15. SUBSEA TUNNELS

Arild Palmstrom
Ing. A. B. Berdal A/S

1. INTRODUCTION

Special for subsea tunnels is that they pass under bodies of water that are inexhaustible and where drainage into the tunnel has no lowering effect whatever on the groundwater line. The downgrade excavation of such tunnels therefore include the possibility of having large inflows of water to cause great problems for the excavation works and even to drown the tunnel.

The special problems in subsea tunnelling are therefore:

- Short distance to the inexhaustible body of water
- Limited knowledge of the rock mass conditions
- All leakage water has to be pumped out both during construction and during the operation condition.

A subsea tunnel project therefore require thorough planning of the works and include special safety measures.

2. EARLIER SUBAQUEOUS TUNNEL EXPERIENCE

Looking back at previously built "over-land" tunnels, there are many projects that today could be classified as subsea tunnels, for example the tunnelling of water conduits for hydropower developments located below rivers or lakes, Fig. 15.1. The most useful early experience from such subsea tunnelling has been the construction of submerged tunnel piercings, or lake taps which is a Norwegian speciality in hydropower works. The piercing is effected by excavating a tunnel in rock under the lake bottom, up to a preselected point, from where a controlled hole-through is made by a final round of blasting. In this way a reservoir is made accessible for hydropower exploitation using the storage volume available below the original water level.

Lake taps are further described in Chapter 14.

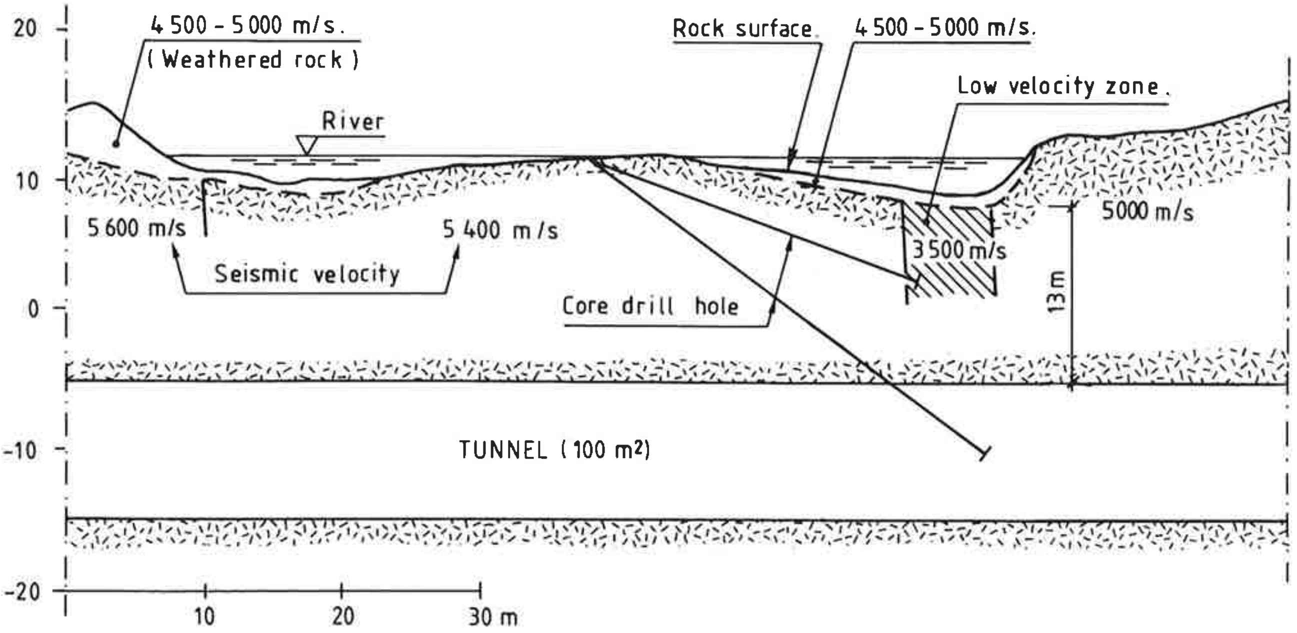


Fig. 15.1

Rygene power plant (1974–76): The 2 km long, 100 m^2 tailrace tunnel crosses under the 100–200 m wide Nidelven river in two locations with a minimum rock cover of 13 m

3. SOME FACTS FROM RECENT SUBSEA TUNNELS

The most serious uncertainty associated with subsea tunnelling, is related to sudden water infiltrations. Neither the number of water-bearing zones nor the maximum inflow rates can be predicted beforehand. Norwegian experience shows that the risk of large water inflows is greatly reduced when sealing of water-bearing zones is performed as pregrouting ahead of the tunnel face. This pregrouting is included in the exploratory drilling programme. When a water-bearing zone has been detected by the exploratory drilling, additional holes are drilled and grouting is done through all the boreholes showing water leakage. After the grouting is completed, the tunnel can be further excavated through the sealed zone. The grouting process is also described in Chapter 17.

One major uncertainty for the tunnel cost are the supporting and grouting works, governed by the actual rock mass conditions. This is demonstrated in Fig. 15.3 where the recorded variations in construction costs with different rock mass qualities are shown. For subsea projects the amount of the rock supporting works can never be known until the tunnel breakthrough. It is therefore of the greatest importance to work out tender documents with risk sharing provisions as described in Chapter 9.

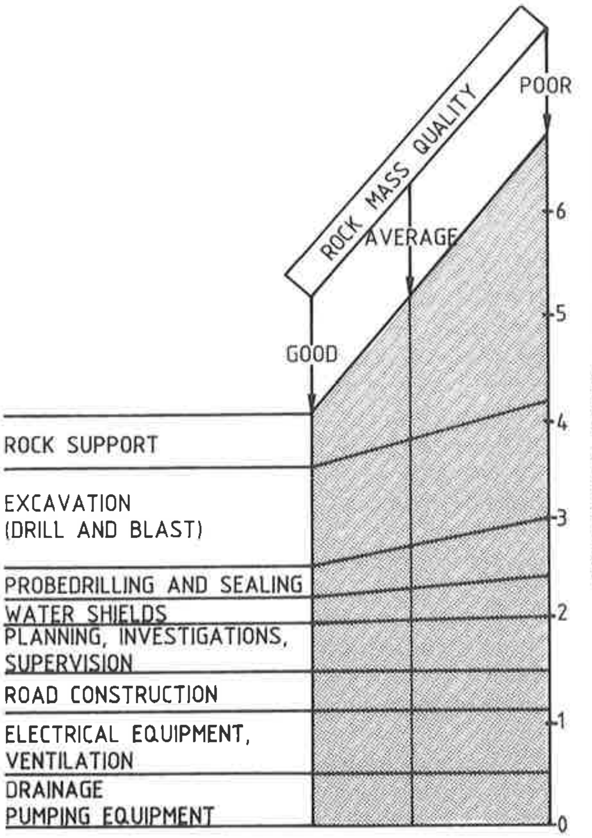


Fig. 15.3 Breakdown of costs for a two-lane subsea road tunnel

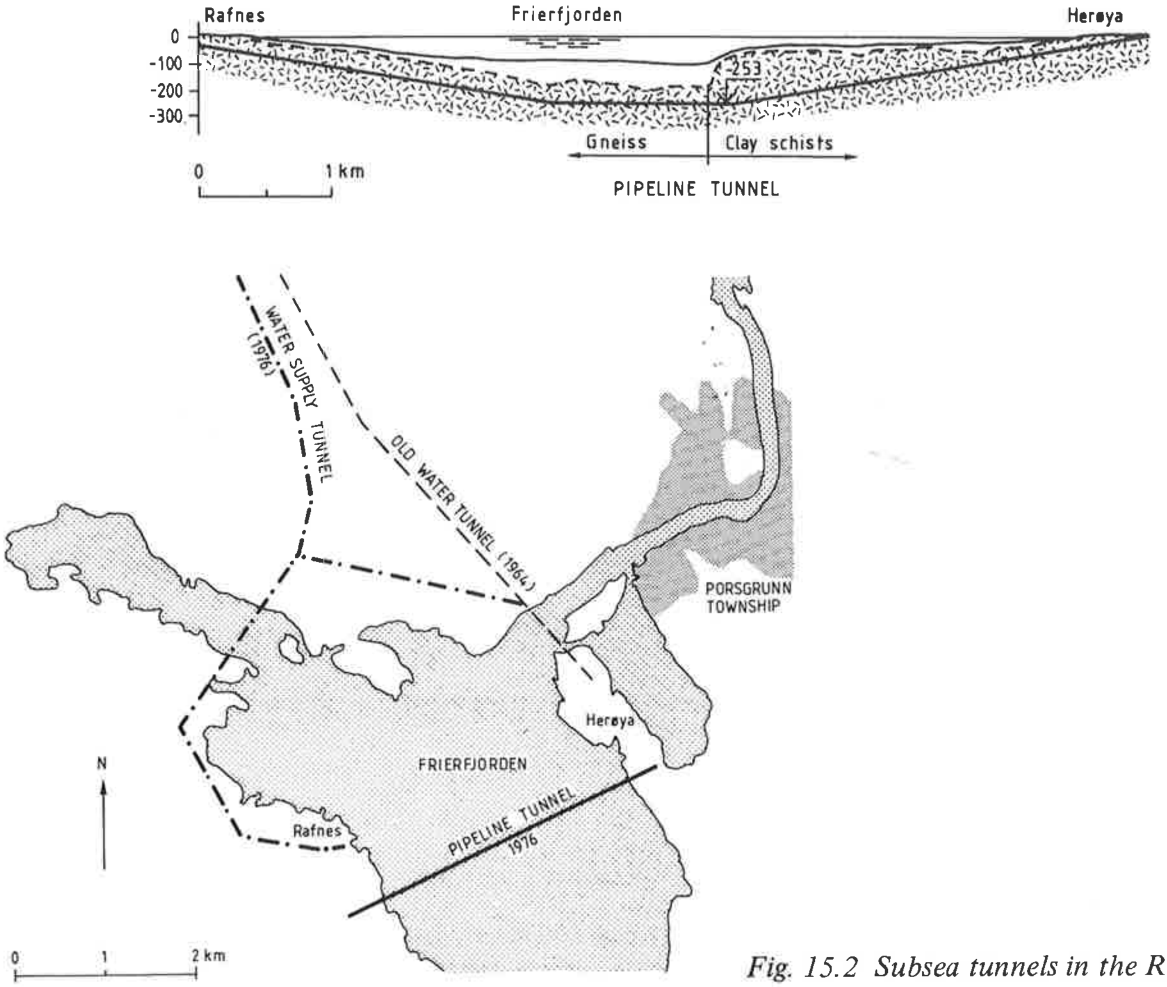


Fig. 15.2 Subsea tunnels in the Rafnes area

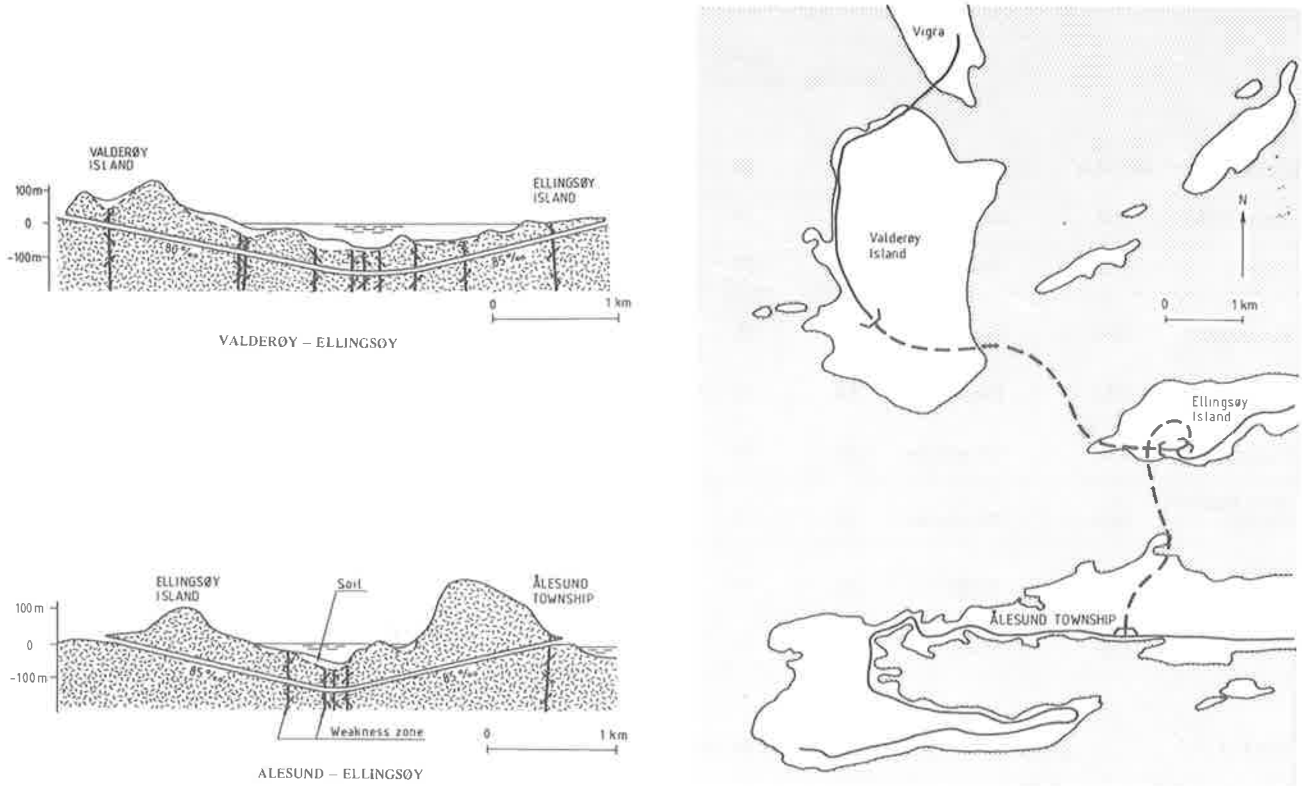
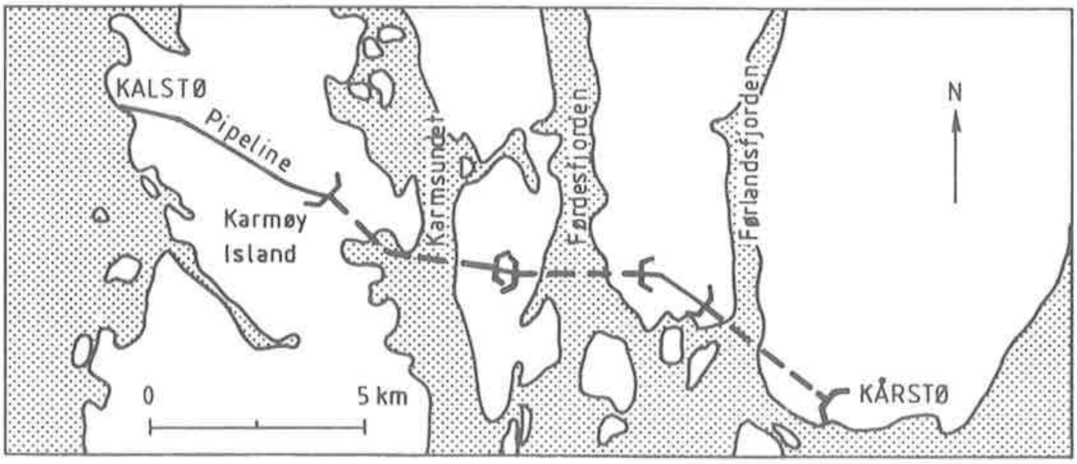
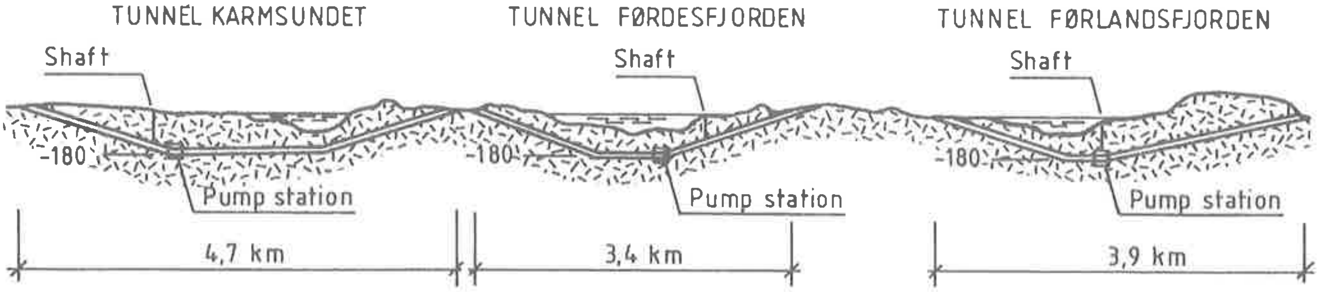


Fig. 15.4 *The subsea road tunnels Ålesund-Valderøy (project no 7-8 in Table 15.1)
Tunnel cross section 70 m^2*



PLAN



PROFILES

Fig. 15.5 *The Kårstø subsea gas pipeline tunnels (project no 3-4 in Table 15.1)
Tunnel cross section 26 m^2*

			LENGTH	CROSS SECTION	DEEPEST POINT	PRE-INVESTIGATIONS	WEEKLY PROGRESS RATES			
PROJECT	YEAR OPENED	PURPOSE	km	m2	m	% of construction costs	average m	max m	WORKING HOURS PER WEEK	ROCK TYPE
1. Rafnes-Herøya	1974	Gas pipe-line	3,6	16	-253	1,7	37	97	130	gneiss
2. Vardø	1982	Traffic	2,6	50	-88	5,0	17	60	75	schist
3. Karmsundet	1984	Gas pipe-line	4,7	26	-180	1,9	33	92	105	greenstone, greenschist, gneiss
4. Førdesfjord	1984	Gas pipe-line	3,4	26	-160	1,9	26	63	105	gneiss
5. Førlandsfjord	1984	Gas pipe-line	3,9	26	-170	1,5	36	85	105	gneiss, phyllite
6. Shore Approach, Hjartøy	1987	Oil pipe-line	2,3	26	-110	4,0	39	92	105	gneiss
7. Ålesund - Ellingsøy	1987	Traffic	3,5	70	-140	1.0	35	55	105	gneiss
8. Ellingsøy - Valderøy	1987	Traffic	4,3	70	-140	1.0	38	65	105	gneiss

Table 15.1 *Data from eight Norwegian subsea tunnels*

4. EXPERIENCE

The experience from nine Norwegian subsea rock tunnels is that the overall rock mass quality has been fair to good for tunnelling. In weakness zones varying from 5 to 400 m in width, the quality has been poor to very poor. Special rapid rock supporting concreting methods were used successfully in some instances, making a safe advance possible even where the stand-up time of the rock masses was very short.

Experience from the sealing of water leakages shows that normally about 8-10% of the tunnel length has had to be pregrouted. The average water leakages into the permanent tunnels vary between 75-400 l/min per km tunnel.

There is at present experience from subsea tunnels down to 250 m below sea level, and firm plans for 7-8 long tunnels down to more than 300 m. With the experience from several long "over-land" tunnels with ground water heads up to 1000 m it is expected that within 10 years subsea tunnels may be constructed down to as much as 500-600 meters below sea level, with reasonable costs and construction time.

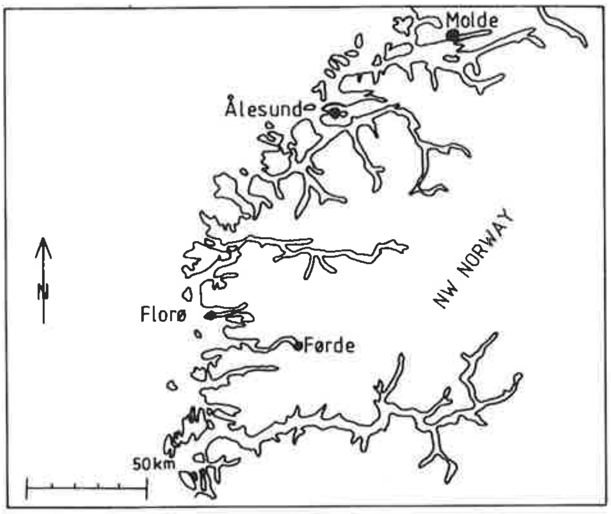


Fig. 15.6

Part of the Norwegian coast showing the need for connections to pass the fjords. Many of these may be constructed as subsea tunnels