The Design and Construction of the Grout Jet to Seal an Underground Reservoir

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ABSTRACT

During the 1980's the authors completed the curtain waterproofing and digging well engineering of a gold mine in Sanshan Island, the waterproofing engineering of an open-air supported underground mining layout in Panshi Nickel Mine and the waterproof and reinforcing engineering of the foundation of the winnowing machine room in Datong Mine by means of grout injection. In 1992, the authors completed the sealing engineering of an underground reservoir in an island by using once again a new grout injection technique. The diameter of the reservoir was 26 m, the depth was 4.5 m. The wall of the reservoir was constructed by means of a single revolving pipe with grout injection. The original design was to first set up a temporary retention shield under the concrete baseplate, after this was completed on a large area the concrete baseplate under-drainage was poured. Through experimentation it was proved that an effective retention shield was not formed in the sea by means of the cement sodium-silicate grouting. The final sealing engineering was achieved by using the new technique of the three pipe revolving grout injection.

THE GEOLOGIC AND HYDROLOGIC CONDITIONS

The ground layer of the underground reservoir can be divided into three layers:

1. The fine sand layer on the earth's surface. The layer was coral fine sands and shell fine sands containing silts. The layer was of good water permeability and the thickness was 3.5 - 4.0 m.

2. The coral reef layer. The layer was dendritic coral reef filled with fine sands and distributed continuously, the water permeability of which was high and the thickness was 0.5 - 1.6 m. The filling materials in the partial coral reef was rather dense and the water permeability was comparatively low.

3. The coarse sands layer. The layer was mainly composed of coarse sands (coral sands, shell sands) containing many dense reef blocks and clam shells, the thickness of which was 0.1 - 0.5 m.

Moreover, more than 100 tonnes of cements had been injected in the previous static stress grouting tests, this added to the complexity of geologic conditions.

THE SEALING DESIGN

The structural design

Through analysis and test the responsible departments, Guangdong Coal Mine Construction Waterproof and Reinforcing Company and the Mining Engineering Department of Northeastern University decided to replace the cast-in-place concrete baseplate with a high pressure grout injection sealing layer for the permanent bearing structural layer and in order to reform the bearing condition a pot-type curved structure was adopted, see Figure 1.

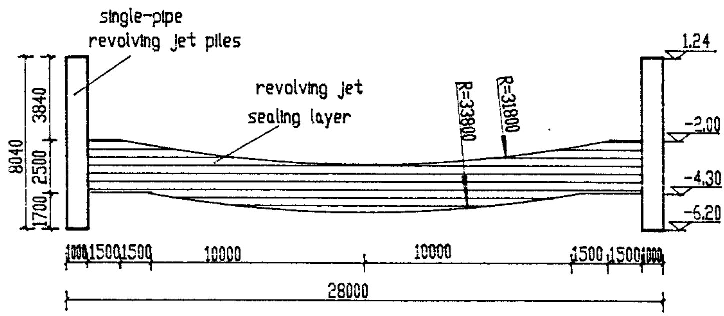

Figure 1. The elevation drawing of the underground reservoir
(anit: elevation rad.m. other mm)

Calculation of the thickness of underground reservoir sealing cement base:

The loads bourne by the seating cement base in the calculations would be considered according to the worst-case scenario in the construction. That is, after sealing and before the construction of the permanent baseplate the water in the reservoir was drained away, at this moment the sealing cement base calculations would bear the largest upwards water pressure.

Because the sealing cement base calculations in water was worse than common concrete, the tensile strength was not permitted to appear in the sealing base calculations. Since the opposite force of the subsoil in the base passed through the sealing cement base to transmit to the wall of the reservoir along the distribution lines marked at an angle of 45° with the vertical direction of the height of the Knife-edge, also, the two distribution lines were not crossed on the surface of the sealing cement calculated baseplate (the diameter of the reservoir was 26 m), the computation method was based according to a circular plate of simply supported beams.

$$Mmax = 0.198p.r^2 = 52.71t.m$$

where

Mmax = the bending moment of the centre of the circular plate, t.m;
P = the formed load by the hydrostatic pressure, t/m^2, taken $2.2t/m^2$;
r = the computating radius of the circular plate, m, taken 11 m;

The thickness computation of the sealing cement calculus:

$$h=\sqrt{3.5KM_{max}/bf_{ct}}+D=2.10m\sim2.50m.$$

where

h	=	the thickness of the sealing cement calculated base, m;
k	=	safety factor, the bended and compressed members computed according to the tensile strength were 2.65;
b	=	the width of the plate, taken 1 m;
f_{ct}	=	the design value of the tensile strength of the cement calculated base, taken 110t/m^2;
D	=	the added thickness due to the mixing of the soil-cements and sands in the bottom of the well, generally taken 0.1 ~ 0.5 m.

On the basis of the above-mentioned computations, it was decided that the thickness of the sealing cement calculated base was 2 m, the thickness along the wall of the reservoir was 2.5 m.

Construction design

(a) The distance of holes. To determine the distance between holes was based on the effective diameter of the pile. According to past experiences in the layer of sand, the effective diameter of a pile could reach 1.5 m, the pitch of holes was calculated to be 1.2 m. In order to test and verify this conclusion in the construction one of the piles was pulled out to the surface, through excavating and examining, the effective diameter of the top of the pile was determined as 1.8 m, it was estimated the effective diameter of the pile below to be about 1.6 m. On the basis of the computation a distance of holes of 1.38 m could be used. To allow for the complexity of the ground layer below and the unfavourable effects produced in the early grouting the distance of the holes was designed to be 1.2 m.

(b) Setting holes. The form of setting holes must be according to two principles as follows: (a) the techniques were feasible, ie the setting of the piles was an equilateral triangle (plum blossom type); (b) the construction was easy. Hence, it was decided to take the parallel chords of equal distance as the axes of setting holes, taking A-A as the centre line (see Figure 2).

(c) Water pressure and lifting velocity. The high pressure water was the power cutting ground layer, the larger the radius of injection the more the pressure. Through experimentation it was decided the ideal water pressure was 33 MPa.

The lifting velocity and water pressure had similar effects on the revolving injecting piles, if the lifting velocity was low, then the repeated injection was too much and the formed radius of the pile was so large as to effect the holes at the II axis; whereas, if the lifting velocity was high, then the radius of the pile was too small and uneven. The lifting velocity determined by experiments was 7 ~ 8 cm/min.

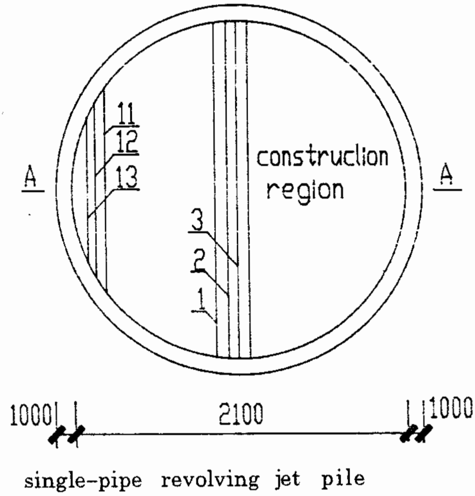

Figure 2. The drawing of setting holes of grout jet

(c) The design height of the injecting grouted top and bottom. The depth of the injecting grouted section in the underground reservoir was 4.7 ~ 7.5 m. According to the design drawing, the upper and lower boundary surfaces of the baseplate were both smooth arched structures, but the baseplate formed by the revolving injected pile sleeve jointing was a setback type. The difference of elevation between piles at the centre was small; the more the pile was close to the wall of the reservoir, the larger the difference of elevation; the largest difference was 0.43 m.

In order to make the construction easy, the design was simplified as follows. The whole circle was divided into a certain number of annular bands, the differences in elevation between bands were equal, given the differences in elevation of the top of the piles between bands were all 8 cm; we take the height of the top and bottom of the piles computed by the distance from the inner ring lines to the centre of the circle as the height of the top and bottom of the common piles of the holes contained in the band. The width of the annular band was the difference value of the distance from the near inner ring lines to the centre of the circular. The whole reservoir was divided into 34 annular bands, ie 34 groups of data, the largest value of errors in each group of data was under 8 cm, the errors were generally 3 ~ 5 cm.

CONSTRUCTION TECHNIQUES

Skipping operation in sequence

In order to prevent the high pressure injected grouting going from one hole to another, we adopted the skipping operation sequence, that is firstly the holes in the first sequence of the rows were 1, 3, 5, 7, ... , secondly the holes in the second sequence of the rows were 1, 3, 5, 7, ... and then the holes in the second sequence of the rows were 2, 4, 6, 8, ... , in this way we might divide the whole process of construction into four stages.

Locating piles in the holes

In the 530 m^2 construction area about 450 piles needed locating in the holes, the places of which had to be meticulous in design. Locating piles by stages in the construction required a number of reference piles. In order to lessen the cumulative error of the locating piles, we set a still higher demand on the accuracy of the locating piles in stages, we used a steel band tape or a tape line with an auxiliary small steel wire. In this way we could control the error to 2 cm.

Equipment improvement

In the past the grout injection was made as setting holes in straight lines. The four wheels of the high-pressure grout injection vehicle were fixed and the vehicle could only walk along a straight line. Whereas in this construction, we set 27 axes of setting holes in each reservoir, with the construction in the two sequences, we must change the direction of the rows 54 times. Sometimes, the direction must be changed 3 times per shift. It took two hours every time and the labour intensity was great. In order to make the high-pressure grout injection vehicle easier to move and change rows, we modified the equipment. We changed the four wheels into the semi-fixed forms which could turn 90° and unloaded the cable-lift system from the equipment to fix to the non-construction area. It lessened the weight of the equipment greatly. After this improvement it took 15 minutes to move from one row to another, and only took 2 minutes to move from one hole to another. This quickened the construction greatly.

QUALITY INSPECTION

After the grout injection, we should examine the integrity of grouting sealing, strength and effectiveness of the water seal. The methods of examination were as follows:

Appraisal of the grouts effectiveness during the grouting construction required examination of each grouting factor in relation to the design standards.

Taking samples by boring holes

Examination boreholes were generally located at the intersecting point of three piles, that is, the centre of the equilateral triangle. There were four examination holes as shown by the results of the samples, the samples were hard and complete.

The results expressed the peculiarity of the coagulation matter under the different geological conditions. The compressive resistance done were 10.5 MPa, 16 MPa and 20.6 MPa.

Excavation examination

After the sealing engineering, the reservoir was excavated and a waterproof layer laid and the surfaces trowelled. According to the contract, one task of the high-pressure injection sealing was to progress with the waterproofing under an enhanced dewatering condition. The technical norm demanded water penetration to be no more than 20 m^3 per hour, in reality the water penetrating measure was 2 m^3 per hour.

In addition, according to the form of the sealing surface, the centre part of the reservoir was sufficiently level to ensure no problems clearing the base.

CONCLUSION

From 27th January 1992 to 20th March 1992 the sealing engineering of the underground reservoir was completed. 437 holes of 955 linear meters utilising 1060 tonnes of cement. The holes grouted averaged 5.8 per day, the amount of grouting averaged 12.7 linear meters per day and the amount of the cements exhausted averaged out at 1.11 tonnes per day. It was proved to be successful that the technique of grout injection was applied to the sealing engineering practice of the underground reservoir and it also provided a feasible way for the planning of similar engineering in the future.