EXPERIMENTAL STUDY AND ANALYSIS OF EARTHQUAKE DAMAGE OF R/C FRAME BUILDINGS WITH EXTERIOR BRICK BEARING WALLS AND THEIR STRENGTHENING

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SUMMARY

A large amount of multistory R/C frame buildings with exterior brick bearing walls were built in China and now they are being strengthened to resist earthquake. This paper presents the experimental study of the testing models under pseudo static cyclic loading and of two buildings under explosive generated ground shock in field condition. The results of dynamic analysis are very close to the damage characteristics of the test buildings. Finally, some recomendations are presented for strengthening of this kind of building.

INTRODUCTION

During the Haicheng earthquake occured on Feb. 4, 1975 in China, the R/C frame building with exterior bearing walls suffered different extent of damage under intensity VII, VIII, and IX. The damages of the upper parts of the buildings were more severe than that of the lower parts. But the results of calculation by the current Chinese aseismic building code are just opposite, namely, the damage of the lower parts are more severe than that of the upper parts. Therefore, it is necessary to carry out experiments and analysis in order to reveal the mechanism of damage of the buildings and enable the strengthening, which is broadly being conducted in China, more resonable.

EXPERIMENTAL STUDY OF THE EARTHQUAKE-RESISTANT CHARACTERISTICS OF THE BRICK WALL AND FRAME

The structure of R/C frame building with exterior bearing wall consists of frames and brick walls. Hence, the experiments of earthquake-resistant characteristics of the strengthenened frame and wall were conducted respectively. Fig. 1 shows the structures of the models. Besides the vertical loads, the reversed horizontal load were applied at the top of the models. Fig. 2 shows the test arrangement of the strengthened wall. Load-displacement hysteresis loops of the models were obtained (Fig. 3, Fig. 4).

The shear stiffness and strength of the frame have a great difference from those of the brick wall. Brick wall has considerably greater stiffness and less ductility, while the frame is just opposite. When the lateral displacement of the building is small, the frame undertakes a little part of the lateral force, and only after cracking of the brick wall, its carrying capacity can develop fully. This can be seen

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clearly from the load-displacement curve of the strengthened frame and brick wall (Fig. 5).

DYNAMIC RESPONSE OF MULTISTORY R/C FRAME BUILDINGS WITH EXTERIOR BEARING WALLS UNDER EXPLOSIVE GENERATED GROUND SHOCK

Making use of a large quarry blast, the transient ground motions and the resulting vibrations of two buildings were measured (Fig. 6). One of them was unstrengthened, the other was strengthened by R/C columns and tie beams outside the walls. (This is usually used for strengthening buildings in China). The strengthening columns have to be connect with the beams of the frames though the connections usually are just hing type connections. Fig. 7 shows the sketches of the two buildings and the arrangement of accelerometers. The profile of the test field is shown in Fig. 6. The distance from the buildings to the explosive center was 132 m. Fig. 11 shows the records of the accelerations of the ground and each story of the buildings and their calculated values.

After explosion, for the unstrengthened buildings, horizontal cracks appeared on the walls above and under the windows of the third story of the building, the similar cracks appeared on the second story, but much lighter, and there were only light cracks at the corner of a few windows of the first story (Fig. 8). For the strengthened building, inclined cracks appeared at the corners of the windows of the third story, the similar cracks of individual windows appeared on the second story, and there was no crack at the first story. The damage is very similar to that of a natural earthquake, and the upper parts were damaged more severely than the lower parts. The damage of the strangthened building was much lighter than that of the unstrengthened one.

NON-LINEAR DYNAMIC ANALYSIS OF THE BUILDINGS

For the purpose to investigate the dynamic response of the building, the step-by-step integration method was used (Ref. 2). The analytical models are shown in Fig. 9. The dynamic equilibrium equation is:

$$[m]\{\Delta\ddot{u}\}+[c]\{\Delta\dot{u}\}+[k]\{\Delta u\}=-[m]\Delta\ddot{u}_o$$

Where $[m]$ is the mass matrix of the structure, $\{\Delta u\}$ is the displacement increment matrix, $[c]$ is the damping matrix, $[k]$ is the stiffness matrix, and Δu_o is the displacement increment of ground motion.

For non-linear structure, the stiffness matrix changes with the displacement according to the restoring force model. From the previous described model test under cyclic reversed loading, the restoring force models of shear deformation are shown in Fig. 10.

The experimental and calculated values of the frequencies of natural vibration of those two buildings are shown in Tab. 1. The frequencies of the strengthened building are slightly higher than the unstrengthened one and after explosion test the frequencies of both of them got slightly lower.

Table 1 Frequencis of Natural Vibration of the Two Buildings

Condition of buildings	Frequencies of unstrengthened building(Hz)		Frenquencies of Strengthened building(Hz)	
	First mode	Second mode	First mode	Second mode
Before explosion	7.10	20.8	8.33	25.6
After explosion	6.67	19.2	7.69	21.7
calculated values	7.10	19.9	7.90	22.4

Fig. 11 shows the acceleration response of each story of the buildings calculated from the recorded ground motion and the relationship between the story shear and the story drift. The solid lines of the accelerograms represent the calculated values and the dashed lines represent the measured values. It is seen that the calculated values of the accelerograms are very close to the measured ones. Hence, the analytical method is practically applicable.

The result of calculation show that the damage of the upper parts is more severe than that of the lower parts for both buildings and the damage of the unstrengthened building is more severe than the strengthened building. It agrees with the actual damage.

For the purpose of further investigation of the mechanism of earthquake damage of the buildings, a workshop in Haicheng which was damaged during Haicheng earthquake was calculated. The corner of outside wall of the third story of the workshop fell down, the wall of the second story was seriously cracked and there was no damage at the first story on the whole (Fig. 13). The result of a calculation by inputing the acceleration record of a strong aftershock of Haicheng also agrees with the actual damage (Fig. 12).

The same workshop was also calculated by inputing the El-Centro 1940 acceleration record. The result is that the second story suffers most severe damage (Fig. 12). Similar result was obtained by inputing the Taft 1952 acceleration record. These results are different from that calculated by inputing Haicheng earthquake, because different earthquake ground motion has different frequency contents (Fig. 14). The fundamental natural period of the building is 0.35 sec., while the periods of the peak spectral values of the acceleration spectrum of Haicheng earthquake are 0.22 sec. and 0.28 sec. which are between the first and the second period of the building. When the walls began to crack during earthquake, the stiffness of the building deteriorated and its second mode of vibration contributed strongly to the building acceleration because of its resonance with the ground motion. Then the shear force of the upper stories were greater than that of the lower stories and suffered more severe damage. In contrast with this, the periods of peak spectral values of El Centro and Taft acceleration spectrum are 0.28 sec. to 0.45 sec. and 0.4 sec. respectively, the first period contributs strongly to the building acceleration when the walls begin to crack and the shear force of the lower stories are greater than that of upper stories. But the thickness and strength of the walls of the first story were greater than those of the upper stories, so the second story got more severe damage.

CONCLUSIONS AND RECOMENDATIONS

According to the results of the tests and analytical studies, following conclusions and recomendations are obtained:

First of all, for different earthquake ground motion, the response of the structure may differ greatly.

For the investigated buildings, the second mode of vibration contributes strongly to the response accelerations.

Secondly, the building strengthened by outside R/C columns and tie beams suffered minor damage owing to increasing the strength and the ductility of the building, hence, it is an effective method of strengthening.

Finally, because the more severe damage may occur either at the lower stories or at the upper stories, depending upon the charateristics of the ground motion which will be greatly variable even in a definite location, all stories of the building should be strengthened, and not just the lower part or the upper part.

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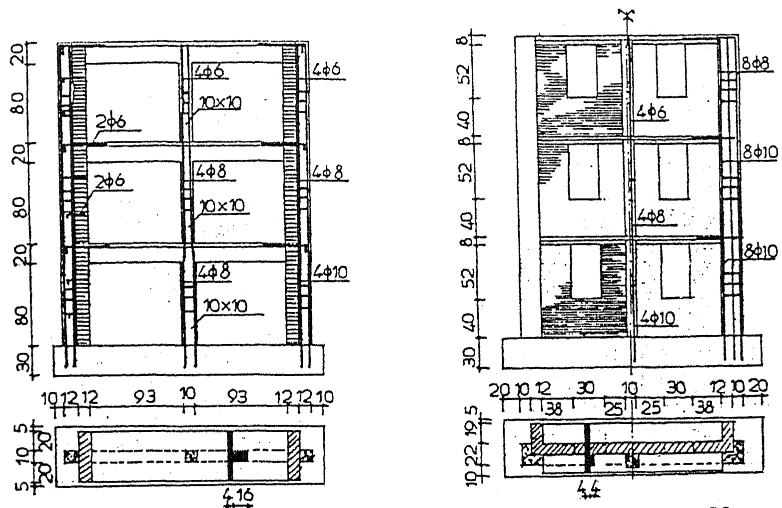


Strengthened frame

Strengthened wall

Fig.1 Structures of test models

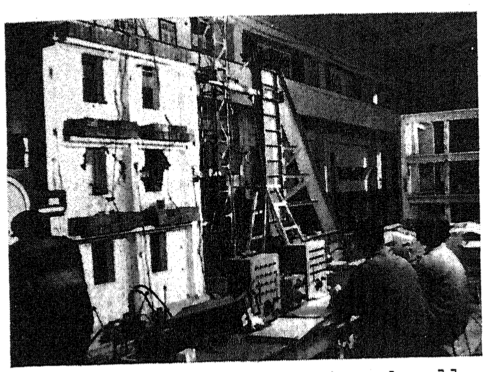


Fig.2 Test of strengthened wall

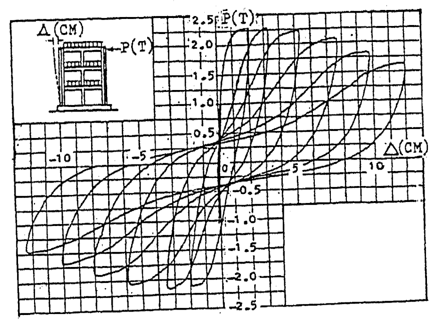


Fig.3 Load-displacement hysteresis loops of strengthened frame

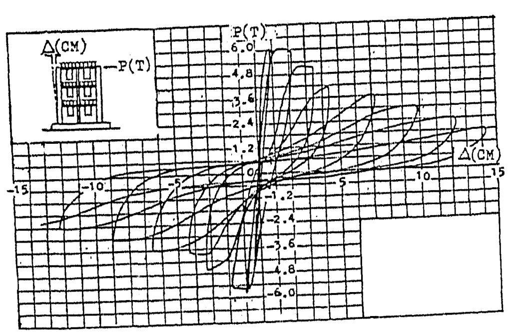


Fig.4 Load-displacement hysteresis loops of strengthened wall

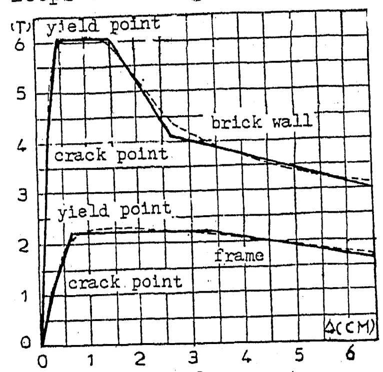


Fig.5 Load-displacement curve of strengthened frame and brick wall

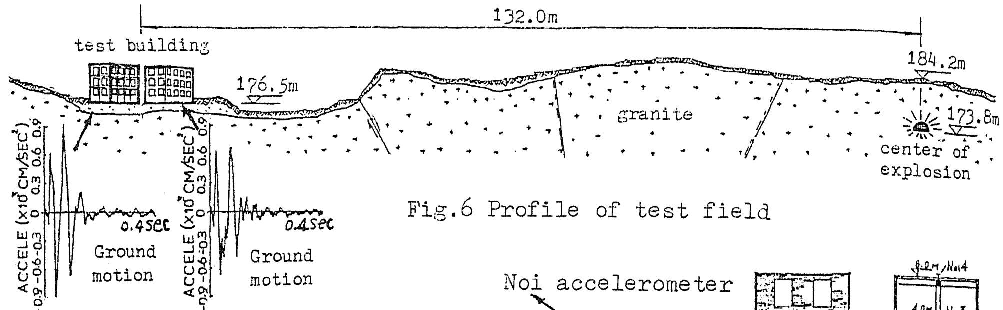


Fig.6 Profile of test field

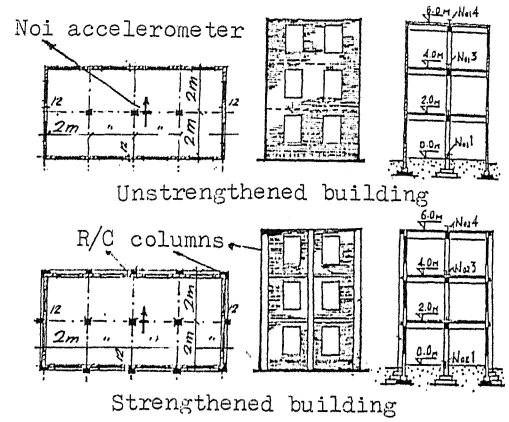


Fig.7 Sketches of test buildings

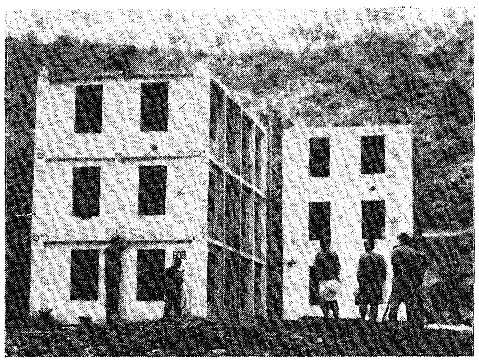


Fig.8 Damage of test buildings

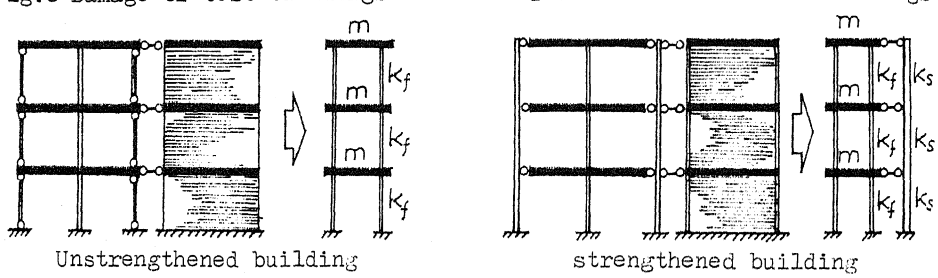


Fig.9 Analytical models of building

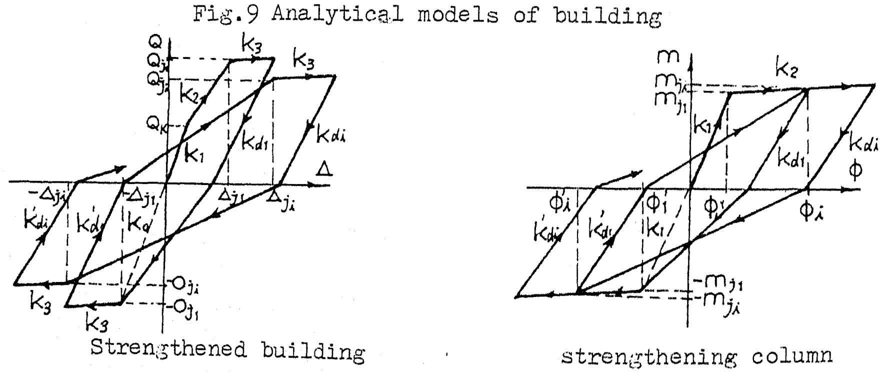
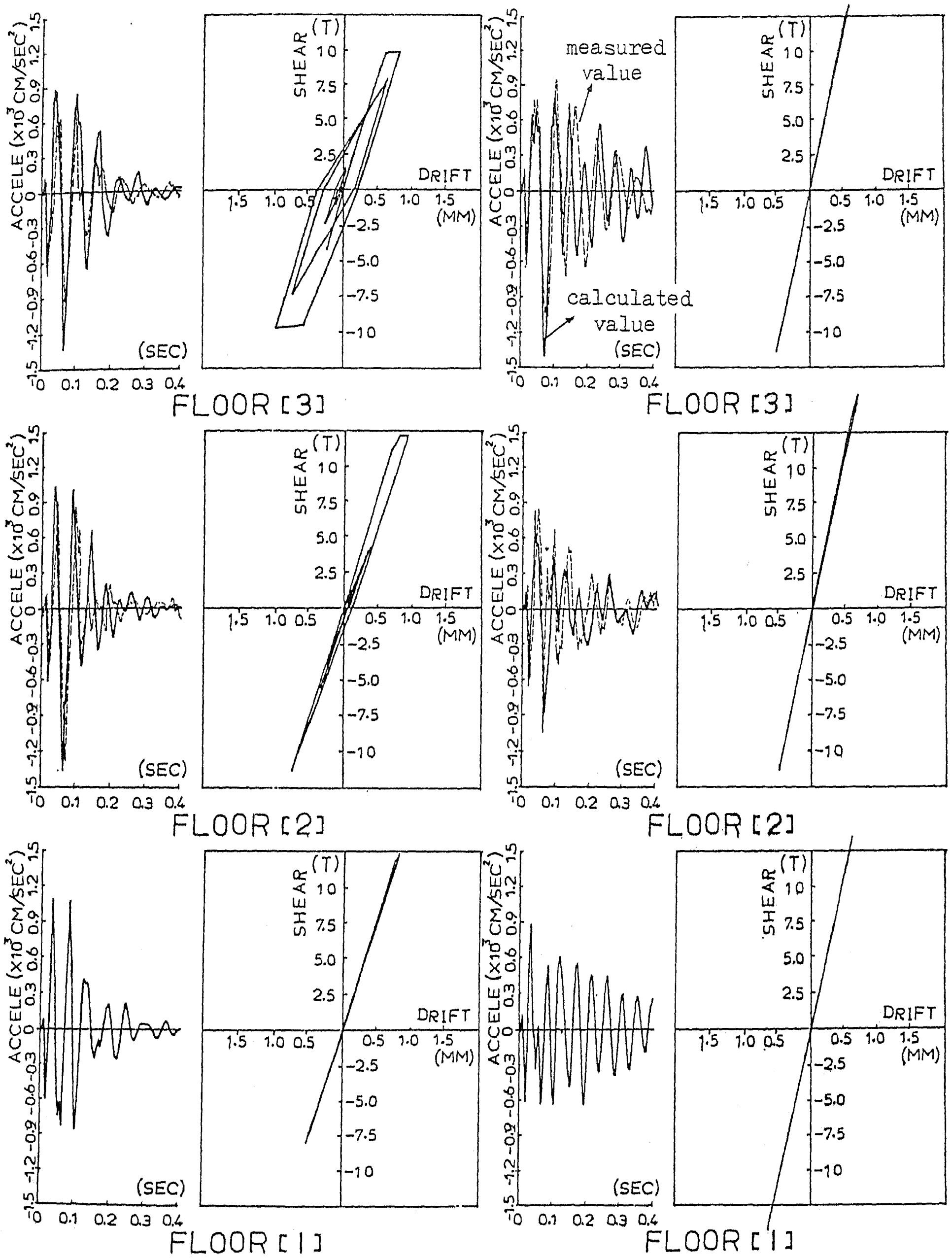
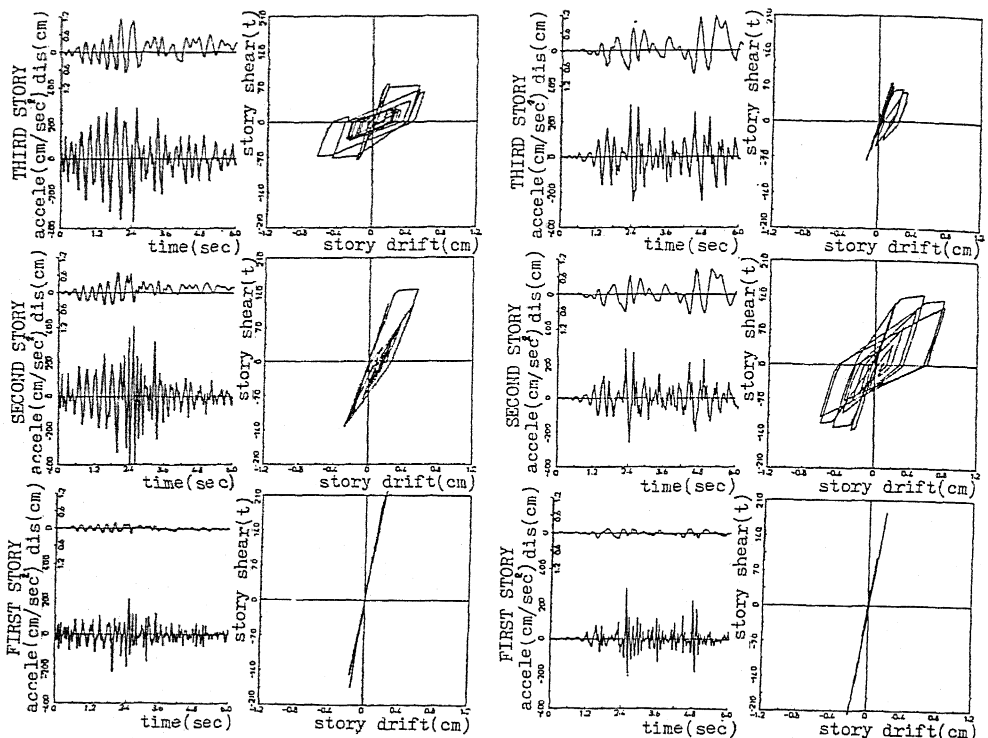


Fig.10 Restoring force models



Unstrengthened building　　Strengthened building

Fig.11 Acceleration response of test buildings.and relationship of shear force and story drift



Response of Haicheng aftershock

Response of El-Centro earthquake

Fig.12 Acceleration responses of the workshop and relationship of shear force and story drift

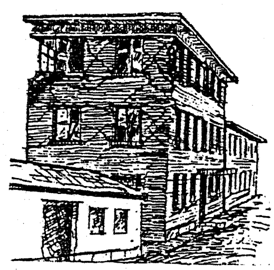


Fig.13 Damage of the workshop in Haicheng

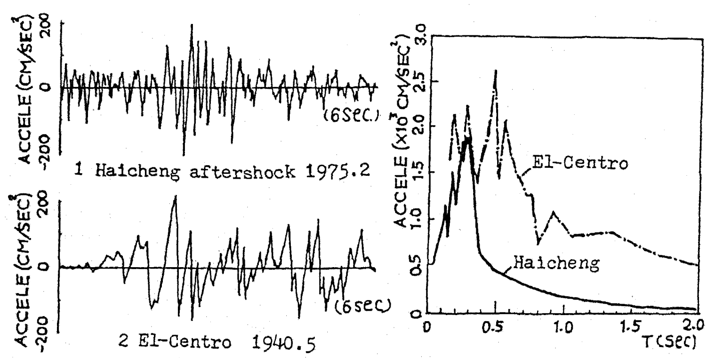


Fig.14 Acceleration records and their spectra