25 OCTOBER 2021
DANISH ROAD DIRECTORATE

STORSTRØM BRIDGE INVESTIGATION REPORT

WORK PLAN AND TIME SCHEDULE FOR DESIGN & CONSTRUCTION

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EXECUTIVE SUMMARY

A 4 km long combined road and rail bridge, Storstrøm Bridge, is being constructed between the islands of Sjælland and Falster. It is being built under a Design and Build Contract by Storstrøm Bridge Joint Venture (SBJV) for the Danish Road Directorate (DRD). The Contract was signed in early 2018, but the Project has suffered significant delays.

COWI North America Ltd. (COWI) was requested by the DRD to provide an unbiased assessment of the time schedule, on which the DRD has based their estimated timing for opening of the new bridge to road traffic and have it ready for installing catenary system for railway by second half of year 2024, and to advise on possible actions which could be taken to improve speed of construction and reliability of predictions.

In this study, the overall construction programme was reviewed with a fresh set of eyes, a site visit was conducted, DRD and COWI site staff were interviewed, the construction schedule was assessed by considering three scenarios, and suggestions on how to improve the schedule are provided.

This report covers:

- A brief description of the bridge (Section 2);
- Current state of design & construction and remaining work (Section 3);
- SBJV's design & construction schedule (proposed, updated, and actual) (Section 4);
- Site visit & observations (Section 5);
- Analysis of schedule for three potential scenarios (Section 6);
- Assessment of construction schedule going forward and recommended measure to improve the construction schedule (Section 7); and
- Summary & recommendations (Section 8).

In this study, three different construction scenarios are considered. Using the progress to date to predict the future is not meaningful as only a few precast segments have been produced and extrapolating their production duration would lead to an unrealistically long construction period. However, there is no doubt that it is feasible to increase the construction speed. It will take some time to ramp-up production and the production rate might vary depending on steps taken related to workforce and equipment. Considering all of these, the three scenarios considered in this study are:

- Scenario 1: Pessimistic case – slow ramp-up and slow progress.

- Scenario 2: Realistic case – ramp-up and progress between Scenarios 1 and 3.
- Scenario 3: Optimistic case – ramp-up and progress expected for a well-organized and experienced design & build team working collaboratively.

This study finds that if radical changes to construction are not implemented by January 2022, it will be unlikely that the new bridge can be opened to road traffic and that it will be ready for installing the catenary system for railway by second half of year 2024.

The radical changes might include one or more of the following (each would take some time to implement, hence, a decision needs to be made regarding which one(s) to adopt quickly):

- Adding a major international contractor with a large workforce (including workers, foremen, engineers, and management staff experienced in similar major bridge construction projects) and equipment to the SBJV team.
- SBJV increasing its own capacity with a large injection of workforce (including workers, foremen, engineers, and management staff experienced in similar major bridge construction projects) and equipment well beyond currently on site.
- Working on multiple fronts by switching to traditional in-situ construction for parts of the bridge.
- Adding one more precast girder production facility.

A significant investment by SBJV has been made in the prefabrication yard and the equipment. The segment fabrication facilities and segment installation equipment are appropriate for the project; however, they need to be utilized much more effectively than they have been to date. Even if the facilities and equipment are used effectively, it will still be very challenging to complete construction by mid 2024.

Completion of design, including design approvals, is not expected to be critical. It is recommended that SBJV be open to DRD's design improvement suggestions for increasing construction speed.

Additional measures are recommended to improve SBJV's operations and construction schedule related to the following areas (see Section 7 for more details):

- General Approach & Culture
- Planning & Scheduling
- Segment Fabrication
- Storage
- Offshore Operations

CONTENTS

1 SCOPE OF WORK

The overarching purposes of this study are:

- To evaluate the design and construction progress to date;
- To assess whether the bridge can be open to road traffic and installation of railway catenary system in the second half of 2024;
- To propose actions to be taken to improve progress of work in order to achieve the second half of 2024 completion goal.

The scope of work of this study includes, but is not limited, to the following:

- Analyse the remaining design and construction tasks to be performed.
- Prepare a work plan for execution of these design and construction tasks, assuming a speed of design and construction that can be expected from an experienced international bridge design & build contractor.
  - Identify factors that might be obstacles to realisation of this work plan;
  - Assess their likelihood and extent of delay they could inflict;
  - Propose actions to minimise the likelihood of these obstacles occurring; and
  - Identify possible mitigating actions to limit their consequences if they occur.
- Describe three scenarios and associated time schedules under these three different assumptions for speed of construction and evaluate the likelihood of each.
  - Assess the probability that the bridge will open to road traffic in the second half of 2024.
  - Describe three different scenarios leading to different opening dates. For each of these scenarios, assess their likelihood and describe assumptions and a justification.
  - Perform critical path analysis of the scenarios and identify the most critical activities in the time schedules.
  - Propose actions to improve progress of work on site.

Taking past performance into consideration when predicting future progress, the following activities are performed:

- Analyse previous Work Schedules and past performance of SBJV on the project.
- Analyse causes for previous delays and slip of the programme, including assessing the effect of mitigation actions taken and/or not taken.

2 PROJECT DESCRIPTION

2.1 Storstrøm Project

The overall Storstrøm Project comprises (see Figure 1):

- The new Storstrøm Bridge, an approximately 4 km long combined bridge with a double-track railway, two-lane carriageway, cycle track and footpath;
- Lowering of existing railway on Falster;
- Embankments on Masnedø and Falster;
- Roads and paths with related drainage;
- Minor Underpasses and a roundabouts; and
- Demolition of the existing Storstrøm Bridge.

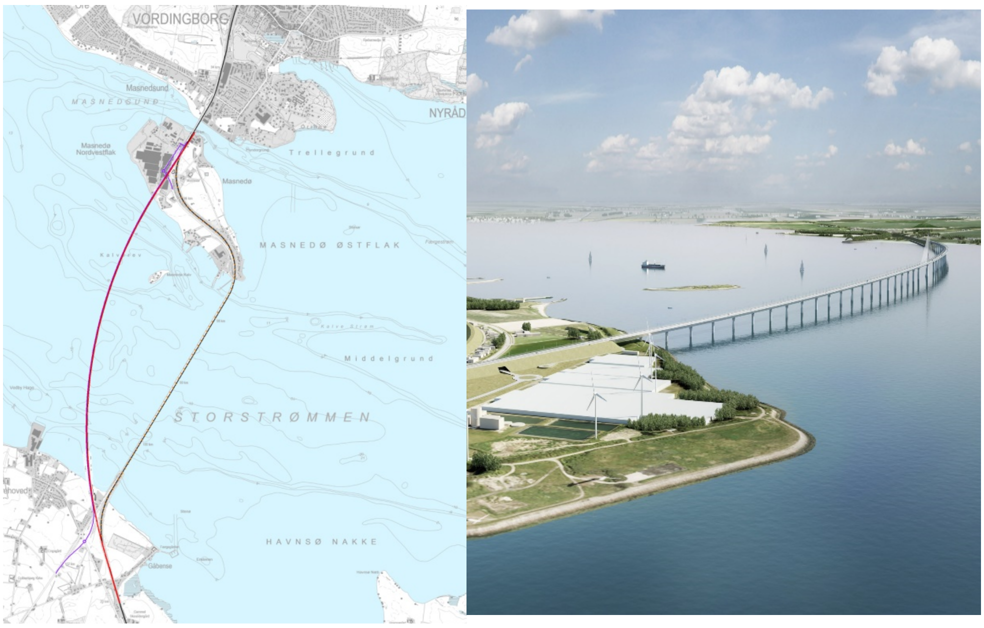

Figure 1 - Storstrøm Project

This report focuses on the design and construction schedule for the new Storstrøm Bridge. The schedule for the other components of the Storstrøm Project is not on the critical path and hence are excluded from this study.

2.2 Storstrøm Bridge

The bridge is a concrete box girder bridge and has a total length of 3,832 m, see Figure 2. The bridge comprises a central main cable stayed bridge (CSB), connected to land by two approach viaducts. The cable stayed bridge has two 160 m long spans over the navigation channels. The south viaduct has 23 spans of 80 m with a total length of 1,840 m. The north viaduct has one span of 72 m and 20 spans of 80 m with a total length of 1,672 m.

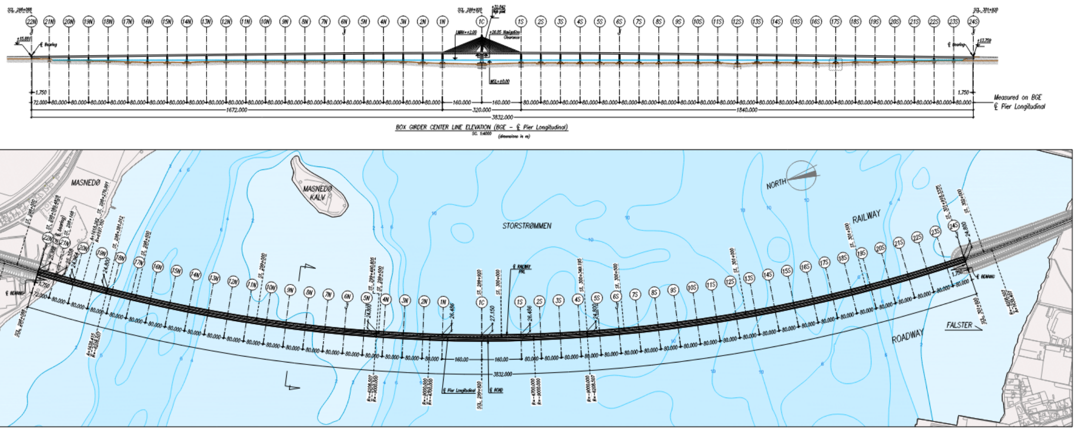

Figure 2 – Bridge Plan & Elevation

For the areas close to Falster and Masnedø the foundations and piers 23S & 22S and 20N & 21N are constructed in-situ by means of a temporary causeway. The remainder of the pier foundations are precast concrete elements. There are three defined types of precast foundation ranging in plan dimensions of 12m x 19m to 20m x 20m, see Figure 3.

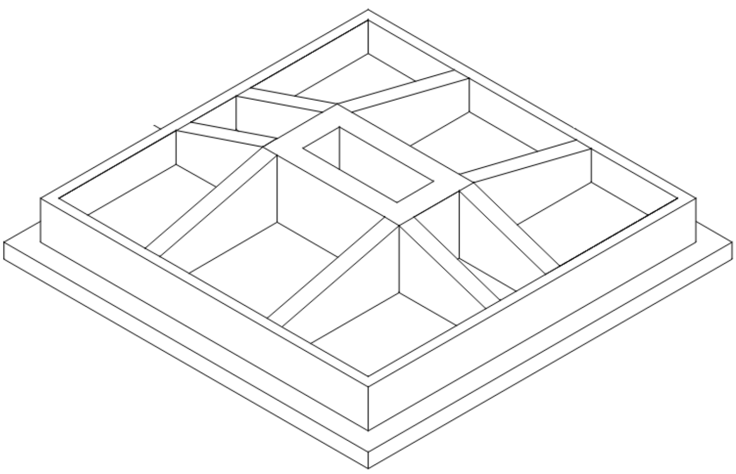

Figure 3 – Typical Precast Foundation

The first few bridge piers and pier heads are constructed using precast pier segments connected to each other using 0.8m tall cast in place "stitches". The later piers are constructed using a jump-form system for the lower pier, precast pier segments connected to each other using 0.8m tall cast in place "stitches" for the upper pier, and then the pier head H1 is cast in-situ. See Figure 4 for the later pier construction.

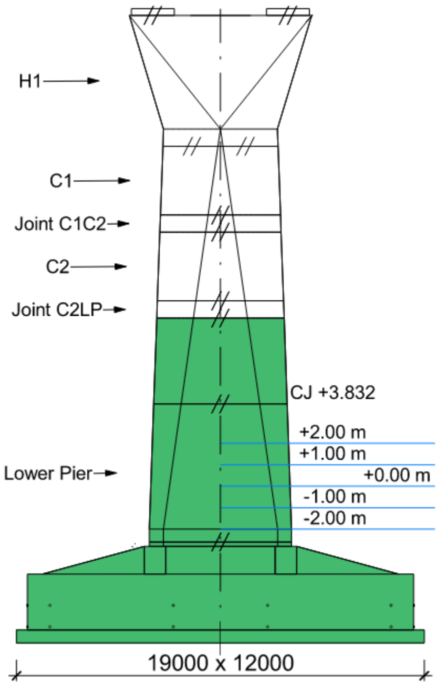

Figure 4 – Precast Pier Segments and Stitches

First two girder spans of the south viaduct (24S to 22S) and first two spans of the north viaduct (22N to 20N) are constructed over land and/or temporary causeway using cast-in-place concrete on falsework. The remainder of the spans are constructed using precast superstructure elements, see Figure 5.

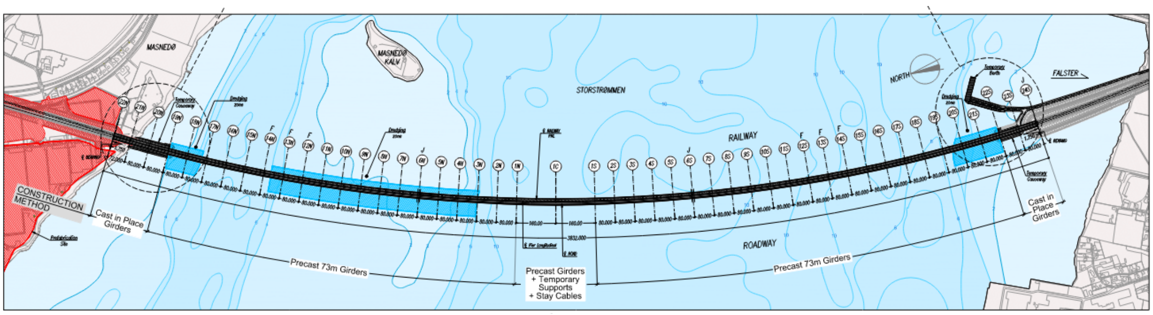

Figure 5 – Bridge Span Lengths

The cable stayed bridge pylon foundation 1C is precast. After the foundation is placed in the channel, the pylon is constructed using cast-in-place concrete methods, see Figure 6.

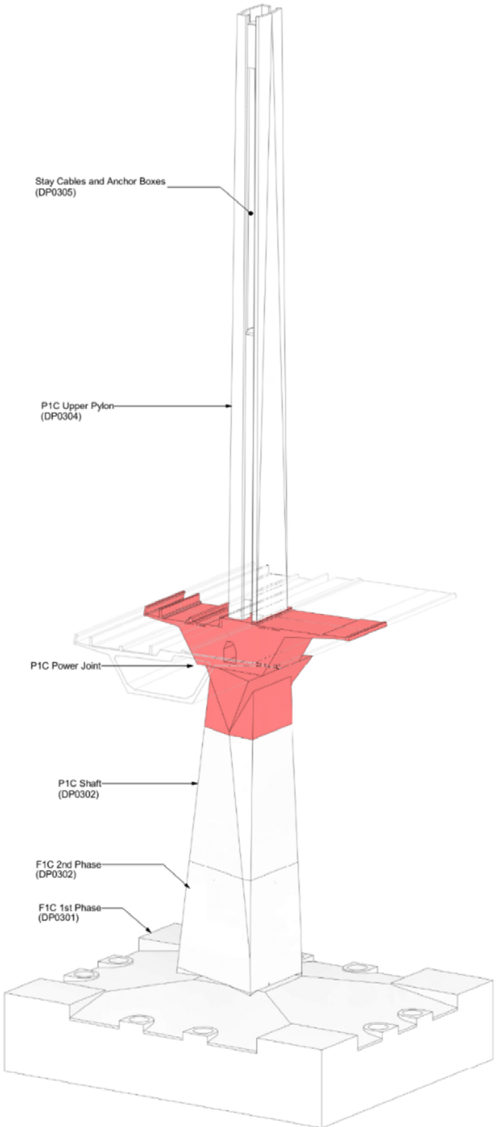

Figure 6 – Precast 1C Foundation and Cast-in-place Pylon

The cable stayed bridge superstructure spans (1C-1S and 1C-1N) comprise precast girders that are erected on temporary piers, see Figure 7. Once the pylon is complete and the girders have been positioned, the stay cables are installed and stressed.

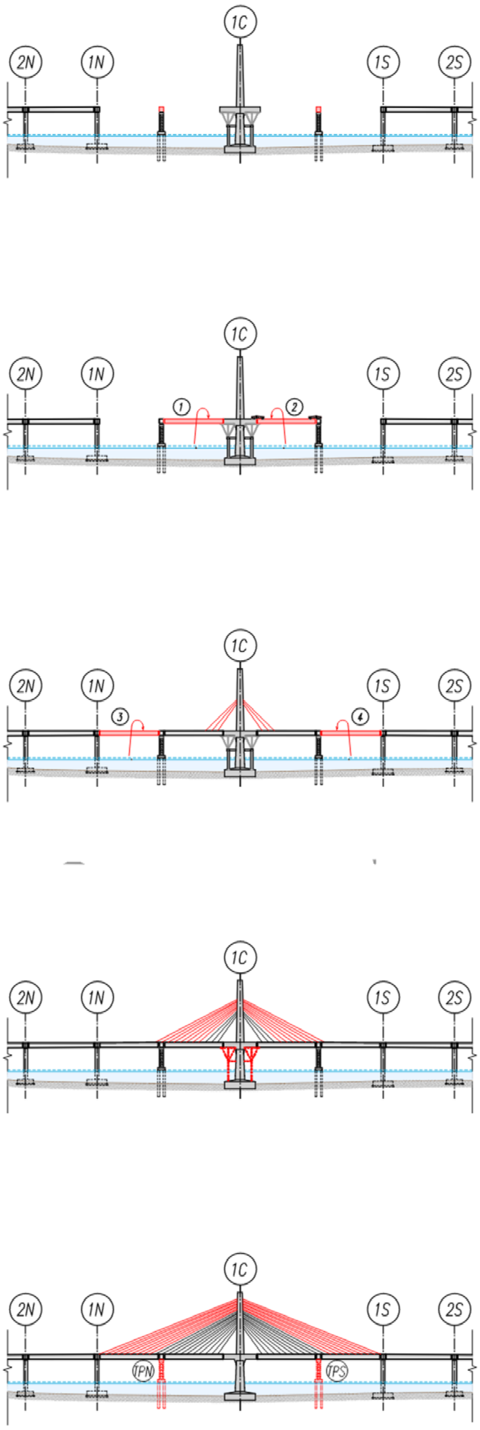

Figure 7 – Main Cable Stayed Bridge Construction

3 CURRENT STATE OF DESIGN & CONSTRUCTION AND REMAINING WORK

3.1 Key Dates

The key dates related to the Storstrøm Bridge design and construction are as follows:

- Contract award – 26 February 2018
- Supplementary geotechnical investigations were completed early 2019
- Basic Design completed February 2019
- Detailed Design is currently underway
- Contractor mobilization on site – October 2018 (start of earth works for yard)
- Prefabrication yard construction – October 2018 to March 2020
- Start of precast segments:
  - Precast pier foundations February 2020
  - Precast pier segments July 2020
  - Precast girders November 2020
- Start of cast-in-place foundations & piers:
  - South viaduct - F23S December 2019
  - North viaduct – F21N March 2021
- Start of cast-in-place spans:
  - South viaduct November 2020
  - North viaduct Not yet commenced
- Start of precast 1C foundation June 2020

The project had a slow start. For example, it took about 2 years from signing the contract to casting first precast foundation bottom slab (for 21S), which should have started on 2019 March (delayed by 12 months).

3.2 Design Progress & Remaining Work

Basic Design for the bridge was completed in 2019. Table 1 summarizes the Detailed Design progress to date and the remaining design work.

Table 1 - Detailed Design Progress (as of 14th September 2021)

	Number of Design Packages in Progress (not yet submitted DRD)[a]	Number of Design Packages in Review (submitted to DRD but not approved / being revised by SBJV)	Number of Approved Design Packages	Total
Pier Foundations[1]	6	4	16	26
Pier Shafts	5	3	10	18
Girders	4	2	6	12
Pylon & cables[2]	0	5	0	5
Land works & other packages	20	21	26	67
Ancillary Works	1	1	1	3
Major Temporary Works	1	0	3	4
Total	37	36	62	135

1) Including 1C and under-foundations (number may vary as some packages containing both foundations and piers have been split in a later revisions). Abutment foundations not included

2) Pylon foundation 1C is included in pier foundations above

a) Numbers from SBJV's DDDP v6, uploaded 10.09.2021

The design status as of 14th September 2021 is summarized on Figure 8, where:

- Green solid and dotted lines: approved
- Yellow: approval process ongoing
- Unboxed elements: DP not submitted yet

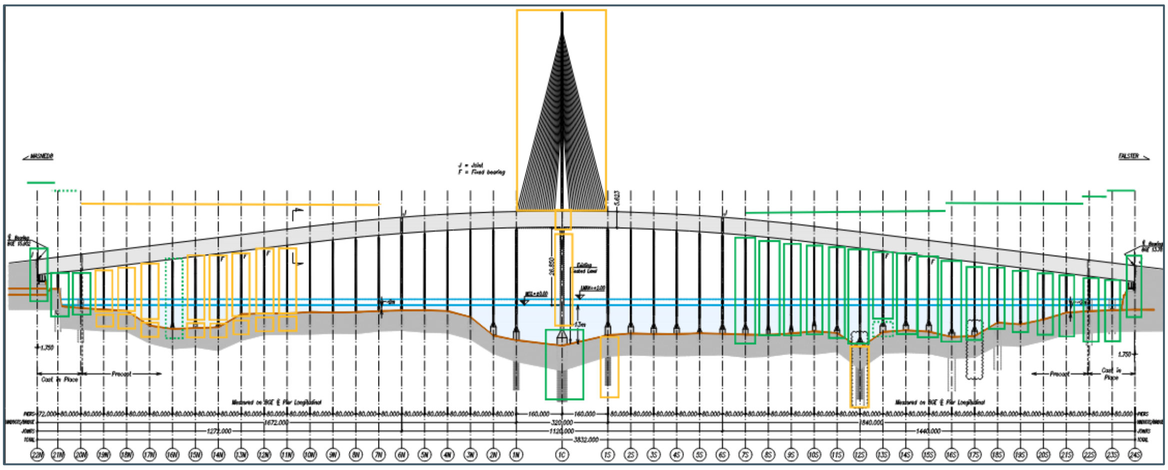

Figure 8 – Design Status as of 14 September 2021

The key take-away from Figure 8 is that the design is well ahead of construction and SBJV has the opportunity to work on construction of many segments and on many construction fronts.

3.3 Construction Progress & Remaining Work

The casting facilities and erection equipment seem to be appropriate for the job. However, there does not seem to be sufficient storage space for all the pieces if the production rate is increased to levels initially planned for the project.

The prefabrication yard on Masnedø Island has the following facilities (see Appendix A for layout):

- A concrete batching plant: main and back-up facilities capable of producing 80 m³ per hour and 40 m³ per hour, respectively. The maximum rate of production to-date has been ~30 m³ per hour. A learning curve is expected to be able to consistently achieve production rates significantly more than that needed to-date to meet the full production needs of in-situ, offshore, and precast construction.

- Shed 2 & yard: Precast girder production line. It is planned to work on four girders at the same time in a production line fashion.

- Shed 3 & yard: Precast pier foundation production facility. There are two beds inside the shed for casting the bottom slab and ribs. The foundations are then moved outside for construction of the pier elevation. In the yard, there are four stations for pier construction.

- Shed 4 & yard: Precast pier segment production facility. One casting bed for each segment type (C1, C2, C3, C4, H1, H2).

- Shed 5: Rebar processing facility (cut & bend).

- Quay (140 m) for loading pier foundations and segments on to barges.

- Storage area for various falsework, SPMTs, materials etc.

Table 2 summarizes the construction progress to date and the remaining work.

Table 2 – Construction Progress (as of 31st August 2021)

	Number of Units Fabrication / Construction underway	Number of Units Fabrication completed	Number of Units Erected	Total	Percent complete
Abutments	0	2	-	2	100%
In-situ Spans	2	0	-	4	~35%
Precast Pier Foundations	2	5	4	40	~15%
Precast Pier Shafts	1	12	8	104	~15%
Precast Pier Tops	2	0	0	45	~2%
Precast Segment 0	0	0	0	40	0%
Precast Girders	1	0	0	44	~1%
Precast 1C Foundation	1	0	0	1	~90%
Pylon	1	0	0	1	~15%
CSB Precast Girders	0	0	0	4	0%
Cable System	0	0	0	1	0%

4 SBJV's DESIGN & CONSTRUCTION SCHEDULE

4.1 SBJV's Proposed & Updated versus Actual Schedule

The production rates for different units are given in Table 3. The production rates given in SBJV's proposal appear to be reasonable and consistent with what is expected from an experienced international design and build team. The actual production is, however, much slower than proposed by SBJV.

Table 3 – Construction / Fabrication Production Rates

	SBJV Proposal	Work Schedule F (months)	Work Schedule G (C2) (months)	Actual (first/ average)
Cast-in-place pier		11.1	5.0	14.7 (P23S)
Cast-in-place girder	2.5 months	5.3	4.5	12 (est.) first girder
Precast Pier foundations	2 units per month	2 (first cycle)	1.6 (first cycle)	9.4 (F21S)
Precast Pier shafts	2 piers worth per month	Included with precast pier foundations	Included with precast pier foundations	Incomplete
Precast Pier Tops	Included in Pier shafts	Included with precast pier foundations	Included with precast pier foundations	Incomplete
Precast Reduced Deck Segments	Included in Precast Girders	0.7	1.0	Not commenced
Precast Girders	2 months (2 spans per month)	3.0 (first cycle)	2.0 (first cycle)	5.4 (est.) first girder
Precast 1C Foundation	Already in place in 2021	8.4	5.0	15
Pylon	25 months	19.2	22.3	Not commenced
CSB Precast Girders	19 months			Not commenced
Cables	3 months	3.1 (phase 1&2)	3.5 (phase 1&2)	Not commenced

5 SITE VISIT & OBSERVATIONS

Nedim Alca of COWI North America visited the site and interviewed the DRD and COWI site staff between 13th & 16th September 2021. The site visit included an inspection of the main Masnedø yard, Sheds 2 through 5, and the abutments and in-situ spans at Falster and Masnedø. A summary of the site visit and interviews is provided below. This is not intended to be a comprehensive list; it provides a flavour of the Project status, what has been working well, what can be improved, and concerns going forward.

- General
  - SBJV mainly engages subcontractors to perform the work on site. Initially the subcontractor supervision by SBJV was inadequate, but this has improved through the use of Site Supervisors. SBJV has also experienced difficulty retaining staff and subcontractors and as a consequence of frequent staff changes, there has been inconsistent production rates and quality. SBJV has recently started to employ 'blue collar' staff to work directly under their control.
  - Subcontractors' lack of sufficient proficiency in English, which is the main language for all site paperwork such as work methods and QA/QC documentation, is leading to subcontractors not understating and/or not addressing project requirements. This is resulting in inconsistencies in construction quality and speed.
  - SBJV increased technical, quality, supervision, and claim staff in Spring 2021, however, still lacking experienced leaders.
  - Decision making process within SBJV seems to be slow. All decisions seem to be taken above the project director level, making it difficult to resolve issues at the site.
  - After a slow start and change of the lead Designer, the design and the design review process has become efficient. Currently, design is well-ahead of construction and approved designs are available for a significant portion of the bridge. Completion of the design is not expected to be critical.
  - The relationship between SBJV and DRD design teams appears to be well, however, SBJV is not open to suggestions for design improvements which might improve construction speed. Designers and Independent Checkers are talking to each other and the weekly design meetings are productive and open.
  - Construction interface & planning are lacking, which is affecting production rate and quality.
  - The number of construction workers appears to be very low for a project of this scale. Most of the production is performed during one shift per day. Workers on site are moved from one area or production line to another to address priority-of-the-day, which is affecting productivity and quality.

  - The main construction site at Masnedø Island has limited storage space to store completed precast components. If and when the precast unit production rate is increased, this might become an issue if there are delays with installation offshore.
  - Offshore work such as precast pier shaft stitch casting, Segment 0 production, precast girder placement, main pylon casting, Power Joint casting, and all operations for the main span construction have not commenced yet and will have learning curves. It might be possible to use the area currently occupied by the Pier 1C foundation to store precast pier foundations, precast pier segments, and/or precast girders. Barges can be rented to store precast girders.

- Quality Management, Inspection, Checking, and Re-work
  - SBJV's approach to quality management needs to be improved. Procedures and documentation for the quality management system, work methods, team meetings etc. are inadequate. Handling of NCR's and remedial & corrective actions do not seem to be effective and do not seem to lead to corrective actions. Communication and collaboration between SBJV's construction and QA/QC teams needs to be improved.
  - The SBJV does not operate their own Project specific document management system (for example, Aconex) but relies upon ProjectWise (managed by the DRD), Microsoft Teams and emails. This mixed use of systems by SBJV, and SBJV not providing sufficient number of Document Controllers, have been challenging for smooth and efficient flow of documents and information between parties to the Contract.
  - Construction quality in general is satisfactory for components constructed to date, however, construction quality remains a concern due to high rate of workforce turnover.
  - Method statements and working procedures are prepared by inexperienced staff and lacking details, except those prepared by specialist subcontractors, such as Fagioli, which are appropriate. The persons nominated as Checker and Approver of these documents need to review these documents more closely. The documents do not appear to be used on site by the non-English speaking subcontractors due to the language barrier.
  - Many Site Query Changes (SQC's) are not closed but this is not causing any work stoppages.

    DRD and COWI teams are working closely with SBJV's QA/QC team to avoid construction delays despite unsatisfactory level of quality system documentation, however, the concerns raised in the previous bullets can lead to work stoppages, rework, and delay. When the production rate increases, special attention needs to be paid to integration of QA/QC process and construction.

- Embankments
  - Construction of the embankments is on-going, however, there seems to be lack of planning leading to rehandling of the material placed. This is not only a quality concern but is also inefficient and costly for the SBJV. Regardless, the work on the embankments is not expected to be on the critical path.
- Abutments and in-situ spans
  - Both abutments are substantially complete. The construction of the Masnedø and Falster in-situ spans is not expected to be on the critical path as the erection sequence, temporary restraints, and closure procedures of the spans next to them can be modified to suit if necessary.
  - Construction of the Falster in-situ spans is underway. There are some cracks and honeycombs in concrete, however, overall quality of construction is good. The construction of the two Falster spans started ~11 months ago (the initial plan was to construct both Masnedø and Falster in-situ spans in 10 months). Falsework design and approval in accordance with the Danish Handbook on Falsework (due to SBJV's lack of planning and lack of sufficient workforce) are some of the challenges.
  - Once the Falster in-situ spans are completed, the falsework will be moved to the north side to construct the Masnedø in-situ spans.
- Dredging and foundation preparation & placement
  - The dredging and foundation preparation for placement of precast pier foundations is not expected to be on the critical path. The learning curve is complete and the appropriate equipment and subcontractors are on site.
  - All dredging for the foundations has been completed. It takes one week per pier to perform the final preparations to place a precast pier foundation.
  - The inclusion piles for Pier 1C are complete. The inclusion piles for the remaining piers (1N, 1S, 12S) are expected to start in October 2021.
  - Pier 21S precast foundation had issues during placement because the survey boat had calibration error. Surface of the ballast was undulating above tolerance. NW corner has a gap of 2-3 cm tall in a 4mx4m area. The foundation will be lifted, the screeding layer corrected and then replaced.
- Precast Pier Foundations & Piers

  - Shed 3 contains two stations for precast pier foundation bottom slab & rib fabrication. A third station is currently being prepared in the yard just outside of Shed 3, which will help improve the production rate.
  - Method statements for work in Sheds 3 & 4 are appropriate.
  - It seems feasible to achieve production rates indicated in SBJV's stand-alone schedule for the precast pier foundations with the facilities on site, however, there must also be an adequate workforce.
  - The catamaran has lifting (currently certified for 2,550 tonnes) and height limitations. These limit the height of pier shaft that can be cast on top of the precast pier foundations. Employing cranes with higher weight capacity and higher reach would minimize number of stitch joints for the pier shafts.
  - SBJV is considering eliminating stitches and cast all upper piers in-situ. This might be a reason why there is currently no production of pier segments.
- Precast Girders
  - The precast girder production line in Shed 2 is sophisticated and well-suited to produce quality segments.
  - Method statements for work in Shed 2 are appropriate.
  - It seems feasible to achieve production rates indicated in SBJV's stand-alone schedule for the precast girders with the facilities on site, however, there must also be an adequate workforce.
  - Segment 0 is key to be able to install fabricated precast girders, however, there are no forms on site currently. In order to speed-up construction and reduce offshore work, it would be beneficial to re-evaluate the Segment 0 construction process. If large crane(s) with sufficient capacity and reach are brought on site, Segment 0 can be cast in its entirety (except for the "wings").
- Pier 1C and Cable Stayed Bridge
  - Pier 1C precast foundation is almost complete and planned to be installed in early October 2021.
  - Currently, no drawings or method statements have been submitted for Power Joint and Upper Pylon.
  - The current plan for offshore casting involves the use of static mixers on a barge. The batched concrete is loaded into mixers for transportation to the quay, and then transferred to the static mixers. The barge is then towed offshore to where the concrete

is needed, such as the pier body stitches, the pier heads, the Lower and Upper Pylon and the Power Joint. The double handling of concrete, instead of pumping directly from the concrete trucks, could lead to concrete waste (due to rejecting batches) and cold joints & honeycombing. Significant learning curve related to offshore in-situ casting is expected.

- The Lower Pylon is planned to be cast in 4m lifts, which is similar to other cable stayed bridges.
- Only preliminary design drawings are available for the temporary works related to the cable stayed bridge main span girder installation.
- Stay anchor boxes design package and stay cable lengths & stressing information have been received.
- The current design for the Power Joint requires many construction joints, which is not desirable for areas with congested reinforcement. It is recommended that the Power Joint be cast with as few construction joints as possible.

- Other
  - Waterproofing system is currently being discussed. The current plan is to install water proofing in the winter, which has been raising quality concerns.
  - The bearing design has changed, which is affecting bearings already on site. In total eight bearings will be discarded, and 56 bearings will be returned to the manufacturer for rehabilitation.
  - The last full programme to be formally submitted by SBJV to the DRD was Work Schedule Revision F on 13th October 2020. The SBJV is now in excess of five months behind this schedule and because of this, it cannot be used with any confidence to determine the SBJV's future activities.

6 ANALYSIS OF SCHEDULE FOR THREE SCENARIOS

Three different design and construction scenarios are considered to assess whether the bridge can be open to road traffic and be ready for installing catenary system for railway in the second half of 2024. In this section, the scenarios and the analysis performed are discussed.

Using the progress to date to predict the future is not meaningful as only a few precast segments for different parts of the bridge have been produced and extrapolating their production duration would lead to an unrealistically long construction period. There is no doubt that it is feasible to increase the construction speed, however, it will take some time to improve the production rate (referred to as "ramp-up") and the actual production rate would depend on many factors, e.g. level & skill of workforce, planning of activities, number of work fronts and more.

The three scenarios considered in this study are (see Figure 8 for a graphical representation):

- Scenario 1: Pessimistic case – slow ramp-up and slow progress. This scenario has progress faster than that observed to date but still very slow compared to that expected from a well-organized and experienced design & build team.

- Scenario 2: Realistic case – ramp-up and progress between Scenarios 1 and 3.

- Scenario 3: Optimistic case – rapid ramp-up and progress expected from a well-organized and experienced design & build team and all parties working collaboratively.

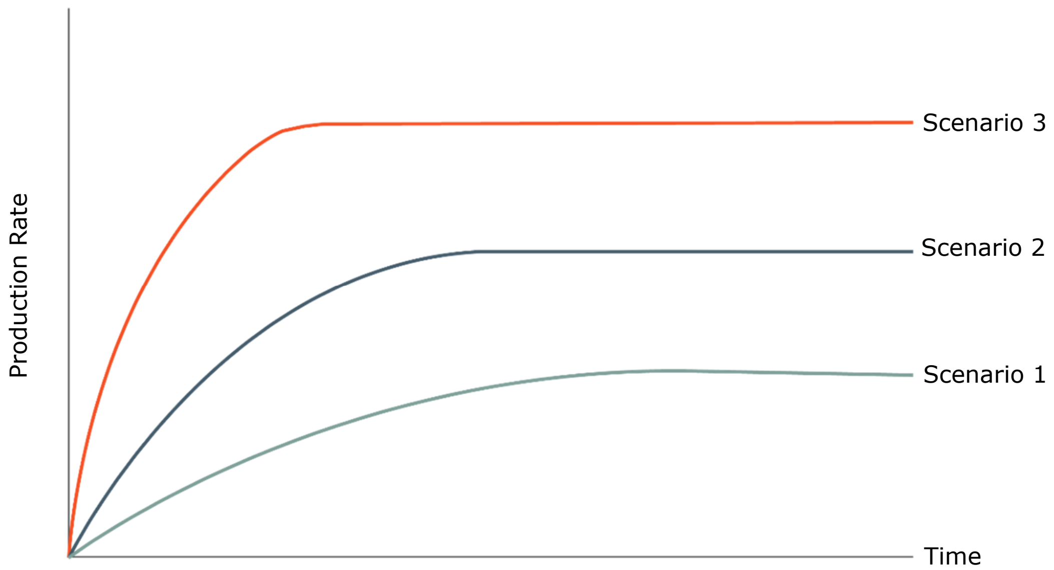

Figure 8 – Graphical representation of the three scenarios

The main assumptions and the assumed production (fabrication and installation) rates used for the three scenarios are shown on Tables 4 and 5, respectively.

Table 4 – Scenario Main Assumptions

	Scenario 1	Scenario 2	Scenario 3
Ramp-up (full production rate achieved by)	1st July 2022	1st April 2022	1st January 2022
Fabrication	Twice as long as Scenario 3	Between Scenario 1 and Scenario 3	Fabrication durations equal to SBJV proposal
Installation	Twice as long as Scenario 3	Between Scenario 1 and Scenario 3	Installation durations equal to SBJV proposal

Table 5 – Assumed Production (Fabrication and installation) Rates for Scenarios

	Scenario 1	Scenario 2	Scenario 3
Precast Pier foundations	1 unit per month (total = 34 months)	1.5 units per month (total = 26 months)	2 units per month (total = 17 months)
Precast Pier shafts	1 pier worth per month (34 months)	1.5 piers worth per month (26 months)	2 piers worth per month (17 months)
Precast Pier Tops	Included in Pier shafts	Included in Pier shafts	Included in Pier shafts
Precast Segment 0	Included in Precast Girders	Included in Precast Girders	Included in Precast Girders
Precast Girders	1 span per month (total = 40 months)	1.5 spans per month (total = 30 months)	2 spans per month (total = 20 months)
Precast 1C Foundation	Already in place in 2021	Already in place in 2021	Already in place in 2021
Pylon	48 months	36 months	24 months
Cable Stayed Bridge Main Span Precast Girders	38 months	29 months	4 months
Cables	12 months	9 months	6 months

The high-level schedules for the three scenarios are shown on Figures 9 through 11 (also included in Appendix B for printing larger format).

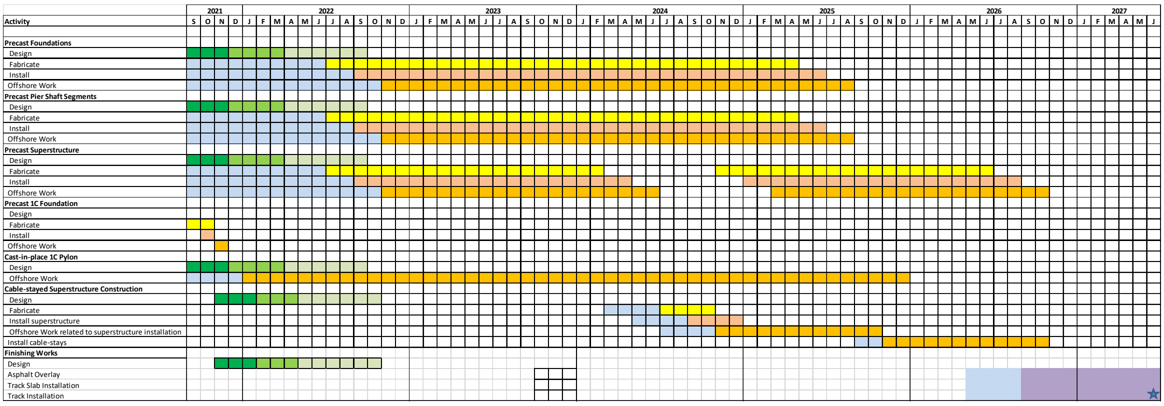

Figure 9 – Scenario 1 High-Level Schedule

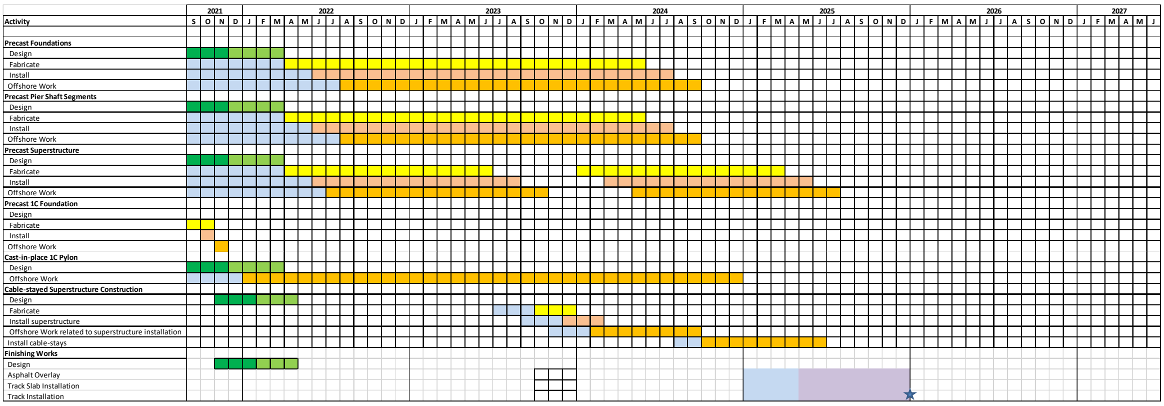

Figure 10 - Scenario 2 High-Level Schedule

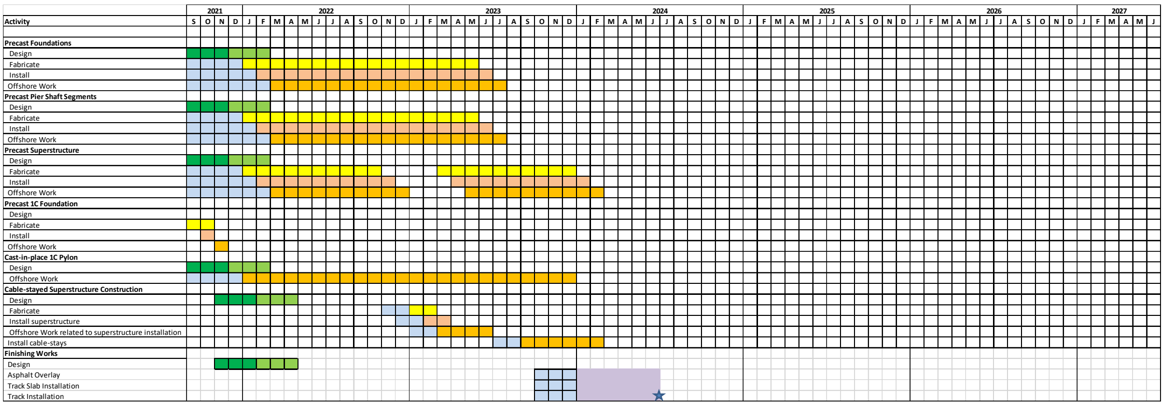

Figure 11 - Scenario 3 High-Level Schedule

Figures 9 to 11 suggest that precast girder production is the critical activity and interrupting the viaduct precast girder production to fabricate the cable stayed bridge main girders will likely adversely affect the overall schedule due to learning curve involved (blue shaded durations).

The analysis and conclusions for the three scenarios are summarized on Table 6.

Table 6 – Analysis and Conclusions of Scenarios

	Scenario 1	Scenario 2	Scenario 3
Estimated completion date	Mid 2027	End of 2025	Mid 2024
Critical path items / issues to resolve	Same as Scenario 2	Production rate, workforce level, work on multiple fronts, offshore works learning curve	Same as Scenario 2
Obstacles	Same as Scenario 2 but less impact	Concrete production rate, precast segment storage space, quality, and safety	Same as Scenario 2 but more impact
Likelihood of occurrence	Possible, however, will still require significant improvements to current production rates	Realistic only if radical changes are implemented (see Section 7 for further discussion)	Unlikely unless radical changes mentioned for Scenario 2 are implemented very fast
Potential mitigations (also see Section 7)	Similar to Scenario 2	Increase workforce (by a factor of 4 or 5), work on multiple work fronts, consider producing CSB main span girders on a second production line, increase concrete supply capacity, bring more & larger marine cranes	Similar to Scenario 2

The main risks to schedule are segment production rate, Segment 0 and Power Joint construction, offshore work, safety, and quality, all of which can add one additional year or more to the durations estimated for the three scenarios.

7 SCHEDULE ASSESMENT & RECOMMENDED IMPROVEMENT MEASURES

The site visit and interviews with DRD and COWI staff, and analysis of schedule scenarios discussed in Section 6 indicate that:

- If radical changes to construction are not implemented by January 2022, it will be unlikely to be able to open the new bridge to road traffic and have it ready for installing catenary system for railway by second half of year 2024.
- The radical changes might include one or more of the following (each would take some time to implement, hence, a decision needs to be made quickly regarding which one(s) to adopt:
  - Adding to the SBJV team a major international contractor with a large workforce (including workers, foremen, engineers, and management staff experienced in similar major bridge construction projects) and equipment.
  - SBJV increasing its own capacity with a large injection of workforce (including workers, foremen, engineers, and management staff experienced in similar major bridge construction projects) and equipment well beyond that currently on site.
  - Working on multiple fronts by switching to traditional in-situ construction for parts of the bridge. This will require significant additional marine equipment (barges, cranes, tugs, crew boats, etc.), falsework and formwork, and infrastructure suitable to allow a large workforce performing offshore work.
  - Adding one more precast girder production facility, first to fabricate the main span precast girders and then, if needed, fabricate some of the typical precast girders. The precast girder production appears to be the critical activity and interrupting the typical precast girder production to fabricate the main span precast girders potentially adds 8 months, 6 months, and 4 months to the durations of Scenarios 1, 2, and 3, respectively (see Figures 9 to 11). The facility does not need to be as elaborate as that in Shed 2 and does not need to be a production line. It could occupy a space slightly larger than the girder itself.
- Significant investment has been made in the prefabrication yard (Sheds 2 to 5, concrete batch plant etc.) and the equipment (SPMTs, catamaran, barges, cranes etc.). The segment fabrication facilities and segment installation equipment are appropriate for the project; however, they need to be utilized much more effectively than they have been to date. Even if the facilities and equipment are used effectively, it will still be challenging to complete construction by mid 2024.
- Completion of design is not expected to be critical.

The following are additional measures are recommended to improve SBJV's operations and construction schedule:

- General Approach & Culture

  - Improve communication between the site office staff and the workforce. Take steps to eliminate language barriers and to improve collaboration.

  - Improve safety and quality culture. Any accident and/or reduction in quality can lead to significant delays.

  - Look for opportunities to work on multiple construction fronts including segment fabrication and installation. Preparation of one additional precast pier foundation casting bed is currently underway, which is useful. Similar actions are needed for all other operations.

- Planning & Scheduling

  - Employ additional experienced construction engineers on site to work on work methods, planning, scheduling and QA/QC.

  - Prepare stand-alone schedules for every segment fabrication and every offshore operation. Currently, stand-alone schedules are available only for precast pier foundation and precast girder fabrication. These are not detailed enough and are based on single work shift.

  - Based on the stand-alone schedules and the actual production rates, continuously revise the construction means & methods and seek for efficiencies in every operation.

  - Revise the rebar details and rethink number and location of construction joints to improve construction speed and to minimize prefabrication yard and marine operations. These might require design changes, which will require approvals by DRD, and hence will require action well ahead of construction.

- Segment Fabrication

  - Increase workforce and number of shifts per day, possibly in all sheds and operations.

  - Pre-fabricate reinforcement cages on several fronts in parallel before placing in the formwork and stitching cages together.

  - Look for opportunities to modify rebar detailing for rapid construction. This will require design changes and hence need proper planning.

  - Precast the pier foundations and piers in only one or two pieces to minimize offshore operations.

  - Precast the cable stayed bridge main span girders on a separate production line. This will avoid interrupting the typical girder production and allow construction of the main span girders independent of the typical girders.

  - Precast the entire Segment 0 (instead of partial precasting). The current scheme for construction of Segment 0 requires many construction joints and large quantities of concrete casting offshore.

  - Revisit concrete production capacity and if needed increase concrete production capacity either on site or by using local concrete suppliers, which might require use of standard concrete instead of SCC.

- Storage in the Masnedø yard is very limited, especially for the precast girders. When the segment production rate is increased or if offshore segment installation is delayed, storage will become an issue. Investigate options and take measures to address potential storage area shortage.

- Offshore Operations

  - Increase the size and number of the cranes. This will allow installing larger precast pier foundation & shaft segments, largest possible Segment 0 segments, and minimize the number of offshore operations and minimize offshore concrete placement.

  - Transport concrete to offshore locations by driving concrete trucks on to barges. The current proposal requires double handling of concrete instead of directly pumping of concrete from concrete trucks, which could lead to concrete waste (due to rejecting batches) and cold joints & honeycombing.

  - Fabricate additional temporary works to allow installing multiple precast girders at the same time.

  - Revisit Power Joint detailing and construction joints. The current design requires multiple horizontal construction joints across congested rebar. It is recommended that the Power Joint be cast with as few construction joints as possible.

8 SUMMARY & RECOMMENDATIONS

In this study, the overall construction programme is reviewed with a fresh set of eyes, a site visit was conducted, DRD and COWI site staff were interviewed, the construction schedule was assessed by considering three scenarios, and suggestions on how to improve the schedule are provided.

The three scenarios considered in this study are:

- Scenario 1: Pessimistic case – slow ramp-up and slow progress.
- Scenario 2: Realistic case – ramp-up and progress between Scenarios 1 and 3.
- Scenario 3: Optimistic case – ramp-up and progress expected for a well-organized and experienced design-build team working collaboratively.

This study finds that if radical changes to construction are not implemented by January 2022, it will be unlikely to be able to open the new bridge to road traffic and have it ready for installing catenary system for railway by second half of year 2024.

The radical changes might include one or more of the following (each would take some time to implement, hence, a decision needs to be made regarding which one(s) to adopt quickly):

- Adding a major international contractor with a large workforce (including workers, foremen, engineers, and management staff experienced in similar major bridge construction projects) and equipment to the SBJV team.
- SBJV increasing its own capacity with a large injection of workforce (including workers, foremen, engineers, and management staff experienced in similar major bridge construction projects) and equipment well beyond currently on site.
- Working on multiple fronts by switching to traditional in-situ construction for parts of the bridge.
- Adding one more precast girder production facility.

Significant investment has been made in the prefabrication yard and the equipment. The segment fabrication facilities and segment installation equipment are appropriate for the project; however, they need to be utilized much more effectively than they have been to date. Even if the facilities and equipment are used effectively, it will still be very challenging to complete construction by mid 2024.

Completion of design, including design approvals, is not expected to be critical. It is recommended that SBJV be open to DRD's design improvement suggestions for increasing construction speed.

Additional measures are recommended to improve SBJV's operations and construction schedule related to the following areas (see Section 7 for more details):

- General Approach & Culture
- Planning & Scheduling
- Segment Fabrication
- Storage
- Offshore Operations

Appendix A Masnedø Yard Layout

Appendix B High Level Schedules for Three Scenarios