Introduction

The Norwegian coast consists of fjords that cut deep into the mountains, straits and islands. The population on the coast has traditionally travelled by boat, but the need for better communication has radically changed this in recent years. A large number of impressive road, tunnel and bridge projects have either recently been opened or are in the process of being planned.

In spite of that, it is still not easy to travel in Norway and long distances with narrow roads and ferries in between give our industry a disadvantage compared with other European countries. Most of the population lives in the southeast of Norway and in this area the road network is fairly well.

Here in Scandinavia we like to think that the Vikings had some positive influence on the countries they visited, and we know that the cultures they met made some impression on them. It is a fact that some of these crossings resulted in lasting relations and permanent settlements.

We can therefore boast of a long tradition in strait crossings. We are also in process of establishing a tradition in symposia on the subject, and I would like to take this opportunity to look back upon what we have achieved in Norway…

I believe that it is important to exchange information between Norway and the Baltic States and I am very pleased to have the opportunity to chair my experience with you.

On the picture, a typical Viking boat.

1. Ferries

I would like to challenge you, bridge and tunnel engineers, with the statement that the first strait crossings of any magnitude had to be made on some floating element. Only the smallest waterways could be forded by the simple structures available. Boats and ferries, in some form, have therefore always been an important means of transport, and the ferryman has made his mark in history and literature.
The crossings were performed by manually operated rowing boats for decades. The population was living along the fjord sea-line and a lot of men had the job to bring people from one side to another. Further on, bigger dampers replaced these boats. When the use of private cars was more common, ferries replaced these boats. In Norway the ferry trips have developed into a modern, safe and comfortable means of transport. The size of our ferries has been standardized according to the length of crossings, and necessary capacity of transport (50 – 150 cars).

The ferry terminals have likewise been standardized in 3 widths according to the size of the ferry, and in 3 lengths according to the variation in tides along our coastline.

Tourist, visited Norway, do like to travel by ferryboats. The ferry trip enables them to see the landscape, the fjords and the mountains in another way. The inhabitants however, want to replace the ferries with bridges. This means a faster and a more predictable solution. Some of our fjords are however very wide and it is a big challenge both technically and economical to overcome.

The planned fixed link to Saarema in Estonia is a similar challenge.

2. Suspension bridges:

Our earliest suspension bridges were suspended by chains or eye bar chains. Around 1850 steel wire was introduced for making cables. At first these bridges were built with relatively stiff girders. The effect of cable elasticity under traffic load was often neglected in the analysis.

The Gulsvik bridge, built in 1905, is an example of such a structure.

Around 1920 flexible suspension bridges with very slender stiffening girders were introduced. Such structures were still being built up to 1968. Fyksesund bridge (see picture) with a span of 230 m, is probably approaching the maximum span limit for this type of bridge under Norwegian conditions. Since then a more substantial stiffening girder has again been used, and its cross-sectional form has gradually been developed into a welded steel box with more streamlined, wedge-formed edges.

Until now, we have built 9 suspension bridges with a main span of more than 400m.

Our longest suspension bridge so far is the Askøy Bridge in Bergen. It was built in 1992, and has a main span of 850 m. The stiffening girder is a welded steel box, suspended from fully galvanized locked coil cables.
We are planning suspension bridges with main spans of 1300-1500 m. With two traffic lanes only, this is a challenge. The main problem with such a slender construction is to stabilize it horizontally. We are performing some research and development work in order to improve the situation, but it is still some way to go.

3. Cable-stayed bridges:

Although we started late with the modern version of cable-stayed bridges, we have now built several structures of this type in Norway.

Our first one was built in Stavanger in 1979. A cable-stayed structure was chosen for aesthetic, rather than economical, reasons.

In general, we pay high attention to aesthetic aspects and solutions are sometimes chosen because of its aesthetic value. In order to encourage the aesthetic, our general director has established the prize “Beautiful Roads”

Skarnsundet Bridge was built in 1991.

It held the word record for a short time with its main span of 530 m. This record has since been exceeded several times, but still holds as far as concrete spans are concerned, as far as I know.

The Grenland Bridge, built in 1996, has only one pylon, but a main span of 305 m.

Great care was taken to provide a nest for a wild falcon in the top of the pylon; - I do not know whether any such bird is at present in residence.
The characteristic fanned cable profile of this type of structure can be seen in the artistic image of the cables of the Helgeland Bridge (1990).

4. Arch Bridges

I have chosen two bridges of different construction and construction materials to represent Norwegian arch structures.

The first one is the Karmsund Bridge, built in 1955 as a three-hinged steel arch. By means of jacking, a calculated force was inserted in the top chord, after which the last joint was bored and riveted, converting it to a two-hinged arch. The arch span is 184 m. The side spans are in concrete. The bridge has recently been rehabilitated.

The other one is Puddefjord Bridge in Bergen. Although it may look like one bridge, it is really two different structures; one built in 1956, the other in 1998. They are almost identical, but the old one has a massive concrete arch, and the new one has a hollow concrete box cross-section. The arch span is 150 m.

For the moment we are projecting an arch bridge both in steel and timber at Nybergsund. Only one of them will be built. The tendering process will decide whether we will choose steel or timber.

5. Segmental Cantilever Concrete Box Girders

The segmental cantilever concrete construction technique was introduced to Norway at the end of the 1950’s. Spans were at first moderate, starting with a main span of 80 m for the Tromsø Bridge which was completed in 1960. The method rapidly gained popularity and proved to be very competitive economically.

It is probably correct to say that this method has dominated Norwegian concrete bridge construction for the last 40 years.

Spans were gradually increased, and towards the end of the last century world record spans had been built.

In fact the world record was beaten twice in 1998, first by Raftsundet Bridge in Nordland, with a main span of 298 m and a total length of 711 m.

Later the same year the Stolma Bridge in Hordaland added 3 m to that record to produce a bridge with a main span of 301 m and a total length of 467 m. Both these bridges have a box cross section with variable height. The cross section height above the pillars is 15 m.
In the mid span, lightweight aggregate is used, in order to reduce the dead weight and enable a longer span.

On the big picture you can see Raftsundet, with The famous tourist steamer “Hurtigruta” underneath. Stolma, on the little picture.

6. Floating bridges

Two Norwegian bridges have been built in locations where the combination of deep water and wide crossing called for new solutions. Floating bridges were chosen in both places. They are the Bergsøysundet Bridge, completed in 1992, and the Nordhordland Bridge, completed in 1994.

Both bridges float with a horizontal curvature which enable them to transfer horizontal forces from environmental loads and traffic as an arch thrust to the abutments. The transfer link for the trust is designed to provide sufficient flexibility to allow for the tidal differences.

Both bridges float on lightweight aggregate concrete pontoons.

Both of them use high strength steel in their superstructure. They are however different in many ways.

Bergsøysundet Bridge has a steel truss superstructure, consisting of members of tubular steel. It floats on 7 pontoons and has a total length of 933 m.

The floating part of Nordhordland Bridge has a superstructure with a welded, closed octagonal cross-section made by steel plates of 14 – 20 mm thickness. It floats on 10 pontoons and is 1246 m long.

The Nordhordland bridge has a high bridge section at one end, allowing the passage of larger ships near its southern shore. This part is a cable-stayed structure in concrete, with a main span of 172 m.

On the picture you can see Nordhordalandsbrua to the right and Bergsøysund to the left.
7. **Submerged Floating Tunnels**

The idea of crossing waterways by a tunnel, using pontoons on the surface, or tethered to the sea bottom, dates far back. The concept of a submerged floating tunnel for road traffic, on the other hand, is relatively new - although it has been on the agenda in all our symposia on Strait Crossings. The beauty of it is that we are using Archimedes’ principle in a modern design. In fact, it is the same principle that provides the buoyancy for ferries and floating bridges.

A submerged floating tunnel may now be a realistic alternative due to recent research carried out in Japan, Italy, Norway and elsewhere. One proposed solution is shown here. Such structures are at present under consideration in several possible locations in various parts of the world. The reason why they have not been a realistic alternative in Norway so far is not only a technical one. It is also a question of cost. The question of who is going to build the first one still remains unanswered. Perhaps someone will give us a clue during this symposium?

8. **Immersed Tunnels**

No immersed tunnels for road traffic have yet been built in Norway, but the technique is well known from numerous projects in many parts of the world. At present one such tunnel is under design in Oslo, and I would like to outline it briefly for you. It is being designed with two separate rectangular channels, each carrying three lanes of traffic.
7 tunnel elements will be produced in a dry dock, floated into position, immersed and coupled together, to make a total length of some 742.5 m. Soil conditions under the tunnel are predominantly soft clay, covered by a 0.5 to 2m layer of contaminated slam. Piling to rock 25 - 40m below the seabed has been planned.

9. Subsea Tunnels

Norway has to-day some 22 subsea tunnels with a total length of almost 90 km. The first of these was built right up in the North of Norway in 1983, connecting the town of Vardø to the mainland. It has a length of 670 m and goes down to 88m below sea level. Tunnels are not very photogenic structures, but this picture will illustrate some typical features.

Our longest sub sea tunnel lies under the Bømla Fjord in Hordaland, and is 7.9 km long. The deepest one connects the island of Frøya in South Trøndelag to the mainland and descends to a depth of 264 m below sea level.

10. Timber Bridges

Timber has long traditions in bridge construction in Norway. It is a material that is abundantly available in this country. In early days it was formed and joined with ordinary carpentry tools. Spans were however moderate.

In general, an increasing interest for timber bridges has been registered in the Nordic countries. The Nordic countries has fulfilled a research program, which ended up with recommendation both w.r.t construction details and preservation methods.

On the big picture, Tynset Bridge, with a main span of 70 m. World record!!
New techniques using glued, laminated timber has given new life to timber bridge construction and we have been able to increase the spans significantly. Recently, we have opened Tynset bridge in Norway with main span of 70 m, which is world record.

Other typical examples of timber bridges is Evenstad and Kvebergs. Evenstad Bridge spans the river Glomma in Hedmark. It has 5 spans of 36 m, and a total length of 180 m. Kvebergs Bridge from 1906 as an example of a typical old timber truss bridge.

11 Future challenges

At mentioned in the introduction, Norway has a lot of fjords and some of them are pretty wide. Until now, ferryboats have been the only solution for transport across these fjords. We investigate however the possibility to replace some of these ferries with bridges or tunnels.

Sometimes, the fjords are too deep to enable subsea solutions. Floating bridge or submerged floating tunnels has so far been evaluated. These solutions are however relatively sensitive w.r.t. stream, wind, waves and anchoring conditions.

A Norwegian Consulting Engineering Company, Dr. Ing Aas-Jacobsen has recently presented bridge solutions that enable us to build a bridge with a main span up to 3000m.

The concept is a combination of a cantilever concrete bridge, a cable stayed bridge and a suspension bridge.

Conclusion

I have made a brief survey of some interesting aspects of Norwegian bridge construction. It has been a pleasure to present for you; new structures, construction techniques and the application of new materials. Hopefully, we can exchange information within this area.

Our good cooperation between Norway and the Baltic countries will continue. We have already been involved in Latvia (Bridge Management System) and Estonia (link to Sareema) and look forward to further cooperation.