Influence of steel pipe on mechanical properties of airport cement concrete pavement

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Abstract. This paper studies the influence of steel pipe on mechanical properties of airport cement concrete pavement. The flexural and compressive strength of concrete are analysed when different steel pipes are added into ordinary concrete. It is shown that the flexural and compressive strength of ordinary concrete are higher than those of concrete containing steel pipe at the age of 7 and 28 days. The compressive strength of concrete decreases more than the flexural strength when the steel pipe is added into concrete. The flexural strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe and DN40 welded steel pipe can still meet the mechanical properties of airport concrete. Compared with DN32 welded steel pipe and DN40 welded steel pipe, the selection of Φ32 seamless steel pipe is beneficial to the mechanical properties of concrete.

1. Introduction
Ice and snow on airport cement concrete pavement significantly impacts aircraft landing in winter because ice and snow reduce the friction coefficient between the tire and the pavement surface. The traditional method of ice and snow removal with snow-melting chemicals or machine induces traffic delay and needs a large number of manpower, chemicals and machine, which is labor intensive and time-consuming. It is necessary to conduct timely and high-efficient removal of ice and snow to avoid the adverse effects of snow-melting chemicals on concrete pavement. Therefore, a new technology using heat pipe melting snow is proposed. Heat pipe has attempted to introduce into melting ice and snow in some special area, where are bridge deck, sharp turn covered with ice and snow [1-5]. At present, heat pipe technology has been demonstrated to melt ice and snow on airport cement concrete pavement. Some researchers compared the responses of traditional versus snow-melting airport cement concrete pavement under aircraft loads, temperature loads and their coupling effects [6]. Heat pipe, as thin-wall hollow steel pipe, affects static response characteristic of pavement structure. However, the influence of steel pipe on mechanical properties of pavement is unclear. Therefore, it needs a systematic study on the influence of steel pipe on mechanical properties of airport cement concrete pavement.

2. Experiment

2.1. Materials
The raw materials include cement, fine aggregate, coarse aggregate, water and water reducer. The mix proportions of concrete are given in Table 1. The cement is Ordinary Portland Cement 42.5. The fine
aggregate is river sand, and its fineness modulus is 2.8. The sand ratio is 0.28. The mixed water is tap water. The ratio of water to cement is 0.42. The dimension parameters of three kinds of steel pipes are given in Table 2. The steel pipes include Φ32 seamless steel pipe, DN32 welded steel pipe and DN40 welded steel pipe in Figure 1, and their wall thickness is 3 mm, 3.25 mm and 3.5 mm, respectively.

Table 1. Mix proportions of concrete.

| Cement (kg m⁻³) | Fine aggregate (kg m⁻³) | Coarse aggregate (kg m⁻³) | Water (kg m⁻³) | Water reducer (kg m⁻³) |
|-----------------|------------------------|---------------------------|---------------|-----------------------|
| 325             | 579.9                  | 567.9                     | 851.8         | 136.5                 | 6.5                   |

Table 2. Dimension parameters of steel pipe.

| NO. | Steel pipe               | Wall thickness (mm) | Inner diameter (mm) | Outer diameter (mm) |
|-----|--------------------------|---------------------|---------------------|---------------------|
| B   | Φ32 seamless steel pipe  | 3                   | 26                  | 32                  |
| C   | DN32 welded steel pipe   | 3.25                | 35.75               | 42.25               |
| D   | DN40 welded steel pipe   | 3.5                 | 41                  | 48                  |

Figure 1. Three kinds of steel pipes.

2.2. Experiment program
In the paper, the mixture is stirred for 90 seconds. The concrete is used in actual airport pavement engineering. The concrete has good workability in this study. The specimens for flexural strength are prepared in the mold of 15 cm×15 cm×55 cm according to GB/T 50081-2016. The specimens for compressive strength are prepared in the mold of 15 cm×15 cm×15 cm according to GB/T 50081-2016. The steel pipe is placed in the middle of the specimen, and the center of steel pipe is 7.5 cm from the other four sides. The specimens are cured for 1 day at 20±2°C and 60% relative humidity, and then removed from the mold. The specimens are cured for 6 and 21 days at 20±2°C and above 95% relative humidity in the air. At the age of 7 and 28 days, the specimens are tested according to GB/T 50081-2016.

3. Results and discussion
In the experiment, the flexural strength, compressive strength and their ratios are analysed.

3.1 Flexural strength
The flexural strength of concrete containing different pipes is shown in Figure 2. At the age of 7 days, it can be seen from Figure 2 and Table 3 that the flexural strength of ordinary concrete is 4.81 MPa; the flexural strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipes is 4.64 MPa, 4.55 MPa, and 4.22 MPa, respectively. The hollow part of Φ32
seamless steel pipe accounts for 66.0% of the total sectional area. The hollow area ratios of DN32 and DN40 welded steel pipes are 71.6% and 73.0%, respectively. The ratio of flexural strength of concrete containing different pipes is shown in Figure 3. Although the modulus and stiffness of steel pipe are higher than those of concrete, the flexural strength ratios of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe are 96.5%, 94.6%, and 87.9%, respectively, which means that the corresponding flexural strength of concrete decreases by 3.5%, 5.4%, and 12.1%, respectively.

At the age of 28 days, the flexural strength of ordinary concrete is 5.70 MPa; the flexural strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe is 5.25 MPa, 5.21 MPa, and 5.06 MPa, respectively. The flexural strength ratios of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe are 92.2%, 91.4%, and 88.8%, respectively. The flexural strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe decreases by 7.8%, 8.6%, and 11.2%, respectively.

The flexural strength values are as follows: ordinary concrete > concrete containing Φ32 seamless steel pipe > concrete containing DN32 welded steel pipe > concrete containing DN40 welded steel pipe. It can be inferred that the outer diameter and hollow area ratio of steel pipe has a significant effect on the flexural strength of concrete.

### Table 3. Flexural strength and ratio of flexural strength.

| NO. | Concrete specimen                        | Flexural strength (MPa) 7d | Flexural strength (MPa) 28d | Ratio of flexural strength 7d | Ratio of flexural strength 28d |
|-----|----------------------------------------|---------------------------|----------------------------|--------------------------------|-------------------------------|
| A   | Ordinary concrete                      | 4.81                      | 5.70                       | 100.0%                         | 100.0%                        |
| B   | Concrete containing Φ32 seamless steel pipe | 4.64                      | 5.25                       | 96.5%                          | 92.2%                         |
| C   | Concrete containing DN32 welded steel pipe | 4.55                      | 5.21                       | 94.6%                          | 91.4%                         |
| D   | Concrete containing DN40 welded steel pipe | 4.22                      | 5.06                       | 87.9%                          | 88.8%                         |

### 3.2 Compressive strength

The compressive strength of concrete containing different pipes is shown in Figure 4. It can be seen from Figure 4 and Table 4 that the compressive strength of ordinary concrete is 35.51 MPa at the age of 7 days, and the compressive strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe is 32.27 MPa, 31.84 MPa, and 27.62 MPa, respectively. The ratio of compressive strength of concrete containing different pipes is shown in Figure 5. The compressive strength ratios of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe,
and DN40 welded steel pipe are 90.9%, 89.7%, and 77.8%, respectively, which means that the corresponding compressive strength of concrete decreases by 9.1%, 10.3%, and 22.2%, respectively.

At the age of 28 days, the compressive strength of ordinary concrete is 44.44 MPa; the compressive strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe is 37.57 MPa, 36.66 MPa, and 35.59 MPa, respectively. The compressive strength ratios of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe are 84.5%, 82.5%, and 80.1%, respectively. The compressive strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe decreases by 15.5%, 17.5%, and 19.9%, respectively.

The compressive strength values are as follows: ordinary concrete > concrete containing Φ32 seamless steel pipe > concrete containing DN32 welded steel pipe > concrete containing DN40 welded steel pipe. It can be seen that the compressive strength of concrete decreases with the addition of steel pipe at the age of 7 and 28 days. Although the wall thickness of steel pipe increases, the compressive strength of concrete decreases because of an increase of its outer diameter. It can be inferred that the outer diameter of steel pipe has a significant effect on the compressive strength of concrete.

### Table 4. Compressive strength and ratio of compressive strength.

| NO. | Concrete specimen                              | Compressive strength (MPa) | Ratio of compressive strength |
|-----|------------------------------------------------|-----------------------------|-------------------------------|
| A   | Ordinary concrete                             | 35.51                       | 100.0%                        |
|     |                                               | 44.44                       | 100.0%                        |
| B   | Concrete containing Φ32 seamless steel pipe | 32.27                       | 90.9%                         |
|     |                                               | 37.57                       | 84.5%                         |
| C   | Concrete containing DN32 welded steel pipe   | 31.84                       | 89.7%                         |
|     |                                               | 36.66                       | 82.5%                         |
| D   | Concrete containing DN40 welded steel pipe   | 27.62                       | 77.8%                         |
|     |                                               | 35.59                       | 80.1%                         |

#### 3.3 Ratio of compressive strength to flexural strength

Figure 6 shows the ratio of compressive strength to flexural strength of concrete containing different steel pipes. At the age of 7 days, the ratio of compressive strength to flexural strength of ordinary concrete is 7.39; the ratios of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe are 6.96, 7.00, and 6.54, respectively. At the age of 28 days, the ratio of compressive strength to flexural strength of ordinary concrete is 7.80; the ratios of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe, and DN40 welded steel pipe are 7.15, 7.04, and 7.03, respectively. The ratio of compressive strength to flexural strength of concrete at the age of 28 days is higher than that of 7 days. The ratio of compressive strength to flexural strength of ordinary concrete is higher than that of concrete containing steel pipe. The larger the diameter of steel pipe is, the smaller the ratio of compressive strength to flexural strength of concrete containing steel pipe is.
4. Summary
At the age of 7 and 28 days, the addition of steel pipe to ordinary concrete greatly reduces the flexural and compressive strength of concrete. The larger the diameter of steel pipe is, the smaller the flexural and compressive strength of concrete is. The effect of adding steel pipe to ordinary concrete on compressive strength of concrete is greater than that of flexural strength. The negative influence of different steel pipes on flexural and compressive strength is as follows: concrete containing DN40 welded steel pipe > concrete containing DN32 welded steel pipe > concrete containing Φ32 seamless steel pipe. The flexural strength of concrete containing Φ32 seamless steel pipe, DN32 welded steel pipe and DN40 welded steel pipe is more than 5.00 MPa at the age of 28 days.

For concrete containing Φ32 seamless steel pipe and DN32 welded steel pipe, the ratios of 7-day flexural and compressive strength are higher than that of 28 days. But the ratio of 7-day flexural and compressive strength is less than that of 28 days for concrete containing DN40 welded steel pipe.

The compressive strength of concrete decreases more than flexural strength when the steel pipe is added into concrete. The addition of steel pipe in concrete reduces the ratio of compressive strength to flexural strength. The larger the diameter of steel pipe is, the smaller the ratio of compressive strength to flexural strength of concrete containing steel pipe is.

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