BRIDGES in NORWAY

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Contents

Bridge Technology in Norway

1.1.1 A historical development

Figure 4.17 Hjallar Bridge is from around 900.
The name of this simple construction principle is flagstone bridges.

Bridge technology development has happened along with an appropriate infrastructure in Norway. With the need for more effective and higher standard of roads, bridges have been adapted and developed to cross-wider rivers and fjords. It is typical the radical innovations done are based on innovations from abroad that have been further developed for local conditions. A Speciality in Norway has been slender suspension bridges and the free cantilever bridges made in concrete.

World War II was a critical point for Norwegian roads and bridge construction. After the reconstruction of all the damage and breakdowns from these years, a rapid growth of vehicles in size and weight happened. This has resulted in:

- Repair and increase of axle load and increase of widths of the existing road network
- Development of effective infrastructures along the coast line
- Bypass roads and separate highways made for cars only
- Separate pedestrians and bicycle roads
- Crossings with overpasses

It has been a rapid technical evolution after World War II. We have much more knowledge about material behaviour and manufacturing techniques. The use of computers and new software has resulted in calculations that are more accurate. This makes it possible to exploit the existing materials and come up with more complex construction techniques. This gives an opportunity to come up with more slender constructions and to create longer spans.

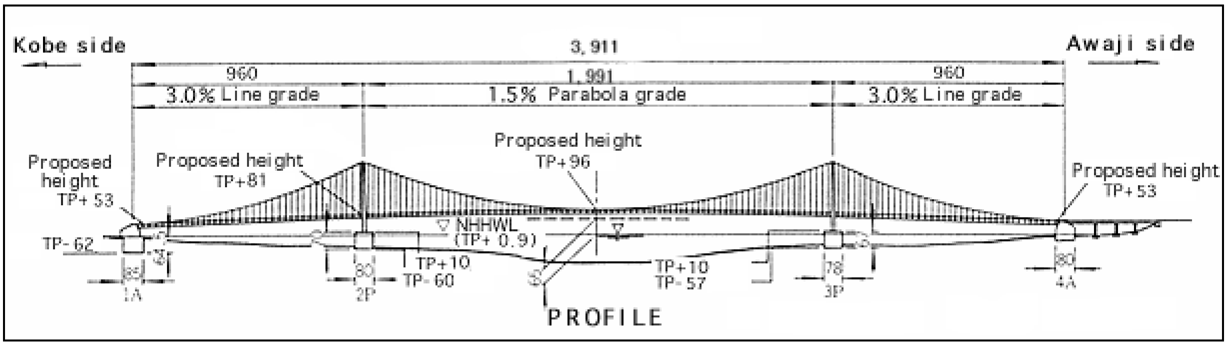

Figure 4.18 The world's longest span on a bridge is Akashi Bridge with 1991 meters. This is a suspension bridge made in Japan (/36/, /38/,/39/)

Laminated wood, aluminium, pre-stressed concrete, light weighted concrete, polyurethane, epoxies and prefabricated elements in steel and concrete has become common. The development of new painting systems for steel structures has been a success. Example of development improvement of construction techniques is subsea moulding, free cantilever scaffolding and glide formwork. On the control side, equipment and methods have significantly improved with non-destructive testing using x-rays, ultrasound and fibre-optics technology (ref. /34/).

The offshore industry has been an international success but this industry has adapted to perform larger and more complex structures. Offshore yards competing less in the bridge technology segment since they are better off to be in the offshore industry. The reason for this is the organisation is adapted to perform more complex tasks than bridges.

1.1.2 Concrete Bridge Technology

Concrete is currently the most common material used in Norwegian bridge design. This dominant position has basis in its suitability and availability.

Lack of steel after World War I also led to the use of concrete for bridges with longer spans. Domestic production of cement and lack of capital to buy steel strengthened the position of concrete versus steel. The same story was repeated after World War II, with even more strength. Development of pre-stressed concrete is also important for concrete structures to reach an even longer span. The first pre-stressed concrete structure made in Norway was Vormsund Bridge (1950). Concrete has in general been utilised more in Europe than in USA.

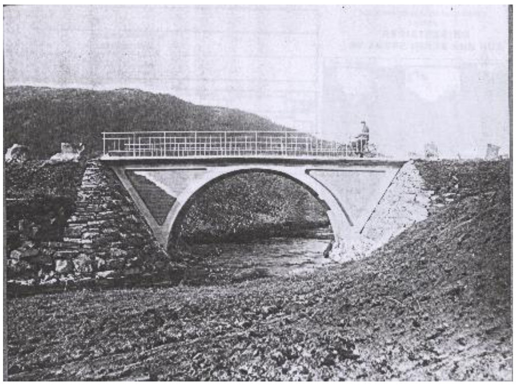

Figure 4.19 The picture above is Leir Bridge in Grong, Northern Trøndelag.

The picture above is Leir Bridge in Grong, Northern Trøndelag. A team in Northern Trøndelag County were early adopters of the new technology. The example above is the oldest existing bridge with reinforcement bars, Leir Bridge in Grong, built in 1912 and the first larger concrete bridge to be built was Namsen Bridge in 1920. Reinforced bars were introduced by Monier in France in 1880 and came soon to Norway. The first standard for reinforcement concrete in Norway was published in 1912 (ref. /34/).

Concrete has a high compression capacity, but the tension capacity is very limited. The traditional construction techniques for bridges have been arch bridges and rigid frame bridges: These construction techniques exploit concrete` s excellent ability to take compression.

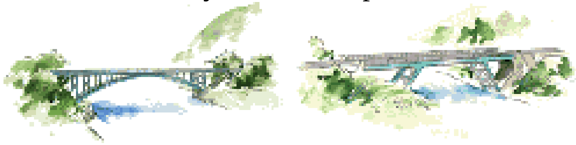

Figure 4.20 Arch bridges and rigid frame bridges

Free cantilever structures are currently the most competitive structures for spans between 120 and 300 meters in Norway. The longest bridge built so far in the world is Stolmasundet (1998, ref. /38/, /39/) with a main span of 301 meters. Also Sundøy, and Raftsundet are among the longest bridges in the world using this construction technique with a main span of 298 meter. High strength concrete and lightweight aggregates have been important factors to make these span lengths possible.

The first bridge built with free cantilever construction technique build in Norway was Tromsø Bridge (1960). Post-tensioned concrete cleared the way for the free cantilever bridge with longer spans.

Figure 4.21 free cantilever construction techniques.

Concrete has had a strong position in relation to steel because of uncertainty about the corrosion of steel, at the same time as concrete has been seen as a material which lasts forever in the same way as Norwegian rock. This view is now a little bit more balanced after some bad experiences with concrete bridges built during the 70`s. The reason for these problems may be related to different aspects and it is difficult to put a finger on one single factor.

- To much optimisation and bad design (wrong static system)
- reduction of concrete cover for protection of reinforcement bars
- use of sea water instead of pure fresh water
- experiments with different unsuitable additives like accelerators
- Carelessness and inaccuracies during construction
- (tight covering boards during construction block the water to escape during hardening (controversial))

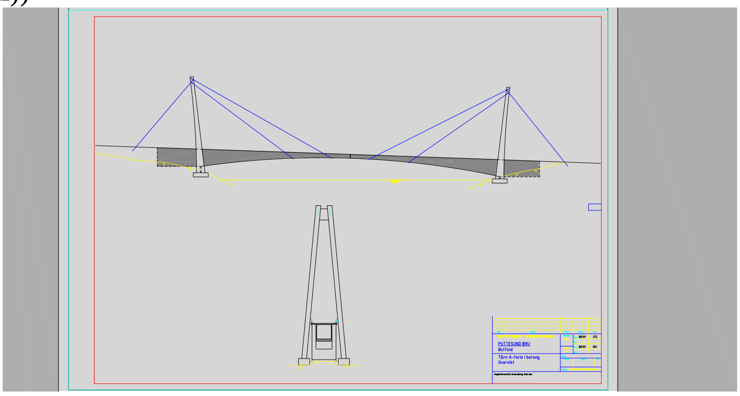

Figure 4.22 Puttesund Bridge, with a distinct deflection in the middle. The bridge is strengthened with cables and steel towers to neutralize errors caused by bad design.

The success for the free cantilever construction technique is based on the following:

- Development of higher strength of the concrete material itself
- Development of post tensioned concrete technology
- Effective construction method
- Standardised cross section widths and some other important details
- Entrepreneurs have made investments production equipments which are adapted to production of these bridges
- Light weighted concrete

•It is built about 115 free cantilever bridges in Norway

•Tromsøybrua, with a span length of 80m was built in 1960.

•Stolmabrua, with a span length of 301 m was built in 1998

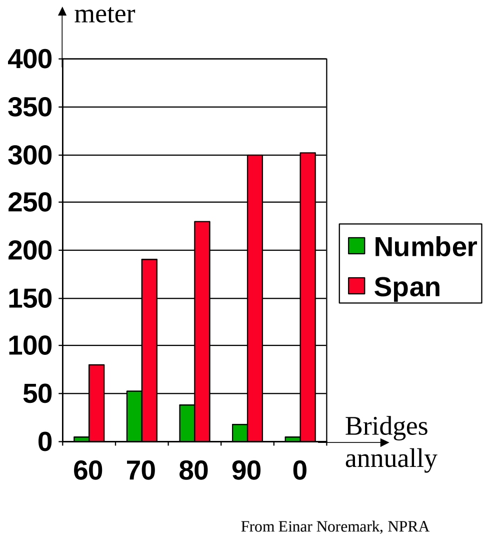

Figure 4.23 The figure above shows that the demand for FFB-bridges is reduced, since most of the places where such bridges are relevant now have a bridge.

Figure 4.24 Sundøy Bridge in an example of best practice for the free cantilever girder bridges in concrete. Sundøy Bridge is a copy of Raftsundet Bridge that was completed in 1998.

<u>Supply network</u>

Planning stage: Public Authorities (Central, County and Municipal) in cooperation with NPRA and private expertise regarding bridge design. See design stage.

Design stage: Directorate of Public Roads, Bridge Technology Division, NPRA county office, Rogaland, Aas-Jakobsen as. Johs Holt as, Reinertsen as, Instanes as and Smidt & Ingebrigtsen AS

Construction stage: The trend is that the actors in the construction stage are fewer and larger. The market has been characterized by acquisitions and consolidation. Currently are AS Anlegg, NCC, Vegdekke, Christie & Opsahl AS and maybe Selmer-Skanska considered as most competitive entrepreneurs for this construction technique.

1.1.3 Steel Bridge Technology

A few rolled iron and forged iron bridges were built from the end of the 18th century and at the beginning of 19th century. Several suspension bridges with cables made of steel and hinged bolts were also built at that time. Some accidents at suspension bridges in Europe meant that this construction technique almost died except in France and Norway.

German companies delivered the first steel truss bridges, but after 1885 almost all of them were built by Norwegian companies and at the same time the span lengths increased rapidly.

During history the start-up of manufacturing of iron- and steel has taken place in about 50 different places in Norway. Currently there are only 2 iron mills left based on scrap iron. These are in Mo i Rana in Nordland and Scana Stavanger in Rogaland. Pig iron is only produced in Tyssedal in Hordaland as a by-product during melting of ilmenite for use for titan white painting. The previous crisis for steel production took place around 1870 when charcoal was replaced by coke. The only manufacturing company that survived this crisis was Nes iron mill in Arendal. This factory was closed in 1959 after 400 years activity. The most notable supplier of steel has been Cristiania Spigerverk. But this has mainly been reinforcement bars for use in concrete. Most of the steel bought for use in steel bridges has always been bought form abroad (/44/).

NPRAs “duplex system” has been a success regarding the protection of steel structures against corrosion. These systems consist of thermal sprayed zinc and aluminium coating, alone or further coated with paint. Such systems in Europe have been used to protect structural steel against corrosion. From 1965 has this system been used for all new Norwegian highway bridges. Experience with NPRAs own “duplex system” system shows that steel can be very efficient against corrosion but it demands that the painting system is handled correctly. The Skarnes Bridge (1976) in Hedmark is one example and it has been in operation in about 30 years without any maintenance or no visible corrosion. The duplex system is currently delivered by Jotun (/46/).

After World War II the development of welding techniques and development of steel materials adapted to welding have led to a rapid evolution of use of steel in bridge design. During this period of time friction bolts have replaced rivets and welded girders have mostly replaced rolled steel beams. Rolled steel was in normal use until the late 60ties. Composite bridges in steel and concrete have been developed to optimise cross-sections further.

Norwegian rules and regulations for steel structures are valid for steel qualities up to 460MPa (ref./47/). A trend seen lately is the use of higher steel qualities to lower the manufacturing and construction cost. The step is taken from 350MPa to 420MPa after offshore has used this quality for most of the main structures in the last decade. The process to choose higher steel qualities is slow and conservative. The challenge with higher steel qualities is that the weld must have the same strength as the base metal piece. To achieve such quality can be challenging and too much wrought of the base material may destroy the steel properties. Nordhordaland floating bridge, which was finalized in 1994 was designed with steel qualities up to 540Mpa to save weight. The entrepreneur did not understand the challenge that lay in such a job and made no money on that project. This particular entrepreneur has normally been operating in the offshore market.

Currently the most important manufacturer of steel bridges is Scanbridge in Sandnessjøen. 10 years ago there were at least 2 more companies competing in the same market. Important suppliers have been Alfred Andersen A/S in Larvik, Hø-sveis in Hønefoss and Meråker in Northern Trøndelag. Scanbrigde has close to a monopoly on steel bridges in Norway. Fosdalen in Malm in Nor-Trøndelag has been competitive within the smaller steel bridges market. The difference is that Fosdalen has only one possible assembly line, but Scanbridge has several.

Supply network:
Planning stage: Public Authorities (Central, County and Municipal) in cooperation with NPRA and private expertise regarding bridge design. See design stage.
Design stage: The design can be performed by Directorate of Public Roads, Bridge Technology Division, NPRAs county offices in Rogaland and Nord-Trøndelag, Aas-Jakobsen, Johs Holt, Reinertsen, Instanes, Smidt & Ingebrigtsen AS, Interconsult and Structuras.
Construction stage: Scanbridge is the most important supplier. Fosdalen is an important supplier for smaller bridges

For large structures can offshore companies do the design and construction work but they are normally to expensive. Alfred Andersen in Larvik may still have the competence but this is currently not core activity for them.

1.1.4 Timber Bridge Technology

The history of the timber bridge technology is a history of the use of a material that has a long and proud tradition in Norway. The material has had success regarding long lasting durability especially in inland areas with less rain like Hedmark and Oppland counties. Most extreme is the existing stave churches that are 800-900 years old. Timber is and has been central in Norway regarding construction techniques and architecture both for houses and other constructions. The advantage for timber has been easy access in addition to that it's easily workable and suitable.

Until the 1860`s, bridges have basically been built by use of timber for rigid frame bridges and truss bridges with spans up to 35 meters or with rocks like flagstone or vault bridges with spans up to 18 meters. Around 1870, the introduction of truss bridges happened after descriptions from USA.

Few bigger bridge structures were built with timber after 1900, except during World War I and II when access to steel as a structural material was limited. At that time bridges could be built with spans up to 50 meters based on limited traffic and use of horses and carts. With entry of the car and more heavy vehicles become the demand for new construction techniques. Especially trains and railways were important for development of new construction techniques in steel.

In 1960,glued laminated timber began to be used and introduced in Norway and timber as a structural material was used for the second time. Bridges built in Norway during the 60`s and 70`s were impregnated. A strong belief that this would give the bridges long lasting durability resulted in a lack importance in detail design and protection of the wood material. In addition, lack of maintenance led to bridges cracking. The surface disintegrated and bridges looked shabby. This led to the bridges getting a bad reputation and fewer bridges were built during the 80`s.

The Olympic Games in Lillehammer in 1994 was an opportunity to use larger dimensions for larger structures. Laminated wood was used in several huge buildings like the Viking ship and Kristin's Hall. The basis for the initiative was a result of amongst others, the R&D project "Timber visions" (ref. /26/) and the Nordic project "bridges built in timber". This happened independently and as a coincidence at the same time. NPRA Hedmark saw this as an opportunity to introduce timber as a alternative to challenge steel and concrete as a construction material also in bridges. A R&D project was defined and established in the autumn of 1992. The project was funded by the participants and the Research Council of Norway with 43 % (ref. /28/).

The participants in the initial development project were:

1. NPRA, Hedmark (ref. /30/)
2. Moelven Industries, laminated wood division (ref. /27/)
3. Norwegian Institute of Wood Technology (ref. /29/)

4. The central bridge division in NPRA (ref. /30/)

Based on previous experiences and an evaluation of projects abroad, the following construction concepts were defined:

- A visible and clearer load carrier system
- To combine aesthetics forms with attractive design based on simplicity and functionality
- Use of laminated wood and node design with plates and dowels in steel (to take bigger loads)
- Use of impregnation with both CCA and creosote in combination
- Emphasise on constructive protection and robust design
- Use of steel in transversal beam and other parts in steel for details gives a more optimal construction

In parallel based on this information, Nydalsdumpa a pedestrian and bicycle bridge in Ringsaker was built. Nydalsdumpa was the first bridge in the new generation of timber bridges. Based on that experience bigger bridges were designed for ordinary traffic loads. The two first one was Evenstad Bridge built over Glomma in Østerdalen (Hedmark county) and Løken Bridge which crosses highway 3 in Løten which become opened in 1996 was the beginning of a new époque within Norwegian bridge design and construction.

Figure 4.25 Tynset Bridge

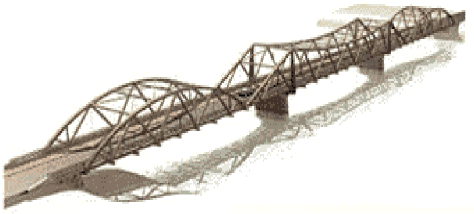

Figure 4.26 Flisa Bridge

A best practice for laminated wood bridges is Flisa Bridge The bridge was designed based on experiences from other timber bridges built lately, especially Evenstad Bridge and Tynset Bridge. The longest span on Tynset is 70 meter, for Flisa 70.5 meters. At an early stage a brainstorming session was held in Trysil to come up with a solution for a new Flisa Bridge. Several alternatives have been discussed but suggestions inspired by the old bridge became the winner. The superstructure could be built in steel or timber. Timber was chosen because the construction cost on this structure was competitive with steel. Flisa Bridge is currently the world's longest timber bridge with its 197 meters length divided in 3 spans. The bridge replaces an old bridge from the 1912 version built in steel. The new bridge has the same form as the old one and it is build on the same foundation. It has 2 full roadways and a separate walkway, the double of the previous bridge. The old bridge has been replaced because of a narrow road path and in addition the general condition of the old steel framework was bad with large corrosion problems and some collision damages.

<u>Supply network</u>

Planning stage: Public Authorities (Central, County and Municipal) in cooperation with NPRA and private expertise regarding bridge design. See design stage.

Design stage: The design can be performed by Directorate of Public Roads, Bridge Technology Division, NPRAs county office in Hedmark, Norconsult, Aadnesen, Statkraft Grøner, Reinertsen as and Svenska Trebroar

Manufacturing stage: Moelven Industries

Construction stage: The most important entrepreneurs were Mesta, Vegdekke, ECO-bygg and Svenska Trebroar.

1.1.5 Radical bridge innovations

Concrete and steel bridges are mature products and well accepted. The laminated timber bridges may have crossed the chasm but do not have the same respectability as steel and concrete structures. There exist different bridge concepts depending on required span lengths and soil conditions. Medium sized bridges are bridges with span lengths between 120 and 300 meters, big bridges are bridges spanning more than 300 meters. Dominant bridges greater than 300m in span length are suspension and cable-stayed bridges. Possible challengers are the Submerging Bridge, Floating Bridge, Hybrid Bridge or Tube bridges for longer spans. Such bridges are huge projects that represent *large* investments.

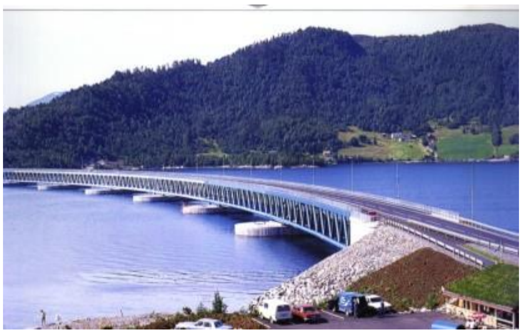

Figure 4.27 Nordhordaland floating bridge

Middle span lengths ranging between 120 and 300 meters such as free cantilever bridges have been the most competitive, but steel is more common for that range in Europe (/17/). Calculations indicate that an arch bridge in steel may clearly compete with the cantilever bridge but because of lack of experience with that bridge, the entrepreneurs will not take that risk without any compensation.

Examples of bridge concepts, which have not crossed the chasm, are the steel arc-bridge and the tube bridge. What have been mentioned are the **Steel Arc Bridge**, **Tube Bridge** and **Hybrid Bridge** the construction side, **aluminium** and **composite** materials on the material side.

Figure 4.28 Gimse Bridge, steel arc-bridge alternative. Sør-Trøndelag County.

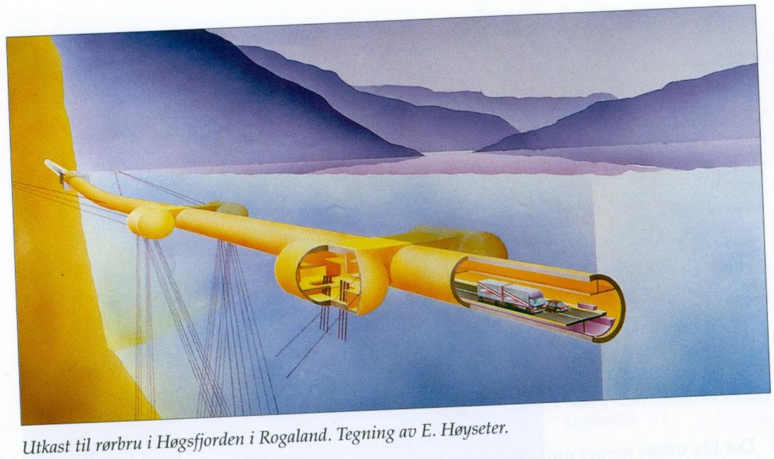

Figure 4.29 A draft of the Høgsfjord tube bridge concept. Rogaland County.

Figure 4.30 -Hologaland Bridge, Hybrid Bridge alternative.

The hybrid bridge has potential to reach spans up to 3000m. The hybrid bridge is an idea by the Norwegian consultant company Aas-Jacobsen. This construction technique is a combination of a free-cantilever, cable-stayed, and suspension bridge. The Hybrid Bridge has potential to connect Sicilia to the main land of Italy.

An example of a radical bridge innovation is the laminated timber bridge. Laminated timber bridges are a radical innovation, which have had commercial success. The most important materials used are **concrete** and **steel**. T**imber** technology is now challenging both these within a range of span lengths. This has happened in spite of doubts from many structural engineers about the durability of such bridges compared to those made from steel and concrete.

The laminated timber construction technique has been possible as a result of the following:

1. Timber bridges have aesthetics that people like
2. Enthusiasm for new technology
3. Correct timing. Norway is ready for this technology. There are some experiences with use of this material abroad.
4. The big hall constructions in connection with the Winter Olympic Lillehammer demonstrated the potential of the material. Especially Vikingskipet and Kristins hall.
5. Moelven Industries had knowledge and skills for the manufacturing of laminated timber, which was a basis for the development of timber bridge solutions in Norway.
6. Support from NPRA and others with R&D funding and support (bridge technology section, NPRA Hedmark).
7. Coincidence was an important factor. Several independent environments started to get interested about this possibility at the same time.

Xerox has some relevant experience with outsourcing R&D as part of their own venture company (/20/), and Ely Lilly did outsourcing of a lot of their R&D (/21/).

1.1.6 Radical bridge innovations

Out from the inquiries I have identified demand for 3 main categories bridges:

1. A lot of **smaller and middle sized bridges** in connection to expansion and improvement of the existing road network. These are often standard solutions and **based on well-known technology**, mostly built in concrete and some in steel. These bridges are especially relevant for bypass roads, main approaches and exodus roads in connection to the cities and repair of bendy and dangerous road sections in the main road network. The challenge for these bridges is standardisation and simplification of solutions to lower the manufacturing/construction cost. These are mature products with components adapted to each other over a long period of time. This is why sub optimisation on one component may lead to a row of changes on other component that is also standardized. The development may therefore be too high. This effect is known also from other industries. Among other reintroductions of timber as a material in the house construction industry is Sweden (ref. /53/).
2. **Middle sized bridges with more identity and more focus on aesthetics**. This is in connection with development of more proper cyclists and pedestrian networks in towns and densely populated areas and overpass bridges. These bridges will have more variety with respect to the use of material and construction techniques. The characteristics about these structures are that the design and construction may be a bit higher than the standard bridge solutions. The architect has a more central role when other bridges life cycle`s costs are more central.
3. Transport of people and goods are more expensive in Norway than other countries, because of long distances and narrow and bendy roads. There is a need for **larger bridges with long spans to cross wider valleys and fjords** to make Norway more efficient. The distances in Norway are not a competition advantage for Norwegian industry. New construction techniques and further

development of existing construction techniques has made it possible to stretch span length gradually. There are 2 floating bridges that have been built and the tube bridge is at the idea stage. Norway has long tradition in using suspension bridges, and we have some examples of using cable-stayed bridges. The characteristics about these construction techniques are the development cost is high, and that these bridges are not built every year. The challenge is to take care of the knowledge gained during construction of these bridges and to be able to develop these structures further. One way of taking care of and developing the team/technology further is to export these ideas/innovations to be used abroad. The last idea that the consultant Aas-Jakobsen introduced is the Hybrid Bridge. This construction technique may be built with a main span up to 3000 meters which is far in front of the existing world record. Lately has Norwegian Technology Network become established. This is an agreement made that binds NPRA to assist in the marketing of products and services abroad. Aas-jakobsen is a part of this agreement.

Materials:

1. **Concrete** is the most common material used in bridges. It is more commonly used in Norway than other countries in Europe. The reason for this is historically based. It could be produced without buying products from abroad. Currently NPRA is in front in Norway with respect of the development of high strength and durability. The offshore industry earlier on with its deep platforms was the main developer. NPRA has several people engaged full time in R&D on the development of concrete products.

2. **Steel** is the second material. Offshore is dominant in R&D of this material. NPRA has no employees with an emphasis on metallurgy and welding techniques, and has less focus on R&D on steel material.

3. **Timber** has strengthened its position after several bridges built with the use of this material. The knowledge on how to handle timber is based on experience from the house industry in Norway. Moelven Industries has manufactured laminated wood beams for several decades. The experience with this material is still limited compared to steel and concrete, so there are still some excitement connected to the maintenance costs and durability of these structures.

4. **Aluminium** and **composite** materials has been used. These materials are currently not seen as a big challenge to concrete, steel and timber.