Shell Structure Water Cellar’s Rapid Construct Technology

Wen Xian ZHUANG a, De Qing YIN a, Shu Fa CHEN b

a Lianyungang Bureau of Water Resources, Lianyungang 222000, China;
b Huaihai Institute of Technology, Lianyungang 222000, China
Email: zhuangwenxian@yeah.net

Abstract: Tradition concrete water cellar’s problems, such as high cost, long construction term, easy to crack, are pointed out. A new construct method, and it’s matching airbag mould, of constructing concrete shell structure water cellars, are introduced. Combine with full-scale verifying cellar’s construct test, full-load water storage test, analyzed the technology in terms of construction term, cost, crack resistance, air bag pressure etc. It is believed that this new technology can successfully solve the problems that tradition technology has, and it will have a good prospect in rainfall resources utilization.

1. Introduction
Water cellar is an important infrastructure in solving the problem of water shortage in many seasonal areas. Traditional concrete cellars, built with the process of "large foundation pit excavation, layered mould and casting, backfill soil behind the cellar”, has long construction term, high cost and poor crack resistance, and it’s unit water supply cost is very high. With the development of economy and society, the gap between water supply and demand is widening, rainwater resource exploitation is becoming more and more important. R&D high performance-price ratio water cellars’ construct technology can bridge the gap between water supply and water demand, and will promote the development of rainwater resource exploit industry.

Aiming at the existing problems of traditional concrete cellars, R&D a set of new technology, including airbag mould and construct process, which can rapid construct shell water cellar in low cost, and form a new path of constructing concrete cellar, which can also be used to construct biogas cellar.

2. Airbag mould
Airbag mould, as figure 1 shows, made of PVC netted sandwich cloth, has 4 basic characteristics:(1) the material of the airbag has a high tensile strength;(2) there is a valve on the top of the airbag, which can control air in and air out; (3) the airbag has good air tightness and can automatically form a specific shape after filled certain pressure air; (4) the airbag can be reused many times.
3. **Construction process and control points**

Construction process, as figure 2 shows, including: excavate foundation pit, pave the floor concrete, blow up and install the airbag, concreting side the wall and the roof, backfill soil to the roof of cellar.

![Airbag Image](image)

**Figure.1 Airbag**

![Construction Process Images](image)

**Figure.2 Construction Process**

Technical control points and construction precautions:

1. **Excavate the foundation pit**

Select parent soil segment, which is convenient both for collect rainwater and use water, and excavate the foundation pit according to the outer diameter of the water cellar. The upper side wall of the foundation pit is vertical and the lower part is hemispherical. First use an excavator rough dig, then manual correct the wall, avoid over excavation and backfilling as soon as possible.

2. **Pave the floor concrete**

Pave predetermined thickness fine concrete in the pit to construct cellar floor. Vibrate the floor concrete manually.

3. **Install the airbag mould**

Blow up the airbag mould to predetermined pressure to verify it’s shape parameters and air tightness, close the valve and install it in the pit. Fix the airbag with temporary support and soil bags, which were used to control the airbag mould from floating.

4. **Concreting the side wall**

Fill the gap, between the foundation pit and the airbag mould, with small slump fine concrete slowly and symmetrical, withdraw the temporary support from the gap synchronously, artificial vibrate the fresh concrete, make sure the airbag mould will not be pierced by sharp objects.

5. **Concreting the roof**

Pre-bury an inlet pipe in the side wall, pave predetermined thickness concrete along the top of the airbag mould to construct the cellar roof, remove the soil bags when they obstruct the construction.
Embed the outer ring of manhole cover into the concrete of cellar mouth.

(6) Backfill soil

When the concrete reaches 20% of it’s design strength, exhaust the airbag and remove it, watertight the inner wall with cement mortar. Backfill soil to the top of the cellar when the concrete reach 60% of it’s design strength.

4. 30m³ concrete cellar’s construct test

4.1 Geological condition

The cellar was constructed in Ganyu District, Lianyungang. The soil is silty clay with a weight of 2.70kN/m³, there is no ground water in the pit after excavation.

4.2 Parameters of the construction

The airbag mould is about 60kg weight, it’s design work pressure is 8.5kPa, it’s diameter is 3.80m and it’s volume is about 30m³.

Construct equipment: air charge and exhaust device, concrete mixer, generator set, water tank, excavator, soil bags, Φ 100 × 3/300 PVC hard plastic pipe which was used as temporary support between the gap of the pit and airbag.

Building materials: C25 fine concrete, made of P.O.42.5 ordinary Portland cement, medium sand and gravel; M7.5 cement mortar, made of P.O. 42.5 Portland cement, fine sand; PVC inlet pipe; manhole cover.

Pit excavate requirements: the pit is 4.00m deep, the upper part is 4.00m diameter cylinder, and the bottom is 4.00m diameter hemispherical.

The water cellar’s inner diameter is 3.80m and it’s outer diameter is 4.00m. The wall of the cellar is 10cm thick. The cellar mouth’s inner diameter is 70cm, it’s outer diameter is 90cm, it’s height is 25cm.

3 days after the cellar was constructed, exhaust the airbag and remove it, wetartight the inner wall with cement mortar. 28 days after the cellar was concreted, backfill soil to the top of cellar.

4.3 Results and discussion

(1) Construction term

Work time of each process: pit mechanical excavation, 2h; manual correct the pit wall,1-2h; pave the cellar bottom, 0.5h; airbag installation, 0.5-1h; side wall and roof construction,3-4h; remove the airbag and watertight the inner wall, 2h; backfill soil to the top of the cellar, 1-2h.

Shell structure cellar’s construct technology, using airbag mould instead of traditional steel template, can construct large volume cellar in 1d.

(2) Construction cost

| Work content      | Work amount | Unit cost   | Total (yuan) |
|-------------------|-------------|-------------|--------------|
| Pit Excavation    | 40 m³       | 15 yuan/m³  | 600          |
| Concrete          | 6 m³        | 300 yuan/m³ | 1800         |
| Airbag Rent       | -           | -           | 100          |
| Labor Cost        | 8           | 100 yuan/labor day | 800 |
| Other Fees        | -           | -           | 200          |
| **Total**         |             |             | **3500**     |

Shell structure cellar use less concrete and labors, compared with traditional cellar. A 30m³ volume shell structure cellar, whose market price is about 5000 yuan, can collect 50m³ rainwater a year, it’s water supply cost is 2 yuan/m³.
(3) Crack resistance

A full-load water storage test was carried out, after the cellar was constructed, and the result showed that the cellar had a perfect water tightness, which met the requirements of anti-cracking and anti-permeability.

The soil, which is filled back behind tradition concrete, will loss it’s intensity under the influence of water, and cannot provide enough pressure to prevent the cellar from being cracked by the internal water pressure. Meanwhile, the tensile stress \( \sigma \) and elastic deformation ability of concrete are limited, so tradition water cellars, volume reach \( 25m^3 \), are easy to crack.

Shell structure cellar, constructed in parent soil pit, has a better crack resistance: 1), airbag mould can automatically compensate concrete’s shrinkage, under the influence of the soil bags on the mould, and make the concrete cellar wall and the foundation pit fit closely together; 2), parent soil has a higher density, soil particles’ molecular stress is strong, so it can offer a large passive earth pressure to the cellar body.

The cellar’s stress condition is shown in Figure 3, and the mechanical equilibrium can be shown as formula (1) and formula (2).

\[
\int_{-\delta}^{\delta} p_{w} dy = 2\sigma \delta + \int_{r}^{r+\delta} p_{w} dy
\]

\[
p_{w} \cdot 2r = 2\sigma \delta + p_{w} \cdot 2(r + \sigma)
\]

(\( r \)- Cellar’s inner diameter; \( \delta \)- Thickness of cellar wall; \( p_{w} \)-Internal water pressure; \( p_{a} \)-Passive earth pressure; \( \sigma \)-Tensile stress)

Use data of soil 4# from [7], as the static test curve diagram 2 shows, the corresponding pressure \( p_{w} \), the initial pressure strain of the soil, is 50kPa, ignore the elastic deformation and the tensile stress \( \sigma \) of the concrete cellar wall, according to formula (1) and formula(2), the cellar can withstand a maximum hydraulic pressure of 50kPa(5m water column). The cellar’s internal diameter is 3.8m, which meet the anti-crack safety requirement. Analysis tradition cellar’s crack resistance in the same way, use data of soil 3# from [7], as the static test curve diagram 2 shows, the corresponding pressure \( p_{w} \), the initial pressure strain of the soil, is 35kPa, ignore the elastic deformation and the tensile stress \( \sigma \) of the concrete cellar wall, according to formula (1) and formula(2), the cellar can withstand a maximum hydraulic pressure of 35kPa(3.5m water column). Traditional cellar is easy to crack when it’s volume reach \( 25m^3 \), which matches the reality.

(4) Air pressure
The air pressure can help the mould to keep shape since fresh concrete has pressure on the mould, small air pressure in the mould will lead to the deformation of the cellular and uneven cellular wall thickness, large air pressure will lead to the problem of airbag fabric’s insufficient tensile strength.

New technology use artificial vibration instead of mechanical vibration. According to” Code for acceptance of constructional quality of concrete structures” (GB50204-92), calculate the fresh concrete’s maximum side pressure \( F' \) on the airbag mould by formula (3) and formula (4), which were produced under mechanical vibration, and select the smaller one. Combine the empirical value of \( \beta \) "mechanical vibration concrete’s side pressure will increase about 56% than that of artificial vibration", correct \( F' \) with coefficient 0.65 and get \( F \).

\[
F' = 0.22 r_c t_0 \beta_1 \beta_2 V^{\frac{1}{2}} \quad (3)
\]
\[
F' = r_c H \quad (4)
\]
\[
F = 0.65 F' \quad (5)
\]

\( F' \) is the concrete’s maximum side pressure on the mould, kN/m². \( r_c \) is the concrete’s gravity density, 24 kN/m³. \( t_0 \) is the concrete’s initial setting time, \( t_0=200/(T+15) \), \( t_0=2.5h \) in this project. \( \beta_1 \) is the correction coefficient of concrete slump, \( \beta_1=1.0 \) in this project. \( \beta_2 \) is the admixture influences correction coefficient, \( \beta_2=1.0 \) in this project. \( V \) is concrete’s construct speed, \( V=1.0m/h \) in this project. \( H \) is the calculated height of concrete’s side pressure, \( H=2.5m \) in this project.

By substituting the relevant parameters into formula (3), formula (4) and formula (5), we will get 8.58kN/m² as the work pressure of the airbag mould. Inflate the airbag mould to 8.5-9.0kPa, make sure the airbag mould can stand the pressure of 15kPa, that mean the fabric’s design tensile strength should reach 1500N/5cm. The airbag’s actual tensile strength is 3000N / 5cm, which meets the requirement.

(4) Airbag buoyancy control

This paper did not quantitative analysis the mould’s buoyancy since the influence factors were very complex. In actual construction, we use 800kg soil bags and steel bars on the airbag to control it from floating. About 3.5h later, removed the soil bags and steel bars when they hindrance the cellar mouth’s construction. It can be analyzed as: 1) the bottom concrete of the cellar, been constructed before the mould was installed, did not generate buoyancy, and the fresh concrete, without mechanical vibration, affected by the friction of both sides and the shear resistance, will have a lower side pressure on the mould than the theoretical hydrostatic pressure;2) when constructed the cellar roof, the bottom and side wall concrete had initial setting, and the weight of roof concrete could meet the requirement of prevent the airbag from floating.

5. Conclusion

(1) Introduced a new process and matching equipment of constructing shell structure water cellar, which also has the value of constructing biogas cellar, urban underground storage cellar.

(2) 30m² volume water cellar’s construct test showed that the technology, introduced in this paper, can rapid construct high crack resistance cellar in low cost.

(3) Analyzed the cellar’s crack resistance, expound the method of calculating the airbag pressure, which provide a reference of construct larger volume cells.

Acknowledgement

In this paper, the research was sponsored by the Social Development Fund of Lianyungang (Project No. SH1515).

References

[1] XU Hong-yan, HE Bing-hui, LI Cheng-zhang, et al. Study on Cellar in Loess Zone[J]. Journal of Soil and Water Conservation, 2004, (18):58-62.

[2] DING Kun-lun, SUN Wen-hai, JIA Yan-nan. Research on Coping Measures in Arid and Water shortage Conditions[J]. China Rural Water and Hydropower,2014,(2):43-45.
[3] CAI Chuan-bing. Investigation on the Status Quo of the Construction Management of the “People's Water Cellar”[N]. Yuxi Daily, 2014-5-30(3).

[4] ZHU Qiang, LI Yuan-hong. On the Theoretical and Practical Significant of Rainwater Harvesting and Utilization[J]. Journal of Hydraulic Engineering, 2014,(3):60-64.

[5] ZHANG Heng-jia. General Situation and Zoning of Utilization for Rainwater Resource in China[J]. Journal of Irrigation and Drainage, 2008,27(5):125-128.

[6] Lianyungang Flood Conservancy Project Management. Small Water Cellars’ Rapid Construct Equipment and Methods[P]. CN 2012100161451, 2014-12-17.

[7] Lianyungang Flood Conservancy Project Management. An Airbag Mould Used to Build a concrete Cellar[P]. CN 2016203051885[P], 2016-8-17.

[8] GUO Shuan-ning, WANG Bao-ming, GONG Zhao-tong. Analyses and Evaluations of the Geotechnical Engineering Characteristics of the Compacted Fill[J]. Soil Engineering and Foundation, 2000, 14 (3) :28-30.

[9] DU Rong-jun. Concrete engineering template and bracket technology [M]. Beijing: Mechanical Industry Press, 2004.

[10] PAN Jian-yun. Experimental Study of Concrete Lateral Pressure on Formwork [D]. Hangzhou: Zhejiang University, 2014.