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SEISMIC PERFORMANCE OF STRENGTHENED BUILDINGS IN 1985 ZIGONG, SICHUAN EARTHQUAKE

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SUMMARY

What is the seismic performance of a strengthened building? The authors try to give an answer through the investigations of buildings underwent the strike of 1985 Zigong, Sichuan Earthquake. The seismic performance of strengthened and unstrengthened buildings, strengthening techniques, and examples of typical buildings are described in the paper. It shows that strengthening existing buildings lacking in earthquake resistance before an earthquake can be given enormous reduction of earthquake disaster.

INTRODUCTION

After the great 1976 Tangshan earthquake, about two billion square meters of building floor area have been strengthened in 47 critical cities and 12 critical regions in recent ten years in China. Extensive studies have been performed to create appropriate techniques for evaluation and strengthening of existing buildings and to identify the effectiveness of those techniques. Under the impetus of a growing awareness of seismic hazards, there is an increasing effort being devoted to assessing the seismic performance of strengthened buildings during an earthquake. The difficulties in solving this problem are due to lack of the strengthened buildings underwent an earthquake strike and unreality in experiment with simulation methods. Therefore, investigation of the performance of strengthened buildings during an earthquake is the best way to solve the problem.

At about 7:15 a.m., March 29, 1985, Zigong city, Sichuan Province was shaken by a 4.8 magnitude earthquake with peak intensity of VII. One people was killed; 280 injured; and nearly 106 million Chinese yuan in property destroyed. Field observation and analysis show that strengthened buildings have good performance during the earthquake.

BUILDINGS AND BUILDING DAMAGE

The earthquake was centered near Liangaoshan and Yanzishan(104°49"34"E, 29°22'08"N). Shaking was reported as far away as Chengdu and Chongqing cities. Fig.1 identifies epicenters, tectonic lines, the major area affected by the quake and indicates the seismic intensity ratings. The iso-seismals are oval in shape and their main axis appear in north-east direction.

Buildings Zigong is the city with a long history of salt making. It has a population of 362 thousand in urban area. The total floor area of buildings is about 9.2 million square meters. The buildings consist of following categories:

- Non-earthquake resistant buildings, including old buildings, they were built before 1950's; and simply constructed buildings, they were built in 1960's, and most of them are brick masonry buildings with thinner and/or cavity brick bearing walls
- Earthquake resistant buildings. They were built after the late of 1970's.
- Strengthened buildings. During the period of 1979 to 1984, 540 thousand square meters of building floor area were strengthened.

Earthquakes Zigong city is a highly seismic region. Since 1475, nine earthquakes with magnitude of 4 and above occurred in the city, including earthquakes of October 1954, 5.0 magnitude and April 1965, 4.6 magnitude. Remarkably, magnitude was minor to moderate, focus was shallow, occurrence was frequent, damage in the epicentral area was moderate to severe.

Building Damage During the earthquake, 2.10 million square meters of floor area of buildings were damaged. Among them, 165 thousand square meters were severely damaged or collapsed, 601 thousand square meters damaged, and 1.34 million square meters were slightly damaged. As regards strengthened buildings(totalled 540,000m^2) , 92% of them were intact, only 8% of them suffered moderate or slight damage.

In regarding to the buildings owned by Housing Department of Municipality 93% of the strengthened buildings (36 thousand square meters) were intact, on the contrary, 95% of the unstrengthened buildings (112 thousand square meters) were damaged ranging from severe to slight damage.

There are three neighbouring two story buildings with brick walls, timber roof and slab in the Zigong second hospital. Two of them were strengthened before the quake and functioned properly during and after the event. The unstrengthened one, however, was damaged severely and was evaluated as hazardous building.

Two neighbouring brick buildings with four stories and same structural system are situated in Liangaoshan. The unstrengthened one was severely damaged and demolished. Thanks to strengthening by ring beams, the other one stood well during the earthquake.

EVALUATION AND STRENGTHENING TECHNIQUES

Evaluation The safety factors of seismic strength of the wall(K) can be calculated by the following formula:

$$K=[A/F]_R / [A/F]_{min}$$

Where, $[A/F]_R$ denotes the real ratio of wall to floor area of the wall considered, $[A/F]_{min}$, the minimun ratio of wall to floor area of the floor concerned.

Strengthening Techniques The following strengthening techniques are used in Zigong city:

- Using cement mortar coatings or reinforced cement mortar coatings attached to single or both surfaces of brick wall to increasing its strengths(Fig.2)
- Using additional reinforced concrete or reinforced cement mortar coating ring beams, steel tie rods, and/or reinforced cement mortar tie coatings for increasing integrity of floor and the whole building(Fig.3,4). and
- Using additional reinforced concrete columns and ring beams as well as steel tie rods for increasing the ductility, integrity and lateral resistant strengths of multistory brick building(Fig.5).

EXAMPLES OF STRENGTHENED BUILDINGS

Building 1 Typical three story brick housing with corridor exposure(Type 71-1)

It was built in early 1970's. The grade of mortar is 25#. The roof structure supporting on gable bearing walls consists of tiles, rafters, and purlins. The floor structure is formed by precast R/C slabs. Cast-in-situ R/C ring beams are laid on exterior walls at the floor level for each story. Two ϕ4 tie steel bars are laid on wall intersactions each 600mm along the hight. The plan and elevation are shown in Fig.6. The building was evaluated by current seismic evaluation criterion(Refs 5). It follows that the earthquake resistance of transversal walls coincides in criterion's requirements. The longitudinal walls, however, are small for their earthquake resistance. The safety factors of earthquake resistance for longitudinal walls are shown in Fig.8 with dot and dash line. The building was strengthened in 1984. The rear longitudinal wall(A axis) and exteriorly longitudinal walls of kitchen(E axis) were strengthened by adding cement mortar coating with thickness of 30mm on exterior surface of the wall(Fig.2a). Reinforced cement mortar coating ring beam(Fig.3c) and R/C ring beams(Fig.3b) were placed at the top level of interiorly transversal walls in first, second stories and third story respectively.

Building 2 Office building of Zigong Third Radio Plant It is also three story brick building with interior corridor as shown in Fig.7. The brick walls was laid by normal brick and 10# grade mortar with cavity except staircase walls in first and second story and all of the interiorly longitudinal walls. Those walls are solid brick walls and their thickness are 240mm and 120mm respectively. The thickness of cavernous brick walls is 240mm. The roof structure is the same with Bldg.1. The floors were made of precast R/C slabs. The cast-in-situ R/C ring beams are placed on the top of the brick wall at the eaves level. The building was evaluated by current criterion(Refs.5). It shows that the seismic strengths of transversal walls conformed to the requirements specified in the criterion. The safety factors of seismic strengths of longitudinal walls are shown in Fig.8 with solid lines.The building was strengthened in 1984. The exteriorly longitudinal walls and intersactions of interior and exterior walls were strengthened by vertical reinforced cement motar coating belts(Fig.4b). R/C ring beams(Fig.3a,b) and steel tie rods (Fig.4a) were placed at the top level of each story's walls.

Thanks to strengthening before the event, the two exampified buildings mentioned above were intact and showed good performance during the earthquake.

CONCLUSION

1. Strengthening existing buildings lacking in earthquake resistance before an earthquake is an effective strategy for earthquake disaster mitigation.

2. Adding cement mortar coatings, reinforced cement mortar coatings, steel tie rods, ring beams, reinforced concrete columns are powerful measures for strengthening existing non-earthquake resistant buildings.

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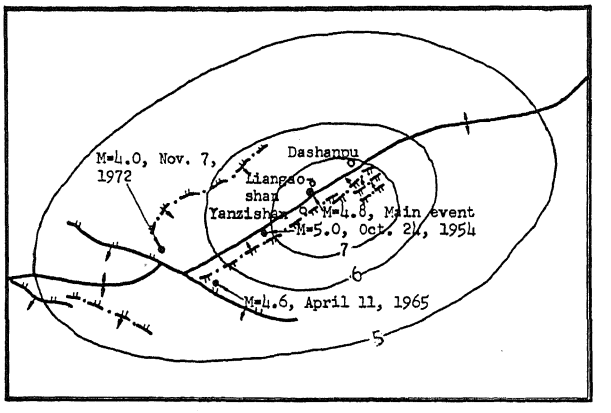
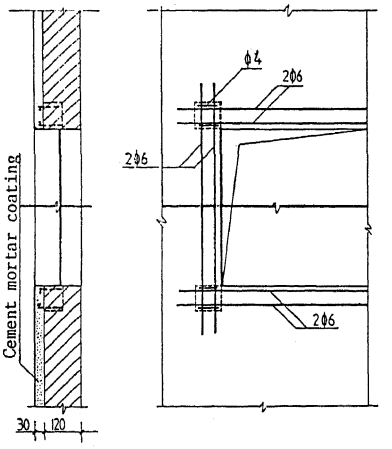
5. "Aseismic Criterion for Evaluation of Industrial and Civil Buildings (TJ 23-77)"

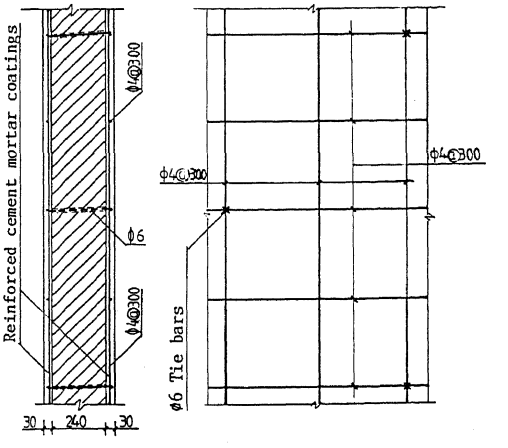


Ground anticlinal axis
Ground fault
T_{1j} Strata hidden fault
Iso-Seismals

Fig.1 Epicenters, Tectonic lines and Intensity Map of 1985 Zigong, Sichuan Earthquake

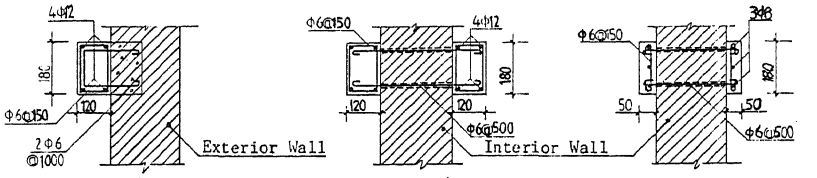


a. Adding cement mortar coating on single surface of the wall



b. Adding reinforced cement mortar coatings on both surfaces of the wall

Fig.2 Adding cement mortar or reinforced cement mortar coatings to the wall surfaces for strengthening brick buildings

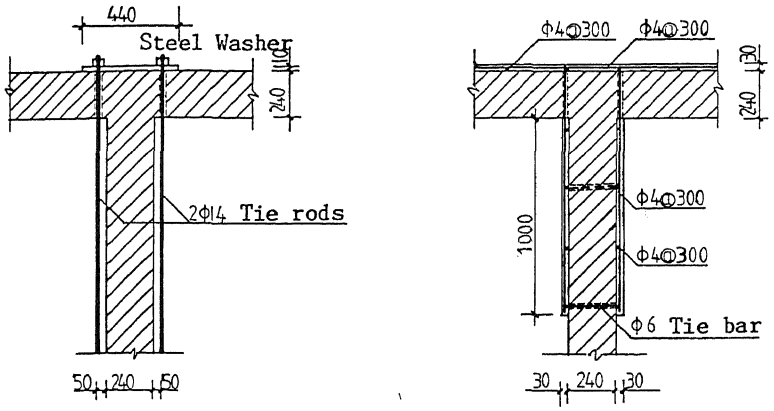


a. Single R/C ring beam

b. Double R/C ring beams

c. Double reinforced cement mortar coatings ring beams

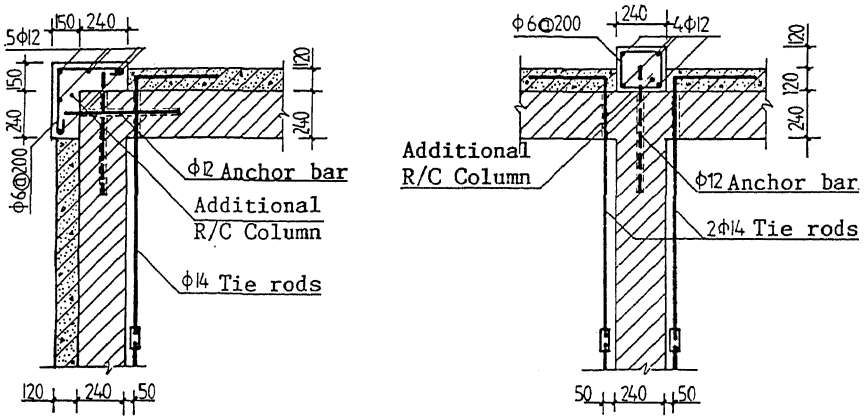
Fig.3 Adding ring beams for strengthening



a. Adding steel tie rods

b. Adding reinforced cement mortar coating belts

Fig.4 Strengthening wall intersactions



a. Adding R/C angle column

b. Adding R/C rectangular column

Fig.5 Strengthening walls by reinforced concrete columns

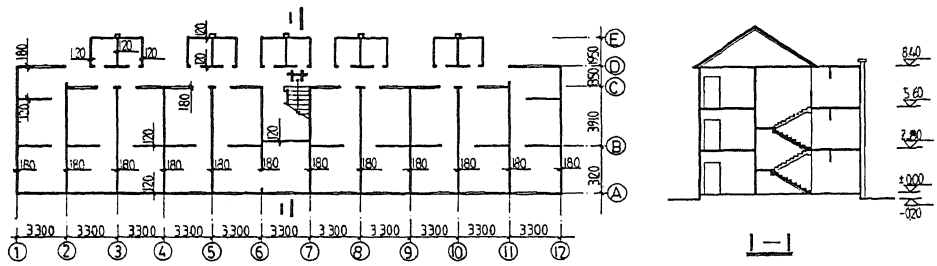


Fig.6 Typical three story brick housing with corridor exposure

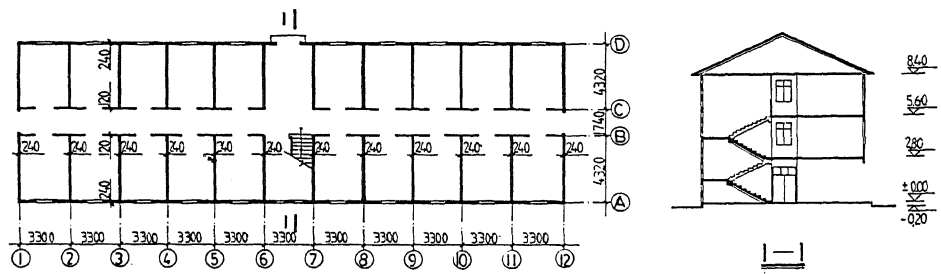


Fig.7 Plan and elevation of office building of Zigong Third Radio Plant

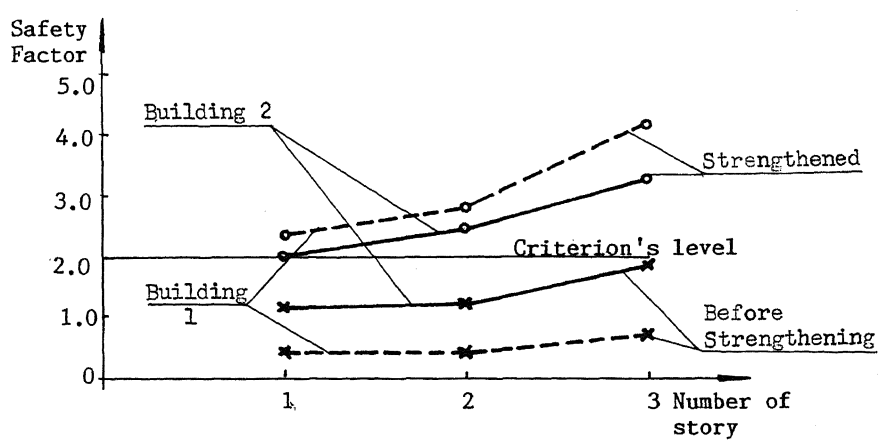


Fig.8 Safety factors comparison between origional and strengthened longitudinal walls