Statens vegvesen

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Preferred solution, K12 – Appendix R
Risk assessment

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CONCEPT DEVELOPMENT, FLOATING BRIDGE E39 BJØRNAFJORDEN

Preferred solution, K12

Appendix R – Risk assessment

CLIENT

Statens vegvesen

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REPORT

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SUMMARY

Appendix R, Risk Assessments describes the risk management process applied for concept development and assessment of the four concepts K11 to K14. The objectives of the risk management process can be considered three-fold:

- An optimization of design choices and construction methods for each of the four concepts to achieve a balanced risk profile and identify mitigations that can secure budget/schedule and minimize risk of violating rules and regulations.
- A comparative risk assessment to identify and highlight inherent differences between concepts to be used for concept evaluation and selection of preferred concept.
- An assessment of preferred concept to identify and highlight strength and weaknesses as well as mitigation measures for this and coming phases.

The assessment is carried out for both risks related to the construction and installation phase as well as risk related to the operational phase. The resulting risk ranking is part of the overall concept evaluation.

Concept evaluations are given for both construction and operation and a resulting overall concept evaluation is presented based in the assessed significance of construction and operation risks.

Comparative risk assessments conclude K12 to be the preferred concept and in addition the most robust concept.

A specific risk assessment for the preferred concept K12 is undertaken to outline the weaknesses and on this basis give input to the design and the construction and installation methods in terms of identified risk mitigations for the significant risks in construction as well as operational phases.

The resulting risk registers for the preferred concept are presented along with an evaluation of the obtained result.

Evaluation of risks considering construction as well as the permanent situation for the floating bridge over Bjørnafjord shows that even though a number of significant risks are and generally will be part of such a project, there is identified no showstoppers for concept K12. Thus, the concept seems robust from a construction and an operational point of view.

0	15.08.2019	Final issue	I. B. Kroon	S. Wiborg	S. E. Jakobsen
REV.	DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY

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1 Introduction

Risks are an inherent part of both the design, construction and operational phase of a major infrastructure project such as the floating bridge E39 Bjørnafjorden. If identified and mitigated already in the early phases it will contribute to an optimized design and construction.

During this phase, four concepts are being evaluated and by the end of this phase one concept is selected. The concept selection is based on a comparative evaluation of cost, visual impact and risk and on an absolute evaluation of the compliance to rules and regulations of each of the concepts. The overall process behind the concept selection is outlined in Figure 1-1.

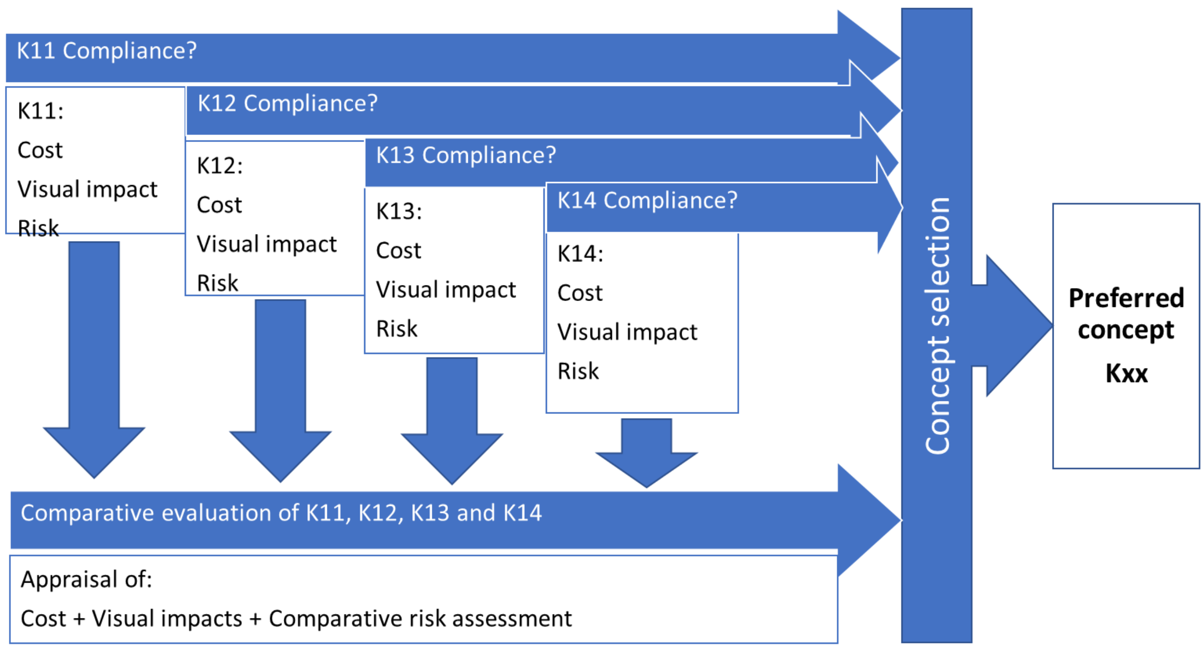

Figure 1-1 Process for risk assessment and concept evaluation

Risks for each of the four concepts are therefore identified, assessed and to some extent mitigated. Based on these risk assessments, the comparative assessment forms the basis for ranking of the concepts according to their respective risk profile. This assessment will be carried out for both risks related to the construction and installation phase as well as risks related to the operational phase.

The risk ranking is part of the overall concept evaluation conditional on concept compliance with rules and regulations. After concept selection the risks assessment process focus on the preferred concept in order to optimize the design and the construction and installation methodology.

The objectives of the risk management process can be considered three-fold.

1. An *optimization of design choices and construction methods* for each of the four concepts to achieve a balanced risk profile and identify mitigations that can secure budget/schedule and minimize risk of violating rules and regulations.
2. A *comparative risk assessment* to identify and highlight inherent differences between concepts to be used for concept evaluation and selection of preferred concept.

3. A *risk assessment of preferred concept* to identify and highlight strength and weaknesses as well as mitigation measures for this and coming phases.

Naturally, the three objectives and the process behind them are closely connected. The risk management process for each of the concepts will create the foundation for the comparative risk assessment. Through the course of this phase, the individual risk management process shall ensure continuous focus on the largest risks for each concept such that the concepts are brought to same level of maturity which will ensure that concept selection can be carried out based on the best possible basis and that the risk assessment for the preferred concept can be taken to the next phase.

Considering the method for concept evaluation in *Figure 1-1*, risk and cost are considered independent parameters that factor into the concept evaluation. Since many risks are typically associated with cost, it is important to distinguish between cost and risk:

- Cost related to the materials, fabrication and installation. The cost estimate includes uncertainties related to unit prices, quantities at present stage of design, market uncertainties etc., i.e., it includes the likely variations. The cost is based on the base case concepts without including the impact to the design or construction methods and hereby induced costs from possible undesired and less likely events, i.e. excluding risk add-ons.
- Risks reflecting uncertainties in the concept, arising as a consequence of a possible undesired event or change related to new technology or construction methods, modelling assumptions, insufficient data or analysis, accidents etc. Risk contribution may also relate to robustness of the structure in situations beyond the design codes.

Risk can to some degree be monetized as expected cost by weighing the cost of an undesirable change by its probability. However, due to the complex nature of many of the considered risks their consequence is not easily monetized, nor is the likelihood of occurrence easily estimated.

This particularly concerns risks related to the robustness of the concept. Therefore, adding expected add-on cost subject to very large uncertainties in risk estimates to the baseline cost is not considered to add significant value during this phase. Instead, risks are considered separately in addition to the cost estimate to ensure that they receive the relevant attention during the design process. If a certain risk causes a design change, the cost of such a change will naturally be included in the cost estimate and the risk will be reduced or eliminated correspondingly.

During this stage of the project there will be uncertainty with respect to the verification of the minimum requirements and this will be highlighted when relevant. The consequence of such risks can be very significant and ultimately change the design completely. Therefore, it is not sensible to include such risk in the cost estimate at this point. Instead, such risks will be captured by the risk management process, which will ensure that the necessary focus and risk reducing measures are taken before the concept evaluation. The identified risks related to the minimum requirements will provide an overview of any potential threats or reasons for the design not to be complying when a detailed design is carried out.

The following chapter will outline the framework and methodology for risk management according to codes and recommended practices for marine and infrastructure projects. This will be followed by a description of the process and assessment carried out for the installation and operational phase, respectively, of the floating bridge across Bjørnafjorden.

2 Risk management framework

General principles for risk management such as those described in ISO 31000, ITIG and DNV are applied in the project. They are generally very generic and applies to different types of projects in all stages from development to construction and operation.

Risk management can simplified be described as the systematic process of:

- Identifying hazards and risks that may impact the project cost and programme
- Assessing the risk level (may be qualitative or quantitative)
- Identifying mitigation measures (both existing and new) and responsible

The following sections will go through the methods for conducting the three basic steps outlined above.

2.1 Hazard identification

The hazard identification is one of several tools that may be used to systematically identify risks (REF DNV). It is particularly relevant to identify and evaluate hazards early in the project.

Hazards are generally defined as events having a potential to impact the project in relation to cost and programme, structural integrity, safety (of people) or environment (ITIG and DNV). The potential impact to third party as well as impact to reputation may also be relevant depending on the project.

During this early design phase of the floating bridge across Bjørnafjorden project, where the bounds for ordinary bridge construction are being pushed, the primary focus is on cost and structural integrity (safety of the structure). When these risks have been mitigated to an acceptable level and one concept has been chosen risks related to other e.g. HSE, environment and reputation may be considered.

Hazards are generally identified through a hazard identification (hazid) workshop, a structured brain storm, in which all disciplines are represented. The hazid workshop constitute a very beneficial and important process where concerns and potential risks are shared between disciplines, specialists and management. This creates a joint awareness of the challenges in the project and the actions to be taken to reduce the largest risks.

The hazard identification workshop is generally documented in a risk register. The risk register lists the identified risks, the risk evaluation and mitigation measures. The typical categories to be documented are the *hazard, consequence, cause, existing risk reducing measures, risk level, actions/mitigation measures, responsible, comments* (REF DNV). These typical parameters are also used here and the risk level is included for the relevant concept(s). The headers used are shown in *Table 2-1* below. The format used for this register makes it easier to compare concepts while at the same time being able to extract the risk register for each individual concept. Furthermore, it ensures that the four risk assessments are conducted in a comparable manner such that the risks of one concept is not considered in more detail than another.

Table 2-1 Headers used in risk register

ID		Hazard description						Risk level				Mitigation	Responsible
Index no	Phase	Hazard	Design criteria	Consequence	Cause	In-place mitigation measures	Comment	K11	K12	K13	K14	Further mitigation measures/ actions	Responsible

2.2 Risk assessment

Risk is generally considered the product of probability of occurrence and consequence (or severity). Consequences typically relates to programme, cost, structural integrity, safety (of people), environment and reputation and mitigations to design changes, concept changes and further investigations. Focus during this risk assessment is the structural integrity. As outlined in chapter 1, it is in this phase not considered preferable to evaluate the risks quantitatively i.e. with a cost and an associated likelihood. Instead, risks are categorized and evaluated qualitatively, in accordance with RP DNV, according to the following terms and colouring.

- High - red
- Medium - yellow
- Low - green

The three risk categories are defined and evaluated in accordance with DNV. This means that risk that are low are considered either to result in an acceptable range of consequences or to be associated with very low probability of occurrence. Cost effective mitigations measures are considered and implemented if relevant. Medium and High risks require that further mitigation measures must be identified and if possible in this phase carried out. High risks will generally be associated with very severe consequence which require major design changes or even significant concept changes. Effect of mitigation measures are either unidentified or very expensive or extensive.

Since the evaluation is qualitative in only three categories and based on several discussions within the project group the uncertainty in respect to the resulting evaluation is small compared to a full quantitative evaluation. However, the result is on the other hand less refined than that of a quantitative assessment, but the qualitative approach is found to be the most appropriate at this level of project maturity.

Naturally, the knowledge available, or lack thereof, can affect the risk. Some risks are directly the result of a limited knowledge basis based on the general maturity of the project and the fact that a detailed design has not been performed. However, it is, for all significant risks discussed if additional analysis could impact the results/evaluation significantly. In that case the potential impact of additional analysis will be listed in the risk register and in the discussion of the risks.

2.3 Mitigation measures

Identification of implemented and further mitigation measures constitutes an important part of the risk assessment. Already implemented mitigation measures are used to highlight already imposed actions and to support a risk evaluation. New mitigation measures or actions to be taken to reduce the risk are key in the risk management process. Such actions may be identified during the hazid workshop, providing a broad support and encouragement to take the agreed actions. Agreed actions must be documented in the risk register along with the person responsible. Thus, the risk register can later serve as a check list for the identified actions and ensure that risks are actively being managed.

3 Risk significance

The significance of the operational and construction risks identified will be assessed based on the value and magnitude according to *Table 3-1*.

Table 3-1 Value of significance for comparative evaluation

Value **Magnitude**	**Large (Operational Risk)**	**Medium (Construction Risk)**
Equal/Negligible negative	0	0
Small negative	-	0
Medium negative	--	-
Large Negative	---	--

The overall comparative ranking will be based on the significance of two impacts. The individual ranking will be assembled in an appraisal summary table, and the concept with the least (-) will be the most desirable concept. All concepts will be ranked according to the same principles.

Construction risk are set to a medium value in the ranking whereas operational risks are defined to have high value. The reasoning for the difference in weight is twofold. First, the general maturity of the design itself is higher than that of the construction processes giving higher weight to the identified critical design issues, which will if not solved influence the operation phase. Second, the operation phase is reflecting the lifespan of the bridge and the issues identified to a large degree relate to risk of not complying with the set-out rules and regulations whereas the construction phase is a temporary phase, where most risks relate to delays or increased construction costs, which are of course important but of smaller value for the decision at current point in time.

4 Comparative risk assessment: Operational Phase

This chapter will outline the methodology and risk management process related to operational phase that was carried out during the course of the project. A comparative risk evaluation for the risks across the four concept has provided a risk-based ranking and ultimately the risks for the preferred concept are handled on a more absolute basis in the concept evaluation.

4.1 Risk process

Figure 4-1 illustrates the principles of the risk management processes that was adopted during this phase of the project. During the previous phases of the project, several risk and technology qualification activities were conducted. These were based on earlier stages of the concepts that, in this phase are referred to as K11 and K13. Information from available FMECAs, Hazids and uncertainty assessments was gathered and collated to form one basic risk register, which reflected all relevant risks that were raised during the previous phase. Some of these risks are naturally not relevant to all concepts and this was marked in the register.

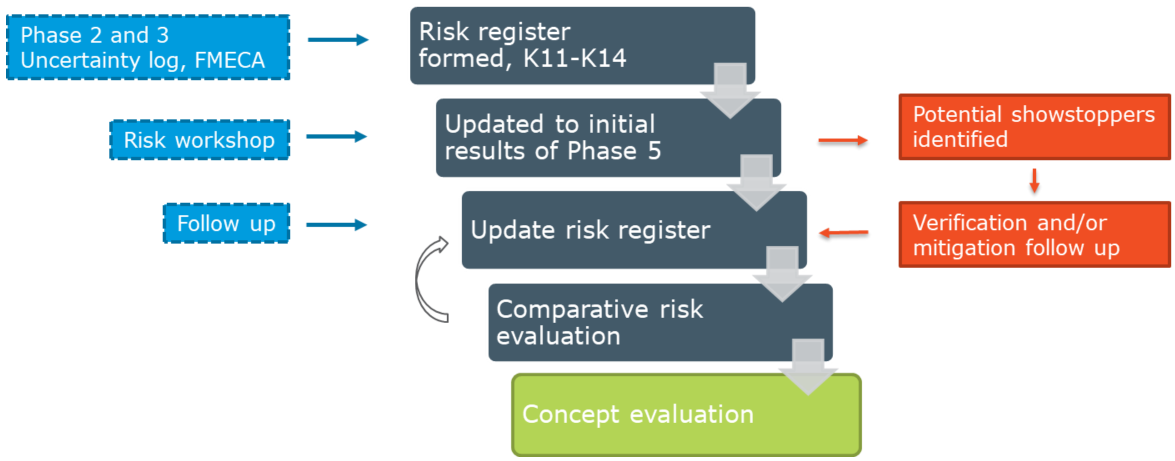

Figure 4-1 Illustration of the risk management methodology applied during this phase

A risk workshop – ORA workshop 1 - was conducted on February 27th 2019 with representative from all disciplines except geotechnical, for which a separate meeting with NGI was held March 3rd 2019. During the workshop, the risks from the pre-identified register (based on the risks identified from the previous phases of the project) were discussed and their relevance and risk level assessed. Focus was in general on risks that might impact the concept evaluation but all topics, including those identical for all concepts, were generally covered. In addition, new risks specific to the ongoing work with the four concepts were identified.

Following the risk workshop has been an iterative follow-up phase. The different disciplines are continuously performing new analysis, design changes are been decided and mitigation measures implemented. Thus, the design is developing along with the risk profile.

Follow-up sessions have therefore been held with selected disciplines and the management team to ensure that 1) the risk register reflects the development and most recent updated to the design and 2) the agreed mitigation measures are carried out. And finally, a follow-up workshop for operational risk – ORA Workshop 2 - was held May 14th 2019.

Thus, the risk register presented in section 8.3 represents the design at Milestone 7, 24/5 2019 for the comparative assessment and concept selection. Several updates and iterations have been included and risk levels have changed following mitigation actions being carried out or new analysis results immerging.

Workshop participants are listed in chapter 8.1.

Based on the updated risk register, the comparative risk evaluation is carried out in the following section and a ranking of the four concepts is provided as input to the concept evaluation.

4.2 Comparative risk evaluation

The risk register documented in section 8.3 considers both risks that are alike for all four concepts as well as risks that differentiate the concepts.

For the comparative risk assessment that will serve as input to the concept evaluation, only the risks that differentiate between the concepts are selected. These are shown in Table 4-1 in a short format where only hazard, risk level and mitigation measures are shown.

Index no	Hazard	In-place mitigation measures	K11	K12	K13	K14	Further mitigation measures/actions
1.00	Parametric excitation - Dynamic stability	Anchorage will provide stability for K12, K13, K14. New criterion taken as basis for K12 and K14 - DB criterion very strict	High	Low	Low	Low	K11 Mitigations by introduction of dampers at the tower is being investigated. Alternatively, change in the bridge geometry may move critical modes into an area with higher damping or lower excitation. Efficiency of mitigations still uncertain and risk level high. Mitigation is working but uncertain if possible to implement. . K12, K14: If required introduce more damping though improved mooring configuration. Likely not needed CFD study under finalization to reduce uncertainty in drag coefficients.
2.00	Bridge global instability (static buckling)	Analysed and checked for K11 - anchors for K12 and K14 mitigate risk. Phase difference for waves has been analysed	Medium	Low	Low	Low	Effect of inhomogeneous sea and wind is being analysed - Evaluation of possible coupling effects between different environmental contributions. Inhomogeneous static wind on bridge (shielding from mountain) - analysis ongoing
10.00	Ship collision/submarine collision with mooring lines - loss of line(s)	Design includes loss of two anchors. It is geometrically unlikely to hit more than one line Mooring lines designed for ship impact Robustness check of loss of four anchors OK for all concepts	NA	Low	Low	Low	Check for parametric excitation without 2 anchor lines for K12
16.00	Loss of mooring lines	Bridge must be operational with 2 mooring lines lost according to DB. Robustness check shows capacity for loss of four lines.	NA	Low	Low	Low	Robustness check for loss of 1 or 2 anchor groups
23.00	Geohazard: loss of anchors due to landslide	Design includes loss of two anchor lines Robustness check with loss of four anchor lines reveals sufficient residual capacity.	NA	Low	Low	Low	
26,00	Insufficient operational availability	Availability studies from previous phases indicate availability above 99.5%.	Medium	Medium	Low	Low	"Verify availability above 99.5% can be obtained for all solutions K11-K12 might need mitigation such as wind screens due to effect on vehicles from high turbulence intensity. Long term statistics for wind to improve basis of design Local analysis of wind climate"

Table 4-1 Risks relevant for comparative assessment

From the table it is seen that the topics of the listed risks are

- Parametric excitation
- Global instability
- Anchors and mooring lines (including geohazard)
- Ship collision
- Operational availability

Figure 4-2 shows a pie chart comparing the distribution of risk level between the four concepts including all identified risks.

From the charts it is clear that K11 differ from K12, K13 and K14, however, the latter three have a nearly identical operational risk ranking. Where K11 has the most "not relevant" risks it also is the only option with a high risk and it has more Medium risks compared to K12, K13 and K14. Thus, in order to provide a better evaluation, the specific risks where concepts differ significantly must be considered.

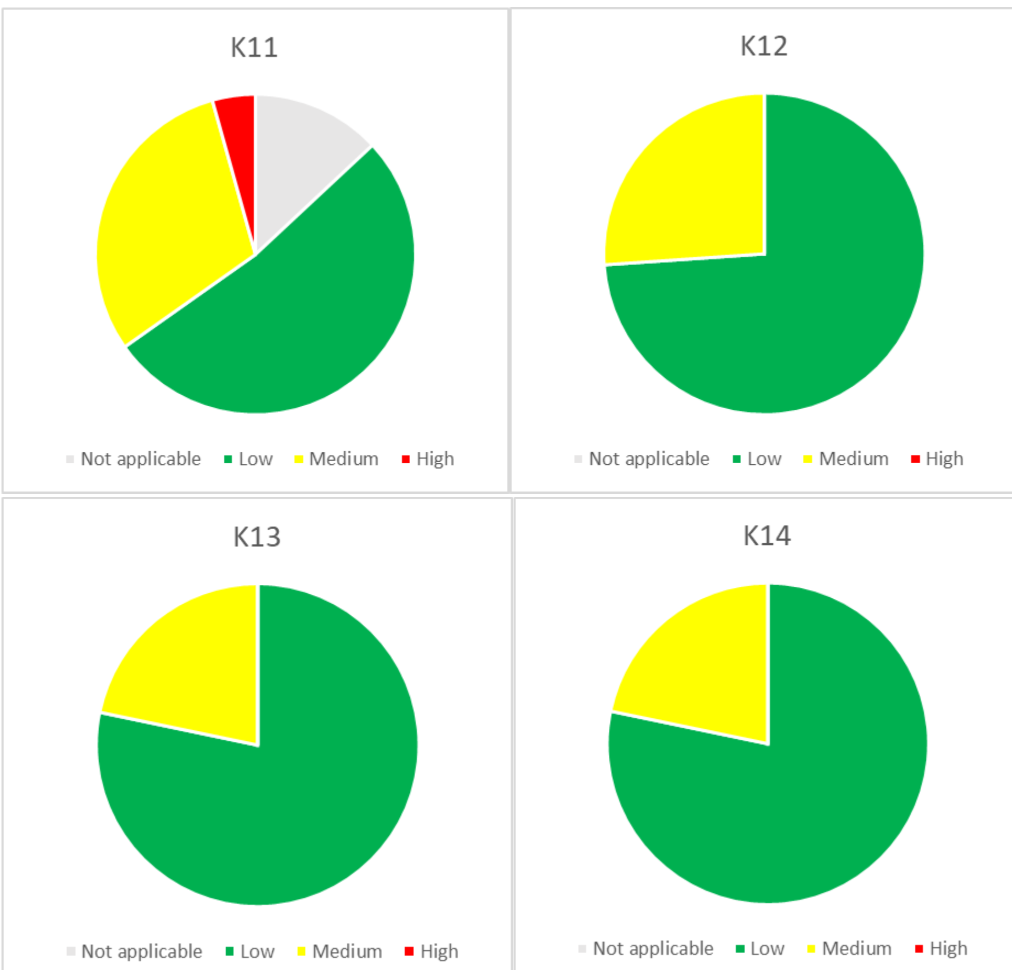

Figure 4-2 Pie chart showing distribution of risk levels for each concept

4.2.1 Parametric excitation

The most critical risk, marked as High in K11, is currently the risk of parametric excitation, which is a severe challenge for especially K11 but also to a smaller degree for K12 and K14. K13 is the only concept that is not challenged by parametric excitation. This is due to the straight shape of the bridge and the fixed boundary condition in both ends, which prevent the buildup of axial forces and the induced geometric stiffness changes. The risk of parametric excitation can be challenging to mitigate in this phase and can be triggered by swell sea given a specific wave period, direction and long-crestedness. Currently, a conservative check of the phenomenon with a harmonic wave input has been applied. A specific study addressing the concept sensitivity with respect to input changes has been carried out. It is essential to either mobilize sufficient amount of damping or to move critical modes away from a lowly damped area or away from sources of excitation. For K11, mitigating measures are thus either to increase the bridge curvature (thereby extending the bridge significantly while lowering the critical eigenmodes into a highly damped area) or to change the pontoon shape to a shape with significantly higher drag coefficient. For the moored concepts viscous damping on the mooring lines will contribute to significant damping in the critical modes, and if more damping is required one could simply add more mooring or tune the mooring lines to achieve a higher damping. All of the identified mitigation measures at this stage involve significant design changes that will lead to a new concept, and therefore these changes are not adopted in the design and cost estimate. Instead, it is considered a risk and it is for K11 evaluated as high, since consequences are large and mitigation both in terms of further analysis and test an in terms of concept change are not immediately available.

4.2.2 Global stability

Uneven loading across the length of the bridge can in extreme cases lead to static buckling. The effect of inhomogeneous sea and wind is being studied including analysis of inhomogeneous static wind on bridge (shielding from mountain), phase differences for waves and evaluation of possible coupling effects between different environmental contributions. However, analysis has not been completed and there is a risk that an unfavorable response is observed that may cause design changes. The phenomenon is a risk for K11 whereas for K12, K13 and K14 the mooring mitigate this risk as the inhomogeneous load is carried directly by the mooring and not the bridge girder. At current state of analyses the risk for K11 is assessed to be Medium.

4.2.3 Mooring

Considering the charts, the most prominent difference between the four concepts, in terms of risk, is the number of "not relevant" risk for K11. These are naturally due to the fact that no mooring system is included in K11. The mooring of K13 and K14 is of similar nature and extent (4x2x4=32 lines) whereas K12 has less mooring lines (3x2x2=12 lines). Generally, K12 is less sensitive than K13 and K14 to risks related to anchors/mooring lines, since the arc shape allows K12 to resist ordinary non-accidental loading situations without mooring. A primary risk for the moored concepts has been geohazards where landslides may take out up to one cluster (2-4 mooring lines). The requirement is that the bridge shall sustain loss of 2 mooring lines, which is confirmed OK by analyses. Further the response of the bridge concepts under loss of on cluster of mooring lines has been evaluated, and the bridges are robust for all the tested scenarios. Hence, the loss-of-mooring related risk can be considered mitigated and the risk for K12, K13 and K14 is Low. It is noted that K13 has a higher sensitivity to loss of mooring lines due to large strong-axis moments towards the pylon but is still within acceptable limits.

4.2.4 Ship collision

Ship collision was initially a large risk – particularly collisions between the deckhouse and the bridge girder. With present update of design basis, ship collision is not a major risk. However, K11 is generally slightly more sensitive towards ship collisions compared to the remaining three concepts due to the lack of mooring lines. The mooring lines contribute to the total damping level in addition to its stiffness contribution.

The consequence of a ship impact larger than the design value or with e.g. a sharp object (container crane) rupturing the bridge girder is not expected to cause a complete loss of bridge for any of the four concepts. However, it may result in partial collapse of bridge section or severe damage. The likelihood of impact is similar for all concepts. K11, is generally less robust towards ship impact and an additional cost has been introduced in the cost-estimate to account for this reduced robustness. The only advantage for K11 compared to K12, K13 and K14 in terms of ship impact is that submarine impact to the mooring lines can be excluded.

4.2.5 Operational availability

Operational availability must be at least 99.5% meaning that the bridge can only be allowed unavailable 44 hours per year. The availability has been analysed in previous phases and found sufficient. However, the metocean design basis provided in this phase indicate that there could be an issue with closure due to wind effects on vehicles. For certain wind direction in the southern sector the turbulence intensity is specified to 30% which will reduce the wind speed for which closure of the bridge must be considered. The alignment for K11 and K12 is particular sensitive to the highly turbulent wind from the southern sector and therefore these are assessed to Medium risk of exceeding criteria compared to K13 and K14 for which risk is assessed Low. Further analysis based on long term distribution of the wind should be undertaken but in agreement with NPRA this risk is flagged here but should not at current state impact the recommendation of concept.

4.3 Operational risk concept ranking

Due to the severe risk related to parametric excitation and the inferior performance with respect to ship collision and global stability, K11 is considered the least favorable option from a risk perspective at the current point in time.

K12, K13 and K14 all have different advantages and disadvantages and the overall difference between the three is not large. K12 has one additional Medium risk, but since this relates to the operational availability, which shall not determine the recommendation of concept, they are evaluated to have only negligible difference in risk.

The ranking of the four concepts with respect to risks during the operational phase is displayed in *Table 4-2*.

Table 4-2 Ranking of concepts with respect to operational risks with significance ranking in ()

Operation risk ranking	K11	K12	K13	K14
Ranking	4	1	1	1
Significance	(- - -)	(0)	(0)	(0)

5 Comparative risk assessment: Construction and Installation

This chapter outline the process for the risk assessment during construction and installation as well as a comparative risk assessment

5.1 Risk process

A preliminary construction methodology for each of the four concepts was initially developed based on experience from the offshore industry, ordinary bridge construction and experience and learning from previous phases of the project. This methodology, documented in Appendix N, served as the basis for identifying and discussing risks.

A risk workshop – CRA workshop 1 - was conducted on March 6th 2019 with participants having competences covering all phases of the installation. NGI were not able to participate, but a separate follow up meeting/mini workshop was held the following week in which the input regarding anchor installation and soil condition was included. Continuous monitoring of the risks and mitigations has been ongoing, and a follow-up workshop has been carried out.

A list of participants from the workshops is documented in chapter 8.2.

During the workshops, the following overall phases were considered:

- Assembly of bridge elements to bridge section(s)
- Construction of Cable Stayed bridge
- Construction of North abutment
- Towing of bridge sections
- Installation of bridge section(s)
- Mooring lines installation and hook-up

The construction of the cable stayed bridge and the abutment are relatively similar for all four concepts and are generally associated with a limited uncertainty as the processes are known from ordinary bridge construction. These were therefore only considered briefly. The focus was primarily on the assembly, towing and installation, as these are relatively new methods with limited or no experience. Further, there are significant differences between the concepts when it comes to these phases.

A very brief description of the difference in towing and installation can be outlined as:

K11 Towed and installed in one piece. Tugs used to install bridge and connect to abutment using an adjustment piece.

K12 Similar to K11 but with mooring lines installed after the bridge is installed.

K13 The floating bridge is divided into three pieces that are towed to site one by one. The middle section is installed first using mooring lines. The remaining sections are installed using mooring lines and locking devices to secure connection. Last, tensioning of bridge is performed.

K14 Similar to K13 without tensioning. Tugs are used to connect to secure the geometry when connection to abutment using an adjustment piece.

To evaluate the risks in a comparative manner, a generic installation process was developed for the risk assessment. It means that the process or phases were defined such that they to the widest extent possible apply to all concepts. Naturally, there are inherent differences such as the mooring lines that only applies to K12, K13 and K14 and this will be noted in brackets. The following steps were defined:

1. Tow bridge section to bridge location and assess weather
2. Orientate bridge for connection to 1st end (abutment or installed section)
3. Connect winch wires to 1st end / shore bollards
4. Rotate bridge section and connect winch wires to 2nd end
5. Pull bridge section towards 1st end and engage primary guiding system
6. Rotate bridge section to final orientation
7. Ballast bridge section at 1st end to engage secondary guiding system and secure connection
8. Install mooring lines to pontoon (typically 4 for storm safe) (Only K13, K14)
9. Pull assembled bridge to 2nd end to engage primary guiding system
10. Ballast bridge section at 2nd end to engage secondary guiding system and secure
11. Install remaining mooring lines (not K11, all mooring lines for K12)
12. Make up final welds of bridge girders towards 1st and 2nd end (installed section / abutment)
13. Tension bridge and infill for K13 only

While these steps are generic to nearly all concepts, the installation of the first middle section of K13 and K14 does not follow this scheme and was considered separately.

During the CRA workshop 1 each of the listed phases was discussed and risks identified and the follow-up workshop had focus on the changes which were implemented to the construction process. Focus was generally on the safety of the structures and the processes.

Topics such as personnel safety, environmental impact and reputation, which are also included in DNV Recommended practice were not included explicitly at this stage. Since the project is only at concept level with uncertainties regarding the method alone, the focus was kept on this. However, at a later stage personnel safety, environmental impacts and reputation may be included.

In addition to the risk workshop, a separate knowledge sharing/lessons learned session from Hålogaland was carried out on March 13th 2019 where Assad Jamal, Design Project Manager from COWI's design team for Hålogaland Bridge participated along with welding specialist Steen Ussing also COWI.

A follow-up workshop – CRA workshop 2 – was held May 14th 2019 to complete the basis for the comparative risk assessment.

The risk register was developed and updated along with the development in the construction and installation method. The full risk register is attached in section 8.4.

5.2 Comparative risk evaluation

Based on the full risk register in 8.4, the risks that are different for the four concepts are extracted and listed in Table 5-1. There are a significant number of risks, but it is noticed that there is only one risks with the risk level "High". This reflects, that even though there is uncertainty related to many processes they are generally not considered potential showstopper but manageable given that appropriate mitigation measures are carried out in this and later phases.

Index no	Phase	Hazard	In-place mitigation measures	K11	K12	K13	K14	Further mitigation measures/actions
11.00	Transport/ float floating bridge (K11+K12)/ sections (K13+K14) to site	Loss of control unknown response/ unforeseen extreme weather during tow	Tug management system (known from offshore when moving platforms) Weather windows are generally used Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Medium	Medium	Low	Low	Simulations can be performed in a later phase. Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)
13.00	Orientate and connect winches of floating bridge (section)	Behaviour and deformation of floating 4.5km uncertain	Tow management system (known from offshore) The crew will have experience from the tow to site Weather windows are generally used	Medium	Medium	Low	Low	Simulations can be performed in a later phase Test/confirm bridge/tug interaction in fjord before actual operation Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)
14.00	Ballast and connect	Unsuccessful connection (using guide system) to K13,K14 middle section due to large movements		NA	NA	Medium	Medium	Movements and anchor tension to be analysed to verify base case for K13 and K14
15.00	Ballast and connect	Problems in deformation of bridge to fit last end to guide system and make final connection in north.	Adjustment piece, see #17, will account for a range of tolerances for K11, K12 and K14	Low	Low	High	Medium	To be considered in further detail in this phase. Initial analyses show that it is much more difficult to deform K14. More analysis will likely lead to reduction of risk to medium for K13, but still challenging operation
17.00	Ballast and connect	Connecting last end for K11, K12 and K14 may be unsuccessful due to building tolerances	An adjustment piece is included for K11, K12 and K14 to mitigate problems for a range of building tolerances	Medium	Medium	NA	Medium	Analysis/verification of adjustment piece for a realistic range of tolerances and forces. Final positioning analysis to be performed taking into account the position of pull in winches, building tolerances and elongation/contraction of bridge due to temperature.

								Establish weather criteria to limit the first order motions of the bridges during connection.
19.00	Anchor and mooring line installation	Unsuccessful mooring/anchor installation operation	Geotechnical investigation of mooring location supplemented with reserve/backup anchor location - backup locations identified and found satisfying	NA	Low	Low	Low	Further analysis awaiting results of the 2018 soil investigation campaign
20.00	Mooring lines(anchorage)	Damage to mooring lines during wet storage	K12 anchor locations moved to deep and even basin mitigating this risk	NA	Low	Low	Low	Alternatives are available for K13 and K14 e.g. storing on barge Further analysis of current wet storage location for K13 and K14 to be conducted in the coming phase
21.00	Mooring lines(anchorage)	Uncertainty regarding how much and when anchor lines should be tensioned	Preliminary spot checks show that low top tension (~100t) on the mooring lines during summer storm conditions will be sufficient. Length of the mooring line to be used as the governing parameter for final tensioning (such as with the stay cables). The correct length can be indicated/marked on the chain during mooring installation. Numerous methods for tensioning of the chains are described in the marine operations document	NA	Low	Low	Low	Further detailing of method in later phase
24.00	Mooring lines(anchorage)	Unsuccessful connection of mooring lines to anchor - line buried or "lost"	Connect buoy or other mark to ensure lines are not lost/buried at seabed	NA	Low	Low	Low	
29.00	Mooring lines(anchorage)	Gravity anchors in north- ensure seabed is sufficiently flat - limited experience blasting in -60m		NA	NA	Medium	Medium	

Table 5-1 List of risks that differentiate the concepts

Figure 5-1 shows the division of the risk levels for each of the four concepts. It is clearly noticed that K11 distinguish itself by having the largest faction of "Not relevant" risks.

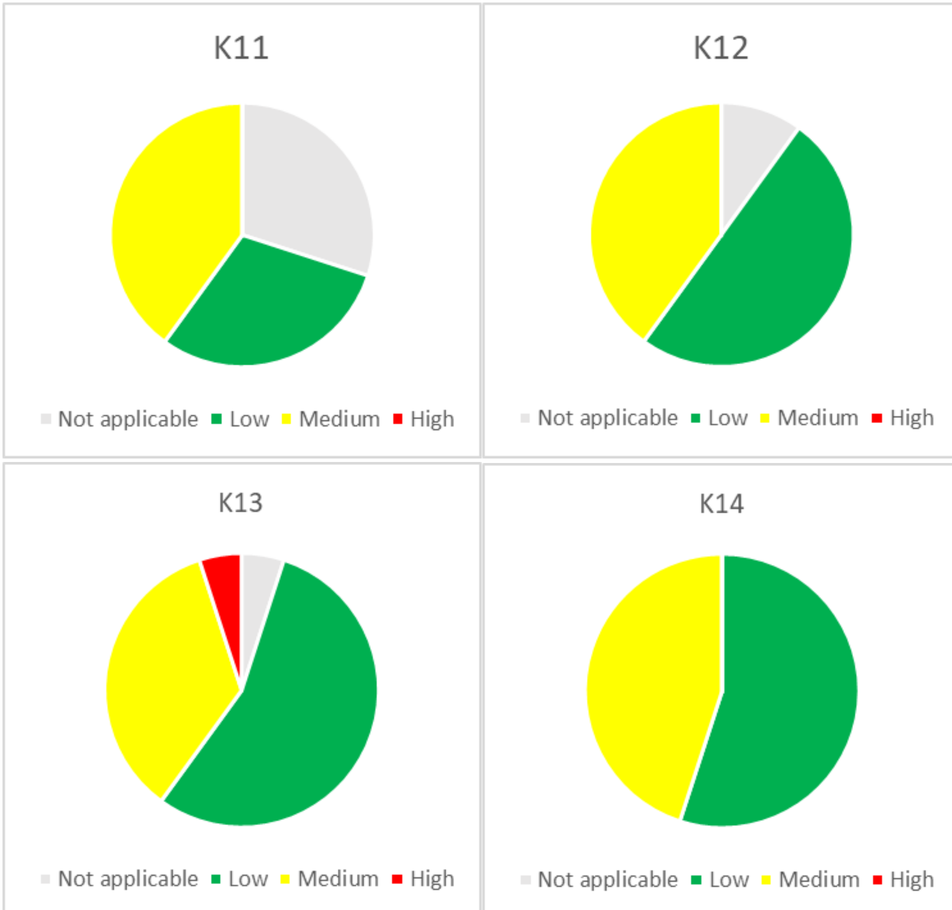

Figure 5-1 Pie chart showing distribution of risk levels for each concept

Thus, the immediate assessment of the four concepts clearly favors K11. K13 is least attractive in terms of construction and the remainders of the concepts appear relatively equal from the simple overview of risk levels with a preference for K12. In order to provide a more nuanced assessment select topics that are considered to include the most prominent risks are extracted and listed below.

- Towing to site
- Mating and connection bridge end to abutments (or other section)
- Welding of moving sections
- Mooring lines/Anchorage
- Tensioning of mooring lines

These topics do not cover all the risks listed in Table 5-1, but they cover the ones considered to be most severe and those where the difference between the concept is largest.

5.2.1 Towing

Towing of a full 4.5km bridge has never been done and is therefore connected with uncertainty. This mainly concerns K11 and K12 which are planned to be towed in this way. K13 and K14 are divided into smaller sections of 1-2km. Towing of approx. 1km was done for the Nordhordlands bridge in the 80ies without any recorded problems. Tug management systems are known from the offshore industry and will be used during the tow, which involves approximately 14 tug boats. The bridge is very flexible and one challenge will be to control and coordinate the movements during the tow. Simulations are considered a viable mitigation that should reduce the risk of unforeseen behaviour. Furthermore, test towing may be conducted to ensure sufficient control once the bridge has been assembled, before the real tow commence.

5.2.2 Mating/connection of floating bridge end

The method for mating of bridge sections is different between the concepts. K13 stands out as it is straight and has a tensioning system that is used in combination with a sliding mechanism. This method is new compared to ordinary bridge installation and therefore associated with uncertainty and at this point in time significantly higher risk. For the remaining concepts the bridge is towed/pulled into position and if necessary deformed (using tugs) until the guiding system is met. Both K11 and K12 are quite flexible due to the curvature and K14 may experience more challenges when trying to deform. Furthermore, K11 and K12 are only going to connect to the abutment where K13 and K14 will have sections that must be connected to the floating middle section. Overall K11 and K12 are considered to have an advantage in this respect. To handle tolerances in the final connection in north an adjustment piece has been introduced to reduce the risks of not being able to/experience difficulties in making the final mating.

5.2.3 Welding of floating sections

K13 and K14 will require welding of the three sections at site. Welding must happen in a controlled environment with no movements. Typically, locking devices are used to fixate two sections before welding of ordinary bridge girders. Experience from other bridge projects indicate that the welding of the periphery takes approximately 2 days. Installation of ordinary bridge girder sections are prone to movements from wind impact. The floating bridge sections will in addition to impact from wind be affected by waves. The most important mitigation at this stage is to calculate the forces that the locking devices must be designed for to ensure that it is within a reasonable range.

K13 and K14 are considered to have a larger risk due to the sectional installation whereas both K11 and K12 only will require welding at sea when connecting the full bridge to the abutment/cable stay bridge.

5.2.4 Mooring lines/ Anchorage

The installation of anchors and connection of mooring lines to the anchorage is associated with some risk, which have impact to the construction risk for K12, K13 and K14. For K13 and K14 the risk is generally higher due to the 32 of anchors needed compared to only 12 for K12, however, there mere repetition has not led to increase of the risk from Low to Medium since the anchor installation in general and the connection of mooring lines is seen as a well proven technology. The anchors in north needed for K13 and K14 only are however gravity anchors for which a sufficiently flat seabed need to be established by blasting. Since blasting at 60m water depth is not a usual operation, the risk is set to Medium for that operation.

5.2.5 Tensioning mooring lines

Both K12, K13 and K14 have mooring lines that will be installed either during (K13, K14) or after (K12) bridge installation. There are different methods for tensioning mooring lines, typically known from the offshore industry. The simplest, and likely most cost effective, is to use one or more boats to pull the lines. Alternatively, winches can be installed on the pontoons. Overall, the mooring operation including the tensioning is considered a Low risk at current state which is only present for K12, K13 and K14.

5.3 Construction risk concept ranking

In terms of comparative risk assessment, it was generally seen that only one High risk was identified. The concerned the connection of K13 in north, which is not a well-known operation that must be analyzed further to reduce risks and uncertainties. Connection of K13 is more complex due to tensioning system and sliding mechanism introduced to avoid the expansion joint. In addition, a significant amount of medium risks have been identified, many of these originating from uncertainty related to the applied construction methods.

Considering the identified risks, K11 is due to its simplicity superior to the other concepts. This is primarily due to the non-existing mooring system but other factors such as the reduced number of welding operations on sea and the flexibility of the structure when connecting to the abutment also favors this option. The largest risk related to K11 is the towing operations.

In terms of construction risks K12 is quite similar to K11 with some additional risks due to the installation of the 12 anchors and mooring lines. Anchor locations are found ok and back-up locations identified and the risks therefore moderate. K12 has advantages due to the one-piece installation but also a larger risk during the towing process compared to K14. K14 has, in addition, uncertainty related to the on-site connection and welding processes, 32 compared to 12 anchors and mooring lines, gravity anchors in north and possibly higher risk of difficulties in achieving the correct shape when connecting in north.

Based on the above evaluation, *Table 5-2* displays the ranking of concepts with respect to risks during construction and installation.

Table 5-2 Ranking of concepts with respect to risks during construction with significance ranking in ()

Construction risk ranking	**K11**	**K12**	**K13**	**K14**
Rank	1	2	4	3
Significance	0	0	(- -)	(-)

6 Comparative risk input to concept evaluation (24/5 2019)

Based on the comparative risk assessment carried out for both the construction and operational phase, a risk-based ranking of the concepts has been defined, reflecting the current risk level of the concepts. The ranking is listed in *Table 6-1*.

Table 6-1 Ranking of concepts with respect to risk with significance ranking in ()

Risk ranking	**K11**	**K12**	**K13**	**K14**
Operation risk, rank	4	1	1	1
Operation risk Significance	(- - -)	(0)	(0)	(0)
Construction risk rank	1	2	4	3
Construction risk, significance	(0)	(0)	(- -)	(-)
Overall risk rank	**4**	**1**	**3**	**2**
Overall risk, significance	**(- - -)**	**(0)**	**(- -)**	**(-)**

The overall ranking is dominated by the ranking for the operational phase of the bridge, see chapter 3 on significance of the operational and construction risks, where quite significant risks currently are present. Especially risks related to the ability of the design to fulfill the minimum requirements cause the operational risk to weight high in comparison to construction risks and additionally construction processes and resultingly risks are seen to be less mature than the design itself and the related operational risks.

In comparison construction risks does favor K11 and K12 to K14 and in particular K13 due to the installation and tensioning aspects.

From an operational point of view K11 is, primarily based on the risk of parametric excitation, ranked as the least favorable concept. In addition to this, K11 is performing worse with respect to global instability, operational availability and ship impact. The latter is merely in terms of robustness and not related to the design criteria, which are fulfilled. Parametric excitation is a higher-order response triggered by swell sea given a specific wave period, direction and long-crestedness. The likelihood cannot easily be evaluated, and it is likely that significant design changes are necessary to mitigate the phenomenon. This risk, which primarily concerns K11, but to a smaller degree also K12 and K14 has major impact on the overall ranking, since consequence are large and mitigation both in terms of further analysis and test an in terms of concept change are not immediately available. It should, however, be highlighted that K11, in terms of construction risk and a number of other issues, is considered the most favorable option. This benefit does, however, not outweigh the risk related to parametric excitation in the overall evaluation and results in K11 being the least attractive option ranked 4 from an overall risk perspective.

In operation, the remaining three concepts, K12, K13 and K14 each have different sets of risks, however, these result only in a marginally different risk level and none of the risks are comparable to the magnitude of risk for K11.

For K13, there is, however, significant uncertainty related to the installation of the bridge which leaves K13 as ranked 3 from an overall risk perspective.

Since K12 and K14 have equal level of operational risk the difference in construction risks governs the recommendation. Thus, being superior in terms of construction risks, the overall preferred option is K12.

It is, irrespective, important to mention that all four concepts are feasible in our opinion. K11 does as reflected in the risk assessment carry significant risk of necessary design changes, with impact on cost and possibly other parameters.

K12 is recommended from a risk perspective and in addition this concept is also the most robust concept. Should construction by the methodology set out for K12 show some undiscovered difficulties it is possible to install in sections, like for K14. But the opposite is not possible, since K14 cannot be installed in one piece due to lack of stability in the temporary phases. And if parametric excitation should show to be less of an issue, the number of anchors/moorings for K12 could be optimized or even removed in a later phase. Thus, K12 carry in addition to the least risks also a high degree of robustness.

7 Concept risk evaluation – Preferred concept K12

Option K12 has been selected as the preferred concept at Milestone 7, 24/5 2019 and, thus, the continuing risk assessment and evaluation is focused around K12. The following sections focus on all the identified risks relevant for K12, i.e. an absolute risk evaluation as compared to the earlier evaluations which were more centered around the comparative risk assessment.

7.1 Operational risk for K12

The operational risks for concept K12 are listed in *Table 7-1* and further details can be found in the full register in chapter 8.5.

Index no	Hazard	In-place mitigation measures	K12	Further mitigation measures/actions
1,00	Parametric excitation - Dynamic stability	Anchorage will provide stability for K12 New criterion taken as basis for K12 - DB criterion very strict	Low	K12: If required, introduce more damping through improved mooring configuration. Likely not needed. CFD study shows significantly higher viscous drag coefficients than used in the analysis; thus, giving increased safety margin. Other possible mitigations could be introduction of dampers at the tower or, alternatively, change in the bridge geometry which may move critical modes into an area with higher damping or lower excitation. Efficiency of such mitigations uncertain and currently not necessary. Preliminary studies shows that introduction of a linear damper in the tower/bridge connection may be sufficient to satisfy the stringent onset-criterion as in DB.
2,00	Bridge global instability (static buckling)	Anchors significantly increase the static buckling capacity of the bridge. Phase difference for waves has been analysed	Low	Inhomogeneous static wind on bridge (shielding from mountain) - analysis ongoing. More detailed wind load model.
3,00	Hydrodynamic interaction between pontoons		Low	
4,00	Combined behaviour of floating bridge and cable stayed bridge	Full model including both floating bridge and cable stayed bridge. Analysis shows fine combined behaviour.	Low	Cable exitation can be mitigated by introdiction of dampers if necessary.

5,00	Influence from simplifications in structural analysis model on dynamic properties (beam elements), local stress variations	Technology Qualification Analysis Several independent analysis (using different analysis tools) has been conducted. Independent model verification	Low	Further independent model verification
6,00	Ship collision impact with pontoon - design vessel	Scenario analysed for design load and have similar response for all solutions	Medium	Re-evaluation of column design with increased torsional capacity will fully solve the problem. Column capacity can be increased if necessary, but increased volumes not part of cost estimate.
36,00	Ship collision impact with pontoon - vessel smaller than design vessel	Scenario analysed for design load and have similar response for all solutions	Low	
34,00	Ship collision - vessel larger than design vessel	K12 was checked for 50% increased energy for pontoon collision normal to the bridge axis. Small differences in response was observed; negligible towards the ends (stiffness-dominated) but somewhat larger in the middle of the bridge.	Low	Robustness check for loss of pontoon to be considered in following phase. Loss of pontoon will cause large weak-axis moments and plastification of bridge girder, but likely not global collapse.
7,00	Ship collision with low bridge - forecastle deck, bow or containers hit girder	Girder height determined to reduce risk of forecastle/bow/container collisions Lower level of girder is +11.5m according to DB.	Low	
8,00	Ship deck house collision impact with girder - local damage	Local analysis undertaken showing minor damage	Low	Robustness check in damaged condition
9,00	Ship deck house collision impact with girder -global response - South	Robustness check in damaged condition yields acceptable results (see appendix G)	Low	Global analysis of girder collision
35,00	Ship deck house collision impact with girder -global response - North	Additional strengthening of girder near north abutment has been introduced	Low	Robustness check in damaged condition
10,00	Ship collision/submarine collision with mooring lines - loss of line(s)	Design includes loss of two anchors. It is geometrically unlikely to hit more than one line Moorings lines designed for ship impact Robustness check of loss of four anchors OK for all concepts	Low	

13,00	Corrosion on pontoon, columns and girder of low bridge - potentially leak into pontoon	Girder and columns: standard for bridge in general Inspection and maintenance program defined for pontoon	Low	
15,00	Fatigue - girder and column	Possible to have good structural details with low stress concentrations. Local design with sufficient capacity	Low	Addtional inspection programme (potentially supplemented with SHMS) is a potential mitigation.
16,00	Loss of mooring lines	Bridge must be operational with 2 mooring lines lost according to DB Robustness check shows capacity for loss of one group	Low	
17,00	Increased girder stress due to marine growth or other reason for increased weight of pontoon	Marine growth on pontoons considered in design	Low	Not expected to be necessary, but it needed adjustment of ballast is possible. Autonomous hull cleaning is also available
18,00	Vandalism, terrorism - cable stay bridge	One cable can be lost without structural collapse	Medium	DB require Risk analysis - to be performed in another phase
19,00	Vandalism, terrorism - floating bridge	Bridge must be operational with 2 mooring lines lost according to Design basis	Medium	DB require Risk analysis - to be performed in another phase
20,00	Airplane/heli crash into tower or cables	Likelihood is extremely small	Low	
21,00	Fire/explosion on bridge or in adjacent tunnel		Medium	Go through study and identify potential actions Document availability -see risk no 26
22,00	Fractures in rock at tower location (cable stay bridge)	Has been investigated and location found ok. New fractures will not form	Low	
23,00	Geohazard: loss of anchors due to landslide	Design includes loss of two anchor lines Robustness check with loss of four anchor lines reveals sufficient residual capacity.	Low	
24,00	Comfort/movements not within criteria		Medium	
26,00	Insufficient operational availability	Availability studies from previous phases indicate availability above 99.5%.	Medium	Verify availability above 99.5% can be obtained for all solutions K12 might need mitigation such as wind screens due to effect on vehicles from high turbulence intensity. Long term statistics for wind to improve basis of design Local analysis of wind climate

Table 7-1 List of operational risks for concept K12

The risk register for K12 is developed as an extract of the risk register for the comparative risk assessment and is further developed to reflect the latest state of information.

From *Table 7-1* it is seen that the topics of the listed medium risks for K12 are:

- Operational availability (design criteria)
- Comfort criteria (design criteria)
- Ship collision (design criteria)
- Fire and explosion
- Vandalism/terrorism to floating or cable stayed bridge

Some of the medium risks relate directly to fulfillment of design criteria and others are more general of nature. The medium risks for K12 are unchanged from the comparative risk assessment. With respect to the operational availability and the comfort criteria further work shall be put into these criteria in the coming phases. The medium risk registered for ship collision is reflecting that the design forming basis for the cost estimate does not fully fulfill the requirements to ship collision loading as is, i.e. the columns are overutilized but it is expected that further analyses will bring utilization down and the cross sectional area is therefore not increased, but the high utilization is registered as a risk to the assess cost of K12. Thus, this should be seen as a cost add-on risk which can be mitigated by a (smaller) change of the column design.

For risks related to fire, explosion, vandalism and terrorism the risk level is defined as medium to indicate the uncertainty related to these topics based on the limited work that has been put into these topics at current point in time.

More significant risks, which through the project phases are brought to low risk level by extended analyses are:

- Parametric excitation
- Global instability
- Local and global ship collision
- Anchors and mooring lines (including geohazard)

The status of the assessed risk levels are shown in Figure 7-1. More risks are identified in this phase, and of 25 relevant operational risks 6 are medium risk level and 19 assessed to low level based on extensive analysis and design work. For reference 23 relevant risks were addressed at Milestone 7, 24/5 2019 distributed with 6 medium and 17 low risks for K12.

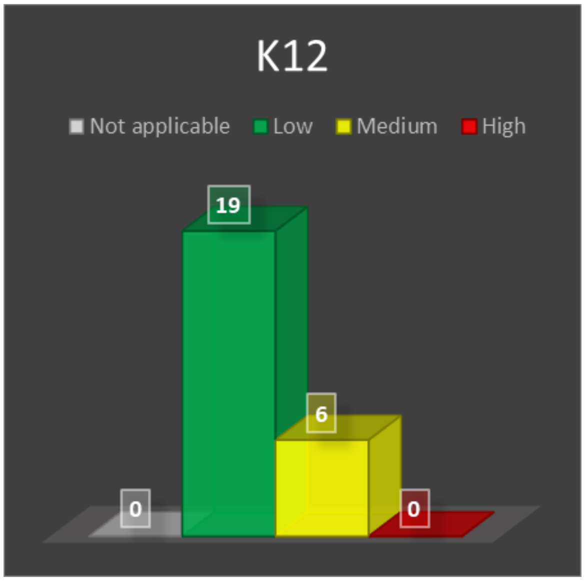

Figure 7-1 Chart showing distribution of operational risk levels for concept K12

7.2 Construction risk for K12

The construction risk identification undertaken as part of the comparative risk assessment had to be of a relative general nature to accommodate the comparison between concepts. Also, time constraints did not allow for a very detailed planning of the construction of the four concepts, but time was instead spent on highlighting the inherent differences and the risk associated with these.

Thus, subsequent to selection K12 as the preferred concept further work has been put into the method statements for the construction works. In particular the marine operations are detailed further, see Appendix N: Construction and Marine Operations, K12 /5/. This has resulted in updated baseline construction work steps as compared to those used for the comparative assessment. The specific K12 steps are:

1. Anchor installation
2. Mooring line installation
3. Construction of Cable Stayed bridge in South
4. Construction of North abutment
5. Assembly of bridge elements to bridge section
    a. low floating bridge
    b. high floating bridge
6. Connect low and high floating bridge
7. Installation of North section
8. Tow bridge to bridge location and assess weather
9. Wait for weather window

10. Connect bridge in weather window:
    a. Orientate bridge for connection to 1st end North section
    b. Connect winch wires to 1st end North
    c. Pull bridge section towards 1st end North and engage guiding system
    d. Rotate bridge to final orientation and connect winch wires to 2nd end South
    e. Engage positioning system joint in north
    f. Pull bridge to 2nd end south to engage positioning system joint
    g. Install locking joints in both ends (system in south allows for infill section)
    h. Connection (and tensioning) of mooring lines to pontoon (1x4 for storm safe situation)
11. Connection (and tensioning) of remaining mooring lines (2x4)
12. Make up final welds of bridge girders towards 1st north and 2nd south end including infill section in south

The construction risk register is based on the comparative risk register updated and focused on the absolute risks for K12 to identify and mitigate the specific construction risks. A construction risk workshop was held 12/8 2019 to consolidate the construction risk register.

The construction risks for concept K12 are listed in *Table 7-2* and further details can be found in the full register in chapter 8.6.

Index no	Phase	Hazard	In-place mitigation measures	K12	Further mitigation measures/actions
1,00	Cable stayed bridge	Site for tower foundation not appropriate		Low	
3,00	Cable stayed bridge	Problems constructing stay cable bridge	Well known method that has been carried out multiple times before	Low	
4,00	Cable stayed bridge	Extreme weather while cable stay bridge await floating bridge installation	Cable stay bridge (temporary without floating bridge) is checked for 100 year storm	Low	Dampers can be introduced if it should show necessary
5,00	Assembly of floating low bridge ("sausage factory")	Reduced flexibility and robustness during assembly cause delay		Low	Consider if assembly should be done in parallel assembly lines to add redundancy
6,00	Assembly of floating low bridge ("sausage factory")	Welding of sections - movements damage/delay welding	Welding to occur on barge in sheltered waters. Relative movements of deck section on barge prevented by high stiffness of grillage. Locking system will be used for the joints to be welded to the free-floating bridge (every 5th joint).	Low	Alternatively, a larger barge can be used to minimize relative movements. Number of sections may be optimized.

7,00	Assembly of floating low and high bridge deck and pontoons	Challenges during welding of pontoons and deck sections in water	Critical connection between column and deck will be welded in yard/shop. The connection between the column sections will be secured with a temporary locking system Pontoon and column will be moored towards barge to reduce movements. Operation has to be repeated many times and will be carefully planned. Operation is not in itself time critical.	Low	
8,00	Assembly of floating low bridge ("sausage factory")	Loss of anchorage system during skidding and moving	Design of anchorage system is proved for 100y weather condition and skidding/moving will be done in controlled weather situation, thus, with large redundancy.	Medium	A description of the method for skidding and moving the bridge should be evaluated and detailed.
31,00	Assembly of floating high bridge	Uncertainty related to assembly of floating high bridge on barge with jacking tower	Stability check made and OK Subcontractor of jacking system has evaluate method/system.	Low	
32,00	Connection of low and high floating bridge	Challenges in the connection of the assembled low and high bridge	Assembly can be done in weather window. Assembly will be made in protected water inshore	Medium	Detailing of assembly may be downscaled from the system for connecting bridge at site.
36,00	Install North section	Challenges in installation of the north section of the floating bridge	Not time critical operation - just need to be installed prior to tow and installation of remaining part of floating bridge Ballasting assumed to accommodate for tidal variation.	Low	
11,00	Transport of floating bridge to site	Loss of control/ unknown response/ unforeseen extreme weather during tow	Tow management system (known from offshore when moving platforms)Weather windows are generally used. Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Medium	Simulations can be performed in a later phase, at least once during planning and once just prior to the operation. Backup tugs and backup management system must be implementedRobustness option, not base case: K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)
13,00	Connect bridge in weather window	Problems in orientating and connecting winches of floating bridge in north	Tow management system (known from offshore) The crew will have experience from the tow to site #11 Operation will be in weather window Experience from connection of high and low floating bridge #32	Medium	Simulations can be performed in a later phase Test/confirm bridge/tug interaction in fjord before actual operation Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)
15,00	Connect bridge in weather window	Problems in engaging guiding joint in north, rotate bridge to final position, pull in and fit	Guiding joint in north proposed Positioning joints in north and south included in design	Medium	Methods shall be evaluated and detailed further.

		positioning joints in north and south.	Adjustment piece, see #17, will account for a range of tolerances for K12 in south Experience from connection of high and low floating bridge #32		
17,00	Connect bridge in weather window	Connecting 2nd south end may be unsuccessful due to building tolerances (south) or problems with locking system (north and south)	An adjustment piece is included to mitigate problems for a range of building tolerances. Analysis/verification of adjustment piece undertaken for a realistic range of tolerances and forces. Weather criteria established to limit the first order motions of the bridges during connection.	Low	
16,00	Connect bridge	Welding of bridge sections at sea - challenging/ time consuming	Introduction and dimensioning of locking joints in north and south. Strain limitation introduced. Experience from connection of high and low floating bridge #32	Low	
34,00	Connect bridge in weather window	Parametric excitation during installation	Construction schedule includes installation of mooring lines to central pontoon (1x4 for storm safe situation) within the weather window	Low	
35,00	Connect bridge in weather window	Weather window for connecting bridge deteriorate	Clear definition of points of no return and possible fall-back options. Once engaged and central mooring in in place structure is safe for 10y summer storm.DNVGL OS-H101 regulationsDynamic update of weather window and continuously assess shortest duration to next safe condition.Point of no return is when operations to engage locking system starts.	Low	
19,00	Anchor installation	Unsuccessful anchor installation operation	Geotechnical investigation of mooring location supplemented with reserve/backup anchor locations - backup locations identified and found satisfying Standard operation Installed 1 year prior to bridge connection	Low	
33,00	Mooring line installation	Unsuccessful mooring line installation operation	Standard operation Installed 1 year prior to bridge connection	Low	
20,00	Mooring lines(anchorage)	Damage to mooring lines during wet storage (on seabed)	K12 anchor locations moved to deep and relative even basin mitigating this risk. Mooring lines (wire and chain) chosen to have sufficient on-bottom stability for wet storage.	Low	

21,00	Mooring lines(anchorage)	Uncertainty regarding method - how much and when anchor lines should be tensioned	K12 shown safe in summer storm condition in the majority of all possible weather combinations. Middle mooring pontoon will be hooked up in the installation weather window for additional safety. The length of the mooring line will be used as the governing parameter for tensioning. Standard offshore technique used.	Low	
24,00	Mooring lines(anchorage)	Unsuccessful connection of mooring lines to anchor - line buried or "lost"	Connect buoy or other mark to ensure lines are not lost/buried at seabed Installed 1 year prior to bridge connection.	Low	
26,00	All installation phases	Ship collision	Pontoon anchorage point +5m depth below water level avoiding most impacts to mooring lines during construction (and operation)	Medium	Vessel traffic control - if not already in place. Is Bjørnafjorden closed for ship traffic during installation? Further design basis needed

Table 7-2 List of construction risks for concept K12

The topics of the medium level risks are:

- Anchorage problems during skidding and moving of the floating low-bridge at the inshore assembly line
- Challenges in the connection of the low and high floating bridge sections
- Loss of control during tow/transport of the 4.5 km floating bridge from assembly location to site
- Problems in orientating and connecting winches of floating bridge in north
- Problems in engaging guiding system, rotating bridge to final orientation, connection winch wires in south and engaging positioning system joints in north and south
- Ship collision risk in all construction phases

A number of mitigations are identified and many already implemented in the proposed construction and marine operations. Some of the medium risk operations such as the tow to site have an inherent risk, which will remain irrespective of the mitigations implemented. The entire operation of construction a floating bridge of these dimensions is of course not standard, and focus shall be on risk mitigation continuously throughout design and construction. However, the identified risks are all of manageable character given appropriate evaluation and detailing.

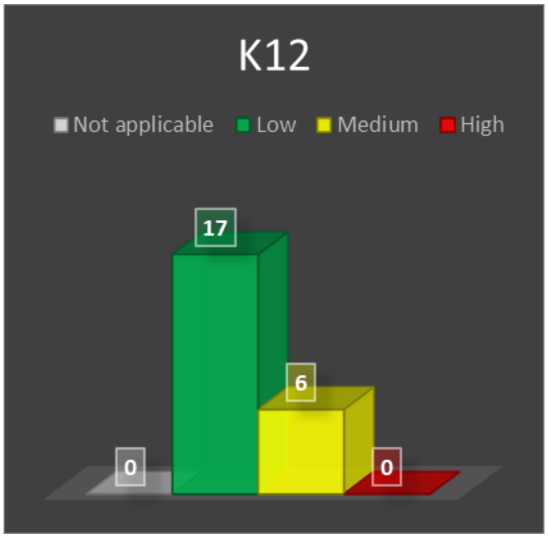

Figure 7-2 Chart showing distribution of construction risk levels for concept K12

From Figure 7-2 it is seen that 23 relevant risks have been identified and of these no high-risk items and 6 medium risk items. At Milestone 7, 24/5 2019 there were 8 medium risks and 10 low risks and also no high risk compared to the 6 medium risks and 17 low risks now. Thus, even though several new risks have been identified based on the more detailed descriptions of the operations the absolute number of medium risks is still reduced by further work with the method statements and detailed analyses.

7.3 Evaluation K12

Evaluation of risks taking into account construction as well as the permanent situation for the floating bridge over Bjørnafjord shows that even though a number of significant risks are and generally will be part of such a project, there is identified no showstoppers for concept K12. Thus, the concept seems robust from a construction and an operational point of view.

Risk analysis and assessment is an inherent part of the design and construction process and shall be carried out and updated on a regular basis to obtain safe and optimized solutions.

8 Enclosures – Additional documents

8.1 Operational risk workshop participants

ORA Workshop 1 (27/2 2019):

Name	Responsibility
Svein Erik Jakobsen	Project manager
Per Norum Larsen	Engineering manager
Rolf Magne Larssen	Object lead, K11 and K12
Anders Nesteby	Object lead, K13 and K14
Martin Storheim	Discipline lead, analyses
Henrik Polk	Discipline lead, cable stayed bridge
Inge-Bertin Almeland	Discipline lead, floating bridge
Anne Kristine Lunke	Co-discipline lead, floating bridge
Sverre Wiborg	Discipline lead, concept evaluation
Inger Kroon	Risk
Maria Grønnegaard	Risk
Inger Lise Johansen	Statens vegvesen (NPRA)
Ole Dag	Statens vegvesen (NPRA)

ORA Workshop 2 (14/5 2019):

Name	Responsibility
Svein Erik Jakobsen	Project manager
Per Norum Larsen	Engineering manager
Rolf Magne Larssen	Object lead, K11 and K12
Anders Nesteby	Object lead, K13 and K14
Martin Storheim	Discipline lead, analyses
Sverre Wiborg	Discipline lead, concept evaluation
Inger Kroon	Risk
Inger Lise Johansen	Statens vegvesen (NPRA)

8.2 Construction risk workshop participants

CRA Workshop 1 (6/3 2019 + 12/3 2019):

Navn	Ansvar
Per Norum Larsen	Engineering manager
Rolf Magne Larssen	Object lead, K11 and K12
Anders Nesteby	Object lead, K13 and K14
Jørgen Kjellsen	Discipline lead, fabrication and marine operations
Jan Larsen	Fabrication and marine operations
Petter Bjerkseth	Fabrication and marine operations
Lars Bjar	Discipline lead, moorings
Søren Lausten	Fabrication
Inger Kroon	Risk
Maria Grønnegaard	Risk
Henrik Polk	Discipline lead, cable stayed bridge
Sverre Wiborg	Discipline lead, concept evaluation

Additional contributors	
Knut Schröder	Discipline lead, geotechnics
Per Bollingmo	Discipline lead, geology

CRA Workshop 2 (14/5 2019):

Navn	Ansvar
Per Norum Larsen	Engineering manager
Rolf Magne Larssen	Object lead, K11 and K12
Anders Nesteby	Object lead, K13 and K14
Jørgen Kjellsen	Discipline lead, fabrication and marine operations
Lars Bjar	Discipline lead, moorings
Henrik Polk	Discipline lead, cable stayed bridge
Inger Kroon	Risk
Inger Lise Johansen	Statens vegvesen (NPRA)

CRA Workshop 3 (12/8 2019):

Navn	**Ansvar**
Svein Erik Jakobsen	Project manager
Per Norum Larsen	Engineering manager
Rolf Magne Larssen	Object lead, K11 and K12
Jørgen Kjellsen	Discipline lead, fabrication and marine operations
Stefan Schlömilch	Fabrication and marine operations
Lars Bjar	Discipline lead, moorings
Søren Lausten	Fabrication specialist
Knut Beck Engebretsen	Fabrication and marine operations specialist
Henrik Polk	Discipline lead, cable stayed bridge
Sverre Wiborg	Discipline lead, concept evaluation
Inger Kroon	Risk

8.3 Comparative risk register – Operational phase (24/5 - 2019)

24.05.2019 Bjørnafjorden - Operational risk register

ID	Hazard description					Risk level				Mitigation	Responsible	Additional info
Index no	Hazard	Consequence	Cause	In-place mitigation measures	Comment	K11	K12	K13	K14	Further mitigation measures/actions	Responsible	Existing risk register, UX = Nor U-X= Mul X= Nor X-X = Mul
1.00	Parametric excitation - Dynamic stability	Safety, Cost	Design (wind/swell)	Anchorage will provide stability for K12, K13, K14. New criterion taken as basis for K12 and K14 - DB criterion very strict	Quantification of damping to be used in analysis model is uncertain. Most uncertainty related to long period horizontal modes K13 without expansion joint is the basis. If expansion joint is introduced risk is "yellow" Swell is conservatively modelled as harmonic using the upper limit. Optimally it would be modelled as a stochastic process but this is very cumbersome. On-set criteria provided by SVV is, with the current solution not fulfilled. Instead a more detailed approach has been chosen. Uncertainty regarding HsTp gamma combination in extreme sea states - information requested from SVV K11 in very sensitive area wrt viscous damping. Change in damping will give large impact.	High	Low	Low	Low	K11 Mitigations by introduction of dampers at the tower is being investigated. Alternatively, change in the bridge geometry may move critical modes into an area with higher damping or lower excitation. Efficiency of mitigations still uncertain and risk level high. Mitigation is working but uncertain if possible to implement. K12, K14: If required, introduce more damping through improved mooring configuration. Likely not needed. CFD study under finalization to reduce uncertainty in drag coefficients.	Martin Storheim	U9, U10, U20, U1, U12
2.00	Bridge global instability (static buckling)	Safety, Cost	Design	Analysed and checked for K11 - anchors for K12 and K14 mitigate risk. Phase difference for waves has been analysed	Uneven environmental loading along bridge. Bridge response is quite sensitive to changes in drag coefficient. CFD analysis ongoing. A new loading scheme (from SVV) may be introdcued.	Medium	Low	Low	Low	Effect of inhomogeneous sea and wind is being analysed - Evaluation of possible coupling effects between different environmental contributions. Inhomogeneous static wind on bridge (shielding from mountain) - analysis ongoing	Martin Storheim/ Ketil Aas Jacobsen	
3.00	Hydrodynamic interaction between pontoons	Safety, cost	Design		Can potentially increase load by 10-20% for specific conditions, but not affecting ULS. Pontoon distance influence effect (lower distance -> larger impact) With 125m between pontoons this is no major issue	Low	Low	Low	Low	Analysis ongoing	Martin Storheim	U-17
4.00	Combined behaviour of floating bridge and cable stayed bridge	Safety, cost		Full model including both floating bridge and cable stayed bridge.	Limited exerience from other similar structures During all phases of concept developement there has not been any indication of unforeseen issues Impact generally larger for K11 (larger global displacements), but no significant difference	Low	Low	Low	Low	Analysis for cable stayed bridge ongoing (consider risk of exitation of cables - but damping can be introduced if necessary)	Henrik Polk	U-39
5.00	Influence from simplifications in structural analysis model on dynamic properties (beam elements), local stress variations	Safety, cost	Simplified 3D float structural modelling in phase 3	Technology Qualification Analysis Several independant analysis (using different analysis tools) has been conducted during the previous phases Independent model verification	Variation in eigenmodes (5-10%) considered in analysis of e.g. parametric exitation	Low	Low	Low	Low	Independent model verification Shear deformation to be checked	Martin Storheim	U11, U13, U14
6.00	Ship collision impact with pontoon (vessel smaller than design vessel)	Availability, Safety, Cost	Human error, technical error, weather ect	Scenario analysed for design load and have similar response for all solutions	Updated ship collision impact load of 138-237 MJ (in DB) recieved 05.02.2019. Alternative distibution recieved 08.02.2019 All bridge concepts are robust w.r.t. damage from a collision event in terms of flooding, loss of waterplane stiffness and damage to bridge girder. Column damage identified as most critical	Medium	Medium	Medium	Medium	Re-evaluation of column design with increased torsional capacity will fully solve the problem .	Martin Storheim	37, U-3, U5, 35
34.00	Ship collision - vessel larger than design vessel									Robustness check for loss of pontoon to be considered in following phase and considered comparable for all solutions. Loss of pontoon will cause large weak-axis moments and plastification of bridge girder, but likely not global collapse.		
7.00	Ship collision with low bridge - forecastle deck, bow or containers hit girder	Availability, Safety, Cost	Human error, technical error, weather ect	Girder height determined to reduce risk of forecastle/bow/container collisions Lower level of girder is +11.5m according to DB.	Vessels from North/South route may drift and hit Likelihood of this scenario low K11 more sensitive for impact No design requirements for bow collision or like to girder in design basis only deckhous collision. Thus, only robustness check. K11 analysed and more robust than original anticipated. Global collapse is not likely.	Low	Low	Low	Low		Martin Storheim	
8.00	Ship dech house collision impact with girder - local damage	Availability, Cost	Human error, technical error, weather ect	Local analysis undertaken showing minor damage	Girder load increased to 367 MJ (doubled) compared to original DB. Alternative distibution recieved 08.02.2019	Low	Low	Low	Low	Robustness check in damaged condition	Martin Storheim	U5
9.00	Ship deck house collision impact with girder -global response - South	Availability, Safety, Cost	Human error, technical error, weather ect	Robustness check in damaged condition yields acceptable results (see appendix G)	K11 will due to lack of anchorage have larger response K11 not designed for the increased forces, but uncertainty added in cost estimate	Low	Low	Low	Low	Global analysis of girder collision	Martin Storheim	U-3, U5
35.00	Ship deck house collision impact with girder -global response - North	Availability, Safety, Cost	Human error, technical error, weather etc	Additional strengthening of girder near north abutment has been introduced	Response of collision similar for all scenarios due to fixation in north which means that effect from anchor lines becomes insignificant K11 worst but all show high utilization, not included in design but added in cost estimate	Low	Low	Low	Low	Robustness check in damaged condition		

10.00	Ship collision/submarine collision with mooring lines - loss of line(s)	Safety, cost, availability	ship collision, submarine	Design includes loss of two anchors. It is geometrically unlikely to hit more than one line Moorings lines designed for ship impact Robustness check of loss of four anchors OK for all concepts	K12 has now only 3 anchor groups compared to 4 for K13 and K14 and, thus, has less likelihood of impact.	NA	Low	Low	Low	Check for parametric exitation without 2 anchor lines for K12	Martin Storheim	
11.00	End Anchorage - loads in abutment	Safety, cost	Design	Loads included in design								11
12.00	Limited experience with large expansion joint (originally considered in K13) - larger than currently installed -100 years life	Cost, Additional O&M		Fixed connection for K13 is basecase according to sec 3.6.2 in report -035								U-24
13.00	Corrosion on pontoon, columns and girder of low bridge - potentially leak into pontoon	Additional O&M	Inadequate corrosion protection coating, surface preparation or coating application Unknown long term behavior of coating.	Girder and columns: standard for bridge in general Inspection and maintenance program defined for pontoon	phase 3: The Super Duplex Stainless Steel with 25% Cr affects weld to adjacent steel or is not fully corrosion resistant Coating broken down faster than assumed in calculations. Pontoon design life longer than "normal" experience base for anodes. Anode consumption rate higher than calculated. Phase 3: Proposed to submerge plate of 25% CR SDSS with adjacent carbon steel plates in similar environment to confirm behavior	Low	Low	Low	Low			U8, 22, 23, U-30, 2-1, 35
14.00	Leakage into pontoon compartment- combined with Risk no 13											
15.00	Fatigue - girder and column	Cost, Additional O&M	Girder - related to introduction of "fagværk" Connection to column		K13 critical both with and without expansion joint Tensile stresses in girder relative low and will not increase risk significant and included in SN curves	Low	Low	Low	Low	Addtional inspection programme (potentially supplemented with SHMS) for K13 is a potential mitigation.	Martin Storheim	24, 35
16.00	Loss of mooring lines	Safety, cost, availability	Fatigue, overload	Bridge must be operational with 2 mooring lines lost according to DB Robustness check shows capacity for loss of one group	All concepts are checked OK. K13 has a higher sensitivity to loss of mooring lines due to large strong-axis moments towards the pylon, but within acceptable limits.	NA	Low	Low	Low		Martin Storheim	
17.00	Increased girder stress due to marine growth or other reason for increased weight of pontoon	Safety, O&M		Marine growth on pontoons considered in design	Marine growth on mooring lines?	Low	Low	Low	Low	Not expected to be necessary, but it needed adjustment of ballast is possible. Autonomous hull cleaning is also available		30,31
18.00	Vandalism, terrorism - cable stay bridge	Safety, cost, availability	Cut stay cables	One cable can be lost without structural collapse	Phase 3 included conventional protection of cable anchors in normally accessible areas.	Medium	Medium	Medium	Medium	DB require Risk analysis - to be performed in another phase		27, U-14, 25, 26, U-42
19.00	Vandalism, terrorism - floating bridge	Safety, cost, availability	Ship collision, pontoon waterfilled, cutting mooring lines	Bridge must be operational with 2 mooring lines lost according to Design basis	Phase 3 design includes no "public" access to pontoon from sea or column from bridge. The corrosion resistant alloy in splash zone is robust to minor mechanical damage (scraping)	Medium	Medium	Medium	Medium	DB require Risk analysis - to be performed in another phase		27, U-14, 25, 26, U-42
20.00	Airplane/heli crash into tower or cables	Safety, cost		Likelihood is extremely small	Bergen Airport 20km away	Low	Low	Low	Low			U-44
21.00	Fire/explosion on bridge or in adjacent tunnel	Safety, cost, availability	Accident with explosive material wither on or below bridge		Design basis refer to separate study (10200942-RIS-RAP-001)	Medium	Medium	Medium	Medium	Go through study and identify potential actions Document availability -see risk no 26	??	
22.00	Fractures in rock at tower location (cable stay bridge)	Safety, cost		Has been investigated and location found ok. New fractures will not form	Tower foundation on rock	Low	Low	Low	Low		Per Bollingmo	
34.00	Soil conditions for anchor locations - in particular K12 with new anchor locations	Cost, redesign		Anchor locations for K12, K13, K14 considered ok.	OBS - not operational risk, is merged to construction risk register #19						Knut Schrøder	
23.00	Geohazard: loss of anchors due to landslide	Safety, cost, availability	Landslide	Design includes loss of two anchor lines Robustness check with loss of four anchor lines reveals sufficient residual capacity.	3 anchor lines (or one cluster) may be lost in a landslide -included in robustness check, OK for all concepts. New information form SVV not available this phase	NA	Low	Low	Low		Martin Storheim	1-7, 1-8
24.00	Comfort/movements not within criteria				Comfort from bridge itself approx 1/3 of criteria, but wind on vehicle much larger (~3 times allowable limit).	Medium	Medium	Medium	Medium		Sverre/Martin	
25.00	Bridge landing north - soil condition	Cost		No relevant - new location decided								U3, U19
26.00	Insufficient operational availability	Availability	Wind, maintenance, accidents, ice on cables, false VTS alarm	Availability studies from previous phases indicate availability above 99.5%.	Procedures for when to close bridge (wind, VTS, ice) should be defined at a later stage Wind (large wind speeds) is governing for availability in previous phases and is expected to be similar for all solutions. K11-K12 are sensitive to the zone with 30% turbulence intensity resulting in large down-time unless mitigated due to the road line direction close to the southern shore K13 without expansion joint in basecase	Medium	Medium	Low	Low	Verify availability above 99.5% can be obtained for all solutions K11-K12 might need mitigation such as wind screens due to effect on vehicles from high turbulence intensity. Long term statistics for wind to improve basis of design Local analysis of wind climate	Ketil Aas Jakobsen	
27.00	Extreme weather condition - unsafe to drive	Safety of users	Extreme wind	Availability - see risk no 26. The bridge will be closed when it is unsafe to drive.								32
29.00	Ballast types in operational phase			Identified during phase 3 - not relevant anymore	In previous phase only solid ballasting was allowed - likely connected to concrete pontoons							U6

8.4 Comparative Risk Register – Construction (24/5 - 2019)

24.05.2019 Bjørnafjorden - Construction Risk register													
ID		Hazard description					Risk level				Mitigation	Responsible	Additional info
Index no	Phase	Hazard	Consequence	Cause	In-place mitigation measures	Comment	K11	K12	K13	K14	Further mitigation measures/actions	Responsible	Existing risk register, UX = Nor U-X= Mul X= Nor X-X = Mul
1.00	Cable stay bridge - Tower foundation	Site for tower foundation not appropriate	Change of alingment	Poor rock condition and large forces to be transferred		Rock conditions at tower foundation site are expected to be good (discussed with Per Bollingmo) Identical for all solutions and thus not essential for comparison	Low	Low	Low	Low	To be indetified		
2.00	Cable stay bridge	Opportunity to reduce size of cable stay bridge for K11	Opportunity cost saving			OBS - not construction risk K11 cable stay bridge could be slightly shorter.							
3.00	Stay cable bridge installation	Problems constructing stay cable bridge	Cost, delay		Well known method that has been carried out multiple times before	Tower cast in-situ and on land. Bridge construction is not including unusual processes and should not constuitute any general problems	Low	Low	Low	Low			
4.00	Stay cable bridge	Extreme weather while cable stay bridge await floating bridge installation			Cable stay bridge (temporary without floating bridge) to be designed for 100 year storm -	Check is ongoing	Low	Low	Low	Low	Ensure that cable stay bridge (without floating high bridge) can stand 100 year conditions - dampers can be introduced		
5.00	Assembly of floating bridge ("sausage factory")	Reduced flexibility and robustness during assembly	Delay, long construction period			Assembly of floating bridge is on critical path K11, K12 is, in base case, assembled as one (except high floating bridge). Three parallell fabrication processes is feasible for all four solution. This would save time but be more costly	Low	Low	Low	Low	Consider if K11-K14 assembly should be more than two parallell assembly lines	Jørgen, Per	
6.00	Assembly of floating bridge ("sausage factory")	Welding of sections - movements damage/delay welding			Welding to occur on barge.	Welding on the barge will be sensitive to waves. Check ongoing - to be completed before 30/6. Will most likely be the same for K11-K14	Low	Low	Low	Low	Welding must be largely weather independent to ensure continous assembly process. Check of construction conditions in terms of wave height etc ongoing		
7.00	Assembly of floating bridge ("sausage factory")	Challenges during welding of pontoon and deck in water -	Cost, damage, delay	Unexpected or uncontrolled movements	Critical connection between column and deck will be welded in yard/shop	Check not yet started	Medium	Medium	Medium	Medium	More traditional deck-mating issue. Solvable in later phase		
8.00	Assembly of floating bridge ("sausage factory")	Loss of anchorage system during skidding and moving	Cost, damage, delay		Design will include loss of one anchor	Several anchorage will be nessesary to keep bridge steady. Consequence may be larger for K11, K12, but method for skidding and moving not yet specified in any detail sufficient for assessment.	Medium	Medium	Medium	Medium	Anchor design to be conducted in a later phase More detailed cost analysis in next phase		
9.00	Assembly of floating high bridge	Assembly method and site may not be optimal (or available)	Delay		A new construction method has been chosen to eliminate this risk, see #31	To be assembled in dry dock - however, there is only one dry dock that is large enough. Column and pontoon not stable alone. Temporary pontoon could provide stability such that "sausage factory" method could be used					Alternative method used, see #31	Per/Jørgen	
31.00	Assembly of floating high bridge	Uncertainty related to assembly of floating high bridge on barge with jacking tower	Cost, damage, delay	Unexpected or uncontrolled movements	Stability check made and OK	New method where a barge and jackup tower is used . Principles known from offshore. Stability check undertaken and OK Assembly to be investigated further in next phase	Medium	Medium	Medium	Medium	Assembly to be investigated further in next phase		
10.00	North abutment	Complexity of final connection in north - especially tensioning for K13	Cost, damage, delay			Abutment in itself is standard. Earlier assessed risk is merged into #15 - North abutment do not constitute any problem in terms of design and cnstruction but the connection to floating bridge is a challenging task							
11.00	Transport of float floating bridge(K11+K12)/bridge sections(K13+K14) to site	Loss of control/ unknown response/ unforeseen exteme weather during tow	Cost, damage, delay	Loss of tug boat, tow line failure and general uncertainty regarding transportation of bridge/bridge sections	Tow management system (known from offshore when moving platforms) Weather windows are generally used Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Towing distance approx 10-15 km. K11+K12 towed in one 4.5 km section, K13+K14 towed in 1-2km sections Likelyhood of collision is larger for a large one-piece transport due to space limitation and limited experience with towing of 4.5km long structures . Approx 14 tugs will be needed to transport K11+K12. Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits Towing of especially large sections will be weather sensitive	Medium	Medium	Low	Low	Simulations can be performed in a later phase. Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)		
12.00	Transport/float floating bridge(sections) to site	Unknown effects/movements/deformation of floating bridge	Damage, delay			Merged into #11						Pe/Jørgen	
13.00	Orientate and connect winches of floating bridge (section)	Behaviour and deformation of floating 4.5km uncertain	Delay, damage	Uncertainty regarding manouvering of 4.5 km bridge. Uncertainty of weather sensitivity	Tow management system (known from offshore) The crew will have experience from the tow to site Weather windows are generally used	No experience in manouvering a 4.5km bridge section.	Medium	Medium	Low	Low	Simulations can be performed in a later phase Test/confirm bridge/tug interaction in fjord before actual operation Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)		
14.00	Ballast and connect	Unsuccessful connection (using guide system) to K13,K14 middle section due to large movements	Delay			Uncertain how much middle section will move once installed. More ballast operations lead to larger overall risk. Not yet analysed. Uncertain magnitude of tension in the anchor lines (see risk no . 21) Middle section likely OK but next operations more complex	NA	NA	Medium	Medium	Movements and anchor tension to be analysed to verify base case for K13 and K14	Pe/Jørgen	

15.00	Ballast and connect	Problems in deformation of bridge to fit last end to guide system and make final connection in north.	Damage, delay, fatalities	Loss of tug during pull of K11, 12, 14 to fit 2nd end to guide system - spring effect -due to blackout or other technical error Uncertaint with respect to deformation of K14 Unforeseen issues during tensioning of K13	Adjustment piece, see #17, will account for a range of tolerances for K11, K12 and K14	K14 will need the largest pull to be deformed sufficiently due to higher stiffness of bridge However, K13 is more complex due to tensioning system and sliding mechanism. Infill must be introduced (If expansion joint is reintroduced the risk picture will change)	Low	Low	High	Medium	To be considered in further detail in this phase. Initial analyses show that it is much more difficult to deform K14. More analysis will likely lead to reduction of risk to medium for K13, but still challenging operation		
16.00	Ballast and connect	Welding of bridge sections at sea - challenging/ time consuming	Delay, cost	Damaged welds due to movements during welding. Delay of welding process due to weather	Dimensioning of locking device for conservative values done.	K13, K14 will have three sections that needs welding at bridge site It is critical that temporary structures keep section to be welded steady during welding of periphery Experience from other project indicate that welding of periphery only takes approx 2 days K13,14 welding of "moving" pieces is connected with larger uncertainty and will be more sensitive to weather. Strain limit to be defined	Medium	Medium	Medium	Medium	Strain limitation to be analyses - even in weather window this may be problematic. Being analysed.		
17.00	Ballast and connect	Connecting last end for K11, K12 and K14 may be unsuccessfull due to building tolerences	Delay, cost		An adjumstment piece is included for K11, K12 and K14 to mitigate problems for a range of building tolerances	New and less conservative sectional forces will be applied in analysis in next phase.	Medium	Medium	NA	Medium	Analysis/verification of adjustment piece for a realistic range of tolerances and forces. Final positioning analysis to be performed taking into account the position of pull in winches, building tolerances and elongation/contraction of bridge due to temperature. Establish weather criteria to limit the first order motions of the bridges during connection.		
18.00	Ballast and connect	K14 may not deform as much as needed to connect	Cost, delay	Uncertaint with respect to deformation of K14		Merged into #15					Deformation of K14 to be calculated Tensioning "system" as for K13 may be needed	Jørgen, Per	
19.00	Anchor and mooring line installation	Unsuccessful mooring/anchor installation operation	Cost, delay	Unexpected soil condition - boulders or ammunition	Geotechnical investigation of mooring location supplemented with reserve/backup anchor locations - backup locations identified and found satisfying	There is generally low experience with rejected anchor installation and likelihood is considered small. Typically rejection is due to rotation tolerances that are not fulfilled.	NA	Low	Low	Low	Further analysis awaiting results of the 2018 soil investigation campaign		
20.00	Mooring lines(anchorage)	Damage to mooring lines during wet storage	Cost, delay, install new lines	Seabed is not flat and an uneven seabed may damage lines	K12 anchor locations moved to deep and even basin mitigating this risk	K12 no problem with new anchor locations at the deep and flat basin - but K13 and K14 to be analysed further	NA	Low	Low	Low	Alternatives are available for K13 and K14 e.g. storing on barge Further analysis of current wet storage location for K13 and K14 to be conducted in the coming phase		
21.00	Mooring lines(anchorage)	Uncertainty regarding method - how much and when anchor lines should be tensioned	Cost, delay		Preliminary spot checks show that low top tension (~100t) on the mooring lines during summer storm conditions will be sufficient. Length of the mooring line to be used as the governing parameter for final tensioning (such as with the stay cables). The correct length can be indicated/marked on the chain during mooring installation. Numerous methods for tensioning of the chains are described in the marine operations document	Weather windows and bridge respons in temporary states influence the tensioning. Same tensioning for K12, 13 and 14 will be applied. However, K12 has only 12 lines and K13 and K14 32 lines. However, not in itself significant for differeing in risk. Base case is a pull vessel combined with a spacer. It is chosen due to cost/time/flexibility. Several alternatives exsist. Winch on pontoon is most well-known but likely most expensive compared to a pull vessel. A pull vessel would, however, pull in the entire bridge which should be considered. Preliminary spot checks show that it will be sufficient to have a low top tension (~100t instead of ~300t) on the mooring lines during summer storm conditions. For the final tensioning one can use the length of the mooring line as the governing parameters (such as with the stay cables). The correct length can be indicated/marked on the chain during mooring installation. The length will be adjusted according to final anchor position and as built lengths of wires and chains. The chain will then be pulled in until the marked link is at the chain stopper. This methodology is used offshore for the installation of FPSOs which don't have chain lockers on board. There are numerous methods for tensioning of the chain. These are described in the marine operations document	NA	Low	Low	Low	Further detailing of method in later phase	Per, Jørgen	
22.00	Mooring lines(anchorage)	HSE risk during anchor operation	Injuried, fatalities	Accident when operating heavy machinery and material in tension		Mooring operations are generally considered high-risk due to personell working close to heavy machinery with high tension structures. Deleted since it is preconditioned that HSE risk can be brought to acceptable level for such operations. Thus, uncertainty in method in #21 includes safe installation.					Update if basecase for K12 is changed to include more lines and tension comparable to K13, K14	Per	
23.00	Mooring lines(anchorage)	Tensioning of mooring lines for K12, K13, K14 - uncertainty regarding method				Merged into #21					Analyse base case method further	Jørgen	
24.00	Mooring lines(anchorage)	Unsuccessful connection of mooring lines to anchor - line buried or "lost"	Cost, delay		Connect buoy or other mark to ensure lines are not lost/buried at seabed	Mooring lines are connected after anchor installation to avoid SIMOPS	NA	Low	Low	Low			
29.00	Mooring lines(anchorage)	Gravity anchors in north- ensure seabed is sufficiently flat - limited experience blasting in -60m	Cost, delay	Unforeseen issues during blasting in deep water	K12 no anchor in north	Gravity anchors are used in north due to soil conditions - Explosived to be used under 60 meter water to even out seabed K12 no anchor group in north	NA	NA	Medium	Medium			
25.00	Tensioning of bridge (using winches)	Welding of infill during large tension - difficult and dangerous operation, HSE	Injuried, fatalities			K13 is the only solution where it is necessary to induce tension in bridge Deleted since it is preconditioned that HSE risk can be brought to acceptable level for such operations. Thus, uncertainty in method in #15 includes safe installation.					Detailing of operation to be analysed further		Identified by Jørgen

8.5 Operational Risk Register – K12 (30/6 - 2019)

30.06.2019 Bjørnafjorden - Operational risk register

ID	Hazard description					Risk level	Mitigation	Respon sible	Addition al info
Index no	Hazard	Consequence	Cause	In-place mitigation measures	Comment	K12	Further mitigation measures/actions	Responsi ble	Existing risk register, UX = Nor U-X= Mul X= Nor X-X = Mul
1,00	Parametric excitation - Dynamic stability	Safety, Cost	Design (wind/swell)	Anchorage will provide stability for K12 New criterion taken as basis for K12 - DB criterion very strict	Quantification of damping to be used in analysis model is uncertain. Most uncertainty related to long period horizontal modes Swell is conservatively modelled as harmonic using the upper limit. Optimally it would be modelled as a stochastic process but this is very cumbersome. On-set criteria provided by SVV is, with the current solution not fulfilled. Instead a more detailed approach has been chosen. Uncertainty regarding HsTp gamma combination in extreme sea states - information requested from SVV	Low	K12: If required, introduce more damping through improved mooring configuration. Likely not needed. CFD study shows significantly higher viscous drag coefficients than used in the analysis; thus giving increased safety margin. Other possible mitigations could be introduction of dampers at the tower or, alternatively, change in the bridge geometry which may move critical modes into an area with higher damping or lower excitation. Efficiency of such mitigations uncertain and currently not necessary. Preliminary studies shows that introduction of a linear damper in the tower/bridge connection may be sufficient to satisfy the stringent onset-criterion as in DB.	Martin Storheim	U9, U10, U20, U1, U12
2,00	Bridge global instability (static buckling)	Safety, Cost	Design	Anchors significantly increase the static buckling capacity of the bridge. Phase difference for waves has been analysed	Uneven environmental loading along bridge. Lateral load on bridge is somewhat sensitive to viscous drag, but this is not a concern as CFD simulations indicate a low stationary drag coefficient. Effect of inhomogeneous sea is small. The effects of an alternative wind load model is evaluated. The new model improves how aerodynamic coefficients are taken into account for skew wind.	Low	Inhomogeneous static wind on bridge (shielding from mountain) - analysis ongoing. More detailed wind load model.	Martin Storheim/ Ketil Aas-Jakobsen	
3,00	Hydrodynamic interaction between pontoons	Safety, cost	Design		Hydrodynamic interaction will primarily affect weak-axis response. With 125 m pontoon spacing hydrodynamic interaction is not considered to be important, but it may be for lower pontoon spacings.	Low		Martin Storheim	U-17
4,00	Combined behaviour of floating bridge and cable stayed bridge	Safety, cost		Full model including both floating bridge and cable stayed bridge. Analysis shows fine combined behaviour.	Limited exerience from other similar structures During all phases of concept developement there has not been any indication of unforeseen issues	Low	Cable exitation can be mitigated by introdiction of dampers if necessary.	Henrik Polk	U-39
5,00	Influence from simplifications in structural analysis model on dynamic properties (beam elements), local stress variations	Safety, cost	Simplified 3D float structural modelling in phase 3	Technology Qualification Analysis Several independent analysis (using different analysis tools) has been conducted. Independent model verification	Benchmarks between the various solvers show low differences. The first 10 eigenmodes are captured well in all softwares under similar assumptions. Still, a variation in eigenmodes (5-10%) considered in analysis of e.g. parametric exitation Independent model verification has the purpose of comparing output from Orcaflex with RM Bridge.	Low	Further independent model verification	Martin Storheim/ Arne Bruer	U11, U13, U14
6,00	Ship collision impact with pontoon - design vessel	Availability, Safety, Cost	Human error, technical error, weather ect	Scenario analysed for design load and have similar response for all solutions	Updated ship collision impact load of 138-237 MJ (in DB) recieved 05.02.2019. Alternative distibution recieved 08.02.2019 K12 concept is robust w.r.t. damage from a collision event in terms of flooding, loss of waterplane stiffness and damage to bridge girder. Column damage due to exceedance of torsional capacity is identified as most critical when the most conservative scenario is selected. The column is reinforced to partly mitigate this, but not fully due to the likelihood of reduced collision energies following a planned re-routing of the navigational channel (not included in DB).	Medium	Re-evaluation of column design with increased torsional capacity will fully solve the problem. Column capacity can be increased if necessary, but increased volumes not part of cost estimate.	Martin Storheim	37, U-3, U5, 35
36,00	Ship collision impact with pontoon - vessel smaller than design vessel	Availability, Safety, Cost	Human error, technical error, weather ect	Scenario analysed for design load and have similar response for all solutions	The design vessel represent one possible impact scenario with a mass and velocity. Other vessels (higher mass and lower velocity or the opposite) may excite the bridge in a different manner, particularly if dynamic amplification is important. The simulations have shown that the bridge response is not largely affected by dynamic amplification, and the impact from smaller vessel such as high speed ferries does not have sufficient energy to cause a governing bridge response. K12 concept is robust w.r.t. damage from a collision event in terms of flooding, loss of waterplane stiffness and damage to bridge girder.	Low		Martin Storheim	37, U-3, U5, 35
34,00	Ship collision - vessel larger than design vessel	Availability, Safety, Cost	Uncertainty in ship collision risk assessment and resulting requirements	K12 was checked for 50% increased energy for pontoon collision normal to the bridge axis. Small differences in response was observed; negligible towards the ends (stiffness-dominated) but somewhat larger in the middle of the bridge.	Requirements are fulfilled, but hazard could be seen as a robustness check towards requirements.	Low	Robustness check for loss of pontoon to be considered in following phase. Loss of pontoon will cause large weak-axis moments and plastification of bridge girder, but likely not global collapse.	Martin Storheim	

7,00	Ship collision with low bridge - forecastle deck, bow or containers hit girder	Availability, Safety, Cost	Human error, technical error, weather ect	Girder height determined to reduce risk of forecastle/bow/container collisions Lower level of girder is +11.5m according to DB.	Vessels from North/South route may drift and hit Likelihood of this scenario low No design requirements for bow collision or like to girder in design basis only deckhous collision. Thus, only robustness check. Scenario analysed and concept is more robust than original anticipated. Global collapse is not likely.	Low		Martin Storheim	
8,00	Ship deck house collision impact with girder - local damage	Availability, Cost	Human error, technical error, weather ect	Local analysis undertaken showing minor damage	Girder load increased to 367 MJ (doubled) compared to original DB. Alternative distibution recieved 08.02.2019	Low	Robustness check in damaged condition	Martin Storheim	U5
9,00	Ship deck house collision impact with girder -global response - South	Availability, Safety, Cost	Human error, technical error, weather ect	Robustness check in damaged condition yields acceptable results (see appendix G)		Low	Global analysis of girder collision	Martin Storheim	U-3, U5
35,00	Ship deck house collision impact with girder -global response - North	Availability, Safety, Cost	Human error, technical error, weather etc	Additional strengthening of girder near north abutment has been introduced	Bridge response in northern end from collision similar for all scenarios due to fixation in north (stiffness dominated) K12 show high utilization, not included in design but added in cost estimate	Low	Robustness check in damaged condition	Martin Storheim	
10,00	Ship collision/submarine collision with mooring lines - loss of line(s)	Safety, cost, availability	ship collision, submarine	Design includes loss of two anchors. It is geometrically unlikely to hit more than one line Moorings lines designed for ship impact Robustness check of loss of four anchors OK for all concepts	K12 has only 3 anchor groups of 4 anchors, i.e.,12 anchors and,this, the geometrical proibability of impact is low. Further, impact directly to a mooring line may cause loss of the mooring line, but the global residual strength is sufficient to prevent progressive collapse.	Low		Martin Storheim	
13,00	Corrosion on pontoon, columns and girder of low bridge - potentially leak into pontoon	Additional O&M	Inadequate corrosion protection coating, surface preparation or coating application Unknown long term behavior of coating.	Girder and columns: standard for bridge in general Inspection and maintenance program defined for pontoon	phase 3: The Super Duplex Stainless Steel with 25% Cr affects weld to adjacent steel or is not fully corrosion resistant Coating broken down faster than assumed in calculations. Pontoon design life longer than "normal" experience base for anodes. Anode consumption rate higher than calculated. Phase 3: Proposed to submerge plate of 25% CR SDSS with adjacent carbon steel plates in similar environment to confirm behavior	Low			U8, 22, 23, U-30, 2-1, 35
15,00	Fatigue - girder and column	Cost, Additional O&M	Girder - stress concentrations due to longitudinal truss work Grider - column transition	Possible to have good structural details with low stress concentrations. Local design with sufficient capacity	Preliminary analysis show moderate stresses in truss work, and it is expected that the fatigue consequence of these are manageble without large increase in weight.	Low	Addtional inspection programme (potentially supplemented with SHMS) is a potential mitigation.	Martin Storheim	24, 35
16,00	Loss of mooring lines	Safety, cost, availability	Fatigue, overload	Bridge must be operational with 2 mooring lines lost according to DB Robustness check shows capacity for loss of one group	Checked - OK	Low		Martin Storheim	
17,00	Increased girder stress due to marine growth or other reason for increased weight of pontoon	Safety, O&M		Marine growth on pontoons considered in design	Marine growth on mooring lines?	Low	Not expected to be necessary, but it needed adjustment of ballast is possible. Autonomous hull cleaning is also available		30,31
18,00	Vandalism, terrorism - cable stay bridge	Safety, cost, availability	Cut stay cables	One cable can be lost without structural collapse	Phase 3 included conventional protection of cable anchors in normally accessible areas.	Medium	DB require Risk analysis - to be performed in another phase		27, U-14, 25, 26, U-42
19,00	Vandalism, terrorism - floating bridge	Safety, cost, availability	Ship collision, pontoon waterfilled, cutting mooring lines	Bridge must be operational with 2 mooring lines lost according to Design basis	Phase 3 design includes no "public" access to pontoon from sea or column from bridge. The corrosion resistant alloy in splash zone is robust to minor mechanical damage (scraping)	Medium	DB require Risk analysis - to be performed in another phase		27, U-14, 25, 26, U-42
20,00	Airplane/heli crash into tower or cables	Safety, cost		Likelihood is extremely small	Bergen Airport 20km away	Low			U-44
21,00	Fire/explosion on bridge or in adjacent tunnel	Safety, cost, availability	Accident with explosive material wither on or below bridge		Design basis refer to separate study (10200942-RIS-RAP-001)	Medium	Go through study and identify potential actions Document availability -see risk no 26		
22,00	Fractures in rock at tower location (cable stay bridge)	Safety, cost		Has been investigated and location found ok. New fractures will not form	Tower foundation on rock	Low		Per Bollingmo	
23,00	Geohazard: loss of anchors due to landslide	Safety, cost, availability	Landslide	Design includes loss of two anchor lines Robustness check with loss of four anchor lines reveals sufficient residual capacity.	2 anchor lines (one cluster) may be lost in a landslide - included as robustness check, found OK Further check with loss of one side of two adjacent mooring clusters shown OK. New information form SVV not available this phase	Low		Martin Storheim	1-7, 1-8
24,00	Comfort/movements not within criteria				Comfort from bridge itself approx 1/3 of criteria, but wind on vehicle much larger (~3 times allowable limit).	Medium		Sverre Wiborg/ Martin Storheim	
26,00	Insufficient operational availability	Availability	Wind, maintenance, accidents, ice on cables, false VTS alarm	Availability studies from previous phases indicate availability above 99.5%.	Procedures for when to close bridge (wind, VTS, ice) should be defined at a later stage Wind (large wind speeds) is governing for availability in previous phases and is expected to be similar for all solutions. K12 is sensitive to the zone with 30% turbulence intensity resulting in large down-time unless mitigated due to the road line direction close to the southern shore	Medium	Verify availability above 99.5% can be obtained for all solutions K12 might need mitigation such as wind screens due to effect on vehicles from high turbulence intensity. Long term statistics for wind to improve basis of design Local analysis of wind climate	Ketil Aas-Jakobsen	
11,00	End Anchorage - loads in abutment	Safety, cost	Design	Loads included in design					11
14,00	Leakage into pontoon compartment combined with Risk no 13								

37,00	Soil conditions for anchor locations	Cost, redesign		Anchor locations for K12 considered ok.	OBS - not operational risk, is merged to construction risk register #19			Knut Schrøder	
25,00	Bridge landing north - soil condition	Cost		No relevant - new location decided					U3, U19
27,00	Extreme weather condition - unsafe to drive	Safety of users	Extreme wind	Availability - see risk no 26. The bridge will be closed when it is unsafe to drive.					32
29,00	Ballast types in operational phase			Identified during phase 3 - not relevant anymore	In previous phase only solid ballasting was allowed - likely connected to concrete pontoons				U6

8.6 Construction Risk Register – K12 (15/8 - 2019)

15.08.2019 Bjørnafjorden - Construction Risk register											
ID		**Hazard description**						**Risk level**	**Mitigation**	**Responsible**	**Additional info**
Index no	Phase	Hazard	Design criteria	Consequence	Cause	In-place mitigation measures	Comment	K12	Further mitigation measures/actions	Responsible	Existing risk register, UX = Nor U-X= Mul X= Nor X-X = Mul
1,00	Cable stayed bridge	Site for tower foundation not appropriate		Change of alignment	Poor rock condition and large forces to be transferred		Rock conditions at tower foundation site are expected to be good (discussed with Per Bollingmo)	Low			
3,00	Cable stayed bridge	Problems constructing stay cable bridge		Cost, delay		Well known method that has been carried out multiple times before	Tower cast in-situ and on land. Bridge construction is not including unusual processes and should not constitute any	Low			
4,00	Cable stayed bridge	Extreme weather while cable stay bridge await floating bridge installation		Cost, delay	Environmental loading in temporary phases	Cable stay bridge (temporary without floating bridge) is checked for 100	Check completed	Low	Dampers can be introduced if it should show necessary		
5,00	Assembly of floating low bridge ("sausage factory")	Reduced flexibility and robustness during assembly cause delay		Delay	One assembly line is sensitive to specific assembly problems		Assembly of floating bridge is on critical path K12 is, in base case, assembled as one (except high floating bridge). Three parallel fabrication processes are feasible. This would save time but be more costly	Low	Consider if assembly should be done in parallel assembly lines to add redundancy		
6,00	Assembly of floating low bridge ("sausage factory")	Welding of sections - movements damage/delay welding		Cost, delay	Relative movements of deck sections to be welded. Many repeated operations.	Welding to occur on barge in sheltered waters. Relative movements of deck section on barge prevented by high stiffness of grillage. Locking system will be used for the joints to be welded to the free-floating	The majority of welds will be performed on the supported grillage, without relative motions between the sections. 1 of every 5 joints between the sections will be between sections on the barge and the free-floating bridge. A locking system will be used in order to keep the strain to a minimum	Low	Alternatively a larger barge can be used to minimize relative movements. Number of sections may be optimized.		
7,00	Assembly of floating low and high bridge deck and pontoons	Challenges during welding of pontoons and deck sections in water		Cost, damage, delay	Unexpected or uncontrolled movements. Many repeated operations.	Critical connection between column and deck will be welded in yard/shop. The connection between the column sections will be secured with a temporary locking system Pontoon and column will be moored towards barge to reduce movements. Operation has to be repeated many times and	Critical connection between column and deck will be welded in yard/shop to avoid fatigue issues etc. The operation is to be considered a traditional deck-mating issue. Many solutions exists and will be proposed in later phase High bridge mating and welding operation likely more complex than low bridge. Acceptable welded column area for skidding and moving can be defined to optimize production time.	Low			
8,00	Assembly of floating low bridge ("sausage factory")	Loss of anchorage system during skidding and moving		Cost, damage, delay	Unexpected or uncontrolled movements Many repeated operations.	Design of anchorage system is proved for 100y weather condition and skidding/moving will be done in controlled weather situation, thus, with large redundancy	Several anchorage will be necessary to keep bridge steady. 20 anchor lines is proposed and is basis for cost estimate.	Medium	A description of the method for skidding and moving the bridge should be evaluated and detailed.		
31,00	Assembly of floating high bridge	Uncertainty related to assembly of floating high bridge on barge with jacking tower		Cost, damage, delay	Unexpected or uncontrolled movements	Stability check made and OK Subcontractor of jacking system has evaluate method/system	New method where a barge and jackup tower is used . Principles known from offshore. Stability check undertaken and OK Subcontractor of jacking system has evaluate method/system	Low			
32,00	Connection of low and high floating bridge	Challenges in the connection of the assembled low and high bridge		Cost, damage, delay	Challenging operation	Assembly can be done in weather window. Assembly will be made in protected water inshore	Assembly of high and low bridge will have to be done in same way as for connection of bridge at site, i.e. with guiding, positioning and locking joints Not yet detailed, but may be downscaled from the system presented for the site connection.	Medium	Detailing of assembly may be downscaled from the system for connecting bridge at site.		
36,00	Install North section	Challenges in installation of the north section of the floating bridge		Cost, damage, delay	Challenging installation of the first 330m (2x125m+80m) of the floating bridge in north. Tidal variation may be problematic.	Not time critical operation - just need to be installed prior to tow and installation of remaining part of floating bridge Ballasting assumed to accommodate for tidal variation	Consequences may be large, but operations not directly time critical and sufficient time for both planning and execution remains leading to low probability . Serves as test case for tow and installation of floating bridge.	Low			
11,00	Transport of floating bridge to site	Loss of control/ unknown response/ unforeseen extreme weather during tow		Cost, damage, delay	Loss of tug boat, tow line failure and general uncertainty regarding transportation of bridge/bridge sections	Tow management system (known from offshore when moving platforms) Weather windows are generally used Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Towing distance approx. 10-15 km. K12 towed in one 4.5 km section. Likelihood of collision/damage is larger for a large one-piece transport due to space limitation and limited experience with towing of 4.5km long structures . Approx. 12 tugs will be needed to transport K12. Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Medium	Simulations can be performed in a later phase, at least once during planning and once just prior to the operation. Backup tugs and backup management system must be implemented Robustness option, not base case: K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)		
13,00	Connect bridge in weather window	Problems in orientating and connecting winches of floating bridge in north		Delay, damage	Uncertainty regarding manoeuvring of 4.5 km bridge. Uncertainty of weather sensitivity Behaviour and deformation of floating 4.5km uncertain	Tow management system (known from offshore) The crew will have experience from the tow to site #11 Operation will be in weather window Experience from connection of high and low floating bridge #32	No experience in manoeuvring a 4.5km bridge section except from the tow to site #11	Medium	Simulations can be performed in a later phase Test/confirm bridge/tug interaction in fjord before actual operation Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)		
15,00	Connect bridge in weather window	Problems in engaging guiding joint in north, rotate bridge to final position, pull in and fit positioning joints in north and south.		Damage, delay	Systems problems or loss of tug during pull of K12 due to blackout or other technical error	Guiding joint in north proposed Positioning joints in north and south included in design Adjustment piece, see #17, will account for a range of tolerances for K12 in south Experience from connection of high and low		Medium	Methods shall be evaluated and detailed further.		

17,00	Connect bridge in weather window	Connecting 2nd south end may be unsuccessful due to building tolerances (south) or problems with locking system (north and south)		Delay, cost	Tolerances exceeded, technical problems etc.	An adjustment piece is included to mitigate problems for a range of building tolerances. Analysis/verification of adjustment piece undertaken for a realistic range of tolerances and forces. Weather criteria established to limit the first order motions of the [illegible]	Adjustment piece only applied in south end. This is the point of no return in the weather window for connection of bridge. Once locking system is engaged and central mooring is in place K12 can withstand a 10y summer storm.	Low			
16,00	Connect bridge	Welding of bridge sections at sea - challenging/ time consuming		Delay, cost	Damaged welds due to movements during welding. Delay of welding process due to weather	Introduction and dimensioning of locking joints in north and south. Strain limitation introduced. Experience from connection of high and low floating bridge #32	It is critical that temporary structures keep section to be welded steady during welding of periphery Experience from other project indicate that welding of periphery only takes approx. 2 days Strain limit defined to 0.02% corresponding to 10% of yield strength.	Low			
34,00	Connect bridge in weather window	Parametric excitation during installation		Delay, damage	Wind, swell	Construction schedule includes installation of mooring lines to central pontoon (1x4 for storm safe situation) within the weather window	K12 is not able to withstand parametric excitation without anchors in summer storm, but with one of the 3 anchor groups engaged K12 has sufficient capacity against parametric excitation	Low			
35,00	Connect bridge in weather window	Weather window for connecting bridge deteriorate		Cost, damage, delay	Unpredictability of weather conditions	Clear definition of points of no return and possible fall back options. Once engaged and central mooring in in place structure is safe for 10y summer storm. DNVGL OS-H101 regulations Dynamic update of weather window and continuously assess shortest duration to next safe condition. Point of no return is when operations to engage	Many operations have to be undertaken in the weather window for connection the bridge and mooring up the central pontoon. Point of no return is once it is decided to engage the locking system. Operations before this in the weather window can be reversed.	Low			
19,00	Anchor installation	Unsuccessful anchor installation operation		Cost, delay	Unexpected soil condition - boulders or ammunition	Geotechnical investigation of mooring location supplemented with reserve/backup anchor locations - backup locations identified and found satisfying Standard operation Installed 1 year prior to bridge connection	There is generally low experience with rejected anchor installation and likelihood is considered small. Typically rejection is due to rotation tolerances that are not fulfilled. Anchors have standard size (Ø 6-8m) and can be installed with reverse system to retract in case penetration depth is not sufficient. Split in two risks #19 for anchor installation and #33 for mooring line installation	Low			
33,00	Mooring line installation	Unsuccessful mooring line installation operation		Cost, delay		Standard operation Installed 1 year prior to bridge connection		Low			
20,00	Mooring lines(anchorage)	Damage to mooring lines during wet storage (on seabed)		Cost, delay, install new lines	Seabed is not flat and an uneven seabed may damage lines	K12 anchor locations moved to deep and relative even basin mitigating this risk. Mooring lines (wire and chain) chosen to have sufficient on-bottom	K12 no problem with new anchor locations at the deep and flat basin. The location for the 4 northernmost lines not quite as good as for the 8 southernmost, but on-bottom stability is no problem with the chosen mooring lines.	Low			
21,00	Mooring lines(anchorage)	Uncertainty regarding method - how much and when anchor lines should be tensioned		Cost, delay		K12 shown safe in summer storm condition in the majority of all possible weather combinations. Middle mooring pontoon will be hooked up in the installation weather window for additional safety. The length of the mooring line will be used as the governing parameter for tensioning. Standard offshore technique used.	Weather windows and bridge response in temporary states influence the tensioning. Base case is a pull vessel combined with a spacer. It is chosen due to cost/time/flexibility. Spot checks show that the K12 bridge is safe in a summer storm condition in the majority of all possible weather combinations. For extra safety the middle mooring pontoon will be hooked up in the installation weather window. For the final tensioning one can use the length of the mooring line as the governing parameters (such as with the stay cables). The correct length can be indicated/marked on the chain during mooring installation. The length will be adjusted according to final anchor position and as built lengths of wires and chains. The chain will then be pulled in until the marked link is at the chain stopper. This methodology is used offshore for the installation of FPSOs which don't have chain lockers on board. Numerous alternative methods for tensioning of the chains are available	Low			
24,00	Mooring lines(anchorage)	Unsuccessful connection of mooring lines to anchor - line buried or "lost"		Cost, delay		Connect buoy or other mark to ensure lines are not lost/buried at seabed Installed 1 year prior to bridge connection	Mooring lines are connected after anchor installation to avoid SIMOPS, but mooring lines can alternatively be connected on deck before anchor installation.	Low			
26,00	All installation phases	Ship collision		Delay, damage		Pontoon anchorage point +5m depth below water level avoiding most impacts to mooring lines during construction (and operation)	Ferry traffic pass through bridge site. Additional traffic cross Bjørnafjorden (21000 yearly) One piece installation is faster but will also require full closure whereas installation in smaller sections requires more time but may	Medium	Vessel traffic control - if not already in place. Is Bjørnafjorden closed for ship traffic during installation? Further design basis needed		

9,00	Assembly of floating high bridge	Assembly method and site may not be optimal (or available)		Delay		A new construction method has been chosen to eliminate this risk, see #31	To be assembled in dry dock - however, there is only one dry dock that is large enough. Column and pontoon not stable alone. Temporary pontoon could provide stability such that "sausage factory" method could be		Alternative method used, see #31		
10,00	North abutment - Construction	Complexity of final connection in north		Cost, delay			Abutment in itself is standard. No risk of significance identified for construction of abutment. Earlier assessed risk is merged into #15 - North abutment do not constitute any problem in terms of design and construction but the connection to floating bridge is a challenging				
12,00	Transport floating bridge to site	Unknown effects/movements/deformation of floating bridge		Damage, delay			Merged into #11				
18,00	Connect bridge	Bridge may not deform as much as needed to connect		Cost, delay	Uncertainty with respect to		Merged into #15				
22,00	Mooring lines(anchorage)	HSE risk during anchor operation		Injuries, fatalities	Accident when operating heavy machinery and material in tension		Mooring operations are generally considered high-risk due to personnel working close to heavy machinery with high tension structures. Deleted since it is preconditioned that HSE risk can be brought to acceptable level for such operations. Thus, uncertainty in method in #21 includes safe installation.				
23,00	Mooring lines(anchorage)	Tensioning of mooring lines - uncertainty regarding method					Merged into #21		Analyse base case method further		
29,00	Mooring lines(anchorage)	Gravity anchors in north- ensure seabed is sufficiently flat - limited experience blasting in -60m		Cost, delay	Unforeseen issues during blasting in deep water	K12 no anchor in north	Gravity anchors are used in north due to soil conditions - Explosives to be used under 60 meter water to even out seabed K12 no anchor group in north				
25,00	Tensioning of bridge (using winches)	Welding of infill during large tension - difficult and dangerous operation, HSE		Injuries, fatalities			Deleted since it is preconditioned that HSE risk can be brought to acceptable level for such operations. Thus, uncertainty in method in #15 includes safe installation.		Detailing of operation to be analysed further		
27,00	Towing	Unforeseen extreme weather during towing		Delay, damage		Weather windows are generally used	Merged into #11		Difference between K11-K14?		
30,00	Installation	Unforeseen extreme weather during installation		Delay, damage		Weather windows are generally used	Merged into #13				
28,00	All installation phases	Loss of power/control of tug boat		Delay, damage		Backup tug?	Included in other risks - deleted 14/5 2019				
14,00	Ballast and connect	Unsuccessful connection (using guide system) to middle section due to large movements		Delay			Uncertain how much middle section will move once installed. More ballast operations lead to larger overall risk. Not yet analysed. Uncertain magnitude of tension in the anchor lines (see risk no . 21) Middle section likely OK but next operations more complex		Movements and anchor tension to be analysed	Pe/Jørgen	
2,00	Cable stayed bridge - Navigation span	Opportunity to reduce size of cable stay bridge		Opportunity cost saving			OBS - not construction risk K12 cable stay bridge could be slightly				

9 References

/1/ ISO 31000 Risk Management

/2/ ITIG, The International Tunneling Insurance Group: A code of practice for risk management of tunnel works, January 2006

/3/ DNV: Risk Management in Marine – and Subsea Operations, Recommended Practice DNV-RP-H101 January 2003

/4/ Bjørnafjorden floating bridge, Appendix N: Fabrication and Marine Operations, 10305546-16-RAP-169

/5/ Bjørnafjorden floating bridge, Appendix N: Construction and Marine Operations, K12, SBJ-33-C5-AMC-28-RE-114

10 Enclosures

/1/ Risk register – Operational phase (15.08.2019)

/2/ Risk register – Construction phase (15.08.2019)

Concept development, floating bridge
E39 Bjørnafjorden

Appendix R – Enclosure 1

Risk register – Operational phase

30.06.2019 Bjørnafjorden - Operational risk register

ID	Hazard description					Risk level	Mitigation	Responsible	Additional info
Index no	Hazard	Consequence	Cause	In-place mitigation measures	Comment	K12	Further mitigation measures/actions	Responsible	Existing risk register, UX = Nor U-X= Mul X= Nor X-X = Mul
1,00	Parametric excitation - Dynamic stability	Safety, Cost	Design (wind/swell)	Anchorage will provide stability for K12 New criterion taken as basis for K12 - DB criterion very strict	Quantification of damping to be used in analysis model is uncertain. Most uncertainty related to long period horizontal modes Swell is conservatively modelled as harmonic using the upper limit. Optimally it would be modelled as a stochastic process but this is very cumbersome. On-set criteria provided by SVV is, with the current solution not fulfilled. Instead a more detailed approach has been chosen. Uncertainty regarding HsTp gamma combination in extreme sea states - information requested from SVV	Low	K12: If required, introduce more damping through improved mooring configuration. Likely not needed. CFD study shows significantly higher viscous drag coefficients than used in the analysis; thus giving increased safety margin. Other posslble mitigations could be introduction of dampers at the tower or, alternatively, change in the bridge geometry which may move critical modes into an area with higher damping or lower excitation. Efficiency of such mitigations uncertain and currently not necessary. Preliminary studies shows that introduction of a linear damper in the tower/bridge connection may be sufficient to satisfy the stringent onset-criterion as in DB.	Martin Storheim	U9, U10, U20, U1, U12
2,00	Bridge global instability (static buckling)	Safety, Cost	Design	Anchors significantly increase the static buckling capacity of the bridge. Phase difference for waves has been analysed	Uneven environmental loading along bridge. Lateral load on bridge is somewhat sensitive to viscous drag, but this is not a concern as CFD simulations indicate a low stationary drag coefficient. Effect of inhomogeneous sea is small. The effects of an alternative wind load model is evaluated. The new model improves how aerodynamic coefficients are taken into account for skew wind.	Low	Inhomogeneous static wind on bridge (shielding from mountain) - analysis ongoing. More detailed wind load model.	Martin Storheim/ Ketil Aas-Jakobsen	
3,00	Hydrodynamic interaction between pontoons	Safety, cost	Design		Hydrodynamic interaction will primarily affect weak-axis response. With 125 m pontoon spacing hydrodynamic interaction is not considered to be important, but it may be for lower pontoon spacings.	Low		Martin Storheim	U-17
4,00	Combined behaviour of floating bridge and cable stayed bridge	Safety, cost		Full model including both floating bridge and cable stayed bridge. Analysis shows fine combined behaviour.	Limited exerience from other similar structures During all phases of concept developement there has not been any indication of unforeseen issues	Low	Cable exitation can be mitigated by introdiction of dampers if necessary.	Henrik Polk	U-39
5,00	Influence from simplifications in structural analysis model on dynamic properties (beam elements), local stress variations	Safety, cost	Simplified 3D float structural modelling in phase 3	Technology Qualification Analysis Several independent analysis (using different analysis tools) has been conducted. Independent model verification	Benchmarks between the various solvers show low differences. The first 10 eigenmodes are captured well in all softwares under similar assumptions. Still, a variation in eigenmodes (5-10%) considered in analysis of e.g. parametric exitation Independent model verification has the purpose of comparing output from Orcaflex with RM Bridge.	Low	Further independent model verification	Martin Storheim/ Arne Bruer	U11, U13, U14
6,00	Ship collision impact with pontoon - design vessel	Availability, Safety, Cost	Human error, technical error, weather ect	Scenario analysed for design load and have similar response for all solutions	Updated ship collision impact load of 138-237 MJ (in DB) recieved 05.02.2019. Alternative distibution recieved 08.02.2019 K12 concept is robust w.r.t. damage from a collision event in terms of flooding, loss of waterplane stiffness and damage to bridge girder. Column damage due to exceedance of torsional capacity is identified as most critical when the most conservative scenario is selected. The column is reinforced to partly mitigate this, but not fully due to the likelihood of reduced collision energies following a planned re-routing of the navigational channel (not included in DB).	Medium	Re-evaluation of column design with increased torsional capacity will fully solve the problem. Column capacity can be increased if necessary, but increased volumes not part of cost estimate.	Martin Storheim	37, U-3, U5, 35
36,00	Ship collision impact with pontoon - vessel smaller than design vessel	Availability, Safety, Cost	Human error, technical error, weather ect	Scenario analysed for design load and have similar response for all solutions	The design vessel represent one possible impact scenario with a mass and velocity. Other vessels (higher mass and lower velocity or the opposite) may excite the bridge in a different manner, particularly if dynamic amplification is important. The simulations have shown that the bridge response is not largely affected by dynamic amplification, and the impact from smaller vessel such as high speed ferries does not have sufficient energy to cause a governing bridge response. K12 concept is robust w.r.t. damage from a collision event in terms of flooding, loss of waterplane stiffness and damage to bridge girder.	Low		Martin Storheim	37, U-3, U5, 35
34,00	Ship collision - vessel larger than design vessel	Availability, Safety, Cost	Uncertainty in ship collision risk assessment and resulting requirements	K12 was checked for 50% increased energy for pontoon collision normal to the bridge axis. Small differences in response was observed; negligible towards the ends (stiffness-dominated) but somewhat larger in the middle of the bridge.	Requirements are fulfilled, but hazard could be seen as a robustness check towards requirements.	Low	Robustness check for loss of pontoon to be considered in following phase. Loss of pontoon will cause large weak-axis moments and plastification of bridge girder, but likely not global collapse.	Martin Storheim	

7,00	Ship collision with low bridge - forecastle deck, bow or containers hit girder	Availability, Safety, Cost	Human error, technical error, weather ect	Girder height determined to reduce risk of forecastle/bow/container collisions Lower level of girder is +11.5m according to DB.	Vessels from North/South route may drift and hit Likelihood of this scenario low No design requirements for bow collision or like to girder in design basis only deckhous collision. Thus, only robustness check. Scenario analysed and concept is more robust than original anticipated. Global collapse is not likely.	Low		Martin Storheim	
8,00	Ship deck house collision impact with girder - local damage	Availability, Cost	Human error, technical error, weather ect	Local analysis undertaken showing minor damage	Girder load increased to 367 MJ (doubled) compared to original DB. Alternative distibution recieved 08.02.2019	Low	Robustness check in damaged condition	Martin Storheim	U5
9,00	Ship deck house collision impact with girder -global response - South	Availability, Safety, Cost	Human error, technical error, weather ect	Robustness check in damaged condition yields acceptable results (see appendix G)		Low	Global analysis of girder collision	Martin Storheim	U-3, U5
35,00	Ship deck house collision impact with girder -global response - North	Availability, Safety, Cost	Human error, technical error, weather etc	Additional strengthening of girder near north abutment has been introduced	Bridge response in northern end from collision similar for all scenarios due to fixation in north (stiffness dominated) K12 show high utilization, not included in design but added in cost estimate	Low	Robustness check in damaged condition	Martin Storheim	
10,00	Ship collision/submarine collision with mooring lines - loss of line(s)	Safety, cost, availability	ship collision, submarine	Design includes loss of two anchors. It is geometrically unlikely to hit more than one line Moorings lines designed for ship impact Robustness check of loss of four anchors OK for all concepts	K12 has only 3 anchor groups of 4 anchors, i.e.,12 anchors and,this, the geometrical proibability of impact is low. Further, impact directly to a mooring line may cause loss of the mooring line, but the global residual strength is sufficient to prevent progressive collapse.	Low		Martin Storheim	
13,00	Corrosion on pontoon, columns and girder of low bridge - potentially leak into pontoon	Additional O&M	Inadequate corrosion protection coating, surface preparation or coating application Unknown long term behavior of coating.	Girder and columns: standard for bridge in general Inspection and maintenance program defined for pontoon	phase 3: The Super Duplex Stainless Steel with 25% Cr affects weld to adjacent steel or is not fully corrosion resistant Coating broken down faster than assumed in calculations. Pontoon design life longer than "normal" experience base for anodes. Anode consumption rate higher than calculated. Phase 3: Proposed to submerge plate of 25% CR SDSS with adjacent carbon steel plates in similar environment to confirm behavior	Low			U8, 22, 23, U-30, 2-1, 35
15,00	Fatigue - girder and column	Cost, Additional O&M	Girder - stress concentrations due to longitudinal truss work Grider - column transition	Possible to have good structural details with low stress concentrations. Local design with sufficient capacity	Preliminary analysis show moderate stresses in truss work, and it is expected that the fatigue consequence of these are manageble without large increase in weight.	Low	Addtional inspection programme (potentially supplemented with SHMS) is a potential mitigation.	Martin Storheim	24, 35
16,00	Loss of mooring lines	Safety, cost, availability	Fatigue, overload	Bridge must be operational with 2 mooring lines lost according to DB Robustness check shows capacity for loss of one group	Checked - OK	Low		Martin Storheim	
17,00	Increased girder stress due to marine growth or other reason for increased weight of pontoon	Safety, O&M		Marine growth on pontoons considered in design	Marine growth on mooring lines?	Low	Not expected to be necessary, but it needed adjustment of ballast is possible. Autonomous hull cleaning is also available		30,31
18,00	Vandalism, terrorism - cable stay bridge	Safety, cost, availability	Cut stay cables	One cable can be lost without structural collapse	Phase 3 included conventional protection of cable anchors in normally accessible areas.	Medium	DB require Risk analysis - to be performed in another phase		27, U-14, 25, 26, U-42
19,00	Vandalism, terrorism - floating bridge	Safety, cost, availability	Ship collision, pontoon waterfilled, cutting mooring lines	Bridge must be operational with 2 mooring lines lost according to Design basis	Phase 3 design includes no "public" access to pontoon from sea or column from bridge. The corrosion resistant alloy in splash zone is robust to minor mechanical damage (scraping)	Medium	DB require Risk analysis - to be performed in another phase		27, U-14, 25, 26, U-42
20,00	Airplane/heli crash into tower or cables	Safety, cost		Likelihood is extremely small	Bergen Airport 20km away	Low			U-44
21,00	Fire/explosion on bridge or in adjacent tunnel	Safety, cost, availability	Accident with explosive material wither on or below bridge		Design basis refer to separate study (10200942-RIS-RAP-001)	Medium	Go through study and identify potential actions Document availability -see risk no 26		
22,00	Fractures in rock at tower location (cable stay bridge)	Safety, cost		Has been investigated and location found ok. New fractures will not form	Tower foundation on rock	Low		Per Bollingmo	
23,00	Geohazard: loss of anchors due to landslide	Safety, cost, availability	Landslide	Design includes loss of two anchor lines Robustness check with loss of four anchor lines reveals sufficient residual capacity.	2 anchor lines (one cluster) may be lost in a landslide - included as robustness check, found OK Further check with loss of one side of two adjacent mooring clusters shown OK. New information form SVV not available this phase	Low		Martin Storheim	1-7, 1-8
24,00	Comfort/movements not within criteria				Comfort from bridge itself approx 1/3 of criteria, but wind on vehicle much larger (~3 times allowable limit).	Medium		Sverre Wiborg/ Martin Storheim	
26,00	Insufficient operational availability	Availability	Wind, maintenance, accidents, ice on cables, false VTS alarm	Availability studies from previous phases indicate availability above 99.5%.	Procedures for when to close bridge (wind, VTS, ice) should be defined at a later stage Wind (large wind speeds) is governing for availability in previous phases and is expected to be similar for all solutions. K12 is sensitive to the zone with 30% turbulence intensity resulting in large down-time unless mitigated due to the road line direction close to the southern shore	Medium	Verify availability above 99.5% can be obtained for all solutions K12 might need mitigation such as wind screens due to effect on vehicles from high turbulence intensity. Long term statistics for wind to improve basis of design Local analysis of wind climate	Ketil Aas-Jakobsen	
11,00	End Anchorage - loads in abutment	Safety, cost	Design	Loads included in design					11
14,00	Leakage into pontoon compartment combined with Risk no 13								

37,00	Soil conditions for anchor locations	Cost, redesign		Anchor locations for K12 considered ok.	OBS - not operational risk, is merged to construction risk register #19			Knut Schrøder	
25,00	Bridge landing north - soil condition	Cost		No relevant - new location decided					U3, U19
27,00	Extreme weather condition - unsafe to drive	Safety of users	Extreme wind	Availability - see risk no 26. The bridge will be closed when it is unsafe to drive.					32
29,00	Ballast types in operational phase			Identified during phase 3 - not relevant anymore	In previous phase only solid ballasting was allowed - likely connected to concrete pontoons				U6

Concept development, floating bridge
E39 Bjørnafjorden

Appendix R – Enclosure 2

Risk register – Construction phase

15.08.2019 Bjørnafjorden - Construction Risk register											
ID		**Hazard description**						**Risk level**	**Mitigation**	**Responsible**	**Additional info**
Index no	Phase	Hazard	Design criteria	Consequence	Cause	In-place mitigation measures	Comment	K12	Further mitigation measures/actions	Responsible	Existing risk register, UX = Nor U-X= Mul X= Nor X-X = Mul
1,00	Cable stayed bridge	Site for tower foundation not appropriate		Change of alignment	Poor rock condition and large forces to be transferred		Rock conditions at tower foundation site are expected to be good (discussed with Per Bollingmo)	Low			
3,00	Cable stayed bridge	Problems constructing stay cable bridge		Cost, delay		Well known method that has been carried out multiple times before	Tower cast in-situ and on land. Bridge construction is not including unusual processes and should not constitute any	Low			
4,00	Cable stayed bridge	Extreme weather while cable stay bridge await floating bridge installation		Cost, delay	Environmental loading in temporary phases	Cable stay bridge (temporary without floating bridge) is checked for 100	Check completed	Low	Dampers can be introduced if it should show necessary		
5,00	Assembly of floating low bridge ("sausage factory")	Reduced flexibility and robustness during assembly cause delay		Delay	One assembly line is sensitive to specific assembly problems		Assembly of floating bridge is on critical path K12 is, in base case, assembled as one (except high floating bridge). Three parallel fabrication processes are feasible. This would save time but be more costly	Low	Consider if assembly should be done in parallel assembly lines to add redundancy		
6,00	Assembly of floating low bridge ("sausage factory")	Welding of sections - movements damage/delay welding		Cost, delay	Relative movements of deck sections to be welded. Many repeated operations.	Welding to occur on barge in sheltered waters. Relative movements of deck section on barge prevented by high stiffness of grillage. Locking system will be used for the joints to be welded to the free-floating	The majority of welds will be performed on the supported grillage, without relative motions between the sections. 1 of every 5 joints between the sections will be between sections on the barge and the free-floating bridge. A locking system will be used in order to keep the strain to a minimum	Low	Alternatively a larger barge can be used to minimize relative movements. Number of sections may be optimized.		
7,00	Assembly of floating low and high bridge deck and pontoons	Challenges during welding of pontoons and deck sections in water		Cost, damage, delay	Unexpected or uncontrolled movements. Many repeated operations.	Critical connection between column and deck will be welded in yard/shop. The connection between the column sections will be secured with a temporary locking system Pontoon and column will be moored towards barge to reduce movements. Operation has to be repeated many times and will be carefully planned	Critical connection between column and deck will be welded in yard/shop to avoid fatigue issues etc. The operation is to be considered a traditional deck-mating issue. Many solutions exists and will be proposed in later phase High bridge mating and welding operation likely more complex than low bridge. Acceptable welded column area for skidding and moving can be defined to optimize production time.	Low			
8,00	Assembly of floating low bridge ("sausage factory")	Loss of anchorage system during skidding and moving		Cost, damage, delay	Unexpected or uncontrolled movements Many repeated operations.	Design of anchorage system is proved for 100y weather condition and skidding/moving will be done in controlled weather situation, thus, with large redundancy	Several anchorage will be necessary to keep bridge steady. 20 anchor lines is proposed and is basis for cost estimate.	Medium	A description of the method for skidding and moving the bridge should be evaluated and detailed.		
31,00	Assembly of floating high bridge	Uncertainty related to assembly of floating high bridge on barge with jacking tower		Cost, damage, delay	Unexpected or uncontrolled movements	Stability check made and OK Subcontractor of jacking system has evaluate method/system	New method where a barge and jackup tower is used . Principles known from offshore. Stability check undertaken and OK Subcontractor of jacking system has evaluate method/system	Low			
32,00	Connection of low and high floating bridge	Challenges in the connection of the assembled low and high bridge		Cost, damage, delay	Challenging operation	Assembly can be done in weather window. Assembly will be made in protected water inshore	Assembly of high and low bridge will have to be done in same way as for connection of bridge at site, i.e. with guiding, positioning and locking joints Not yet detailed, but may be downscaled from the system presented for the site connection.	Medium	Detailing of assembly may be downscaled from the system for connecting bridge at site.		
36,00	Install North section	Challenges in installation of the north section of the floating bridge		Cost, damage, delay	Challenging installation of the first 330m (2x125m+80m) of the floating bridge in north. Tidal variation may be problematic.	Not time critical operation - just need to be installed prior to tow and installation of remaining part of floating bridge Ballasting assumed to accommodate for tidal variation	Consequences may be large, but operations not directly time critical and sufficient time for both planning and execution remains leading to low probability . Serves as test case for tow and installation of floating bridge.	Low			
11,00	Transport of floating bridge to site	Loss of control/ unknown response/ unforeseen extreme weather during tow		Cost, damage, delay	Loss of tug boat, tow line failure and general uncertainty regarding transportation of bridge/bridge sections	Tow management system (known from offshore when moving platforms) Weather windows are generally used Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Towing distance approx. 10-15 km. K12 towed in one 4.5 km section. Likelihood of collision/damage is larger for a large one-piece transport due to space limitation and limited experience with towing of 4.5km long structures . Approx. 12 tugs will be needed to transport K12. Initial analysis of overall stiffness and response from tugs pulling is made and found well within limits	Medium	Simulations can be performed in a later phase, at least once during planning and once just prior to the operation. Backup tugs and backup management system must be implemented Robustness option, not base case: K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)		
13,00	Connect bridge in weather window	Problems in orientating and connecting winches of floating bridge in north		Delay, damage	Uncertainty regarding manoeuvring of 4.5 km bridge. Uncertainty of weather sensitivity Behaviour and deformation of floating 4.5km uncertain	Tow management system (known from offshore) The crew will have experience from the tow to site #11 Operation will be in weather window Experience from connection of high and low floating bridge #32	No experience in manoeuvring a 4.5km bridge section except from the tow to site #11	Medium	Simulations can be performed in a later phase Test/confirm bridge/tug interaction in fjord before actual operation Backup tugs and backup management system must be implemented K12 could be assembled at site in 2 pieces - can mitigate risk (could be low)		
15,00	Connect bridge in weather window	Problems in engaging guiding joint in north, rotate bridge to final position, pull in and fit positioning joints in north and south.		Damage, delay	Systems problems or loss of tug during pull of K12 due to blackout or other technical error	Guiding joint in north proposed Positioning joints in north and south included in design Adjustment piece, see #17, will account for a range of tolerances for K12 in south Experience from connection of high and low		Medium	Methods shall be evaluated and detailed further.		

17,00	Connect bridge in weather window	Connecting 2nd south end may be unsuccessful due to building tolerances (south) or problems with locking system (north and south)		Delay, cost	Tolerances exceeded, technical problems etc.	An adjustment piece is included to mitigate problems for a range of building tolerances. Analysis/verification of adjustment piece undertaken for a realistic range of tolerances and forces. Weather criteria established to limit the first order motions of the	Adjustment piece only applied in south end. This is the point of no return in the weather window for connection of bridge. Once locking system is engaged and central mooring is in place K12 can withstand a 10y summer storm.	Low			
16,00	Connect bridge	Welding of bridge sections at sea - challenging/ time consuming		Delay, cost	Damaged welds due to movements during welding. Delay of welding process due to weather	Introduction and dimensioning of locking joints in north and south. Strain limitation introduced. Experience from connection of high and low floating bridge #32	It is critical that temporary structures keep section to be welded steady during welding of periphery Experience from other project indicate that welding of periphery only takes approx. 2 days Strain limit defined to 0.02% corresponding to 10% of yield strength.	Low			
34,00	Connect bridge in weather window	Parametric excitation during installation		Delay, damage	Wind, swell	Construction schedule includes installation of mooring lines to central pontoon (1x4 for storm safe situation) within the weather window	K12 is not able to withstand parametric excitation without anchors in summer storm, but with one of the 3 anchor groups engaged K12 has sufficient capacity against parametric excitation	Low			
35,00	Connect bridge in weather window	Weather window for connecting bridge deteriorate		Cost, damage, delay	Unpredictability of weather conditions	Clear definition of points of no return and possible fall back options. Once engaged and central mooring in in place structure is safe for 10y summer storm. DNVGL OS-H101 regulations Dynamic update of weather window and continuously assess shortest duration to next safe condition. Point of no return is when operations to engage	Many operations have to be undertaken in the weather window for connection the bridge and mooring up the central pontoon. Point of no return is once it is decided to engage the locking system. Operations before this in the weather window can be reversed.	Low			
19,00	Anchor installation	Unsuccessful anchor installation operation		Cost, delay	Unexpected soil condition - boulders or ammunition	Geotechnical investigation of mooring location supplemented with reserve/backup anchor locations - backup locations identified and found satisfying Standard operation Installed 1 year prior to bridge connection	There is generally low experience with rejected anchor installation and likelihood is considered small. Typically rejection is due to rotation tolerances that are not fulfilled. Anchors have standard size (Ø 6-8m) and can be installed with reverse system to retract in case penetration depth is not sufficient. Split in two risks #19 for anchor installation and #33 for mooring line installation	Low			
33,00	Mooring line installation	Unsuccessful mooring line installation operation		Cost, delay		Standard operation Installed 1 year prior to bridge connection		Low			
20,00	Mooring lines(anchorage)	Damage to mooring lines during wet storage (on seabed)		Cost, delay, install new lines	Seabed is not flat and an uneven seabed may damage lines	K12 anchor locations moved to deep and relative even basin mitigating this risk. Mooring lines (wire and chain) chosen to have sufficient on-bottom	K12 no problem with new anchor locations at the deep and flat basin. The location for the 4 northernmost lines not quite as good as for the 8 southernmost, but on-bottom stability is no problem with the chosen mooring lines.	Low			
21,00	Mooring lines(anchorage)	Uncertainty regarding method - how much and when anchor lines should be tensioned		Cost, delay		K12 shown safe in summer storm condition in the majority of all possible weather combinations. Middle mooring pontoon will be hooked up in the installation weather window for additional safety. The length of the mooring line will be used as the governing parameter for tensioning. Standard offshore technique used.	Weather windows and bridge response in temporary states influence the tensioning. Base case is a pull vessel combined with a spacer. It is chosen due to cost/time/flexibility. Spot checks show that the K12 bridge is safe in a summer storm condition in the majority of all possible weather combinations. For extra safety the middle mooring pontoon will be hooked up in the installation weather window. For the final tensioning one can use the length of the mooring line as the governing parameters (such as with the stay cables). The correct length can be indicated/marked on the chain during mooring installation. The length will be adjusted according to final anchor position and as built lengths of wires and chains. The chain will then be pulled in until the marked link is at the chain stopper. This methodology is used offshore for the installation of FPSOs which don't have chain lockers on board. Numerous alternative methods for tensioning of the chains are available	Low			
24,00	Mooring lines(anchorage)	Unsuccessful connection of mooring lines to anchor - line buried or "lost"		Cost, delay		Connect buoy or other mark to ensure lines are not lost/buried at seabed Installed 1 year prior to bridge connection	Mooring lines are connected after anchor installation to avoid SIMOPS, but mooring lines can alternatively be connected on deck before anchor installation.	Low			
26,00	All installation phases	Ship collision		Delay, damage		Pontoon anchorage point +5m depth below water level avoiding most impacts to mooring lines during construction (and operation)	Ferry traffic pass through bridge site. Additional traffic cross Bjørnafjorden (21000 yearly) One piece installation is faster but will also require full closure whereas installation in smaller sections requires more time but may	Medium	Vessel traffic control - if not already in place. Is Bjørnafjorden closed for ship traffic during installation? Further design basis needed		

9,00	Assembly of floating high bridge	Assembly method and site may not be optimal (or available)		Delay		A new construction method has been chosen to eliminate this risk, see #31	To be assembled in dry dock - however, there is only one dry dock that is large enough. Column and pontoon not stable alone. Temporary pontoon could provide stability such that "sausage factory" method could be		Alternative method used, see #31		
10,00	North abutment - Construction	Complexity of final connection in north		Cost, delay			Abutment in itself is standard. No risk of significance identified for construction of abutment. Earlier assessed risk is merged into #15 - North abutment do not constitute any problem in terms of design and construction but the connection to floating bridge is a challenging				
12,00	Transport floating bridge to site	Unknown effects/movements/deformation of floating bridge		Damage, delay			Merged into #11				
18,00	Connect bridge	Bridge may not deform as much as needed to connect		Cost, delay	Uncertainty with respect to		Merged into #15				
22,00	Mooring lines(anchorage)	HSE risk during anchor operation		Injuries, fatalities	Accident when operating heavy machinery and material in tension		Mooring operations are generally considered high-risk due to personnel working close to heavy machinery with high tension structures. Deleted since it is preconditioned that HSE risk can be brought to acceptable level for such operations. Thus, uncertainty in method in #21 includes safe installation.				
23,00	Mooring lines(anchorage)	Tensioning of mooring lines - uncertainty regarding method					Merged into #21		Analyse base case method further		
29,00	Mooring lines(anchorage)	Gravity anchors in north- ensure seabed is sufficiently flat - limited experience blasting in -60m		Cost, delay	Unforeseen issues during blasting in deep water	K12 no anchor in north	Gravity anchors are used in north due to soil conditions - Explosives to be used under 60 meter water to even out seabed K12 no anchor group in north				
25,00	Tensioning of bridge (using winches)	Welding of infill during large tension - difficult and dangerous operation, HSE		Injuries, fatalities			Deleted since it is preconditioned that HSE risk can be brought to acceptable level for such operations. Thus, uncertainty in method in #15 includes safe installation.		Detailing of operation to be analysed further		
27,00	Towing	Unforeseen extreme weather during towing		Delay, damage		Weather windows are generally used	Merged into #11		Difference between K11-K14?		
30,00	Installation	Unforeseen extreme weather during installation		Delay, damage		Weather windows are generally used	Merged into #13				
28,00	All installation phases	Loss of power/control of tug boat		Delay, damage		Backup tug?	Included in other risks - deleted 14/5 2019				
14,00	Ballast and connect	Unsuccessful connection (using guide system) to middle section due to large movements		Delay			Uncertain how much middle section will move once installed. More ballast operations lead to larger overall risk. Not yet analysed. Uncertain magnitude of tension in the anchor lines (see risk no . 21) Middle section likely OK but next operations more complex		Movements and anchor tension to be analysed	Pe/Jørgen	
2,00	Cable stayed bridge - Navigation span	Opportunity to reduce size of cable stay bridge		Opportunity cost saving			OBS - not construction risk K12 cable stay bridge could be slightly				