# Seismic Performance Experimental Research on Reinforced Concrete Columns Strengthened with CFRP

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**ABSTRACT:** CFRP has a light weight, high tensile strength, and a high resistance to the corrosion and fatigue. These properties make CFRP attracted increasing interests in civil engineering. Based on shaking table tests of several reinforced concrete (RC) flat slab beamless construction models, the seismic performance of square columns strengthened with carbon fiber reinforced polymer (CFRP) composites are investigated. The effects of CFRP quantity and load types to seismic behavior of RC square columns are studied. According to the test results and Italian-Chinese approaches of FRP-based strategies tailored for seismic retrofitting, one or more calculated methods or opinions will be provided. In the future, with the cooperation activated between the Harbin Institute of Engineering Mechanics and the University of Roma “La Sapienza”, finite element dynamic analysis will be carried out by OpenSees, and approximate agreement between test and theoretical results will be achieved.
**KEYWORDS:** seismic performance, CFRP, shaking table test, OpenSees

## 1. FRP APPLICATION IN STRUCTURAL STRENGTHENTING

In 1980s, scientists in American and Japan researched CFRP applied in concrete structures, repair and strengthening. Between later 1980s and early 1990s, many Japanese universities, scientific research administrations and material factories began to do some jobs on FRP in structures, repair and strengthening. For CFRP has excellent mechanics capability， it is easy to be constructed and has good effects. Especially after San Francisco, Los Angeles, Hanshin, Taoyuan Taiwan earthquake, which lead to a lot of population death and property lost, caused fiber material quickly developing in structures, and ceaselessly validated its advantages. In Japan, U.S., Taiwan, Europe, people make local industry standards and criterions with some researches and organize promote groups and institutes.

In China, FRP research and application is still at the beginning. Government division, scientific research administration, university, civil engineering groups and institutes make into huge efforts and interests to do this job, to keep up with the international development. From 1996, there are so many researchers coming forth, so many monographs and papers publishing, and thousands of structural strengthening projects were to be done. In 1998, the first paper was published in Kunming, in the national building identification and strengthening learning comparing notes symposium. In Jun. 2000, the first national fiber reinforced plastic concrete structure Partial support sponsored by the Science Foundation of IEM (Project Number 2006B04).

technology conference was held in Beijing. At the same year, the fifth national building identification and strengthening conference was held in Shantou. Recently, many conferences related FRP have been organized, which make a good development of FRP. In 2003, Chinese carbon fiber scentific committee had issued a technical specification for strengthening concrete structures with carbon fiber reinforced polymer laminate that provides a local standard and basic criterion for this application.

## 2. THE PRIMARY STUDY AND FRAMEWORK OF SEISMIC PERFORMANCE OF THE CONCRETE COLUMNS WHICH ARE REINFORCED BY CFRP

### *2.1. Material Test*

In this case, we use small stone concrete. At the beginning, we do some trial about the ratio of water, cement, sand and stone.

According to correlative date, we choose four ratios:

| | Water (kg) | Cement (kg) | Sand (kg) | Stone (kg) |
|---|---|---|---|---|
| 1 | 200 | 571 | 539 | 1217 |
| ratio | 0.35 | 1 | 0.994 | 2.131 |
| 2 | 200 | 509 | 539 | 1217 |
| ratio | 0.40 | 1 | 1.078 | 2.434 |
| 3 | 200 | 444 | 539 | 1217 |
| ratio | 0.45 | 1 | 1.214 | 2.741 |
| 4 | 200 | 400 | 539 | 1217 |
| ratio | 0.50 | 1 | 1.348 | 3.043 |

Table 1 the ratio of concrete

According to the ratio and Chinese code, doing standard cube concrete text block,150×150×150mm. Under the standard condition maintaining 28 days, doing press text. The result:

| | Strength(T) | Strength (T) | Strength (T) | Average(T) |
|---|---|---|---|---|
| 1 | 61.2 | 57.2 | 54.0 | 57.5 |
| 2 | 57.5 | 56.5 | 58.0 | 57.3 |
| 3 | 52.5 | 48.8 | 52.4 | 51.2 |
| 4 | 42.2 | 44.8 | 42.0 | 43.0 |

Table 2 concrete text block's Strength of pressure

According to the mark of material text machine, g=980.665. So we get the result of concrete intensity:

(1) 25.6Mpa, (2) 25.5Mpa, (3) 22.8Mpa, (4) 19.1Mpa

By the reason of needing the concrete columniation strength's 25Mpa, we choose the 2nd ratio.

| | υ | E(MPa) | ft（MPa） | fc (MPa) | D(mm) |
|---|---|---|---|---|---|
| concrete | 0.20 | 2.8×104 | 1.78 | 16.7 | |
| Bar reinforcement | 0.30 | 2.0×105 | 335 | | 6.5 |
| Hooped reinforcement | 0.30 | 2.0×105 | 290 | | 2.3 |
| CFRP | 0.17 | 2.3×105 | 3430 | | |

Table 3 model of material

### *2.2. Experiment Structures*

Seven one-story flat slab beamless concrete frame structures, 2000×1800mm in length and width, are shown in Figures as below. The uniform rigid slab of thickness 200mm is supported on four columns of height 1250mm rigidly connected to the top slab and to the foundation beams. All columns are 150×150mm sections.

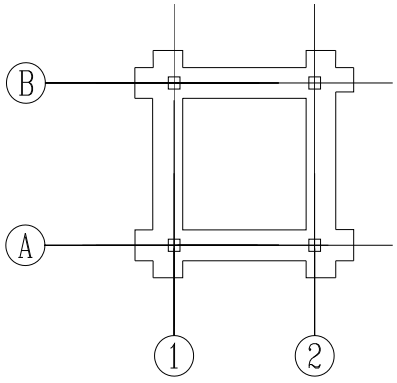



Figure 1. Foundation beams

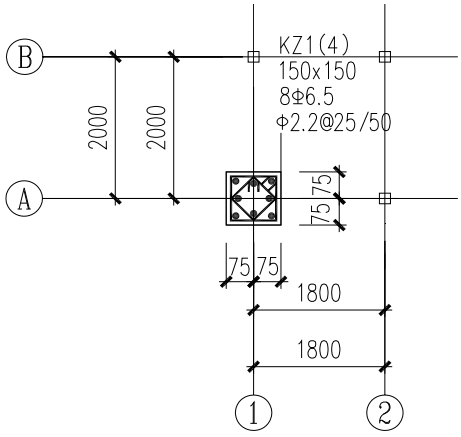



Figure 2. Sections and columniation

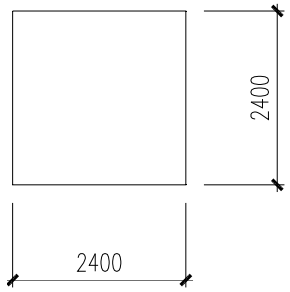
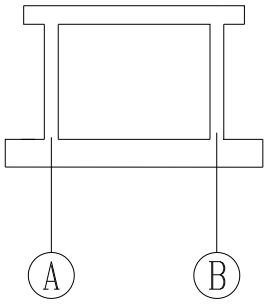



Figure 3. Lateral view(N-S)



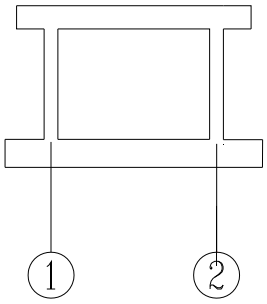




Figure 4. Lateral view

Figure 5. Size of rigid slab

### *2.3. Quasi-static Test*

#### *2.3.1 Measuring Devices*

Two displacement sensors and sixteen strain sensors, which located in test structures, are shown in Fig.6. The sixteen strain sensors are stuck to columns' surfaces 30mm from the top slab and the foundation beams.

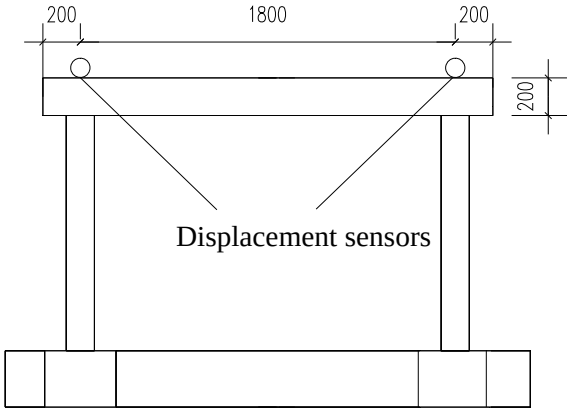



Figure 6. Displacement sensors

#### *2.3.2 Loading Program*

(1) Vertical load: 9.7T on the slab.
(2) Lateral cyclic loading: 1T→2T→3T→4T.
(3) Trial date: Dec. 14th , 2007
(Note: 1T=1000kg)

### *2.4. Shaking Table Test*

#### *2.4.1 Technical Data*

(1) Area：5m×5m
(2) Weight(Max)：30T
(3) Output(Max)：50T
(4) Frequency：0.5～40Hz
(Note: 1T=1000Kg)

### *2.4.2 Measuring Devices*

Thirty-two strain sensors (16 on longitudinal bars, 16 on columns' surfaces), whose locations are as same as quasi-static test. Two displacement and acceleration sensors located on structures, are shown in Fig.7.

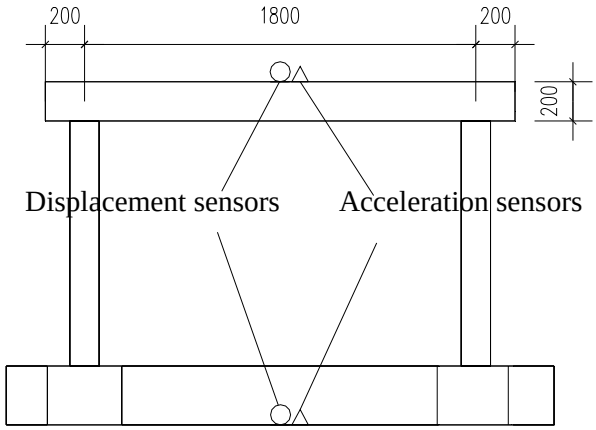



Figure 7. Displacement and acceleration sensors

### *2.4.3 Loading Program*

(1) Vertical load: 9.7T on the slab.
(2) Seismic wave: EL- Centro.
(3) Modality analysis.
(4) Input acceleration stages: 0.05g→0.10g→0.20g→0.30g
(5) Trial date: Dec. 18th , 2007
(Note: 1T=1000kg)

## 3. CONCLUSION

Promotes with great effort independent innovation in the country today, on the one hand, we must continue deep research the performance of FRP, speed up the manufacture domestically advancement of the FRP material, develop the application potential of FRP, expand its application scope in the quakeproof disaster reduction. The application of FRP still has many problems to solve, such as anchor, bend question and endurance failure, stress relaxation and so on. Also need to strengthen the material modification and the innovation research, yet need to make the deep exploration to it in the structure use and the examination technology. In recent years, the similar as the internationally situation, our country has much fervor to the study and use of FRP, everywhere are developing vigorously. FRP as the primarily subjected to tension nonmetallic material, it is impossible to

substitute for the steel products, but it is one kind of very important supplement.

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