

## SLIDES IN NORWEGIAN WATER TUNNELS

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Approximately 5000 km of tunnels have been constructed in Norway over the years, mostly in connection with hydropower development. The guidelines for rock support is that rock support has been installed only where found necessary. That means that where poor rock with low stability occurs, extensive reinforcement measures like cast-in-place concrete linings have been applied. In portions of the tunnel with good stability none or little rock support is used.

As almost all rocks are hard-rock, the poor rock conditions with instability mainly caused by occasional weakness zones (i.e. crushed zones and clay zones), the main parts of the tunnels are unlined.

In some headrace or tailrace tunnels slides in the tunnel have been detected because a sudden increase in head loss takes place. In most of the transfer tunnels possible slides are not detected unless

- they are inspected, or
- the slide completely blocks the tunnel, or
- the slide develops up to the surface.

Table 1 outlines some slides, which have occurred in Norwegian water tunnels.

From the examples of some slides and rock falls given in Table 1 the following conclusions can be drawn:

- severe slides have occurred in the tunnel where insufficient rock support has been installed in weakness zones or faults, mainly because
- shotcrete has been applied on swelling clay shortly after blasting, or
- the concrete lining has been too short.

Table 1. Examples of some slides and rock falls in Norwegian water tunnels

Project	Occurrence	Elapsed time	Slide caused by
Hemsil 1 power plant	1965. 200 m <sup>3</sup> slide in the 12 m <sup>2</sup> headrace tunnel	8 years	Weakness zone with swelling clay
Vemork power plant	1989. Slide in headrace tunnel, which developed up to the surface	75 years	Clay infected rock masses. The tunnel has little rock cover and is located in the zone of weathering.
Savalen power plant	1983. Slide in the by-pass tunnel headrace where concrete lining had been applied. (The by-pass was made because a slide took place during tunnel excavation)	12 years	Insufficient rock support of a talc-chlorite rich weakness zone
Rendalen power plant	1985. Two slides and several block falls	14 years	Insufficient support of clay zones
Brokke power plant	1983. Local block falls in headrace tunnel	15 years	Loosening of blocks in connection with high rock stresses
Trollheimen power plant	2000. Large slide in transfer tunnel	30 years	Area with many shears
Mauranger power plant	1977. A large slide in headrace tunnel blocked the tunnel	3 years	Weakness zone with swelling (the zone had been concrete lined, but the lining was too short)
	2000. Large slide in a transfer tunnel	25 years	Crushed zone with clay (the zone had been concrete lined, but the lining was too short)
Rafnes industrial plant	1976. Three large slides and several small one in the water supply tunnels	10 days	Weakness zones and shears with swelling clay supported with shotcrete
Jørundland power plant	1983. A small slide and some rock falls in the headrace tunnel (35 m <sup>2</sup> )	10 years	In connection with a weakness zone
Fortun power plant	1995. One large and several small slides or block falls in a transfer tunnel	35 years	Clay zones insufficiently supported
Vinstra power plant (after extension)	1993. 4000 m <sup>3</sup> slide in the headrace pressure tunnel. The slide material had been transported by the water 1 km	1 year	Chlorite and talc containing weakness zone in a phyllite
<u>Sundsborn power plant</u>	1983. Large slide in the headrace tunnel	12 years	
	1995. Large slide in a transfer tunnel (10 m <sup>2</sup> ) which was almost blocked. Much of the slide material had been transported some hundred meters by the water	24 years	Clay-rich crushed zone (the zone had been concrete lined, but the lining was too short)
<u>Duge power plant</u>	1981. 7000 m <sup>3</sup> rock fall in tailrace tunnel	11 years	Occurred between two weakness zones
<u>Songa power plant</u>	1975. Large slide in a transfer tunnel (15 m <sup>2</sup> )	5 years	
	1999. Slide in a transfer tunnel	28 years	Weakness zone
Nye Skjerka power plant	1999. Small slide	1 year	Shears insufficiently supported

slide = downfall of > 10 m<sup>3</sup> material; block fall = falls of single blocks or small volumes