Finite element analysis of CFRP reinforced silo structure
design method

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Abstract. Because of poor construction, there is a serious problem of concrete quality in the silo project, which seriously affects the safe use of the structure. Concrete quality problems are mainly seen in three aspects: concrete strength cannot meet the design requirements, concrete cracking phenomenon is serious, and the unreasonable concrete vibration leads to a lot of honeycombs and surface voids. Silos are usually reinforced by carbon fiber cloth in order to ensure the safe use of silos. By the example of an alumina silo in a fly ash plant in Binzhou, Shandong Province, the alumina silo project was tested and examined on site. According to filed test results, the actual concrete strength was determined, and the damage causes of the silo was analysed. Then, a finite element analysis model of this silo was established, the CFRP cloth reinforcement method was adopted to strengthen the silo, and other technology like additional reinforcement, rebar planting, carbon fiber bonding technology was also expounded. The research of this paper is of great significance to the design and construction of silo structure.

1. Introduction
Reinforced concrete silos are widely used in the fields. However, due to the characteristics of alumina and construction defects, less than two years after the use of Silo there have been varying degrees of damage, peeling, cracking, steel corrosion and so on in the silo. Reinforcing silo is very important. In this paper, the on-site investigation of alumina silo is carried out, and the silo is identified and strengthened. The reinforcement scheme of silo is given.

2. Project summary
In a fly ash factory in Shandong, Binzhou Province, alumina silo is a reinforced concrete tube structure, which is reinforced. The appearance of the alumina silo is shown in Figure 1. The diameter of alumina silo is 25m, the height is 40m, and the design strength grade of concrete is C35. Alumina silo is a shallow silo. The design life of the strengthening project should meet the requirements of the design life, and the durability of the reinforced material should meet the requirements of the original design life.

3. The Field inspection of alumina silo

3.1. The compressive strength of concrete beams, columns and walls
In order to determine the location of the components, the columns under the elevation 8.50m are numbered according to the design drawings and the actual situation at the site. In order to locate the
components conveniently, according to the design drawings and the actual situation at the site, the columns under the elevation 8.50m are numbered. The number is shown in Figure 2.

![Figure 1. Silo appearance](image1.jpg) ![Figure 2. Column number](image2.jpg) ![Figure 3 Silo model](image3.jpg)

The compressive strength of concrete under elevation 8.50m is tested by rebound core drilling method, test results are shown in Table 1.

### Table 1. Strength test results of component

| Component location                  | Strength estimation (MPa) | Component location                  | Strength estimation (MPa) |
|-------------------------------------|--------------------------|-------------------------------------|--------------------------|
| Walls between 1# and 2# columns     | 26.5                     | 6# column                           | 28.8                     |
| Walls between 13# and 14# columns   | 40.4                     | 16# column                          | 35.9                     |
| Walls between 16# and 7# columns    | 24.7                     | Beam between 1# and 13# column      | 36.2                     |
| Walls between 7# and 8# columns     | 26.5                     | Beam between 13# and 14# column     | 36.5                     |
| Walls between 17# and 18# columns   | 32.4                     | Beam between 5# and 15# column      | 38.3                     |
| 12# column                          | 26.8                     | Beam between 6# and 16# column      | 37.9                     |
| 1# column                           | 26.5                     | beam between 7# and 17# column      | 38.6                     |
| 13# column                          | 31.1                     | Beam between 5# and 6# column       | 40.1                     |
| 14# column                          | 35.9                     | Beams between 1# and 2# column      | 38.6                     |
| 15# column                          | 35.2                     | Beam between 18# and 17# column     | 39.3                     |
| 5# column                           | 30.8                     | /                                   | /                        |

3.2. Column crack detection

The cracks on the Column below 8.50m are tested by knocking and picking. The test results are as follows. Because the depth of the crack exceeds the depth of the reinforcing layer, the normal bearing capacity and durability of the column are affected.
3.3. Compressive strength of concrete on silo wall

The compressive strength of silo wall concrete above 8.50m above grade is checked by rebound drilling core synthesis method. Walls is divided into 5 layers, each height is 6.0m, 6.0m, 6.0m, 6.0m.

| Component location | Strength estimation (MPa) | Component location | Strength estimation (MPa) |
|---------------------|---------------------------|---------------------|---------------------------|
| 1-1                 | 30.6                      | 3-4                 | 32.3                      |
| 1-2                 | 30.6                      | 3-5                 | 30.3                      |
| 1-3                 | 29.0                      | 4-1                 | 33.8                      |
| 1-4                 | 31.4                      | 4-2                 | 34.3                      |
| 1-5                 | 29.0                      | 4-3                 | 32.2                      |
| 2-1                 | 26.9                      | 4-4                 | 33.5                      |
| 2-2                 | 29.0                      | 4-5                 | 34.3                      |
| 2-3                 | 27.1                      | 5-1                 | 31.4                      |
| 2-4                 | 30.7                      | 5-2                 | 29.4                      |
| 2-5                 | 24.5                      | 5-3                 | 32.4                      |
| 3-1                 | 30.3                      | 5-4                 | 34.8                      |
| 3-2                 | 30.3                      | 5-5                 | 36.3                      |
| 3-3                 | 28.8                      | /                   | /                         |

and 7.5m respectively. Test results are shown in Table 2.

4. Reinforcement calculation

The parameters of the damaged silo are shown in table 3. Using the SILO module of PKPM software series of China Academy of Architectural Sciences, the conclusion is obtained.

| Parameter name                  | parameter values | Parameter name                  | parameter values |
|---------------------------------|-------------------|---------------------------------|-------------------|
| Silo diameter dn/m              | 25                | Silo wall thickness t/mm        | 450               |
| Silo wall height h/m            | 31.5              | Design value of tensile strength of steel bars fy/(N•mm-2) | 360               |
| Bulk densityγ                   | 12                | Concrete strength grade C25    |                   |
| Elastic modulus of steel ES     | 2.0×105           | /                               | /                 |

The model is builded, as shown in Figure 8. Through the calculation and analysis of the finite element software, a reasonable reinforcement scheme is obtained.
5. Reinforcement scheme
(1) In order to increase the strength of concrete on the walls, the walls of the 0.000-7.000m are strengthened with single side reinforcement. New C18@200 horizontal reinforcement and C18@200 vertical reinforcement are added to the silo walls. (2) The inner cylinder and outer cylinder are strengthened by increasing section method. The column is enlarged, 400mm long. New 7C25 Stress steel bar and C12@200 stirrups are added to each column. The lower steel of silo column are embedded in 500mm. the upper steel of silo column are embedded in 500mm.(3) From the elevation 8.500 to the elevation 40.000m, carbon fiber is adhered on the silo wall. The wall of the silo is pasted with 3 layers of carbon fiber cloth with 300mm width and spacing of 800mm, and 100×5@600 steel strip is adhered.

6. Construction of repairing and strengthening

6.1. Construction of embedded steel bar
(1) The depth of the planting steel bars should not less than 25d, and meet the related requirements of technical specification for post-installed fastenings in concrete structures (JGJ145-2013)(2)The position of drilling should avoid the original reinforcement steel bars. The wasted residue in the hole should be cleaned up after drilling.

6.2. Engineering construction of sticking carbon fiber cloth
Because of the material properties, carbon fiber cloth cannot be folded, so it is necessary to pay special attention to the control of storage and loss. Fully unloaded the silo before the carbon fiber reinforcement.

6.3. Construction of enlarged section
(1) During the construction, the decorative layer of the original concrete structure should be knocked out and the defects existing in the concrete are cleaned to the dense parts. (2) The original and newly designed steel bars shall be treated with rust removing, and the measures of unloading load or propping up shall be taken before welding on the stress steel bar.

7. Conclusion
(1) The method of increasing section and sticking carbon fiber can reduce the cost, shorten the construction period, the carrying capacity of the silo component can meet the requirement
(2) Due to the different damage conditions of silo, the reinforcement calculation is carried out according to the field identification of silo, and the economic and reasonable strengthening scheme is analyzed.
(3) Construction site to vibrate dense, to avoid the construction quality, resulting in defects, thus affecting the life of reinforced concrete silo.

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