Size effect of concrete column retrofitted by fiber-reinforced polymer (FRP)

Pengpeng Zhang¹,*, Xinsheng Xu², b
¹, ²School of Civil Engineering and Architecture, University of Jinan, 336 Nanxinzhuang West Road, Jinan 250022, Shandong, China
*pp_chang@126.com, bxinsheng_xu@163.com

Abstract. At present, the research on the size effect of fiber-reinforced polymer (FRP) reinforced concrete members is not enough, besides the conclusions about size effect are different. It is of great theoretical significance and engineering application value to study the size effect of FRP reinforced concrete members in this field. In this paper, the study status from two aspects containing plain concrete columns and reinforced concrete columns for the retrofitted effect were analyzed and some new problems were put forward in this field. Also the paper mainly discussed the size effect of FRP constraint ratio and column slenderness ratio on FRP retrofitted concrete columns, and the effects of different load forms of FRP reinforced concrete columns under eccentric loading, repeated loading and unloading, and horizontal cyclic loading on the size effect of FRP retrofitted concrete columns, and the influence of the single factor change of FRP paste way, type, package type and the concrete strength on the FRP reinforced concrete column. Besides, the changing tendency and regularity of the size effect of FRP strengthened concrete columns under the condition of muti-factors were given.

1. Introduction
The concrete structure has become one of the most common and widely used architecture in China, which will still the mainstream of civil engineering construction in a long future period of time. Besides, the geological disasters occur frequently in China and many buildings are in sub-health status. So the retrofitting of concrete structure has become an important task of the civil engineering industry and a significance research. As a kinds of composite materials, fiber-reinforced polymer has many advantages, such as light weight, high strength, corrosion resistance, good durability and simply construction. At present, researches on FRP reinforced concrete column have achieved fruitful results, but because of the cost and mechanical restrictions, the scale models were mainly studied by people. The experimental and the simulative data can reflect the actual engineering performance which is still a uncertain problem. The study on the size effect of FRP reinforced column is still relatively limited. The influences of size effect can not be ignored. Besides, a large number of studies have confirmed the existence of size effect. However, the research is not enough, and the conclusions are different.

2. Size effect of FRP reinforced plain concrete columns
No size effect. Tests were carried out on carbon fiber-reinforced polymer (CFRP) reinforced concrete columns with different sizes by Akogbe Kokou. M. T. Romuald. [1] The test showed that the CFRP reinforced concrete columns do not have the size effect. At the same time, Elsanadedy H M et al. [2] carried out an experimental study with three kinds of CFRP reinforced concrete columns which were different in size and found that the size effect was not obvious.
Partial size effect. An experiment about 18 concrete circular-columns under axial compressive load was carried out by Fantan Bu et al. [3]. And the test found that there was obvious size effect on the concrete circular-columns. But the ultimate stress and peak strain decrease with the increase of columns’ sizes. The study aiming at glass fiber-reinforced polymer (GFRP) reinforced concrete columns with different height, diameter and thickness was carried out by Silva A G et al. [4]. The test showed that there was no obvious size effect on different slenderness ratio columns, but with the increase of diameter, the size effect got clear obvious.

Size effect. Gusheng Tong et al. [5] tested the compressive strength of 27 basalt fiber-reinforced polymer (BFRP) reinforced concrete square-columns with similar geometric of three different sizes. The research showed that the compressive strength has obvious size effect.

3. Size effect of FRP reinforced concrete columns
At present, it is found that FRP reinforced concrete columns also have the size effect. Finite element analysis software ANSYS was used to calculate and simulate the size effect of BFRP reinforced concrete columns with similar geometry under axial compression load by Qiulan Wu et al. [6]. According to the date of the above-mentioned references, some results for the ultimate compressive strength data of FRP reinforced concrete columns are shown in Table 1 to Table 3, concrete-columns-size’s expression in the table, for circular-column: diameter*height, square-column: length*width*height.

| Table 1 | Test results of CFRP reinforced concrete columns in above-mentioned references. |
| Date sources | Size (mm) | Number of layers | Average compressive strength (MPa) |
|-------------|-----------|------------------|----------------------------------|
| Reference [1] | 100*200 | 1 | 64.6 |
| | 200*400 | 2 | 64.9 |
| Reference [2] | 50*100 | 1 | 146.2 |
| | 100*200 | 1 | 94.5 |
| | | 2 | 146.0 |
| | 150*300 | 1 | 76.4 |
| | | 2 | 111.5 |
| | | 3 | 144.2 |
| Reference [3] | 152*304 | 2 | 64.0 |
| | 304*608 | 4 | 66.0 |
| | 51*102 | 1 | 64.0 |
| | 152*304 | 3 | 90.0 |

| Table 2 | Test results of GFRP reinforced concrete columns in above-mentioned references. |
| Date sources | Size(mm) | Number of layers | Average compressive strength (MPa) |
|-------------|-----------|------------------|----------------------------------|
| Reference [4] | 150*300 | 2 | 89.5 |
| | 150*450 | 2 | 91.2 |
| | 150*600 | 2 | 85.8 |
| | 150*750 | 2 | 87.6 |
| | 150*750 | 3 | 128.1 |
| | 250*750 | 2 | 55.8 |
| Reference [6] | 150*450 | 3 | 79.6 |
Table 3 Test results of BFRP reinforced concrete columns in above-mentioned references.

| Date sources | Size(mm)     | Number of layers | Average compressive strength (MPa) |
|--------------|--------------|------------------|----------------------------------|
| Reference [5]| 100*100*300  | 1                | 41.4                             |
|              |              | 2                | 46.9                             |
|              | 150*150*400  | 1                | 38.7                             |
|              |              | 2                | 41.3                             |
|              | 200*200*600  | 1                | 36.6                             |
|              |              | 2                | 38.0                             |

From above mentioned-tables, it can be concluded that different references on FRP reinforced concrete columns have the different conclusion about size effect. The main factors that influence the size effect of FRP reinforced concrete column are the FRP constraint ratio and the slenderness ratio of columns. There are some conclusions about size effect of FRP reinforced concrete column, and the influence of the component size on the mechanical behavior of FRP reinforced concrete columns is summarized. However, the influences about the size effect of FRP reinforced concrete columns are not summarized. Besides, the following discussions are the influences of FRP constraint ratio and slenderness ratio of column for reinforced concrete columns.

4. The influences of FRP constraint ratio

4.1 Equal FRP constraint
Size effect. Some studies showed that test specimen had size effect when their FRP constraint were equal. Simulation analysis on 27 BFRP reinforced concrete columns with the size effect was conducted by Qiulan Wu et al. [6]. There were three kinds of sizes, which were 150*450mm, 200*600mm and 250*750mm, respectively. The number of FRP bonding layer is 3 layers, 4 layers and 5 layers respectively. The study showed that the ultimate load increases with the increase of specimen size, but the strength decreased. The specimens had size effect.

No size effect. However, some studies found that the test specimen which they have the same FRP constraint did not have the size effect. Akogbe Kokou. M. T. Romuald’s [1] paper showed that the influences about the size for compressive strength on the CFRP confined concrete cylinder under the axial load. And 24 concrete cylinder test specimen that ratio of height to diameter is 2:1 with different sizes were tested. Small, medium and large diameter sizes of columns were 100mm, 200mm and 300mm, and the number of layers of CFRP corresponding to the test specimen is 1, 2 and 3, respectively. Figure 1 is the relationship between the average value of each specimen size and its compressive strength from the reference [1] and [6]. As can be seen from Figure 1, at the same constraint, the results of the study in reference [1] for FRP reinforced concrete columns do not have the size effect. But the study found the obvious size effect on FRP reinforced concrete columns in reference [6].

4.2 Different FRP constraint
Experimental study on the size effect of BFRP confined concrete square-columns were carried out by Gusheng Tong et al. [5]. The specimen were divided into three kinds of different sizes, a total of nine groups, each group had three test specimen. The size of specimen in the 1-3 group is 100*100*300mm, and the constraint form of BFRP are not pasted, one layer and two layers, respectively. The size of specimen in the 4-6 group is 150*150*450mm. Besides the size of specimen in the 7-9 group is 200*200*600mm. The test showed that the BFRP confined concrete columns had obvious size effect, and with the increase of constrained layer, the size effect got more obvious.

4.3 Effect of slenderness ratio on reinforcement
Silva A G et al. [4] studied the influences of column’s height, diameter and GFRP thickness on GFRP reinforced concrete cylinders. The specimen was composed of 18 columns. It was divided into two
groups: the first group of columns’ diameter is 150mm, and its height is 300mm, 450mm, 600mm and 750mm respectively. The diameter of the second group was 250mm, the height was 750mm. In addition, the two groups of GFRP adhesive layer was not the same. The test showed that there is no size effect for the same thickness of GFRP, the diameter of 150mm, different height of the concrete cylinder.

As shown in the Figure 2, with the increase of diameter, FRP reinforced concrete columns had obvious size effect and its compressive strength was reduced significantly when they have the same ratio of length to diameter and the thickness of GFRP.

The effect of test specimen size, slenderness ratio and FRP reinforced type for the FRP reinforced columns were studied in some other reference. The conclusion was that the slenderness ratio nearly did not have influence on the reinforced effect in the above-mentioned three kinds of columns, no matter it is the CFRP reinforced concrete column or GFRP reinforced concrete columns. The conclusion was that the slenderness ratio nearly did not have influence on the reinforced effect in the above-mentioned three kinds of columns no matter what is the CFRP reinforced concrete columns or GFRP reinforced concrete columns.

Figure 1 The size effect curve graph of the specimens in some references. Figure 2 The size effect curve graph of the specimens in References [4].

5. Conclusion
(1) Nowadays, most study focused on compressive property with the size of FRP reinforced concrete columns under the axial load. It is necessary to further study on the load forms of eccentric compression, repeated loading and unloading, and horizontal cyclic loading.

(2) The effect of FRP constraint ratio and slenderness ratio of columns is different for the size effect of FRP reinforced concrete columns.

(3) It is necessary to further study the effect of FRP paste type, FRP type, FRP wrapped method and concrete strength grade et al. for the size effect of FRP strengthened concrete columns.

Acknowledgements
Funding provided by the Natural Science Foundation of Shandong Province of China NO.ZR2014EEM036 and the School of Civil Engineering & Architecture Engineering at University of Jinan are acknowledged.
References

[1] Akogbe Kokou. M. T. Romuald. 2011 D. Size effect on axial compressive strength of CFRP confined concrete cylinders. School of Civil Engineering, Dalian University of Technology

[2] Elsanadedy H M, Al-Salloum Y A, Alsayed S H, et al. 2012 J. Experimental and numerical investigation of size effects in FRP-wrapped concrete columns. Construction and Building Materials, vol 29, pp56-72

[3] Fangtan B. 2015 D. Experimental study on the size effect of axial compression performance of concrete columns confined with GFRP. School of Civil and Transportation Engineering, Guangdong University of Technology

[4] Silva A G, Rodrigues C C. 2006 J. Size and relative stiffness effects on compressive failure of concrete columns wrapped with glass FRP. Journal of Materials in Civil Engineering, vol 18(3), pp334-42

[5] Gusheng T, Yongsheng L, Qiulan W. 2009 J. Size effect on square section column concrete confined with basalt fiber sheets. Concrete, vol 21(3), pp6-8

[6] Qiulan W, Gusheng T, Yongsheng L, 2011 J. Finite element analysis on the compression course of reinforced concrete(RC) quadrat columns confined by BFRP. Concrete, vol 34(6), pp55-56