Application of Flexible Membrane Lining to A Reservoir

H. Yoshikoshi & T. Masuda
Tokyo Electric Power Co., Inc., Japan

ABSTRACT: Tokyo Electric Power Co., Inc. has provided a water stoppage work on the ground surface to prevent leakage through the surrounding ground of the upper reservoir of a pumped storage power plant. PVC membrane was installed to 60% of the whole area where the water stoppage work was implemented, i.e. at relatively flat portion of the reservoir bottom with a maximum water depth of 40 m. Because of the large area and high water pressure, extensive investigations were carried out through studies on case histories, various tests on mechanical and physical properties of the membrane and design considerations for protection and anchoring of the membrane. Behavior of the membrane after ponding the reservoir has been monitored by observing leakage, ground water level, and settlement of foundation. Any behavior abnormal has never been observed yet.

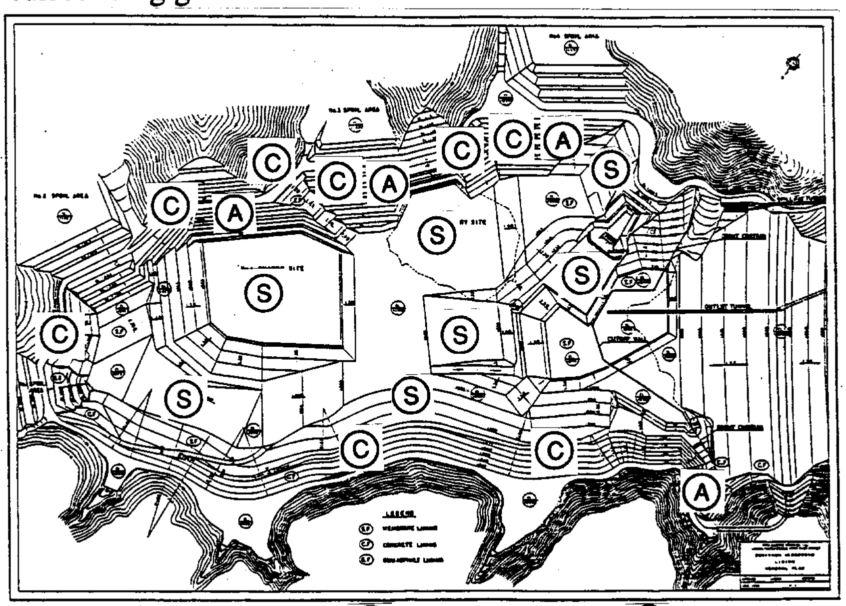
1 INTRODUCTION

Tokyo Electric Power Co., Inc. constructed Imaichi Pumped Storage Power Plant to meet a growing electric power demand in Tokyo Metropolitan area. This power plant has the two dams and turns out a maximum of 1,050 MW, making use of an effective head of 524 m between two dams and a maximum discharge of 240 m^3/sec.

As a result of extensive investigations on water leakage from the upper reservoir (Kuriyama Reservoir), it was decided to cover the entire reservoir area of 300,000 m^2 with three kinds of lining to prevent seepage through the surrounding ground.

As a lining material, a flexible membrane was adopted for a relatively flatter area of the reservoir bottom, while a concrete slab or a gum-asphalt mixture was adopted for a steeper slope at each bank. Kuriyama dam and reservoir is briefly described in Table 1.

The area to be installed with a flexible membrane accounted for 60% of the total lined area, and the membrane would have to withstand a water pressure of more than 40 m. Table 2 shows the amount of each lining type. Figure 1 shows a plan of Kuriyama reservoir lining.



(S) FLEXIBLE MEMBRANE (C) CONCRETE SLAB (A) GUM-ASPHALT MIXTURE

Figure 1 Plan of Kuriyama Resevoir lining

Table 1 Brief Description of Kuriyama Dam and Reservoir

Type	Embankment dam with center impervious earth core
Height	97.5 m
Crest length	340 m
Crest width	10 m
Slope gradient	1:2.7 (upstream face) 1:2.0 (downstream face)
Volume	2.52 million m^3
Catchment area	0.9 km^2
Highest water level	EL 1090 m
Lowest water level	EL 1063 m
Available drawdown	27 m
Gross storage capacity	6.89 million m^3
Effective storage capacity	6.2 million m^3
Reservoir area	0.32 km^2

Table 2 Areas of each lining

Lining type	Lined area (m^2)	Remarks
Flexible membrane	195,000	Gradients gentler than 1:3
Concrete slab	86,000	Gradient of about 1:1.5
Gum-asphalt	38,000	Quarry site and spoil area slopes
Total	319,000	

The paper deals with an outline of the flexible membrane design, with particular attention to the following points.

(1) Membrane material, seaming and anchoring methods

(2) Subgrade preparation and protective layer's structure

(3) System of drainage below the lining

2 DESIGN OF FLEXIBLE MEMBRANE LINING

(1) Selection of membrane material and thickness

Of adoptable materials in each of plastic, synthetic rubber and asphalt families, PVC (polyvinyl chloride) was chosen for the membrane for its elongation performance, seam strength, and economy. A PVC plasticizer of the linear phthalic acid type (diethylhexaphthalate) was selected for its greater durability in comparison with those of the nonlinear phthalic acid type.

A membrane of 1.5 mm thickness was selected to improve durability and protectability from puncturing, whereas the great majority of precedent cases employed a 1 mm thick one. It has been reported that membrane durability is improved significantly and that plasticizer loss is reduced, if a membrane of 1.5 mm or thicker is used. (Sembenelli, et al., 1986) (See Fig. 2)

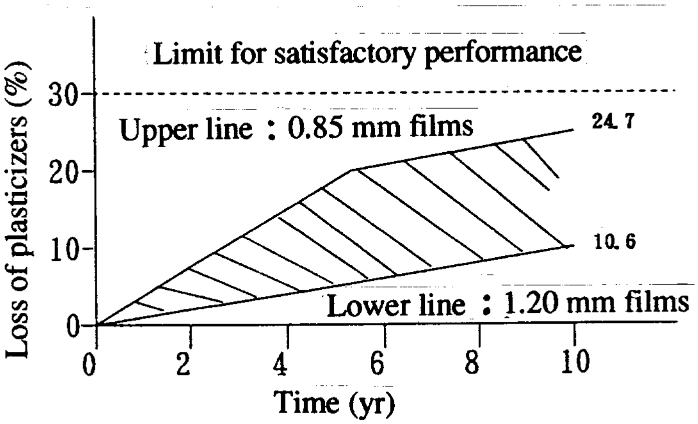


Fig. 2 Loss of plasticizer with time

Table 3 summarizes the quality control tests carried out on the PVC membrane material and the criteria for acceptance.

All results of the quality control tests satisfied the criteria. Of these, results on elongation are shown in Fig. 3.

Table 3 Quality control criteria for PVC membrane material

	Item	Test method	Criterion
Dimensions	Mean thickness	JIS B 7503	>1.5 mm
	Thickness tolerance	ditto	±0.05 mm
Properties	Hardness	ditto	65 to 90
	Specific gravity	ditto	1.20 to 1.35
	Tensile strength	ditto	>14 MPa
	Elongation	ditto	>340%
	Tensile stress at 100% elongation	ditto	>4 MPa
	Peel strength	ditto	>4.5 MPa

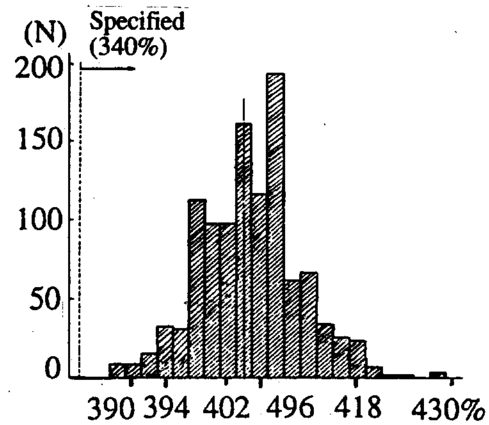


Fig. 3 Elongation of the membrane

(2) Seaming method

Thermal welding was adopted as the PVC seaming method, since this would facilitate construction and also assure reliability. The width of the overlap in this type of seam must be determined so that the seam does not peel off before the base material fails. A 2 cm joint width was selected to give an adequate safety margin, based on the predicted tensile load on a unit length of the membrane, the tensile strength of the PVC membrane material itself and the peel strength per unit length of the material. A dual seam structure was adopted to facilitate quality control tests on seamed lines. The entire seamed length was tested after welding by a method which check air and water-tightness by injecting pressurized air into the space, air channel, between two seams lines. Figure 4 shows the detail of the seam.

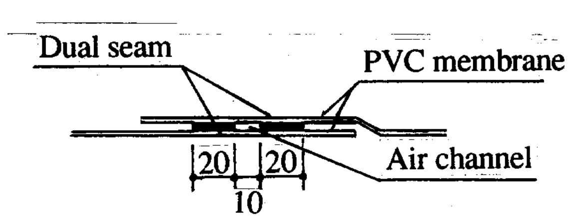


Fig. 4 Detail of seam (mm)

Table 4 summarizes the quality tests carried out on membrane joints and their acceptance criteria. Of these, results on strength are shown in Fig. 5.

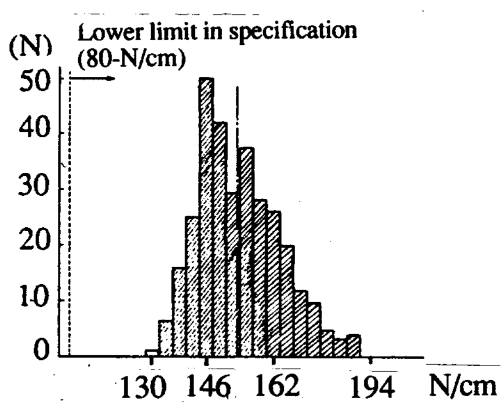


Fig. 5 Strength of the seam

Table 4 Quality control criteria for membrane joints

Item	Test method	Criteria
Width	Measurement	>2.0 cm
Strength	JIS K 6301	>80 N/cm
Joint performance	• Pressurized air injection test • Vacuum test	No leakage

(3) Anchoring

The end of PVC membrane was anchored to a reinforced concrete beam which is connected with the concrete lining. The anchor beam was then overlaid with a PVC membrane to ensure water tightness as shown in Figure 6.

(4) Subgrade preparation

After referring to experiences at other preceding sites, the subgrade of membrane were determined to be prepared under the following requirements:

1 Strong enough to withstand the load acting on the membrane.
2 Smooth and free from gravel to protect the membrane from punctures when under pressure.
3 Cushioning the membrane from the load applied by workers and construction equipment during construction.
4 Watertight so that leakage from defects in the membrane, even if it occurs, does not accelerate.
5 Stability and resistance to scouring by water flowing over its surface.

Model tests were carried out to examine the effects of geotextiles as an underlay for geomembranes (Fukuoka, 1990). Figure 7 shows the test apparatus. These tests clarified that without a geotextile, water leaking from a membrane defect flows vertically through the subgrade. With a geotextile, on the other hand, water spreads radially outwards and the flow rate is below one-tenth of that when no geotextile is present. The flow rate through a defect of 1 cm in diameter is about 0.1 m^3/day when the subgrade has a permeability coefficient of 10^{-4} cm/sec.

Taking into consideration the requirements stated above and these test results, the following subgrade structure was adopted:

1 The surface soil of low-bearing-capacity was completely excavated and removed.
2 The subgrade surface was shaped smoothly using a roller compactor.
3 All gravel particles greater than 10 mm in size were removed by hand from the surface.
4 The subgrade was overlaid with a geotextile (SPANBOND, made of non-woven polyester fabric)

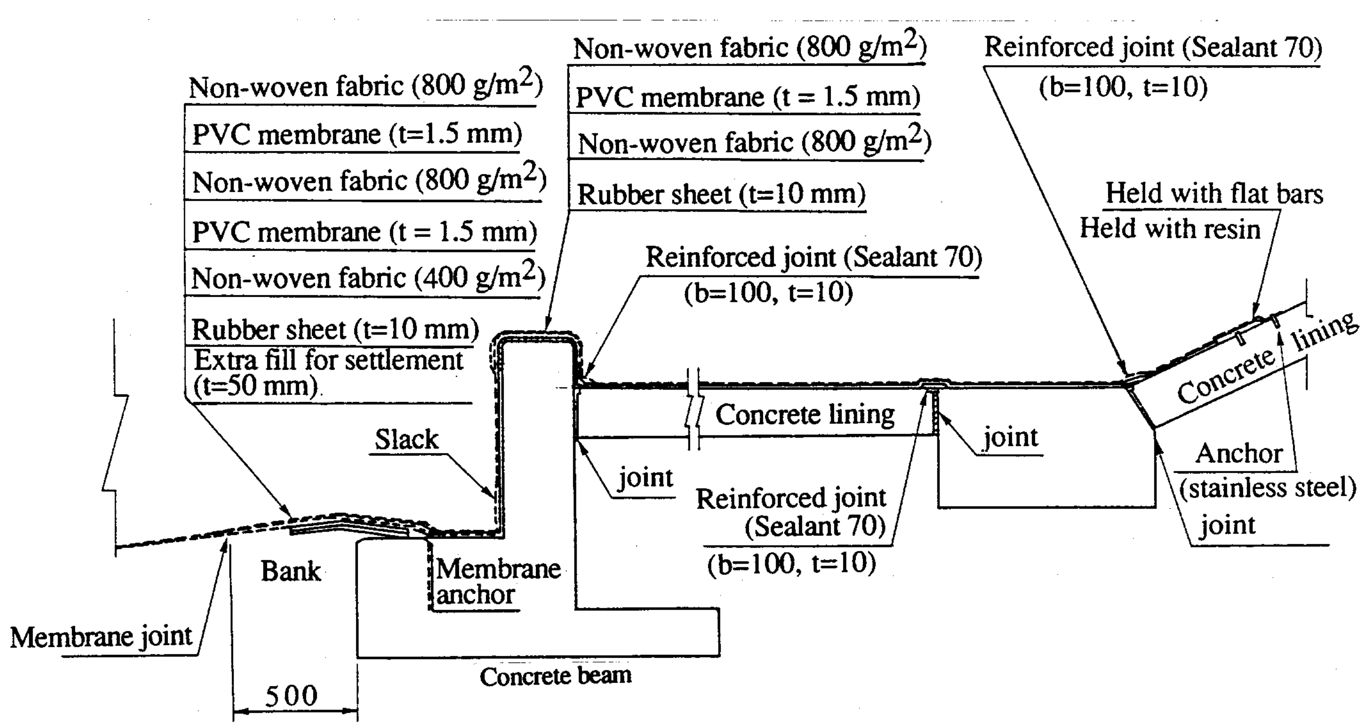


Fig. 6 Structure of membrane anchor

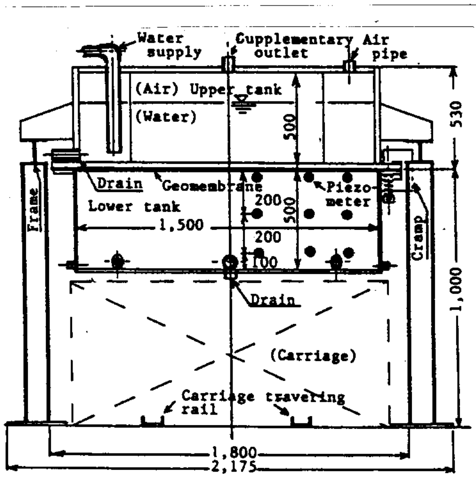


Fig. 7 Test apparatus

(5) Protective layer

The PVC membrane was overlaid with a protective sand and gravel layer to ensure its durability against ultra-violet radiative and heat. The protective layer was also expected to be effective against some vandalism or animals. Following studies were carried out with regard to the protective layer:

1 Safety of the PVC membrane during the protective layer construction
Field tests were carried out for different thicknesses of the protective layer and types of construction equipment to prevent the damage to the membrane during construction.

2 Stability of the layer against sliding
An analysis of sliding was implemented to examine the stability of the protective layer based on measured coefficient of friction between the geotextile and the PVC membrane.

3 Stability of the layer against waves in reservoir
For sections of the protective layer above low water level, tests were conducted to determine the optimum protective structure against waves and for retaining fine soil particles.

Based on the results of these studies, four different structures were adopted depending on the slope gradient and whether the layer was to be affected by waves. Figure 8 shows a typical protective layer structure for a slope on which waves act.

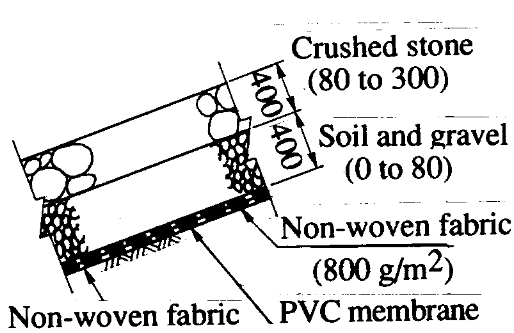


Fig. 8 Typical protective layer structure (mm)

3 DRAINAGE SYSTEM UNDER FLEXIBLE MEMBRANE

A drainage system was installed under the lining to prevent the accumulation of leakage water behind the lining, increase in porewater pressure in the foundation and resulting damage by uplift of the lining.

To prevent the acceleration of water leakage from defects in the PVC membrane, the drain pipes were embedded under impermeable soil of 50 cm thickness, thus separating the lining hydraulically from the drainage system.

Perforated pipes collect water and lead it into five steel vessels under the lining to pump up collected water into the reservoir. The pipes were installed in excavated trenches. The trenches were backfilled with filter materials of crushed stone around the pipes, and then the drainage system was overlaid with impermeable soil. Figure 9 illustrates a perforated pipe in its trench.

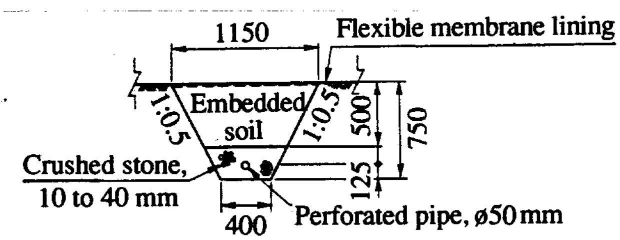


Fig. 9 Perforated pipe in excavated trench (mm)

4 LINING PERFORMANCE

After completion of the lining installation, the reservoir was filled in 1990. Porewater pressure gauges (piezometers) were installed in the foundation of the lining and surrounding hillside ground in order to monitor the leakage from the reservoir. The ground water level is now at a steady state.

Settlement meters were also installed in the relatively soft portion of the foundation. Although settlements of 20-30 cm have been observed, no defect is found in the membrane by site inspection.

To monitor the long-term performance of the flexible membrane lining, a special field test section where PVC membranes were installed, is secured within the limits of drawdown in an upstream part of the reservoir.

5 REFERENCES:

Sembenellietal, P and Claps, G., "Geomembranes for Cofferdams," 3rd. International Conference on Geotextiles, 1986, Vienna, Austria

Fukuoka, M., Science University of Tokyo, "Large Scale Permeability Test for Geomembrane-subgrade System" 3rd. International Conference on Geotextiles, 1986, Vienna, Austria

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