4. Construction of a subsurface dam

4-1 Methods of construction of a subsurface dam

The various construction methods of a subsurface dam are listed in Table 4.1.

In some countries including Japan, there have already been several examples of subsurface dams. The majority of them were constructed by a method known as "cut-off wall by underground diaphragm wall (e.g. soil-cement mixing wall method)". Theoretically, a subsurface dam utilizes a "cut-off wall" for groundwater storage, and can be built using the “cut-off wall” method appropriate for local conditions.

Table 4.1: Methods of construction of a subsurface dam

Category	Type of construction method	Construction method and structure	Features
Application of method of cut-off wall under ground	Wall of steel sheet	Piling steel sheets continuously	This method is suitable for weak ground, but piling into gravel layers or basement rock is difficult.
	Wall of steel tubing	Piling steel tubes continuously	
	Underground diaphragm wall	Casting reinforced concrete wall on-site	There are various methods according to the ground conditions. They all require highly sophisticated equipment.
	Column-type underground diaphragm wall	Casting wall of mortar piles continuously on-site	This method was used to construct the subsurface dam at Miyako Island in Japan. It requires highly sophisticated equipment.
Application of ground improvement method	Grouting method	Injection of mortar into boreholes drilled intermittently	This method was partially used in the construction of the subsurface dam at Miyako Island. It is widely applicable because small and medium-size equipment can be used. However, confirmation of the effect of water cut-off is somewhat difficult.
Application of general dam construction method	Method of concrete dam construction	Structure of concrete dam under ground fully or by half (excavation/construction of dam body/filling back)	This is suitable for the "torrent dam"-type subsurface dam whose crest is exposed above the ground surface (there are some examples in countries such as Kenya). The construction costs are higher than those of the "earth dam"-type subsurface dams. Countermeasures against water leakage are required. For deep excavation, the costs would be too high.
	Method of earth dam construction	Structure of earth dam under ground	This method was used for this project. Dams of this type can be constructed using ordinary civil engineering equipment, and construction management is easy. However, countermeasures against water leakage are required. For deep excavation, the costs would be too high.

In this project at Nare, the "earth dam" method shown at the bottom of Table 4.1 was adopted for the following reasons:

1) The "fossil valley" was buried deep (about 8 m below the ground surface), and it had almost no groundwater run-off in the dry season. It was thus possible to apply this method.

2) This method does not require sophisticated machines and could be carried out with those available in Burkina Faso.

3) The cost of construction, including transportation and rental of machines, was the lowest.

4-2 Characteristics of the subsurface dam built at Nare

The characteristics of the subsurface dam built at Nare for this model project are as follows:

(1) Site
In the fossil valley in the Koulikare Quarter, Nare Village, Tougouri District, Namentenga Province, Burkina Faso

(2) Structure of the dam body
"Subsurface earth dam" (see Fig. 4.1)
- Depth of the base: 3.0 m to 11.4 m below the ground surface (maximum height of the dam: 8.4 m)
- Crest length: 216.3 m
- Width (thickness): 8.6 m at the base, 3.0 m at the crest
- Volume: 7,144 m^3
- Filling materials: clayey silt (heavily weathered layer of basement rock)
- Permeability coefficient: 10^{-7} to 10^{-8} cm/sec (very partly, 10^{-6} cm/sec)

At the upstream side of the base of the dam, an "anchor key" with about a 3- to 4-m width and a 1.5-m depth (protrusion into the basement rock) was formed to protect the base. At a level just above the crest, about a 1-m-thick layer of gravel with a similar diameter was laid to ensure good permeability.

(3) Water source of the subsurface dam reservoir
Shallow groundwater within the fossil valley buried along the Kolongo River, a tributary of the Gouaya River that is a part of the Niger River basin

(4) Dimensions of reservoir
- Maximum extent of reservoir area: 13.4-km length, about 150-m average length (lowest estimate), about 2-km^2 area
- Volume of reservoir layer: About 9,000,000 m^3 (estimate)
- Water storage capacity: About 1,800,000 m^3 (estimate)

(5) Amount of construction work
- Excavation: Excavation of soil: 51,213 m^3, excavation of rock: 4,377 m^3, total: 55,590 m^3
- High-density filling (the dam body): 7,144 m^3

- Medium-density filling (upstream and downstream sides of the dam): 26,662 m^3
- Low-density filling (above the dam): 21,814 m^3

(6) Used machines
- Bulldozers: 2 to 3 units
- Backhoes: 1 to 2 units (excavators)
- Trucks: 2 to 3 units (dump trucks)
- Rollers: 1 to 2 units (Komatsu JV100)

(7) Duration of construction
From 15 November 1997 to the end of June 1998. This period included the construction of other experimental facilities, and the actual duration devoted to the construction of the subsurface dam was about 4.5 months.

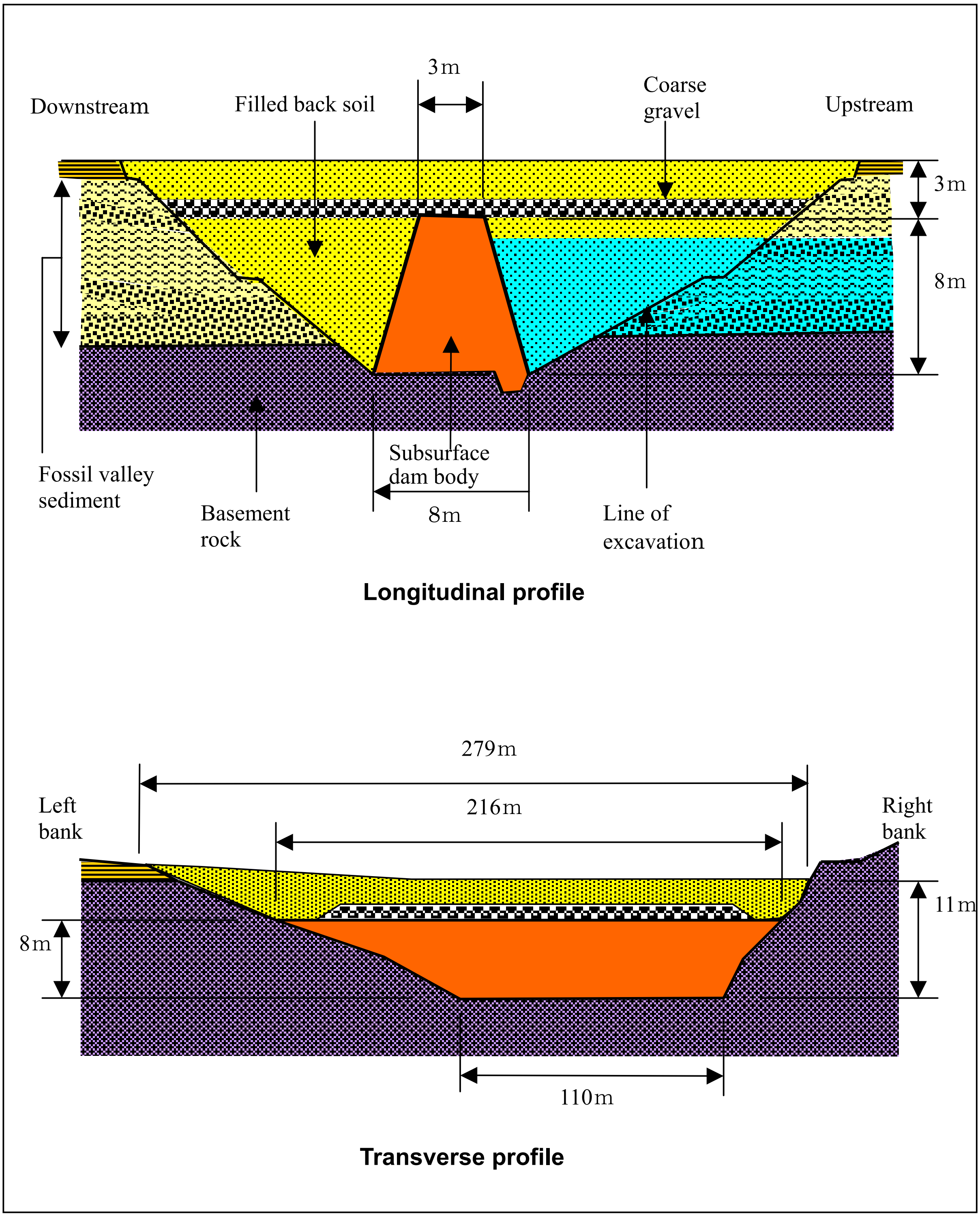

Fig. 4.1: Schematic diagram of the structure of a subsurface dam

4-3 Construction of the subsurface dam

(1) Excavation

The construction of a subsurface dam requires much larger excavation than the size (length, width, depth) of its body. Excavation for construction site access roads is also necessary.

In the case of the subsurface dam in Nare, the scale of the excavation was as follows:

- Length: 307.1 m (including the excavation for construction site access roads)
- Width: 50 m maximum
- Depth: 12.9 m maximum
- Total amount of excavation: 55,590 m^3

The total amount of excavation was thus 7.8 times as much as the volume of the dam.

During excavation, the following difficulties had to be dealt with:

1) Although the excavation was carried out during the dry season when the groundwater decreased in the fossil valley, it encountered difficulties due to water springing from the sandy layers at an intermediate depth of the fossil valley sediment or from the boundary between the sediment and the basement rock. Because subsurface dams are constructed across shallow groundwater channels, this water springing during the construction is not rare. It is thus necessary to pay sufficient attention to the choice of season and the construction method.

2) On the right bank, the buried structure of the fossil valley proved to be the same as that estimated from the preliminary survey, but on the left bank, the fossil valley extended beyond the estimated limit. In general, the results of the preliminary survey are not always completely accurate, and the participation of geologists experienced in supervising construction is thus very important.

(2) Construction of the dam body

As the material of the dam body, the heavily weathered layer of basement rock (clayey silt), which was extracted 300 m from the dam site, was used.

Before the construction of the dam body, filling and pressing tests with the material were carried out to establish quality control standards for filling:

- Thickness of spread layer per filling: 30 cm
- Thickness of pressed layer per filling: 25 cm
- Number of pressings: 6 back-and-forth passes with Komatsu roller JV100
- Water content of the material before filling: Optimal water content ± 1%
- Dry density of the pressed layer: Higher than 90% of the maximum dry density
- Permeability coefficient of pressed layer: Lower than 10^{-5}cm/sec

After excavation down to basement rock of the fossil valley, filling the dam body was carried out according to the quality control standards described above. In the process of filling, the following quality tests were carried out:

- Tests of the water content of the material: 52 layers, 130 points in total
- Tests of the dry density of the pressed layers: 52 layers, 130 points in total
- Measurements of the permeability coefficient of the pressed layers: 12 layers, 38 points in total

All the results of the quality tests were good and satisfied the standards. The permeability coefficients of the pressed layers were about 10^{-7} to 10^{-8}cm/sec (10^{-6}cm/sec at only 2 tests out of 38), which were much better than the required value.

It should be remembered that the foot and base of the dam must protrude into basement rock of the fossil valley to prevent water leakage.

As stated above, the material of the dam body was extracted from the heavily weathered layer of basement rock (argillaceous silt) located about 300 m from the dam site. However, surplus soil (fossil valley sediment) produced by excavation at the dam site might be usable as the material of the dam body. Such re-use would reduce "the devastated area" by the construction of the subsurface dam. For future "subsurface earth dam" projects, it is thus recommended to survey in detail the geological nature of the dam site from this viewpoint as well.

(3) Backfilling of the excavation

Parallel to the construction of the dam body, the excavated space of both the upstream and downstream sides of the dam body was backfilled. The backfilled portion was pressed by 3 back-and-forth passes with Komatsu roller JV100.

The excavation was initially backfilled to the crest level of the dam. Then, to obtain good permeability, gravel with a similar diameter was laid about 1 m thick, followed by additional backfilling (also pressed by 3 back-and-forth passes with the roller).

As the dam body was made of material from the other site, surplus soil, the amount of which was almost equivalent to the volume of the dam, was left after backfilling. This surplus soil was used to fill back the site from which the material of dam body was extracted.

(4) Treatment after construction

After backfilling was completed, the landform of the dam site was almost restored. However, restoring the natural vegetation was so slow that the ground remained bare for about two years after the dam construction. To protect the natural vegetation from possible grazing by livestock animals, a wire fence was set around the construction site and *Acacia senegal* was planted within it in 2001. The rate of survival was about 60% (in January 2002), but plenty of natural vegetation was growing and the construction site had the appearance of shrub forest.

Photo 4.1: Construction of the subsurface dam -1

Photo 4.2: Construction of the subsurface dam -2

Photo 4.3: Construction of the subsurface dam -3

Photo 4.4: Construction of the subsurface dam -4