E39 Stord – Os: Fjord crossings Langenuen

Illustration: Norconsult

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BRIDGE PYLONS IN STEEL – FEASIBILITY STUDY FOR LANGENUEN SUSPENDED BRIDGE

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1 SUMMARY AND CONCLUSIONS

The main objective of the present study is to verify whether it is feasible to lift the complete steel pylons from horizontal condition to their in-place condition. Various bridge pylon designs have been studied, and the challenge has been to find the crane load- and reach limitations of available Heavy Lifting Vessels, and then verify these data against realistic pylon designs and the corresponding elevation of the center of gravity.

It can be concluded that each pylon can be installed by means of a single-lift operation, based on the center of gravity calculations on a preliminary design and comparisons with a revised design subjected to strength calculation. Areas of potential improvement are identified and will be addressed in further design stages.

In addition, this report introduces an alternative configuration in which the lower pylon legs and the upper A-frames are lifted separately. In such a configuration, the HLV crane capacity limit would no longer be a critical factor. However, the number of lifting operations to perform would increase. The alternative might involve other logistical advantages for the project, but this has not been part of the scope.

To fabricate and install the bridge pylons it is proposed to assemble the A-frames in a dock, and to connect the lower legs to the upper A-frames in floating condition. This is because all docks available in Norway are either too narrow or too short for complete dock assembly. It is proposed to transport the pylons by means of a wet tow to the up-ending site.

Alternatively (for overseas suppliers), the A-frames can be delivered complete but transported overseas as deck load on a barge or semi-submersible transportation vessel (SSCV). However, before up-ending and lift-in, the pylons must be lifted off from the barge and to sea.

A method to hook onto, up-end and lift in the pylons by the HLV is feasible. The critical factor of the operation is that the crane must be able to complete the up-ending and further lift-in without shifting grip. Assistance by a second crane shall be avoided.

A brief analysis of suitable facilities in the vicinity of the expected bridge site at Langenuen is presented. It is assumed that the Mechanical/ Structural disciplines will be able to carry out fabrication by resorting to a combination of service barges and facilities on land.

The study proposes the establishment of in-house facilities for panel fabrication, volume sections assembly, and surface protection. Areas for outdoor assembling of complete A-frames limit the list of potential domestic tenderers.

The fabrication of panels and volume sections for the pylons requires a high capacity for plate cutting, transportation/ handling of heavy sections, and semi-automatic panel lines. High output SAW welding machines and tandem machines for double-sided welding is considered a requirement. However, specialist competence and experience with volume production of high strength steel structures are considered essential, more than the equipment.

To conclude on a throughput time for approximately 9000 t steel is complicated, because the project master plan (including civil) and the need for building new fabrication/ panel lines to meet critical milestones are unknown. However, it is assumed probable to expect a delivery time from contract to lift-in of approximately 10 to 18 months, without affecting the logistics of the project master plan. To meet tight milestones, it is considered that parts of the scope can be subcontracted to sub-suppliers who are proven capable in previous projects. When the project master plan is known, a complete delivery time for installed pylons can be established.

2 INTRODUCTION AND OBJECTIVE

The Method Department at Kværner's main yard at Stord has tendered for - and been awarded a limited feasibility study to investigate the feasibility and relevant methods to fabricate complete pylons at protected shop facilities, load-out and transportation to installation site location, and the feasibility to up-end the pylons in one piece and lift them from sea to target location. The background for the study and the task description is detailed in Attachment 1- Mime-no. 19/257825 "Oppdragsbeskrivelse- FoU-prosjekt Ferjefri E39 Brutårn i stål for hengebru over Langenuen".

From the project background description it is understood that similar bridge pylons in Norway have been exclusively built in reinforced concrete, using the slip forming technique. The initiative to investigate the possibility to build the pylons in steel is due to the strong position, experience, and facilities of Norwegian and Foreign yards supplying large steel structures for the oil-and-gas industry, and which invites to investigate this alternative approach for benchmarking against the concrete design. It is also evident that the nearshore depth at the location in Langenuen and the shipping channel allows access for large heavy lift vessels (HLV) that have the necessary capacity and reach.

Kværner has through many years developed the strategy to perform prefabrication of large modules and structures indoors on its premises, and to transport and install at the target sites with a minimum of resources and work hours. This has improved compatibility, quality, and timely delivery of the projects. The methods and processes presented in this document are based on well-known principles in the engineering industry, both domestic and overseas. All the methods explained in this short study are therefore available for application or adaptation for any qualified bidder invited to tender.

The task description contains a sketch showing a concrete pylon alternative. It is understood that the conversion of design into a steel-based version is a part of the study, and the overall design should in this conceptual phase have similarities to this concrete version. If such design proves feasible to fabricate, transport and install, then further design development is expected to lead to an improvement of the general constructability and cost. For this study, assistance from the Norwegian Public Roads Administration (NPRA) to evaluate the strength and main dimensions of the draft proposals are granted.

The present feasibility study has been an iteration process, in which various A-frame designs have been tested towards the chosen crane limitations. The report discusses the feasibility of the most critical stages, such as up-ending and lifting, first, and the subjects of fabrication and transportation in the succeeding chapters.

3 STRATEGY AND KEY FACTORS FOR THE FEASIBILITY STUDY

The fabrication- and assembling phase of the bridge pylons is found relatively uncomplicated, and the methods can be adapted to the facilities and expertise available at each competitive supplier. The feasibility of the fabrication phase is therefore mainly governed by a combination of availability of outdoor space for assembling and facilities for load-out of the pylons. It will be possible to conclude in a yard prequalification phase.

The most critical aspects of the feasibility study have been to find a realistic weight of the complete steel pylons, and to verify availability of lifting vessels that have enough crane capacity and reach for both the up-ending and the lifting onto the foundations at the location. Two different HLV's are found to have the required crane capacitiy, both with two rotatable crane booms. However, both cranes are also limited by lifting height for the main hooks but have Auxiliary hooks of 2500 t capacity per crane and approximately the same maximum hook height.

For this study case one of these vessels is chosen for the evaluations, mainly because better data and a lifting capacity curve are available for this vessel. Kværner has applied this vessel for many projects and has agreements with the owner to receive the Statfjord A topside modules (and other potential demolition projects) to the Kværner demolition site during the period from 2024. Frequent presence in the Sunhordland region might improve the possibility to obtain a good agreement with the HLV owner. The strategy is that if one of these vessels can perform the installation, feasibility can be stated. But in a consecutive study phase more precise data for the second (or any additional) identified crane vessels should be investigated and confirmed.

As a basis for the study the task definition document presents a reinforced concrete pylon design, shown in Figure 6. Based on a previous concept study of pylons for suspension bridges for the Bjørnafjord bridge, similar steel pylons gave an idea of possible skin plate and longitudinal stiffener thicknesses. Based on this a first conceptual elevation sketch was made, and weight and center of gravity (CoG) coordinates calculated. With skin plates mainly between 40 and 50 mm, the complete pylon was found to weigh above 6000 t, which significantly exceeds the crane capacity for lifting the pylon in one piece.

A revised design was proposed, based on square columns from bottom to top, and conical columns only from foundation to the crossbeam. The revised design is shown in Figure 8, in section 5.2. The principle design with an A-frame configuration like the concrete design in Attachment 1 is chosen. This is discussed by Norconsult from an architectural point of view in their "Skisseprosjekt, bru over Langenuen og Søreidsvika", referenced in attachment 3, and found expedient and good looking. It is also mentioned that the A-frame aperture also has similarities to the planned pylon for the Bjørnafjord stayed bridge. It is mentioned as a positive asset that there are recognizable similarities between the two bridges in the same E39 road section.

Based on this adjusted design (and early strength estimates), the new weight was brought down under the critical maximum limit for lifting. Based on this preliminary design, the analysis for up-ending and lifting was made, using hand calculations for weight, and location of CoG and buoyancy centers. The feasibility study is made based on this conceptual design and hand calculated data. No 3D model is developed, and illustrations are created in a sketch program called Snagit 2019.

Midway in the study process, a revised design based on strength calculations results were received from NPRA, resulting in lower weight and a more comfortable margin with respect to crane capacity. The revision did also include a reduced road box design (29.0 m wide compared to previously 34.3 m). At a later stage, it is recommended to build a more accurate model to evaluate weight, buoyancy, the position of center of gravity, and the center of buoyancy.

The key factors for compliance with the crane vessel specifications are the following:

- Highest allowable location of hook points (lugs) relative to the crane hooks
- Verify a proper vertical distance from the hook point down to the pylon CoG, to ensure safe up-ending and lifting operations
- Verify the ability of the vessel to pick up the A-frame from horizontal (floating) position and perform up-ending in one operation without conflicting with the vessel hull.
- Need for excavation of seabed in front of the pylon foundations to meet the HLV operator's demand for a safe distance.

3.1 AVAILABLE VESSELS MEETING THE MINIMUM LIFTING CAPACITY AND REACH

As the height of the considered pylon geometries exceeds 200 m, the only lifting configuration found possible is the use of a twin boom crane, hooking the A-frame with one boom at each side of the frame. To meet these demands, two alternative HLV's are found suitable for the lift operation.

3.1.1 SAIPEM 7000

The vessel is owned by Saipem and is often stationed in Stavanger (in readiness state). The vessel with a lifting diagram is shown in Figures 1 and 2. As shown in the diagram, only the 1st auxiliary hook has sufficient hook height to lift the bridge pylons. The main hooks have approximately 25 m lower hook height at radius 75 m, which is in the region of the CoG of the complete A-frame.

The diagram is giving maximum heights measured from the upper deck level. At offshore conditions, the normal operation draft is 27.5 m, while in calm conditions inshore lifting is often undertaken at a lower draft. For lifting the Langenuen bridge pylons an operation draft of 20 m is assumed. Using the 1st Auxiliary hooks, the diagram shows a total hook height of 139 m at lifting radius 75 m. The maximum load per auxiliary crane is then 2480 t. (There is a slight capacity reduction from radius 70 to 75 m).

Figure 2 shows Saipem 7000 performing a tandem lift by the two 1st auxiliary hooks at normal operation draft 27.5 m. As can be seen in the picture the hooks are of the 4-prong type, but only 2 prongs are used in this lift. Similarly, the use of two prongs for the pylons will be preferable, since the arrangement for unmanned release of slings will be necessary.

The mobilization and operation costs of this vessel over a few days will probably exceed 100 MNOK, but the cost will be dependent on the vessel location at the time of hire as well as the market situation. If the hire can be combined with other engagements in the Sunhordland region, Saipem might be able to offer a favorable price.

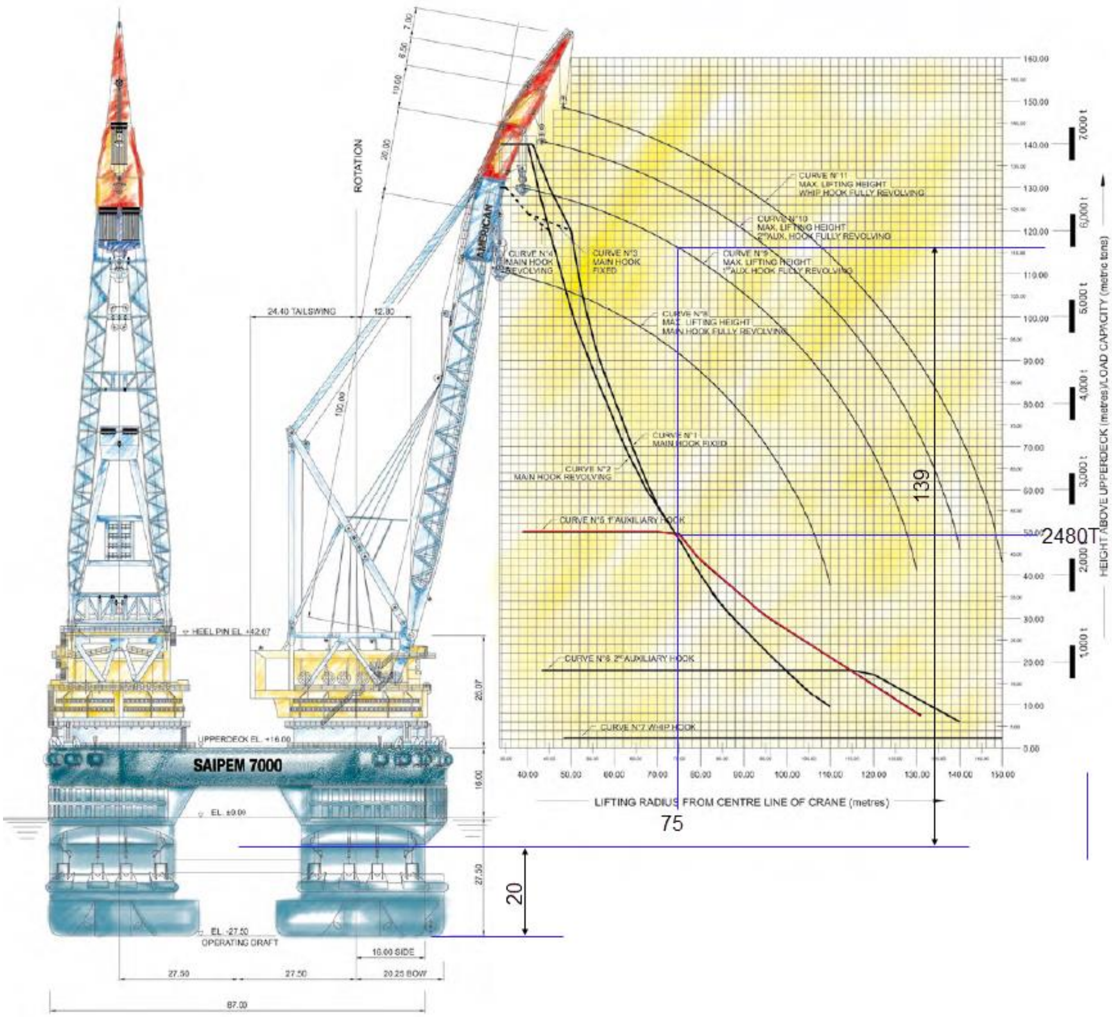

Figure 1: Saipem 7000 lifting capacity diagram

Figure 2: Saipem 7000 in operation offshore

3.1.2 SLEIPNIR

The HLV Sleipnir is owned and operated by Heerema and is a new HLV. It is the largest semi-submersible crane vessel (SSCV) ever built. Figure 3 shows the vessel at its first assignment.

Although the main hook capacity is 2 x 10000 t, the auxiliary hook capacity and lifting height are quite similar to Saipem 7000. Because the lifting diagram for Sleipnir is not available, the feasibility study has been done from the Saipem 7000 data only, but Sleipnir is certainly a strong competitor. One advantage for Sleipnir is that the crane booms seem to be slimmer by width, which can be an advantage when the pylon A-frames are lifted centrically between the two booms and might allow shorter trunnions to be attached to the pylon structures.

Figure 3: HLV Sleipnir at its first assignment

3.2 WEIGHT LIMIT FOR COMPLETE PYLON IF LIFTED IN ONE PIECE

From the lifting diagram presented for Saipem 7000, shown in Figure 1), the absolute weight limit is 2480 t per crane (including the lifting slings, shackles, and so on). No reduction factor for the tandem operation of the two cranes are foreseen, but a dynamic amplification factor (DAF) is assumed to be 5 %, previously used in the Kværner 's yard harbor. For the study the maximum weight of the lifting gears is stipulated to 100 t, which puts the max effective lifting capacity to 4623 t, rounded down to 4600 t.

The reach for the crane is set at 75 m, due to the slightly higher maximum lifting weight at this radius. Increasing the radius to 80 m reduces the lifting capacity as well as the maximum hook height. The capacity can be further increased to gross 2500 t per crane by reducing the radius to 70 m. If the operation draft of 20 m is concluded, this is however a plausible alternative only for the lift on the north side of Langenuen, where the depth contour is deeper close to shore.

The maximum crane hook height is based on a vessel draft of 20 m. Saipem 7000 has performed several lifts with a draft of 8 m, identical to transit draft with dry pontoon tops. The maximum capacity at this draft is 5000 t but might vary depending on the lifting radius. In this condition, the margins for hook height can be increased by 10 m and the feasibility of the operation is improved considerably.

3.3 DEPTH AND ACCESS AT THE BRIDGE TOWER LOCATIONS SPECIFIED

The location of the bridge is in Attachment 1 “Oppdragsbeskrivelse” described by Figure 4, with both foundations placed mainly on dry land, close to the sea line. In the Norconsult report (Attachment 3) it is referred to another alternative, where the foundation of the south side (Jektevik) is placed in shallow waters near the shore. This alternative is not studied. If this brings the foundation further out from the shoreline, this will possibly represent a reduced uncertainty for the lifting operation and crane reach. Figure 5 shows the basic bridge location scaled and transferred into a map containing the depth contours (Norgeskart.no).

In chapter 6, on Figures 19 to 21, the HLV is scaled into this map to illustrate where a moderate excavation might be required to obtain sufficient clearance between the vessel hull and the seabed. The requirement is normally 10 m horizontally, and 5 m vertically (below pontoons). These requirements are based on the HLV operating in DP (dynamic positioning) mode. A rough simulation shown in Figure 19 and 20 indicates that a considerable rock volume (probably exceeding 1000 m^3) may have to be blasted and removed. However, if the operator sees the operation feasible with dry pontoon decks (in transfer draft), such excavation seems to become unnecessary. A seabed survey and advice from potential HLV operators will be necessary for a later phase to estimate the excavation volume properly.

Another possibility to avoid excavation may be to place a distance barge along the shore, allowing the HLV to slightly lean against the barge. Barge fenders must be arranged onshore. Such a distance barge might also serve as a passive safety bumper in order to reduce the standard distance margin to rock bottom in case of a DP system fall-out. If a service barge is hired for the installation period, this barge could also serve as a distance barge for the pylon lift(s). On the north side, shown in Figure 21, seems to confirm that no excavation of the seabed is necessary.

Figure 4: Langenuen Bridge - Conceptual location

Figure 5: Langenuen Bridge scaled into a map showing depth contours

4 EVALUATED PYLON DESIGNS

4.1 DESIGN CONCEPT BASED ON CONCRETE PYLON DESIGN

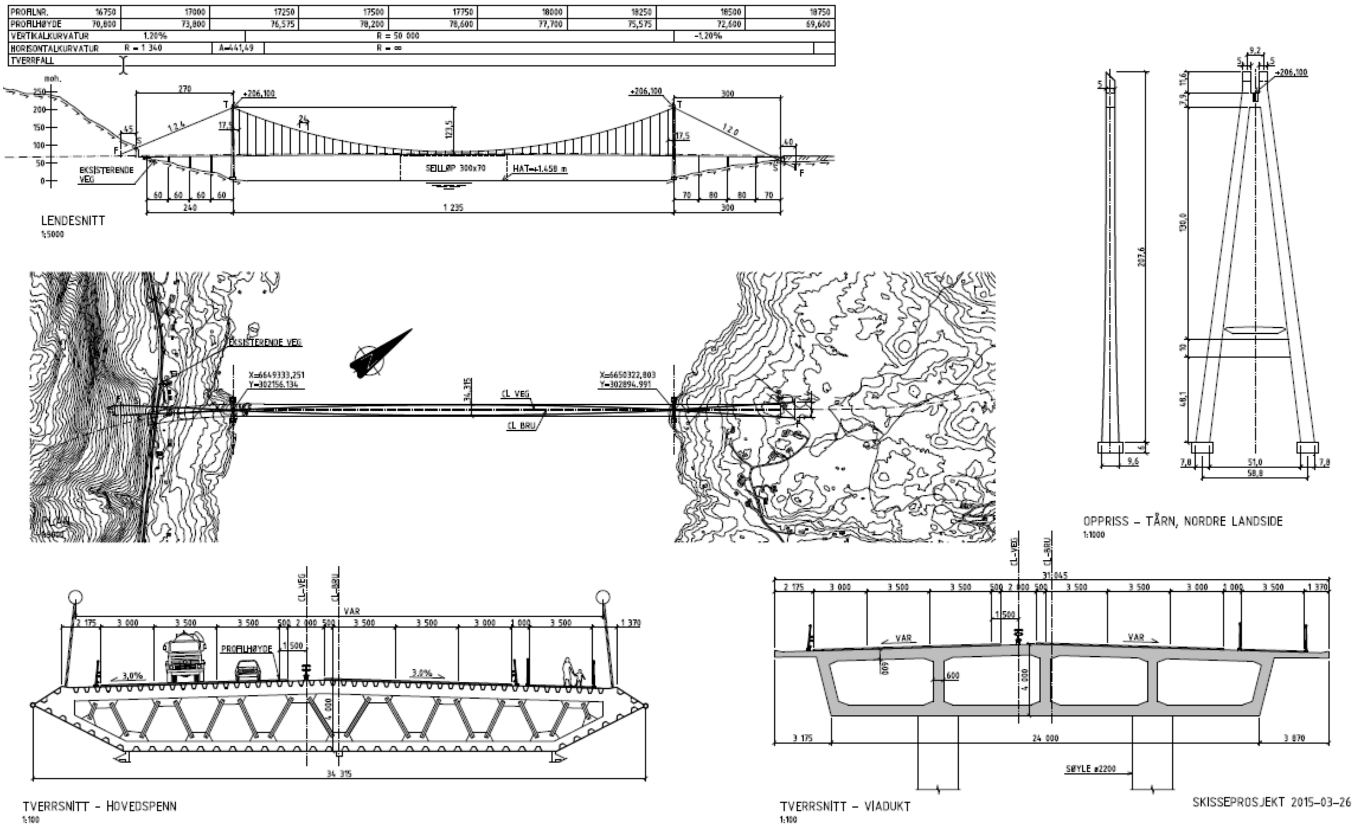

Figure 6: Drawing B- K10_001_altB of Langenuen bridge issued by NPRA for study of steel pylons. Taken from attachment 2, "Alternative B- K10_001_altB"

The reference drawing B- K10_001_altB in Figure 6 is developed with pylons in reinforced concrete. This represents the "starting point" for developing a steel-based concept. The A-frame design is in the end view shown with a straight outer generatrix from bottom to top and columns trapezoidal from the foundation to a level of 100 m. Viewed from the side, the column width is trapezoidal all to the top. The road box at an elevation approximately 66 m is shown with a total width of 34.3 m. However, early in the study, it was informed by NPRA that the road box cross-section is reduced to a total width of 31.3 m, due to reduced shoulder width by 1.5 m in each direction.

Figure 7 shows the first draft that was made. The draft is based on the configuration shown in the task description documents. The skin plates were assumed to be 50 mm at the lower legs (below the cross beam) and 40 mm above. An assumption was made that the stiffeners need to be slightly thinner, 700 mm high, and spaced at approximately 1000 mm.

In the initial conceptual steel pylon design, the column boxes have a trapezoidal variation of the cross-sections up to 100 m above the foundation, and constant column width further up to the top. The principle used for preliminary estimation of weights was that stiffeners (longitudinal and cross stiffeners at every 3 m height) constitute a constant percentage of the skin plate weights. A conservative calculation gave a 70 % uplift of the (simulated) skin plate weight. The concept maintains the elevation of the foundation around 6 m above sea level.

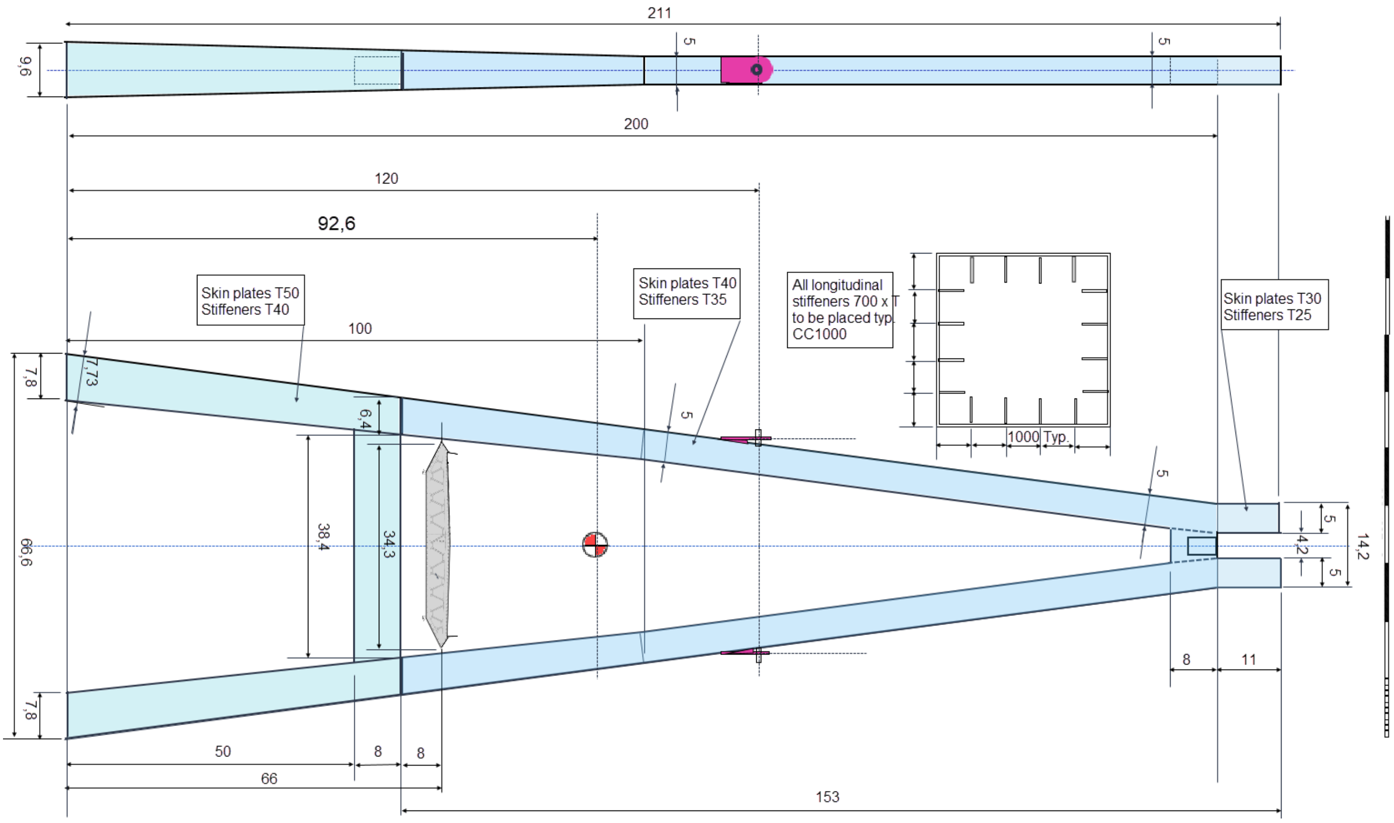

Figure 7: First concept sketch for A-frame

Based on this design the total weight of the A-frame was estimated to 5900 t, and CoG elevation at 92.6 m above foundation interface. The location of the CoG is well below the crane hook points, but the total weight is excessive and excludes lifting in one piece.

4.2 MODIFIED PYLON DESIGN- BASE CONCEPT FOR COG HEIGHT AND HLV PERFORMANCE DETERMINATION

The conceptual A-frame design in Figure 8 was developed to reduce the weight below the critical 4600 t, and to perform the up-ending and lifting study. The outer flank is maintained as a straight line, while the pylon legs below the cross beam are made trapezoidal, with cross-sections 8 x 8 m at the lower end and reduced to 5 x 5 m below the cross beam. The skin plates were chosen as 50 mm at the lower legs and 40 mm elsewhere. Hand calculations confirmed that the weight is still excessive (4885 t) but considered feasible to be further optimized by reducing the size of skin plates and stiffeners when a structural analysis is available.

The CoG height for this concept decreased slightly to 89.6 m, which is positive for the lifting operation. The hook points at el. 120 m above the foundation are set at 12 m below the maximum crane hook height (with HLV at 20 m draft). This distance is considered necessary in order to make the slings (grommets) flexible enough to install and release by gravity after the lift without the assistance of personnel. The hook points are proposed made as trunnions, which must be quite strong and stand the shift of load direction during the up-ending. A solid tube with inner stiffeners is assumed to cross through the columns to the opposite side. This might obstruct a central lift shaft in one column but might be cut away after completed lifting for the insertion of lift shaft infill.

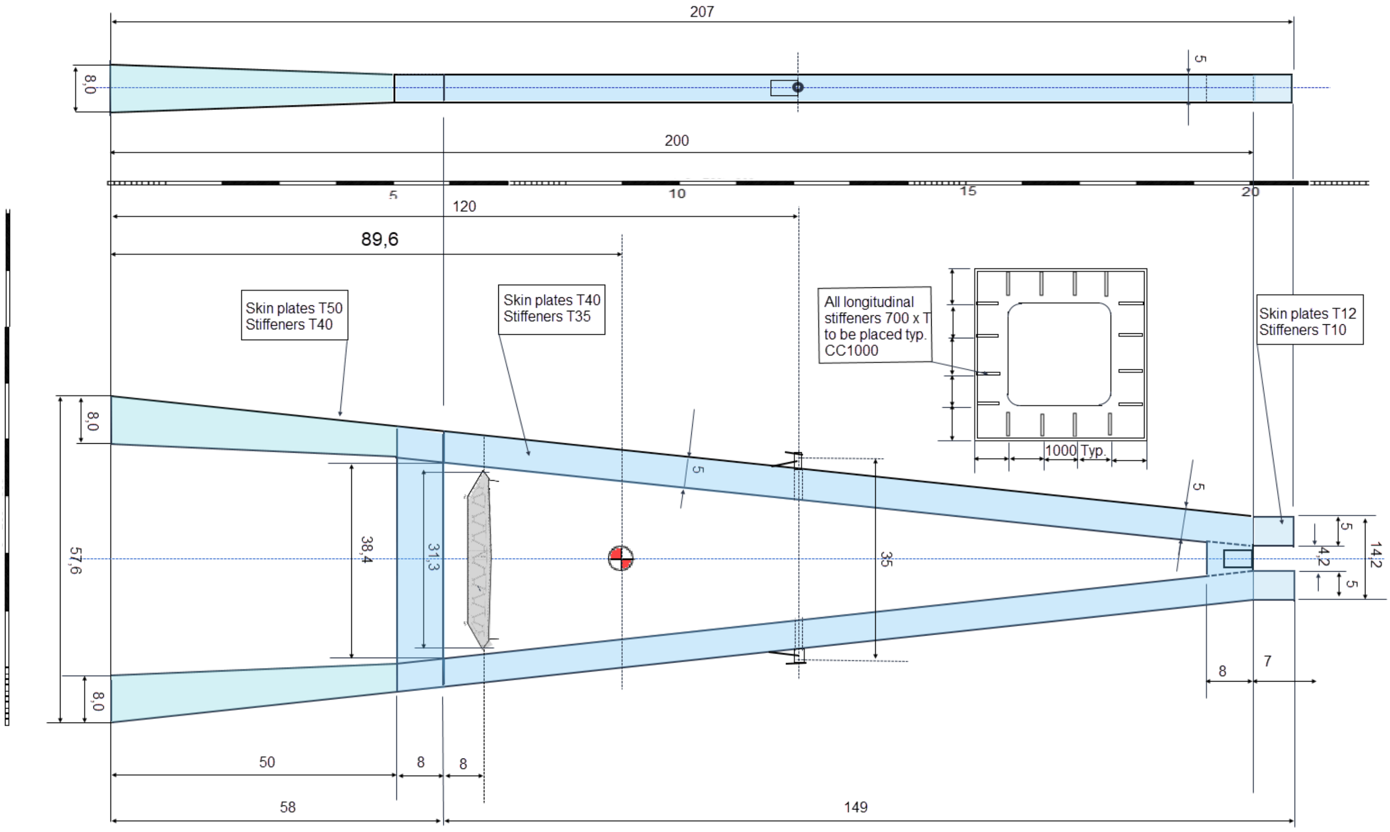

Figure 8: Modified pylon design used for up-ending verifications

4.3 New (revised) design based on strength estimates

A pylon design based on static and environmental loads was suggested by NPRA. Figure 9 shows a revised concept with a trapezoidal variation of square cross-sections varying from 8 x 8 m to 5 x 5 m. The dimensions of skin plates and stiffeners are shown in Figure 10. The estimate was based on an “RM Bridge” model and the main results are presented in figures 10 and 11.

Quality S420 M/ML is assumed by NPRA, and the choice of dimensions was based on keeping the stresses safely below the tensile strength of this material. The table in Figure 11 illustrates stress values at various heights above the ground. All values are below 300 MPa, representing a utilization below 70 %.

The NPRA has estimated the gross weight of the revised pylon design to be below 4500 t, including cross stiffeners at every 3 m height and cable saddles. This weight represents a margin to the maximum lift weight of 100 t. Reducing the lifting arm to 70 m increases the margin to 300 t. Although it would be preferable to have a larger margin at this conceptual stage, it is considered that a potential weight growth is possible to manage due to the present conservatism in material utilization. This revised design with performed strength and weight estimates is the main basis for the conclusion of the feasibility of the lift-in operation discussed in section 5.3.

The revised concept is not calculated in detail with regard to the position of CoG and volume metacenters (for verification of the up-ending properties), but simply evaluated as a uncertainty judgement against the modified design, shown in section 5.2. It is assumed that in a potential next development phase more detailed design and strength calculations will be carried out, and the margin to maximum lift weight will not jeopardize the feasibility of the operation.

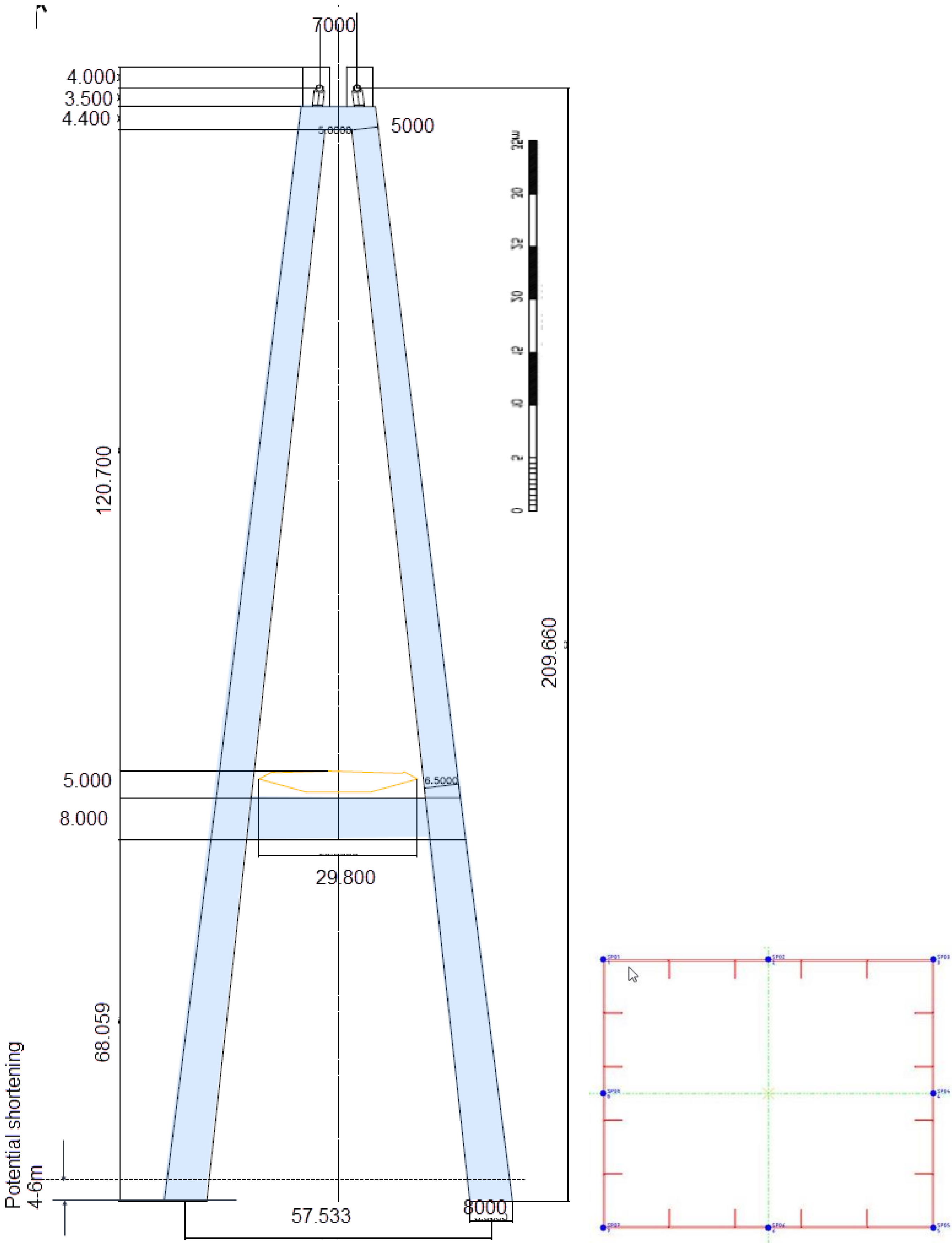

Figure 9: Revised design as the basis for strength and weight calculations

Cross sections				Stiffeners				
Name	width-x	width-y	Wall-thickness [mm]	Stiffener - length [mm]	Stiffener - thickness [mm]	Number of stiffeners	Distance between stiffeners [m]	Length of each pl. section [m]
CS1	**8.00**	**8.00**	**45.00**	**350.00**	**30**	**7**	**1**	23.9
CS2	7.50	7.50	43.33	350.00	30.0	7.0	0.94	23.9
CS3	7.00	7.00	41.67	350.00	30.0	7.0	0.875	23.9
CS4	**6.50**	**6.50**	**40.00**	**350.00**	**30**	**7**	**0.8125**	7.8
CS5	6.30	6.30	40.00	350.00	29.32052466	7	0.902	11.0
CS6	6.00	6.00	40.00	350.00	28.33333333	5	1	18.7
CS7	5.50	5.50	40.00	350.00	26.66666667	5	0.917	18.7
CS8	**5.00**	**5.00**	**40.00**	**350.00**	**25**	**5**	**0.8333**	75.0

Figure 10: Revised design - Selected skin plates and stiffeners dimensions

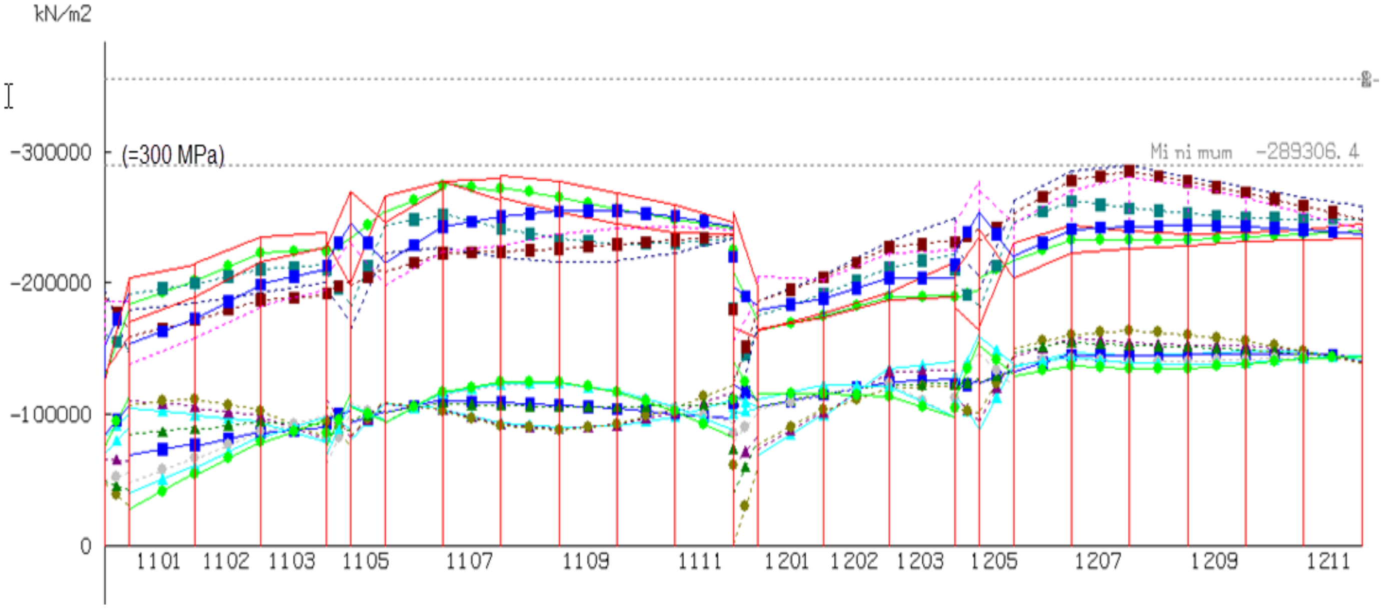

Figure 11: Table of strength estimation corresponding with revised pylon configuration

4.4 Alternative pylon design if splitting is required due to excessive weight

Although it seems feasible to keep the pylon weight under 4600 t allowing lifing in one piece, an alternative approach is briefly studied. The method is based on a (temporarily) bolted splice just below the cross-beam, el. 50 m above the foundation, shown in Figures 8 and 12. The lower vertical/trapezoidal legs are then to be lifted in before the upper A-frame. The CoG for the (upper) A-frame will then move much nearer to the location of the lifting lugs. Hand calculation shows that the CoG location is only 3.7 m below the lifting lugs (for the studied pylon design), and the new weight of the A-frame is estimated to 3488 t.

If the trapezoidal variation of cross-sections is implemented as described in section 4.3, the distance from CoG to lugs will be improved. The matter can be solved in the detail design phase, or easily handled by flooding the cross-beam partly with water to lower the CoG height well below the hook points.

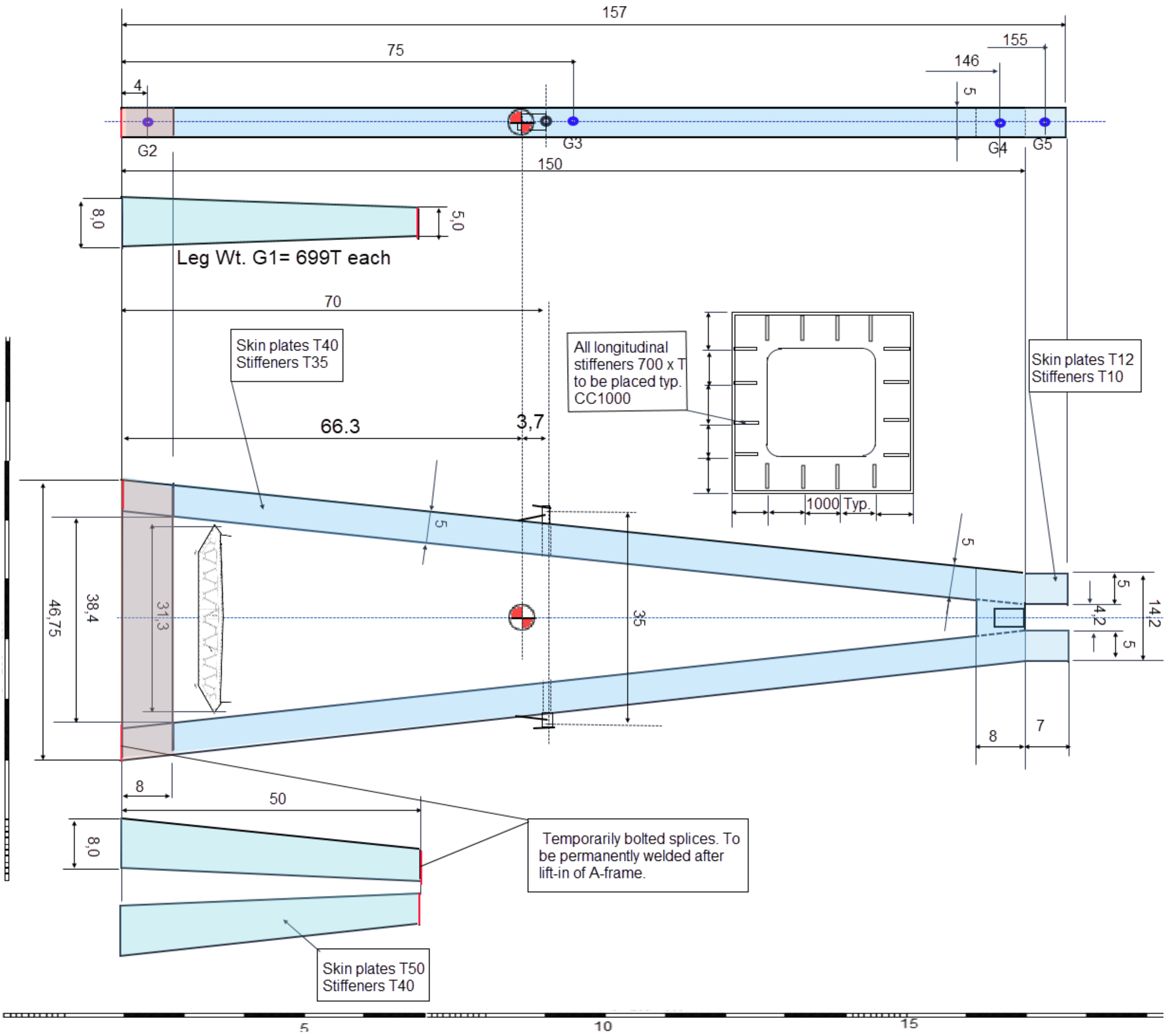

Figure 12: Split A-frame concept for installation in separate parts

5 METHODS FOR PYLONS UP-ENDING AND INSTALLATION

The main objective of the present study is to verify whether it is feasible to lift the complete steel pylons from horizontal condition to their in-place condition. Therefore, the study has concentrated on the following main construction steps:

- Fabrication at a local or foreign shop
- Transportation to Bømlafjorden (local to Langenuen) in self-floating condition, alternatively on a towed barge or submersible (self-propelled) barge
- Up-ending by an HLV (SSCV) with DP (dynamic positioning) properties without re-hooking (Alternatively first lifting the pylon from barge to self-floating condition)
- Maneuver the HLV with pylon into position and set down on a precast foundation
- Keep crane hooks attached until pylon is bolted to the foundation and secured stable
- Release lifting gear from trunnions automatically (without manned assistance)
- Repeat the process from up-ending for the second pylon

The whole operation period for the HLV should be minimized (targeted to 1 week). Close cooperation with the HLV operator will be necessary during a forthcoming phase to optimize the detailed methods.

5.1 PROPOSED LOCATION FOR PYLON UP-ENDING

In theory, it is fully possible to perform the up-ending in the shipping channel next to the installation locations. However, due to frequent passings of ferries and ships, another location in the Bømlafjorden is proposed. At Jektevik the currents are also more dominant than in the wide Bømlafjorden. A proposed location is shown in Figure 13, midway between Fluholmane and Hidle. At this location, demolition activities for old jackets have formerly been performed, due to preference of low currents in the middle of the fjord. From this location to Jektevik there is a sailing distance of approximately 14 km.

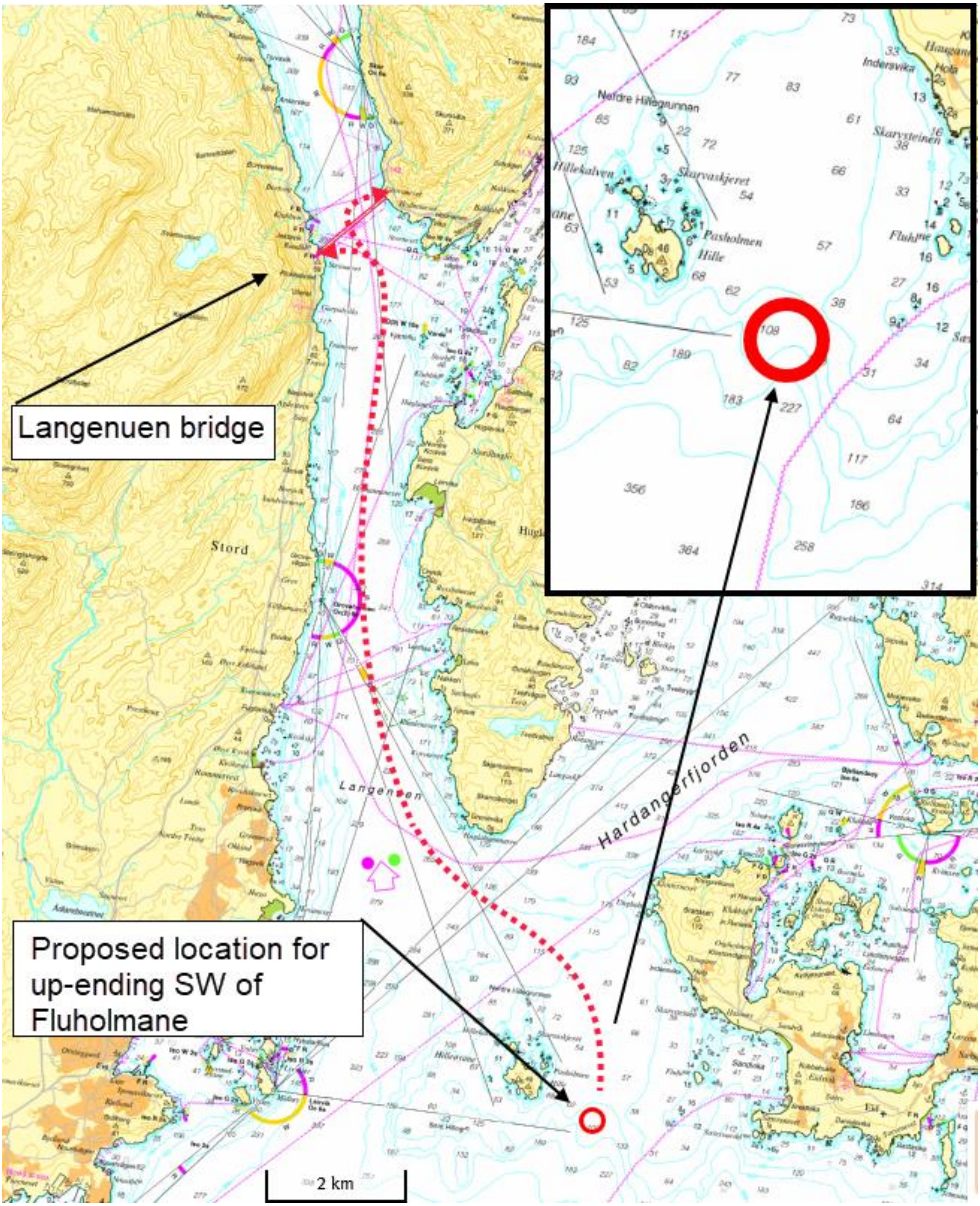

Figure 13: The proposed location for pylon up-ending

5.2 PYLON UP-ENDING, BASE CONCEPT

The main factor governing the choice of method is that once the A-frame is hooked for the up-ending, the crane cannot shift hook points until the A-frame is lifted in place on the foundation. The only way found that can avoid mobilization of a second crane for the up-ending is that the A-frame is placed floating in the sea, and up-ended from this condition. Another critical factor is that the length from the lugs to the top of pylon exceeds the reach of the auxiliary crane hooks on both two identified crane vessels. To meet this limitation, a start position for up-ending with the pylon held (by tug boats) at an angle to the vessel centerline, as shown in Figure 14. As a safety feature, the A-frame can be fendered against the hull by Yokohama-fenders. The slings are supposed hooked onto the trunnions at this position, with the starboard crane (Aux. hook 1) at radius minimum 80 m. Trunnions are then located approximately 1 to 2 m above sea level. This represents step 1 in the operation.

It should be noted that the tug boats used for the tow to the up-ending site may assist under the up-ending to basically hold the pylon stable without contact with the HLV hull fenders. The minimum clearance between pylons and hull/ fenders will be decided in cooperation with the lifting contractor. The clearance may be increased by turning the port crane clockwise a few degrees more than illustrated in Figure 14.

In a further detailing study conditional weather criteria will be properly addressed.

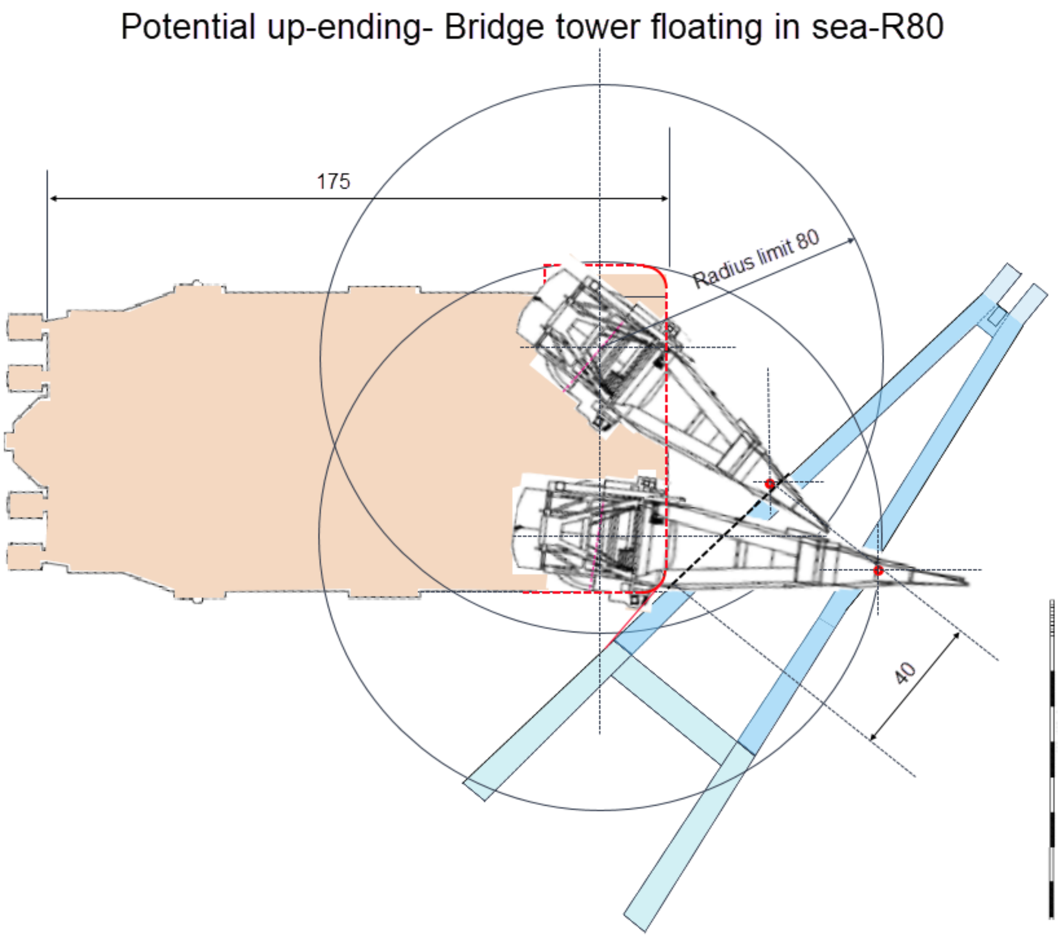

Figure 14: Up-ending step 1: A-frame up-ending from the self-floating condition

At this position the lower legs shall be flooded by seawater, to obtain the critical angle to turn the legs underneath the vessel pontoon at the lowest possible lift height. Alternatively, if the A-frame is towed in floating condition from the assembly yard, further studies on what the floating condition/trim would be like for these two options (flooded legs vs. not flooded legs) would be required before the tow.

When the a-frame is lifted to an inclination of 70°, the plan view will look like Figure 15. An elevation view is shown in Figure 16.

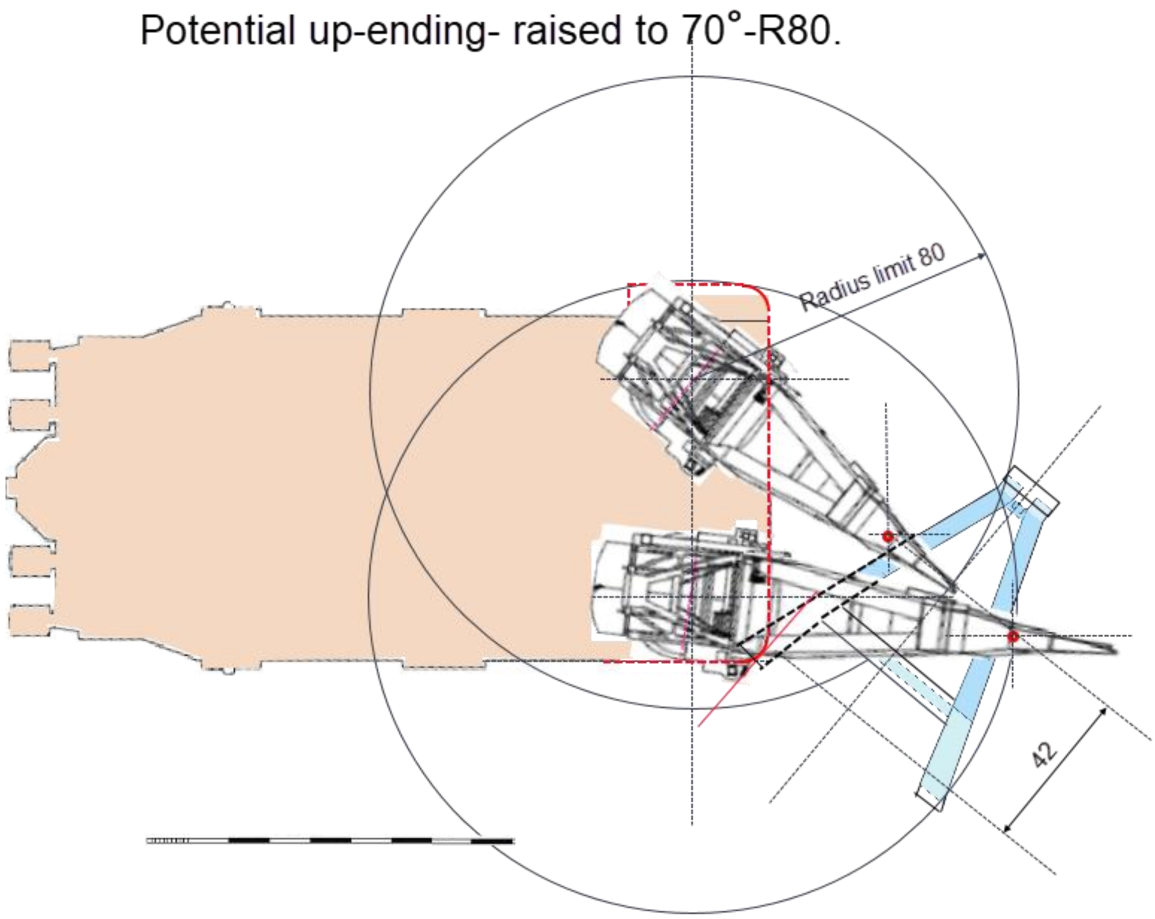

Figure 15: Up-ending step 2: A- frame lifted to 70° from horizontal

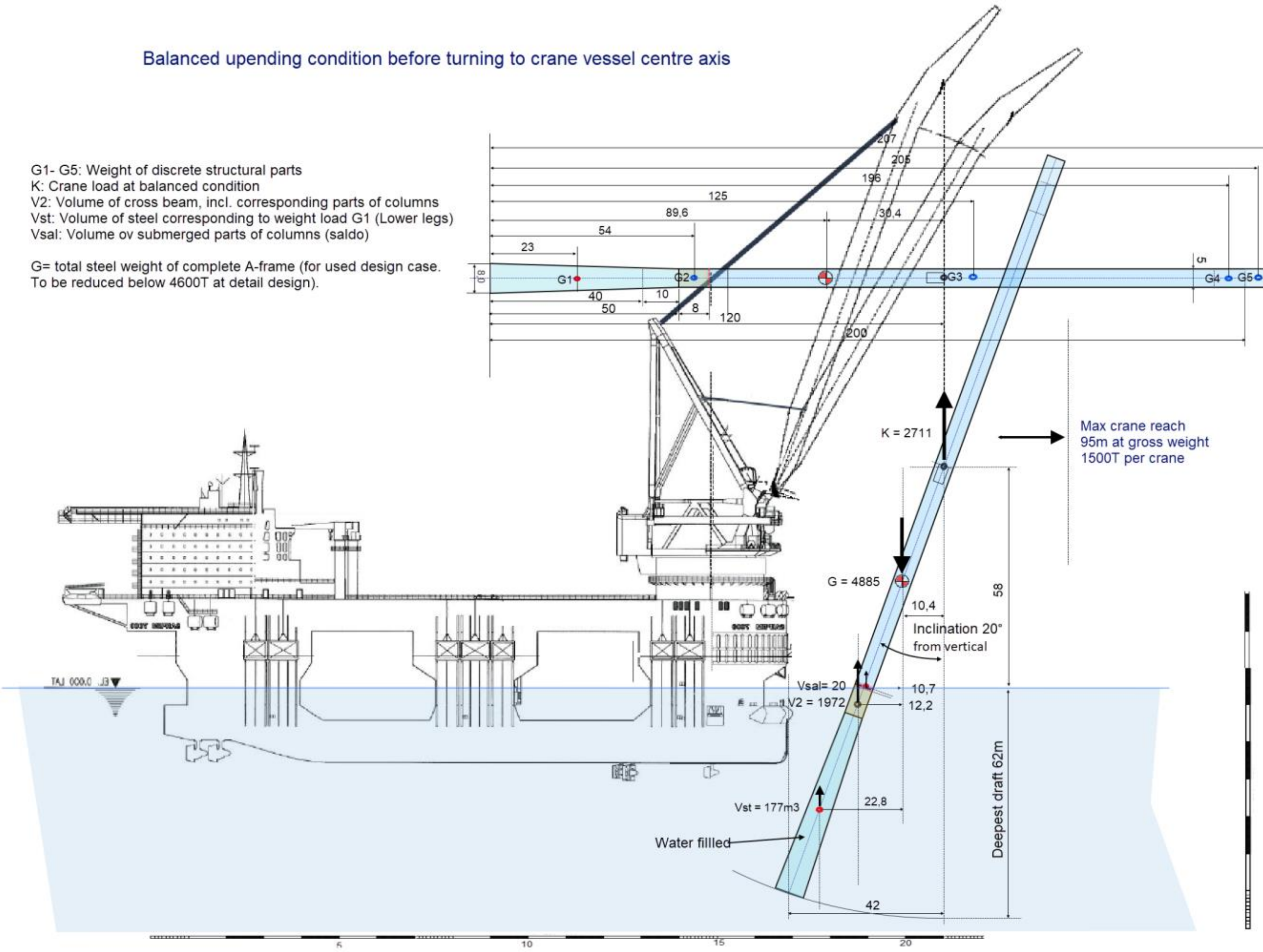

Figure 16: A-frame inclined 70°

In Figure 16 the distance from (starboard) crane hook (vert.) to vessel hull is shown to be 42 m, which is the distance from port crane hook (vert.) to the hull measured parallel to the A-frame center line, shown in Figure 15. It can also be seen from Figure 15 that at this angle, the A-frame top passes under both the Sb and Port crane booms and can freely be rotated to the hull central axis, without any interface problem with hull or booms. Full visualization of this clearance is only possible in a 3D model. To reduce the uncertainty, it is possible to increase the lifting radius of the starboard crane before the hoisting to 70° inclination, since the load is significantly below the max load 2300 t per crane.

The intermediate inclination 70° is chosen after some attempts to calculate a balanced and stable condition before the turning operation to a concentric position. In this state, the sum of moments for weight and updrift volumes (buoyancy) around the CoG and the hook load is in balance.

With the lower legs (up to the underside of the cross beam) are water-filled, it was found that the buoyancy of the cross beam is the dominant factor. Moment balance was found when the top of the cross beam breaks the surface, or closely after. At the shown balanced state, the crane hooks are at 58 m above sea level. Any further lifting will quickly bring the A-frame towards a vertical position, due to quickly reduced buoyancy. It should be remarked that the cross beam is assumed to be 5 m wide, i.e. the same as the column widths at this height. If the cross-beam width is reduced, the buoyancy is similarly reduced, and the 70° angle will be obtained at an earlier point, corresponding to a lower hook height.

The turning operation is proposed performed by keeping the Sb crane fixed, and turning by operating the port side crane only, shown in Figure 16. When performing this operation coordinated steps of port crane rotation, hoisting, and booming out is necessary. It might be possible that an increased DAF factor above 5 % is needed. This is feasible since at this state the crane load is calculated to approximately 60 % of the full capacity (2711/4600 t).

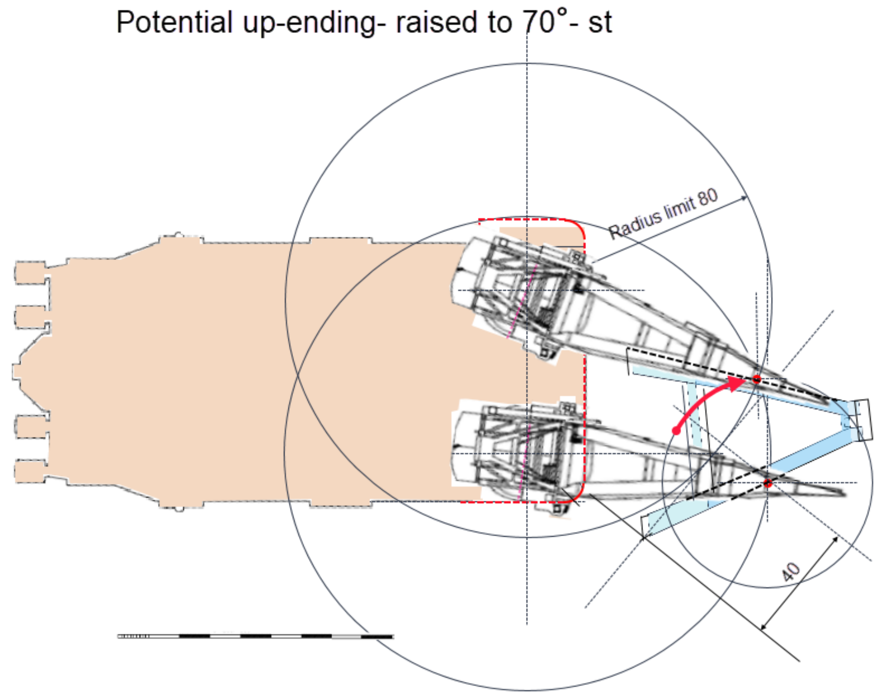

Figure 17: Up-ending step 3: A-frame turned by port crane maneuvering

From step 3, shown in Figure 17, the A-frame can be moved towards the hull center axis by coordinated rotation of both cranes without any further hoisting or booming.

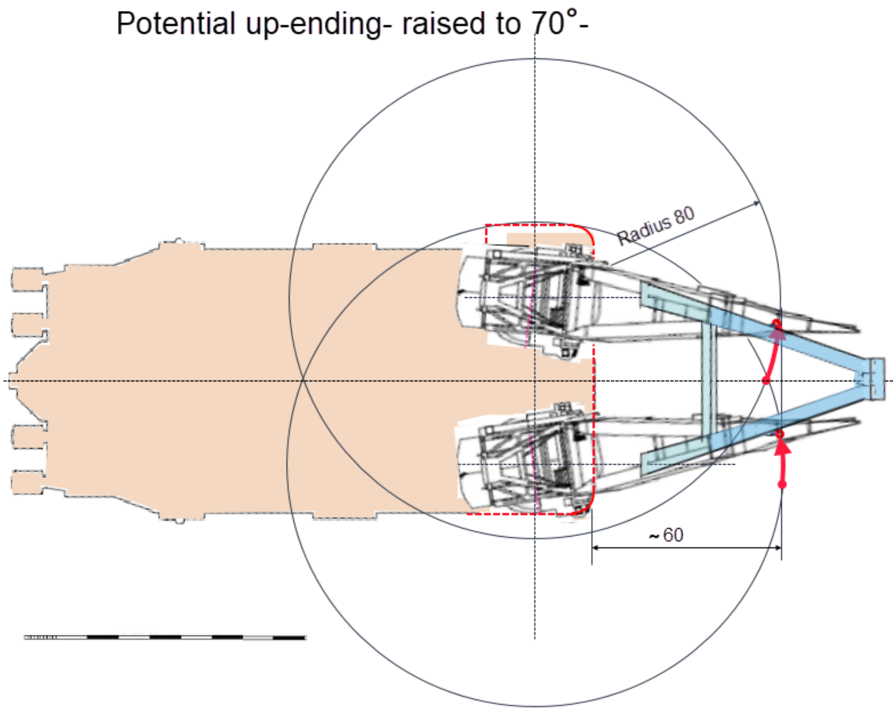

Figure 18: Up-ending step 4: A-frame turned to a concentric position with the vessel

As illustrated by the figures, all steps of turning show a safe distance between A-frame and hull. The further up-ending continues by parallel booming in both cranes to radius 75 m. From step 4, shown in Figure 18, the hoisting is continued to installation height, and the vessel moved to the installation position with the A-frame as hanging load, stabilized by wires from constant tension utility winches on the vessel. For up-ending at a deep-water location the draft might probably be reduced to transit draft (8 m).

Based on the above analysis, it is deemed feasible that the up-ending can be performed with the A-frame completely assembled, performed by one of the two prequalified HLV's. However, this must be confirmed by the vessel operator in a later design phase.

Uncertainties:

- Weight increase. Risk considered to lead in a positive direction, since upper columns in calculated cases (see section 4.2) have a constant profile and exaggerated size of stiffener profiles. Both weight and height of CoG are possible to reduce. The weight of the cable saddles (2 x 60 t) is not fully accounted in the studied design but is expected to be counteracted by the revised design alternative (see section 4.3), where the column profiles are conical/ trapezoidal all from the bottom to top, leading to a lower CoG height.
- Lifting at reduced draft. It is confirmed that during inshore operation Saipem undertakes lifting to 5000 t in transit draft (8 m). This will increase the distance between A-frame and hull before the alignment rotation. HLV Operator to confirm in the next phase of development.
- Clearance between crane booms and A-frame. The position of lifting trunnions can be lowered around 10 m, and still, the stability will be sufficient. The length of the lifting slings will increase correspondingly, and clearance increases.

5.3 Pylon lifting and installation

A major driver for the study of a steel alternative to pylons in reinforced concrete is the installation time. By lifting complete A-frames onto precast and prepared foundations it should be possible to perform up-ending of each A-frame in one day, and perform installation lift the next day. In a FEED phase design development must focus on efficient and accurate set-down, securing by several initial bolts, moment of release of lifting slings, and so on. Both a rough positioning "bumper guide" system and an accurate bucket & pin system is assumed necessary. A bolting system must be developed. Most likely tension stays down to rock should end in threaded sleeves for the tiedown bolts. Preinstalled bolts sticking out of the foundation during installation would be vulnerable during the engagement movement. Figure 19 shows a principle for bolting down the steel columns for a concept developed for a suspended bridge over Bjørnafjorden.

The figure shows a pairwise location of ground bolts around the longitudinal stiffeners. The sketch shows threaded rods, but threaded sleeves w/ extension rods introduced after set-down is recommended.

It is a matter to decide if securing wires should be attached to the A-frames at a level below the hook points, two ea. pointing inwards and towards the seaside, to be used for stabilizing and securing the tower before the release of the lifting slings. If necessary, the wires directed towards the sea can be fastened and tensioned by anchors and anchor pontoons with tensioning winches. The use of such equipment is standard for inshore and offshore operations in the petroleum industry.

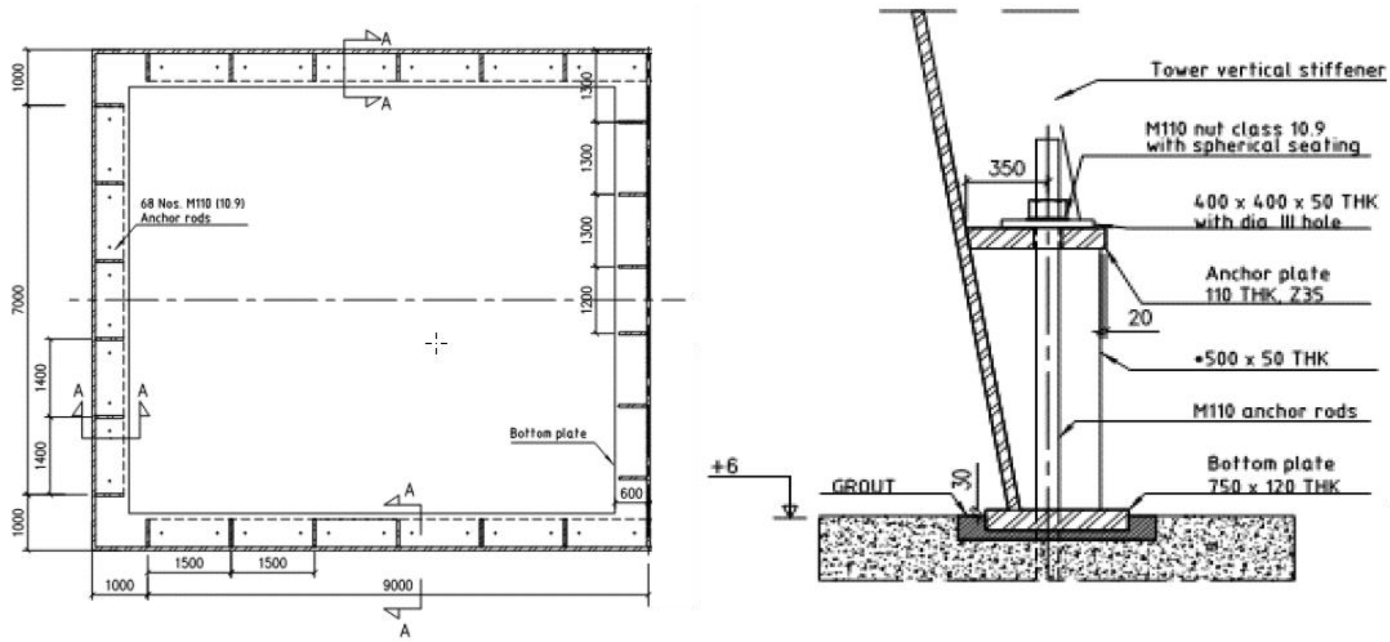

Figure 19: Connection flange to the reinforced concrete foundation – An example from a suspended bridge concept. Taken from attachment 4, p.70.

All bolting performed on the inside of the tower columns requires easy access to the inside. If temporary bulkheads are used in the lower leg ends during towing operations, these are recommended made removable and removed before the up-ending operation. Access to the inside can be arranged either by a small access tunnel through the foundation to the middle of each column, or by a hatch somewhere in the column skin plates.

Due to the early stage of design, it is proposed that an extra day is planned for the HLV operation time for each lifting operation, leading to a total duration of the lifting operation between 6 to 7 days for both pylons. If the pylons are delivered on barges, then an increase in total duration of 1 day per tower is considered realistic.

In the following subsections the proposed method for installing the pylons at both locations is presented and discussed. What is not studied in detail is the weather criteria for the installation. It is obvious that calm sea and near windless conditions will be a great advantage. The limiting criteria will be set in a further development phase in cooperation with the potential installation contractors.

Based on this conceptual study, it can be concluded that the HLV S7000 is able to perform the installation of the bridge pylons in one single lift. However, further optimization of the proposed methods is recommended. The alternatives of split pylon installation described in section 5.4 are added as a reserve for consideration in case of unforeseen weight increase.

5.3.1 Pylon lifting at location Jektevik

Figure 20 shows the plan situation when Saipem 7000 has maneuvered into position with the A-frame hanging at radius 75 m, i.e. the reach when the capacity for the 1st auxiliary hooks is near the maximum. The vessel is scaled into a map with depth contours (Norgeskart.no).

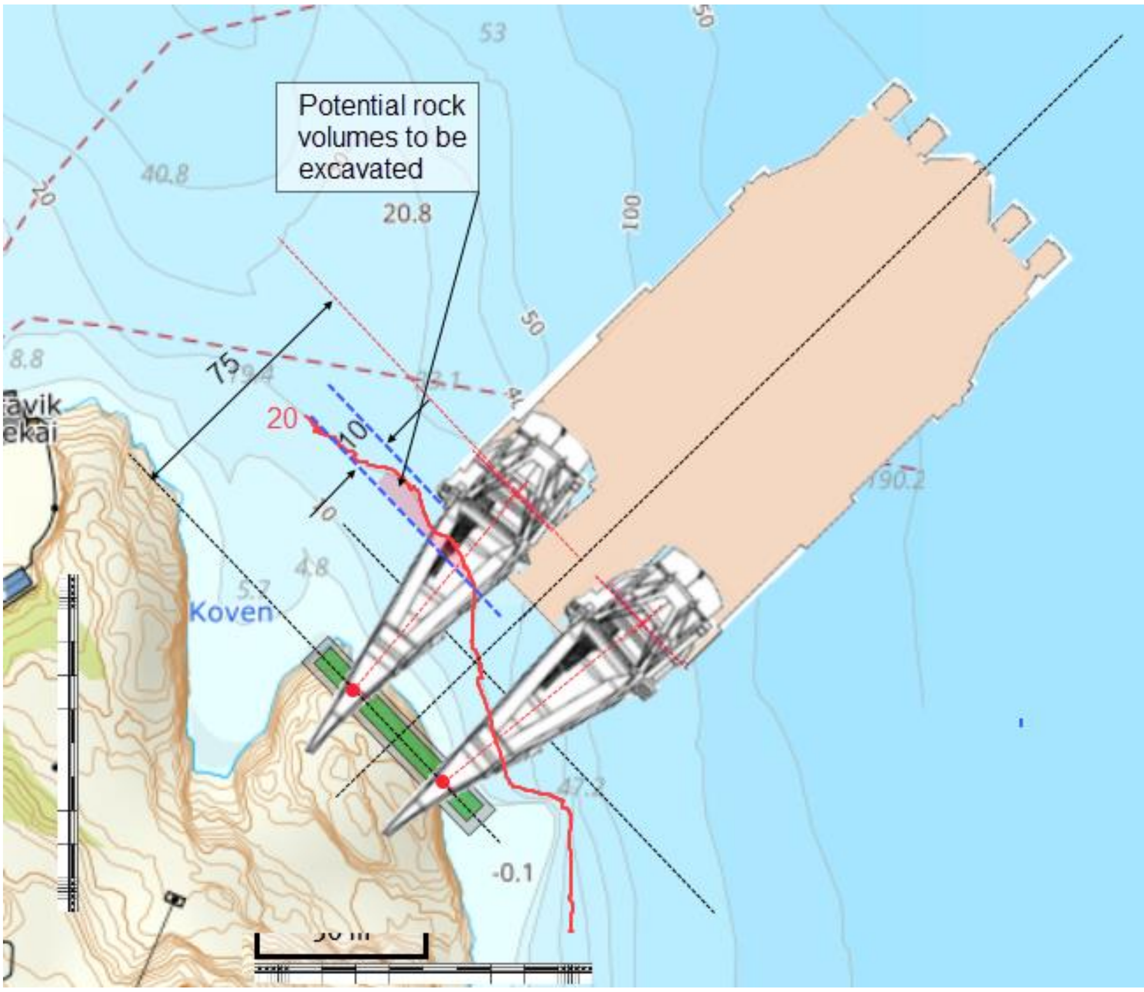

Figure 20: The HLV in position at Jektevik for set-down of A-frame

Figure 21 shows an elevation illustrating the vessel holding the A-frame at a distance 2 m above the foundation, which for the study is set to +6 m level. For the study it was assumed that the operation is made at a vessel draft of 20 m, i.e. 12 m deeper than transit draft. Both sketches have indicated a certain volume of rock that might be required excavated, to obtain safe distance against touching rock. However, it is understood (from similar operation experience) that the operation might be done at transit draft 8 m. If so, it is considered possible that the lifting can be done without any excavation, subject to acceptance by the operator. Anyway, a verifying depth measurement in the critical area will be necessary.

Reducing the operation draft to 8 m does also open up the possibility to reduce the lifting arm to 70 m, and thereby increasing the maximum crane capacity by 40 t to 4640 t. For the northern pylon (Hodnanes side) it is obvious that the lifting arm will be reduced, due to the deeper conditions.

Figure 21 also indicates the potential problem if the crane booms come too near the A-frame when it is elevated to the highest position. The fact that the crane centers are 55m apart makes the booms turn slightly inwards. This fact increases the clearance to the A-frame. If a conflict turns out to be real, it can be avoided by either extending the outreach of the trunnions, or by lowering the trunnion position as required. For the studied design there are 30 m down to the A-frame CoG. Lifting at transit draft will have the same positive effect, increasing the distance between the crane boom and A-frame by 1.5 m. To exclude any doubt about the conflict, accurate modelling of the vessel boom and a 3D animation of the up-ending and lifting operation is recommended.

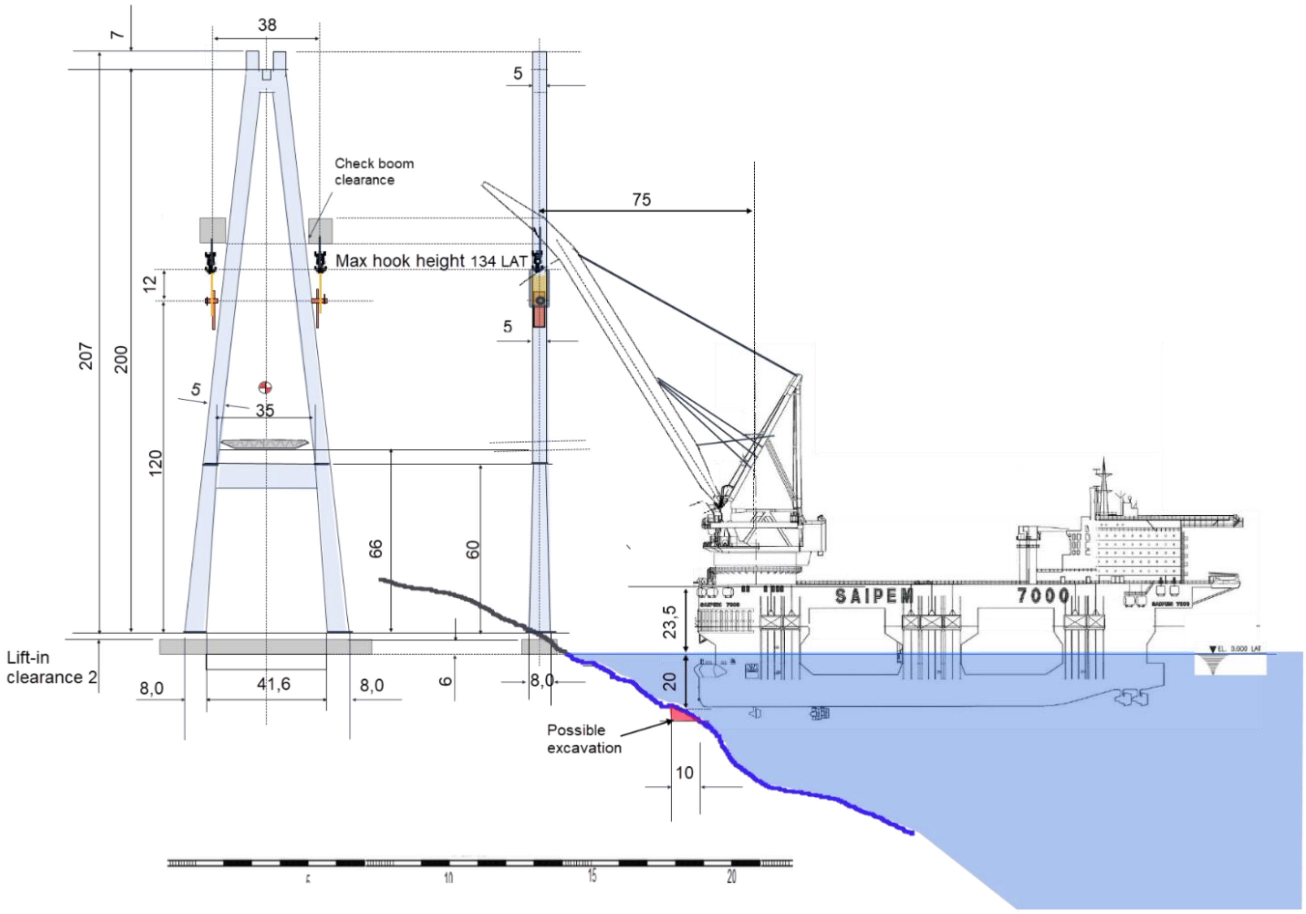

Figure 21: Elevation sketch showing HLV when the A-frame touches bumper guides

During the sailing to location, approach movement, and set-down, it is assumed that stabilization wires from tugger-winches on deck or crane house will be used to stabilize the heave and prevent pendulum movements.

Uncertainties:

- Weight increase is considered to be low risk, discussed earlier in section 5.2.
- Touch sea bottom. To be excluded by bottom excavation or perform lifting at transit draft. May also be eliminated or reduced if the foundation is placed further out in the sea.
- Touch between booms and A-frame. Minimum, due to realistic precautions.
- Method to release slings without manned assistance to be developed.
- Stabilization of A-frame before the release of cranes. To be taken care of in detail design. Possible to connect and tighten stabilization wires to A-frame during insertion of all bolts, grouting, curing, and tensioning. Possible to arrange temporary bolts and guides externally of the columns, in order to secure until final tensioning of permanent bolts.
- Access to columns inside. To be handled in detail design.
- General access to the work location. It is assumed that this will be arranged by civil during the civil1 preparations. It is feasible to arrange mooring facilities for a service barge, and access by road close to the foundation.

The proposed method in this study is deemed feasible despite the above-mentioned uncertainties.

5.3.2 PYLON LIFTING AT LOCATION HODNANES

The challenges at location Hodnanes (NE pylon) is regarded technically very much alike as for Jektevik (SW pylon). Figure 22 shows the vessel scaled into the map. Plentiful distance to the 40m depth contour is marked.

The uncertainties are also very much the same as in section 5.3.1, except that the depth conditions allows the lifting radius to be reduced to 70 m, offering a higher weight margin. Here the access for personnel is quite restricted, but it is assumed that this can be fixed by civil during their initial activities. The mooring of a service vessel along the shoreline is realistically feasible. If a suitable barge is used, it is possible to apply the storage facilities at the Jektevik location also to serve the Hodnanes site. By using a shuttle ferry of suitable capacity, all goods and personnel can be shipped out from Jektevik over a driving ramp to the service barge and further to shore.

The proposed method applied at Hodnanes is deemed feasible despite the above-mentioned uncertainties.

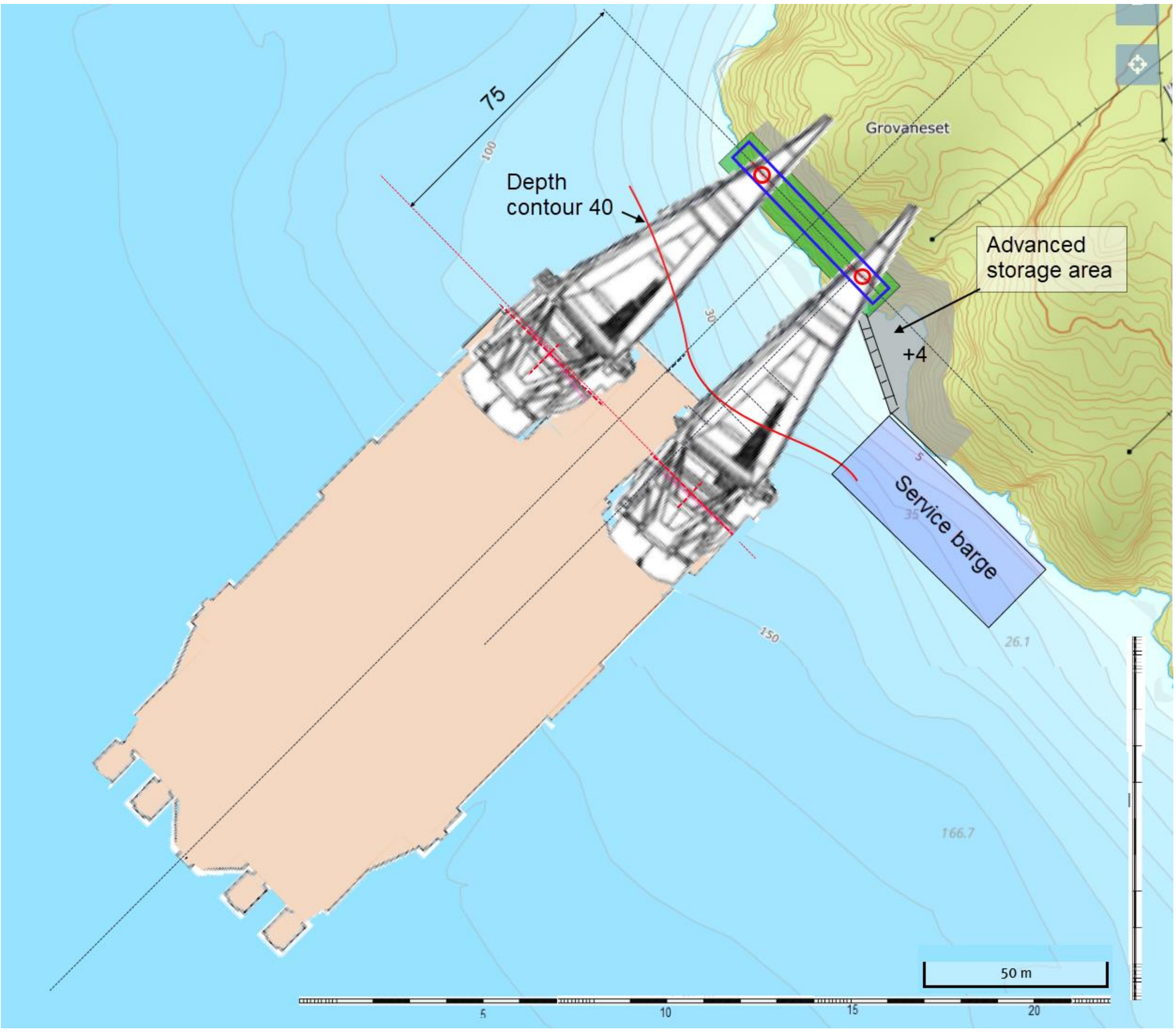

Figure 22: The HLV in position at Hodnanes for set-down of A-frame

5.4 VERIFICATION OF FEASIBILITY FOR ALTERNATIVE SPLIT CONCEPT

The split A-frame concept, shown in Figure 12 earlier, requires an alternative method for pylon installation, in case the assumptions in this study lead to total weight exceeding the lifting capacity limits (4600 t). The concept is based on the installation of the lower legs (for the studied design calculated to 699 t each) in two separate lifts. The following procedure is considered logical:

- Lift the lower legs onto foundations separately, adjust onto pre-shimmed landing points and secure by bolting.
- Install a distance beam between the column tops, to obtain the tolerances for the interface to the A-frame.
- Finalize the bolting and grouting of the ground flanges, including the curing of grout and post-tensioning of thread rods.
- Lift in the upper A-frame by the chosen HLV, adjust, make up (by temporary bolting) and secure by wire stays to ground.
- Weld interface connection permanently and remove stays.

This approach is assumed to require the same HLV operation duration for A-frame up-ending and installation as for the base alternative. However, the split alternative eliminates any concerns about weight versus crane capacity. The lower legs are supposed lifted earlier by another (lighter and cheaper) crane vessel, for instance, a shear-leg barge type Taklift 4 (Smit Takmarine) or Rambiz/Gulliver (Scaldis). This class of vessels is available at much lower rates than the HLV/ SSCV type vessels.

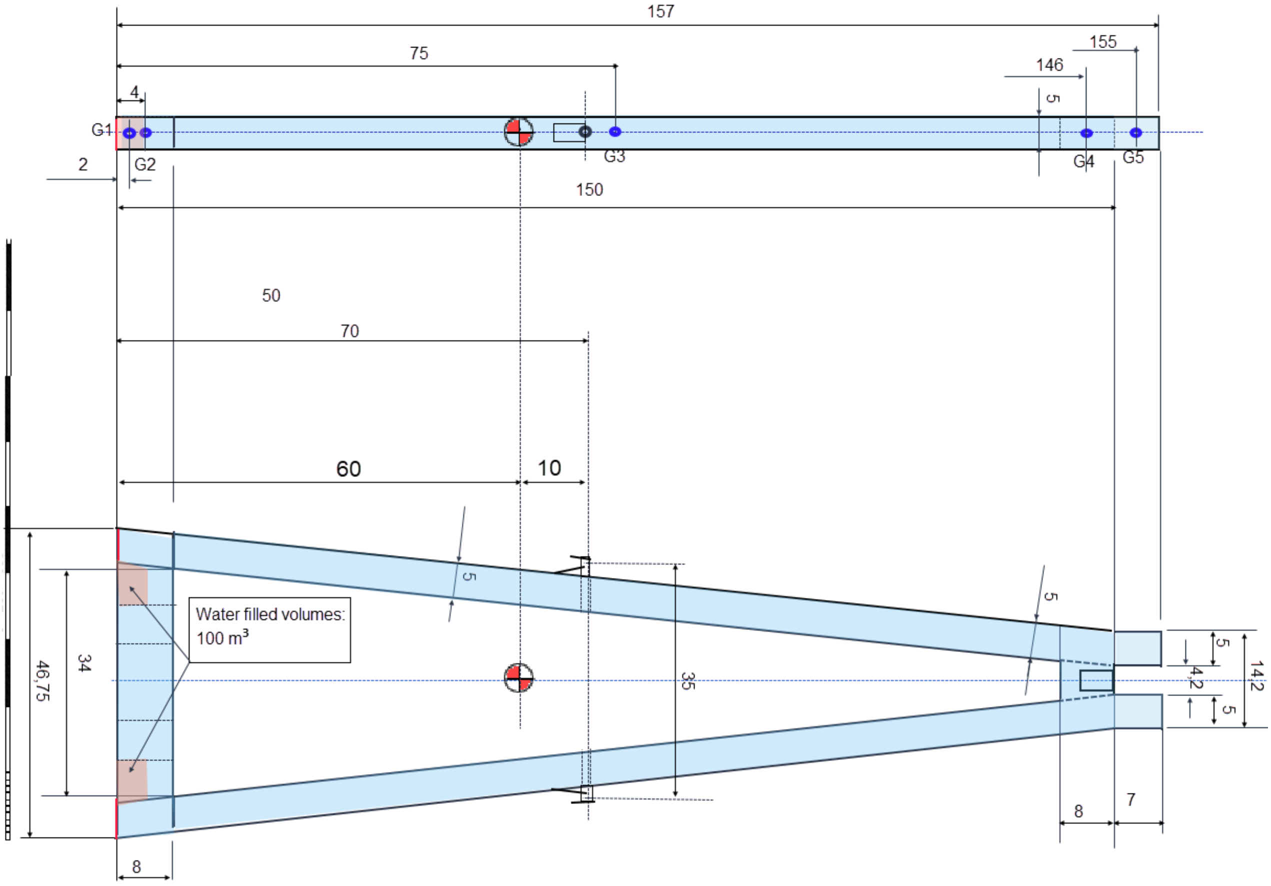

Figure 23: Illustration of split A-frame with new CoG location

When up-ending the upper A-frame from floating condition, the procedure will be very much the same as described in section 5.2, Figure 14 to 17. The concern of the interface between vessel pontoon and A-frame will be eliminated. However, it is required to increase the distance between the hook points and the A-frame CoG by some meters. Figure 23 shows how filling separate compartments in the cross beam by just 100 m^3 water increases the distance to the CoG to 10 m.

An advantage of the split frame concept is that the size and weight of the lifting trunnions might be reduced due to lower crane load (approximately 3500 t). The split A-frame allow a possible variation that could give a significant logistical advantage to the project. If the cross beam is integrated with the lower legs, and a temporary (distance) truss integrated with the A-frame, the lower columns and crossbeam can be installed as one integrated section. The resulting weight is not exceeding the capacity of available shear legs. When installed, the building of the viaducts from the shore sides can be completed before the upper A-frame installation, allowing good access platform and “flying start” of the A-frame installation and further bridge building-activities.

For this modified alternative, there is one uncertainty to mention. To lower the CoG of the upper columns safely below the hook points, the temporary beams to hold legs at an exact distance must act as a yoke for water bags of necessary size and weight. Such bags are ordinary equipment used for load testing of cranes. The bags will be fastened eccentrically in order not to clash with the cross beam. The resulting tilt of the A-frame can be compensated by tugger winches on the HLV deck, pulling the hanging load to the vertical line. The water bags will pass in between the lower legs and stay active until safe interconnection bolting is completed and the crane un-hooked. The uncertainty consists of the risk for water bags puncture and overturning of the A-frame. This could be counteracted by using a multiple of bags, so that the bursting of one bag will not make the heave unstable. The concept is shown in Figure 24, applying 4 water bags (4 x 250 t) to bring the CoG 10 m below the lifting trunnions. The weight of bags might be significantly reduced if lifting at transit draft is agreed by the HLV operator. Flooding of 10 to 15 m of the legs on each side could be evaluated as an alternative.

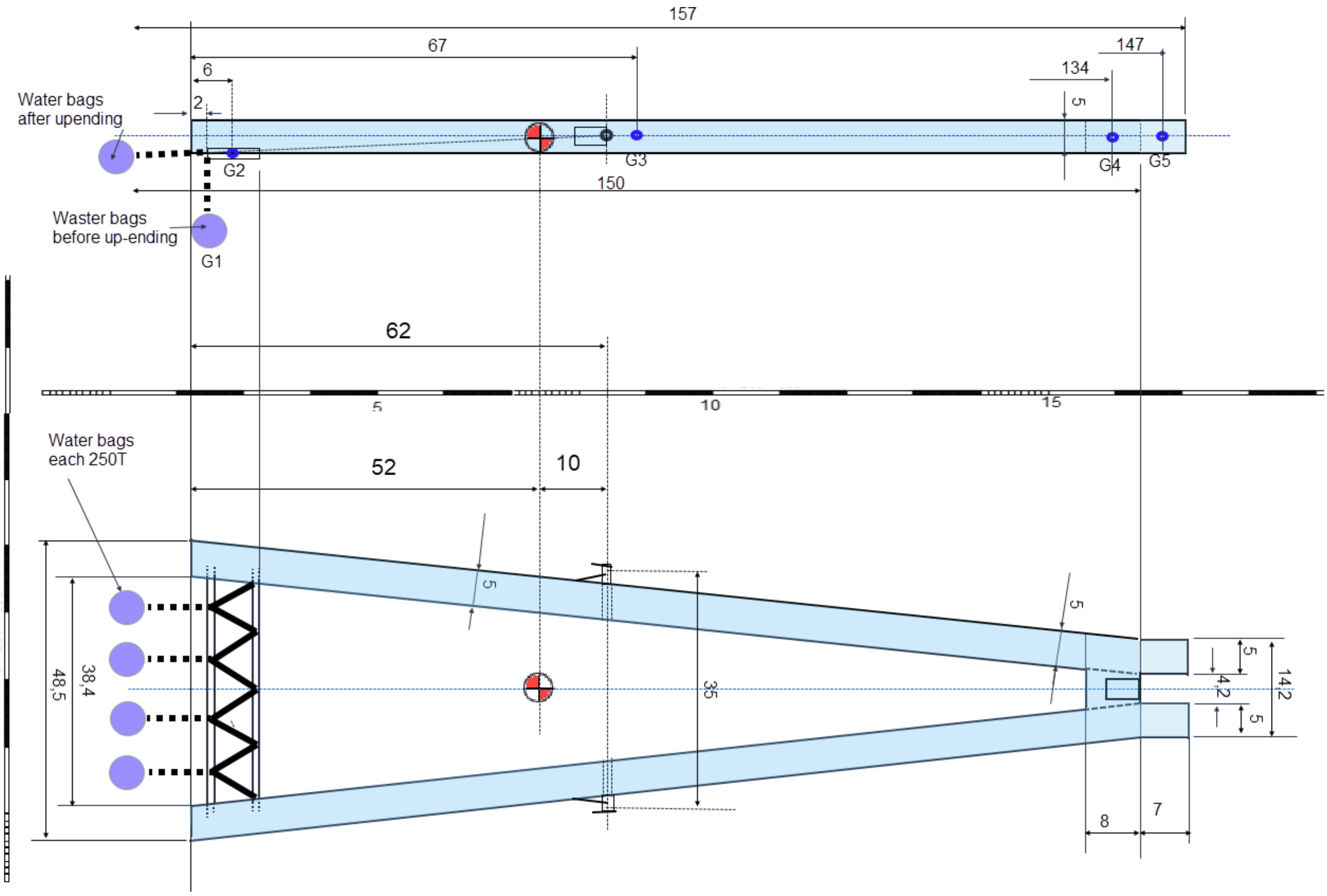

Figure 24: The split A-frame with temporary cross beam and 1000 t of temporary counterweight applied

5.5 Requirements for personnel access to installation locations

The organizing of installation activities of the A-frames and the follow-on activities is considered to benefit from good access and certain storage areas. Both locations at Jektevik and Hodnanes are located close to the shore, and without existing access road, so it natural to look for good access from the seaside. At Jektevik there is however a close distance to the ferry quay and parking facilities, so it is natural to look for a possible utilization of this capacity.

In onshore projects combining civil and heavy mechanical/ structural installation, it is normal that the civil activities are prioritized in the first phases, and when the Civil 1 phase (in-ground foundations) is over, the established areas are disposed of by both trades.

For a Mechanical /Structural contractor, it looks preferable to serve the activities by a service barge close to the pylon foundations. Such barge will give space for workshop containers, tool storage, lump rig for a limited staff (15 to 20 persons), and so on. Since a similar barge is needed at both locations, but staggered by a week or so, it is possible for the mechanical contractor to use one barge and to shift mooring position over night. However, a service barge is assumed to be useful or required also for the civil contractor, and could be dimensioned to the needs of both contractors. The ferry quay at Jektevik itself is quite busy, as it is occupied for 21 ea. departures per day. Due to the length of the ferries, the adjacent old ferry ramp is blocked and cannot be used, shown in Figure 25.

As a rule of thumb, civil contractor normally demands more than three times the actual installation areas to be used for storage of rebars, gravel/sand, rock, machinery park, and so on. The figure shows the pylon installation foundation and two viaduct pillars 70m apart. The overhead contour of the elevated viaduct is also marked in. Due to the close location to the quay and parking areas at Jektevik, it is assumed as a large potential for rational logistics that the terrain near the pylon foundation is flattened for storage and access from the sea, and that a short road connection to the ferry quay area is established. Figure 25 indicate such area in brown, including filling the small bay Koven by masses excavated in the project.

At the elevated area shown in grey, there is a small area flattened for road service purposes. This area could be expanded (at elevation +22-25) for mainly civil purposes. The photo in Figure 26 also indicates areas that might be hired or made available by NPRA for the project. These are just proposals for evaluation by the civil discipline.

Figure 26 gives a brief assumption/proposal for suitable facilities at the Jektevik site.

At the NE Hodnanes side, the access to the foundation close to the shore is much more restricted. It is assumed that civil contractor will define the necessary access requirements for the excavation and foundation works, and temporary facilities established is presumed also available for the mechanical/structural contractor. For the mechanical works, a proposal for a suitable arrangement which is not depending on a connection road is included in Figure 22.

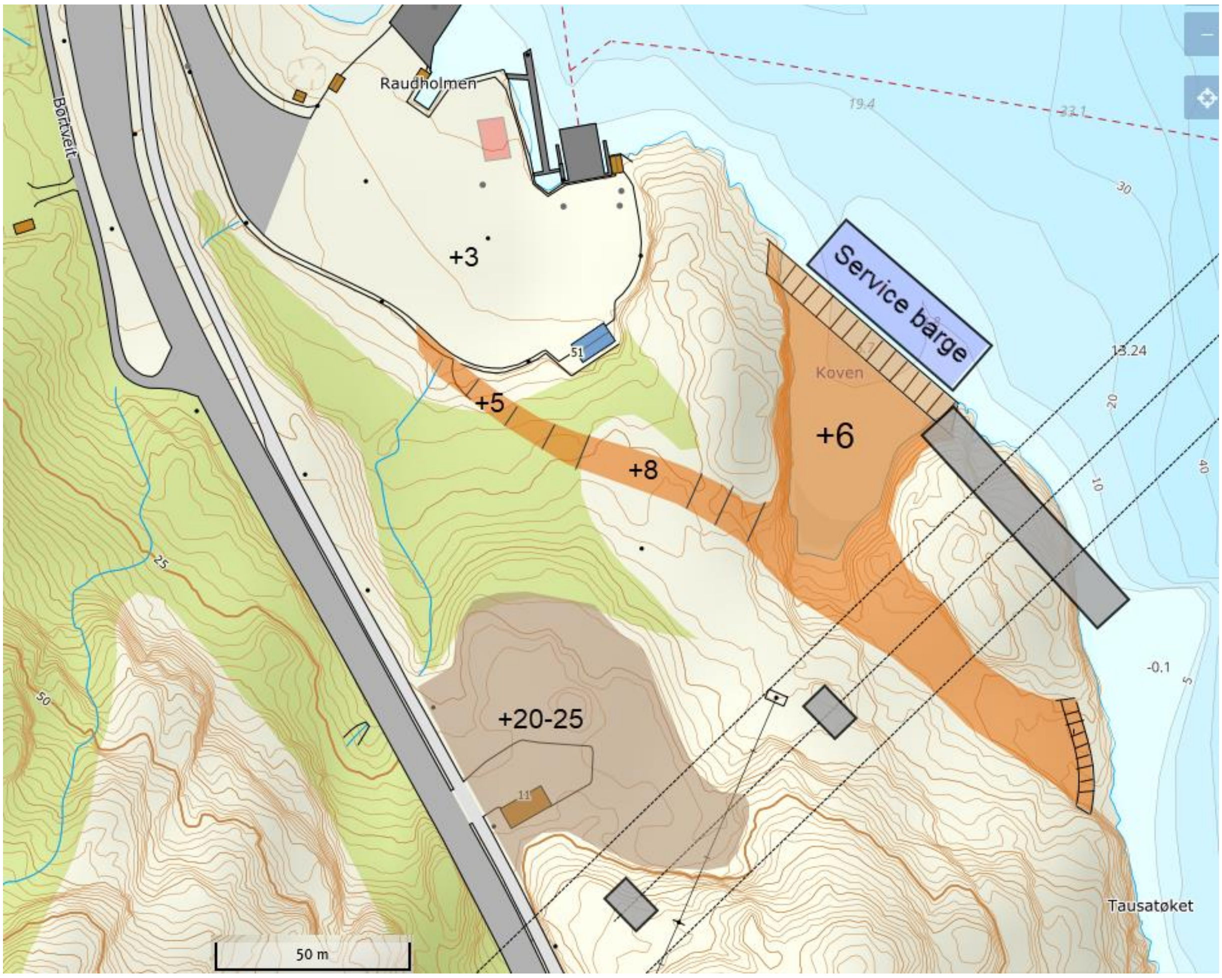

Figure 25: Proposed installation location facilities at the Jektevik in the southwest location

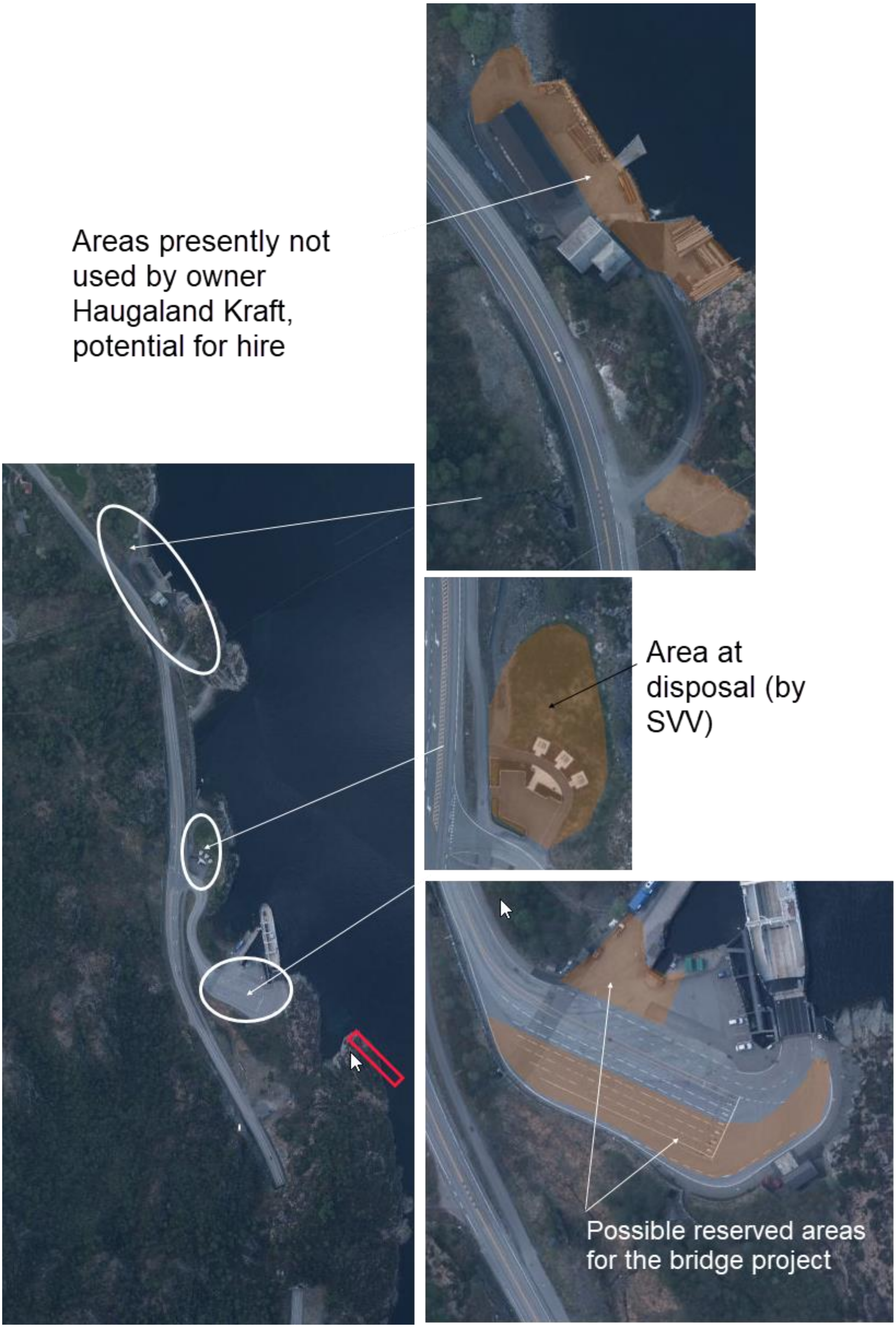

Figure 26: Areas potentially available close to Jektevik

5.6 FOLLOW ON ACTIVITIES AFTER LIFTING

Upon A-frames set-down, securing of pylon stability and release of crane slings, several mechanical/ structural activities are supposed. It is considered that a handover date of the pylons will be defined as “Ready for start pulling suspension wire strands over Langenuen”. In general, the main method proposed is that the cross beam and upper A-frame above should be fabricated and outfitted internally as complete as possible, including the lift trunk or tracks, cage and machinery, as well as internal cables, and so on. Full protection against water intrusion during the tow and up-ending should be arranged. Follow-on activities which are expected are:

- Freshwater wash down of lower leg internals, due to salt residues. The need for surface protection from the fabrication stage is to be defined. This is considered to require building of scaffolding towers, at least up to the cross beam. If the bottom bulkhead is not removed before up-ending, or a horizontal bulkhead is established at an intermediate height (for balanced up-ending), these shall be removed as necessary.
- Final grouting under bottom flange surface by expanding concrete or epoxy-based mastics.
- When grouting is cured, perform final tensioning of foundation thread rods.
- Removal of external bumpers and guides, and paint touch-up.
- If required: Remove lifting trunnions externally and internally by davits at column tops, and use of Access Technique, including touch-up.
- Establish/ re-establish the tower access lift trunk in lower legs.
- Install electrical cables and instruments as defined by Bridge Builder contractor.
- Dismount scaffolding and cleanup.
- If required: Establish a system for dehumidification driers in upper and lower legs, to operate automatically after sealed hatches are opened.
- Any other activities as defined by the contract.

For the alternative split A-frame, shown in section 5.4, the follow-on activities should cover detailing the connection, including bumpers and guides, securing by wire stays, and method of connection by welding or bolting. For the split A-frame concept the requirement for salt washout cleaning will be minimal.

6 METHODS FOR PYLONS FABRICATION

In general, the preliminary designs of the Langenuen pylons are challenging more by capacity than by technology or facilities. Many fabrication items consist of panel production in heavy plates (25 to 40 mm) with longitudinal and transversal stiffeners. Standard weld bedding and high output semi-automated welding portals are ideal for the work. In general, this fabrication can be adapted to any steel shop facility of a certain size both domestic and abroad. With one contractor for minimum construction and installation of both pylons, the possibility to compensate lack of in-house capacity with subcontractors of fabricated panels or volume sections. Good possibilities for establishing a comprehensive bidders list should be present.

In this chapter conditions for both domestic and foreign construction are discussed. It is unclear how the delivery time of the finished A-frames will influence on the total project plan, including the road tunnels and interconnections at both sides of Langenuen. Due to the extensive scope for the civil infrastructure, it is assumed possible to accept a delivery time from contract to lift-in approximately 10 to 18 months, without affecting the logistics of the project master plan. The gain for the steel alternative will consist in that the pylons fabrication is performed in parallel with the civil 1 works (including infrastructure and foundations), instead of in extension of such work, as necessary for the reinforced concrete alternative. Therefore, a multidiscipline project master plan should be established to define the preferred lead time for the pylon fabrication and installation. In addition to not exclude tenderers that might be competitive based on more conventional fabrication methods and/or long transportation time.

6.1 POTENTIAL FABRICATION WORKSHOPS, DOMESTIC AND FOREIGN

As part of the screening of the steel pylon alternative contra the reinforced concrete concept, a simple evaluation of potential Norwegian bidders for delivering complete pylon structures afloat at the up-ending site is done. For foreign deliveries, no qualification restrictions are discussed, as mainly the restrictions and cost for transportation and loading/offloading are relevant for comparison.

6.1.1 POTENTIAL NORWEGIAN TENDERERS

A full screening of Norwegian tenderers regarding all relevant matters of facilities and qualifications is not performed but will be natural in a Tender Prequalification phase. A primary qualification may be the access to a drydock large enough to assemble most volume sections of the pylons before bringing the assembly afloat. In Norway, there is no dock available at present that can take the full length and width of the studied pylon in one piece. However, there are at least three docks within quite short distances to Langenuen, from where the transportation of the pylons in floating condition is regarded feasible.

When performing this evaluation, the ability to assemble the upper pylon including the cross beam as one unit, and the lower legs as two separate units were considered, as none of the identified docks are large enough for the complete pylon assembly. The three locations identified are:

1. **Semco Maritime- Hanøytangen** (Dock dimension: 125 x 125 x 17 m).

   Strengths:

   - Regarded large enough for assembling both upper pylons simultaneously, and the lower legs apart, ready for the out-docking operation.

- Available inshore locations for assembling complete A-frames by use of cofferdams.
- Inshore towing route to up-ending site.

Weakness:

- Not own prefabrication capacity for steel sections.
- No dock crane of adequate capacity available, but a driving ramp down to dock bottom allows receival of large steel sections over the quay.
- The dock might be busy as a site for rig maintenance projects.
- The site might be used in a partnership with domestic or foreign fabricators of steel sections/part assemblies, to offer complete pylons.

2. **Kværner- Stord Yard** (Dock dimension: 165 x 83 x 7.3 m).

   Strengths:

   - Easy dock operation. Full dock crane coverage to 1050 t. Own internal transportation capability up to 1000 t.
   - High expertise and capacity for semi-automized fabrication of panels. Comprehensive experience in fabrication and assembly of structures for offshore use.
   - Large assembly halls for optimal indoor fabrication. Established good relations to subcontractors in Poland, to increase their own capacity.
   - Comprehensive marine experience and experience with- and available inshore locations for assembling complete A-frames by use of cofferdams.
   - Short towing route to up-ending location.

   Weakness:

   - Assembling both A-frames in dock simultaneously will require certain modifications of the dock.

3. **Aibel, Haugesund** (Dock dimension: 283 x 46(44) x 8.2 m).

   Strengths:

   - On the condition of a slightly slimmed design (max A-frame width 43 m under the cross-beam), both upper frames and separate lower legs may probably be placed inside the dock simultaneously, and out-docked in one dock flooding operation.
   - Own capacity for steel sections fabrication. Own yard in Thailand for low-cost supply of steel assemblies (or complete pylons).
   - Large assembly halls for optimal indoor fabrication.
   - Semi protected but a feasible route to the up-ending site exists.
   - Comprehensive marine experience.

   Weakness:

   - Per the studied design (Figures 8 and 9), the dock is approximately 3 m too narrow. It could be made feasible if the A-frame is modified equivalently, or a part of the A-frame flanks are made as part of the separate lower legs (This will increase the work scope in a cofferdam).

- Only 50 t cranes over dock- heavy sections to be placed by shear leg/trailers.
- Somewhat restricted harbor space for A-frame assembling afloat.

These three locations are all considered capable to qualify for parts- or full supply of the A-frames.

6.1.2 POTENTIAL FOREIGN TENDERERS

Based on experience in the market for supplies to the oil & gas market, foreign suppliers are in most cases synonymous with the Far East (Korea, China, Singapore) or the Middle East (Dubai). Many of these suppliers/ yards in these regions have the required production capacity, experience, and facilities for delivering steel structures. It is also highly likely that the rates per ton offered by many of these suppliers are low compared to Norwegian or even European companies. In the last decade, many projects have seen a big escalation due to a lack of expertise to handle the complexity mostly related to the mechanical, piping, and EIT disciplines. The total cost of the projects has therefore seen increases even beyond the price level from Norwegian tenderers. In this project there is expected to be a low content of the “white trades”, and there should be less reason to doubt the deliverability of pylons from foreign tenderers, both in terms of delivery time, quality, and cost escalation.

However, one factor which is highly real for comparison is the method to be applied for transportation from the yard to the up-ending site. In this study, it is assumed that the A-frames should not be transported as wet tow as proposed for the Norwegian alternatives. This is due to the experienced high accelerations and worst sea states to be used for overseas transport. This should be a matter for more investigation in a later project phase.

For foreign fabrication alternatives, the following main methods are assumed realistic:

Method 1:

- Onshore assembly to full length and completion.
- Lifting- or skidding onto the deck of transport barge or ship. A semi-submersible heavy transport vessel (SSHTV) might be more expensive than ordinary ships. To avoid double transport, pylon 2 to be lifted on top of pylon 1, associated by proper grillage and sea fastening.
- By arrival at Bømlafjorden, the hired in HLV/SSCV lifts off the two pylons (one by one) and continues with up-ending by the auxiliary hooks.

Method 2:

- In principle, a foreign supplier can fabricate the same type of preassemblies (200 to 1000 t) for supply to an assembly yard (for instance Hanøytangen) if a partnership is established.
- The transportation from the yard is then possible to perform with a smaller ship, more limited by deadweight only than by deck space.

6.2 Proposals for fabrication friendly design

In section 4.3, the updated and preliminary verified design concept is indicated with 5 to 7 longitudinal stiffeners on the inside of the columns skin plates, 7 ea. stiffeners in the lower leg sections, and 5 in the upper legs. For efficient fabrication of panels, it will have an impact if the longitudinal stiffeners are parallel to each other, and that the stiffener nearest the panel edge is terminated on a horizontal frame (approximately 3 m apart) when the panel width is narrowing. This may make double-sided welding possible without intermediate installation and fixing of the next stiffener. The ideal procedure will be to preposition (and tack weld) all longitudinal stiffeners simultaneously, and after welding install all cross stiffeners. The panels flatness must be secured by solid hold-down fixtures to the weld bedding during welding, panel turning, and local flame heating to eliminate buckling, and the installation and fixing of cross stiffeners.

Another matter for efficient fabrication is the choice of weld types. For the stiffeners, it is expected that double-sided fillet welds or part pen welds are adequate. Full pen welds will be required for all plate splices and the corner welds. Final detailing of this is supposed concluded in detail design when optimization of dimensions and stress levels at all locations are concluded.

Besides the matters mentioned here, it is generally advised to search for implementation of the fabricator's own method proposals, which can be of major importance to adapt to the yard facilities and production expertise.

6.3 In-house assembly of volume sections

Established fabrication yards normally have available assembly halls suitable for assembling and testing large modules or pre-assemblies. Such facilities used for modules and topsides for the oil & gas industry are usually quite potent about dimensions, crane capacities, door openings, available in-house transportation equipment, and so on. The logistical conditions in such facilities are normally ideal and advantageous compared to outdoor assembling. However, for mainly steel section assembling (often called the Black Box approach), outdoor assembling might be cost-effective and adequate, if the climate conditions allow it. In Norway, indoor assembling is established as the norm both for weather protection as well as for optimal HSE conditions and for personnel and material logistics.

Assembling of four panels to a volume section can be done on a weld bedding with the starting lower panels placed on supports approximately 1.2 m high. At this height, the volume section can easily be picked up by SPMT's (self-propelled multi-wheel trailers), and moved to surface treatment shops and further to the pylon assembly site. There is no question about the general feasibility of such steel section assembly.

In-house painting facilities is recommended as a must since the external side of the pylons potentially shall stand the weather conditions at Vestlandet for the lifetime of the bridge. It is therefore assumed that the right step for surface treatment is after completed volume section assembly, when such treatment can be done in-house in specialized surroundings and climate control. The interface weld zones will be masked off for painting after complete pylon assembly.

Specifying a maintenance-less paint system for the entire lifetime of the bridge itself (potentially up to 100 years) seems unrealistic and planning for a general maintenance and repair program is rational. A means to significantly reduce the challenge of maintenance in areas with restricted accessibility is to install a grid system of small scaffolding lugs. These have been proven very useful for climbers and scaffolders during maintenance at locations as tall masts, high crane pedestals, under the deck of semisubmersible rigs, and so on. One special measure used for extreme surface protection used offshore is metallization, which often is specified on underdeck surfaces of rigs. A full system including an adapted intermediate and top paint system increases the required inspection and maintenance intervals significantly.

Performing surface protection under outdoor conditions may reduce the quality of the surface protection, and lead to future huge costs for maintenance if not subjected to adequate quality control. Key factors are to obtain sufficient SA grade during sandblasting and control of humidity versus temperatures during application and curing.

Internally in the pylons, it is assumed that the shop primer from the steel supplier is kept, but painting not made part of the specification. It is proposed that the column voids are protected purely by sealing the openings for access to the lift shaft (or ladders) and the exit doors at the top, in addition to one or more dehumidifiers. The automatically controlled air drier will ensure that every time a door is opened for inspection, the drier will run until the humidity is brought down under a critical value. This system is frequently applied in the offshore business, for instance, to eliminate corrosion inside double bottoms or MSF box girders, where access is required for rare inspection purposes.

A major requirement for efficient preassembling is the high accuracy of physical dimensions, controlled by qualified procedures, equipment, and personnel for dimensional control. In critical interfaces like the foundation flange and installation guides, the surfaces are recommended scanned in 3D for accuracy within an mm scale.

6.4 ASSEMBLY OF COMPLETE PYLONS

Earlier in section 6.1 different approaches for assembly of pylons were indicated, based on the availability of a large dock. At Aibel Haugesund the dock width and at Kværner Stord and Semco Maritime Hanøytangen the dock length prevents the complete pylons to be completed in the dock. At Aibel the dock is about 3 m too narrow, but since the physical dimensions of the A-frame are not settled, the alternative is proposed “kept warm” until further. If the dock should be inaccessible for one of the tenderers, it is possible for them to assemble the pylons onshore near a deep-water quay, and to combine lifting into the sea by the contracted Up-ending and Lifting Installation Contractor upfront of the up-ending. Kværner has, for example, two potential quays near locations that can be used for load-out with the HLV in transit draft. However, such an arrangement will depend on the type of contract defined by NPRA, regarding combined responsibility for fabrication and installation.

The basic concept for assembling complete pylons is to fabricate and assemble the upper A-frame and the lower legs separately, and to perform assembling of these three parts in self-floating condition. The splice should be located just below the lower side of the cross beam, shown in Figure 12 earlier. When all parts are assembled in the dock and internal splices completed and touch-up performed, the dock will be flooded and the lower legs towed and ballasted into an accurate mating position against the A-frame.

To bring the lower legs afloat implicates that the end openings are equipped with a temporary bulkhead from the lower side to approximately middle height. However, risk assessments might conclude that the bulkheads should be made at full height. In the mating end, the bulkhead shall be located a meter or so apart from the splice, in order to give space for welding when the cofferdam is placed and emptied. A rough estimate of the A-frame and leg buoyancy shows that the draft will be approximately 2 to 2.5 m only, so the internal bulkheads do not need to cover the full cross-section. To arrange a cofferdam at 2 m depth is considered fully safe and feasible.

The A-frame and the legs should be accurately guided by external guide plates and stopper plates so that when some temporary holding bolts are tightened (underwater by divers), the legs will reach the exact target position in line with the upper A-frame. If necessary, a section of the leg should be trial installed against the interface, in order to exactly shim the contact points. The upper A-frame should not be water-filled in order to avoid salt contamination and requirements for cleaning and drying out. The lower legs should be marginally ballasted to match with the draft and alignment with the upper frame. The operation is proposed performed with the upper frame inside the dock and the legs pointing out of the dock. Upon completed mating and connection by bolts, the joints are recommended full pen welded and subjected to QC. When complete measurement control is performed, the bucket and pins and bolted connection brackets are cut off, and paint touchup performed.

The access to the underside is possible by a conventional cofferdam, like the type used for ship hull extension in the former ship era. No complexity is foreseen to execute such operations, subject that accurate tolerances are applied in the mating interfaces. Upon completed mating, the temporary bulkheads (in the mating end) shall be removed. The bulkhead in the lower end must be made in such a way that it can be easily removed when the legs are being flooded. The bulkhead should be designed so that it is kept in place against the sealing face by the external water pressure. When the legs are water-filled, the release will be done with a minimum of force. A flotation tank could be attached to the upper panel edge to make it buoyant when released, and simple to pick up from the boat.

Generally, the method to mate the A-frame and lower legs in floating condition is considered fully feasible and offers a solution for efficient utilization of the docks identified in the Rogaland/ Vestland region.

6.5 FACILITIES AND EQUIPMENT FOR FABRICATION AND ASSEMBLY

Figure 27: A modern welding portal of the size needed for column panel production

In general, the fabrication of the complete pylons is conventional steel structure production. The main fabrication will be panel lines for efficient splicing by welding and installation of longitudinal and cross(web) stiffeners. Generally, to match the scope of a total of 8000 to 9000 t steel both large production halls and specialized panel lines with semi-automatic or robotized equipment will be needed. It is considered that for Norwegian yards an investment in automized production equipment to maximally improve productivity, quality, and competitiveness for this project as well as for similar future projects will be focused in a tender phase. It is regarded that automized fabrication with a minimum of manhour consumption per ton will compensate for the low hourly rates applied in low-cost countries. Together with reduced transportation costs a Norwegian content in bridge construction might become fully competitive.

Kværner has recently put a new panel line into duty, with a portal rail width of 11 m. The effective operation width is 9 m. The picture in Figure 27 shows a setup for box girder production. The welding machines are of type SAW (submerged arc welding) using DC (direct current) with a high heat output and weld deposit (2 x 15 kg/hr), which for some purposes generates some shrinkage and plate buckling. This can be minimized by moderate strings in the first pass, and intermediate turning/flame heating from the backside to straighten up. Other types of welding techniques are evaluated but found less efficient than the SAW process. However, the use of AC (alternating current) may increase the output to some degree. Per date, the output of welding sources is limited to 1000 A. No welding machines above this output are presently available on the market.

In this study, the material quality of choice is the S420 M/ML grade based on the steel columns for a concept developed for a suspended bridge over Bjørnafjorden as mentioned in section 5.3. It is recommended that the choice of material quality should be carefully considered as the final material choice for the bridge pylons will be of importance regarding qualifications to tenderers and their choice of equipment. Suppliers to offshore projects in Norway are familiar with the offshore quality 420 steel according to Norsok norms, which is also a high strength steel. This steel requires a very moderate tempering only, for thicknesses up to 50 mm. In contrast to S460 M/ML which is a material quality that requires up to 200°C preheating. Lack of preheating will result in micro-cracks, and a higher focus on quality control (QC) and documentation. Preheating- for instance by inductive “hose/band type heaters” requires more manual work to handle and will affect manpower consumption factors (mhrs/t) significantly. However, preheating may reduce the tendency of plate buckling to a certain degree.

Also, to achieve efficient panel lines and assembly halls, suitable cranes and transport devices are required for the fabrication. The length of box sections that can be turned, manipulated and transported will normally set the length of panels from prefabrication. The larger the volume sections can be delivered from prefabrication, the more efficient the A-frame assembly and touch-up can be performed.

Generally, there is no strong reason to disqualify a tenderer based on chosen fabrication methods, other than the results in terms of price and deliverability. High quality can be obtained also by more manual and conventional methods.

6.6 ESTIMATION OF DURATION FOR YARD FABRICATION AND ASSEMBLY

The available duration from start fabrication (plate cutting) to load-out will be of high importance to conclude the feasibility in terms of cost and construction time compared to reinforced concrete pylons. As a work hypothesis, it is assumed that the pylon fabrication and assembling can be performed in 12 months in parallel to civil preparations at site. In the full concrete alternative, the build-up of the A-frames cannot be started before the foundations and infrastructure are ready and might take about 6 months before completed to the milestone “Ready for suspension wire strand pulling”. Given that the steel pylon alternative can meet the same potential start date for tower building, the main advantage of the steel pylon may be the shorter time for tower construction and installation.

The shortest possible production time might be improved if a proper conceptual design and major strength calculations are done in a previous FEED phase, allowing the major steel plate thicknesses to be pinned. This will allow tenderers to place capacity reservations with the steelworks based on established Frame Agreements on the condition of receiving contract award. Large suppliers in the offshore industry have offered durations down to 2 months from order to delivery of first batch of plates. Such arrangement will improve the steel alternative compared to slip formed concrete.

For tenderers to be able to decide the available/ preferable yard throughput time, it is recommended that a Master Plan for the whole Langenuen Bridge and road connections are developed before a potential next phase of concept studies or FEED design. The throughput time is difficult to estimate without knowing the base material choice. As a preliminary estimate the manpower consumption factor (for direct prefabrication work) the Norsok standard 420 steel for the type of structures involved is 25 to 30 mhrs/t Should such figures be competitive, investment in new parallel panel lines with specifications for increased automatization could be of interest.

Shorter throughput time than 12 months could also be feasible, but hardly without setting out a certain part of the scope for panel or volume sections fabrication. The choice of steel material will also have significant influence on delivery time, which is was discussed earlier in section 6.5.

6.7 PYLONS TOWED AFLOAT

Assuming delivery from a local yard and an inshore towing route, the tow to the up-ending location is regarded feasible using two tug boats. The tug boats should be used for station keeping of the floating pylon until the HLV has started the up-ending and has established full stability of the structure. If the pylons are delivered from the Kværner yard at Stord, the tug boats can then revert to the yard to bring the second pylon to the up-ending site, while the first one is upended and brought to Langenuen for lift-in. Another alternative is to tow the first pylon to the up-ending location for anchoring upfront of the start up-ending, while the second pylon is gathered.

Before the tow, all arrangements for flooding the lower legs by water should be prepared, including an opening on the upper (deck) side to evacuate the entrapped air during the flooding. The main slings might be preferred by the HLV operator to be pre-installed onto the lifting trunnions and temporarily tied on top of the frame. The rationality must be evaluated against the requirement of installing a proper sling platform. The wet tow to the up-ending site might save costs for transportation compared to the use of a towed standard barge or submersible transportation vessel.

6.8 PYLONS TRANSPORTED ON BARGE OR SEMI-SUBMERSIBLE HTV

The transportation of pylons on a barge or semi-submersible heavy transport vessel (SSHTV) is considered realistic in combination with delivery from a foreign yard. In this case, a piggyback arrangement with the second pylon supported on top of the first one is assumed, subject that supporting grillage between the two items can be done without the need for welding attachments to the upper pylon. Any welding to the lower part of the pylons will require touch-up, which should be avoided because the repair cannot be performed before the pylon is installed, and with significant access challenges involved. Any repairs on the upper (dry) side of the pylons can be done before up-ending, if sufficient time before the operation is accounted for.

Upon arrival at the up-ending site, the HLV will lift off the pylons by use of the main hooks. It is assumed that the trunnions located for the pylon up-ending and lift-in can be used also for the lift into the sea. Lifting arrangement and gear suited for the second hook and at optimal longitudinal position must be arranged (Not studied in detail in this report). If a semi-submersible transport vessel is used, the second pylon can be floated off the grillage by submerging the vessel, and welded lifting lugs thereby avoided.

6.9 ALTERNATIVE TRANSPORTATION CONCEPTS

In case the transportation of completed pylons from overseas vendors is concluded too costly compared to other concepts, the transportation as straight volume sections limited to a 500-1000 t per item might be an alternative. The principle allows all the volume sections for both pylons to be transported on a single ship, subject that access to one of the potential local docks for final assembly of the pylons is agreed.

7 RECOMMENDATIONS FOR FURTHER WORK

Development of certain factors will improve the predictability and reduce the uncertainties in this project. The following subjects are recommended for further evaluation:

- Establish a multidiscipline Project Master Plan.
- Build a 3D design model, for more accurate weight and CoG calculations.
- Based on more refined weight and CoG calculations, recheck the up-ending calculations and installation feasibility.
- Based on improved data, perform an early benchmarking of the Concrete Pylon alternative against the Steel alternative.
- Approach the potential HLV Operators directly, to reduce the uncertainty of available data and information, like lifting capacity diagrams, minimum lifting draft, etc. Develop a 3D animation film to illustrate and prove the general bridge pylon installation method and sequences.
- In a potential FEED phase, integrate method engineering expertise in the development, including expertise from potential HLV operator(s).
- Evaluate different contracting strategies. Will separate contracts for fabrication, transport, lifting, and installation be chosen- exclusively for Pylons or combined with the bridge road box? Alternatively- is an EPC Bridge Builder contract planned?
- If a distance barge is considered preferable at the Jektevik installation site, specifications of the barge dimensions and shore fenders to be developed.
- Optimisation of A-frame design, such as the width of the A-frame at the footing. Explore the possibility of a slimmer design.
- Design necessary wire stays to secure pylons on foundation after lift-in and until final grouting and bolting to the foundation is completed.

8 ATTACHMENTS

Attachment 1 - Mime-no. 19/257825 “Oppdragsbeskrivelse- FoU-prosjekt Ferjefri E39 Brutårn i stål for hengebru over Langenuen”

Attachment 2 - Drawing “Alternative B- K10_001_altB” Langenuen Bridge

Attachment 3 - “Skisseprosjekt, bru over Langenuen og Søreidsvika”

Attachment 4 - Bjørnafjorden Suspension Bridge- K2 & K2 Design Summary

Attachment 5 – Structural analysis – RM Bridge