Research and Application of Over-filling Monitoring Technology for Underwater Cast-in-place Piles

Yongbin Wei¹, Zhen Cao¹*
¹ China State Construction Engineering Corporation, Beijing, 101300, China
*Corresponding author’s e-mail: zhencaocq@163.com

Abstract. The quality of the pile head is the construction controlling difficulty of the concrete cast-in-place pile technology when the bored piles, especially the deep foundation piles, are filled with underwater concrete. The hammer method and volume estimation method are widely used to control concrete over filling in the prior technology. However, in the actual operation, these two methods are inclined to cause misjudgment by the field technicians, so it is difficult to accurately determine the height of the concrete, resulting in the under or over height of the pile head, which seriously affect the construction quality and greatly increase engineering costs in construction sites. In order to solve this problem, based on the principle that the mud density of the bored pile and the concrete density are different, and the pressure difference is generated at a certain depth, in this paper a liquid pressure sensor, data acquisition module, wireless communication module, remote network server and monitoring terminal were used to develop an overfilling controlling device for underwater concrete bored piles. Several engineering field tests were carried out and the test results showed that the device could accurately monitor the timing when concrete reaches the designed pile top elevation position and the specific quantitative height in the underwater pouring process, and can alarm after exceeding the limit as while. The method is simple and practical, and has high promotion value.

1. Introduction
When the bored piles, especially the deep foundation piles, are filled with underwater concrete, the quality of the pile head is the controlling difficulty of the concrete cast-in-situ pile technology [1-3]. In the prior technology, the widely used concrete over-filling controlling methods are hammer method and volume estimation method [4]. The hammer method is measured by a hammer with a measuring rope. The hammer weight is about 1 kg and is tapered, which is manually placed into the pile hole. Since the concrete contains coarse aggregate such as gravel, when the hammer passes through the concrete, the feel of the measuring person is different from the feeling in the mud, and the concrete is confirmed by this feeling. The elevation of the surface shows that as the height of the concrete surface increases, the measurement error becomes larger and larger and the elevation controlling of the concrete surface is difficult to be precise. The volume estimation method is based on the design parameters of the pile to calculate the theoretical amount of concrete to be poured. Due to the complex and variable conditions of the pile foundation and the perfusion process, most of the theoretical calculations cannot meet the requirements of the over-filling monitoring, resulting in too high elevation of the concrete pile surface. After the excavation of the foundation pit, the piles in the pit are of different heights and are in the form of "stone forest". The immediate consequence is: (1) Excessive over-filling causes waste of engineering materials, resulting in an increase in engineering costs; (2)
less-filling causes serious quality accidents, which must be reworked, which is also difficult; (3) Intercepting of pile heads would be difficult, cost of disposal will increase and the disposal will also cause environmental pollution; (4) The construction period of the foundation pit would also be extended.

To solve the above problems, through the market and technical research, combined with the actual situation of the site, this paper developed an over-filling monitoring device for underwater concrete bored piles, and achieved the expected results through field tests.

![Figure 1: Schematic diagram of over-filling controlling device for underwater cast-in-place piles.](image)

2. Principle and structure of monitoring device

When the concrete is poured, the medium passing through the specified section is mud and concrete in turn, and the density difference between mud and concrete is significant. The liquid pressure sensor can detect this difference obviously. According to this feature, the monitoring device uses the pressure sensor to monitor the pressure change, which would indirectly monitor the specific location where the concrete arrives. The monitoring device is composed of a liquid pressure sensor, a data acquisition module, a communication module, a remote network server, a monitoring terminal, and an installation fixture. As shown in Fig. 1, the liquid pressure sensor is connected to the data acquisition module through an aviation plug, and the communication module is connected to the monitoring terminal. The data acquisition module transmits the data monitored by the liquid pressure sensor to the remote network server, and is then received by the communication module. And displayed in the monitoring terminal. The specific scheme is as follows: (1) To accurately monitor the over-filling height of the concrete, the density of the concrete $\rho_1$ to be poured, and that of mud $\rho_2$ should be first determined; (2) The liquid pressure sensor be installed through the fixture at the height of the design pile top of the steel cage, as shown in the Fig. 2, it should be placed under the steel cage to the pile hole, and the designed concrete pile height $h$ is set on the monitoring software. At this time, the sensor is at a height $H$ from the mud level, and the sensor pressure value is $F_1$; (3) Then the concrete is injected through the conduit in the pile hole, and the concrete level rises slowly, the submerged liquid pressure sensor reaches the designed height $h$, and the monitoring terminal alarms, and the sensor pressure value is $F_2$. The monitoring process is shown in Fig. 3.
The value \( h \) of the concrete overfill height set on the monitoring software can be calculated by the following formula:

\[
\rho_2 g H = F_1 \tag{1}
\]

\[
\rho_1 gh + \rho_2 g (H - h) = F_2 \tag{2}
\]

According to the above formula, it can be known:

\[
h = \frac{F_2 - F_1}{(\rho_2 - \rho_1) g} \tag{3}
\]

### 3. Engineering field application

In a pile foundation project of Hubei Province of China, the actual field test was carried out using the underwater concrete over-filling monitoring device developed. The pile diameter of the project is 0.8m, the length of the pile body is 20m, the elevation of the pile top is 7m away from the ground, the strength of the concrete is C35, the slump is 180-220mm, and the designed height is required to be 0.9m. Through the monitoring terminal, the monitoring curve is divided into four stages, as shown in
Fig. 4. In Stage (I), before the concrete reaches the sensor: the pressure monitored by the sensor comes from the height of the medium above the sensor. At this stage, the medium in the upper part of the sensor is mud, the pressure of the sensor is stable, the curve tends to be horizontal, and the slight jitter of the curve is caused by the perfusion (such as: In the process of large mechanical vibration or in the process of drawing and rising action vertical pipe, etc.); In stage (II), the concrete approaches and submerges the sensor: because the difference in density between concrete and mud is significant, the curve appears to rise slightly and tends to be horizontal in a short time. This is the characteristic sign that the concrete reaches the sensor, which means that the concrete filling speed needs to be slowed down; In stage (III), the concrete surface height continues to rise rapidly: the upper medium of the sensor is composed of mud and concrete, the comprehensive density continues to increase, and the sensor pressure value becomes larger, the curve rises rapidly; In stage (IV), the concrete surface reaches the set designed height and alarms: at this stage, the concrete is stopped and the pipe is pulled out. The density of the medium in the upper part of the sensor tends to be constant, and the pressure value is gradually stabilized.

After 28 days of curing time, through the verification from site excavation, the actual height of concrete is 0.91m, the error is 0.09m, which meets the design standards [5], indicating that the monitoring data of the device is reliable and fully meets the construction requirements. In order to verify the reliability of the monitoring results, multiple over-filling monitoring was carried out, and the monitoring data (see Table 1) indicated that the construction specifications were also met.

| Pile number | Designed height | Monitored height | Actual height | Monitoring error |
|-------------|-----------------|-----------------|--------------|-----------------|
| D34         | 1               | 1.14            | 1.04         | 0.10            |
| D86         | 1               | 0.97            | 0.90         | 0.07            |
| D153        | 1               | 1.16            | 1.03         | 0.13            |
| D206        | 1               | 1.12            | 0.97         | 0.15            |
4. Conclusion

In view of the problems in the prior technology that the concrete over-irrigation height cannot be accurately controlled and the construction cost and quality are affected, the underwater concrete-filled pile over-filling monitoring device developed in this paper can accurately monitor the concrete when it reaches the designed pile top elevation position and the specific quantitative over-filling height during the underwater pouring process, and timely overrun alarm, and is easy to operate, with high promotion value.

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