WORKING STATE MONITORING OF A PILE-SUPPORTED 18-STORY FRAME-SHEARWALL STRUCTURE

SONG Jianxue
Zhengzhou University, China

ZHOU Tonghe
Zhengzhou University, China

Abstract

In a reinforced concrete Pile-Raft foundation, it was found that the tested load bearing capacity of the pile was a little smaller than the designed one. For distributing the structure load evenly, the raft thickness was increased from 550mm to 750 mm. Foundation base and column stresses were monitored during the course of construction. The monitored results show that the soil stress was evenly distributed no matter whatever under cushion cap or directly under raft. From the initial stage to the final one, the load bearing ratio between pile and soil developed from 0.04 to 2.20.

INTRODUCTION

In 2003, the building of a pile-supported 18-story frame-sharewall structure began in Zhengzhou, a Central China metropolis. A flat surface extended on the construction site, with flat bedding, alluvial soil and diluvial soil layer. The foundation consisted of ledged-piles, cushion caps and raft. The effective length of pile was 24.5m, and the diameter is 0.5m. On the lower segment of the pile, there were three ledges on the lateral side of the pile. The diameter of the ledge was 0.94m. The piles were rectangular or quincunx-shaped located. According to the load distribution, there were 2 to 8 piles under each column. The pile concrete was C30, and the longitudinal reinforcement is 8Φ14HRB335, spiral stirrups wasΦ8@100~200HPB235. The piles were bedded in Layer-8 silt.

Originally, the thickness of raft was designed as 550mm, with concrete as C35. After the construction of piles, the static and dynamic load bearing test were carried out on site. The test reported that the characteristic load bearing capacity of a single pile was 1534 kN, however, the designed one was 1960 kN, so the original designer was not satisfied. In order to strengthen the foundation structure, and to ensure the safety of structure, the thickness of the raft was increased from 550mm to 750mm, for the purpose of distributing the upper load evenly in soil, and extending the concentrated load to the outer area of cushion cap[1][2]. At the same time, bedding soil stress and reinforcement stress in the column at the key location had to be monitored, in order to trace the stress of bedding soil and reinforcement, then the working state of structure could be determined, and the building safety could be appraised.

Therefore, 15 bedding soil stress sensors and four reinforcement sensors were employed to trace the evolution process of real stress. The locations of sensors are shown in Fig 1.

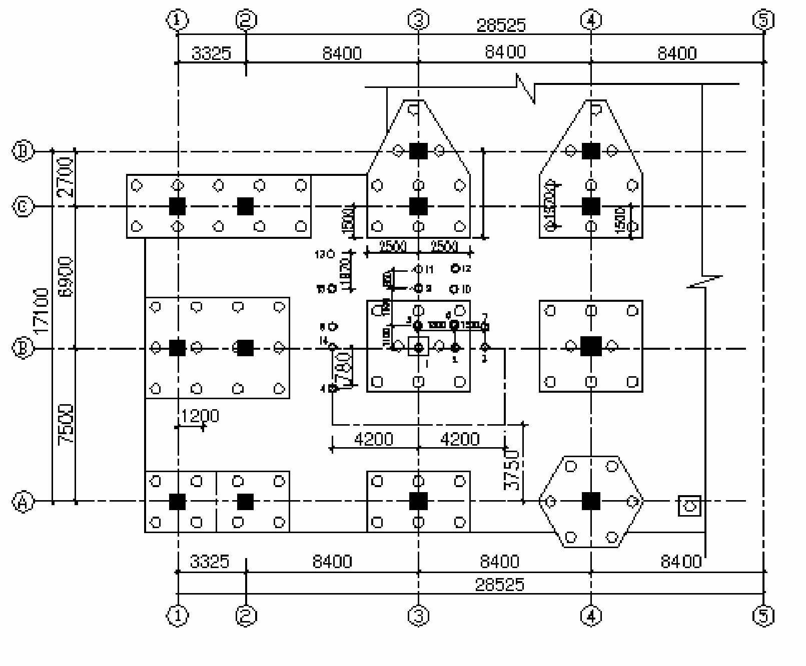

Figure 1. Locations of soil stress sensors.

ON SITE STRESS MONITORING

Reinforcement Stress

The vibrating wire style reinforcement axial load sensors were employed. The measuring range is -100MPa (compression)~200MPa (tension); with precision as 0.5%, The size of the sensor is Φ (30-86) ×190mm. In the range of 1000m, no revising is needed for the signals number. After the installation of stress sensors, the signal wires had to be protected very carefully.

Bedding Soil Stress

The vibrating wire style soil cells were employed. The measuring range is 10kPa ~4MPa ; with precision as 1%, The size of sensor was Φ101×22mm.

In order to ensure the success of soil cells, they were installed after the cushion coat was completed. First, holes were drilled on the cushion coat, with a diameter of 250mm, the bottom of the hole was 30mm lower than the bottom of cushion cap. The original state of the soil should not be disturbed violently. With the face of sensor towards the bedding soil, the sensor was placed in the hole, and the surrounding area was filled with tamped sand. Then the concrete with the same composition as a cushion coat was cast.

Monitoring of the first bedding soil stress was carried out 7d after the raft and cushion caps were cast, and the first reinforcement stress monitoring was done 7d after the column was cast. Then, after every two structure floors were completed, the stress monitoring was done, until the structure was finished completely.

ELASTIC ANALYSES OF LOAD EFFECTS

The Calculation Model of Reinforcement Axial Force

For the determination of reinforcement axial force in key column, an analysis model is chosen as shown in Fig 2. The construction load:

Dead load of floor being constructed: 3.5 kN/m^2
Live load of floor being constructed: 0.5 kN/m^2

The thickness of on-site casting reinforced concrete slab was 120mm. The section dimensions of beam KL-3 was 300×650 mm, and KL-B1 was 350×750 mm. The cross section of the column was 900×900mm. The height of the basement was 4.8m, the height of 1-2 floors was 4.5m, and the height of 3-18 stories was 3.6m. The gravity of reinforced concrete was taken as 25 kN/m^3, then the dead load of slab-beam-column was deduced as 5.3 kN/m^2.

With the load described above, taking the configuration of the structure into consideration, the axial force N_1 in the column at the monitoring location may be derived by the elastic Finite Element method, and the developing course of N_1 from the basement ceiling finished until the completed structure can be calculated.

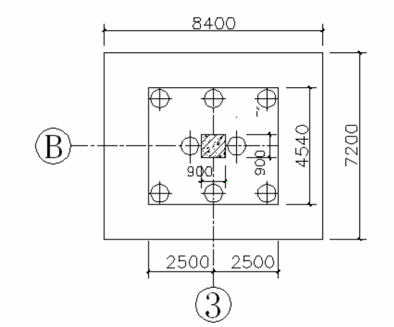

Figure 2. Analysis Model.

The Calculation Model for Bedding Soil Stress

The grid dimensions of structural columns are 8.4×7.2m, and the thickness of the raft is 750mm. Therefore, the gravity of the raft is W_1=1134 kN. The thickness of the cushion cap is 1.5m, and the size of the cap is 5m×4.54m, then its gravity is

$$W_2 = (1.5-0.75)\,m\times 5m\times 4.54m\times 25kN/m^3 = 426\ kN.$$

Within the scope of analysis model, the load of the structure was balanced by the reaction sum of soil and piles (8 piles in the scope of calculation model). The bedding soil stress monitoring provided the magnitude and distribution of soil stress, then the reaction of soil in between the piles could be obtained, then the reaction of piles was determined correspondingly. Furthermore, the load sharing features of the pile and in between the soil were traced.

THE MONITORING RESULTS AND ANALYSIS

Axial Load of Reinforcement

Since 2004-3-25, after the column (on the intersection of Axis-3 and Axis-B) in the basement was cast, until 2004-12-11, when the main structure was erected, the axial forces in the reinforcement were measured 14 times (No. 1 sensor was null). The axial force developing course is shown in Fig 3.

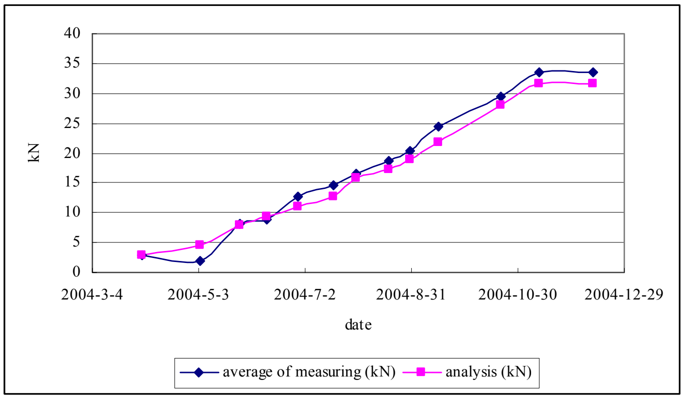

Figure 3. Comparison of average monitored and calculated axial force in reinforcement.

Fig 3 shows that the measured axial force in the reinforcement is rather close to the calculated one from the beginning to the end. However, the measure force is a little greater than the elastic analysis one. In the elastic analysis, only one story of construction surface load is considered, however, in practical construction, one and a half, even two stories of strut and concrete form might exist simultaneously, which leads to the insufficient load in the calculation model, so the measured axial force is a little bigger than the calculated one. When the top story was finished (No. 18 story, 2004-11-11), the axial force in longitudinal steel of column reached the maximum. At this time, the calculated one was 6% smaller than the measured one.

Fig 3 denotes that during the main structure being built, all the measured axial force in sensors were close to the calculated ones, and they developed in almost the same pace, and the developing magnitudes were closely. Therefore, it maybe concluded that the real load effect and calculated ones in the column was very close, and the column was working as the designed mode. Then it was derived that the frame-shearwall structure still kept the designed one, and no significant internal force re-distribution occurred.

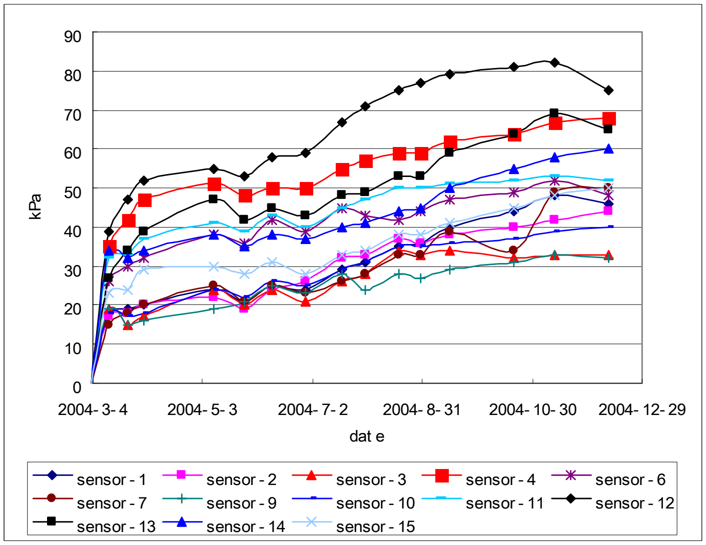

Figure 4. Soil stress during construction

Bedding Soil Stress and Analysis
Since 2004-3-3, when the cushion coat was finished, until 2004-12-11, when the main structure was erected, the bedding soil stresses were measured 16 times (Sensor-5 and Sensor-8 was null). The soil stress developing courses are shown in Fig 4.

Fig 4 denotes that during the main structure being built, all the measured soil stress developing curves are similar in shape and magnitude, they developed in almost the same pace and tendency, and no abnormality was shown. Therefore, the measured soil stress is reliable. The soil stress developed with the pace of the construction course. However, some factors perturbed the general trend. For example, during May 2004 and July 2004, when the migrating workers returned to their rural home, the construction pace slowed down. During this period, because of reaction redistribution between pile and soil, the bedding soil stress decreased slightly. Then, it developed steadily and smoothly. When the top story was finished (No. 18 story, 2004-11-11), because no more load was put on the monitored area, the soil stress kept the same. At last, soil stress decreased a little, due to the reaction redistribution between pile and soil.

Fig 4 also shows that soil stress has little relation with location. No matter whether under cushion cap or directly under the raft, the soil stress was random. So, an important conclusion may be drawn that when the thickness of the raft is big enough (750mm in this example), the bedding soil stress is distributed evenly.

Assuming the soil stress is evenly distributed, no matter whether under cushion cap or directly under the raft, the average soil stress (measured) is used to deduce the supporting reaction provided by the soil in between the piles at each stage of construction. Correspondingly, the supporting reaction provided by the piles (8 piles in the calculation model) is obtained. The development of reactions of piles and soil are shown in Fig 5.

Fig 5 manifests the reaction redistribution between piles and soil. At the initial stage, the load was mainly burden on soil. For example, just after the raft was cast, the total structure load was 26 kPa, and the soil stress was 25 kPa. With the increase of soil settlement, the load was transferred more and more to the piles. At the later stages of construction, the soil stress increased a little, however, the reaction in piles increased significantly.

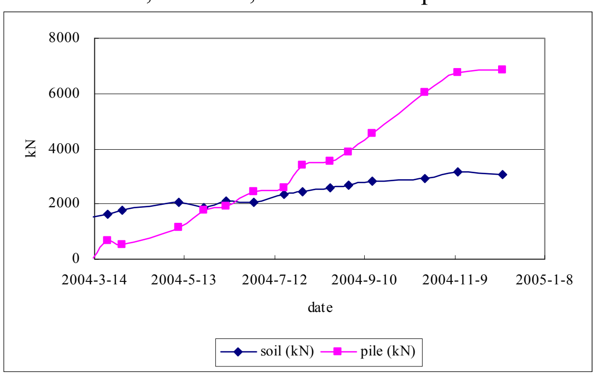

Figure 5. Load sharing ratio between pile and soil.

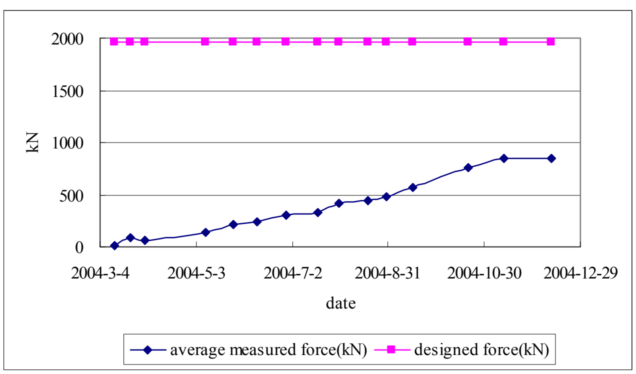

Figure 6. Load bearing values for a single pile.

Based on the measured average soil stress, the supporting reaction provided by a single pile may be determined. The evolution process of the average load bearing value of a single pile and the designed value are shown in Fig 6. It may be derived that the load bearing capacity of pile still has a large margin.

CONCLUSIONS

(1) For a casting, reinforced, concrete pile-cushion cap-raft foundation, when the load bearing capacity of pile is not sufficient, and increase the thickness of the raft, which may result in more evenly distributed soil stress, no matter whether under cushion cap or directly under the raft.
(2) During the course of construction, the load effect is shifting from soil to pile significantly. At the initial stage, the load is mainly burden on soil (4% in this example). With the increase of soil settlement, the load is transferred more and more to the piles. At the final stages, the load bearing ratio between pile and soil reaches the maximum (in this example, it reached 2.2).

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