Oscillation of floating caisson in deep water

Autor(en): **Wan-Shou, Yin / Yin-Yue, Lin / Sui-Zhang, Zhao**

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VIII

Oscillation of Floating Caisson in Deep Water

Oscillation de caisson flottant dans l'eau profonde

Schwingung des schwimmenden Senkkastens im tiefen Wasser

YIN WAN-SHOU
Associate-Chief Engineer
Bureau of Bridge Construction
Wuhan, People's Republic of China

LIN YIN-YUE
Bridge Engineer
Bureau of Bridge Construction
Wuhan, People's Republic of China

ZHAO SUI-ZHANG
Chief Engineer
Bureau of Bridge Construction
Wuhan, People's Republic of China

SUMMARY
During the construction of two floating caissons of a bridge across the Yangzi River in China, an abnormal late autumn flood caused the breaking of side anchoring cables and set up a dangerous oscillation in the floating system. The paper presents the description of the incident, method of restoring the control, and some related discussions.

RESUME
Durant la construction de deux caissons flottants d'un pont sur le fleuve Yangzi en Chine, une crue exceptionnelle de fin d'automne a causé la rupture de câbles d'ancrage latéraux et a entraîné une oscillation dangereuse du système flottant. L'article présente une description et une discussion de l'incident et des mesures prises pour rétablir le contrôle.

ZUSAMMENFASSUNG
Während des Baus einer Brücke über den Yangzi-Strom in China rissen infolge eines Hochwassers die seitlichen Verankerungskabel der zwei schwimmenden Senkkasten. Das ganze System begann zu schwingen und wurde dadurch stark gefährdet. In diesem Aufsatz wird der gesamte Bauprozess beschrieben sowie die Massnahmen erläutert, mit welchen das System wieder unter Kontrolle gebracht worden ist.

1. INTRODUCTION

Reinforced concrete floating caissons, rectangular in plan 18.2 m by 22 m, were adopted for the foundation work of piers No. 4 and 5 in a bridge across the lower Yangzi River. While constructing the caisson of No. 5, an abnormal flood caused the side anchoring cables to break suddenly in succession. The arrangement of the anchorage system is shown in Fig. 1.

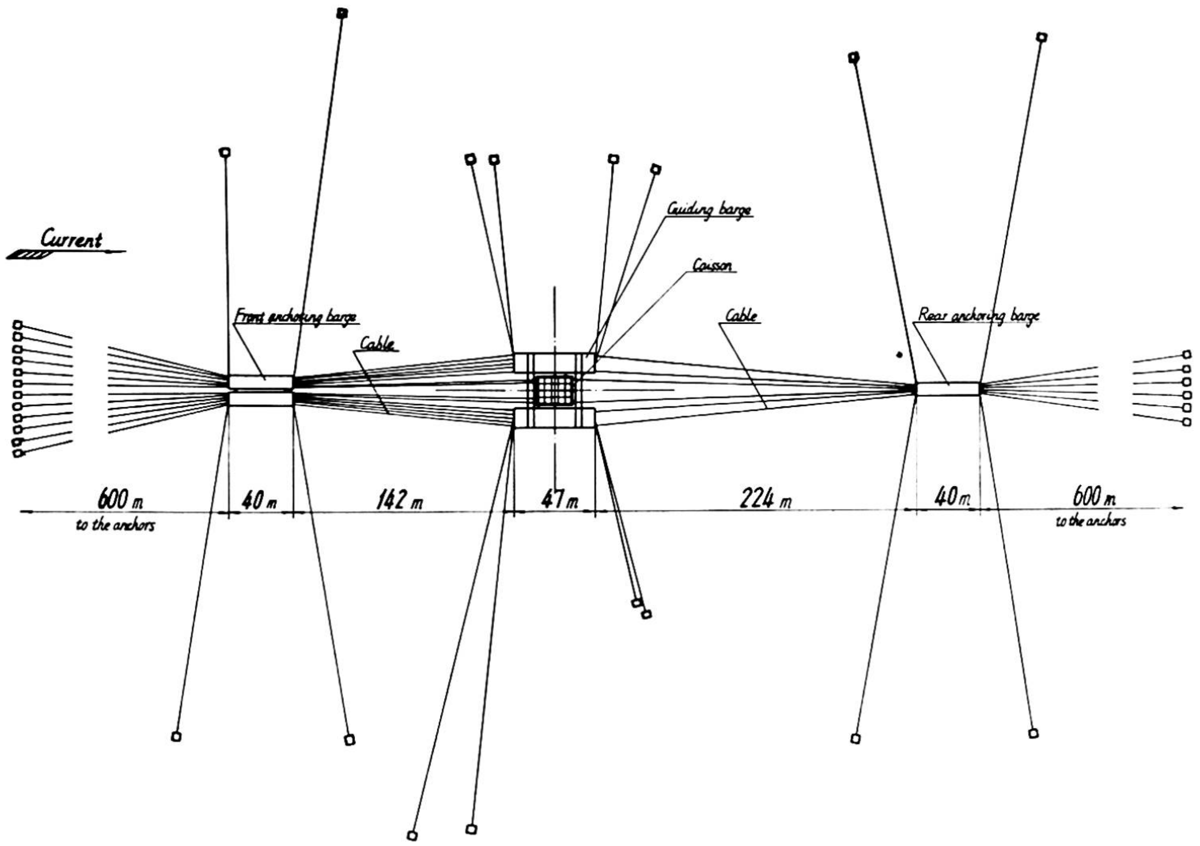

Fig. 1 The Arrangement of Anchoring System of Pier No. 5

The floating caisson with its guiding barges began to swing transversely to the axis joining the anchoring barges. This was an incessant oscillation of large amplitude and low frequency. The oscillation made the position of the caisson out of control, and the main cables connecting the guiding and anchoring barges were highly overstressed. Several days afterwards, same thing happened to the caisson of pier No. 4, and similar oscillation started, that made the condition still more critical.

2. DESCRIPTION OF THE EVENT

Piers No. 4 and 5 are situated in the mid-stream of the river. During the time of oscillation, the depth of water was 30 m, and current velocity was 2.5 m/sec. The caisson of pier No. 5 had been constructed to the height of 20.2 m, its immersed depth was 14.2 m. The amplitude of oscillation reached 15 m, and the average cyclic period was about 3 minutes. The total weight of the caisson and the guiding barges was nearly 7,000 tons. The maximum amplitude of oscillation for caisson of pier No. 4 reached 29.3 m.

During oscillation, both the upstream and downstream anchoring barges displaced very slightly. However, the stresses in the main cables connecting the anchoring and guiding barges fluctuated with the change of position of the floating body continuously. The main cables on the outer side (convex edge) were tightened and those on the inner side (concave edge) were slackened. The maximum movement of the floating body had a tendency to deviate constantly to the rightside of the current flow.

In elevation, the caisson also fluctuated up and down. The magnitude of fluctuation was about 1 m.

The guiding barges were kept in position with 8 side anchors. The direction of the anchors, the cable lengths, and the composition of each cable were all different from one another. Altogether 12 side anchoring cables were replaced for pier No. 5, some had been replaced twice.

3. THE CAUSE OF THE OSCILLATION

The floating body - the caisson together with guiding barges, was held in place in the river with a great number of anchoring cables. It constituted an elastically supported structural system in space. The stresses in the maintaining cables varied continuously, depending on the action of wind and water current. Owing to the effect of Karman Vortex, eddy current was constantly formed on both sides and in the wake of the floating system. The component forces from the swirls perpendicular to the current flow acted alternatively on the sides of the floating body. At first, it caused vibration of small amplitude. But when the side anchoring cables were broken, the self-exited action of the swift current amplified the oscillation rapidly. Finally, the restraint of the main connecting cables ahead and behind the floating body, kept the oscillation restricted at certain limit and avoided further divergency.

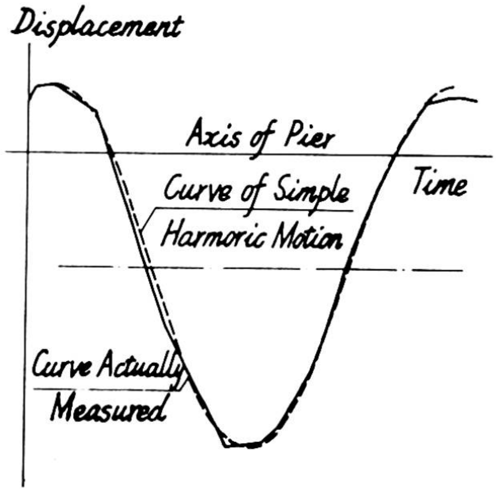

Fig. 2 Cyclic Time-Displacement Curve

An actually measured vibration curve of the floating body was plotted. It closely resembles that of a simple harmonic motion, as shown in Fig. 2. Utilizing the analytical solution of simple harmonic motion as an approximation, the maximum force of inertia of the floating body was found to be 13.1 ton-force, and the kinetic energy, 98 ton-force-meters.

4. MEASURES TO CHECK THE OSCILLATION

At first, to alleviate the tension of the main connecting cables at upstream side, two 700 HP tug boats had been applied alongside the floating body and ran against the current. But this was found to have little effect on the oscillation.

Then another method was attempted by tightening the side anchoring cables slowly and simultaneously to check the oscillation. It momentarily appeared to be a success, as the amplitude was decreased from 11.5 m to 4.1 m. But the cables broke again a few hours later, and the whole event happened again.

The above attempts had made it clear that the oscillation of the floating body could not be stopped by simple, ordinary means.

In order to increase the damping effect by introducing a counteracting force always opposite to the direction of motion and at the same time not to overstress the existing cables, a damping contrivance was devised to restrict the oscillating impetus.

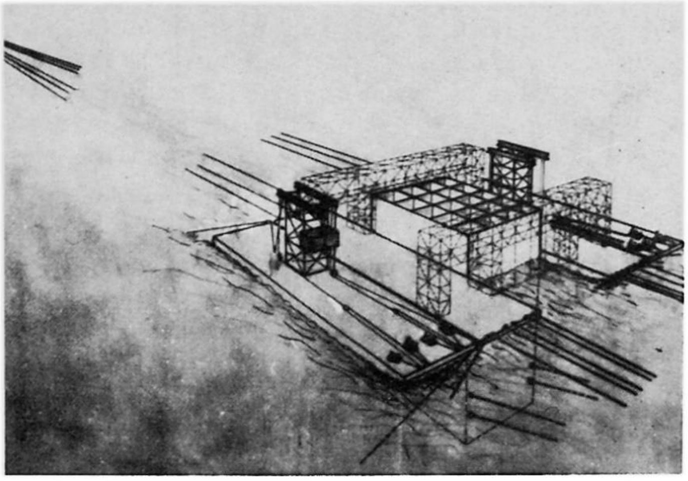

Fig. 3 Working Boat with Damping Contrivance Move Together with the Floating System

The arrangement and the working principle are as follows:

Two working boats were employed, on each boat there were one lifting tower, two sets of counterweights of 20 tons each, and two electrical winches. The boats were connected to the guiding barges side by side, and moved together with the floating body as shown in Fig. 3. The counterweight was attached to a movable pulley running on a main working wire rope which was suspended from and passing through two fixed pulleys on top of the tower. The working rope was connected on one end by pulley blocks to a side cable reaching a concrete anchor, and on the other end to the electric winch.

When the floating body was swinging to one side with the working boats, the movement lifted the counterweights on one boat, the work thus done transformed the kinetic energy into potential energy, which would be dissipated when the weights were later lowered down mechanically to and rested on the deck by the winch. When the swing was reversed, similar work was done on the other boat. Thus by a series of repetitions of such damping process the dynamic energy would be dissipated step by step

The working procedure is shown schematically in Fig. 4. When the floating body set to move the counterweight on the front side boat kept on the deck the main working rope was in slackened condition and would be wound up slowly by the winch, while the counterweight on the rear side boat would be slowly lifted up with the winch on brake, the working rope was then taut. When the oscillation attained its maximum reach, the winch on the rear boat would release the working rope and lower down the counterweight. The operations would be reversed when the floating body began to move back.

The pull in the side anchoring cable was safely limited to within 10 ton-force during all the time. To keep the floating body in well balanced con-

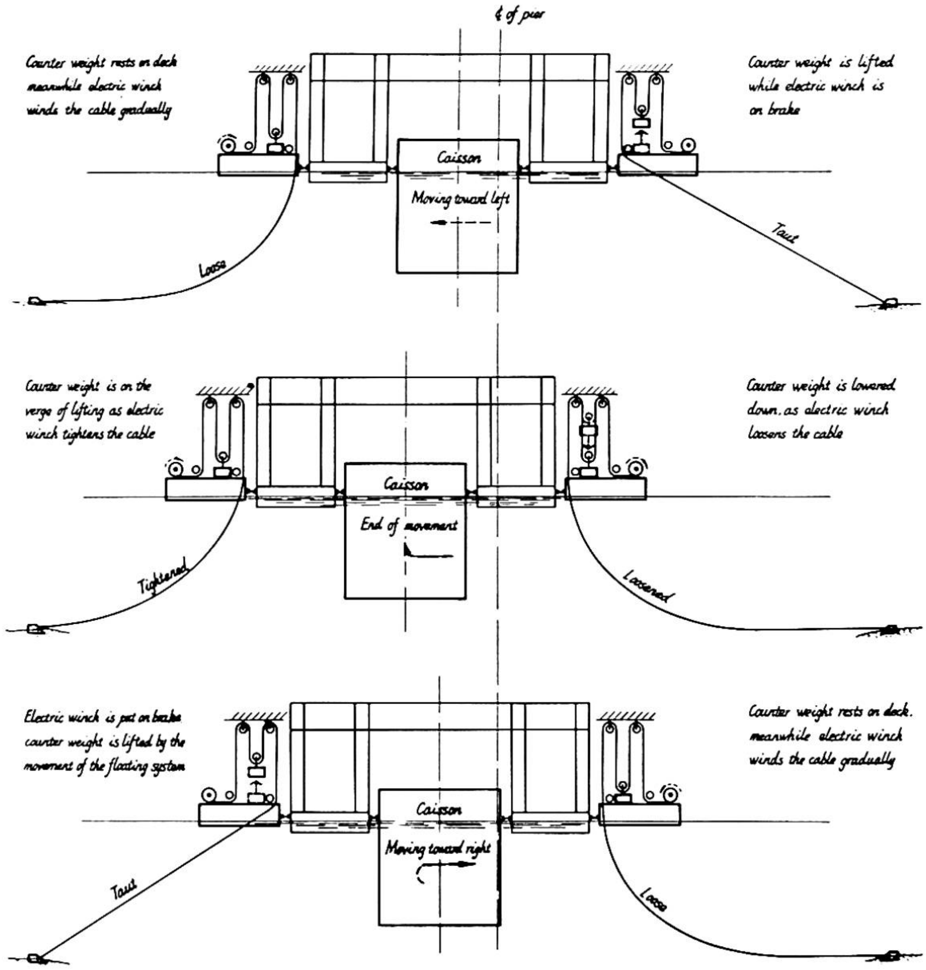

Fig. 4 The Working Principle of the Dissipation of Energy

dition during moving, two similar sets of counterweights connected to two side anchors were used on each working boat.

With the aid of the working boats, the oscillation was effectively controlled, and the amplitude decreased from 11 m to 1.5 m for pier No. 5 (Fig. 5, when the counterweights were purposely put out of action, oscillation quickly resumed to its original magnitude). Then side anchoring cables were tightened without any difficulty, the amplitude was finally restricted to within 1 m. The same measure was taken at pier No. 4, and the amplitude was restricted to 0.5 m. Throughout the entire event, about 13,000 cycles of oscillation with large amplitude occured at pier No. 5 before construction work resumed to normal.

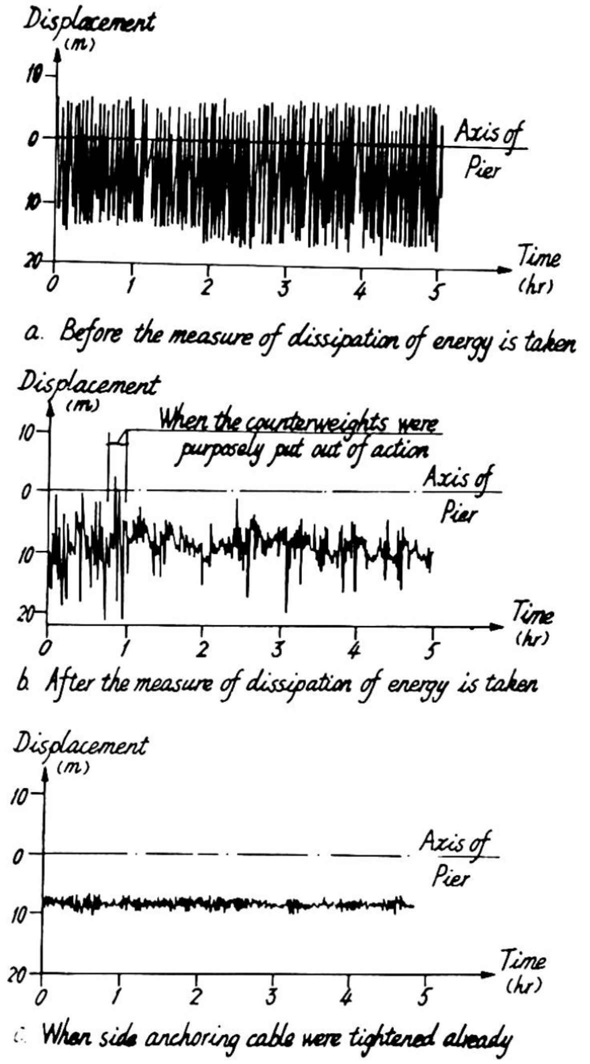

Fig. 5 Oscillation Curve of Caisson at Pier No. 5

5. A FEW REMARKS

In the construction of floating caisson with cable anchorage system for deep water foundation special attention should be paid to the dynamic problem.

During arranging the anchoring system, the stresses in different anchoring cables should be kept as even as possible, and it is important that the cable lengths and the composition of cables should not differ too widely from one another.

When figuring the acting forces on the cables, the following should be taken fully into consideration:

- The effect of changing direction of the current flow.

- The forces acting on the floating system from different directions with different dynamic coefficients.

- The initial prestressing of cables during tightening.

- The dynamic effect of current force on the cables.

When figuring the strength of cables, the following are important factors:

- The fatigue influence of the high frequency vibration of cables in swift current.

- The bending, squeezing and abrasion of cables at fairleaders.

Finally, special precautions for figuring the anchoring cables, anchoring chains and anchors should be drawn and strictly adhered to.