Statens vegvesen

Notat

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Vår dato: 23.06.2020

Technical note on swell conditions in Bjørnafjorden

Introduction

Throughout the project it has been challenging to determine the swell conditions in Bjørnafjorden, and since these waves are smaller than locally generated wind waves, they did not receive the same focus at the start of the project. But swell can still be critical in a scenario with swell and no wind. Since one then will be outside the range where pontoon radiation damping is large, and the lack of wind and thereby aerodynamic damping, gives low damping for such a scenario.

There are mitigating effects such as viscous damping on pontoons and mooring lines along with other passive damping systems which will reduce the importance of swell waves. But regardless, it is important to get predictions which is as good as possible for swell conditions and correlation with other environmental contributions.

In this note we will limit ourselves to discuss the work done to establish swell conditions in Bjørnafjorden, the present status, and what needs to be done to have an adequate description of swell conditions and correlation for design.

Conclusions

NORCE (2020) gives the most reasonable physical explanation for the presence of swell in Bjørnafjorden, but the wave energy levels they report are far too conservative to be used in design. Before wave diffraction and a more realistic reflection coefficient is included, and corresponding wave heights are verified against measurements, the results from these analyses should only be taken as a reasonable explanation of the physical process.

It is also noted from NORCE (2020) that most swell waves come from the south with a wave direction of approximately 200 degrees, and the largest waves are seen in the north of the transect selected for results. Since this transect follows the phase 2 road line, where wave buoys also are located, that means the present road lane to a large extent will be sheltered from these waves. The exact implications of this will have to be assessed with updated analysis in the model, but the present results seem to indicate that the largest waves will go straight ashore, the northern part of the bridge will be subjected to some swell and the southern part will be more or less sheltered.

Since most swell waves are reflected waves of Austneset just north of Stord, this also opens the possibility for mitigating measures.

The general conclusion from all relevant reports is that large offshore waves is needed to get any significant swell into Bjørnafjorden, typically associated with storm events which also will give strong wind. It is still possible that larger "pure swell" events might contribute with wave energy, but the magnitude is expected to be significantly smaller. With a full hindcast database the magnitude of such events can be identified.

The most reasonable way forward to establish a more robust and detailed description of swell conditions in Bjørnafjorden would be to generate a hindcast database of swell on site from a verified model. But we are not there yet, and it seems that we still must rely on simpler measures to estimate swell conditions.

The best way forward seems to be to generate a transfer function between NORA10 and measured low frequent wave heights at DWR3, then if model data is present to support it, generating a transfer function between wave heights at DWR3 and along the present road line. If we assume that the spectral peak period prevails from offshore, and that wave directions can be taken from simulation results, one can generate a reasonable hindcast database from these transfer functions and the full length of NORA10. But it is still recommended to focus efforts into establishing a verified model as basis for a swell hindcast.

Discussion

General

We briefly go through all the work done to establish swell conditions in Bjørnafjorden throughout the project. Also, some recommendations to further work are included.

Challenges and limitations using measured data

We have had wave measurements up and running for the past 5 years, which also captures swell waves. The main challenge with regards to measured swell waves are that they are small, so that it is difficult to distinguish between noise and actual waves. Experiences from wind sea events suggests that we can clearly identify events when the significant wave height (Hs) is larger than 0.5m, but since the largest swell event is about 0.25m it is difficult to assess the spectral information. But in my opinion the measured swell wave heights can be taken as an upper limit for actual wave energy on site.

Note that in this context, measured swell waves are taken as the integration of the low frequent part of the measured wave spectrum, for periods larger than 10s.

Summary of work done in the project

We have had 5 “contracts” where the scope or part of the scope have included investigations of the presence and magnitude of swell in Bjørnafjorden.

- SINTEF (2015) [1]
- Norconsult (2016) [2]
- DHI (2018) [3]
- Norwegian meteorological institute (2019) [4]
- NORCE (2020) [5]

In addition, we have performed some minor work internally, comparing and calibrating proposed models with in-situ measurements.

We will not do a comprehensive review of the reports here, but rather include a brief summary of conclusions related to swell conditions from each report.

SINTEF (2015)

Uses a nested SWAN model. The swell part of the report is not the main objective of the report, but rather a minor part where the model is run without wind forcing and 100 year offshore conditions. It should be noted that the model is run without reflection.

They conclude that swell contributions from both Korsfjorden and Selbjørnsfjorden will be of similar magnitude of 0.1m, with wave directions of 349 and 195 respectively. This gives a combined significant wave height around 0.15m. Results are given for 3 points in the middle of the crossing, and there is little variation between the 3 points.

Norconsult (2016)

Uses a model called STWAVE, which don’t account for reflection, to establish a set of transfer functions between offshore and inshore wave conditions.

In the transect of the bridge crossing they conclude with a Hs = 0.31m as the largest wave height for a 100 year condition. They also conclude that around 80% of the wave energy comes from NW whereas the remaining 20% comes from SW. Dominant wave direction 300 – 320 degrees. A general trend in the results is largest wave heights in the north of the crossing.

They have also investigated reflections from the north with a program called CGWAVE and concludes that reflected wave energy from the north into the location of the bridge crossing is small and considered negligible.

The conclusion is the main contributor to swell energy at the bridge crossing is due to refracted ocean waves from islands to the NW of Bjørnafjorden.

DHI (2018)

DHI is responsible the wave and current measurement campaign in Bjørnafjorden, and have in that context run some cases with Mike21 to gain knowledge of larger observed storm events. The most relevant in this context is given in chapter 3.7 where the hurricane Nina is investigated with different sets of parameters in the software. For reference the hurricane Nina is roughly a storm with a 50 year return period.

With regards to swell the two most interesting cases are a case run without wind forcing and a reflection coefficient of 0.5 and the same case but with no reflection.

Analysis with 50% reflection gives a Hs = 0.5m, whereas without reflection yields Hs = 0.22m. The report also shows a comparison between measured and calculated wave spectra for the time period, and it seems clear that the model with 50% reflection overestimates low frequent wave energy. Hence, it seems reasonable to assume that the actual reflection coefficient is smaller than this, but no attempts have been made to investigate this.

The results indicate that similar magnitude of wave energy comes from both SW and NW.

Norwegian meteorological institute (2019)

Uses a none-stationary SWAN model, with offshore waves from NORA10 spectral data, and wind forcing from calculated WRF wind fields, resulting in a 15 year long hindcast database. The wind generated waves from these simulations seem reasonable, but calculated swell is small, in the range of a couple of cm during storm conditions where other investigations and measurements have found a significantly larger level.

This SWAN model is run without any reflection, hence it seems a reasonable assumption, that if these calculations are correct, that refracted wave energy will be small, and that the governing contribution for wave energy from swell will be reflected wave energy. This is however not consistent with findings from Norconsult, where analyses also are run without reflection, and much larger waves from swell are found.

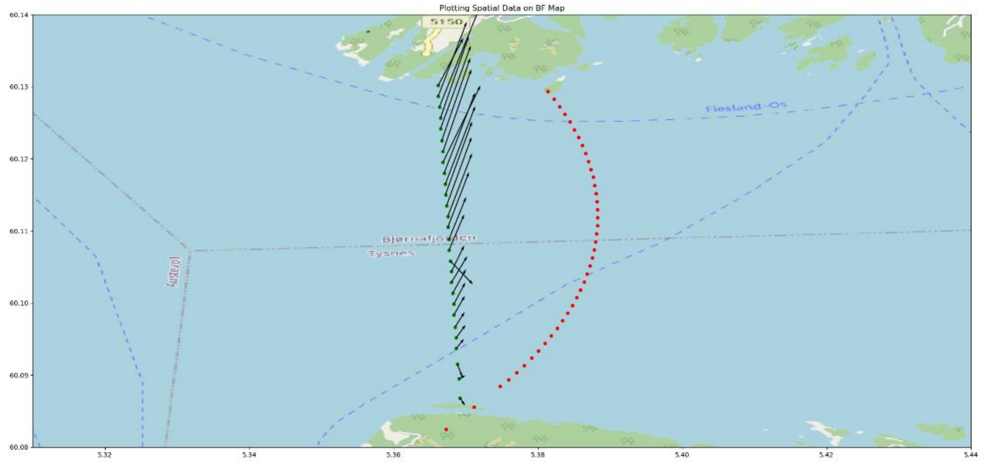
The general conclusion from this work is that we get reliable estimates locally generated wind sea, but the model seems to be underestimating offshore waves propagating into Bjørnafjorden.

NORCE (2020)

NORCE considers swell only, and do this based on a classical calculation procedure and an inverse ray tracing procedure. The differences between the two are significant, up to 6 times difference in the most severe conditions and locations. It is stated that the inverse ray tracing procedure indicate a theoretical upper level of swell. Which might be ok from an academic standpoint, but have limited value for us. Even though the wave measurement system in place is not without flaws, it would be safe to say that swell waves with such a magnitude would be captured, and we don’t see any indications that such a magnitude do occur.

From inverse ray tracing the main source of swell is reflection from Austneset just north of Stord, and is therefore highly dependent on which reflection coefficient is chosen in the analysis. In this report they have investigated a reflection coefficient of 0.5, 0.3 and 0.0, and the resulting largest significant wave heights along the bridge are 0.85m, 0.69m and 0.33m respectively. But it is uncertain which is the most realistic.

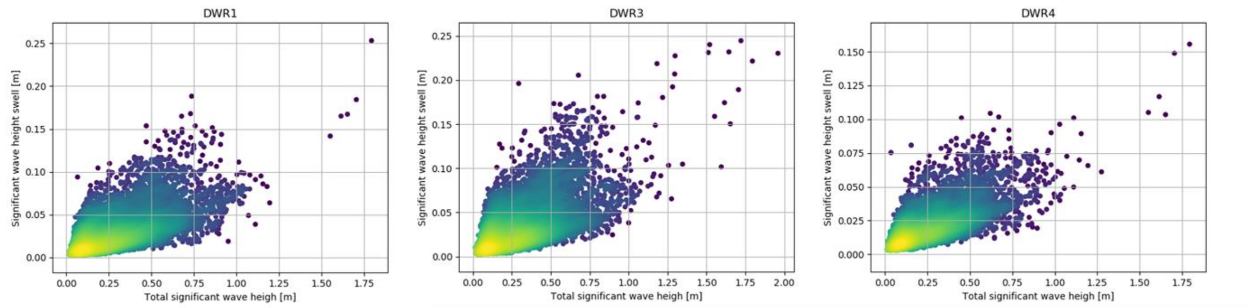
It is also noted that the main source of wave energy comes from the south, and with a fairly "steep" wave direction of approximately 200 degrees. Looking at the chosen transect across the fjord, it is evident that the southern part of the transect is sheltered and the largest waves occur to the north. This raises an interesting point, since the chosen transect is located along a straight line approximately following the phase 2 road line. The present road line is located slightly to the east and curving inward to the east. The consequence is that the critical wave trajectories documented in the report will go straight on the hit the shore and not the bridge, this is illustrated in the figure below.



That does not mean that some rays won't be able to reach the bridge, but that the largest ones reported certainly won't. Indicating that the proposed swell levels are overly conservative.

It is also noted that the inverse ray tracing method does not account for wave diffraction, which is likely to significantly overestimate the results. They also use unrealistically steep input wave spectrums, which also will tend to overestimate the results.

Observations indicate that the spatial variation along the transect is more evenly distributed than what the analysis results suggests, the largest observations are seen in the center of the crossing, and similar magnitude is seen to the north at DWR1. Roughly half the significant wave height is seen to the south at DWR4. See figure below.



NORCE have also stated that the model was very sensitive with regards to grid size, and have concluded that a grid as small as 15x15m was required. Which can be one part of the explanation why the conclusions between results from Norconsult (125x125m) differ so much.

They also conclude that the classical method yields unconservative results, these results are of similar magnitude as found in MET (2019), and I would agree that the wave heights are unrealistically low. Which is also supported by measured low frequency wave energy.

NORCE states that calculations indicate that ocean waves in Bjørnafjorden results from offshore waves generated by local low-pressure systems, i.e. storm events. From offshore wave directions from 255 to 275 degrees. This information along with an offshore hindcast is enough information to say something about correlation between environmental contributions.

If the conclusions are correct, and the majority of swell comes from reflected waves from Austneset, then it is also possible to introduce mitigating measures at this location, and thereby significantly reducing the magnitude of swell in Bjørnafjorden.

Discussion

It seems fair to say that the results from NORCE (2020) inverse ray tracing is a conservative upper limit. And in my opinion, the wave measurements show no indication that such high wave energy is present in Bjørnafjorden, hence the conclusion that it is far too conservative. On can certainly argue how well the measurement system works for small low frequent waves. But the waves we talk about here, at Hs=0.8m is certainly large enough to be clearly detected in measurements. And our experience from wind seas which in practice is significantly more difficult to measure, is that we can clearly identify events with Hs over 0.5m without any post processing. It is therefore considered unlikely that such large events with swell would go unnoticed.

All these models have a set of input parameters which when changed can give entirely different results. One will typically recommend using default parameters as much as possible in such software, but default settings are usually set up for typical application, which we most likely are well outside. It also seems that the model results are highly sensitive to bathymetry resolution. In my opinion, the use of model data which are not verified or calibrated against measured data have limited value, will always be topic for discussion, and it is nearly impossible to say for certain which of the models give the most credible results.

Although we expect the magnitude of swell from NORCE's calculations to be overly conservative, we do believe the physical principle to be the most reasonable.

If NORCE's calculations are correct, that means that the current road line for the most part can be sheltered from swell. It is recommended that this is investigated further.

Recommendations for further work

It is important to establish a reliable hindcast database for swell in Bjørnafjorden. This database should preferably be "linked" with other databases such as wind and wind seas such that it can be used to say something concrete about correlation between environmental contributions. This "link" is considered adequate if one uses offshore wave conditions from the NORA10 database as basis for calculations. A hindcast database is also necessary to establish more complete statistics for swell, preferably in terms of Hs-Tp contours. Spectral information of swell is also needed, both in terms of shape of wave spectra, directional spreading and wave direction. Along with information about spatial variation along the length of the bridge.

In a perfect world one would have a perfectly calibrated model to generate this database, then we would have all the information we need. But in the first place, I would strongly recommend that efforts are made to quantify a reflection coefficient, which will give a strong indication whether the general physical mechanisms are captured in NORCEs calculations. To gain understanding about what gives swell in Bjørnafjorden, and how this is distributed along the crossing is more important information to gain from the model than the actual energy level, for that we have other simpler methods. If one is to generate a hindcast from model data, it is strongly recommended to use a realistic offshore spectrum as input in the model, either a JONSWAP spectra with gamma 2.0 – 2.3, or preferably wave spectra directly from NORA10. And I would verify or calibrate this model against the measured low frequent wave energy from DWR buoys. If this is not feasible, the information can still be used to assess spectral shape, direction and spatial variation across the bridge. However, if one are not able to replicate measurements by the model I would be careful to accept that all wave energy comes from the south. It could then be possible to establish two scenarios, one with swell dominating direction from the south and one with dominating waves from the north. Both with corresponding spatial variation. But I expect that a verification of a reflection coefficient will give some insight to this. If a significant reflection coefficient is found, that would strongly support the findings from NORCE, i.e. that waves from 200 degrees will dominate.

If one are not able to establish reliable hindcast data directly from a model, it can be a possibility to use the same procedure as was used for the last phase of the project. But it is suggested to run more sophisticated calculations based on the database, like Hs-Tp contours and correlation between other environmental contributions. It is also suggested to calculate statistics for a pure swell scenario (with no wind) if relevant, which is an important condition for design.

The procedure that was used in the last phase of the project resembles that in Norconsults (2016), but instead of basing transfer functions on model data, we used the measured low frequent wave energy from DWR buoys along with the NORA10 database as basis. Initial transfer functions from Norconsult where used as starting point and calibrated against measurements with Q-Q plots. Since it seems there can be significant difference between swell at the location of wave buoys and the actual bridge location, it is recommended that transfer functions are calculated at the location of the present road line. To do this it is probably necessary with updated model data.

The disadvantage with this sort of procedure is obviously that you gain no information about spectral shape, wave direction or spatial variation. What you can gain from measurements on this topic is rather limited, and it is therefore recommended that this information is taken from model data.

References

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[3] "Wave and Current Measurements in Bjørnafjorden, Hordaland, Norway. Data Report 8", Project number 13800746, DHI, 2018

[4] "Wave conditions in Bjørnafjorden. SWAN-model simulations: 2002-2017(June). Validation, statistics and return value estimates.", Rev. 01, Norwegian Meteorological Institute, 2019

[5] "Ocean waves in Bjørnafjorden", REPORT 6070-T2019003-R000 - 2020, NORCE, 2020