Solution of Subsurface dam for water supply

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Abstract. Subsurface dam is a dam system that built in earth's work to reserve water and to increase levels of aquifer ground. Region with harsh climate conditions, low rainfall, land is uncultivated, low level of ground water then capacity to provide water is limited. Therefore, subsurface dam is a solution to help to improve the groundwater table, provide water during dry season. At coastal land, beside the advantage of reserve water, the subsurface dam also helps to present infiltration of salt water. This article discusses about subsurface dam, solutions to build the subsurface dam and its application scale, advantages and disadvantages of applying subsurface dams in Vietnam. Moreover, the author proposes solutions for water supply to areas which are shortage of water in Ninh Thuan province, Vietnam. Key words: Subsurface dam, Ninh Thuan, Hydrogeology, Water Supply Solutions.

1 Introduction

Subsurface dam is an underground structure, used to raise the groundwater level and store water in the soil. This type of construction has many advantages in terms of stabilizing water sources. Furthermore, compared with the reservoirs, the subsurface dams that raise water to store water will reduce factors that adversely affect the surface and the environment. In particular, the subsurface dams are suitable for water-scarce areas or areas affected by salt water, this is proven through the studies on the application of underground dams for water supply in Africa (Kenya, Ethiopia), South America (Brazil), Asia (Japan, India, Korea, China) and so on.

The effectiveness of the subsurface dams can be seen through the ability to store water in the soil, such as the Miyakojima project in Japan, for water supply up to 50,000 m$^3$/day [1-13]. In terms of an underground reservoir capacity in Japan ranging from 17,000 m$^3$ to 10,500,000 m$^3$ and from 1,543,000 m$^3$ to 4,143,000 m$^3$ in Korea [12], small and medium projects in Kenya (there are about 500 the subsurface dams) and Brazil have ensured the water source for rural population [10, 11, 14]. In Vietnam, the subsurface dams are in a waterbelt or ditches and built on a small scale in the Northern uplands, without large projects and large-scale water supply targets 15.

At present times, due to the impact of climate change, it has changed rainfall, the distribution of rainfall and many areas have water scarcity in the dry season, excess water in the floods, and at the same time, the problem of desertification increases.

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Surveying in the middle of Vietnam, Ninh Thuan province has about 2.898 km$^3$/year of incoming water and forecasted water demand in the period 2020-2039 needs to be about 979.9 km$^3$/year, so the balance of the total amount of water in the province still ensures water security. In actual fact, water shortage often occurs, the quality of groundwater in coastal areas does not meet the standards for water use, due to the mixing of mineral salts and saltwater intrusion, besides the desertification areas go up every year, statistics show that the area increased from 12% (2001) to 12.21% (2004). Building reservoirs on rivers is not convenient, but occupies a large area of land and affects the environment. In particular, in the coastal area, the construction of the reservoirs for water regulation are complicated and it does not give high efficiency. If the reservoirs are built in upstream of the river, it will reduce the amount of water in the coastal area, easily causing saltwater intrusion, due to the influence of the reservoirs for water regulation. Desertification increases, reduced to keep water in the soil, and erosion increases.

To solve the problem of the water supply for water-scarce areas in the dry season, a sustainable solution is to create a stable source of the groundwater for the water supply. From studies in water-scarce regions such as Africa (Kenya, Ethiopia, Burkina Faso), Asia (Korea, Japan, India, China) and the US. On the one hand, the application of underground dams, helps to store more groundwater, the aquifer rises and meets the water supply capacity. Besides, the underground dam has the advantage that it is both an effective water storage facility and a type of construction capable of limiting the influence of salinity on the land. It shows that the solution of building the subsurface dams to store the shallow water for water supply in the dry season is applied most effectively in the central coast of Vietnam.

This paper provides an overview of the characteristics of the subsurface dam and analyzes the application of the subsurface dam for an area in Ninh Thuan province (coastal region of Vietnam). Finally, evaluating the advantages and disadvantages of applying the subsurface dam in Vietnam.

2 Basic characteristics of the subsurface dam

2.1. The structure of the subsurface dam

Subsurface dam is a type of dam built underground, serving the storage and raising of the shallow ground water.

*Subsurface dam is made up of the following components:*

+ Dam: The dam is designed underground, placed on impervious soil or bedrock, the elevation of the dam is designed based on the water storage capacity of the underground aquifer. It is recommended to be at least 0.4 m above the ground to minimize loss due to evaporation.

The dam is built by grouting, soil, concrete, dam-liner plastic, slurry wall, thin steel sheet, mix-in-place, steel sheet pile, clay wall, plastic sheet, stone masonry, buried earth dam, rubble masonry, etc.
2. Classification of dams

Types of dams can be roughly classified Fig 1.
+ Floating dams: Building dams with a crest elevation equal to ground level, usually applied to sloping terrain and mountainous areas.
+ Dams built underground: Build dams underground by clay, soil, steel, concrete, etc.
+ Ditch: Designing the ditches to block the flow to collect water.
+ Waterholes: Making holes in low areas to collect water.
+ Upland water traps: Using filter pipes, placed on the cliffs, to collect groundwater to supply water for local people's daily life.

2.3. Conditions for construction of the dams

- The location of the underground dam is determined based on the impermeable soil and rock foundation, thereby forming an underground basin. The location of the dam should be chosen at the mouth where rainwater from an area, large river basin flows through a narrow passage.
- The geological conditions are suitable for storing a lot of water (large porosity, coarse sand, etc.).
- The location of the dam should avoid polluting sources, locations that may pollute groundwater and surface water.
- The storage of the surface dam must not contain saline soil or saline rock, because that will make the saltwater.
- Avoid fractured rock areas (no water leakage).

3 Application of the subsurface dams in Ninh Thuan province

3.1. Hydrogeological characteristics

The hydrogeological assessment of the geographical area from the Cai River (Phan Rang) to the Dinh cape, shows that the Holocene aquifer distribution is concentrated mainly in the river delta.

According to the results from 634 27 study sites, the thickness of the aquifer varies from 0.0m to 24.5m, with an average of 5.2m 67. Aquifers in the unconsolidated deposits have...
the ability to store water, this water is of good quality, serving the water supply in the area. Using Visual Modflow model to analyze the hydrogeological characteristics of the area.

**Fig. 2.** Location of drilled wells in the study area

**Fig. 3.** Water extraction coefficient partition

In combination with bedrock conditions, build groundwater level contour maps of the study area, thereby determining the height and characteristics of the surface dam.
Fig. 4. The bedrock contour map in the Cai river basin, Phan Rang 7

Fig. 5. The groundwater flow contour Map in the Cai river basin, Phan Rang 7

Estimating the reserve for the whole project area of the Cai river basin (Phan Rang), shows that the underground water extraction capacity is 34,374 m³/day, in the dry season is 114,792 m³/day in the rainy season is 153,957 m³/day.

Based on the hydrogeological characteristics of the main aquifers in the unconsolidated deposits combined with the isovalence diagram of the bedrock contour map and The groundwater flow contour map, it shows that the Holocene unconsolidated deposits distribution area has a good water capacity. On the other hand, there is a stable bedrock and especially water scarcity in the dry season and is affected by salinity. Therefore, the construction of the subsurface dams to regulate water is very reasonable and effective in economic development.
3.2. Analysis of the subsurface dams and water supply capacity

+ Assessment of hydrogeological conditions: Establishing a bedrock map, determining the characteristics of hydrogeological conditions (for example, Figure 4).
+ Determine the groundwater flow contour map for the study area and underground basin (Figure 5).
+ Determine the location of the dam system, the dam is placed on the bedrock, blocked by 2 bedrock areas (Figures 4 and 5), ensuring a stable water storage area.
+ Identify materials for building the dam, using concrete or clay, etc.
+ Determine the dam crest elevation. In the Ninh Thuan province, it is suitable dam elevation at 60m and about 50m height.

![Diagram of subsurface dam and water supply capacity](image)

Fig. 6. Vertical alignment I-I at Phuoc Dinh commune, Ninh Thuan province Viet Nam

**Table 1.** The groundwater extraction rate of sands

<table>
<thead>
<tr>
<th>Features</th>
<th>Silt</th>
<th>Fine sand</th>
<th>Medium sand</th>
<th>Coarse sand</th>
<th>Fine gravel</th>
<th>Coarse gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size (mm)</td>
<td>&lt;0.5</td>
<td>0.5-1.0</td>
<td>1.0-1.5</td>
<td>1.5-5.0</td>
<td>5.0-19.0</td>
<td>19.0-70.0</td>
</tr>
<tr>
<td>Saturation Porosity (%)</td>
<td>38</td>
<td>40</td>
<td>41</td>
<td>45</td>
<td>47</td>
<td>51</td>
</tr>
<tr>
<td>Water extraction (%)</td>
<td>5</td>
<td>19</td>
<td>25</td>
<td>35</td>
<td>41</td>
<td>50</td>
</tr>
</tbody>
</table>

(source: Adapted from Nissen Peterssen 2000)

**Table 2.** List of the subsurface dams in Japan

<table>
<thead>
<tr>
<th>Dam name</th>
<th>Location</th>
<th>Year</th>
<th>Dam height (m)</th>
<th>Dam length (m)</th>
<th>Total reservoir (m³)</th>
<th>Discharge (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabshima</td>
<td>Nagasaki</td>
<td>1974</td>
<td>24.8</td>
<td>59</td>
<td>9340</td>
<td>300</td>
</tr>
<tr>
<td>Tsunegami</td>
<td>Fukui</td>
<td>1982-1984</td>
<td>18.5</td>
<td>202</td>
<td>73000</td>
<td>400</td>
</tr>
<tr>
<td>Tengakuma</td>
<td>Fukuoka</td>
<td>1987-1988</td>
<td>12.5</td>
<td>129</td>
<td>17500</td>
<td>900</td>
</tr>
<tr>
<td>Komesu</td>
<td>Okinawa</td>
<td>1998-2003</td>
<td>51</td>
<td>955</td>
<td>389000</td>
<td>1200</td>
</tr>
</tbody>
</table>

(source: http://www.jircas.affrc.go.jp/12)

**Table 3.** Survey of underground water in Ninh Thuan

<table>
<thead>
<tr>
<th>No.</th>
<th>Commune</th>
<th>Coordinates</th>
<th>Hole size (mm)</th>
<th>Pumping Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitude</td>
<td>Latitude</td>
<td>Height of well (m)</td>
</tr>
<tr>
<td>N4</td>
<td>Phuoc Minh</td>
<td>108.85868</td>
<td>11.44328</td>
<td>110+250</td>
</tr>
<tr>
<td>N5</td>
<td>Phuoc Hai</td>
<td>108.95668</td>
<td>11.51905</td>
<td>110+250</td>
</tr>
</tbody>
</table>
Based on the assessment of water storage capacity, in the Phuoc Dinh commune, Ninh Thuan province, with geological conditions of medium sand, the dam height is arranged from 25m to 30m, the length of dam is from 100m to 300m, the reservoir volume is about from 18,000 m³ to 22,000 m³. Therefore, the water supply capacity of the underground dam can reach 300 ÷ 500 (m³/day), which is equivalent to 6 to 10 drilled wells. With this ability, it is possible to ensure water sources for domestic water and irrigation during periods of the water scarcity (dry season).

## 4 Advantages and disadvantages

### 4.1. Advantages of using the subsurface dams

- Reduce conflicts of interest on water resources, Make best use of water resources in the basin.
  - No damage to agricultural production land.
  - Dam construction materials, can use local materials, low construction cost.
  - Disasters due to water storage process almost do not occur (e.g. flooding, dam failure, pollution...), preventing harmful insects (mosquito).
- Subsurface dams in coastal areas, in addition to the ability to create water supply sources, also have the ability to minimize saltwater intrusion and maintain stable freshwater sources.
- Suitable for creating water supply to dry areas, creating more abundant water supply, increasing groundwater table, reducing evaporation (due to being protected by the soil layer).
- Clean water quality, suitable for domestic water with little treatment cost.

### 4.2. Disadvantages in underground dam construction

- The accurate assessment of geological conditions is very complicated, so the arrangement of the dam is difficult.
  - The design calculation tool has not been standardized, the basis for calculating the source and reserve of groundwater has not yet had a suitable tool and verified its accuracy.
  - It is difficult to determine the groundwater recharge capacity and locate the leak points of the dam.
- The water storage efficiency is low, the volume of water stored is only 10% to 30% of the volume of the underground reservoir.
  - The subsurface dam methods applied in Vietnam are only at the stage of underground water trapping, there are no specific works on underground dams and further evaluation.

## 5 Conclusion

The solution of underground dams applied to create groundwater in the rainy season, using water supply in the dry season is a suitable direction for the solution of water supply for coastal arid regions. In particular, when the total amount of incoming water is still larger than the demand, such as Ninh Thuan Province.
The subsurface dams used in coastal areas, in addition to the ability to supply water, it is also effective in preventing saltwater intrusion.

The Subsurface dams create "underground water reservoir", which are of great significance in supplying water to residential areas. Besides, the subsurface dams avoid environmental problems and disasters caused by water accumulation.

The subsurface dams help to re-establish water balance by reducing groundwater loss. In general, it is also a sustainable and stable solution to ensure water security in the current period of negative impacts of climate change and sea level rise.

The next direction requires more in-depth studies to evaluate the source, reserve and possibility of building dams for the study areas. Then, construction materials for the subsurface dams also need to be studied more specifically, it is recommended to apply for different regions and purposes of water supply.

References


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