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Case History of a Bridge Foundation

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SYNOPSIS A reinforcement open caisson of a bridge was constructed on a sand island. Its constructing characteristic couldn't been foreseen and were calculated conventinally. Besides, there were some mistaken methods in the constructing. Therefore the open caisson broke up to become 4 blocks in the construction. The largest width in these cracks was 80cm. Ivestigation and analysis having been done, the causes of the failure were found. Some repairing methods, such as opposite cutting edge, reinforcement hoop, and so on, adopted. Correct excavation was carried out. The open caisson finally sunk to the rock. The treatment was successful.

INTRODUCTION

A bridge over the Xiang River was built in 1970s in Changsha, Hunan, China. Its total length is 1532m. The main body of the bridge is a reinforced concrete arch bridge and the length is 8×80.5m. The foundation of its 4# pier locating in the main channel was a reinforced concrete open caisson. The depth of the water of the pier position was 4m and the thickness of the overburden layer formed by the loose sandy gravel was 5m. The open caisson was constructed on a sand island and would be sunk through the sand island and the sandy gravel to the unweathered rock stratum. Uniaxial ultimate compression strength of the rock is about 360 kg/cm^2. The thickness of the rock mantle is 1.5~2.0m.

The 4# pier is a sole single direction thrusted pier in the main channel. In other words, if the span of its right or left is destroyed, the pier can still beared horizontal thrusting force of other arch span dead load and wasn't destroyed. Therefore the foundation must be big enough. The open caisson size in plane was 21.0× 18.2m (Fig. 1) and the width of the pier was only 8m, so the length of the foundation cantilever end was (21 −8)/2=6.5m. The highness of the caisson was only 4.5m in order that the foundation cantilever end would not form a hidden reef to the navigating ships under the spans. The wells in the middle row located join of the pier and the foundation, so that the highness was 5.5m. The caisson sunk depending on its

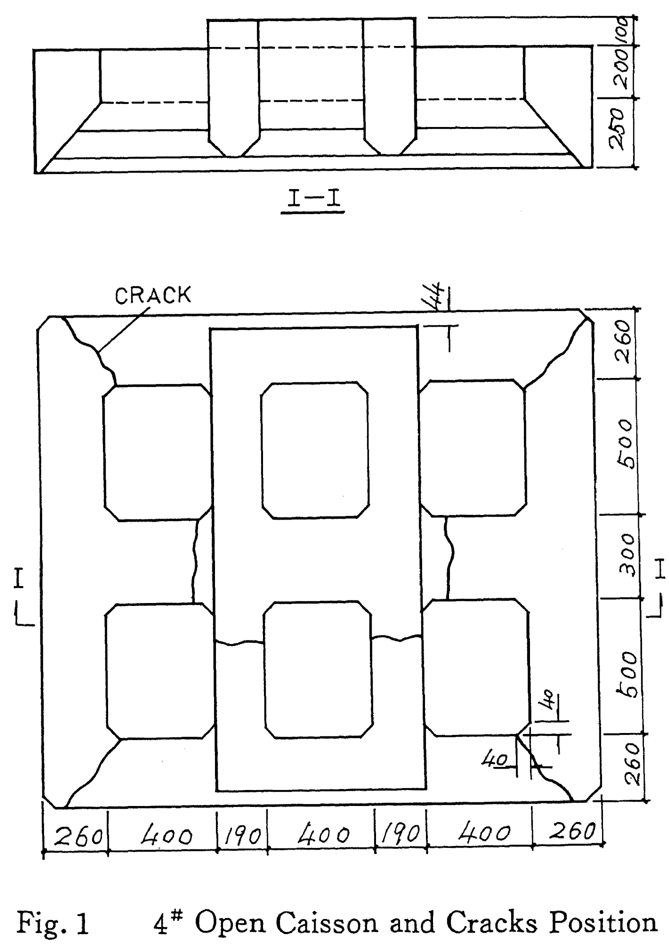

Fig. 1 4# Open Caisson and Cracks Position

weight, so that the dead weight must be quite enough. The total weight of the caisson was

2540t. The thickness of the outside walls Was 2. 6m and the thickness of three interior walls were 3. 0m, 1. 9m and 1. 9m. There were six dredging wells whose sizes were all 5×4m.

CONSTRUCTION

Using"soil form", the caisson was made on the sand island. According to the shape of the cutting edge the soil form was made of packed clay, so it was the inner form work of the cutting edges. Other part of the caisson still adopted timber forms except the inner cutting edges. In the morning Nov. 28, 1971, excavation was carried out in the wells and under the interior walls. The earth under the interior walls and in the wells had been excavated hollow up to the second day morning, but the caisson sunk down little (only 15 cm).

Some time ago the contructors once excavated a trench 50cm deep along the outside walls in order that the caisson sunk down speeding up.

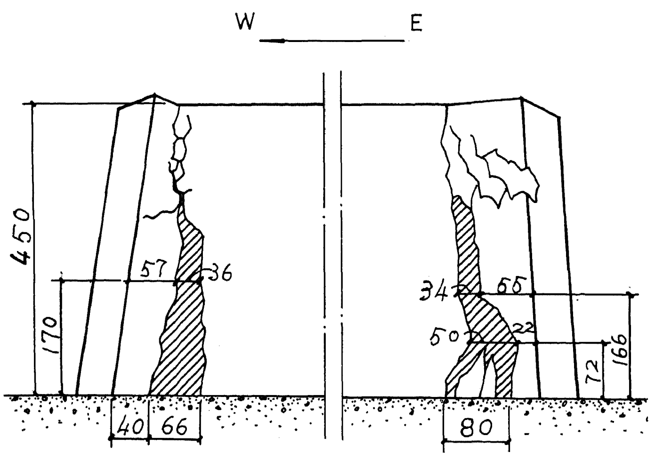

Fig. 2. Part Cracks

By the afternoon Nov. 29, the constructors had found some small cracks on the interior walls and sketched the figure of some cracks on the interior walls with chalk. It was 7 o'clock this afternoon that the caisson broke up with a snap in four blocks and the outside walls were inclined to inside. There were eight big cracks which shapes were big-end-down and the widths of these cracks bottom were 66cm, 80cm, 70cm, 60cm, 50cm, 38cm, 58cm and 60cm respectively (See Fig. 1 and Fig. 2). At each corner of the outside walls there was one crack. At three interior walls there were four cracks. Up to that time the caisson had sunk about 20cm.

ALALYSIS

Investigation and analysis having been done, a report of cause and alalysis was written by the author of this paper. The main cause of the caisson failure was due to the design and calculation, the second was due to the construction. Civil engineers hadn't ever designed such reinforced concrete open caisson with large area and short height in the past in the country so that the designer couldn't foresee the characteristics of its constructing stresses. The constructing stresses of the open caisson were calculated conventionally. These calculations were as follows: calculating bend stress of the cutting edges of the outside walls towards th inside and the outside of wells, calculating bend stress to regard the open caisson as a beam, calculating the moment to bear horizontal forces regarting the caisson as a horizontal frame, and so on. According to these calculation a great number reinforcements were set up in the outside walls and their cutting edges. But the stresses of the interior walls and four corners of the outside walls couldn't be predicted so that these part scarcely had reinforcement and wasn't also set up any shape steel. The results of alalysis and investigation indicating, it was these parts that had big tension stresses. The breaks took place just here. Before breaking the condition bearing forces on the caisson were as follows (see Fig. 3).

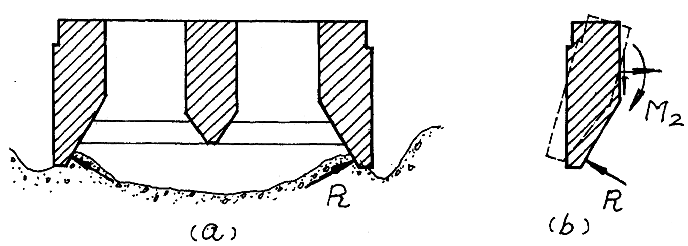

Fig. 3. Condition Bearing Forces on Caisson

1. The soil form having been excavated, the

area of contact of walls cutting edges and the earth was little. The lower part of the cutting edges beared the big earth resistance R which formed the torques M_1 on the outside walls so that the outside walls were turned outside, as shown in Fig. 3.

2. If the caisson had sunk down in the earth, the outside passive earth pressure would partly or all have set-off the earth resistance R in th wells. But as above, a trench was excavated along the outside walls, so the passive earth pressure even the friction vanished.

3. The three interior walls were all very long and big so their weights were very big, too. Before excavating in the wells, the outside walls and interior walls were all supported on the packed soil form with big supporting area. The earth under the interior walls having been excavated hollow, the interior walls took place bend as a beam and at the end of the beam a torque M_2 took place on the outside walls so that outside walls were turned. As above, in the four corners of the outside walls and the three interior walls no reinforcement and no shape steel was set up nearly. Having been passed on to the corners of the outside walls and superposed, the torques M_1 and M_2 formed very big moment and tensile stress at the corners. The bend stress of interior walls were more big. Therefore the interior walls broke up and the corners of the outside walls were ripped open.

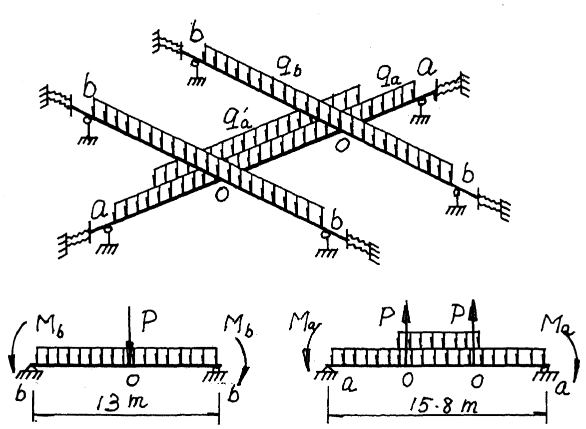

Fig. 4. Bearing Forces of Interior Walls

As consistent with the above explation the calculation of the caisson was carried on again after the investigation. The interior walls, as shown in Fig. 4, were rgarded as a two-cross beam. Let us regarted the joints of the interior walls and the outside walls as semirigid and decomposed the two-cross beam to turn into beam a-a and beam b-b shown in Fig. 4. If the moment M_a and M_b of semirigid end of the beams and force P at the cross point of the beams are knowiug, thus the problem can be solved. In Fig. 4, δ_{oa} and δ_{ob} are the deflections of the beam a-a and the beam b-b at point O respectively; θ_a and β_a are the turning angles of the beam a-a and the outside walls at point a respectively; θ_b and β_b are the turning angles of the beam b-b and the outside walls at point b. According to harmonious conditions of deformation, thus we have:

$$\delta_{oa} = \delta_{ob} \quad (1)$$

$$\theta_a = \beta_a \quad (2)$$

$$\theta_b = \beta_b \quad (3)$$

According to the mechanics of elastic structures, we get

$$\delta_{oa} = \frac{1}{E}(981.8 - 5.144P - 1.322M_a) \quad (4)$$

$$\delta_{ob} = \frac{1}{E}(457.9 + 2.569P - 1.185M_b) \quad (5)$$

$$\theta_a = \frac{1}{E}(259.9 - 1.340P - 0.4586M_a) \quad (6)$$

$$\beta_a = \frac{1}{E}(386.0 - 1.130P + 0.7710M_a) \quad (7)$$

$$\theta_b = \frac{1}{E}(112.7 + 0.5930P - 0.3650M_b) \quad (8)$$

$$\beta_b = \frac{1}{E}(420.4 + 1.175M_b + 0.8630P) \quad (9)$$

Substituting these Eq. (4)~(9) into Eq. (1)~(3), we get

$$1.230M_a + 0.2100P + 126.1 = 0 \quad (10)$$

$$1.540M_b + 0.2700P + 307.7 = 0 \quad (11)$$

$$1.322M_a - 1.185M_b + 7.712P - 523.9 = 0 \qquad (12)$$

Solving these equations, we get

$$P = 54.9t$$

$$M_a = -111.9 \quad t-m$$

$$M_b = -209.4 \quad t-m$$

Thus, we can calculate the moment $M_{3.0}$ and the tension stress $\sigma_{3.0}$ of mid span of beam a-a

$$M_{3.0} = 831.0 \quad t-m$$

$$\sigma_{3.0} = 125.2 \quad t/m^2$$

and the moment $M_{1.9}$ and the tension stress $\sigma_{1.9}$ of mid span of beam b—b

$$M_{1.9} = 850.5 \quad t-m$$

$$\sigma_{1.9} = 124.5 \quad t/m^2$$

The torques of outside walls superposed at the corners and formed moment M_c and tensile stress σ_c, we get

$$M_c = 323.3 \quad t-m$$

$$\sigma_c = 83.57 \quad t/m^2$$

From the above calculating we know that the concrete of the interior walls and the corners of the outside walls beared very big tensile stress. But these part scarcely have reinforcement, so that broke up.

TREATMENT

The people had once planned to blow up the caisson, but a cause of navigation and inhabitant, the caisson couldn't be blown up, and we had to repair it. The methods of restoration were as follows:

1. The upper class of the caisson was bound six hoop with steel ropes ($2\varphi32$mm, $4\Phi21.5$mm) for fixing, and the ropes were tightened with 5t hand-operated winch.

2. A opposite cutting edge with highness 2.0m, as shown in Fig. 5, was constructed at the lower part of each outside walls, but it hadn't been constructed at the corners of the outside walls until then. The outside ground was filled earth 1.5m thick in order that the outside earth pressure could exert on the opposite cutting edge.

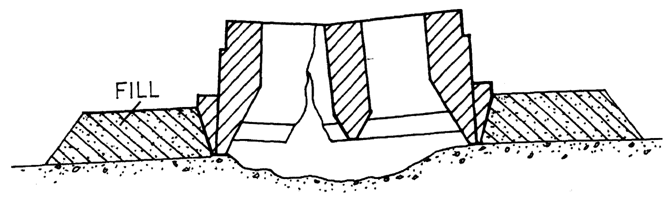

Fig. 5. Opposite Cutting Edge

3. Having cleared out the cracks of concrete fragments, the constructors carefully and evenly excavated the earth in the wells, so the caisson slowly suck 1.1m. The caisson sinking, the earth pressure of the outside fill to the opposite cutting edge pushed the outside walls towards the interior of the wells, thus the cracks closed and the outside walls were readjusted vertical. The remnant cracks were filled with expanding cement concrete and mortar.

4. The opposite cutting edges at the corners of the outside walls were constsucted. These methods were: first, the horizontal reinforcement($23\Phi25$)in the opposite cutting of the outside walls was jointed at the corner of the outside walls, thus they were formed the continuous rings. The timber form having been put up, the concrete of the corner opposite cutting edge was placed. That is to say, the opposite cutting edge and among reinforcement had formed the continuous hoops.

5. A reinforced concrete hoop was constructed again above the opposite cutting edge. The horizontal reinforcements rings ($5\Phi25$ and $13\Phi16$)were set up in the hoop.

6. The height of the open caisson was changed from 4.5m to 5.5m. The dredge wells were changed from 5×4m rectangular wells to round wells with a diameter of 3.0m. A lot of reinforcements were set up in the placing increment of concrete of the interior walls and the outside walls. They were joined in the outside walls each-other and formed rings along the

outside walls. The reinforcements of the interior walls were extended into the outside walls, and so on.

7. The repaired caisson looked as if a new one, but it still had a shortcoming. The original interior walls were hardly set up reinforcement. Although a lot of reinforcements were set up in the repair, but these reinforcements were set up in the upper class, namely in repairing concrete. That is to say, the interior walls could bear big negative moment and couldn't bear big sagging moment. Therefore the constructors must adopt correct methods in the construction, otherwise they could still break up. In order to construct carefully and correctly, we decided to adopt a wethod pumping and excavating openly. When the caisson began to sink, the earth under the interior walls wasn't excavated and the constructors only excavated the earth under the outside walls and in the wells. The earth under the interior walls was pressed down, so that the interior walls only beared negative moment. Up to the fifth day the caisson had sunk into the earth 90 cm deep, thus the bearing area was changed into two part earth under two cross point of the interior walls. That is to say, the earth under the two cross point wasn't excavated. This methods speeded up the caisson sinking, too. In other 7 days the caisson sunk down for 8m near the rock. When the caisson sunk down near the rock, the earth under two cross point of the interior walls were excavated hollow, too, in order to construct speeding up. But before long, two small cracks were found at the mended positions of the interior wall with thickness 3.0m. Because the caisson had already sunk in the earth very deep up to that time and there were the opposite cutting edge, the two small cracks hadn't expanded. This phenomenon indicating: it is correct for us to adopt the method that the interior walls beared on the earth to sink down.

As above, the caisson sunk through 10m sand and gravel layer to the rock surface in 12 days. From that time on, the other constructing works, suck as chiseling up the rock mantle, laying foundation, filling the wells with concrete, constructing the pier, and so on, were all carried out successful. The bridge have been built-up for 20 years up to now, the bridge and the pier have showed normal. Practice proved the treatment to be successful.

CONCLUSION

Sometimes a open caisson with large area and short height have to be adopted in civil engineering. The stress characteristic of this open caisson must be foreseen by the designers and the constructors and couldn't be calculated conventionally. It is to say, the bend stress of the interior walls and the torque of the outside walls must be foreseen and calculated.

It is correct for the breaking open caisson not to be blown up and to be repaired. Practice proved the treatment methods, such as the opposite cutting edge, the reinforcement hoop and the interior walls bearing on the earth to sink down, is correct.