BRIDGE CROSSING THE TRONDHEIMSFJORD

Technical solution and benefits to society

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ABSTRACT

The Trondheim fjord is approximately 130 km long. The Trondheim metropolitan area, with about 200,000 residents, is located on the south side, midway into the fjord. Fosen is a geographically large area north of the fjord with about 25 000 inhabitants. The distance between Trondheim and the center of gravity of the population of Fosen, is about 40 km by road and ferry. The ferry distance is 7.5 km. The alternative is to drive around the fjord, a distance of about 160 km. The ferry is used by most people. The average daily traffic is about 2,900 cars. It is slightly less than the top three ferry connections on the E39, but more than the other E39-connections.

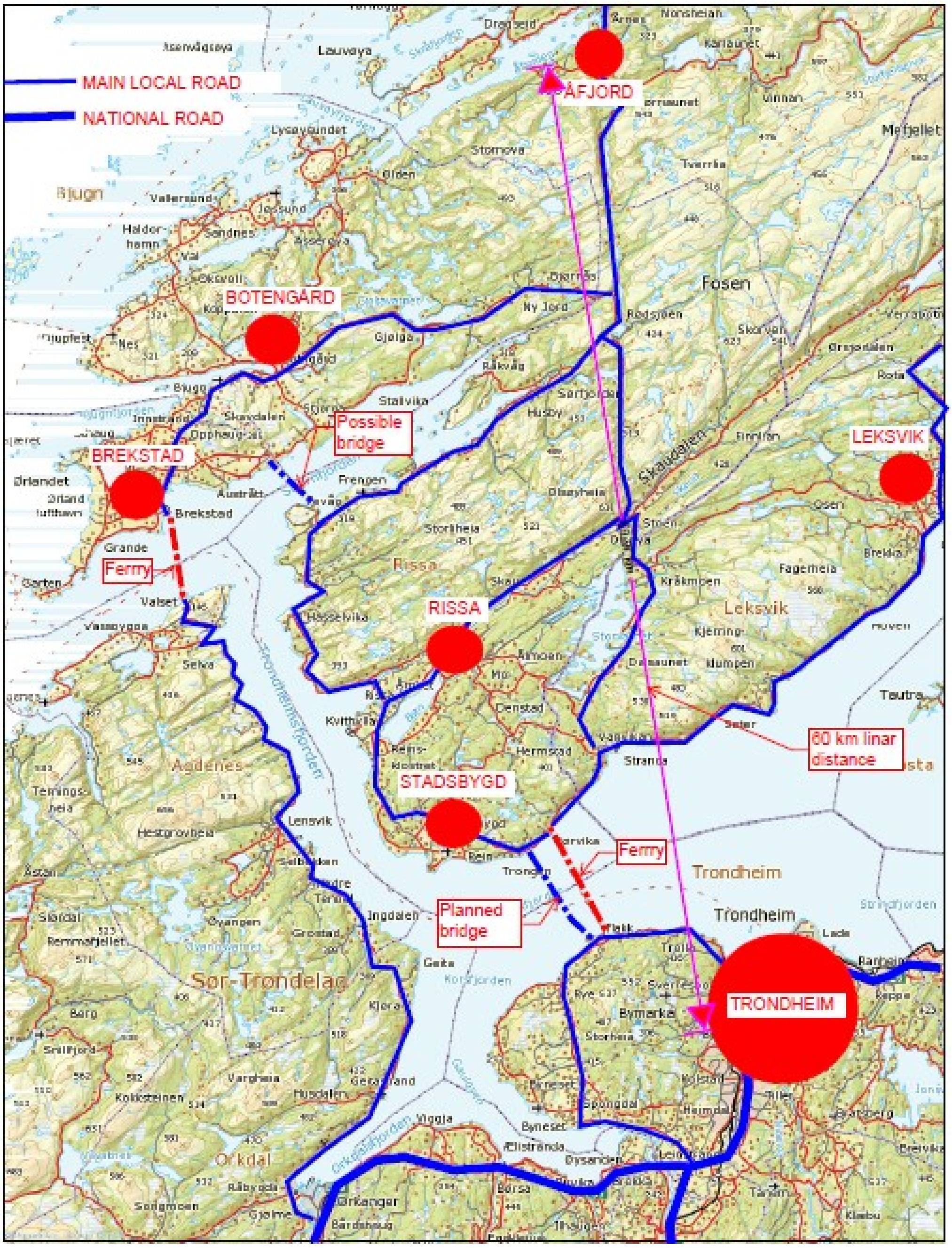
The ferry crosses where the fjord is narrowest. A bridge should be in approximately the same area. If construction is approximately linear, but adapted to topography, it will be about 6.7 km long. The water depth of the fjord along the south side, running for about 1 km, is between 50-100 meters. In that area it is possible to construct a fixed bridge, most likely a cable-stayed bridge. Over the rest of the fjord the depth is about 500 meters to the bottom of the sea and about 1000 meters to the rock. Soils are largely assumed to be clay, at least at the top. In this part, a floating bridge with sideways anchoring is the most appropriate solution.

Rough estimates are made regarding costs and benefits. Cost is estimated between 8 and 15 billion NOK. The expected value is 11.5 billion. It is envisaged that users benefit and saved ferry costs estimates will be 350 million NOK per year at current traffic rates and a possible doubling some years after completing the project. The project is likely to have positive benefits to society calculated according to current estimation methods.

The environmental impact of the project in the operational situation will probably be very positive. Today's traffic will spend 14 % of ferry and High Speed Vessel fuel currently used on the stretch. Traffic will redistribute to a route with shorter driving distance. That will also provide significantly reduced fuel consumption. But the bridge will probably also create new traffic as a result of lower generalized driving costs. The net environmental impact of changes in traffic volume is not calculated, but it can be both positive and negative.

GEOGRAPHY AND POPULATION

The Trondheimsfjord is today crossed by ferry between Rørvik and Flakk. This is the fifth largest ferry connection in Norway. It is used mainly by travelers between Fosen and the Trondheim area, but is also the main connection between Fosen and destinations south of Trondheim.



Figur 1 Roads and towns on Fosen.

About 25 000 people live in Fosen while about 250 000 live in the Trondheim area. The nearest part of Fosen is located about 20 km from central Trondheim with 7.5 km of that distance being covered by ferry. Other villages or towns are located at distances of 40-100 km using the existing roads.

If the ferry were to be replaced by a bridge, one could achieve a journey time of less than one hour between all the larger towns on Fosen and the city of Trondheim. It will provide a time gain of ½ hour during the daytime and somewhat more in the evenings and at night time.

Figure 1 shows the towns of Fosen, the most important main roads and the two ferry routes that cross the fjord. Linear distance between Åfjorden and Trondheim is about 60 km. The current road distance to Brekstad (where Norway's main military air base is located) is about 100 km, including the ferry distance. This can be shortened to about 65 km, but it requires an additional bridge crossing at Stjørfjord. The latter can probably be built with relatively traditional technology, e.g. suspension bridge with a main span of approximately 1400 meters and total length of about 2800 meters.

TUNNEL CROSSING UNDER FJORD IS HARDLY FEASIBLE

Trondheim fjord is wider than most fjords of western Norway. In the area of shortest distance between Fosen and Trondheim the fjord varies from 6.4 to 20 km wide. Where the fjord is narrow, it is about 500 meters deep with a further 600 meters to reach bedrock. This means that a tunnel under the fjord is not a question of where it is narrowest.

The possibility of a tunnel in an area north-east of Trondheim was investigated by SINTEF some years ago. East of Trondheim the rock level is higher. In principle it could be possible to find a tunnel solution, but the tube will be about 40 km long. The depth will be more than 600 meters. Figure 2 shows the depth to bedrock in different parts of the fjord

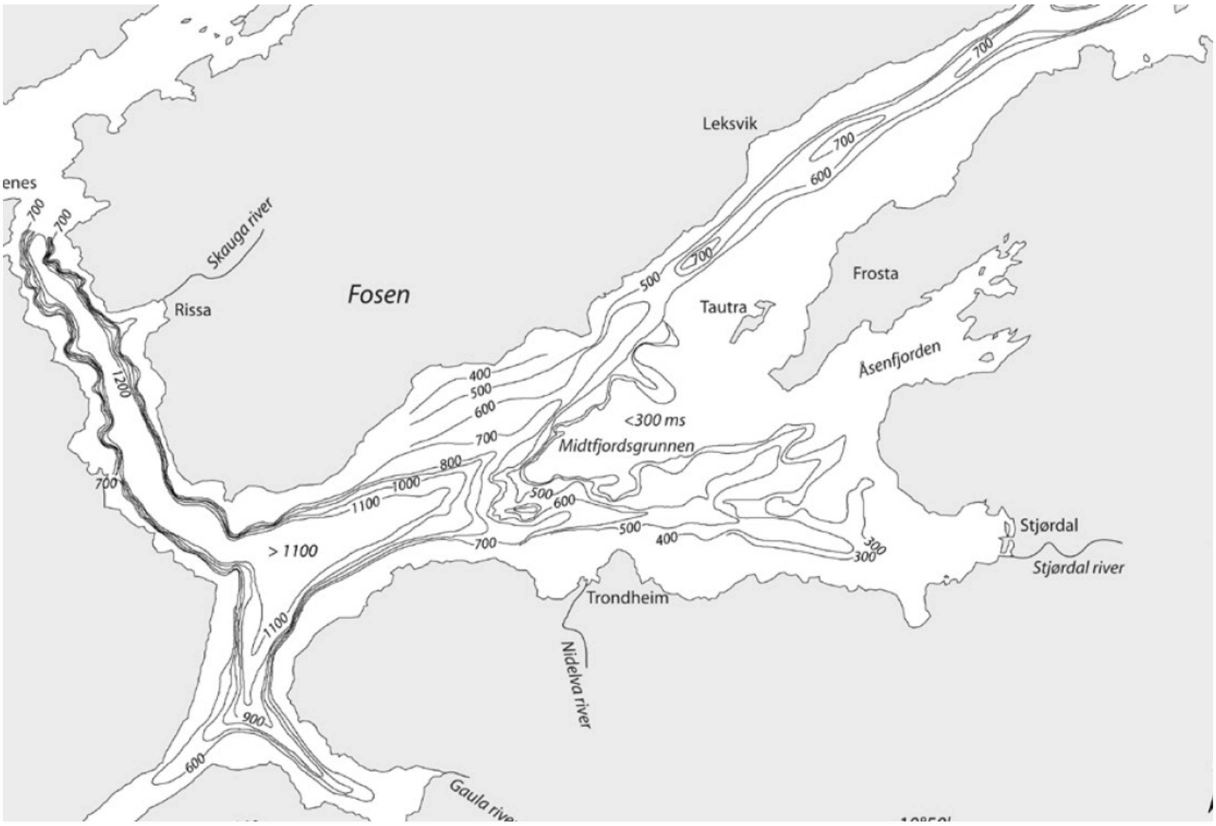


Figure 2 Depth to bedrock in the Trondheimsfjord. SINTEF, ref. 1.

It is perhaps technically possible to build a tunnel at depths greater than 600 meters, but it has not been done before. The deepest sections will need to be located relatively close to land on both sides. This means that the requirement for maximum gradient of 5%, will result in up to 10 km extra length on each side to raise height differences. Total distance between Trondheim and the traffic junction north of the fjord (Vanvikan) will be about 50 km compared with 25 km today, ferry distance inclusive. Travel time gains from such a solution would be modest. This is the main reason why we have focused our attention on a bridge where the fjord is narrowest and the travel distance on main routes is the shortest.

BRIDGE ADAPTED TO SHIP REQUIREMENTS

The requirements of the largest ships that sail along the coast of Norway and visit Trondheim also need to be accommodated. Sailing heights to be accommodated are still determined by the structures built in the fjord (offshore yard in Verdal). These require a height of 90 meters. Larger structures could be built, but have not yet been made. 90 Meter clear height is spacious and will allow all shipping. 70 Meters is a normal maximum. Ref. 2

The fairway should normally have a width of at least 200 meters. In a fjord with significant traffic where towing is also part of the traffic, it is desirable to have a wider fairway.

There are few vessels in use on the Norwegian coast with a draft deeper than 12-14 meters. Some offshore rigs may have a draft of 16-17 meters. The largest cargo ships in international traffic may have a draft of up to about 20 meters, but this is not relevant to the Trondheim Fjord. The large scale oil tankers with a draft of more than 20 meters will also not be catered for.

Basically, it is assumed that a 90 meter free sailing height, a width of at least 200 meters combined with a depth of at least 12 meters will be sufficient to meet all ordinary ships requirements. Desired depth of 16-20 meters will be met if possible.

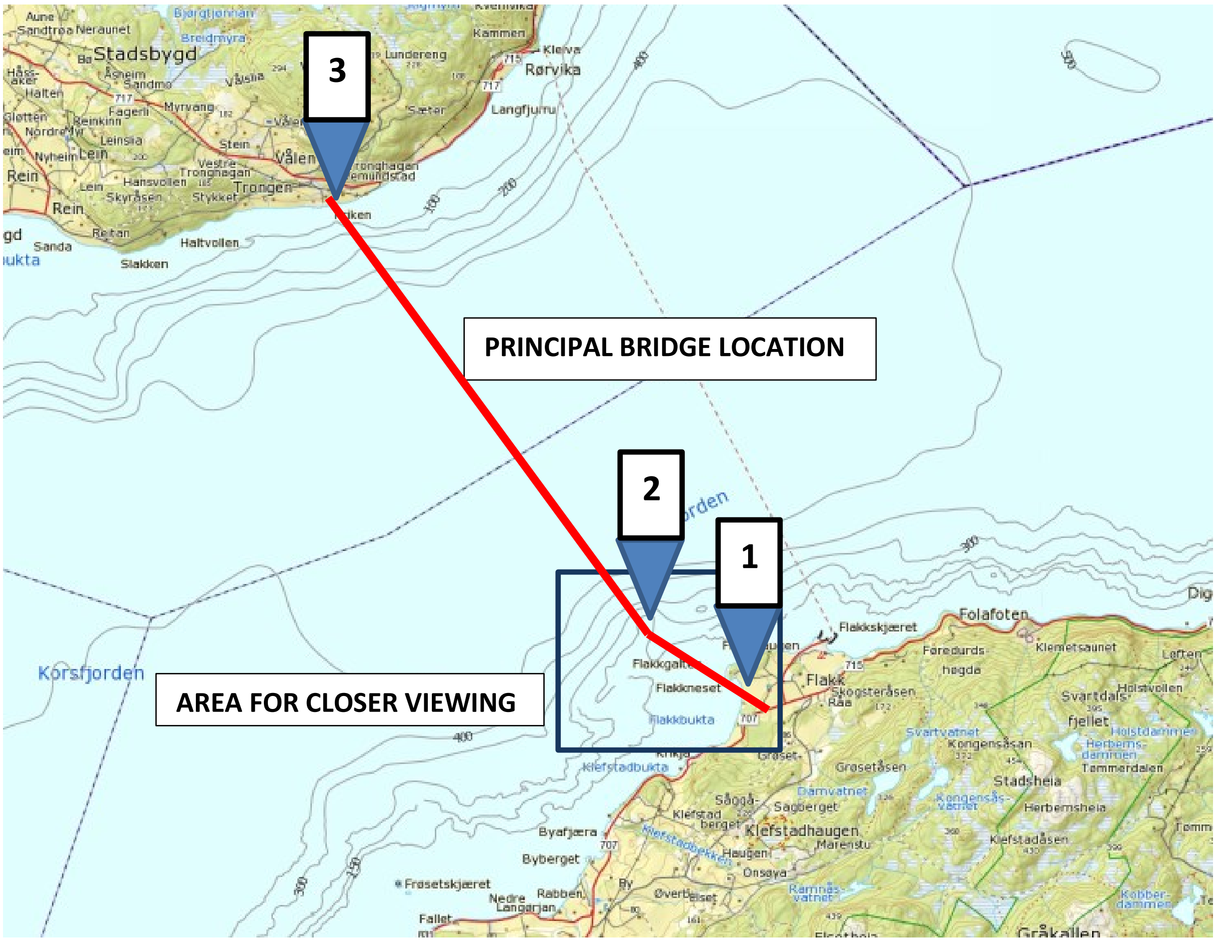
WIND AND WATER CURRENT

The nearest meteorological stations are at Orland and Trondheim. There is reason to believe that relevant wind strength will be covered by the results of these monitoring stations. During the last 10 years Ørland has had a maximum recorded wind speeds of 29 m/s. The maximum observed in Trondheim during the same period is 14 m/s. These winds are well below the values that must be followed in the design of structures.

Strong winds can cause a bridge to be closed because cars can be swept onto the guardrail. This is also an issue on mountain passes in Norway, especially during winter on slippery roads. Ørland has wind speeds of above 20 m/sec for 0.1% of the time. Beyond this speed, the bridge might need to be closed. This indicates that a bridge will rarely need to be closed due to strong wind.

There are significant differences in tidal water in the fjord. There are relatively strong water currents occurring twice a day. With the outgoing tide, the current moves westward along the Fosen coast. The direction is the opposite with the incoming tide. On the Flakk (south) side, the pattern is more complicated.

AS SHORT A BRIDGE AS POSSIBLE



Figur 3 Principal bridge location

At its narrowest, the fjord has a width of about 6.5 km. It is considered possible to place ordinary space built structures at depths of up to about 100 meters. This will normally be based on the foundation of rock. Optimistically considered, this still leaves 5.1 km between the possible permanent structures. As the longest practical length of suspension is about 2 km, only floating structures of some form are therefore conceivable. Another option would be to build floating towers which are lowered onto the seabed as has been done in the North Sea. But the largest construction of this kind made to date is the Troll platform which is sited on the depth of 302 meters and is 472 meters high in total. The depth of the Trondheimsfjord is 500 meters.

Based on the analyses that the Norwegian Public Roads Administration have made in connection with plans for E39 (without ferries) (ref.3), we have concluded that a "traditional" floating bridge with a length of approx. 5.7 km is the most appropriate and interesting solution. This would be constructed between the support on an underwater reef (marked 2) and land on the north side (marked 3) as shown in Figure 3. Point 2 is on an underwater mountain reef with a length of several hundred meters and depth of about 55 meters.

Between land on the south side of the fjord and the underwater reef, there is 1.1 to 1.3 km with a maximum depth of less than 97 meters. In this section it is possible to construct several types of structures. A cable stayed bridge with one tower on Flakkskjæret (point 1, rock above sea level) and span of 700 meters to either side, could be a solution. A cable stayed bridge with two towers could be another solution. A tunnel solution in one form or another is also conceivable.

FLOATING BRIDGE

A pontoon bridge with a length of 5.7 kilometers or more has not previously been constructed. The longest in Norway has a floating portion of 1246 meters. Both ends are anchored in rock onshore, but without additional anchors. The arc of the floating bridge deals with the horizontal forces. The longest in the world is more than 2 km long, with side anchors in shallow water.

It is believed to be necessary to use side anchoring in one or other form. Basically, we assume it will be pontoons at 150-200 meter intervals, with every second pontoon being anchored to the bottom on both sides, ie 300-400 meters between each anchorage.

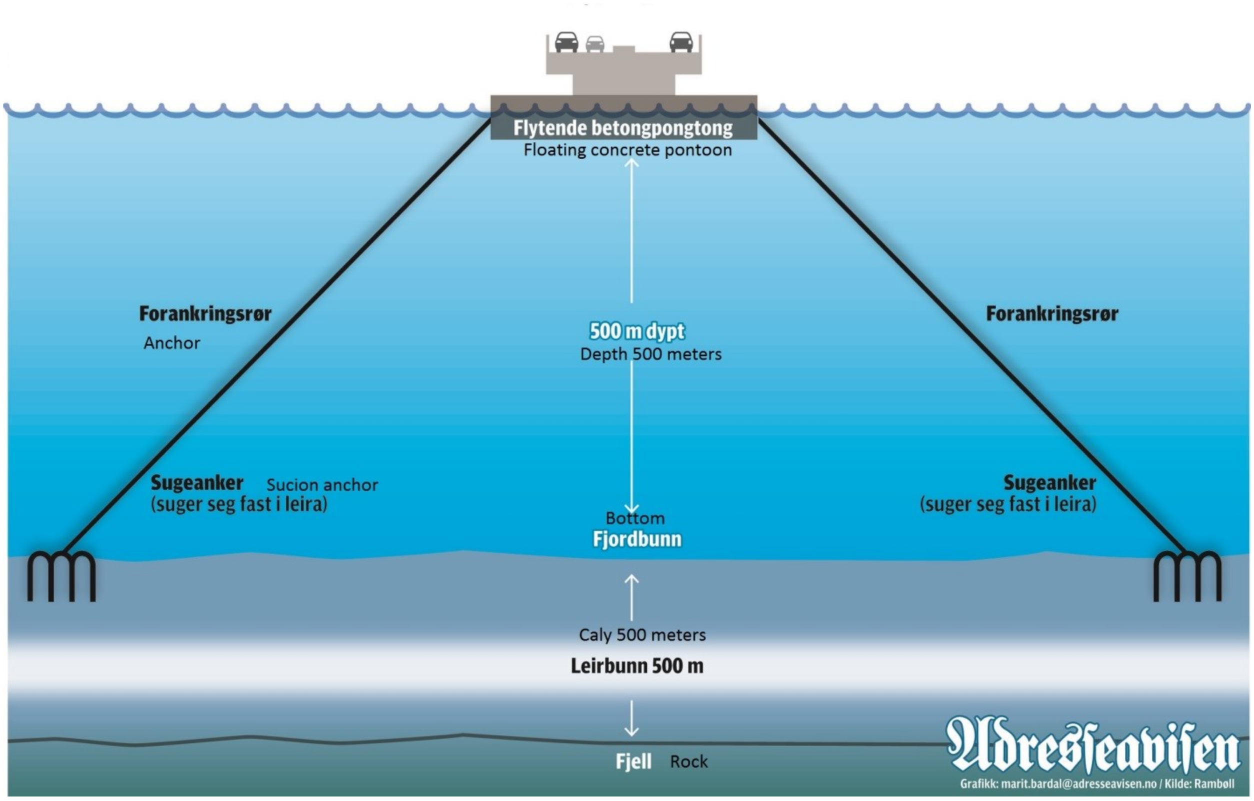


Figure 4 Principle of side anchored pontoon

Figure 4 shows the anchor solution in principle. The demonstration of suction anchors is demonstrated. This is an anchor solution which is widely used with platforms in the North Sea. The bottom of the Trondheim fjord is supposed to be well suited for the use of this type of anchor. Each tether is about 700 meters long. They are made with the same density as water so there will be no deflection. There are several solutions to address this problem.Ref.3.

ORDINARY BRIDGE

There are in principle many solutions for a solid bridge between the southern bank and the shallow rock at – 55 meter, about 1000 meters off the south bank of the fjord. In principle it is also possible to imagine tunnel solutions, a mountain tunnel, submerged tunnel or combinations of the above. Figure 5 illustrate the assumed most appropriate solution.

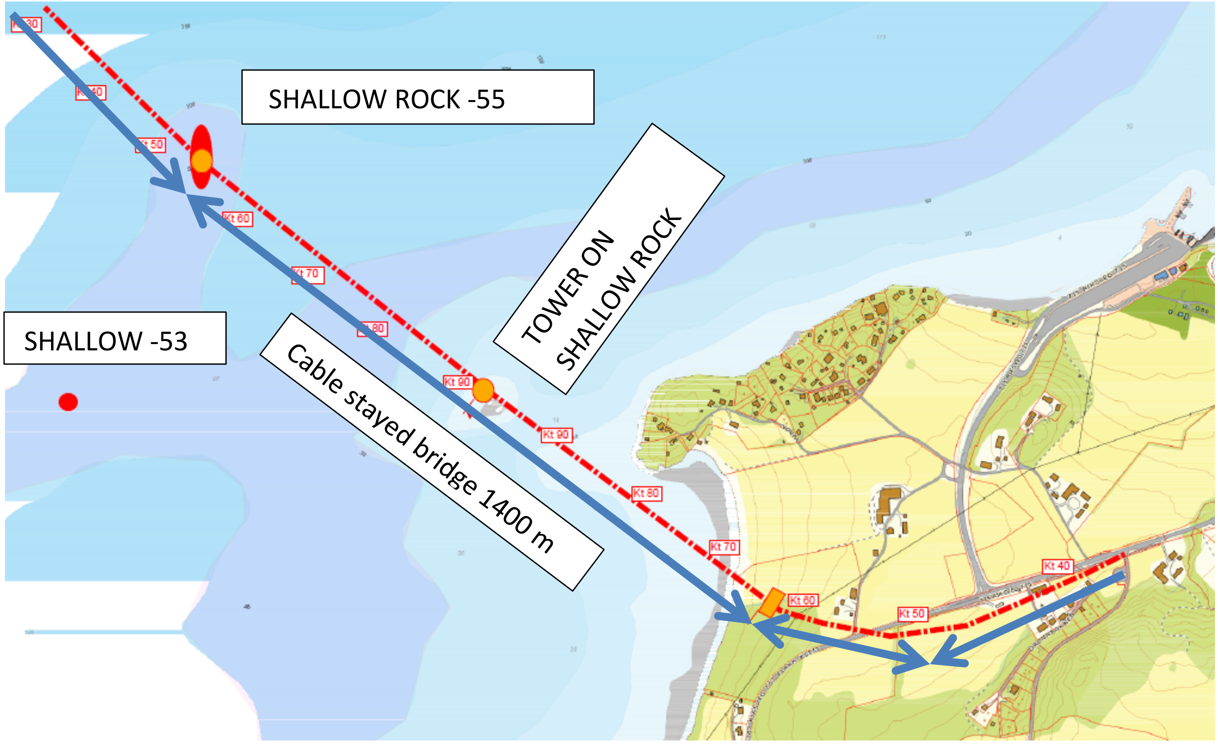


Figure 5 Road alignment close to south bank.

So far it is assumed the bridge is the most appropriate. The maximum depth is 97 meters in the area between the shallow reef and the bank. The shallow reef is approximately 800 meters long, running perpendicular to the direction of the bridge. It has at least two distinct peaks, both at about contour line -55. The north peak, which has the best location in terms of the shortest total bridge length, after investigation, was found to have rock on the top with only small amounts of soil above.

About 300 meters from the shore is shallow rock that rises a few meters above the top water level. It is suitable for the placement of a bridge tower, e.g. for a 1400 meters long cable stayed bridge. But it is also possible to imagine several other types of bridge solutions.

It is possible to establish a fairway with clear height of 90 meters and width of 200 meters. It is natural to have the highest point between land and reef closest to land. The water depth is limited to about 10 meters, but it has little practical significance for current use. On the other side of the tower there will be a 600 meter wide fairway with height varying from 60 to 90 meters. It should be comfortable for all current ships.

INVESTMENT COSTS

A detailed cost estimate is not done, just an estimate based on the unit costs indicated by E39-assessments, ref 3. It is based on the following assumed unit costs:

- Cable stayed bridge, 2.2 million NOK per meter
- Floating bridge, 1,5 million NOK per meter
- Viaduct bridge, 0,4 million NOK per meter
- Roads, 0.1 million per meter

Based on these assumptions, the total cost of the fjord crossing project will be approximately 11.5 billion NOK. This is an estimate that would normally have an uncertainty of + - 40%.
In addition to the investment costs are annual operating and maintenance costs for the bridge. These have not yet been calculated.

Road users will experience a higher car costs. Since the bridge will remain at approximately the same location as the current ferry route, the increased distance per car is about 7.5 km. This gives an additional annual car cost of NOK 19 million for current traffic and 27 million at 40% traffic growth.

For society, it is possible that other indirect costs will appear. There may be longer sailing routes, aesthetics problems, environmental conflicts, conflicts with other interests etc. We do not anticipate major problems with the above, in this particular case, but they have not yet been analyzed.

BENEFIT FOR SOCIETY

Such projects tend to introduce many beneficial elements to the communities. Some of these are included in the calculation methods used in Norway. For other elements, there is a discussion about how they should be specified. It is, however, recognized that previous methods used have underestimated the benefits of improved transport solutions. Ref.4.

The benefits of replacing the ferry with a bridge contain the following major components:

1. No operating and investment costs for ferries
2. The value of reduced travel time costs for ferry passengers.
3. The benefit of increased traffic
4. Transport opportunity available all hours of the year.
5. Regional economic effects, increased value of the resources in the affected area.
6. Reduced environmental costs, pollution to the air due to reduced energy consumption.

Point 1 can be easily calculated. It represents 85 million NOK annually at current traffic level. The amount will change proportionally with traffic.

To calculate point 2, there are established Norwegian computational methods. These are presently under revision. The "old" methods has been used. Time gain per road user can be set at 32 minutes plus hidden latency. Average hourly cost of road users can be set at 155 NOK. Today motorists will annually save time worth 200 million.

Other new items require a more thorough discussion.

INCREASED TRAFFIC

In those cases where fast road link replaces a ferry, there will be an immediate increase in traffic. If toll costs are about the same as the ferry ticket, it is normal to expect a traffic growth of about 40%. This is often interpreted as the newly created traffic, i.e. traveling as was previously not carried by other routes or to other destinations. This interpretation is wrong. To use this simple assumption will considerably reduce the calculated economic benefit of the new bridge Flakk – Rørvik.

A new road solution providing shorter travel time within a network of roads, will in principle attract these types of "new" traffic:

1. Traveling previously carried by other routes. This effect can be great in a network, and small when alternative routes has not easily accessible. The result is usually reduced traffic as a total.
2. Traveling that was previously done by other modes of transport. This effect is generally small where car and bus have little competition from other modes.
3. Travel that previously had other destinations. This effect might be large. This can both increase and decrease traffic as a total. New destinations can be more attractive than the old. That increases total traffic. But they may also have the advantage of reduced distance. This reduces traffic.
4. New travel activity occurs as a result of reduced travel costs on the stretch. The result is net increased traffic.

The ferry crossing Flakk - Rørvik is competing with at least three other travelling routes between Fosen and Trondheim. Some use the ferry Brekstad - Ørland and car via Orkanger, others use the car via Skarnsundet bridge/Innherred and finally a high speed vessel Trondheim – Vanvikan, combined with bus or car on Fosen.

The first two options do have about the same travel time as the use of car via ferry Flakk-Rørvik. They will therefore receive the same benefits from the new bridge as current users of the ferry. 240 000 ferry travelers per year changing to the bridge have been estimated. Those traveling via Skarnsundet today will also have a reduced traveling distance by car. Reduced ferry cost Brekstad - Ørland due to traffic reduction is hardly expected and therefore not included in the calculations. Community benefit is estimated at 32 million NOK per year, considering all current additional road traffic between Fosen and Trondheim.

Current travellers using the fast speed vessel Trondheim - Vanvikan can use a bus across the bridge. They will save travel time compared with today’s situation, but not as much as the current ferry passengers. Current traffic is 200,000 passengers per year. This provides hourly frequency on busses with 18 departures per day. This is better than the current boat frequency. Net benefit by saving travel time for passengers, saved speedboat costs and increased service costs for bus provide a net benefit to society of about 28 million NOK per year.

NEW DESTINATIONS AND NEW TRAFFIC

The bridge will make it more attractive for people from Trondheim region to travel to Fosen, as commuters or for recreational purposes. This will partly be travel replacing travel elsewhere with similar opportunities. It may in sum create more traffic, but also possibly less.

Similarly, people from Fosen will increase traveling to Trondheim, particularly as commuters and users of the opportunities in Trondheim, within commerce, culture and social networks. This will most likely create more traffic, but that is also the purpose! People on Fosen get easier access to activities that add value for them and thus to society.

It is extremely difficult to distinguish between real newly created traffic from traffic that would otherwise have gone to different, but less valuable destinations. Considering the new created traffic, it is reasonable to set the value of society benefit per journey to half the value of existing traffic journeys. New transport users appreciate improved transport opportunity less than previous users. The consequence is less society benefit when making calculations for new users.

Possible dimension of the traffic increase Trondheim - Fosen after establishment of the bridge might be estimated by comparing areas with the same road distance to Trondheim, but with shorter journey times. Table 1 compares the ratios of passenger travel between sites along the E6 south of Trondheim with that of Fosen.

Table 1 Travle frequencies between Trondheim and surrounding region. Journys/day.

Area	Distanse from Trondheim city	Number of inhabitants 2009	Car	Bus, train or boat	SUM
Melhus	15 - 50 km	14500	1,12	0,12	1,24
Midtre Gauldal	50 - 80 km	5900	0,40	0,06	0,45
Fosen	20 - 100(70) km	25000	0,18	0,04	0,22

Fosen cannot expect to have the same travel frequency as Melhus. Most of the buildings in Melhus are located 20-30 km from the city of Trondheim. But with the bridge established, it is least could expectable to have a similar travel frequency as between Trondheim and Midtre Gauldal.

The calculation of the effect of the first year is based on the assumption that the travel rate key figure will increase by a quarter of the difference between Fosen and Middle Gauldal. This provides new traffic of about 460,000 passenger journeys. Some of this is really new, and some results from changing destinations. Benefit to society per journey is set at half of the estimated benefit of current ferry users. Calculated societal benefits are 28 million NOK for the first year.

CALCULATED SOCIAL BENEFIT FROM BRIDGE FLAKK - RØRVIK

Calculated benefit to society for the new bridge is calculated to be 351 million in the first year. It is the sum of saved by reduced ferry and high speed ferry costs by 110 million as well as time benefit to road users of 267 million. The sum of these benefit figures is reduced for car expenses increasing by 16 million and bus service costs increasing by 10 million.

Today's passengers number on the ferry about 1.6 million per year. Along with traffic being transferred from other routes, this will provide bridge traffic of 2.1 million passenger journeys in the first year. In addition the bridge will receive approximately 0.5 million passenger journeys from other destinations and created new traffic. This calculated estimate which will be studied in detail at a later stage. The estimate corresponds to an average daily traffic of 4,400 vehicles.

It is unclear how this figure will evolve over time. The building of the bridge is likely to facilitate greater population growth in Fosen than the average for the Trondheim area as a total. In the last 20 years, all the neighborhoods of Trondheim, except Fosen, have enjoyed strong growth. A bridge will turn this picture around. It would not be unrealistic to expect that growth that doubles traffic would add benefit to society. Annual benefit of 700 million NOK per year within a period of 15-20 years might be realistic. Residents and businesses will benefit from the spacious areas that will be available on Fosen. It will reduce development pressures southward and eastward of Trondheim. A lot of people will regarded this as a significant advantage.

OTHER BENEFITS TO SOCIETY

The value of continuously available transportation all day and night, is controversial. It is included in the current numerical calculation methods by calculating the effect of hidden latency. Hidden latency contributes only with small figures in the calculation. In the same category is the factor reliability. At the traffic peaks you have the risk of lack of ferry capacity. The ferry may also have problems in bad weather conditions. Technical failure occurs with reduced capacity and frequency as a result. Estimation of these effects have not been attempted.

Better Traffic access to a geographic area will normally increase the value in use of the resources available in the area. The main resource is the existing labor and the infrastructure that serves labor. Residents in Fosen will become more effective participants in the relatively large labor market in the Trondheim area. This will increase specialization, innovation and thus power the value of labor in the whole area. Property values in Fosen will increase while they may be reduced in Trondheim since land supply will increase sharply.

Ferry and speedboat are using much fuel per passenger travelling a kilometer compared to car or bus for the same distance. In average situations the ratio is one to ten. This is also important for air pollution. But in normal situations the sea distance is the shortest, so when boat is replaced by car, the total change in fuel consumption is not that high.

The current ferry and high-speed traffic that will cease, has a fuel consumption of approximately 4100 tons per year. Increased car and bus traffic due to bridge will, consume approximately 560 tons per year. Annual fuel consumption is therefore reduced by about 3500 tons. This corresponds to about 11 000 tons of CO_2. In relation to the global environment, the bridge is a very good project considering operation costs and CO_2.

PRESENT VALUE OF BENEFIT TO SOCIETY AND RECOMMENDATION.

The economic calculations in Norway have until recent years used a 4.5% interest rate and a 40 year economic lifespan for roads by discounting future costs and benefits to present value. It is proposed that one reduce the interest rate to 4%. Other countries use 3.5% or lower in the corresponding calculations.

A bridge over the Trondheimfjord will have a technical lifetime of 100 years. One should certainly consider how the combination of interest rate, lifespan and period of calculation affect the present value of the calculated benefit. Table 2 shows the present value of 350 million per year using 15, 25, 40 and 100 year lifespans and calculation periods with different discount rates. Table 3 shows the same for 700 million per year.

Table 2 Present value for 350 mill/year. Bill. NOK

Economic lifespan	Interest			
	3,5 %	4,0 %	4,5 %	7,0 %
15	4,0	3,9	3,8	3,2
25	5,8	5,5	5,2	4,1
40	7,5	6,9	6,4	4,7
100	9,7	8,6	7,7	5,0

Table 3 Present value for700 mill/år. Bill. NOK

Economic lifespan	Interest			
	3,5 %	4,0 %	4,5 %	7,0 %
15	8,1	7,8	7,5	6,4
25	11,5	10,9	10,4	8,2
40	14,9	13,9	12,9	9,3
100	19,4	17,2	15,4	10,0

With an annual benefit to society of 350 million NOK per year, the project will not be of financial benefit in relation to calculated investment cost of 11.5 billion NOK in any of the demonstrated interest / lifespan combinations. With annual benefit of 700 million, the project will be economically viable with a lifespan of 40 years or more and the discount rate of 4.5% or lower.

Operation and maintenance costs of the bridge are not included in the calculations.. It also lacks other cost components, but they are probably relatively modest. On the other hand, the value of a continuously available transportation facility is not included. Other benefits may also occur as discussed.

It is not unlikely that the project is economically viable. Most Norwegian transport projects calculated in the same way are considerably less profitable than this project. The majority of projects having received funding from the government in the last 10-20 years may be in that category. They are implemented despite the lack of profitability calculated.

New computational methods are likely being introduced. They will give better profitability results than that of the old calculation method.

There might be a strong economic reason to bring the project forward as quickly as possible.

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