Journal of Civil Engineering and Urban Planning (2023)
Clausius Scientific Press, Canada
DOI: 10.23977/jceup.2023.051007
ISSN 2616-3969 Vol. 5 Num. 10

Quality Control Index of Sinking Caisson Based on Trigonometric Function Transformation

Wu Huabei, Yao Kangkai, Liu Jian, Wang Li, Hao Shiyu

Sinohydro Sixth Engineering Bureau Co., Ltd., Shenyang, Liaoning, 110000, China

Keywords: Multi-grid caisson, settlement, informatization

Abstract: With the increase of the geometric scale of the caisson, the resistance ratio of the side friction resistance and the end resistance in the sinking process of the caisson will change, which may lead to uneven sinking, displacement, tilt and other phenomena. According to the monitoring results of sinking process of a certain caisson, the paper discusses that the displacement, inclination and relative inclination of sinking process meet the requirements of the standard. In addition, it is found that the evolution of the relative inclination is similar to the decay evolution. The discussion also shows that the rate curves of sinking of caisson at different stages show that with the increase of the size of caisson, the probability of sudden sinking phenomenon in the construction process also increases gradually. Therefore, the relevant measures should be paid attention to and put forward in the construction process.

1. Project overview

Caisson is a construction method for building deep foundation and underground structure, which is suitable for silt foundation and sand foundation. It has the characteristics of small area, less excavation amount, little influence on adjacent structures and nearby geological conditions, convenient construction, short construction period and low project cost. It is widely used in basic engineering such as bridge, sluice, port and so on. In recent years, it is the main foundation type of buildings, especially under soft soil [1-2].A coarse grid caisson structure is proposed to be used in the inlet pump house of an expanding sewage treatment project. It is a rectangular caisson with four squares, the length * width of the caisson is 24.1×19.35 meters, the depth of the caisson is 15.68 meters, and the thickness of the shaft wall is 800mm.The shaft wall is reinforced with Φ25@100 and Φ20@100 steel bars, and the sand layer foundation is reinforced with Φ16@1500*1500 steel bars anchored into the bottom plate 40.The design of the caisson is a rectangular structure with partition wall, divided into four compartments and four times sinking. The landform of the proposed site is a alluvial plain with relatively flat terrain. According to the drilling disclosure, the soil layer involved in the construction of the planned caisson is plain filled soil, silty clay, medium sand and coarse sand. The self-supporting stability of silty clay is poor, and the permeability of medium sand and coarse sand is good. According to laboratory tests, the recommended values of friction resistance between shaft wall and soil during sinking of caisson are as follows: plain filled soil, fk=12kpa.Silty clay, fk=10kpa.Medium sand, coarse sand, fk=18kpa.After comprehensive consideration, the undrained sinking method is proposed for construction.

From the basic mechanism level, with the change of caisson scale, construction environment, side friction resistance and end resistance of caisson, caisson gradually sinks. The biggest difficulty in the sinking of caisson is precise control and uniform sinking. In case of complex geological conditions or improper selection of process methods, there are safety risks such as sudden sinking. Especially the super large caisson, the sinking process may not be uniform, easy to appear displacement, tilt and other situations are more prominent. Compared with circular caisson, it is more difficult to control velocity, crack and deviation correction in the sinking process of square caisson. The whole construction process must implement the principle of "frequent testing and correction, along with deviation and correction" in a timely manner. The relevant personnel should not only prevent the rapid sinking of the caisson, but also take measures to prevent the excessive settlement of the caisson in order to achieve smooth caisson and accurate positioning. Therefore, it is necessary to monitor the construction process in real time. For example, Li Ming [3] et al. monitored the stress of shaft wall and partition wall in the sinking process of caisson, as well as the sinking process. According to articles 7.2.1 and 7.2.2 of GBT51130-2016 Construction Code for Caisson and Pneumatic Caisson [4], the monitoring alarm value during the descending process shall not exceed 150mm.The tilt does not exceed 1.5%, the monitoring frequency is 1 time /d, and the monitoring data should be 2 times /d when it exceeds the alarm value. At present, more monitoring results are obtained based on time series subsidence, deflection and other basic characteristics. These results lack a more detailed series of deformation analyses, lack of analytical results to guide site construction, etc. Therefore, based on the real-time monitoring data on site, it is particularly necessary to propose a class of reference indexes for rapid and accurate analysis and identification of the degree of displacement, tilt and torsion in the sinking process of caisson, and guide the on-site construction according to quantitative indexes. The relevant results also have the significance of engineering practice and guidance.

2. Caisson construction and monitoring plan

According to the characteristics of the project and the specific requirements of the design, the undrained sinking technology is adopted. After the bottom of the pot is formed (the depth is about 1 ~ 1.5m), other units are started to collect soil in the surrounding area. After the subsidence track is formed, all units can operate normally. Only when it is necessary to speed up the subsidence speed or correct the deviation can the soil be collected in the surrounding area of the shaft wall under control. The soil extraction should be unified and coordinated when sinking, the partition wall and edge foot should be strictly controlled, and the principle of "digging the bottom of the pot first, then digging the bottom beam, symmetrical soil extraction, and uniform and continuous sinking" should be followed. Then, under the condition of little deviation of the caisson, the soil extraction should be layered around, symmetrical and even, and the edge foot part should retain a wide soil embankment of about 2.0m.Due to the force requirement of the bottom sealing concrete, the shaft wall is equipped with shear keys, and the vertical soil extraction equipment within the range of the shaft wall and shear keys cannot directly take soil, which becomes a blind area. In order to achieve safe, controllable, efficient and stable sinking of caisson, it is necessary to take soil from the blind area under shear key. We can use the manual coordination method.

According to the Technical Code for Monitoring Construction Foundation Pit Engineering (GB50497-2009) [5], the project should monitor surface soil settlement and horizontal movement, construction (structure) settlement, sinking depth of caisson, migration of caisson body, height difference of caisson, water seepage, surrounding surface conditions and groundwater level monitoring. Through the implementation of information construction, monitoring and monitoring of the whole process to ensure the safety of foundation pit engineering and the surrounding environment. The subsidence monitoring is carried out by using the axis control of caisson structure and the four-corner observation. The settlement, displacement and inclination of the caisson are arranged in 4 groups, as shown in Figure 1.

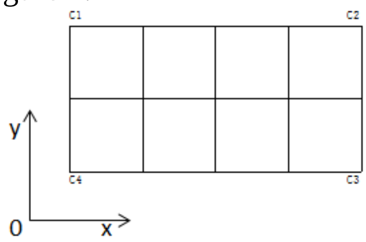


Figure 1: Monitoring and layout diagram of multi-grid settlement and subsidence process

During the sinking process of caisson, the observation of subsidence should be strengthened, and the measurement should be made from half an hour to an hour in the initial sinking stage. The middle settling stage is measured every hour, and the final settling stage increases the number of observations to prevent uneven settlement. The deviation in the sinking process of caisson should be reduced as far as possible, and the measurement control points, elevation control points and other points should be checked frequently. When the sinking of the caisson is close to 2m from the design elevation, the sinking speed of the caisson should be slowed down to correct the deviation, and pay close attention to the sinking speed of the caisson to prevent oversettling, so that the caisson can sink smoothly to the design elevation.

According to articles 7.2.1 and 7.2.2 of GBT51130-2016 Construction Code for Caisson and Pneumatic Caisson, the monitoring frequency is 1 time /d during descent, and the monitoring data should be 2 times /d when it exceeds the alarm value.

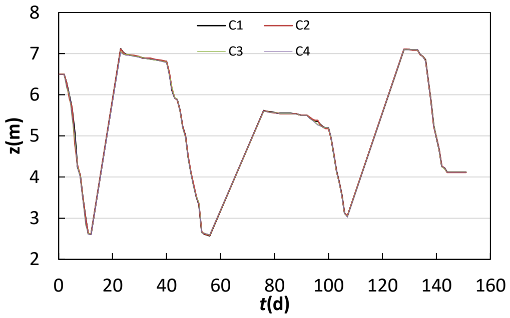
3. Observation results and discussion

3.1 Time Series

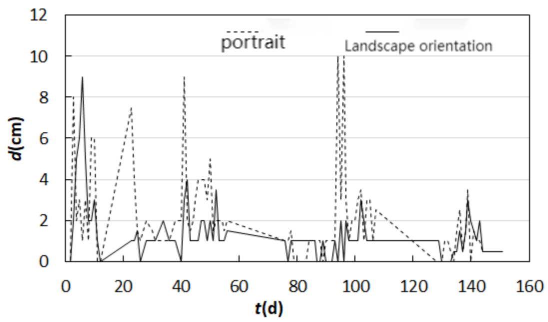
According to the monitoring data, the entire construction process took 151 days. The settlement (Z), lateral and longitudinal displacement (d) and inclination (S) in the construction process are shown in Figure 2.

It can be seen that the four boundary subsidence values of the multi-grid caisson are basically the same, and there is no obvious difference, indicating that the whole structure presents uniform subsidence characteristics. The convex points in the figure are the initial elevation of each derrick, where 0~20d is the sinking process of the first caisson, 20~60d is the sinking process of the second caisson, and so on. From the perspective of displacement, the initial displacement fluctuates greatly, and then gradually weakens. The inclination of caisson also shows the same characteristics.

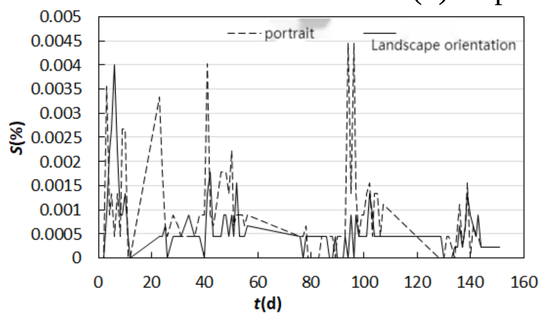
According to the "GBT51130-2016 Caisson and pressure caisson construction Code" 7.2.1 and 7.2.2, the monitoring alarm value during the descent process, the displacement does not exceed 150mm, tilt does not exceed 1.5%.It can be seen that in the whole sinking process, the maximum displacement is 100mm and the maximum inclination is 0.05%, which are less than the standard value and meet the construction requirements.



(a) subside



(b) displacement

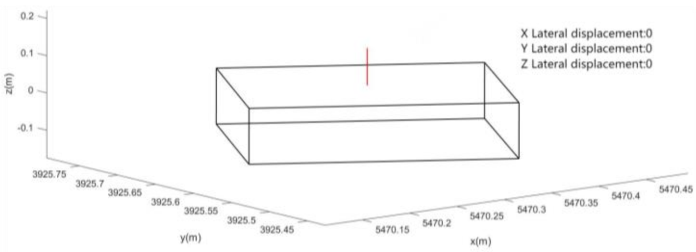


(c) batter

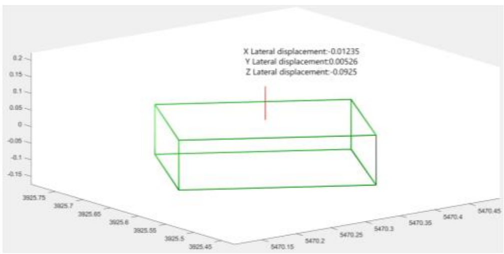
Figure 2: Monitoring results during the caisson

3.2 Sinking process 3D visual technology

In order for researchers to more intuitively discuss the displacement and deformation of multi-grid settlement during construction, we will conduct numerical modeling of the entire structure and observed data. Considering that the plane scale and deformation scale are incongruous, the coordinate scale needs to be pre-processed. For example, the original observation data are geodetic coordinates (x1,y1,z1), if (X1-c)/100=x, (Y1-c)/100=x, (Z1-C)×100=z; Where C is a constant. The scale of the obtained figure shrinks in the plane and increases in the vertical direction, which can better show the process of displacement and tilt in the period. Through matlab calculation, the three-dimensional sinking process of caisson can be obtained, as shown in Figure 3 below. Where T is the total construction time of the whole caisson, and t is any time in the sinking process.



(a) T=0



(b) T=t

Figure 3: 3D dynamic features under the caisson

It can be seen that the whole structure is rigid at the initial moment, and with the progress of excavation, the caisson sinks as a whole, and the inclination is almost unchanged.

3.3 Sinking rate difference characteristics

The coarse grid caisson is a rectangular structure with four squares, which is divided into four compartments and sunk four times. Therefore, it is necessary to discuss the settlement characteristics in each or each section of the subsidence process according to the monitoring results. In order to compare the sinking characteristics of caisson in different stages, dimensionless parameters are introduced to analyze the measured data.

(1) Firstly, the elevations of the four stages of caisson were named Z1, Z2, Z3 and Z4 respectively; The elevation of t at any time in each stage of sinking is Z1i, Z2i, Z3i, Z4i, i=1~4, which is the number of caisson nodes. Then Z1i/Z1, Z2i/Z2, Z3i/Z13, and Z4i/Z4 indicate the normalization of the sinking process of each stage caisson. This promotes comparison and discussion.

(2) If ri, i=1~4 is the sinking rate of caisson, then the sinking rate of the four stages is expressed as: ri=Z1i/Ti, where Ti is the sinking time of each section of caisson.

Therefore, based on the above, the differential characteristics of sinking rate of each section of caisson can be obtained, as shown in Figure 4 below.

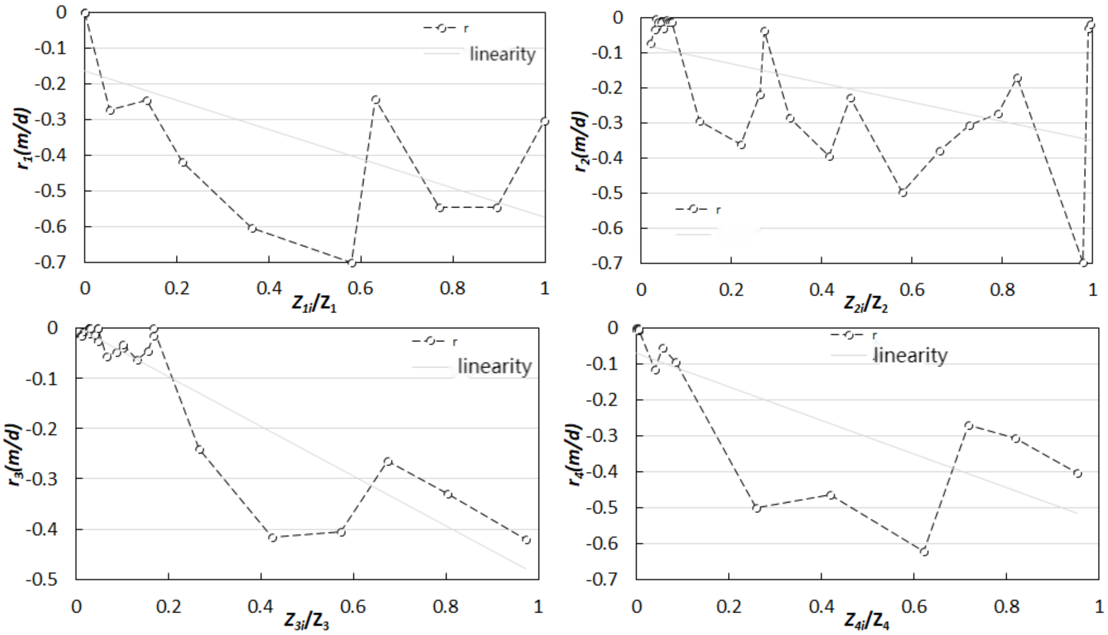


Figure 4: Comparison of the lower penetration rate of each caisson section

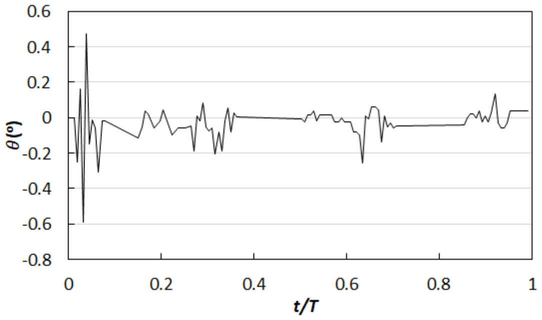
For the first and second sections, because of the low height of caisson at this time, the side friction resistance and end resistance of caisson are small, and the decline rate is more uniform. As can be seen from the figure, the sinking rate of the first and second sections is relatively close. With the increase of the caisson height, the dead weight of the caisson gradually increases, and the groundwater level increases, and the relationship between the lateral friction resistance and the end resistance of the caisson changes. The sinking rate of the third and fourth stage caisson is slowed down compared with the previous two stages. However, the slope of the rate curve shows that with the increase of caisson scale, the probability of sudden subsidence in the construction process is gradually increasing, so attention should be paid to the construction process, and relevant measures to prevent caisson sudden subsidence are proposed.

4. Quality control index based on trigonometric function transformation

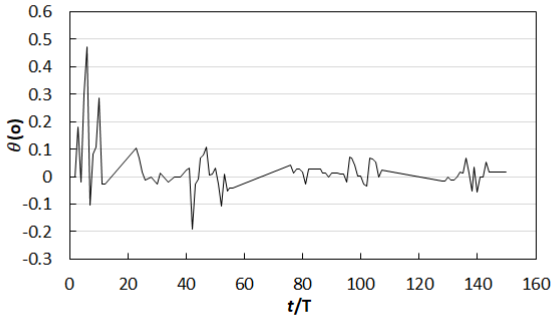
In cartesian coordinate system, C1~C4 coordinate besieged rigid body uniform x axis, y axis formed a certain Angle. In the initial state, this Angle is 90o. With the sinking of caisson in construction, the phenomenon of displacement and tilt occurs in the sinking process, so the Angle between the rigid body and the x axis and the y axis must change at any time.Let's say the X-axis or the Y-axis are vectors $\vec{a}$.the boundary of the rigid body see the vector $\vec{b}$.then its Angle is recorded as θ.It is called relative inclination, so that displacement and tilt are considered in this parameter for comparison and discussion. It can be calculated by using the following equation:

$$COS\theta = \frac{\vec{a} \cdot \vec{b}}{|a| \cdot |b| \cdot} \tag{1}$$

According to the calculation results, the deformation characteristics of rigid bodies at different observation times can be calculated by trigonometric function. To compare the Angle and time should be normalized. The whole calculation process is calculated by matlab, and the calculation results are shown in Figure 5.



(a) Y-line



(b) X-line

Figure 5: Characteristics of the relative inclination of the caisson under the rectangular coordinate system

We can see that the maximum displacement and maximum inclination Angle can meet the requirements of the specification. However, from the above relative inclination change characteristics, there are two current characteristics that need special attention. First, during the construction process, the relative inclination Angle reaches 0.6o at some time, and there is a risk of deflection. Therefore, a new construction quality control standard is proposed here, that is, the relative inclination Angle of the whole construction process should not exceed 0.4o.Second, from the perspective of time series, the whole process presents a kind of attenuation characteristics, which is related to the gradual increase of the size of the caisson and the friction resistance of the side wall and bottom of the caisson. Therefore, a kind of damping oscillation curve can be considered in the future to discuss the special change characteristics.

5. Conclusion

According to the observation results, the maximum displacement of the whole sinking process is 100mm, and the maximum inclination is 0.05%, which is less than the standard value and meets the construction requirements.

According to the change characteristics of the relative inclination Angle, the whole construction process should not exceed 1.0o relative inclination Angle. From the view of time series, the whole process presents a kind of attenuation characteristics, which is related to the gradual increase of the size of the caisson and the friction resistance of the side wall and bottom of the caisson.

The slope of the rate curve of sinking of caisson indicates that with the increase of the size of caisson, the probability of sudden sinking phenomenon in the construction process also increases gradually. Therefore, attention should be paid to the construction process and relevant measures should be put forward to prevent sudden sinking of caisson.

References

[1] Zhang Qi. Treatment of oversettling and tilting of caisson by high-pressure rotary jet grouting [J]. Anhui Architecture, 2011, 18(01):90-91.

[2] Fan Xinfa, Luo Hongbing, Fan Cong. Case study on correction of caisson in soft soil foundation [J]. Geotechnical Foundation, 2014, 28(04):8-10.

[3] Li Ming, Xie Weishi, Chen Guo et al. Analysis of Structural internal force change law in the sinking of large caisson [C]// Construction Technology Magazine, Asia-Pacific Institute of Construction Technology Information Co. , LTD. Proceedings of 2020 National Civil Engineering Construction Technology Exchange Conference (Volume). Construction Technology Magazine

[4] Hu Yuanyuan, Liu Junsheng, Chen Changshi. Experimental analysis of vertical displacement monitoring accuracy of the revised national standard "Technical Code for Construction Foundation Pit Engineering Monitoring" [J]. Urban Survey, 2019(06):133-136+140.

[5] GB/T 51130-2016, Construction code for Caisson and pneumatic caisson [S].