**Appendix to report:**

SBJ-33-C5-OON-22-RE-022

MARINE GEOTECHNICAL DESIGN

**Appendix title:**

# APPENDIX B: SEISMIC EVALUATION

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|---|---|
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CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN

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Prodtex IFE Pure Logic HEYERDAHL ARKITEKTER AS H&BB MIKO MARINE AS BUKSÉR OG BERGING FORCE TECHNOLOGY SWERIM

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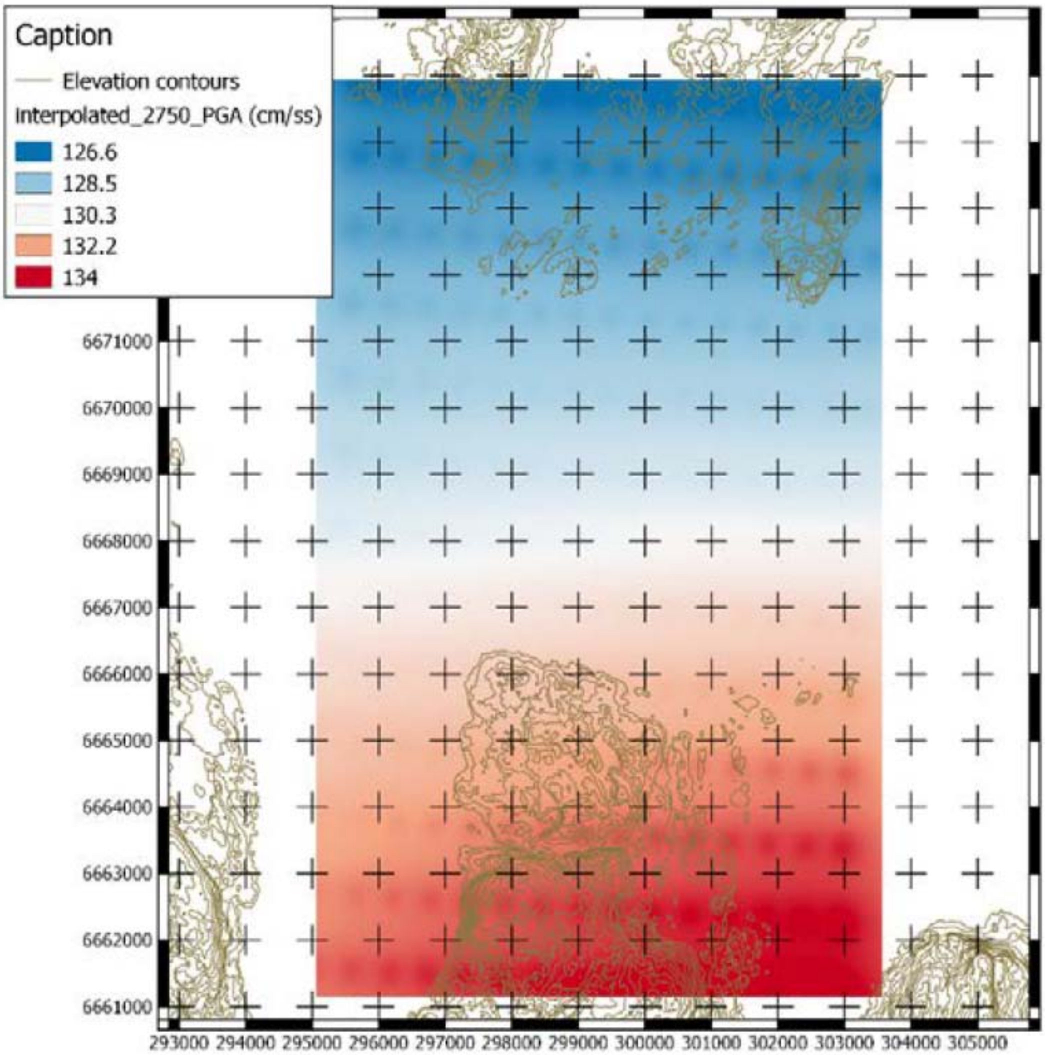
# 1 PSHA AND ACCELEROGRAM PROVIDED BY NORSAR

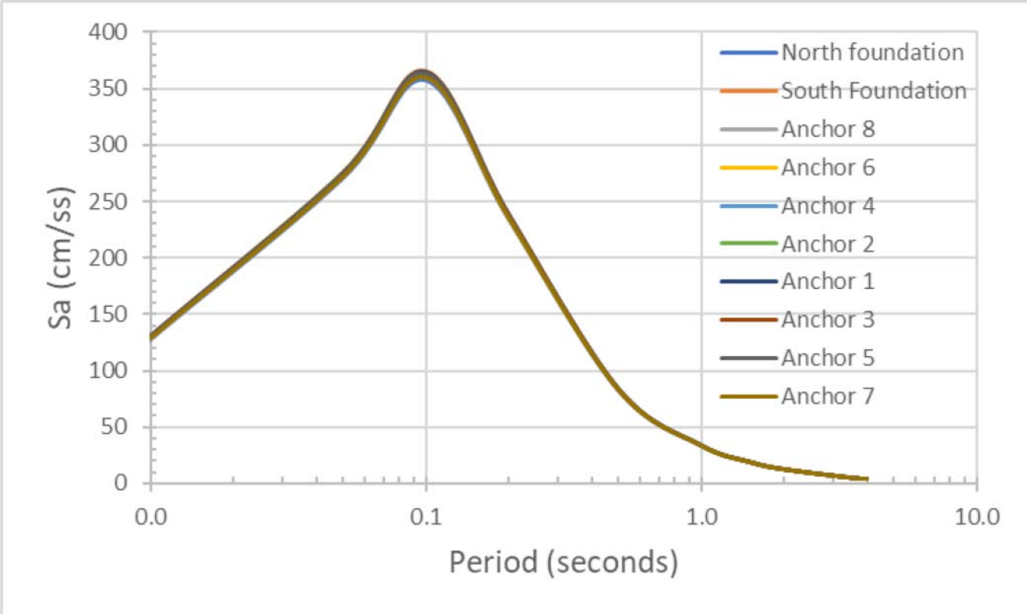
Seismic loading parameters have been developed for Bjørnafjorden by NORSAR and is more thoroughly described in ref. [1]. A short summary is given her.

The Uniform Hazard Spectra (UHS) has been developed for annual exceedance probabilities corresponding to 2750 and 10 000 years recurrence periods with an average shear velocity of $V_{s,30} = 1200\ m/s$. The Uniform Hazard spectra for 2750 recurrence period is shown below in Figure B-1. The figure indicates that the PGA is approximately 130 cm/s$^2$ on average.




> *Figure B-1 Hazard map for the region Bjørnafjorden for exceedance probability corresponding to 2750 years return period.*

Furthermore, the Uniform Hazard Spectra at 5% damping has been calculated at 10 discrete points in Bjørnafjorden, denoted by NORSAR as anchors 1-8 plus north and south foundation. These are shown in Figure B-2 and show little to none variation between the points. Thus, the results are representative for the current anchor positions in this document. Furthermore, the results validate the assumption of using a PGA of 130 cm/s$^2$ (0.133g) in design.



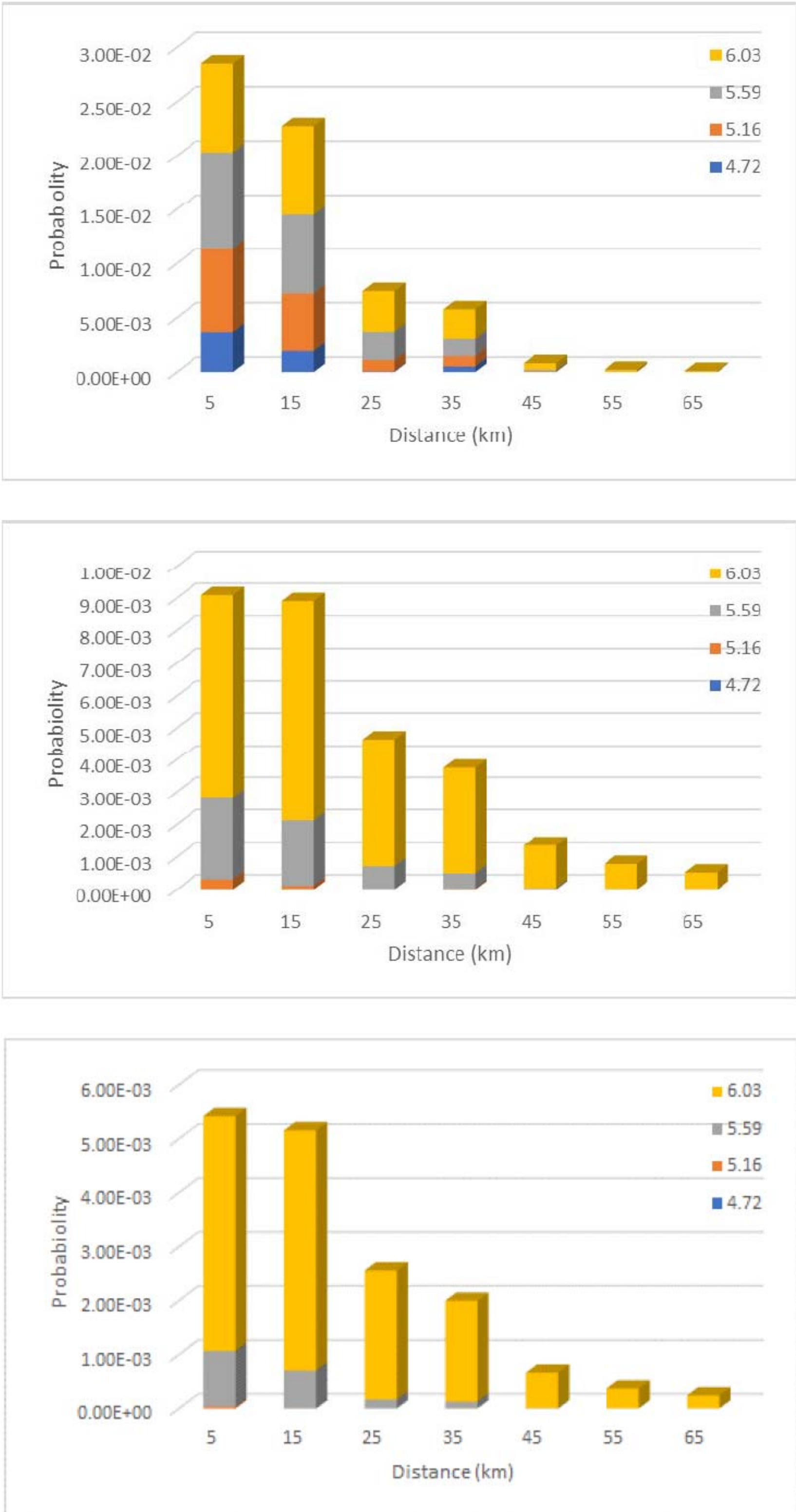

> *Figure B-2 Uniform Hazard Spectra at 5% damping for an exceedance probability to 2750 years return period.*

Based on the results, NORSAR has calculated a disaggregation for the 10 000 year return period. The disaggregation indicates which earthquake magnitudes, and distances that contributes the most the calculated probability for a given period. From Figure B-3 one can observe that it's magnitudes around 6.0 at distances between 10 and 20 km that gives the highest contribution. This information together with the spectral and PGA results was used to select representative ground motion from "Center for Engineering Strong Motion Data". Details of the provided accelerograms are shown below in Table B-1.

For geotechnical earthquake design the annual recurrence period is set to 2750 years, ref. [2] and [3]. Thus, the accelerograms provided by NORSAR are likely conservative. It's plausible that minor earthquakes, or earthquake of similar magnitude but further away is the ones which contributes the most to calculated probability for a given period. Therefore, in order to be more energy consistent, the time series have been scaled as described in Appendix B, chapter 2. However preferably a disaggregation for the 2750 years return period should be calculated and new time series selected based on this prior to detail design phase.

> *Table B-1 Earthquake details for the provided strong motion records.*

| Earthquake Name | Date | Hour | Min | Lat | Lon | Depth | Mag | Distance | Station | lat | lon | Chan | Orient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Whittier Narrows main shock | 01.10.1987 | 14 | 42 | 34.0493 | -118.081 | 15 | 6.1 | 20 | Mt Wilson | 34.224 | -118.057 | 1 | 90 |
| | | | | | | | | | | | | 2 | up |
| | | | | | | | | | | | | | 0 |
| | | | | | | | | | | | | | |
| Whittier afteshock | 04.10.1987 | 10 | 59 | 34.06 | -118.104 | 13 | 5.3 | 19 | Mt. Wilsor | 34.224 | -118.057 | 1 | 90 |
| | | | | | | | | | | | | 2 | up |
| | | | | | | | | | | | | 3 | 0 |
| | | | | | | | | | | | | | |
| Sierra Madre | 28.06.1991 | 14 | 43 | 34.2591 | -118.001 | 12 | 5.6 | 6 | Mt. Wilsor | 34.224 | -118.057 | 1 | 90 |
| | | | | | | | | | | | | 2 | up |
| | | | | | | | | | | | | 3 | 0 |
| | | | | | | | | | | | | | |
| Chamoli aftershock | 28.03.1999 | 19 | 36 | 30.315 | 79.387 | 10 | 5.4 | 15 | Gopeshwa | 30.24 | 79.2 | 1 | 20 |
| | | | | | | | | | | | | 2 | 290 |

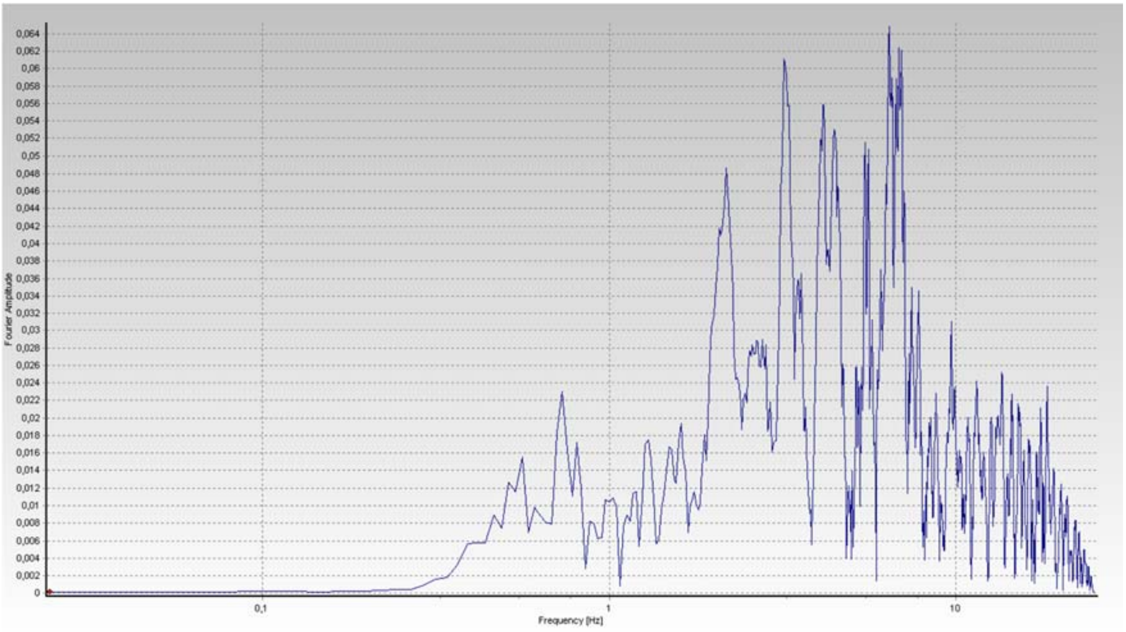



> *Figure B-3 Disaggregation charts for 10 000 years return period PGA (upper), 1.0 (middle), and 3.5 seconds (lower). The color indicates the contributions for different earthquake magnitudes.*

# 2 EARTHQUAKE PARAMETERS AND ACCELEROGRAMS USED IN DESIGN

The accelerograms provided by NORSAR are selected based on 10 000 year return period calculations. It's assumed that these time series are conservative and should therefore be modified. Preferably new time series which are more representative should be selected based on a new disaggregation analyses with a return period of 2750 years. The PGA 130 cm/s$^2$ as calculated by NORSAR is used as a scaling target for the provided time series.

Each ground motion has its own distinct feature and characteristics which can be measured in different ways. With respect to ground motion and eigenfrequency the Fourier transformation is often utilized to quantify the frequency content of an earthquake measurement. An example of this is shown Figure B-4. Although an earthquake can have high energy levels, this does not necessarily correspond to large motions. It's the combination of the frequency content of the accelerogram and the eigenfrequency of the ground that is of importance.

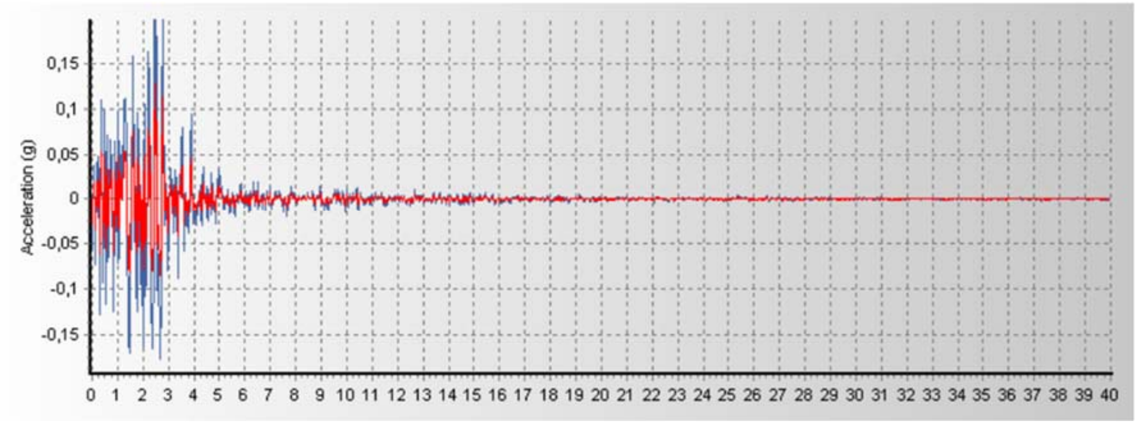



> *Figure B-4 Frequency content, i.e. Fourier transformation, of earthquake Sierra Madre - Channel 3 measured in hertz and amplitude.*

As a simplification the ground motions are scaled to match the 2750 year recurrence PGA calculated by NORSAR. This implies that the earthquakes from Sierra Madre, Whittier Narrows and Whitter Aftershocks are reduced. The earthquake motion from Chamolia has been excluded since it contains no vertical measurements. The time series are normalized with respect the highest PGA in either directions and afterwards scaled to the match the PGA calculated by NORSAR. The scaling factors are given in Table B-2 and an example is shown in Figure B-5.

> *Table B-2 Scaling factors used for the different accelerograms*

| Earthquake | Maximum PGA [cm/s$^2$] | Scaling factor |
|---|---|---|
| Sierra Madre | 270.63 | 0.48 |
| Whittier Narrows | 171.32 | 0.76 |
| Whittier Aftershock | 142.48 | 0.91 |




> *Figure B-5 Comparison of unscaled (blue) and scaled (red) ground motion, Sierra Madre-Ch 3 with time, normalized with respect to gravity.*

The effects of using a constant scaling factor is clearly visible in Figure B-6. The elastic response spectrum is reduced and is closer to the Ground type A spectra which is specified in NS-EN 1998-1:2004+A1:2003+NA:2014, ref. [4]. One can also observe that for certain periods the scaled motion exceeds the spectra given in the Eurocode while for other periods it is lower. This is to be expected for real measurements of earthquakes. A comparison of the different scaled ground motion is shown together with the Ground Type A in Figure B-7. Note that only the components (i.e. measured channels) with the highest acceleration is compared.

One can also observe from Figure B-7 that the ground motion from Sierra Madre has its peak acceleration at a higher period compared to Whittier Narrows and Whitter Aftershocks, and is thus expected to give more different results in dynamic calculations.

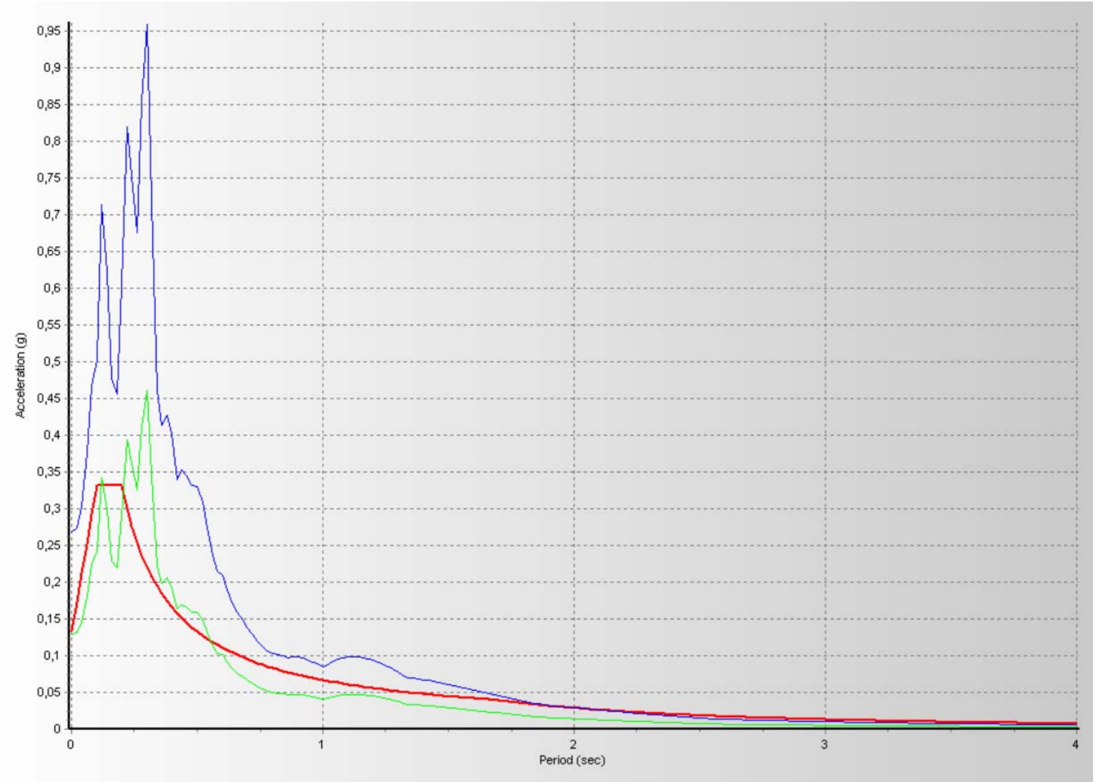
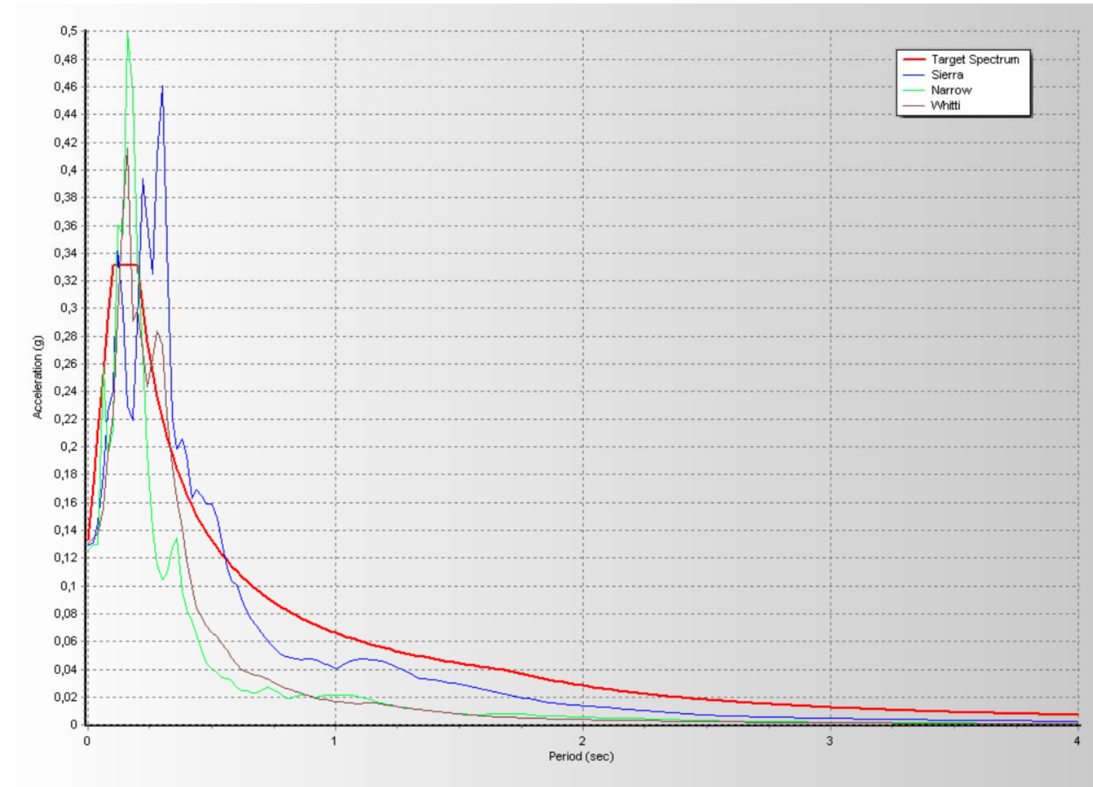



Figure B-6 Response spectra comparison of unscaled (blue) and scaled (red) Sierra Madre Channel 3 ground motion with Ground type A (green) according to Eurocode 8, table NA.3.3, ref [4], with 5% damping.




> *Figure B-7 Comparison of scaled ground motions to Ground type A (green) according to Eurocode 8, table NA.3.3, ref [4], with 5% damping.*

# 3 REFERENCES


[1] NORSAR, «Report Probabilistic Seismic Hazard Analysis (PSHA) for Project E39 Aksdal-Bergen (subproject E39 Bjørnafjorden) Tysnes/Os kommune i Hordaland,» June 2018.

[2] NPRA, «Design Basis – Geotechnical design Doc.no. SBJ-02 C4-SVV-02-RE-002,» 2018-11-12.

[3] Multiconsult/NGI/Aker AS. , «Bjørnafjorden, straight floating bridge phase 3 - Geohazard (Base Case). Doc.no. SBJ-31-C3-MUL-02-RE-100,» rev. O. 2017.

[4] Standards Norway, «NS-EN 1998-1:2004+A1:2003+NA:2014: Eurocode 8 Design of structures for earthquake resistance – Part 1: General rules seismic actions and rules for buildings».