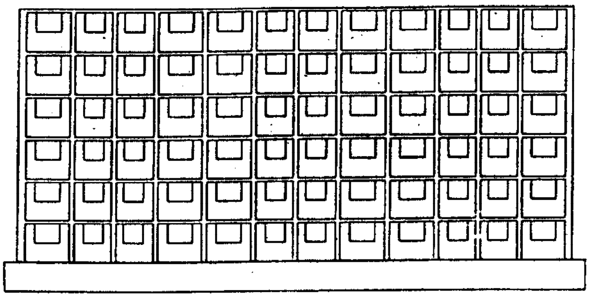
1. INTRODUCTION

Masonry structure is widely used for dwellings in China. Its seismic behavior can be improved by using tie-column and tie-beam or R.C.shear walls. However, traditionally, small bay and depth do not avail architectural layout. A new kind of structure named Multistory Flexible Dwellings greatly improved both adaptability and seismic behavior [1],[2].

The model structure is shown in Fig1. Test research of reversed cyclic loading indicated that the structure had very well seismic behavior and could be used in earthquake-prone area[3].

An inner force distribution method [2],[3] was suggested and could be used in design. In fact, the inner force distribution changed when the structure entered non-linear stage. Test indicated that the maximum inner force in different sub-structures appeared at different times, which is important for structural design.

This paper will study the inner force redistribution.



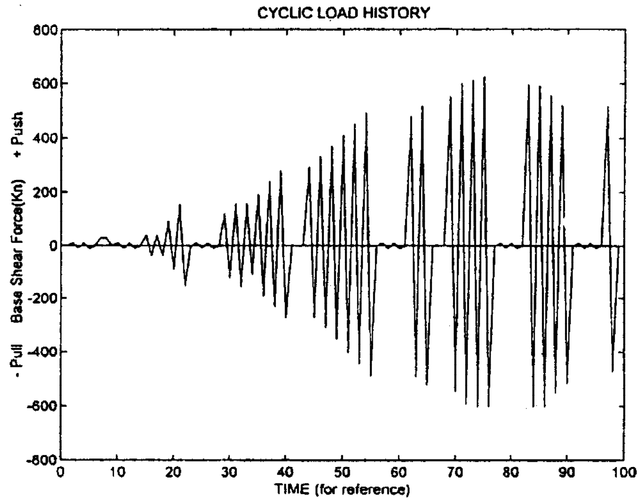


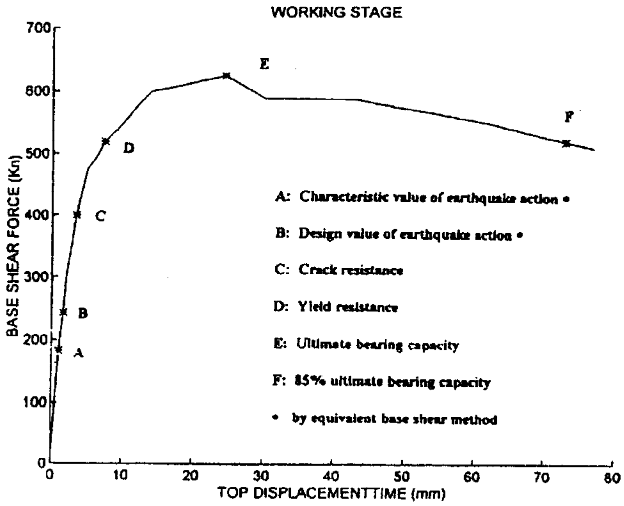
Fig. 1. Tested model (1/4)

Fig. 2. Loading condition

2. TEST PHENOMENA ON INNER FORCE REDISTRIBUTION

A quarter scale model test under reversed cyclic loading was carried out at Tsing Hua University. Fig 2 showed briefly the loading condition. Fig 3 is the schematic curve of top lateral displacement with total shear force.

The model cracked at the bottom of R.C.tube when the total load reached 250 kn., all three tubes cracked at 360 kn., outer C.masonry walls cracked afterwards.



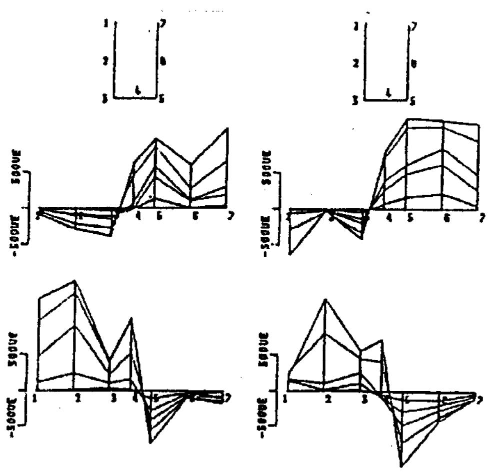


Fig. 3. The schematic curve

Fig. 4. Strain distribution along tubes' section

Steels in R.C.tubes began yielding at 480 kn. Then the curvature ratio of cross section increased rapidly. Fig 5 was the curvature ratio distribution calculated according to the measured strain of steels and concrete. Obviously, plastic hinge occurred before reaching the maximum load.

In tie-column of C.masonry walls, a few steel bars began yielding at 610 kn. before the peak load. More steels yielded in the descending period (fig 3).

From the above description, It can be concluded that different lateral structures did not crack or yield simultaneously but alternately. The R.C.tubes formed the first defense line where the plastic hinge consumed a great amount of seismic energy. The C.masonry walls undertook a principal role in the descending period to form the second defense line. Similar phenomena had been noticed in traditional frame-wall R.C.structures[4],[5].

These features above presented are important for structural design. Shear redistribution must be considered to get the maximum force in structural analysis and R.C.tubes must be designed to possess enough ductility availing the force redistribution. However, theoretical analysis on the shear force redistribution is difficult because that the C.masonry walls' model can not be established perfectly. In general, the key points of the models might be determined by independent specimen tests rather than entire structure.

3. TESTED AND CALCULATED RESULT ON INNER FORCE REDISTRIBUTION

In order to study the force redistribution between R.C.tubes and C.masonry walls, steel and concrete strain of R.C.tubes were measured during the test. Fig 4 is the layout of strain meters at the foot of R.C.tube and the tested strain distribution along the wall section.

Stress-strain relationships of concrete and steels were tested beforehand. According to these relationships and the measured strain, normal stress at corresponding places at any force level could be gotten. Dividing the tube section into several finite elements (fig 5) and calculating the tested objective moment Momc in formula (1), we get

$$Momc = \sum_{i=1}^{n} \pm yi \bullet (Aic \bullet \sigma ic + Ais \bullet \sigma is) \qquad (1)$$

where, yi is the distance between the element center and the axial of tube section,

Aic is the concrete area of element i, Ais is the steel area in element i,

σ ic is the calculated concrete stress of element i, according to concrete constitutive curve and the measured strain,

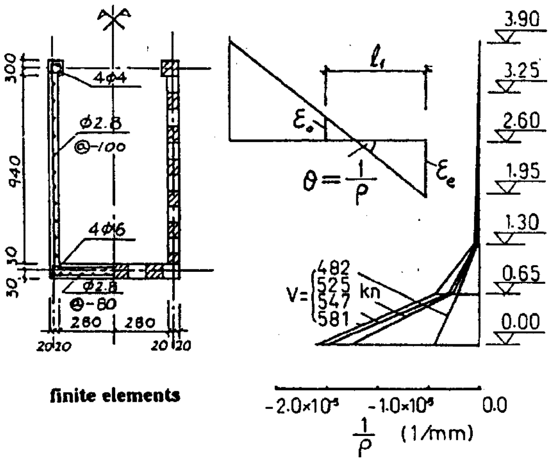
σ is is the calculated steel stress of the element, according to the stress-strain relation and the measured strain.

n is the total number of finite elements.

Momc corresponded to the actual moment of the tube, and the result was drawn in Fig 6 (where V is the total force, Vy is the yield shear force of the structure, see fig 3, point D). The moment was increasing with the load, where the increasing rate was changing too. The changing phenomena reflect the cooperation and force redistribution between the tubes and C. masonry walls.

For more clearly observing the redistribution process, now compare the tested moment Momc with theoretically calculated moment Me in elastic method[1] at corresponding shear force. The compared result is drawn in Fig 7, where 450 slanting line means that the tested moment Momc equals to the calculated Me.

According to these tested points in fig 7, the inner force redistribution could be summed up as three phases, which are simplified by three strait lines:



finite elements

Fig. 5. Curvature ratio

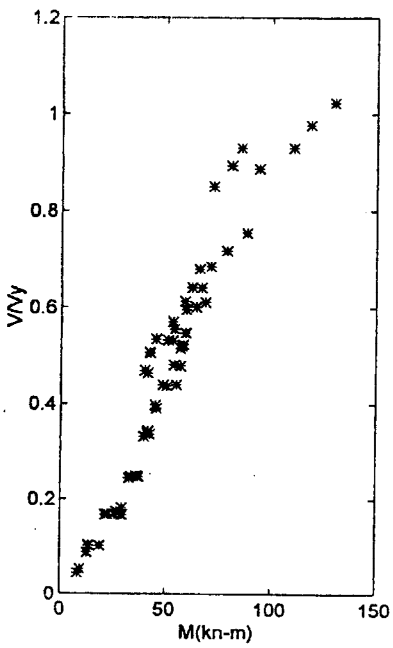


Fig. 6. Tube moment at the foot level

In phase OA before the tube cracked, the value Me/Momc approached 1:1, which meant that the calculated moment corresponded to the tested one. In phase AB, the stiffness degradation took place after the tube cracking. The tested objective moment rate declined, while the inner force ratio of C.masonry walls would be increasing. It would lead to the cracking of masonry walls. In phase BC, after the masonry walls cracked, the stiffness degradation of masonry walls leaded to the increasing of the tubes moment rate until the tube yielding. The force values of those turning points in fig 7 correspond to the test phenomena.

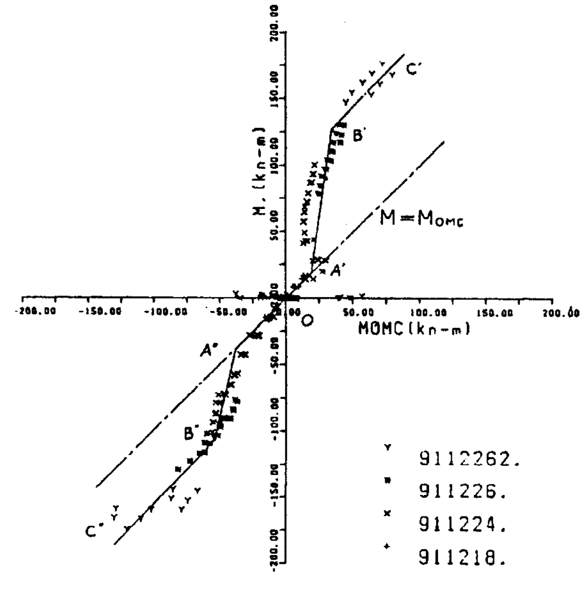


Fig. 7. Comparison between Momc and elastic values Me

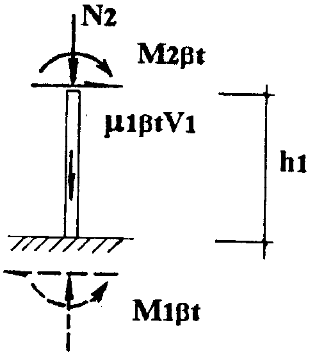


Fig. 8. Simplified model

4. SIMPLIFIED METHOD CONSIDERING THE INNER FORCES REDISTRIBUTION

(1) Elastic phase

Shear distribution, among different lateral structures according to their elastic lateral stiffness Kim and Kit, had been analyzed and combined with test results [1],[2]. So, respectively, shear distribution coefficients of tubes and C.masonry walls are

$$\mu_{im}=\frac{K_{im}}{K_{im}+K_{it}} \tag{2}$$

$$\mu_{it}=\frac{K_{it}}{K_{im}+K_{it}} \tag{3}$$

Where foot note i represent the floor number.

(2) Nonlinear phase

Tube stiffness would degrade after crack or yield, which took place at the bottom of tubes. Therefore, shear redistribution should consider the degradation, which is assumed to be reflected by a stiffness degradation coefficient, the determination of which will be discussed later.

The shear redistribution coefficient of C.masonry walls is

$$\mu_{1\beta m}=\frac{K_{1m}}{K_{1m}+\beta\bullet K_{1t}} \tag{4}$$

The shear redistribution coefficient of R.C.tubes is

$$\mu_{1\beta t}=\frac{\beta\bullet K_{1t}}{K_{1m}+\beta\bullet K_{1t}} \tag{5}$$

Where, K_{1m},K_{1t} is the elastic lateral stiffness of C. masonry walls and R.C. tubes of first floor, respectively.

(3) Stiffness degradation coefficient b

βcould be determined by the test results. The simplified model of R.C.tube in fig 8, where V_1 is the total shear force at first floor, h_1 is the height of first floor, $M_{1\beta t}$ or $M_{2\beta t}$ is the redistributed tube moment at the foot level of first or second floor, respectively.

From the equilibrium condition of the model we have

$$M_{1\beta t}=\mu_{1\beta t}\bullet V_1\bullet h_1+M_{2\beta t} \tag{6}$$

When the tubes are just yielding, M2bt can be assumed to be

$$M2\beta t=\frac{M2t}{M1t}\bullet M1\beta t \tag{7}$$

Where M1t,M2t is the elastic moment at the foot level of 1st or 2nd floor, respectively. Substituting (7) into (6), we get

$$M1\beta t=\frac{\mu 1\beta t\bullet V1\bullet h1}{1-M2t/M1t} \tag{8}$$

Where, M1βt is the redistributed moment and should correspond to the tested value Momc:

$$M1\beta t=Momc \tag{9}$$

Substituting (5) into (8) and into (9), we get

$$\beta=\frac{(1-M2t/M1t)\bullet Momc\bullet\lambda 1/(V1\bullet h1)}{1-(1-M2t/M1t)\bullet Momc/(V1\bullet h1)} \tag{10}$$

Where, $\lambda 1=K1m/K1t$, is the lateral stiffness ratio of C.masonry walls to R.C.tubes at 1st floor. Substituting the elastic calculated moments and test resulted Momc into (10), we can get the relationship between $\beta$and V1/Vy in fig 9. This fig showed that the tube stiffness was degrading gradually with the load increasing. β reached the lowest value when the load

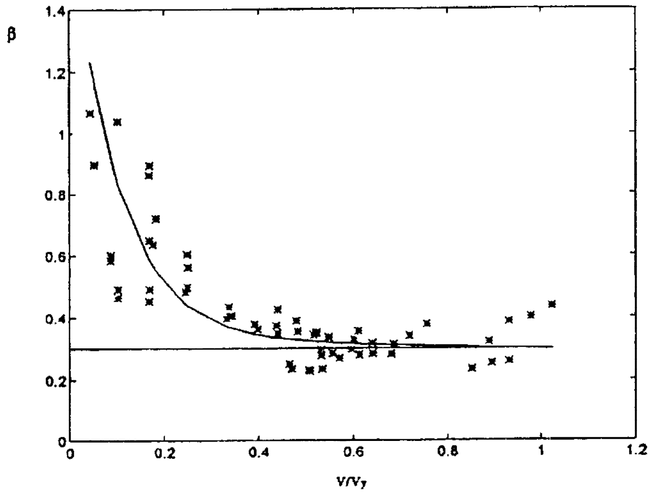


Fig. 9. Stiffness degradation coefficient β

reached 0.5 ~ 0.7 Vy (tubes cracking). After that, β kept the value about 0.3. Considering the most unfavorable condition for the C.masonry walls was the time when the β reached the lowest value, the most suitable value of β should be 0.3 for design.

5. CONCLUSION

This paper revealed the inner force redistribution between the multi-lateral structures according to theoretical analysis and test results. The used finite element technique to value the tubes' moment was proved to be effective.

R.C.tubes formed the first seismic defense line after cracking and yielding. In the descending period, the C.masonry walls played a principal role, which formed the second defense line. The design of them should consider the shear increasing after the tubes entered nonlinear stage.

Considering the force redistribution, a practical simplified design method was put forward. A tube stiffness degradation coefficient was determined by analysis and the tested results.

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