Research on the construction technology of tunnel-type underground reservoir in island areas

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Abstract. The water consumption structure and water demand of remote islands with homestay tourism as the main industries were calculated and analysed. The result showed that there were obvious seasonal differences in the water demand of such islands. Based on the temporal and spatial characteristics of island water resources, it is recommended to build tunnel-type groundwater reservoir, to form the optimal allocation mode of water resources in the surface and underground, dry and rainy seasons and different geographical space. The construction process and technical points of tunnel-type underground reservoir were proposed, which was starting from the whole process including site selection, source determination, clean-up and disinfection, local impermeable, dam-blocking construction, ancillary facilities construction, water level and water quality monitoring and subsequent water purification.

1. Introduction
There are more than 10000 islands in China but only 500 islands are inhabited by residents. Limited by the climatic and geographical conditions of these islands, the freshwater resources are very scarce, and even the basic living water supply demand of some remote islands cannot be guaranteed. As a kind of water resources development project, the underground reservoir can regulate the uneven distribution of water resources in time and space and alleviate the shortage of water resources through the joint regulation and storage of surface and underground water. It has become an important way to reconstruct the tunnels and caverns left over from the war preparations as the underground reservoir for water storage, so as to ensure the safety of water supply for remote islands. In recent years, through the transformation and utilization of abandoned tunnels on the island, Zhoushan City has realized the water storage and internal networking of 35 tunnels on 6 remote islands, with an annual effective water supply of more than 70000 m³, effectively ensuring the water safety of residents on remote islands.

As early as the beginning of the 20th century, Japan, the United States, the Netherlands and other countries began the practice and research of groundwater artificial replenishment [1-2]. Since the establishment of Nangong underground reservoir in Hebei Province in 1975, the application and research of underground reservoir in China has a history of more than 40 years [3-4]. However, the research on underground reservoirs was mainly focused on natural underground reservoirs, while the research on artificial tunnel-type underground reservoirs is basically in a blank situation, which is a direction worthy of attention.
2. Water demand characteristics in island areas
Remote islands have a small local resident population and homestay tourism as the pillar industry. Apart from the scattered plots irrigated by rainwater, there is no water demand for agricultural irrigation and other industrial. With the development of island tourism, the number of tourism practitioners continues to increase, especially during the peak season when many fishermen return. Therefore, the water demand of remote islands mainly includes local permanent islanders, homestays and restaurants, and greening public. In the off-season of tourism (from November to April of the following year), water is mainly used for domestic use by local fishermen and residents of homestays on the island, with some public water including greening and public toilets. In the peak season of tourism (from May to October), in addition to local domestic water, the tourist population surges, and the water consumption of migrant home stay practitioners, greening, road watering and public toilets increases significantly. The water demand types and water demand index values of remote island areas were listed in Table 1.

| Water demand Type       | Tourism off-season indicator values | Tourism peak-season indicator value | Metric Unit                  |
|-------------------------|------------------------------------|------------------------------------|------------------------------|
| Local residents         | 60 to 80                           | 80 to 100                          | Liters/person/day            |
| Homestay guests         | /                                  | 220 to 300                         | Liters/bed/day               |
| Homestay Employees      | /                                  | 70 to 80                           | Liters/person/day            |
| Restaurant              | /                                  | 20                                 | Liters/m²/day                |
| Pool                    | /                                  | 10%                                | Each replenishment of new water accounts for pool volume |
| Public toilet           | 200                                | 400                                | Liters/cubicle/day           |
| Watering Road           | 1                                  | 1.5                                | Liters/m²/day                |
| Greening                | 1                                  | 2.0                                | Liters/m²/day                |

3. Key points of construction

3.1. Site Selection
Abandoned tunnels during the combat readiness period, such as air defense tunnels, grain storage tunnels, etc. Generally, there were water storage pits in the tunnels. The interior walls of the tunnels have been treated with concrete during early use, and the groundwater permeability was low. In consideration of water storage capacity and cost of construction difficulty, such tunnels were preferentially adopted for underground reservoir construction. Before construction, the garbage and sundries in the tunnel should be completely cleaned. Depending on the degree of adhesion of microorganisms and animals and plants on the wall of the reservoir, decide whether to take disinfection measures. It was not necessary to carry out anti-seepage measures for the whole reservoir, but only to take sealing or anti-seepage measures for the leakage points.

3.2. Supplementary water source
In addition to natural crack water, tunnel-type underground reservoirs serve as a medium for combined storage of surface water and groundwater, and their supplementary water sources were generally for other pit wells and surface reservoir. Priority should be given to deep well water or surface reservoir water with good water quality, and there should be no faeces, pesticides, fertilizers and other pollution sources nearby. If there is no such water source, the alternative water source should be pretreated. Before the initial impoundment, the physical and chemical, toxicological and microbiological indexes of the water source shall be tested, and the water can be poured into the reservoir only after the indexes are qualified.
3.3. Reservoir Construction
The main construction project is a blocking wall at the entrance and exit of the tunnel, which is divided into closed and semi-closed types. Generally, except one entrance which is semi closed type, the other exits are built as closed type. In order to increase the amount of water storage and reduce the interference to the water quality, the height of the semi-closed sealing wall should be as high as possible under the economic conditions, and only a gap should be left in the upper part for ventilation and observation of the situation in the tunnel.

The self-regulation ability of the underground reservoir is very weak. To ensure the safety of water sources, the environment around the reservoirs must also be cleaned up. To prevent idle people or animals from entering the water source, protective facilities and signboards shall be set at the entrance. The protection shall be closed as much as possible to prevent insects, dead leaves, air fungi and spores from entering the water body and causing microbial pollution.

Ancillary facilities include pre-buried water intake and water pipelines in the blocking wall in advance, generally PE pipes are used, and pipes passing through the blocking wall need to be provided with waterproof sleeves, and water level gauges and water quality online monitoring facilities, and brick steps, entrance protection facilities, lighting Facilities, etc.

3.4. Regulation and storage mode and pipe network construction
Due to the large spatial and temporal differences in water demand and water resources in the island area, it is recommended to adopt multiple water source joint regulation and storage mode to realize the regulation and storage functions of surface underground, wet and dry seasons and geographical space. The underground reservoir and other pit well water and surface reservoir are interconnected for joint operation. During the rain season, due to the fast inflow of fissure water, the surface reservoir often overflows, so the water pump can be used to lead the pit well water and surface reservoir water to the underground reservoir through the pipeline, which is convenient for the use in low water period. In order to strengthen the joint regulation and storage of different water sources (surface reservoir, underground reservoir, pit, etc.), it is also necessary to build a pipe network connection project, which is of high cost and can be set according to the economic benefits, actual terrain and capital situation.

3.5. Follow-up water treatment measures
The common problem of water quality in underground reservoir was that pH is weakly alkaline, turbidity and total number of colonies exceed the standard, and cannot be directly drunk. Part of the underground reservoirs were affected by the early pollution of the surrounding environment, soil and groundwater, and the TN and nitrate nitrogen were relatively high. Part of the underground reservoirs were affected by the surrounding geology and groundwater, and the trace elements such as manganese and zinc exceed the standard. Part of the underground reservoirs are connected with the surface water source, and the water quality is uncertain due to the influence of the water source. Therefore, it is necessary to strengthen the water quality monitoring of supplementary water sources and storage water, and take appropriate follow-up water purification treatment measures.

4. Case Introduction
Huaniao Island is located at the northernmost tip of Zhoushan City, with 977 residents. There are 62 homestays and 702 beds in total. In peak season, the number of beds is full, the number of tourists on the island is generally 2 times of the number of beds. There are 22 restaurants, 3 swimming pools and 13 public toilets. Considering the leakage rate of the pipe network, it is calculated that the water demand of the Huaniao Island is about 150 tons / day in the off-season and 750 tons / day in the peak season, which is 5 times of that in the off-season. In 2017, the total reserves of 17 pits on the island are about 10780m$^3$, which can only provide 14 days of peak water consumption. The water shortage in summer peak period is more than 20 days and it is necessary to transport 40000 to 50000 tons of water from the island of Zhoushan, at a cost of 50 yuan / ton.
In 2018, two underground reservoir projects and one surface reservoir project were built. The volume of underground reservoir is 160m$^3$ and 2900m$^3$ (see Fig. 1), and the volume of surface reservoir is 14000 m$^3$. In order to facilitate the regulation of water quantity in flood and dry seasons, two underground reservoirs, one surface reservoir and 16 pits in use are connected by laying pipelines, and the overflow and pit water in flood season were pumped to the underground reservoir for storage, after purification and treatment by the water plant, they were supplied to the domestic water in the island, so as to realize the joint regulation and storage of underground water, surface reservoir water and pit water, which is sufficient use of water resources. During the peak season of summer tourism in 2018 and 2019, the island's normal water supply was guaranteed, and it was no longer necessary to carry water from Zhoushan Island.

![Figure 1. Huaniao Island demonstration engineering reality](image)

5. Conclusion
Based on the analysis of the water consumption structure and water demand of remote islands whose main industry is homestay tourism, a specific water demand calculation method is proposed. The empirical analysis shows that there was a significant seasonal difference in water demand on the islands. The tunnel type underground reservoir has the advantages of less evaporation, strong regulation capacity, low investment cost, stable water quality, etc. the technology has the promotion value in Zhoushan City, Zhejiang Province and other coastal provinces of China. Based on the characteristics of the island's water demand and the spatial-temporal difference of water resources, a combination of "multi-source regulation and storage" and "dual water supply" is recommended to optimize the allocation of water resources on the surface-underground, flood and dry seasons, and geographical space. The construction process and technical points of tunnel-type underground reservoir were proposed which was starting from the whole process from site selection, to source determination, to clean-up and disinfection, to local impermeable, to dam-blocking construction, to ancillary facilities construction, to water level and water quality monitoring, to subsequent water purification, and puts forward a new solution to ensure the water safety of island area.

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