Grangemouth Flood Protection Scheme

Port study: shortlisted barrier options report

B2386100-JEC-S4-C03-ZZZ-RE-C-0002 | P01

17 September 2021

Falkirk Council

B2386100

Grangemouth Flood Protection Scheme

Project No:	B2386100
Document Title:	Port study: shortlisted barrier options report
Document No.:	B2386100-JEC-S4-C03-ZZZ-RE-C-0002
Revision:	P01
Document Status:	Draft for comment
Date:	17 September 2021
Client Name:	Falkirk Council
Client No:	B2386100
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File Name:	B2386100-JEC-S4-C03-ZZZ-RE-C-0002-P01 - Port study shortlisted barrier options report.docx

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Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
0	17/09/2021	Draft for comment by Falkirk Council	JM	CDS	RM	AM
P01	24/09/2021	Draft for comment by Forth Ports	JM	CDS	RM	AM

Contents

Executive Summary

Flood risk mapping undertaken by Jacobs has identified that the Port of Grangemouth is at risk of flooding, predominantly by tidal and wave overtopping effects. As part of the Grangemouth Flood Protection Scheme, it is proposed to provide flood defences that provide protection for most of the port area against flooding. To do so, a flood barrier must be formed across the entrance lock channel. Three shortlisted barrier options are presented herein.

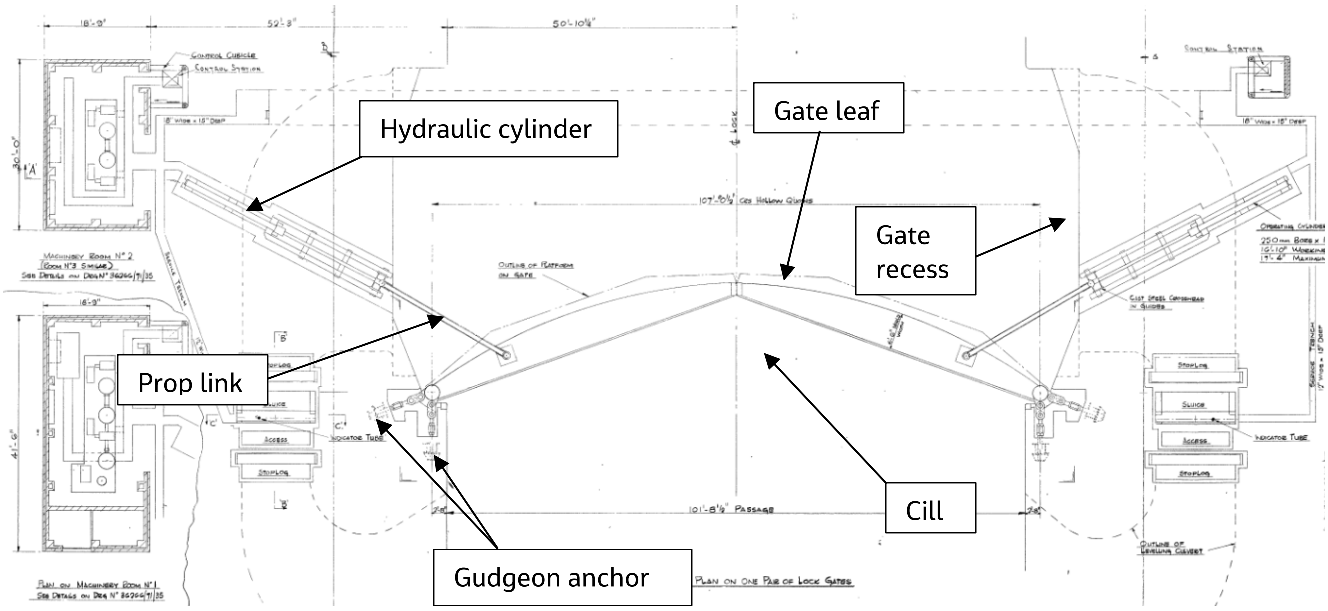
Each barrier option, whilst practicable from a structural perspective, has differing impacts on port operations during construction and deployment. In particular, the impact on the frequency and duration of lock channel closures are varied across the three options, as are the impacts on navigation and the level and type of construction risk associated with each. Outline costs (CAPEX and OPEX) for the options range from £41.1M to £116.9M, excluding the cost of quayside defences.

Important note about this report

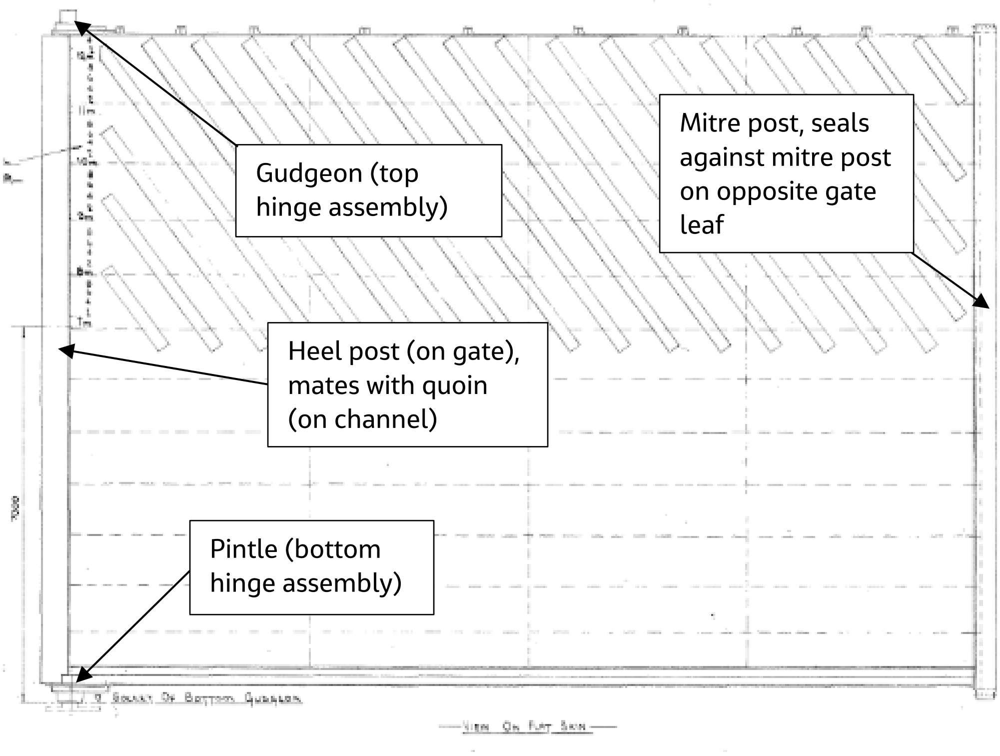
This report has been prepared for Falkirk Council for the sole purpose of engaging stakeholders at the Port of Grangemouth affected by the Grangemouth Flood Protection Scheme in a discussion on the options for providing a flood barrier across the port's entrance lock to be taken forward for further study. In forming the conclusions contained herein, it is presumed that the technical and operational information regarding the lock channel and its associated infrastructure provided to Jacobs by third parties is accurate.

Gate and channel terminology

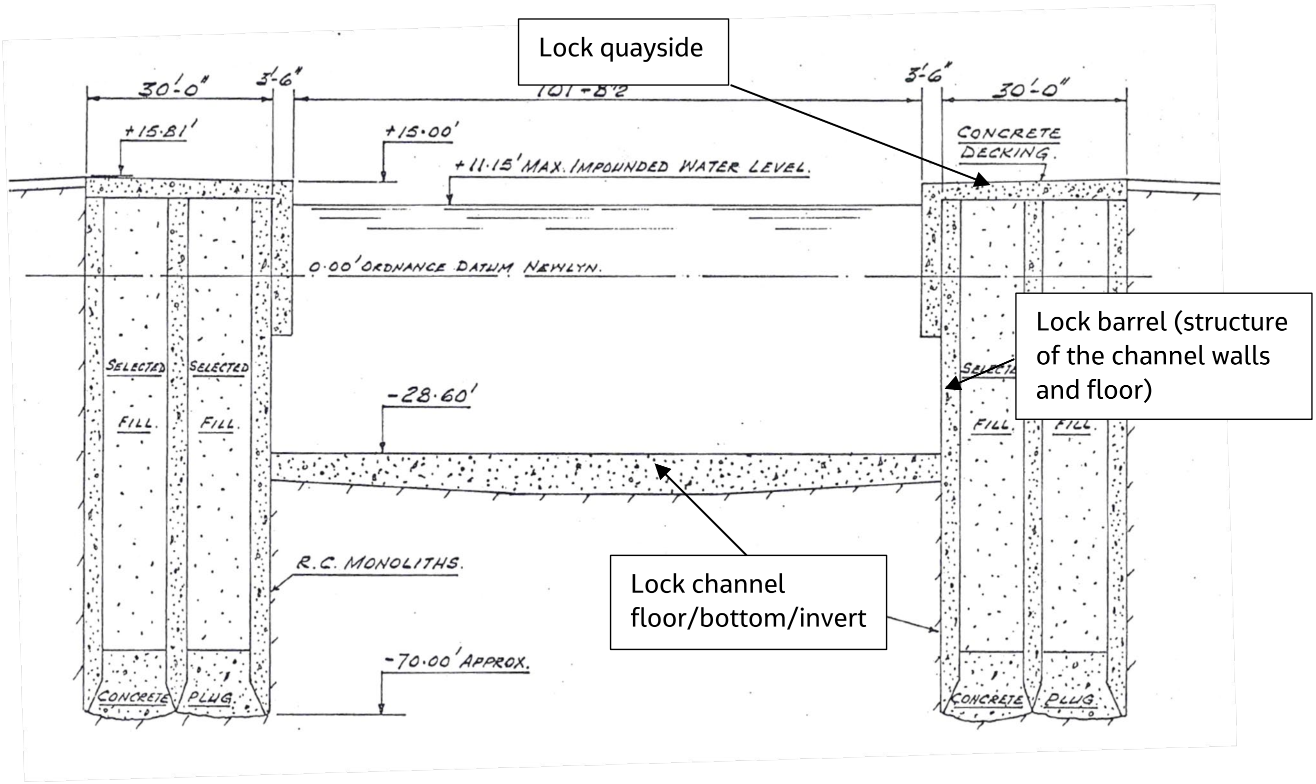
The following diagrams define the terminology used throughout this report in reference to lock gates.



Plan on lock gate arrangement (Forth Ports Authority record drawing)



Gate leaf elevation (Forth Ports Authority record drawing)



Section through lock channel (Forth Ports Authority record drawing)

1. Introduction

Grangemouth is a coastal town located on the Firth of Forth, approximately three miles east of Falkirk. The Port of Grangemouth is the largest container terminal in Scotland and Grangemouth is also home to a large petrochemical plant and one of six oil refineries in the UK,.

Due to the large number of residential properties and the nationally important infrastructure at risk from fluvial and tidal flooding within Grangemouth and the surrounding area, Falkirk Council instructed Halcrow (now Jacobs) in late 2011 to undertake a detailed flood risk mapping study. This demonstrated that, based on current predictions of sea level rise due to climate change, Grangemouth, the port and the petrochemical plant are at significant and increasing risk from tidal flooding. Currently the port experiences some inundation to limited areas from flood events with an annual exceedance probability (AEP) as high as 1 in 2 year (Figure 1).

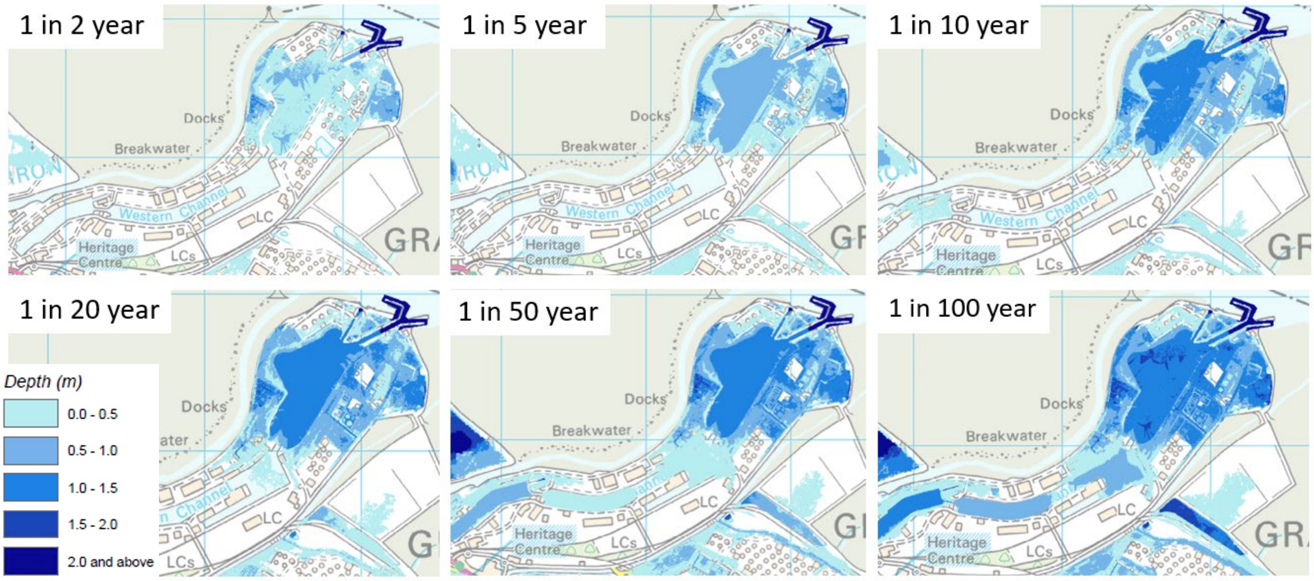


Figure 1: Inundation extent and depths for a range of return periods based on present day sea levels

Inundation extent and depths increase with increasing return period. The flood modelling work carried out so far is based on present day sea levels; due to rising sea levels as a result of climate change, greater extent of inundation with greater associated flood water depths may be expected in future. Figure 2 shows inundation extent based on 2080 sea levels for a 1 in 200 year AEP flood event.

Figure 2: inundation extent and depth for a 1 in 200 year AEP flood event based on 2080 sea levels

Following the outcome of this study, Jacobs were appointed by Falkirk Council in 2015 to undertake the option appraisal and preferred scheme outline design for the Grangemouth Flood Protection Scheme (FPS), including options for the provision of a flood barrier across the entrance lock to the Port of Grangemouth, which is 237.6m long and 31m wide (29m between fenders). This flood defence scheme is to provide protection to Grangemouth, the port and the petrochemical plant from a tidal flood event with a 1 in 200 year + climate change, which would significantly reduce the risk of inundation within the port estate and the consequent disruption to port operations and damage to its infrastructure and property.

A long list of options for providing a tidal flood defence barrier across the lock channel were considered in an optioneering report (B2386100-JEC-S4-C03-ZZZ-RE-C-0001) and the report's conclusion was that the following three barrier options should be considered in greater detail:

1. A new dual-function mitre lock and flood gate at the location of the existing middle lock gate. The base of each gate leaf restrained under the reverse head flood condition by a shot-bolt deployed into a recess in the lock channel floor; the head of each gate leaf propped by a hydraulic cylinder (Option C).

2. A new dual-function mitre lock and flood gate as per Option C but with each gate leaf propped by a frame hinged and recessed within the lock channel walls (Option D).

3. Towed caisson flood gate located at the upstream dock end of the lock channel (Option F).

The option labelling (C, D and F) has been brought forward from the optioneering report for consistency.

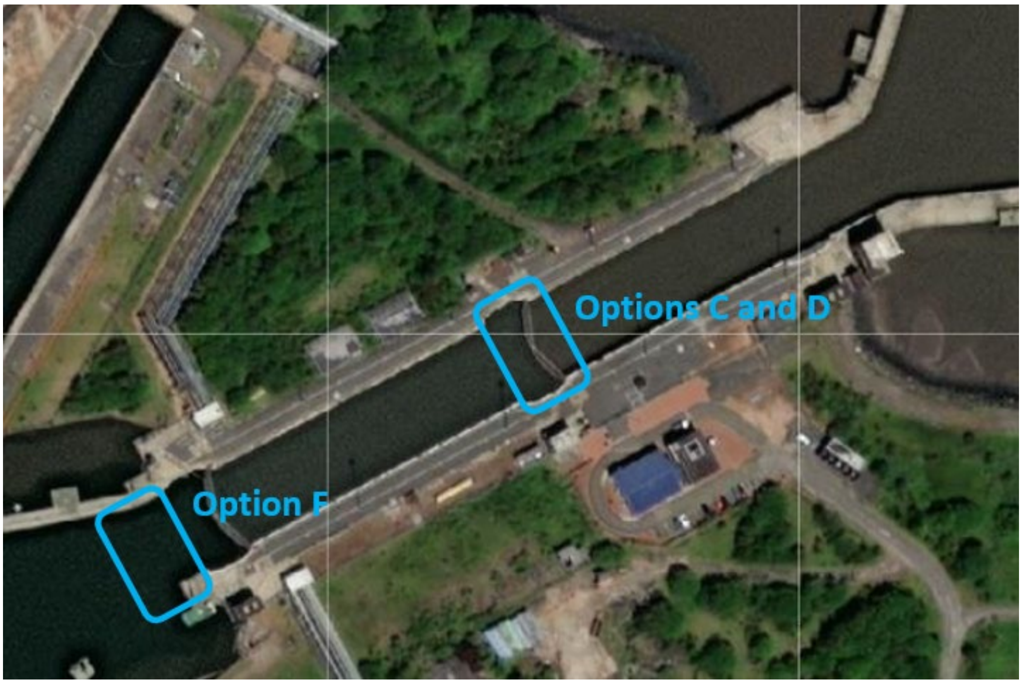


Figure 3: location of gate options C, D and F

This report presents the findings from the initial outline design of each of these three shortlisted barrier options including structural form and operation, constructability and programme, outline costs relating to construction and operation as well as a discussion on the merits of each option in delineating responsibility and risk for each of the options between the local authority, Falkirk Council, and the landowner, Forth Ports. It is not the intention of this report to highlight any one particular option as being preferred; rather, its intention is to present sufficient information to enable a discussion to take place between the local authority and the port on the relative merits of each option. This report is anticipated to form the basis for a series of discussions that will outline the objectives and interests of each party and allow a decision to be made on the option best meeting those interests. It is recognised that these discussions may highlight the requirement for further study of a particular option(s) to provide sufficient comfort to Falkirk Council and Forth Ports before proceeding with the publication of the flood protection scheme alignment.

Option study submitted to Falkirk Council and Forth Ports

→

Discussion on the merits, constructability and practicality of each option, including any likely commercial impacts and navigational restrictions imposed by the option

→

Agreement reached between Falkirk Council and Forth Ports on the alignment and form of the flood barrier crossing the lock channel

2. Key data

2.1 Lock channel plan

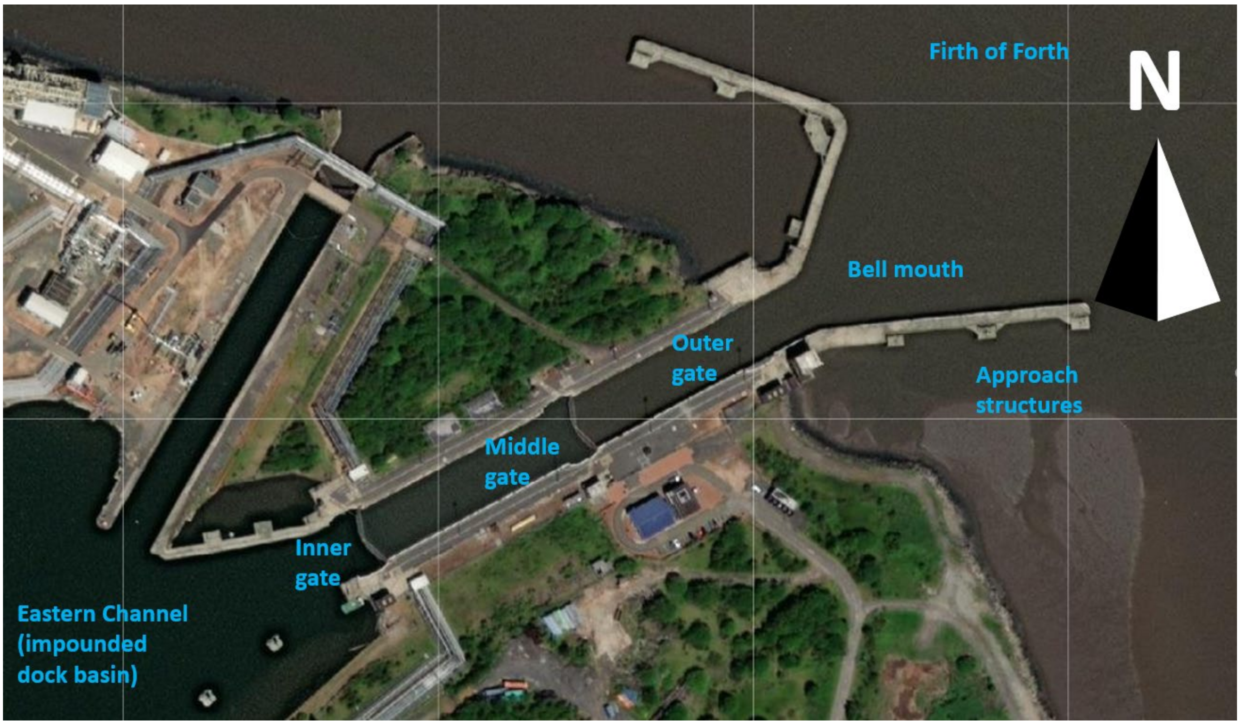


Figure 4: plan view of lock channel and surroundings

2.2 Lock channel photos

Figure 5: view of western leaf of outer lock gate in its open position

Figure 6: view of the middle lock gate looking towards the Firth of Forth

Figure 7: view of the inner gate looking northwest

Figure 8: Admiral, a tanker, transiting the locks on departure from the port

2.3 Lock channel operation

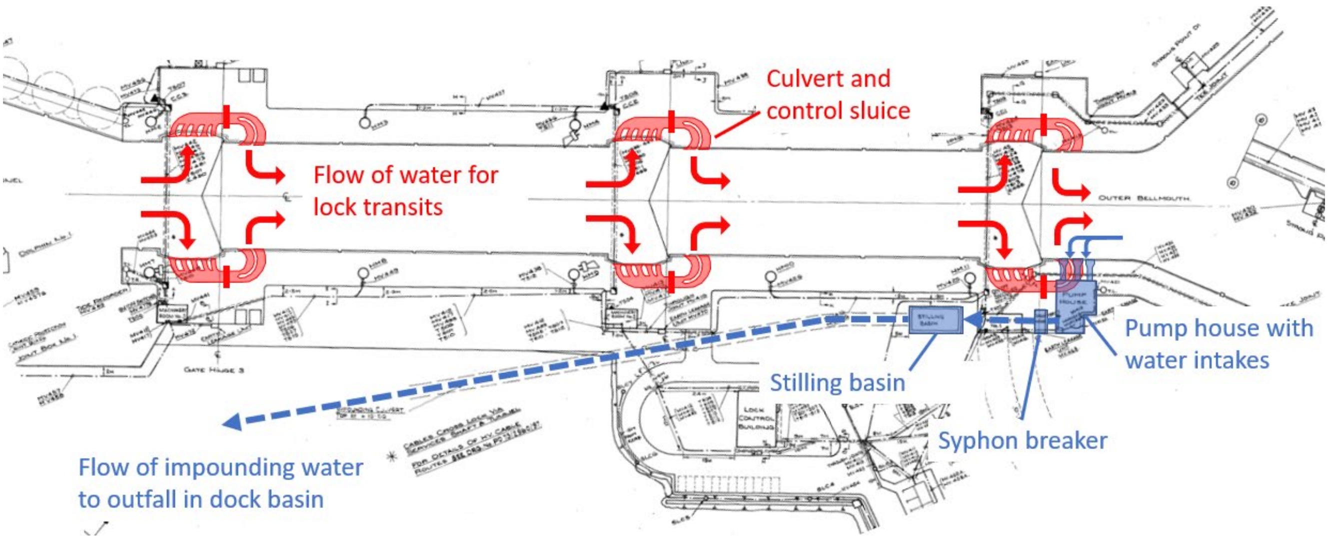


Figure 9: schematic of the flow of water through impounding culverts and levelling culverts (excerpt from Forth Ports Authority record drawing 295)

2.4 Vessels calling at the Port of Grangemouth

Data was obtained from online maritime data supplier FleetMon relating to vessel calls at the Port of Grangemouth over the past two years. The total number of vessel calls over the period was 1,997. These data are presented in the following charts.

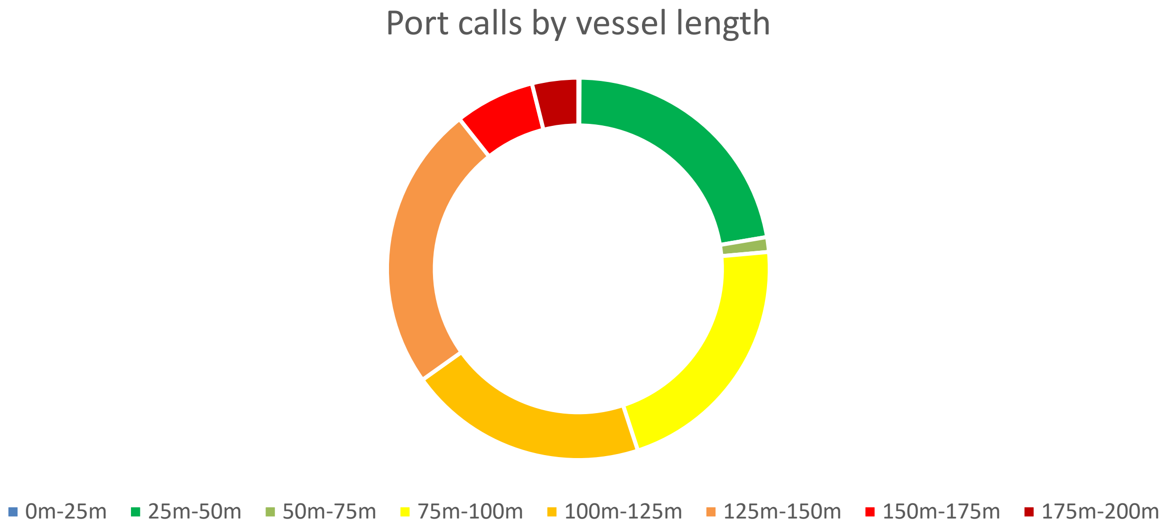


Figure 10: port calls arranged by vessel length

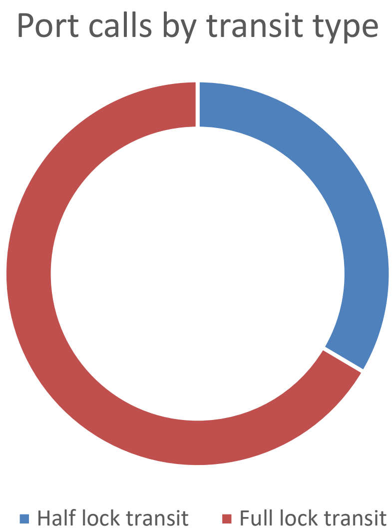


Figure 11: proportion of vessel calls using full lock for transit (i.e. middle lock gate is open for the full transit) and those vessels able to transit in two stages (i.e. outer lock first, then inner lock) with an assumed maximum length for such vessels of 85m

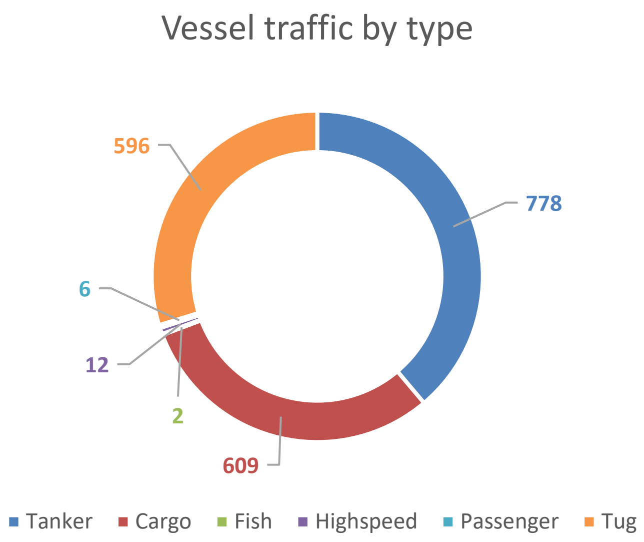


Figure 12: vessel calls by vessel type

2.5 Projected sea level rise and estimated gate closure frequency

As part of the hydraulic modelling carried out for the project, climate change was investigated for the 200-year AEP event and adopts the same scenarios as SEPA's national flood hazard maps (for further information see report B2386100-JEC-S4-C03-ZZZ-RE-C-0002).

Table 1 sets of the projected impact of sea level rise on highest astronomical tide (HAT) and mean high water springs (MHWS) levels. The topographical survey carried out for Jacobs by Malcolm Hughes in November 2020 measured the level of the top deck of the existing mitre gates to be 3.12mOD. This level defines the maximum impounded water level for the port. From 2040, the existing lock gates are overtopped by some spring tides, disregarding the effects of surge. Figure 13 shows a variety of quay levels taken from LiDAR data held on the port area (+/- 0.15m vertical tolerance); according to the tidal data, by 2080 the lowest quay levels will be close to being inundated by the higher spring tides, even without accounting for the effects of tidal surge.

	2020	2040	2060	2080
HAT (mOD)	3.650	3.766	3.904	4.064
MHWS (mOD)	3.050	3.166	3.304	3.464

Table 1: projected impact of climate change on tide levels

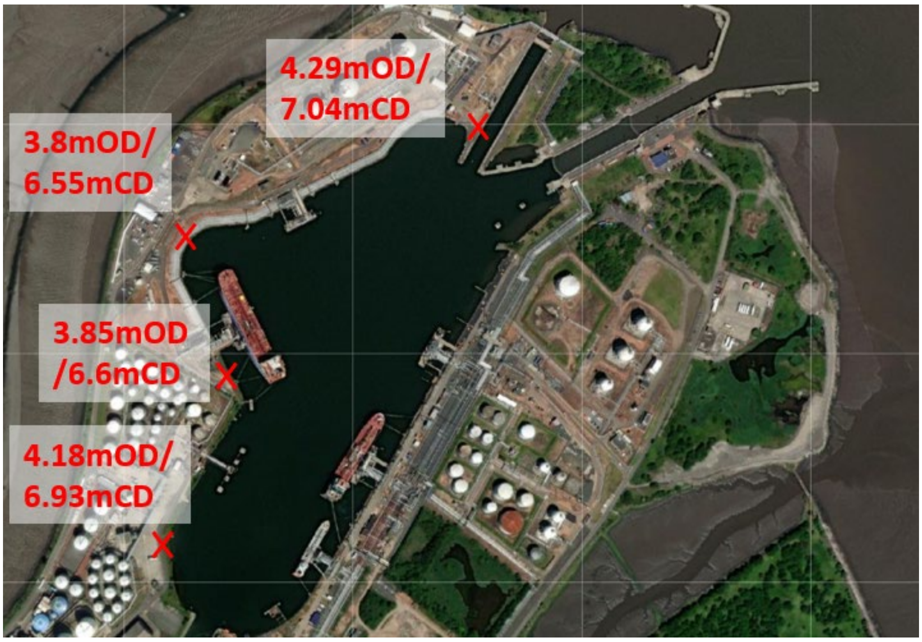


Figure 13: selected quay levels from around the Eastern Channel based on LiDAR data

Table 2 sets out the extreme water levels based on the Coastal Flood Boundary Dataset 2018, as communicated by SEPA to the project team in January 2019, adjusted for sea level rise (refer to B2386100-R-01 for further details). The levels are peak water levels relating to storm surge events with a variety of return periods.

	Peak water level (mOD) by year			
Return period	**2020**	**2040**	**2060**	**2080**
1 in 1 year	3.906	4.022	4.160	4.320
1 in 2 year	3.996	4.112	4.250	4.410
1 in 5 year	4.106	4.222	4.360	4.520
1 in 10 year	4.196	4.312	4.450	4.610
1 in 20 year	4.286	4.402	4.540	4.700
1 in 50 year	4.416	4.532	4.670	4.830
1 in 100 year	4.516	4.632	4.770	4.930
1 in 200 year	4.616	4.732	4.870	5.030

Table 2: peak water level relating to storm surge events for a variety of return periods and adjusted for sea level rise

As can be seen in the data, storms of relatively high AEP (1 in 1 year, 1 in 2 year and 1 in 5 year events) already cause some level of inundation to the port, inundation that increases in depth and extent with sea level rise.

If the port had access to a flood gate on the lock channel that it could use as protection against inundation, estimates may be made of the frequency of gate deployment based on certain assumptions about operation. The actual frequency of deployment will depend to a great extent on the level of inundation regarded as acceptable by the port (the port already experiences occasional inundation) and the level at which the port acts to deploy flood defences (the action level). These levels may have to be established in negotiation between Forth Ports and Falkirk Council, since the interests of the port in keeping the lock channel open for as long as possible may not align with the council's interests in reducing risk as far as practicable.

A further consideration to be made with respect to flood gate deployment is the accuracy that tidal surge forecasts are able to be made by SEPA. This information still requires to be determined for the Port of Grangemouth, but a typical level of forecasting accuracy would be +/- 0.2m. This tolerance must be taken into account by gate operators, as an underestimate of peak water level towards the outer range of tolerance could transform a surge forecast as being lower than critical quay level as being one that inundates parts of the port.

Making the following assumptions, it is possible to make an estimate of gate deployment frequency for the purposes of option appraisal:

1. Critical quay level = 3.8mOD

2. SEPA forecasting tolerance = +/- 0.2m

3. Tide level causing deployment of flood gate: 3.6mOD (critical quay level minus forecasting tolerance)

Based on our assumed forecasted tide level that causes deployment, the following observations are made using the data in Table 1 and Table 2:

- **2030 (assumed year of scheme completion) to 2040**: deployment dependent almost entirely on surge frequency – expected barrier deployment a few times annually. Allow 3 deployments/year.

- **2040**: as above, deployments driven by surge frequency. Less severe (and more frequent) storms now trigger flood gate deployments, leading to an increase in annual deployment. Allow 5 deployments/year.

- **2060**: deployments continue to be driven by surge frequency, but are also increasingly influenced by the higher spring tides. Allow 16 deployments/year based on 10% of spring tides triggering deployment, from a total of 6 tides per fortnight in addition to 15 surge-driven deployments, total: 31 deployments/year.

- **2080**: deployments are heavily driven by the higher spring tides. Allow 78 deployments/year based on 50% of spring tides triggering deployment, from a total of 6 tides per fortnight in addition to 25 surge-driven deployments, total: 103 closures/year.

- **2100 to 2130**: all spring tides now assumed to trigger gate deployment in addition to 25 surge-driven closures, total: 181 deployments/year.

- Total number of deployments over design life of flood scheme: 8,420

It is noted that these observations are limited by, and highly sensitive to, the initial assumptions made on flood gate deployment levels, port quayside protection level, forecasting error, the frequency of storms triggering defence deployment and the estimates of the proportion of spring tides triggering defence deployment from 2060 onwards. As such, the estimates of gate deployment should be viewed as an 'order of magnitude' estimate only to assist in appraising for each option the impact of gate deployment on port activity.

3. Overview of options

In providing flood defences that encompass the Port of Grangemouth, consideration has to be given to the provision of a tidal flood barrier across the entrance lock to the port. The current lock gates are designed to maintain a water level of between 3.17mOD and 3.40mOD within the impounded docks (Mitre Gates, Sluices, Machinery and Anchorages for New Entrance Lock, Maintenance Manual and Operating Instruction Volume 1, Rendel, Palmer & Tritton) and cannot resist a 'reverse head' flood situation, i.e. when the water level in the Forth estuary exceeds the water level in the docks.

Therefore to provide an effective flood barrier, either one lock gate needs to be replaced with another that is able to act as both an ordinary lock gate and a flood defence barrier (termed 'dual-function' lock gate) – see options C and D – or an entirely separate flood barrier is provided – see option F.

Both the mitre gate options C and D would be located in the current middle lock gate position and within the existing gate recesses, predominantly for the reason that the lock channel may be kept operational throughout the works (refer to report B2386100-JEC-S4-C03-ZZZ-RE-C-0001 for full details). Option F, the towed caisson, would abut the inner end of the existing lock channel, separate from each of the existing lock gate positions (Figure 3) due to deployment difficulties envisaged if it were to be placed on the outer end of the channel or at a point within the length of the lock channel (refer to report B2386100-JEC-S4-C03-ZZZ-RE-C-0001 for full details). Each of the options considered in this study would be connected to the proposed alignment of the wider tidal flood protection scheme by a combination of flood walls, flood gates, and demountable barriers.

3.1 Option C - dual-function mitre lock and flood gate with shot bolt/hydraulic cylinder

For this option the proposed dual-function gate would act as per the existing mitre lock gate in the normal operating condition, i.e. when the water level in the impounded dock exceeds the water level downstream in the lock channel and Firth of Forth estuary. The pressure from the upstream differential head of water causes the gate leaves to close together and span the lock channel as a three-pinned arch. Each gate leaf would be approximately 17m wide and 14.5m high including the proposed flood defence section. For the proposed arrangement of the quayside defences interfacing with option C, the layout would be identical to that proposed under option D (see Figure 16).

When the water level on the estuary side of the gate is higher than the water level in the impounded dock (i.e. in a flood situation), the pressure caused by the reverse differential head must be resisted by supports acting externally to the mitre gate leaves. Under option C this restraint would be provided by a shot bolt and a propping hydraulic cylinder.

The shot bolt is a heavy fabricated steel section that is able to be hydraulically actuated from its stowed position at the bottom of each gate leaf into a recess formed in the base of the lock channel (Figure 14). Thus the hydrostatic loading, which would be picked up by the shot bolt, is supported by the existing reinforced concrete lock channel base.

At the top of the gate leaf, a propping force is provided by a prop link, a tubular steel section pinned to a bracket on the gate. The prop link is actuated by a hydraulic cylinder located in a pit on the quay edge that is supported in turn by a piled foundation structure. Hydrostatic loads picked up by the prop link would be supported by the raking piles forming the cylinder pit foundation. A separate structure to resist the hydrostatic loads must be provided because the existing lock walls do not have sufficient structural capacity to bear the high lateral forces.

The middle lock gate leaves would be opened and closed for day-to-day operation of the lock using the prop link and associated cylinders and would not require a separate cylinder set.

This option is similar to that currently designed and under construction for the tidal flood barrier across the entrance lock to the Port of Tilbury in London, which is owned by Forth Ports. The gate would incorporate a demountable section of flood barrier at the top which could be removed if required for shipping overhanging loads.

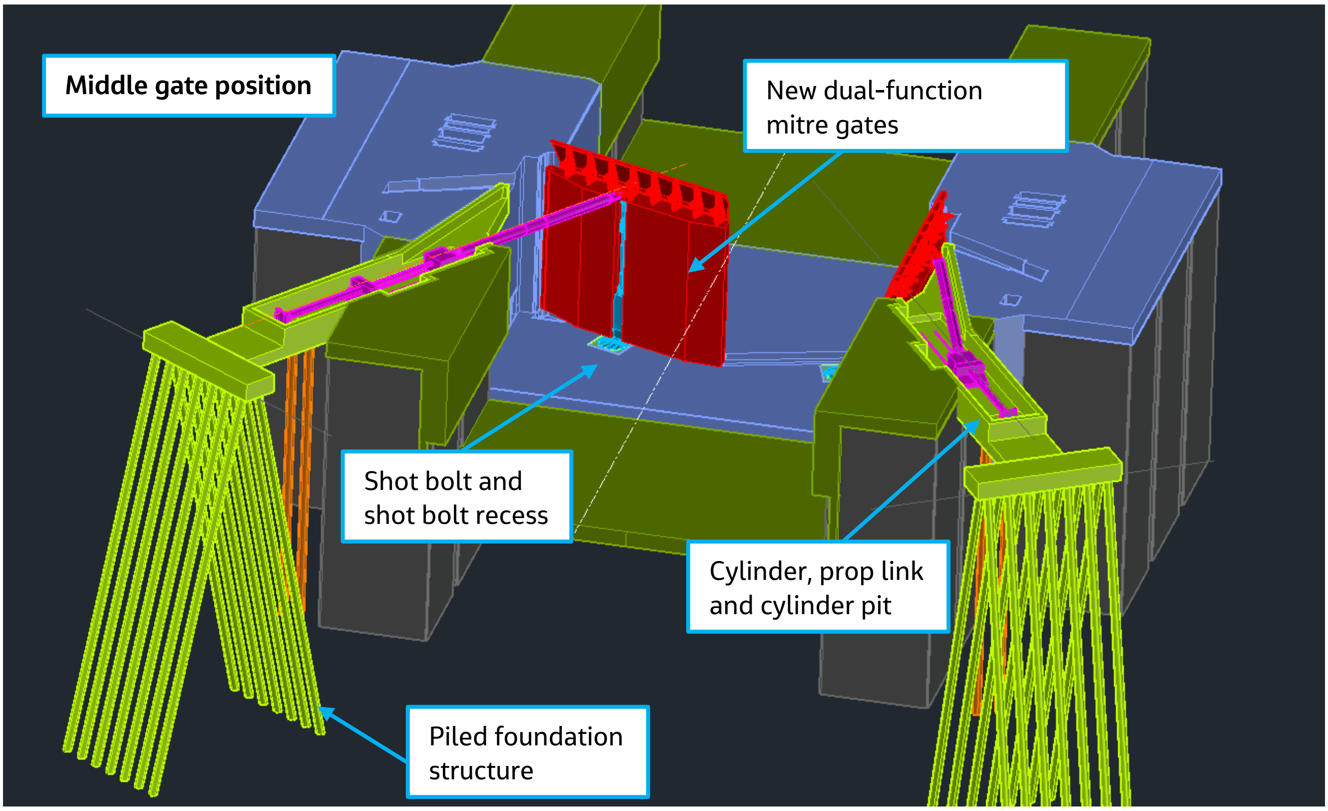


Figure 14: Option C general arrangement: dual-function mitre lock and flood gate with shot bolt/hydraulic cylinder

3.2 Option D - dual-function mitre lock and flood gate with propping frame

As with option C, the dual-function gate would act as per the existing mitre lock gate in the normal operating condition, with the upstream differential head of water causing the gate to span the lock channel as a three-pinned arch. The layout of the proposed quayside defences is shown in Figure 16; for more information refer to 9. Quayside flood defences.

In a flood situation, the hydrostatic pressure caused by the differential head of water on the estuary side of the gate would be resisted under option D by a propping frame, a fabricated steel frame hinged at its mounting and recessed within the lock channel wall. The propping frame is swung out when required by a hydraulic cylinder, and then connected to brackets on the new lock gate leaves. The propping frame would be supported by a foundation structure comprising a tubular steel prop element, the head of which would be contained within a reinforced concrete chamber built into the gate recess wall, designed to pick up thrust loads from each of the propping frame hinges and to allow for some displacement under load. In turn, this prop element would be supported by a piled foundation structure constructed outside the footprint of the existing lock channel structure.

The middle gate would be opened and closed for day-to-day lock operation by cylinders mounted in the existing gate cylinder pits. The cylinders actuating the propping frame would be much smaller and would be housed in their own pits.

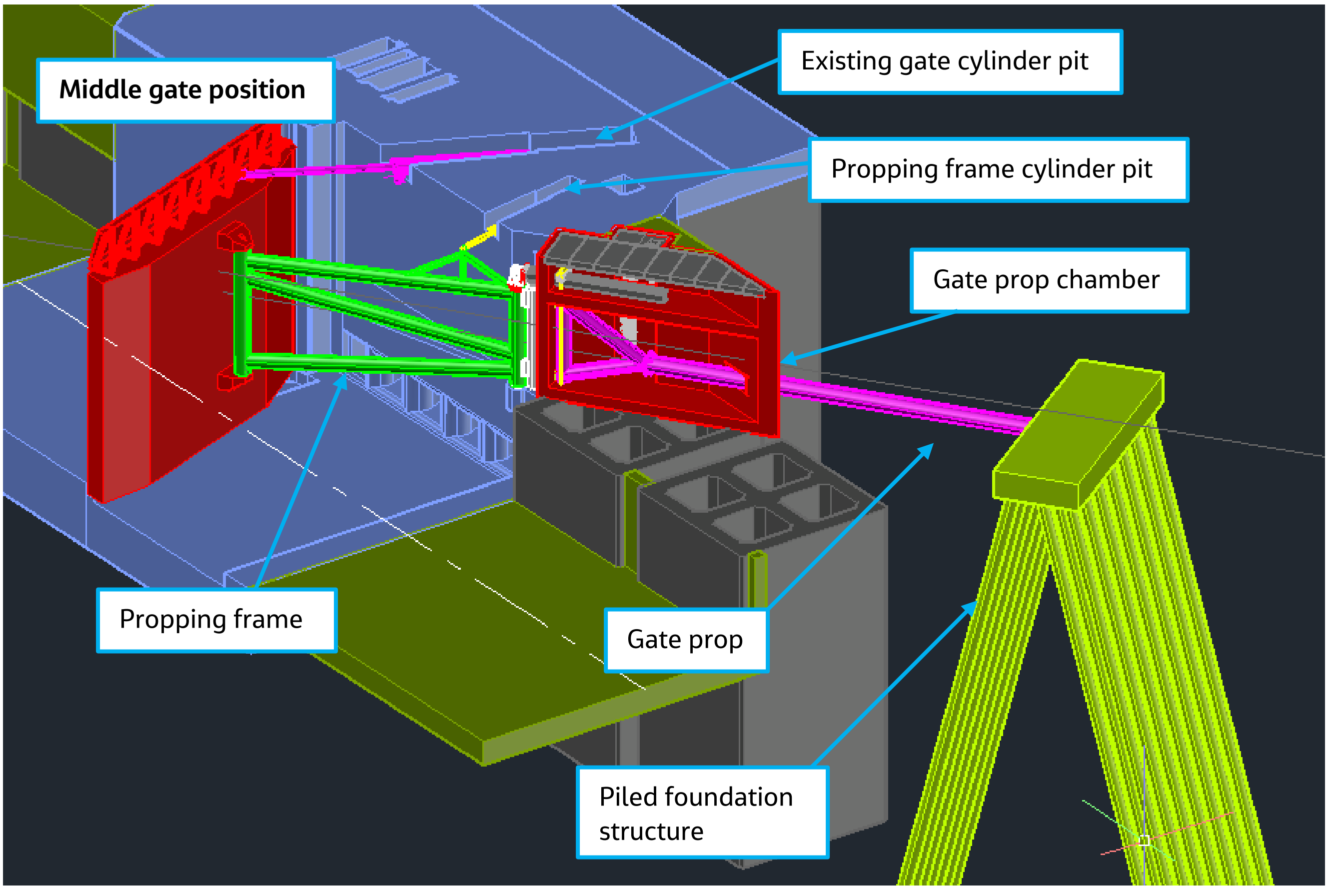


Figure 15: Option D general arrangement (half channel cutaway): dual-function mitre and lock flood gate with propping frame

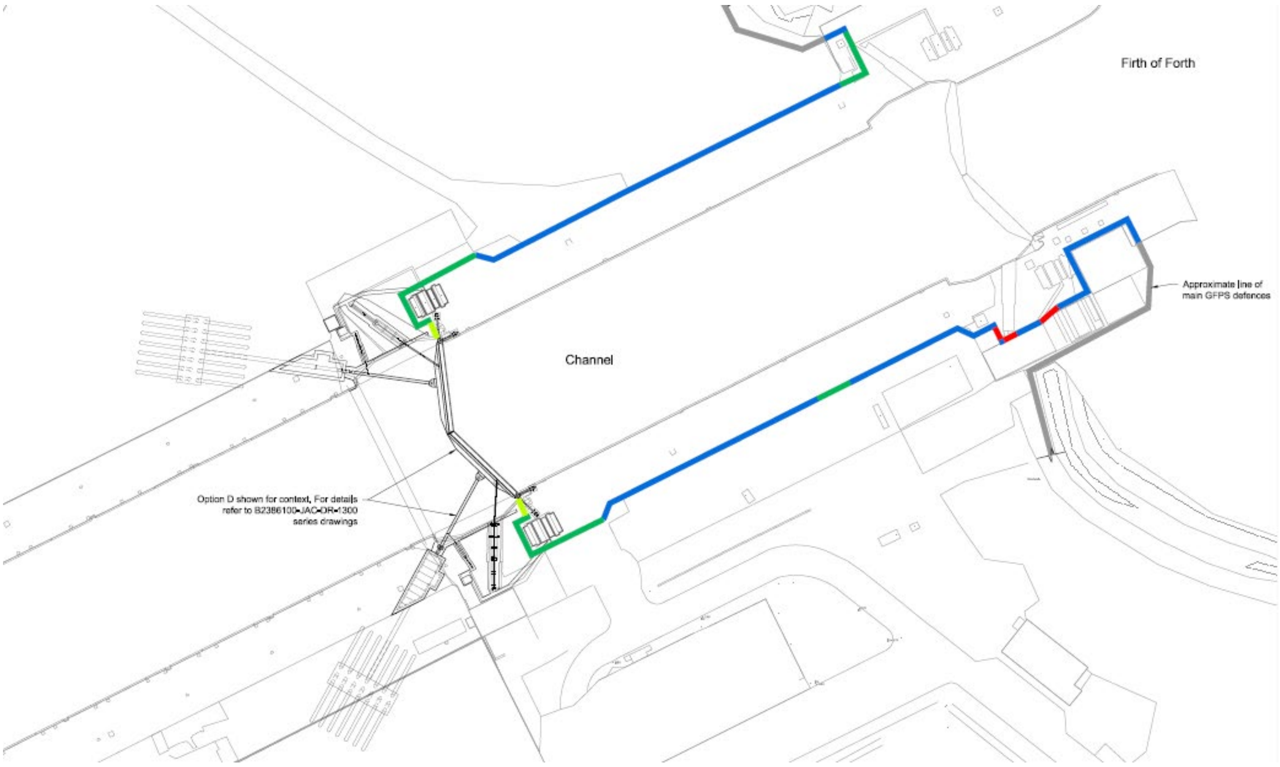


Figure 16: schematic arrangement of the quayside flood defences interfacing with gate option D

3.3 Option F – towed caisson gate

Option F involves the construction of two caisson support structures, or strongpoints, one each side of the lock channel at the inner dock end of the entrance lock. A cill element would span between these support structures adjacent to the base at the end of the lock structure. Within the two strongpoints and the cill, a slot would be formed that would be sized to fit a caisson gate and to allow a seal to be formed by the gate against each of the structures. The caisson gate, which under normal service conditions would be moored nearby within the Port of Grangemouth, would be towed by tugs and moved into position over the slot in the support structures with the assistance of land based winches and then flooded with ballast water to lower it onto the cill. For information relating to the interfacing quayside flood defences, refer to 9. Quayside flood defences.

Seals on the caisson would act against the walls of the slot when the gate is loaded hydrostatically by a reverse head of water, as is the case during flooding, preventing ingress of floodwater into the dock. Following the flood event, the ballast water within the caisson gate would be pumped out and the gate re-floated prior to towing it back to its mooring. The caisson itself would be wedge-shaped and the side walls of the support structures would be battered to facilitate the ballasting and de-ballasting operations.

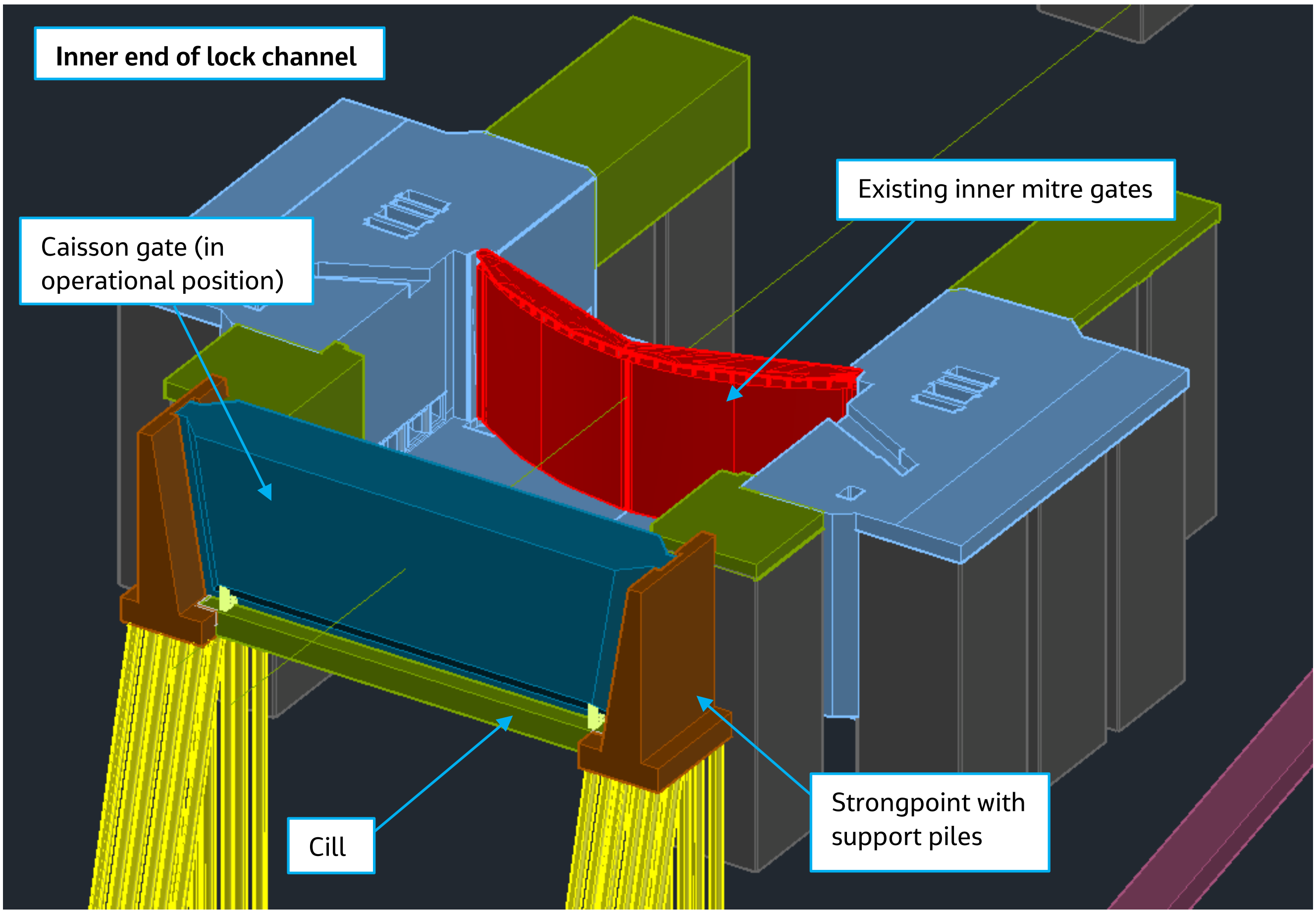


Figure 17: general arrangement of option F: towed caisson with supporting structures

4. Design standards and parameters

4.1 Flood protection levels

Each of the three selected tidal barrier options considers protection levels that are consistent with the wider Grangemouth FPS and are as follows:

- Flood protection level on implementation of the flood scheme in 2030: +5.2 metres above Ordnance Datum (mOD)
- Flood protection level at 2080 (based on predicted climate change): +5.8mOD

The design levels are based on providing protection against a 1 in 200 year AEP tidal flood event in 2080 and include a 0.6m allowance for wave overtopping, which previous modelling work has shown to result in overtopping ingress of 1 litre per second per metre of flood defence. For further details reference can be made to the hydraulic modelling report (B2386100-R-01).

It is acknowledged that the flood defence structures have a design working life of 100 years and therefore may experience increasing flood levels due to climate change between 2080 and 2130. It is anticipated that if a decision is taken later in the design stage to provide 2130 levels of resilience, this may be provided at least partly by allowing for a greater level of overtopping than 1 litre per second per metre of flood defence, which is considered minimal.

For the purpose of option comparison at outline design stage, the 2080 protection level of +5.8mOD (+8.55mCD) was taken to be the design condition. For context, the quay levels on the lock channel edge are approximately +4.3mOD to +4.4mOD which makes the apparent height of the proposed defences 1.4m to 1.5m high at the lock channel edge.

4.2 Design vessels

The maximum size of vessel which can be handled through the lock is 187 metres overall length by 27.4 metres beam by 11 metres draft. From inspection of recent marine traffic records typical sized vessels range from 60m to 180m in length and 10m to 28m in beam. A typical sized tanker using the lock is shown Figure 8.

With reference to the port's marine procedures and guidelines, vessels that are over 145m in length are required to be assisted by two tugs. For lengths between 100m and 145m one or two tugs are generally required depending on the state of the tide, wind speed, and other factors within the docks.

Although a list of design vessels for use in this study has not as yet been made available, it is recognised that a full navigational impact assessment will most likely be required to be undertaken at a later stage to confirm the option selected has no significant impact on navigation through the lock channel. For the purposes of this study, observations of the impact on navigation are made based on the form and position of the new structures, with likely impact mitigation measures being discussed where appropriate.

4.3 Design Standards

The following standards have been used for the outline design of the three short listed options. The latest available National Annexes to the Eurocodes and Published Documents also apply.

- BS EN 1990:2002+A1:2005 Eurocode – Basis of structural design
- BS EN 1991-1-1:2002 Eurocode 1: Actions on structures – General actions
- BS EN 1992-1-1:2014 Eurocode 2: Design of concrete structures – General rules and rules for buildings

- BS EN 1993-1-1:2005 Eurocode 3: Design of steel structures – General rules and rules for buildings
- BS EN 1993-5:2007 Eurocode 3: Design of steel structures – Piling
- BS EN 1997-1:2004 Eurocode 7: Geotechnical design – Part 1: General rules
- BS 6349-1-2:2016 Maritime works – Part 1-2: General – Code of practice for assessment of actions
- BS 6349-1-3:2012 Maritime works – Part 1-3: General – Code of practice for geotechnical design
- BS 6349-1-4:2013 Maritime works – Part 1-4: General – Code of practice for materials
- BS 6349-3:2013 Maritime works – Part 3: Code of practice for design of shipyards and sea locks
- DIN 19704-1:2014 Hydraulic steel structures – Part 1: Criteria for design and calculation

4.4 Design actions

4.4.1 Permanent actions

Permanent actions acting on the structure are determined in accordance with BS EN 1990 and BS EN 1991-1-1 along with their National Annexes. Where appropriate, BS 6349 Parts 1-2 and 1-3 are used as the governing design code for maritime structures.

4.4.2 Hydrostatic actions

The estuarine water levels for Port of Grangemouth have been taken from the Admiralty Tide Tables (2020) and are reproduced in Table 3. Also noted are the design water levels taken to apply within the impounded dock.

Tide	Level OD	Level CD
HAT	+3.65m	+6.4m
MHWS	+3.05m	+5.8m
MHWN	+1.85m	+4.6m
MSL	+0.35m	+3.1m
MLWN	-0.75m	+2.0m
MLWS	-2.15m	+0.6m
LAT	-3.05m	-0.3m
Maximum operational impounded water level*	+3.12m	+5.87m
Minimum operational impounded water level**	+2.89m	+5.64m
*This level is based on a survey undertaken by Malcolm Hughes in November 2020 **This level is deduced using a statement from Forth Ports Authority, Port of Grangemouth, Mitre Gates, Sluices, Machinery & Anchorages for New Entrance Lock – Maintenance Manual and Operating Instructions Volume 1 (Rendel, Palmer and Tritton) which notes a minimal operational dock water level of 0.75ft below the maximum operational level.		

Table 3: tide levels from the Admiralty Tide Tables (2020) with pertinent operational water levels within the Port of Grangemouth

The above levels are used to define two design conditions with respect to water level on each side of a flood defence:

- Flood condition – The water level on the seaward side of the defence is +5.8mOD as noted in Section 4.1. The impounded water level is taken to be at its lowest level to maximise the head difference experienced during the surge. The impounded water level is taken to be the normal impounded level minus 0.23m operational allowance, in line with the design of the original lock gates.

- Operational condition (options C and D) – for the dual-function mitre gate options, an operational case had to be considered where the water level in the dock is at its maximum, with the water level on the estuary side of the gate being taken to be a reasonable minimum. In this case, the minimum selected was LAT as this condition could reasonably be expected to occur with the maximum dock water level on the upstream side of the gate. It is possible that a lower sea level than LAT could occur on the estuary side of the gate however, it is argued that this would constitute an accidental condition, thereby attracting lower partial factors than those applied to the operational case. It is proposed that this be considered in greater detail at detailed design stage. No operational case has been presented for option F (towed caisson) as it is presumed that at least one of the mitre gates in the lock channel will be closed at all times in the deployment of the caisson barrier: see 8.6 for further discussion.

Consideration was given to a potential design situation whereby a surge that rises above the barrier during an overtopping event, causes an increase in hydrostatic pressure on the defence due to a weiring effect. This is considered to be an accidental design situation whereby partial factors of unity would apply to actions. No assessment of the potential design effects has been made as part of this comparative design exercise at outline design stage, but should be considered for the preferred option at detailed design.

4.4.3 Wind

The design effects relating to windage on the defences are not considered to be critical for the types of defences considered, though the effects of wind on operations is discussed in this report where relevant. The risk assessment forming part of any subsequent vessel collision analysis must take into account the maximum wind speed for lock transit which is defined as 40 knots by the Forth Ports Marine Procedures Guidelines and Information document.

4.4.4 Current

Current effects in the lock channel and port are assumed to be negligible. The risk assessment forming part of any subsequent vessel collision analysis must take into account currents in the Firth of Forth that may heighten the probability of a vessel strike at the middle gate location for longer vessels entering the locks.

4.4.5 Waves

The effects of waves on the defences have not been considered at this design stage. The design flood level includes an allowance of 0.6m for wave overtopping and uncertainty.

4.4.6 Ice

The effects of ice formation on the defences have not been considered at this design stage.

4.4.7 Accidental impact

The effects of accidental impact on the defences have not been considered at this design stage. As with other accidental design cases discussed in this section, accidental impacts should be given due consideration at detailed design stage.

4.5 Constraints

The objective of the construction methodology related to each gate option is to minimise disruption to port operations. However, the discussion in sections 6 to 8 indicates that no option is able to be implemented without causing some level of disruption to port operations during construction. This being the case, a set of objectives is required to work to in planning the flood defence works such that informed decisions may be made in options appraisal. The objectives for the gate options are as follows:

- Lock channel possessions for gate construction are limited to 3-4 days in length, with the total number of possessions being kept to a minimum. The number of required lock channel possessions varies depending on the option considered. As with any construction work, there is a risk that problems relating to the works may mean that a construction window closes without the planned work having been completed; this risk is reflected in the programming and costing for each option by extending the duration of each operation requiring a lock channel closure by two weeks.

- Works will be planned to minimise the disruption to the transit of vessels through the lock channel between possessions. As lock possessions will form a very small proportion of the overall programme, it is expected that the majority of the works will take place next to an operational lock channel and as such, may be subject to considerable delays due to constrained working methodologies. To reflect these difficulties, work items on the programme are subject to a 50% increase in duration.

- The solution must preserve as far as possible the current ability of Forth Ports to transit overhanging loads through the lock channel. Depending on the option, some preparatory works (e.g. removing demountable barriers) prior to any such transit may be required; this is discussed for each option in sections 6 to 8.

- The solution must not have any significant impact on navigation through the entrance locks. Sections 6 to 8 discuss some of the implications arising from the implementation of each option and the measures that may be taken at detailed design to mitigate or eliminate navigational impacts.

5. Record information

A review of the documentation held by Forth Ports in the port archives was made, with relevant data being collated for review. The archives did not contain all information relating to the lock channel infrastructure, for example reinforcement details are missing for the majority of concrete elements.

Some of the main record information used to inform the design of each option is listed in Table 4. In addition to these resources, observations were made where possible on the construction photographs for the entrance locks, particularly on general reinforcement arrangement for the channel structure.

Reference No.	Description
FPA/GD/L/3 (FP Ref. 59)	Site Plan & Borehole Locations
FPA/GD/L/4 (FP Ref. 60)	Borehole Logs
FPA/GD/L/5 (FP Ref. 61)	Setting Out Plan
FPA/GD/L/29 (FP Ref. 63)	General Arrangement of New Lock
FPA/GD/L/23 (FP Ref. 64)	Final Site Layout
FPA/GD/L/23 (FP Ref. 64)	Final Site Layout
FPA/GD/L/137 (FP Ref. 221)	Dredging of Inner Bellmouth and Details of Sheet Pile Wall
36266/1 – 76/36 (FP Ref. 1)	Gate Set out Details
36266/1 – 76/37 (FP Ref. 2)	Details of Watertight Bottom Deck
36266/1 – 76/38 (FP Ref. 3)	
36266/1 – 76/39 (FP Ref. 4)	Details of N.W.T Decks Nos 2-4 & 6-12
36266/1 – 76/40 (FP Ref. 5)	Details of Diaphragms
36266/1 – 76/41 (FP Ref. 6)	Details of Heel & Mitre Steelwork
36266/1 – 76/42 (FP Ref. 7)	Details of Flat Skin Plates
36266/1 – 76/43 (FP Ref. 8)	Details of Curved Skin Plates
36266/1 – 76/44 (FP Ref. 9)	Details of Access Trunks and Ladders
36266/1 – 76/51 (FP Ref. 16)	Details of Heel & Mitre Posts and Rubber Sill
36266/1 – 71/24 (FP Ref. 22)	Arrangement of Anchorage
36266/1 – 71/25 (FP Ref. 23)	Anchorage Parts
36266/1 – 71/27 (FP Ref. 24)	Cylinder and Crosshead Arrangement
FPA/GD/L/118 (FP Ref. 186)	General Arrangement of Gate Recess – Gate No. 2 Sht.1
FPA/GD/L/119 (FP Ref. 187)	General Arrangement of Gate Recess – Gate No. 2 Sht.2
FPA/GD/L/120 (FP Ref. 188)	General Arrangement of Gate Recess – Gate No. 2 Sht.3

Table 4: record information used

5.1 Topographical surveys

A topographical survey was carried out in November 2020 by Malcolm Hughes Chartered Land Surveyors. The survey is recorded on Drawing No. 56101_TOPO_MASTER REV_NOV2020_A.

5.2 Geotechnical information

Geotechnical information in the vicinity of the proposed support structures that is used to inform the outline design of each option include the following:

- Historical borehole logs with descriptions of strata encountered but no testing details, dated 1969 (FP ref 59 and 60)
- Borehole logs taken during recent investigation along estuary by Dunelm Geotehnical & Environmental Ltd in August 2019 (contract ref. D9638)

A simplified (and generalised) ground profile is as follows: made ground overlies strata of very soft to soft silts and clays which in turn overlie strata of sand of increasing density. Deep-lying firm clay is present beneath the sand strata at approx. -80mOD.

6. Option C: dual-function mitre gate with shot bolt and prop link

6.1 Scheme description and design approach

6.1.1 Key features of option

The key features of Option C, following an initial refinement and outline design decisions are as follows:

- New steel dual-function mitre flood gate including demountable top section of flood barrier; gate top level: +5.8mOD.
- Shot bolt mounted on each gate leaf which can be hydraulically actuated into a recess in the lock channel floor. This shot bolt supports the hydrostatic loading from the flood water level over the lower portion of the gate leaf.
- Hydraulic cylinders operate each gate leaf under normal conditions via a prop link. Under flood conditions, the system becomes the load path for hydrostatic loading from the flood water level over the upper portion of the gate leaf.
- A foundation structure comprising a reinforced concrete cap and thrust slab with steel tubular piles provides a reaction to the hydrostatic forces arising in a flood.
- Apart from bearing of the shot bolt insert against the existing lock channel floor and the self-weight of one end of the cylinder pit in bearing on the lock channel monoliths, the existing lock channel infrastructure is no more heavily loaded than it is currently.

6.1.2 Description

Option C comprises a dual-function mitre gate which would replace the existing middle mitre gate currently in use in the lock channel. In normal service when the water level in the dock exceeds that in the lock channel, the mitre gate performs identically to the existing gate set, with the mitre arrangement acting to carry the forces arising from the head differential into the quoins in compression through each gate leaf. The gate would be operated via a new, larger set of hydraulic cylinders and prop links provided on each side of the lock channel as a replacement for the existing gate cylinders.

Under flood conditions, the head differential generated by the flood level is resisted in two ways: 1) at the top of the gate, the new cylinder/prop link arrangement acts as a prop at the head of the gate, and 2) a shot bolt provided at the bottom of the gate acts as a restraint for the hydrostatic forces over the lower portion of the gate leaf. In order to more efficiently carry the hydrostatic forces arising over the upper portion of the gate leaf, the cylinder/prop link arrangement is oriented at an angle that more efficiently resists hydrostatic loading on the gate leaves, a positioning that takes the cylinder orientation closer to parallel with the lock channel sides when compared with the existing cylinders. This rotation makes the required cylinder length greater than that provided for the existing cylinders. Loading from the prop link is transferred into the supporting slab beneath the cylinder pit by way of the cylinder/crosshead mounting frame as outlined on drawing B2386100-JAC-DR-202 (Appendix A). The slab in turn carries this load in thrust to the pile group at the rear of the foundation structure where the raking tubular pile pairs are driven to a depth sufficient to provide the necessary reaction to the load. Since the existing cylinders are no longer needed to operate the gate, they would be removed along with the supporting frame, tracks and crosshead and the redundant pit would be infilled.

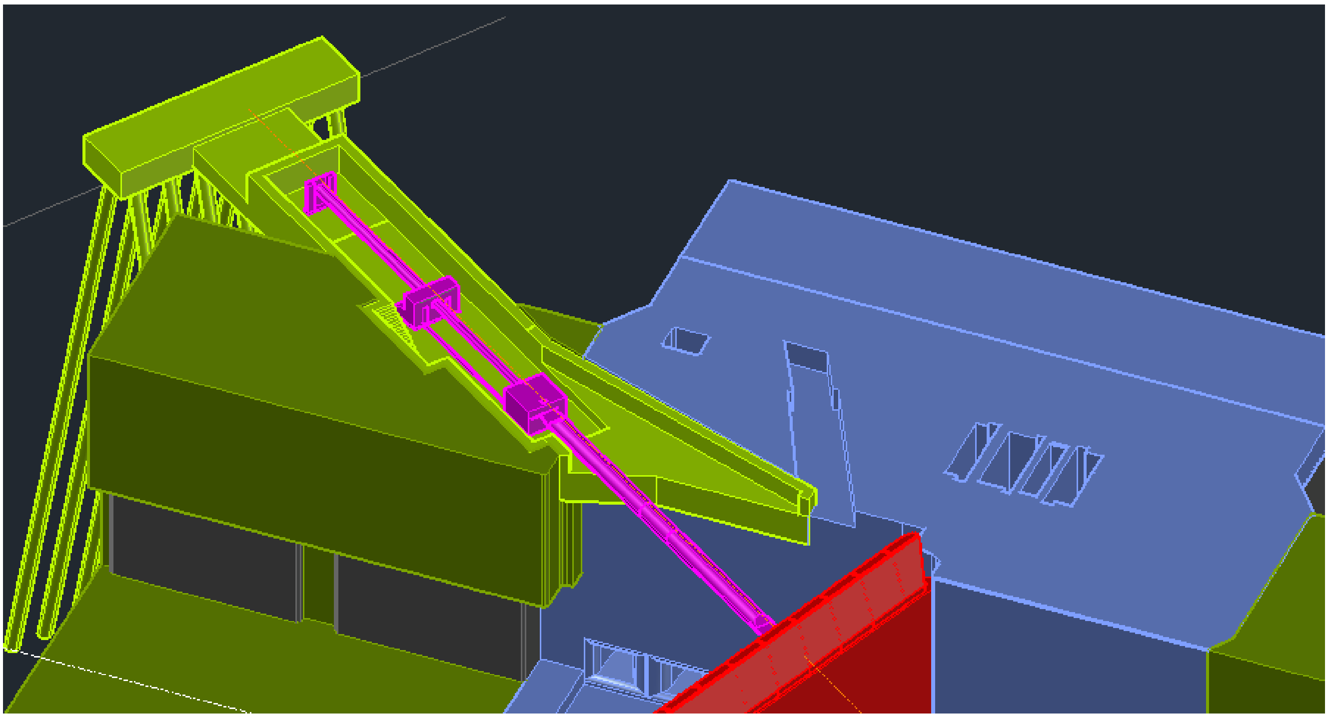


Figure 18: arrangement of prop link, cylinder, crosshead and piled foundation structure. The existing gate cylinder pit (to be infilled) is shown in blue to the right

At the bottom of the gate, the hydrostatic forces generated during the flood event are to be resisted by the shot bolt, a heavy fabricated steel section that is lowered hydraulically into a recess in the lock channel floor via a vertically-mounted cylinder housed within the height of the gate leaf. Thus, hydrostatic load over the lower portion of the lock gate is carried in shear through the shot bolt and is resisted in bearing in the existing concrete floor of the lock channel. The shot bolt is positioned directly below the prop link connection to ensure that there is no plan eccentricity between the two principal supports and that internal gate stresses are minimised. The shot bolt recess would be designed such that the bearing stresses on the existing lock channel floor are acceptably low.

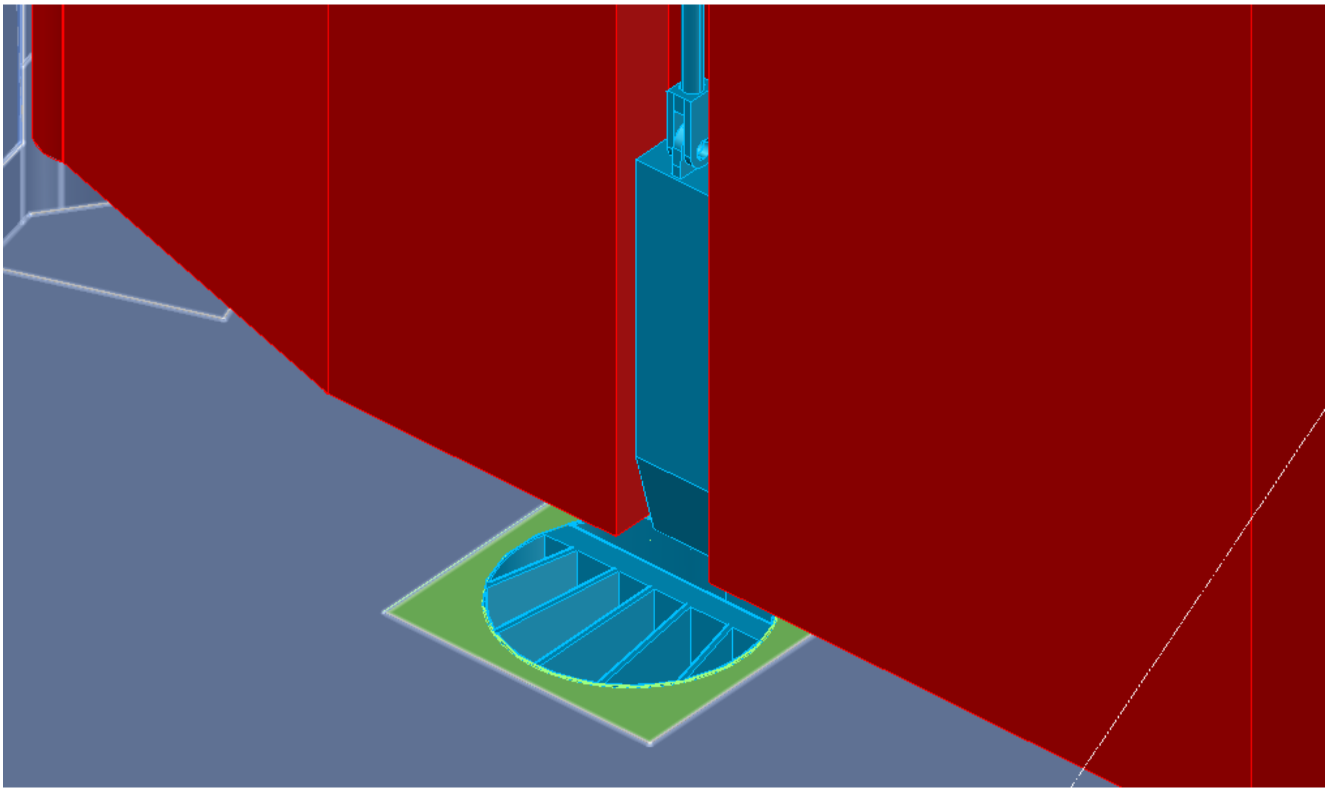


Figure 19: shot bolt and shot bolt recess

The position of the shot bolt and prop link connections along the width of the gate has been selected such that the connection is slightly closer to the gate hinge than the clapping seal where the two gate leaves meet. This ensures that any out-of-balance moment is resisted in compression in the quoin.

As part of the works for the dual-function mitre gate, the primary gudgeon anchors would need to be replaced, which would involve localised break out of the quay deck and the provision of a new anchor arrangement. To protect the existing areas of deck and the existing reinforcement, the break-out would be by hydro-demolition.

The gate would incorporate a demountable section of flood barrier at the top which could be removed if required for shipping overhanging loads. The barrier is shaped to integrate with flood defences provided on the quayside at each side of the lock channel and is flared to minimise the risk of collisions with vessel bow flares. Because the work in removing and installing the barrier would likely involve a considerable number of fixing bolts, the intention is that the demountable barrier section remains in place at all times except when it is required to transit an overhanging load, as installation of this essential defence immediately prior to a flood event may be prevented by high winds precluding the use of cranes.

As only the middle gate is to be upgraded to be able to resist flood loads, any operational accident involving the dual-function gate, for example a vessel strike, would compromise the effectiveness of Grangemouth FPS. Additionally, a vessel strike with one of the outer or inner lock gates would leave the port without the option to swap the middle gate leaves for the inner/outer equivalents to preserve lock channel navigability if interchangeability is not made a specific design requirement of the new gate. For these reasons, the design of the new flood gate ought to investigate the possibility of making the gate leaves interchangeable with the outer/inner gate leaves. Additionally, a second set of flood gate leaves would be provided to be stored within the port close to a heavy lift pad for deployment and installation in the event that the middle gate needs to be replaced to maintain the functionality of the flood defences. A large mobile crane would be needed to lift the gate leaves into the water and from there, a crane barge would be used to manoeuvre the leaves using the built-in buoyancy tanks to reduce preponderance. In this way, resilience is preserved for the lock channel in that a replacement option for the outer and inner gates is available and spare leaves are available for the flood barrier gate in the event that the middle gate position experiences a heavy collision.

6.2 Operation

Day-to-day operation of the dual-function mitre gate for port access purposes is identical to that of the existing mitre gates. Forth Ports staff operate a control panel from the quayside to control the pump set servicing the gate cylinders.

During a flood event, some additional actions are required to be undertaken to ensure the gate is propped against the flood-included forces. At the head of the gate, the prop link needs to be locked in position to enable the hydrostatic loads to be resisted without loading the cylinder itself. It is envisaged that this would be achieved by using a hydraulically activated shear pin to lock the crosshead into position, allowing thrust loads to be transferred directly into the underlying slab without being resisted by the cylinder itself.

At the foot of the gate, the shot bolt would need to be lowered into the recess in the lock channel floor. It is envisaged that both of these actions would be controlled from the same quayside control panel as is used to control the operation of the gate. When the flood level recedes and drops below the operational dock water level, the shot bolt would be extracted from its recess and returned to its stowed position on the gate leaf. The prop link would also be unlocked by hydraulically extracting the shear pin at the crosshead, allowing the gate to return to normal lock gate operations.

The act of closing/opening the gate against a reverse (flood) head is expected to take minutes and will not require any manual work. In the event that the hydraulic power unit develops a fault, a back-up unit will be provided. In the event that the backup unit fails, the gate leaves may be winched closed and the shot bolts/shear pins engaged using a mobile hydraulics pack. In this regard, timing relating to the deployment and removal of the flood defence is comparable to an ordinary lock gate closure and reopening, making this option one of the less impactful options for port operations.

For a forecast flood event it is currently envisaged that the lock would be closed to navigation traffic approximately one hour prior to the anticipated time for the gate deployment (see Table 5). The timing of the gate deployment will be when the flood action water level is reached. This action level will be based on the level at which flooding will start to occur within the port estate less the tide height commensurate with the time for deployment (circa 5-7 minutes) including any emergency operational redundancy measures (circa 55 minutes), forecasting error, and some factor of safety if deemed necessary. This action level will need to be agreed between Falkirk Council and the port.

It is envisaged that a test closure would be undertaken 1 to 2 days beforehand to test the deployment of the shot bolt and the prop link. This would be timed as appropriate between vessel movements.

An example gate operation schedule is shown in Table 5, based on our experience, for an example peak water level forecast of +4.0mOD with an action level of +3.6mOD, requiring the barrier to be in position between HW-1.75hrs and HW+1hrs.

HW-2.75	Gate leaves closed. *In the event that manual winching of gate leaves is required, allow 1hr* Shear pins and shot bolts engaged	5 mins 2 mins
HW-2.25	 *Time risk allowance*	 *53 mins*
HW-1.75	**Gate deployed**	**2.75hrs**
HW+1	**Tide falls back to action level**	
	Shear pins and shot bolts disengaged Gate leaves opened	2 mins 5 mins
HW+1.5	 **Lock channel closed for 3h52**	

Table 5: example gate operation schedule for option C based on an illustrative tide level, for deployment comparison between options only.

6.3 Maintenance

The primary maintenance requirements for this option relate to the mechanical, electrical, instrumentation, control and automation (MEICA) fixtures required for its operation, namely the cylinders actuating the gate leaves, shot bolt and prop link locking pin and the pump sets and hoses associated with each. The shot bolt and locking pins should be worked regularly by port staff to ensure reliable operation. In addition, the seals used on the gate at the mitre, cills and quoins will need periodic inspection and replacement, an operation which may require removal of the gate leaves.

Any maintenance requiring to be carried out to the pintles would likely require a cofferdam to be installed for access (it is understood that this operation has been carried out before at Grangemouth). The gate gudgeon, being a bearing, will be subject to wear and should therefore be regularly inspected and serviced.

As with any critical infrastructure, it is recommended that the gate be inspected on a regular basis to ensure their operability and to carry out any repair work as necessary, which may include repainting works and replacement of seals. Due to the proposed location of the dual-function mitre gate in the middle gate recess, the gate leaves themselves could be lifted out to maintain without requiring closure of the lock channel. The gate itself has an assumed design life of 50 years, in accordance with structures of this type, and as such will require replacement at least once in the service life of the flood defences.

The support structures are designed to meet the full service life with minimal maintenance. However, as with any port asset, repair work due to minor vessel collisions may be anticipated which could require occasional and localised repair. Depending on the level of siltation expected within the lock channel, the shot bolt recess may need to have any silt build-up periodically removed hydraulically by jetting or manually by divers.

6.4 Navigational impact

Option C is designed to have as little impact as possible on the lock operation and vessels entering and exiting the port. The dual-function gate would replace the existing gate set and would not require any alteration of the existing channel geometry that would affect navigation. In the vertical axis, the top of the dual-function gate is set at a higher level than the existing gates to afford the necessary flood protection; this is achieved by way of a demountable flood barrier forming the top section, the top of which is set at +5.8mOD. The quay level along the lock channel ranges from approximately +4.3mOD to +4.4mOD which would make the apparent protrusion of the demountable barrier 1.4m to 1.5m from quay level. The demountable barrier would run the full width of the gate leaves and would be a steel framed fabrication with panels forming the wet barrier face. The size of these elements means that demounting operations would require a crane and a considerable number of bolts to be removed. Therefore, it is considered that the only practical operation of this gate would be to consider the demountable barriers to be in place at all times except when vessels with overhanging cargoes need to pass through the lock channel. This protrusion of the top of the gate will present a collision risk to passing vessels that would need to be adequately mitigated.

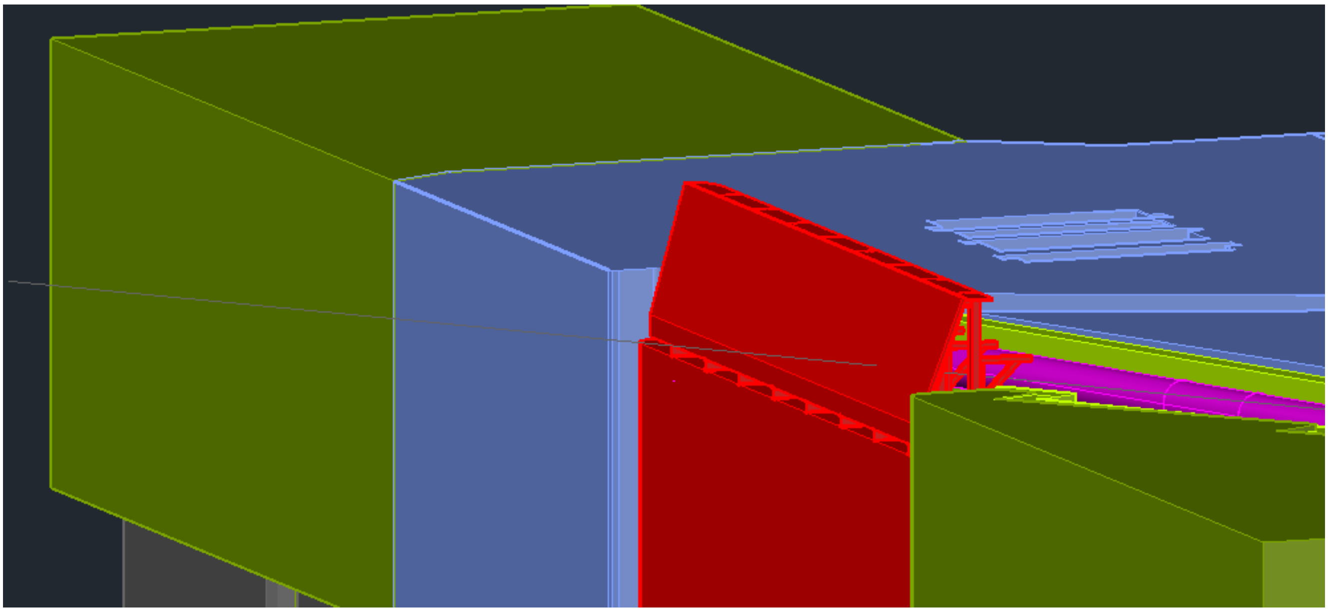


Figure 20: protrusion of demountable flood barrier above gate recess structure

6.4.1 Vessel impact protection

As the new gate geometry includes a protruding section to provide the required level of flood protection, it will require protection from vessels using the lock channel. Experience has been gained from a similar project under construction at the Port of Tilbury. On this project, the dual-function mitre gate to be installed protrudes above quay level and hence requires protective measures to be provided. These measures are discussed in the following bullet points.

- **Impact protection barriers**. The purpose of these barriers is to provide a level of protection to the flood gate from errant incoming vessels that are not properly aligned with the lock channel and could cause damage to the gate, even in its open position. Experience has shown that incoming vessels are most likely to cause damage to the lock channel infrastructure, though risk of damage by outbound vessels also needs to be assessed. A variety of structural forms may be used for the impact protection barriers and it is possible to design the barriers to shear off at a specified load to avoid overloading the supporting structures under a particularly heavy ship impact. Design of any barrier being mounted alongside the lock channel will need to take cognisance of the requirement to be demountable.

- **Demountable barrier flare**. As many of the larger vessels visiting the Port of Grangemouth have highly flared bow sections, one of the greater risks when considering vessel strikes will be due to overhang of the channel edge by the bow flare presenting a clash hazard to any protruding infrastructure. This risk can be lessened by flaring the protruding elements, in this case the demountable gate top sections.

- **Spare barriers**. As it is unlikely that impact risk on the top barrier sections can be completely eliminated, spares may be kept by the port to replace any damaged sections in the event of a vessel collision.

It should be noted that the risk profile for the works at Grangemouth will be different to Tilbury, as Tilbury involves installing a dual-function lock gate at the outer end of the lock channel rather than in the middle position, as is proposed for option C.

6.5 Operational responsibility

The responsibility for the management of flood risk in Grangemouth rests with Falkirk Council, though the flood defences considered in this study are to be constructed on land owned and operated by Forth Ports. In operation, it is anticipated under option C that Forth Ports as the experienced port operator would deploy the dual-function flood gate in its flood defence state at the instruction of Falkirk Council, as it is unlikely that the council has personnel experienced in the deployment of these types of flood defences on hand to act when required. Agreement between Falkirk Council and Forth Ports on the length of time that should be allowed between deployment of the gate as a flood barrier to the peak of a flood event will have to be reached through a process of dialogue and risk assessment.

Because the gate under option C acts as both a functional lock gate and part of the flood defence barrier for Grangemouth FPS, delineating the maintenance responsibilities and liabilities for the structures is not straightforward. It may be expected that maintenance costs relating to the main gate cylinders be borne by Forth Ports as the operator, because the use of the gate for lock transit reasons will far exceed use of the gate for flood defence reasons. Conversely, the MEICA relating to the shot bolt and crosshead shear pin may be considered to be solely part of the flood defence works. As with operational deployment, it is expected that Falkirk Council and Forth Ports will have to reach an agreement on maintenance responsibilities through negotiation.

Liability in the event of damage to the gate either when deployed as a flood defence or when in normal service would need to be negotiated between Falkirk Council and Forth Ports. Likewise, liabilities arising from failure in service would need to be clarified.

6.6 Design risks

The following section highlights some of the main risks associated with this option that may need to be assessed in greater detail at later design stages, should the option be progressed. For full details of the risks considered relating to this option, please see the designers' risk assessment and the port study risk register in Appendix F and Appendix G respectively.

Item	Comment
1. Changes to the design flood level and the impact on the supporting structures	For outline design purposes, a 'characteristic' flood level of +5.8mOD has been assumed across all design options. Whilst this is adequate for comparative purposes at concept stage, detailed design may require a range of flood levels to be considered including 'characteristic' and 'accidental' water levels, the effect of wave action and current and the effect of any weiring of water able to occur over the top of the gate option considered. As this option is being designed for a 100-year service life with an estimated operational date in 2030, by 2080 the predicted level of protection against a 1:200 year flood event will begin to diminish and the gate will be at increasing risk of facing flood stages higher than that designed for. The risk of facing such severe flood levels needs to be considered carefully, as deployment of the barrier under these conditions could lead to overloading of the support structures and potential failure of the gate. It is considered prudent to include for a 'fused' structural element that would fail preferentially in the case of the gate becoming overloaded. A practical candidate for this purpose would be the shear pin connecting the crosshead to its support frame. The aim of this provision is to limit repair of the gate to an easily accessible area and a readily replaceable element rather than risking damage to an inaccessible element e.g. the foundation piles.

2. Vessel collision	The design of option C needs to consider the risk of vessel collision with the dual-function mitre gate either when open (stowed within the gate recess) or closed. It is understood that contact of the lock channel sides and edges by transiting vessels is not uncommon at Grangemouth and the gate design will need to cater for the resulting direct and frictional loads accordingly. It is likely that 'fused' elements such as that discussed under item 1 will be necessary to protect the gate supports from damage in the case of a heavy vessel strike. As with item 1, it is anticipated that this may be achieved through the use of shear pins.
3. Gudgeon level	The level of the gudgeon on the new dual-function gate is proportionately a greater distance from the top of the gate than the same proportion on the existing gates, owing to the increased height of the new gate and the requirement to keep the gudgeon at its existing level. It is acknowledged that having a relatively low gudgeon level may lead to a less efficient gate design, as the gate leaf caters restraining the cantilevering effect of the demountable top section. If the gate design were to find that deflection of this arrangement under load was significant, problems may be encountered in the sealing of the gate leaves against each other and the interfacing quayside flood defence barriers. A similar project currently under construction at Tilbury has a gudgeon level that is proportionately further from the top of the gate than the arrangement proposed under this option. It is therefore anticipated that the gate and interfacing quayside defences can be designed to meet the geometric requirements of option C and this will need to be confirmed at a later design stage.
4. Obstructions to piling	As the supporting structures for this option rely solely on being able to drive a sufficient number of piles to a sufficient depth any obstruction not able to be overcome during piling is likely to have a major impact on the works. By enlarging the foundation structures at detailed design stage, some redundancy may be able to be offered in the piles. The Port of Grangemouth is substantially built on reclaimed land and the area under scrutiny in this port study is wholly so. Obstructions are not uncommonly found in made ground and it is prudent to allow for the probability of encountering timber, boulders, masonry etc. during the piling works. Because the piles for the foundation structures must pass through almost the entire thickness of existing made ground, the risk of encountering such obstructions is heightened when compared with option F, for example. In addition to encountering obstructions in made ground, the risk of obstructions in the natural deposits causing difficulties remains unquantified. Targeted geotechnical investigations would be recommended prior to the detailed design phase to either rule out the possibility of obstructions or to allow the designer to build in some redundancy to the piled foundations.
5. Clashes with existing lock channel infrastructure	Some of the tension piles on the piled foundation structure as designed under option C are within 1.5m of the existing monoliths forming the lock channel, assuming the monolith units have been sunk to the design depth and are plumb. Ground investigation prior to the detailed design stage should aim to verify the assumed geometry to ensure compatibility with the design. If the risk of clashes between the monolith units and the piles is deemed to be too great, pile rake may be adjusted for the affected piles or alternatively, the thrust slab may simply

	be lengthened, offsetting the foundation structure further from the channel edge.
6. Make up of lock channel floor	Option C relies on the lock channel floor being competent enough to carry loading from the shot bolt. The shot bolt insert will need to be sized to bring the stress on the concrete below a safe threshold. As little information is held on the structural make-up of the lock channel floor, it is anticipated that material sampling of the material in the lock channel floor will need to be made prior to detailed design to determine reinforcement provision and concrete strength/condition.

6.7 Construction methodology and programme

The sequencing shown on drawing B2386100-JAC-DR-205 (Appendix A) is referred to throughout this section.

6.7.1 Stages 1 and 2: Mobilisation and enabling works

An excavation is made behind the lock channel structure over the position where the cylinder/prop link foundation structure is located; depth is taken down to formation (soffit) level. Shoring is provided where necessary.

6.7.2 Stage 3: Piling

The raking and intermediate tubular piles are pitched and driven within the excavation. Once the toe level (or a set) is achieved, the piles are tested and cut. Up to this point, the lock channel is still fully functional.

6.7.3 Stage 4a: Lock channel closure 1: gate leaves removed, demolition works and part I of pit formation

This stage of the works relies on having possession of the lock channel for several low tide cycles in advance of the main window of lock channel possession. The possessions will not last longer than six hours on each occasion and as most vessel traffic transits the lock channel over mid-high tide, this is expected to minimise the disruption to Forth Ports.

Vessels transiting the entrance locks do so under full lock transits at this stage of the works as the existing middle gate is taken out of commission. To reduce disruption to transiting vessels, works to remove the gate leaves are undertaken at low water; **the lock channel is closed to traffic for a few hours as each gate leaf is lifted out** to achieve this. The gate leaves are lifted out by a crane barge within the lock channel. Two tidal cycles are allowed for disconnection of the MEICA and the gudgeons and to lift the gate leaves out: one tidal cycle for each leaf. Vessel traffic resumes on the high tide between lifts and following the second lift. Following removal of the gate, work begins on forming the pit for the shot bolt recess to be installed within. A jig comprising a frame with 4 no. hole coring rigs is lowered onto the bed to blind core holes at each corner of the square block to be removed from the channel floor. A separate jig is made up for each shot bolt pit. **This operation is carried out over several low tide possessions** as required to core to the depth of the plug to be removed. To core to the required depth is estimated to take approximately 24 hours' coring time due to the drag inherent to underwater coring. Between shifts, the jig will be lifted out of the lock channel to enable transits to resume.

Following coring of the four corners to the required depth, the jig is redeployed with plunge pulleys and a diamond wire saw to core between the holes. Wire sawing takes place between cored holes and so two sides are cut at one time. It is estimated that two days is required to complete one side cut, and so four days are required to make all side cuts. **A lock channel possession of four days is required to complete this exercise**.

Whilst the lock possession for the wire cutting works is in force, work on hydro-demolition locally to the secondary gudgeon anchors takes place and work to demolish the lock channel deck and top monolith sections to accommodate the new cylinder pit is carried out.

6.7.4 Stage 4b: Lock channel closure 2: part II of pit formation

The floor of the shot bolt pit is formed using the same method as used for the pit sides. Pulleys are fed into the cored holes to direct a diamond cutting wire to cut in the horizontal plane. It is estimated that this cut will take approximately three to four days to make and so a **further lock channel possession of four days is required for this stage**.

As the final shot bolt pit formation works are underway, hydro-demolition is used to form a new gudgeon anchor pocket, further from the channel edge.

6.7.5 Stage 5: Lock channel closure 3: form RC foundation structure, cast in shot bolt pit insert

The reinforced concrete elements forming the cylinder pit, the thrust slab and the foundation pile cap are formed, tied and cast. Gudgeon reinstatement works are undertaken including casting in a new anchor and fixing reinforcing bars locally to the secondary anchor; each location is concreted to finish. The existing cylinder pit is infilled with concrete.

The shot bolt pit inserts are installed in the pits and concreted into position over two successive low tide channel closures.

6.7.6 Stage 6: Lock channel closure 4: install gate leaves

Backfilling is undertaken around the new foundation structure and the quay deck interface is made good following installation of the sliding interface detail. The new gate leaves and their associated MEICA, prop link and gudgeon tie bars are installed, with the gate leaves being lifted in and made operational **over a two-day lock channel closure**.

6.7.7 Programme

The indicative programme for the foregoing works and expected lock channel closure periods are shown in Figure 21.

Activity	Duration (weeks)	Programme (Week Nos.) 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84	Lock channel status
Project start	0		Open
Mobilisation and site setup	2		Open
Excavate to Soffit level of piled foundation	3		Open
Drive strong point and main slab piles	18		Open
Remove existing gates and excavate for new cylinder pi	11		Low tide closures
Cast pile cap	12		Open
Cast cylinder pit	24		Open
Hydro demolish gudgeon anchor areas	3		Open
Infill existing cylinder pit with mass concrete	2		Open
Cut out pocket for shot bolt	20		2x 4-day closures
Place Shot bolt socket and concrete	5		Low tide closures
Backfill around new cylinder pit, form interfaces	3		Open
Construct Mitre Gates	20		Open
Tow mitre gates to site	2		Open
Install mitre gates, prop link, cylinder and M&E	8		2-day closure
Site clearance and demobilisation	3		Open
Project finish	0		Open
Total project duration	84 weeks		

Figure 21: option C programme

6.8 Cost

The full cost breakdown for option F is provided in Appendix E; a summary is provided here. Please note that due to the outline nature of the design stage, an optimism bias of 60% has been applied to the total cost.

Preliminaries	@	5%					£ 915,737
CAPEX total							£ 18,314,741
OPEX total							£ 1,050,000
						Subtotal	**£ 20,280,478**
Supervision costs	@	5%	of CAPEX total				£ 915,737
Engineering costs	@	5%	of CAPEX total				£ 915,737
						Subtotal	**£ 22,111,952**
Profit and contingency	@	20%	of CAPEX total				£ 3,662,948
						Total	**£ 25,774,900**
Optimism bias	@	0%					£ -
		60%					£ 15,464,940
GRAND TOTALS				incl.	**0%**	**O.B.**	**£ 25,774,900**
				incl.	**60%**	**O.B.**	**£ 41,239,840**

The total cost for this option is estimated to be approximately £41.2M including optimism bias at 60% which is consistent with estimates made for the wider FPS. Before optimism bias, preliminaries or costs relating to engineering, supervision and profit are applied, the cost of the scheme is approximately £18.3M, of which £9.0M relates to the provision of the gate fabrication (with spare gate leaves) and a further outlay of £6.0M for the second set of gate leaves assumed to come into service 50 years into the service life of the defences. The balance of approximately £3.3M relates to the construction of the associated civil works.

The operational expenditure (OPEX) is based on annual inspections and maintenance of the MEICA as well as 5-yearly inspections of the gate and 5-yearly inspection and cleaning of the shot bolt recesses.

7. Option D: dual-function mitre gate with propping frame

7.1 Scheme description and design approach

7.1.1 Key features of option

The key features of Option F, following an initial refinement and outline design decisions are as follows:

- New steel dual-function mitre flood gate including demountable top section of flood barrier; gate top level: +5.8mOD
- Propping frame recessed into the wall of the gate recess is swung into position and connected by hydraulic shear pins to the flood gate leaves prior to flood event. The propping frame carries the full hydrostatic load imposed by the flood level on the mitre gate
- Hydraulic cylinders within the existing cylinder pits operate each gate leaf
- A foundation structure comprising a reinforced concrete cap with raking tubular piles supports the prop arrangement comprising a tubular prop member with a strut and tie arrangement at the interface with the propping frame. In turn, this prop arrangement supports the propping frame, providing a reaction to the hydrostatic forces imposed during a flood
- Apart from the self-weight of the gate prop chamber in bearing on the lock channel monoliths, the existing lock channel infrastructure is not structurally relied upon by the option.

7.1.2 Description

Option D, like option C, comprises a dual-function mitre lock gate which would replace the existing middle mitre gate currently in use in the lock channel. In normal service when the water level in the dock exceeds that in the lock channel, the mitre gate performs identically to the existing gate set, with the mitre arrangement acting to carry the forces arising from the head differential into the quoins in compression through each gate leaf. The gate would be operated in the same way as the existing lock gate: via new set of cylinders and prop links from the existing cylinder pits. It is proposed to replace the existing MEICA as the new gate is likely to be heavier than the existing gate. A propping frame, a tubular steel fabrication, is mounted on the gate recess wall behind the gate. The propping frame is actuated by its own smaller cylinder and prop link arrangement which would be positioned in a new cylinder pit adjacent to the existing cylinder pit.

In advance of flood conditions, the propping frame is swung out by its cylinder. When fully extended, connection points on the propping frame align with connections on the gate and the two elements are connected using hydraulic pins mounted on the gate. When the water level on the estuary side of the gate exceeds the impounded dock water level, the forces generated by the differential head are resisted in thrust by the propping frame.

Where the propping frame connects to the gate recess wall, it is restrained by a pintle and gudgeon arrangement, similar to the existing mitre gate. However, in addition to these supports, a concave socket is provided covering the ends of the main propping frame thrust members; these sockets transfer the thrust load from the propping frame to the gate prop arrangement and ultimately, to the foundation structure. Lastly, the propping frame has vertical support at the pintle which resists uplift generated by the angle of the main propping frame thrust members.

Attached to each socket support is a fabricated square hollow section that passes through the wall of a reinforced concrete chamber. These members carry the hydrostatic load from the flood through to the strut and tie arrangement on the gate prop fabrication. The gate prop in turn carries this force axially through to the foundation structure, whose raking piles provide the required reaction. The whole arrangement from gate set, propping frame, gate prop fabrication and foundation structure carries the entirety of the hydrostatic load from the flood event and as such, is subject to deflection under what is a considerable load. To accommodate this deflection, the strut and tie portion of the gate prop member is housed within a reinforced concrete chamber. Where the gate prop passes through the walls of the chamber, details are provided that allow for the necessary translation of one element past the other. In addition, the vertical support to the propping frame includes a sliding bearing to allow for the same translation.

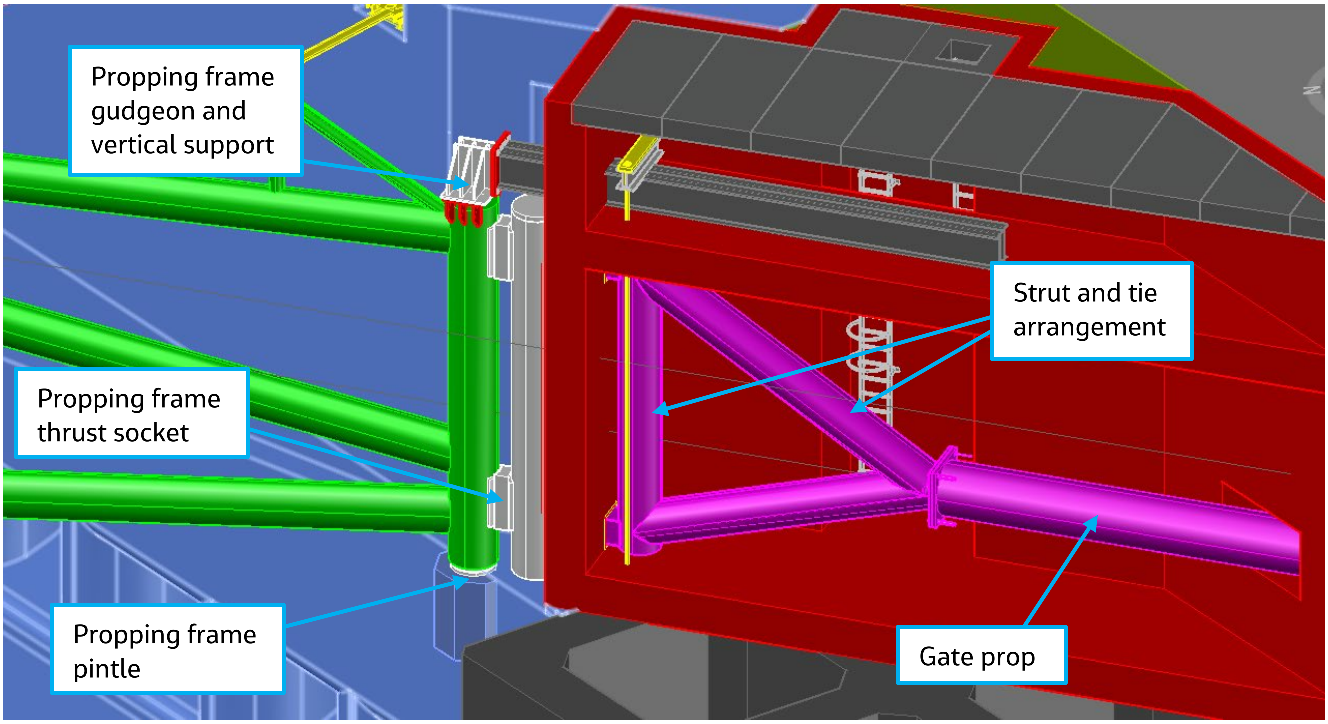


Figure 22: Detail of propping frame supports

The foundation structure contains an additional row of compressive rakers when compared to the design of the same structure under option C. This is due to the increased load it supports as option D has no shot bolt and the foundation structure is designed to carry to entire hydrostatic load imposed on the gate by the flood.

The geometry of the propping frame is limited by the layout of the existing lock channel infrastructure. Because the propping frame would have to be retracted when not operational into a recess behind the gate, the position of the levelling culverts forms a boundary beyond which the lower chord of the propping frame cannot be positioned without partially covering the culvert opening. Furthermore, it was considered desirable to terminate the demolition of the gate recess wall some distance from the roof of the levelling culverts, in order to avoid introducing any structural or durability problems to the gate recess; the recess for the propping frame is more than a metre away from the roof of the levelling culverts except at one location where an additional recess to house the lower propping frame connection bracket on the gate causes the distance from recess to top of culvert to drop to approximately 0.8m. Due to this limitation, the lower propping frame connection cannot be positioned on the gate any lower than around -6.2mOD, almost 3m above the bottom of the gate leaf. The gate design does not form part of this study, but it is expected that this lower connection positioning would be able to be accommodated by the gate designer at detailed design stage. As with option C, the plan position of the connection points from propping frame to the gate would be slightly closer to the lock channel way than to the channel centreline to ensure any out-of-balance moment is resisted in compression in the quoin.

As part of the works for the dual-function mitre gate, the primary gudgeon anchors would require to be replaced, which would involve localised break out of the quay deck and the provision of a new anchor arrangement, as described under option C.

The gate would incorporate a demountable section of flood barrier at the top which is able to be removed if required for shipping overhanging loads. The barrier would be shaped to integrate with flood defences provided on the quayside at each side of the lock channel.

Similarly to option C, only the middle gate would be upgraded to be able to resist flood loads, and any operational accident involving the dual-function gate, for example a vessel strike, would compromise the effectiveness of Grangemouth FPS. As with option C, a second set of flood gate leaves is required to be stored within the port, ready to replace damaged gate leaves.

7.2 Operation

Day-to-day operation of the dual-function mitre gate for port access purposes is identical to that of the existing mitre gate. As indicated under option C, Forth Ports staff operate a control panel from the quayside to control the pump set servicing the gate cylinders.

During a flood event, some additional actions would be required to be undertaken to ensure the gate is secured against the flood-included forces. Operators swing the propping frame into position behind the closed mitre gate and once in position, operate the locking pins that are required to connect the gate to the prop structures. It is envisaged that both of these actions would be controlled from the same quayside control panel as is used to control the gate. When the flood level recedes and drops below the operational dock water level, the propping frame is disconnected from the gate and swung back into its stowed position in the gate recess.

The act of closing/opening the gate against a reverse (flood) head is expected to take minutes and will not require any manual work. In the event that the hydraulic power unit develops a fault, a back-up unit will be provided. In the event that the backup unit fails, the gate leaves may be winched closed and the shear pins for the propping frame engaged using a mobile hydraulics pack. In this regard, timing relating to the deployment and removal of the flood defence is comparable to an ordinary lock gate closure and reopening, making this option one of the less impactful options for port operations.

For a forecast flood event it is currently envisaged that the lock would be closed to navigation traffic approximately one hour prior to the anticipated time for the gate deployment (see Table 6).

The timing of the gate deployment will be when the flood action water level is reached. This action level will be based on the level at which flooding will start to occur within the port estate less the tide height commensurate with the time for deployment (circa 5-7 minutes) including any emergency operational redundancy measures (circa 55 minutes), forecasting error, and some factor of safety if deemed necessary. This action level will need to be agreed between Falkirk Council and the port.

It is envisaged that a test closure would be undertaken 1 to 2 days beforehand to test the deployment of the propping frame. This would be timed as appropriate between vessel movements.

An example gate operation schedule is shown in Table 6 for an example peak water level forecast of +4.0mOD with an action level of +3.6mOD, requiring the barrier to be in position between HW-1.75hrs and HW+1hrs.

HW-2.75	Gate leaves closed. *In the event that manual winching of gate leaves is required, allow 1hr* Propping frames swung into position	5 mins 2 mins
HW-2.25	Shear pins engaged with propping frames *Time risk allowance*	1 min *53 mins*
HW-1.75	**Gate deployed**	**2.75hrs**
HW+1	**Tide falls back to action level**	
	Shear pins disengaged and propping frame stowed Gate leaves opened	3 mins 5 mins
HW+1.5		
	Lock channel closed for 3h53	

Table 6: example gate operation schedule for option D, based on an illustrative tide level, for deployment comparison between options only.

7.3 Maintenance

The primary maintenance requirements for this option relate to the mechanical, electrical and instrumentation (MEICA) fixtures required for its operation, namely the cylinders actuating the gate leaves, propping frames and locking pins and the pump sets and hoses associated with each. In addition, the seals used on the gate leaves at the mitre, cills and quoins will need periodic inspection and replacement, an operation which may require removal of the gate leaves.

Any maintenance requiring to be carried out to the pintles would likely require a cofferdam to be installed for access (it is understood that this operation has been carried out before at Grangemouth). The gate gudgeon being a bearing will be subject to wear and should therefore be regularly inspected and serviced. The propping frames have a hinge assembly similar to the gate and are therefore subject to a similar maintenance regime.

It is recommended that the gate is inspected on a regular basis to ensure its operability and to carry out any repair work as necessary, including any repainting works and replacement of worn seals. As with option C, as the gate occupies the middle lock gate position, the leaves could be lifted out to maintain without having to close the lock channel. The gate and the propping frames have an assumed design life of 50 years, in accordance with structures of this type, as such will require replacement at least once in the service life of the flood defences. The support structures (including the gate prop fabrication) are designed to meet the full service life with minimal maintenance. However, as with any port asset, repair work due to minor vessel collisions may be anticipated which may require occasional and localised repair.

7.4 Navigational impact

From a navigational perspective, option D is very similar to option C; please refer to section 6.4 for relevant discussion. Section 6.4.1 discusses specific impact mitigation measures that are also be applicable here.

7.5 Operational responsibility

The responsibility for the management of flood risk in Grangemouth rests with Falkirk Council, though the flood defences considered in this study are to be constructed on land owned and operated by Forth Ports. In operation, it is anticipated under option D that Forth Ports as the experienced port operator would deploy the dual-function flood gate in its flood defence state at the instruction of Falkirk Council, as it is unlikely that the council has personnel experienced in the deployment of these types of flood defences on hand to act when required. Agreement between Falkirk Council and Forth Ports on the length of time that should be allowed between deployment of the gate as a flood barrier to the peak of a flood event will have to be reached through a process of dialogue and risk assessment.

Because the gate under option D act as both functional lock gate and part of the flood defence barrier for Grangemouth FPS, delineating the maintenance responsibilities and liabilities for the structures is not straightforward. It may be expected that maintenance costs relating to the gate and the main gate cylinders be borne by Forth Ports as the operator, because the use of the gate for lock transit reasons will far exceed use of the gate for flood defence reasons. Conversely, the MEICA relating to the propping frames and locking pins may be considered to be solely part of the flood defence works. As with operational deployments, it is expected that Falkirk Council and Forth Ports will have to reach an agreement on maintenance responsibilities through negotiation.

Liability in the event of damage to the gate either when deployed as a flood defence or when in normal service would need to be negotiated between Falkirk Council and Forth Ports. Likewise, liabilities arising from failure in service would need to be clarified.

7.6 Design risks

The following section highlights some of the main risks associated with this option that may need to be assessed in greater detail at later design stages, should the option be progressed. For full details of the risks considered relating to this option, please see the designers' risk assessment and the port study risk register in Appendix F and Appendix G respectively.

Item	Comment
1. Changes to the design flood level and the impact on the supporting structures	For outline design purposes, a 'characteristic' flood level of +5.8mOD has been assumed across all design options. Whilst this is adequate for comparative purposes at concept stage, detailed design may require a range of flood levels to be considered including 'characteristic' and 'accidental' water levels, the effect of wave action and current and the effect of any weiring of water able to occur over the top of the gate option considered. As this option is being designed for a 100-year service life with an estimated operational date in 2030, by 2080 the predicted level of protection against a 1:200 year flood event will begin to diminish and the gate will be at increasing risk of facing flood stages higher than that designed for. The risk of facing such severe flood levels needs to be considered carefully, as deployment of the barrier under these conditions could lead to overloading of the support structures and potential failure of the gate. It is considered prudent to include for a 'fused' structural element that would fail preferentially in the case of the gate becoming overloaded. A practical candidate for this purpose would be the shear pin connecting the crosshead to its support frame. The aim of this provision is to limit repair of the gate to an easily accessible area and a readily replaceable element rather than risking damage to an inaccessible element e.g. the foundation piles.
2. Vessel collision	The design of option D needs to consider the risk of vessel collision with the dual-function mitre gate either when open (stowed within the gate recess) or closed. It is understood that contact of the lock channel sides and edges by transiting vessels is not uncommon at Grangemouth and the gate design will need to cater for the resulting direct and frictional loads accordingly. It is likely that 'fused' elements such as that discussed under item 1 will be necessary to protect the gate supports from damage in the case of a heavy vessel strike. As

	with item 1, it is anticipated that this may be achieved through the use of shear pins.
3. Gudgeon level and propping frame connection level	The level of the gudgeon on the new dual-function gate is proportionately a greater distance from the top of the gate than the same proportion on the existing gates, owing to the increased height of the new gate and the requirement to keep the gudgeon at its existing level. It is acknowledged that having a relatively low gudgeon level may lead to a less efficient gate design, as the gate leaf caters restraining the cantilevering effect of the demountable top section. If the gate design were to find that deflection of this arrangement under load was significant, problems may be encountered in the sealing of the gate leaves against each other and the interfacing quayside flood defence barriers. A similar project currently under construction at Tilbury has a gudgeon level that is proportionately further from the top of the gate than the arrangement proposed under this option. It is therefore anticipated that the gate and interfacing quayside defences can be designed to meet the geometric requirements of option D and this will need to be confirmed at a later design stage. Similarly to the effect the gudgeon level has on gate design, the level of the lower propping frame connection (itself restricted by the presence and geometry of the existing levelling culverts) has an effect on gate design in the flood condition, in that the bottom 3m of the gate structure is unrestrained except by the pintle and must carry hydrostatic load in shear and bending back to the lower propping frame connection, which acts as the support. Whilst it is expected that the gate design can accommodate this requirement, this is to be confirmed at a later design stage.
4. Obstructions to piling	As the supporting structures for this option rely solely on being able to drive a sufficient number of piles to a sufficient depth any obstruction not able to be overcome during piling is likely to have a major impact on the works. By enlarging the foundation structures at detailed design stage, some redundancy may be able to be offered in the piles. The Port of Grangemouth is substantially built on reclaimed land and the area under scrutiny in this port study is wholly so. Obstructions are not uncommonly found in made ground and it is prudent to allow for the probability of encountering timber, boulders, masonry etc. during the piling works. Because the piles for the foundation structures must pass through almost the entire thickness of existing made ground, the risk of encountering such obstructions is heightened when compared with option F, for example. In addition to encountering obstructions in made ground, the risk of obstructions in the natural deposits causing difficulties remains unquantified. Targeted geotechnical investigations would be recommended prior to the detailed design phase to either rule out the possibility of obstructions or to allow the designer to build in some redundancy to the piled foundations.
5. Clashes with existing lock channel infrastructure	Some of the tension piles on the piled foundation structure as designed under option D are within 2.0m of the existing monoliths forming the lock channel, assuming the monolith units have been sunk to the design depth and are plumb. Ground investigation prior to the detailed design stage should aim to verify the assumed geometry to ensure compatibility with the design. If the risk of clashes between the monolith units and the piles is deemed to be too great, pile rake

	may be adjusted for the affected piles or alternatively, the thrust slab may simply be lengthened, offsetting the foundation structure further from the channel edge.

7.7 Construction methodology and programme

The sequencing shown on drawing B2386100-JAC-DR-306 (Appendix B) is referred to throughout this section.

7.7.1 Stage 1: Lock channel closure 1: Gate leaves removed

In order to create space to work on widening the gate recess, the gate set is removed by crane barge and the lock channel reverts to full lock transits only for the duration of the works. To reduce disruption to transiting vessels, works to remove the gate are undertaken at low water; **the lock channel is closed to traffic for a few hours as each gate leaf is lifted out** to achieve this. Two tidal cycles are allowed for disconnection of the MEICA and the gudgeons and to lift the gate leaves out: one tidal cycle for each leaf. Vessel traffic resumes on the high tide between lifts and following the second lift.

7.7.2 Stage 2: Coring of the gate recess

A silt curtain is installed across the gate recess to catch fines resulting from the coring and cutting processes to be undertaken in the wet on the face of the gate recess wall. The curtain is tied and weighted such that it does not affect vessel traffic in the lock channel. A series of holes is vertically and horizontally cored into the section of the gate recess face to be removed.

7.7.3 Stage 3: Face cutting and foundation pit excavation

Blocks of concrete are sequentially cut from the face of the gate recess using a plunge wire sawing technique between the cored holes. Once cut, blocks are lifted out for recycling.

Behind the lock channel structure, a pit is excavated to allow for the construction of the foundation structure.

7.7.4 Stage 4: Limpet dam installed, demolition of areas of the quay deck

A limpet dam is installed in the corner where the propping frame is to be hinged from to allow for the breaking out of the gate recess structure in this area to be made precisely and in dry conditions. Further demolition occurs in the direction of the foundation structure to allow space for the gate prop chamber to be formed. At the opposite side of the gate recess, hydro-demolition is used to form a new gudgeon anchor pocket, further from the channel edge and a section of quay wall adjacent to the secondary gudgeon anchor is hydro-demolished to allow for strengthening works to take place.

Foundation piles are driven at this stage of the works from within the excavation.

7.7.5 Stage 5: Form pile cap, gate prop and gate prop chamber

The pile cap is formed, tied and poured and the gate prop is lifted into position, assembled and connected to the piled foundation. With the gate prop in position, the gate prop chamber is formed and poured. The vertical propping frame restraint sections are also installed at this stage. Sections of the quay deck either side of the chamber are made good.

Gudgeon reinstatement works are undertaken including casting in a new anchor and fixing reinforcing bars locally to the secondary anchor; each location is concreted to finish.

7.7.6 Stage 6: Lock channel closure 2: Install gate leaves and propping frames

Backfilling is undertaken around the new foundation structure. The new gate and its associated MEICA, prop link and gudgeon tie bars are installed, with the gate leaves and propping frames being lifted in and made operational **over a three-day lock channel closure**.

7.7.7 Programme

The indicative programme for the foregoing works and expected lock channel closure periods are shown in Figure 23.

Activity	Duration (weeks)	Programme (Week Nos.) 4 8 12 16 20 24 28 32 36 40 44 48 52 56 #	Lock channel status
Project start	0		Open
Mobilisation and site setup	2		Open
Remove existing gates	2		Low tide closures
Install silt curtain	2		Open
Core pilot holes and wire saw recess face to required depth	20		Open
Excavate to soffit level of piled foundation	3		Open
Hydro demolition of gudgeon anchor pocket	3		Open
Excavate pocket for new gate prop chamber	5		Open
Install limpet dam and break out recess wall/channel sides	6		Open
Drive strong point piles	18		Open
Cast pile cap	12		Open
Cast gate prop chamber and install gate prop support	15		Open
Set gudgeon anchors and reinstate concrete	2		Open
Reinstate gate recess walls	6		Open
Install propping frame	3		Open
Make good the existing quay interfaces	2		Open
Construct Mitre Gates	30		Open
Tow mitre gates to site	2		Open
Install gates, M&E and new access covers	8		3-day closure
Site clearance and demobilisation	3		Open
Project finish	0		Open
Total project duration	**57 weeks**		

Figure 23: option D programme

7.8 Cost

The full cost breakdown for option D is provided in Appendix E; a summary is provided here. Please note that due to the outline nature of the design stage, an optimism bias of 60% has been applied to the total cost.

Preliminaries	@	5%					£ 921,628
CAPEX total							£ 18,432,553
OPEX total							£ 820,000
						Subtotal	**£ 20,174,180**
Supervision costs	@	5%	of CAPEX total				£ 921,628
Engineering costs	@	5%	of CAPEX total				£ 921,628
						Subtotal	**£ 22,017,436**
Profit and contingency	@	20%	of CAPEX total				£ 3,686,511
						Total	**£ 25,703,946**
Optimism bias	@	0%					£ -
		60%					£ 15,422,368
GRAND TOTALS				incl.	**0%**	**O.B.**	**£ 25,703,946**
				incl.	**60%**	**O.B.**	**£ 41,126,314**

The total cost for this option is estimated to be approximately £41.1M including optimism bias at 60% which is consistent with estimates made for the wider FPS. Before optimism bias, preliminaries or costs relating to engineering, supervision and profit are applied, the cost of the scheme is approximately £18.4M, of which £8.7M relates to the provision of the gate fabrication (with spare gate leaves) and a further outlay of £5.7M for the second gate set assumed to come into service 50 years into the service life of the defences. The balance of approximately £4.0M relates to the construction of the associated civil works.

The operational expenditure (OPEX) is based on annual inspections and maintenance of the MEICA as well as 5-yearly inspections of the gate.

8. Option F: towed caisson

8.1 Scheme description and design approach

8.1.1 Key features of option

The key features of option F, following an initial refinement and outline design decisions are as follows:

- Steel caisson gate with integral ballast tanks fabricated offsite
- Operational position at inner end of lock channel with associated requirement to provide quayside defences along the lock sides to meet adjacent sections of Grangemouth FPS
- Imposed loads during flood event resisted by new structural elements with no reliance on existing lock channel for structural support
- Supporting structural elements to include two strongpoints at either side of lock channel with cill positioned along base of caisson
- Strongpoints to take the form of concrete units that are cast in-situ and supported on steel tubular bearing piles. The piles are designed based on having a length able to resist the applied loads in skin friction
- Sealing arrangement between existing lock channel and proposed structures required to prevent flow (including 'piping' of fines) during the flood situation

8.1.2 Description

Option F comprises a towed steel caisson gate and associated reinforced concrete support structures, supported by steel tubular piles. Caisson gates such as those used to seal dry docks are usually positioned where the design head difference gives inherent advantage for stability and a seal against the existing structure and in this case, would mean positioning the gate at the outer end of the channel. However, it is proposed to position the caisson gate at the inner end of the channel for the following reasons: reliance on tug availability to deploy the gate means that a deployment in relatively calm water carries much less risk; mooring of the caisson gate within the impounded dock means that any deployment on the outer end of the docks would necessarily involve a lock transit, and; siltation of the lock channel entrance is considerable and given the reliance of the caisson gate on its seal slot, this effect could lead to major deployment difficulties. Furthermore, the consistently high water level in the impounded basin also facilitates caisson deployment and has the potential to simplify the caisson design. Note that this 'off-seating' positioning precludes the use of other types of caisson gates, such as hinging caissons.

In preference to modifying the existing channel walls to create a suitable recess for the caisson gate, it is proposed to construct a strongpoint arrangement at the impounded end of the channel that can accommodate the design forces and provide a sealing mechanism against the existing structure to prevent water ingress during a flood event. The reason for this is primarily structural: there is little record information held on the lock channel infrastructure and the record information that is held suggests the monolith units that form the main channel walls are essentially lightly-reinforced gravity structures designed for earth retention purposes but that are poorly suited to resisting the large, concentrated loads that would be exerted by a caisson gate.

On each side of the lock channel, a strongpoint structure would be constructed using reinforced concrete to form the main body of the structure and steel tubular piles are driven into the underlying ground to provide the necessary vertical and lateral support. A slot is formed in the strongpoint upstand element to accommodate the caisson and receive hydrostatic loading through the caisson seal. On the base of the structure, a projection towards the channel centreline exists to form a bearing for the placement of the cill element, which spans between strongpoint structures. To reduce its self-weight and therefore the load passed onto the strongpoint piles, the cill would take advantage of its submersion in water through the inclusion of expanded polystyrene-filed cells to add buoyancy. The cill would also incorporate a slot through which it receives hydrostatic loading from the caisson gate; this load is passed onto the strongpoint structures through the spanning action of the cill. Due to this arrangement, forces resulting from the self-weight of the caisson and its support structures and from the hydrostatic actions developed in a flood event are resisted entirely by the pile groups beneath each strongpoint structure. This is a deliberate design decision taken due to the poor ground conditions in the port, with piles long enough to reach a deep-lying dense sand stratum being the only economical way to support the hydrostatic loads developed during flooding under this option. Based on a review of available geotechnical information (both historical and recent) in the vicinity of the lock channel, the proposed support piles are unlikely to reach bedrock and will be reliant on developing sufficient skin friction. There is an associated constraint on the length of pile that can be delivered to site and handled meaning that some degree of on-site welding would be anticipated.

The design of the caisson gate itself is not within the scope of the design work as caisson gates of this size and type are commonplace and readily fabricated. In order for the outline design of the support structures to be completed, however, the necessary minimum breadth of the gate was determined using some simple stability calculations and using this geometry along with sectional data of similar gates, the stiffness of the caisson gate could be estimated for use in determining the distribution of hydrostatic loads from the flood condition.

As the strongpoints support all loads from the caisson, the lock channel infrastructure would not be not relied upon structurally for this option. However, as the caisson applies significant lateral loading to the strongpoints with a proportion of this load being applied at considerable height above the piled support, the strongpoints would experience some deflection and rotation away from the inner end of the lock channel when loaded. The resulting gap represents a possible ingress into the impounded dock for floodwater. To prevent this occurrence, seals would be provided between the strongpoints and cill and the adjacent lock channel structure (see drawing B2386100-JAC-DR-106). In addition, mass concrete is provided between the cill and the end of the lock channel base to prevent piping beneath the cill element as a result of differential head.

8.2 Operation

It is envisaged that the caisson gate would be moored within the impounded dock during normal operational times (i.e. outwith flood events). Usually, more than 48 hours' notice is provided by forecasters for tidal surges and this allows for the caisson to be towed into the vicinity of the lock channel in advance of its deployment without affecting port operations (it would also be possible to temporarily moor it nearby). In preparation for a forecasted flood event, the caisson gate would first be readied for deployment by running through a list of pre-operational checks. Emergency stops, alarms and tank level gauges are checked before de-ballasting of the caisson begins, assuming the gate is usually ballasted on its mooring. It is expected that the onboard pump sets could empty the tanks of ballast water in approximately 15 minutes. The caisson would then be then released from its mooring and towed by tug to the lock channel before being manoeuvred into position above the gate recess. For fine positioning, it is envisaged that capstans would be provided on each side of the lock in order to winch lines attached to the caisson. The capstans would be located on the estuary-side of the slot to maintain tension in the lines. The caisson is then lowered into the recess by flooding internal cells via the operation of a valve/sluice on the caisson itself. Trim would be checked continually at this point and to ensure a controlled ballasting process, the intake of ballast water occurs over a 15-minute period. The full process of running through pre-operational checks to seating the caisson within its slot depends on where the gate is stored within the impounded dock, but in any case, is anticipated to take approximately one hour to complete. The impact on vessel traffic using the lock channel would be less than this since the de-ballasting and initial tug operations need not affect vessels using the lock channel.

For a forecast flood event it is currently envisaged that the lock would be closed to navigation traffic approximately 30 minutes prior to the anticipated time for the gate deployment (see Table 7). The timing of the gate deployment will be when the flood action water level is reached. This action level will be based on the level at which flooding will start to occur within the port estate less the tide height commensurate with the time for deployment (circa 30 minutes) including any emergency operational redundancy measures, forecasting error, and some factor of safety if deemed necessary. This action level will need to be agreed between Falkirk Council and the port.

Once in position ahead of the forecasted flood event, the water level in the channel rises with the tide until the point at which it exceeds the water level retained behind each set of lock gates. When this happens, the lock gates have no means of resisting the hydrostatic loads developed and are pushed open. This leaves the caisson exposed to the rising tide level and as a head is developed on the estuary side of the gate, the resulting hydrostatic forces compress the fender seals on the caisson gate against the slot walls on the caisson and strongpoints creating a seal against floodwater ingress into the port; the caisson slides towards the port as these seals compress.

As the tide recedes, the caisson gate is gradually unloaded leading to decompression of the fender seals and the gate sliding away from the port. There comes a point when the level of the tide will fall below the level of the water in the impounded dock, causing reverse head forces to be developed on the caisson. A second set of fender seals will be provided on the estuary side of the caisson gate which will engage with the corresponding slot wall thereby preventing loss of impounded dock water before the mitre lock gates can be closed. The lock gates can be closed once the water level has dropped sufficiently and as the caisson gate is in place, the water level in the lock channel will be equal across all gates to the tide level.

Once the lock gates have been closed, the caisson gate may be re-floated. To do this, the caisson use its own pump sets able to expel the ballast water taken on in deployment. To aid in re-floating, the water level on each side of the caisson gate should be equalised to ensure both sets of seals are decompressed. This could be achieved using a set of valves on each side of the gate. Lines attached to the caisson would be tended during the de-ballasting period and once afloat, the caisson would be towed away by tugs back to its mooring, tied up and re-ballasted. From the start of the de-ballasting phase to being pulled clear of the lock channel by tugs is anticipated to be approximately half an hour in duration. When compared with options C and D, this option more demanding on port staff and resources for its deployment and removal. It is also a more time consuming option from the point of view of re-opening the lock channel to vessel traffic.

An example gate operation schedule is shown in Table 7 for an example peak water level forecast of +4.0mOD with an action level of +3.6mOD, requiring the barrier to be in position between HW-1.75hrs and HW+1hrs.

	Pre-operational checks	10 mins
HW-2.75	De-ballasting	15 mins
	Manoeuvre to lock channel vicinity by tug	10 mins
HW-2.25	Position over slot	15 mins
	Controlled ballast	15 mins
HW-1.75	**Gate deployed**	**2.75hrs**
HW+1	**Tide falls back to action level**	
	De-ballasting	15 mins
	Tie lines to tug and pull clear	15 mins
HW+1.5		
	Lock channel closed for 3h45	

Table 7: example gate operation schedule for option F, based on an illustrative tide level, for deployment comparison between options only.

8.3 Maintenance

The caisson gate has a limited amount of MEICA fixtures required for its operation, namely some limited valve equipment (whether manually or hydraulically operated) and pump sets on board the caisson itself for flooding and dewatering purposes as well as some capstans on each quayside to help with the fine positioning of the caisson once it has been towed by tugs into place. As a result, annual maintenance requirements are expected to be limited in scope.

As with any critical infrastructure, it is recommended that the caisson be inspected on a regular basis to ensure its operability and to carry out any repair work as necessary, which may include repainting works and replacement of fender seals. Depending on the scale of the repair work, dry docking may be necessary. The caisson itself has an assumed design life of 50 years, in accordance with structures of this type, as such will require replacement at least once in the service life of the flood defences. The support structures would be designed to meet the full service life with minimal maintenance; as with any port asset, repair work due to minor collisions may be anticipated, and depending on the service life of the seals selected to interface with the lock channel structure, a change in the elastomeric element may be required at intervals through the service life. Depending on the level of siltation expected within the impounded basin, the cill slot may need to have any silt build-up periodically removed by jetting or manually using divers.

8.4 Navigational impact

Option F is designed to have as little impact as possible on the lock operation and vessels entering and exiting the port. Because the gate would be built onto the end of the existing lock channel, the effective length of the lock channel would be increased on the eastern side by the breadth of the strongpoint structure; on the western side, the approach structure already exists and therefore there is no change in channel length on this side. Because the upstand sections of the strongpoint structures would be set back from channel edges, it is not expected that the structures would place any restriction on vessel movements in the horizonal plane; furthermore, if required, the strongpoint structures could be aligned with the lead in structures on each side of the channel to ensure that the space currently afforded to vessels is not compromised (see Figure 24). In the vertical axis, the top of the strongpoint structures would protrude above the existing deck level by approximately 1.5m, though the structures are set back from the existing channel edge. If this arrangement was deemed to be too restrictive to over-hanging cargo navigation, it is possible that a demountable top section of strongpoint could be designed to remove this restriction.

Irrespective of the final arrangement, it is recommended that a full navigational impact assessment is undertaken with specific design vessels to ensure navigation is unimpacted by the works. Should this assessment find that impact mitigation measures are required for the proposed arrangement, the measures discussed under section 6.4.1 are applicable.

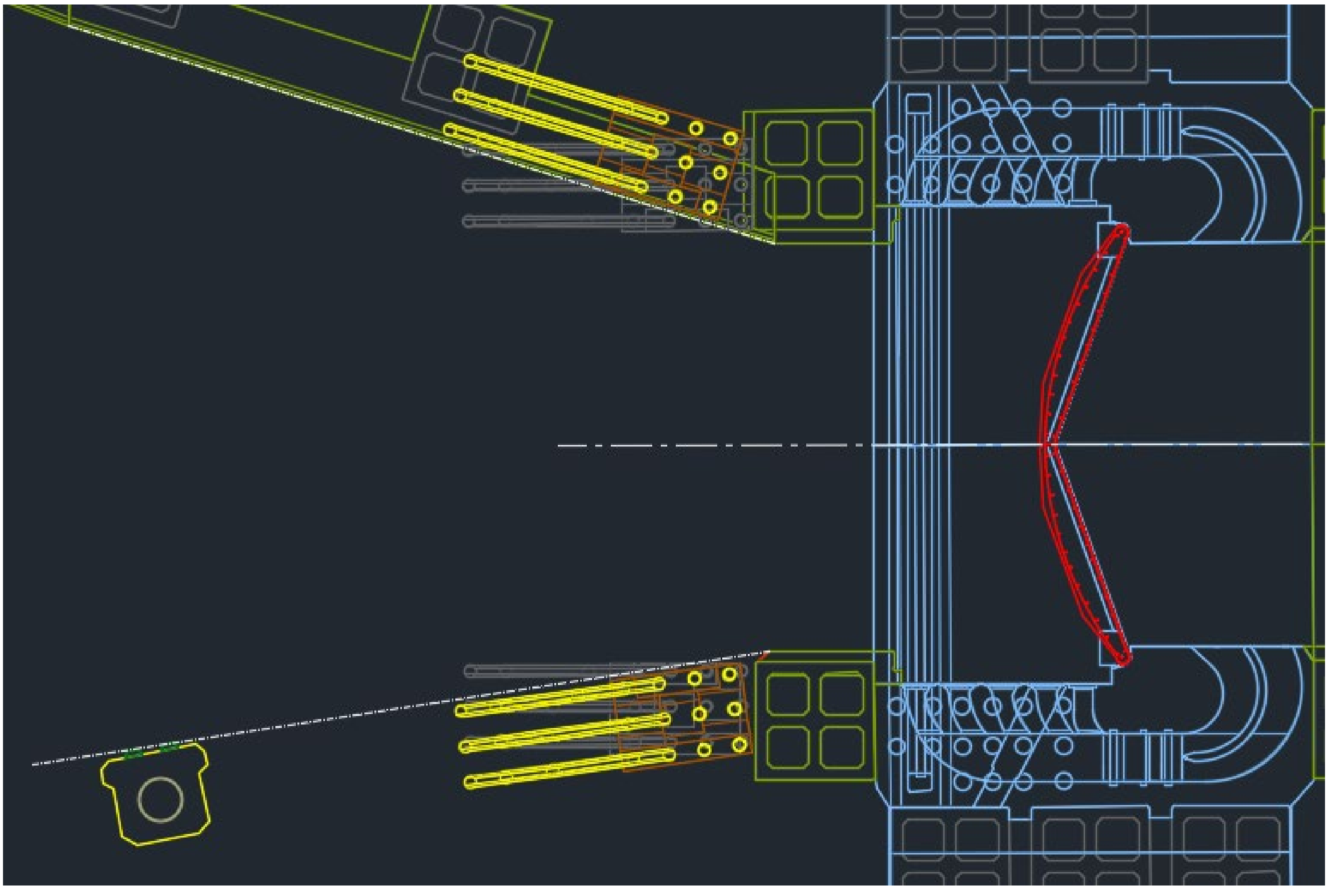


Figure 24: Possible alignment of the strongpoint structures with the existing inner alignment pier/dolphin (arrangement of strongpoints square to existing lock channel shown in grey for comparison; note that the full pile length is embedded and is not expected to have implications for navigation)

8.5 Operational responsibility

The responsibility for the management of flood risk in Grangemouth rests with Falkirk Council, though the flood defences considered in this study are to be constructed on land owned and operated by Forth Ports. In operation, it is anticipated under this option that Forth Ports as the experienced port operator would deploy the caisson gate at the instruction of Falkirk Council, as it is unlikely that the council has personnel experienced in the deployment of these types of flood defence on hand to act when required. Agreement between Falkirk Council and Forth Ports on the length of time that should be allowed between deployment of the caisson to the peak of a flood event will have to be reached through a process of dialogue and risk assessment.

A characteristic of option F as a flood defence solution is its clear delineation from other port assets. In operation, the structure requires no structural support from the existing lock channel infrastructure and is constructed as a separate entity, requiring only the fixing of a seal onto one side of the existing lock channel edge. In this respect, it is an easy option for Falkirk Council and Forth Ports to determine limits of liability and maintenance responsibilities as the day-to-day operation of the locks does not rely on any of the structures provided.

Liability in the event of damage to the caisson gate either when moored or when in operation by vessel collision etc. would need to be negotiated between Falkirk Council and Forth Ports. Likewise, liabilities arising from failure in service would need to be made clear.

8.6 Design risks

The following section highlights some of the main risks associated with this option that may need to be assessed in greater detail a later design stage, should the option be progressed. For full details of the risks considered relating to this option, please see the designers' risk assessment and the port study risk register in Appendix F and Appendix G respectively.

Item	Comment
1. Changes to the design flood level and the impact on the supporting structures	For outline design purposes, a 'characteristic' flood level of +5.8mOD has been assumed across all design options. Whilst this is adequate for comparative purposes at concept stage, detailed design may require a range of flood levels to be considered including 'characteristic' and 'accidental' water levels, the effect of wave action and current and the effect of any weiring of water able to occur over the top of the gate option considered. As this option is being designed for a 100-year service life with an estimated operational date in 2030, by 2080 the predicted level of protection against a 1:200 year flood event will begin to diminish and the gate will be at increasing risk of facing flood stages higher than that designed for. The risk of facing such severe flood levels needs to be considered carefully, as deployment of the barrier under these conditions could lead to overloading of the support structures and potential failure of the gate. Another aspect requiring consideration is that the pile configuration for each of the strongpoints uses a group of twelve piles to resist the loads exerted on them. Any increase in the hydrostatic forces may have a disproportionate impact on the scale of the strongpoint, since if the caisson were to remain the same size and the piles are not to obstruct the lock channel, any additional piles added to the configuration would not take a proportionate share of the load due to their relative remoteness from the main points of load application. Additionally, the piles cannot be moved any closer to one another to be able to fit more sections within the same footprint without introducing inefficiencies in the way the piles behave. It may therefore be the case that the solution would involve widening the span of the caisson, thereby increasing the total load to be resisted further still.
2. Reverse head condition	As described in section 8.2, a reverse head condition is experienced by the caisson following a flood event as the tide recedes. As the strongpoint structures are built abutting the existing lock channel, it is anticipated that any reverse hydrostatic load resulting from this condition would be supported by the existing lock channel structure, something that needs to be assessed in detailed design stage if this option is taken forward. Whilst some level of reverse loading is expected to be able to be accommodated, there is potential for extremely high forces to be developed on the caisson if there is a problem with reclosing the mitre lock gates after they have been forced open by the rising flood tide, as the head differential between operational dock water level and, for example, mean low water springs, is approximately twice as great as the head differential designed for under flood conditions. Another potential way for a reverse head situation to development is following the deployment of the caisson gate in advance of the flood event. If the deployment takes place on a low tide, failure by the lock gates to maintain operational dock water level on the estuary side of the caisson would lead to reverse loading. Whilst it is understood that mechanical interlocks prevent the opening of all lock gates at once, detailed design may have to risk assess the

	potential for operator error in a sequenced opening leading to low water levels in the lock channel, or the potential for an accident such as a collision with the mitre gates.
3. Vessel collision	The risk of vessel collision with the caisson gate either when it is moored or in the case that it is deployed in position needs to be assessed. Given that the port will be effectively closed in the lead-up to and during a flood event, the risk posed by vessels in transit to a deployed caisson barrier would seem to be small. However, the risk of a vessel collision with the gate were it to be moored in an insufficiently-protected location and consequences for the FPS as a whole if the gate could not then be deployed due to damage should be properly assessed.
4. Obstructions to piling	As the supporting structures for this option rely solely on being able to drive a sufficient number of piles to a sufficient depth, and that as discussed under item 1, the configuration of the piles is sensitive to the overall load share between members, any obstruction not able to be overcome during piling is likely to have a major impact on the works. By enlarging the strongpoint structures at detailed design stage, some redundancy may be able to be offered in the piles, though it is possible that some piles (e.g. the compressive raker closest to the lock channel) will remain critical members. The Port of Grangemouth is substantially built on reclaimed land and the area under scrutiny in this port study is wholly so. Obstructions are not uncommonly found in made ground and it is prudent to allow for the probability of encountering timber, boulders, masonry etc. during the piling works. Because the piles for the strongpoints start at such a low level, the risk of encountering such obstructions may be lowered, though this has no impact on the risk of encountering obstructions in the natural deposits, which at this stage remains unquantified. Targeted geotechnical investigations would be recommended as prior to the detailed design phase to either rule out the possibility of obstructions or to allow the designer to build in some redundancy to the piled foundations.
5. Pile congestion	As the strongpoints rely on a layout of piles at 2.75m plan centres, pile verticality tolerance may become an issue leading to pile clashes during construction due to the large pile lengths required. Of particular concern are the raking piles in the configuration, which being the compressive elements, all rake in the same direction. As the rake is greater than 1:6, a tolerance of 1:15 on pile rake should be allowed for if following the guidelines within the ICE Specification for Piling and Embedded Retaining Walls, 3rd ed, a provision with potential to give rise to clashes at depth. A specialist piling contractor may be able to adopt a piling methodology to better the tolerance stated above. Early contractor involvement prior to detailed design would act to mitigate this risk. Alternatively, a staggered layout for the raking piles would mitigate the clash risk, as would adopting a steeper design rake on the external row.

8.7 Construction methodology and programme

The sequencing shown on drawings B2386100-JAC-DR-107 and B2386100-JAC-DR-108 is referred to throughout this section.

8.7.1 Stage 1: Enabling works

In order to create a gap in which to build the strongpoint on the western side of the lock channel, the existing lead-in jetty is required to be partially demolished. At this location, the jetty comprises a reinforced concrete deck that spans between the end monolith of the western side of the lock channel and a remote monolith unit forming part of the lead in jetty. First, holes would be cored in the reinforced concrete deck adjacent to the cut line through which supporting piles are driven. Following driving of the new support piles, reinforced concrete pile heads would be formed to connect the piles to the retained section deck. The deck portion to be removed would then be cored and supported on slings by cranes positioned at the end of the existing lock channel; following this, cuts would be made using road saws to enable the deck to be lifted out. If craneage limitations mean that the deck requires to be lifted out in more than one section, temporary supports are provided to facilitate this. As far as can be deduced from site records and inspection data, the eastern side of the lock channel requires no enabling works.

The areas where the strongpoints are to be constructed will be dredged down to concrete soffit level if bed level on each side of the channel is found to be higher than this. This is likely to be able to be achieved by using a long-reach excavator on the end of the existing lock channel, at each side.

8.7.2 Stage 2: Preparatory works for piling

Depending on how piling is to be undertaken, a piling gate may be necessary to enable piles to be driven. In this event, a gate is fabricated on the quayside before being fixed in position over the end of the lock channel. A crawler crane with piling hammer and vibrator is then used to drive the piles. If a crane can be fitted with a suitable piling leader and hammer, a piling gate may not be required. Advice to be sought from a specialist piling contractor at detailed design stage.

8.7.3 Stage 3: Piling

Piles to be driven in a sequence that enables the piling rig to be positioned on the end of the existing lock channel for the whole work stage. All piles to be cut down to head level using a dive team, or alternatively a surface-controlled wire-cutting method.

8.7.4 Stage 4: Construct cofferdam

Sheet piles, waling and internal props forming the cofferdam installed using crawler cranes and a dive team. A guide frame may have to be positioned over the driven piles to allow the accurate driving of the sheet piles. To form a seal against the existing lock channel structure, the end pile will comprise a clutch welded to a U-pile section. A grout sock will then be placed over within the void created to form the interface with the existing concrete face. Once the props are placed, the cofferdam is pumped out and the pump will run continuously from a sump to keep the excavation dry. The sides of the cofferdam closest to the lock channel are inset from the channel edge to lessen the risk of vessel strikes on the temporary structure. Working within the cofferdam during vessel transits will not be permitted.

8.7.5 Stage 5: Form strongpoint cap

Given the very soft nature of the superficial soil deposits in the area, the soffit of the first lift of the strongpoint pour will need to be supported on the strongpoint piles to prevent settlement; sacrificial steel sections welded to the piles may be required to achieve this. After the first lift is sufficiently cured, the subsequent lifts are borne in bearing and punching shear by the support piles and first concrete lift respectively. Once the concreting works are complete, seals are installed between the strongpoint and the existing lock channel structure. The cofferdam is then flooded and then dismantled.

8.7.6 Stage 6: Lock closure 1: cill installation

The cill would be either constructed on a submersible barge or within a dry dock. Following its construction, it would be barged to site and **the lock channel will be closed to allow installation.** If built on a submersible barge, the barge would be positioned adjacent to the strongpoints and each end of the cill connected to cranes (one on each side of the lock channel) prior to submersion. As the cill element becomes submerged, the cranes support its net weight (which is low due to the expanded polystyrene cell infill used in its construction). The cranes would then guide the cill into position on the strongpoint supports. **Three days** are allowed for the positioning and installation process. If the cill is constructed in a dry dock, floatation devices would be attached to the element prior to submersion to provide the required level of buoyancy to tow to site. These floatation devices would then be used in conjunction with cranes to position and sink the element in a controlled fashion. Once the cill is in position, the lock channel would be reopened to vessel traffic. To complete the cill connection, grout would be tremied into each end of the cill/strongpoint connection to provide fixity. This would be planned to be carried out between vessel transits, avoiding the need for a further lock closure.

8.7.7 Stage 7: Lock closure 2: mass concrete between end of lock channel structure and cill

With the cill in position, the gap between the lock channel and cill is infilled with mass concrete to limit cill deflection in the event of a reverse loading design situation and to prevent piping beneath the cill. To allow for continuity in the underwater pour, **the lock channel will be closed to vessel traffic for four days**. The omega seals between the cill and the mass concrete would be installed on the cill element prior to its installation and, along with any local reinforcement, propped in position by sacrificial timber formwork, negating any need to install these elements at a later stage.

8.7.8 Stage 8: Lock closure 3: Test deployment of caisson

The caisson is towed into position and deployed to check for fit. **A lock channel closure of three hours at low tide** is required to undertake the test.

8.7.9 Programme

The indicative programme for the foregoing works and lock channel closure periods are shown in Figure 25.

Activity	Duration (weeks)	Lock channel status
Project start	0	Open
Mobilisation and site setup	2	Open
Partially demolish and support lead in jetty	6	Open
Drive strong point piles	18	Open
Construct cofferdam around strong points	5	Open
Cast pile cap	15	Open
Cast pre-cast cill on barge	12	Open
Install pre-cast cill and grout connections	5	3-day closure
Cast mass concrete channel base	5	4-day closure
Install omega seals	3	Open
Construct caisson	30	Open
Tow caisson to site	2	Open
Deploy caisson	2	Open
Site clearance and demobilisation	3	Low tide closure
Project finish	0	Open
Total project duration	**65 weeks**	

Figure 25: option F programme

8.8 Cost

The full cost breakdown for option F is provided in Appendix E; a summary is provided here. Please note that due to the outline nature of the design stage, an optimism bias of 60% has been applied to the total cost.

Preliminaries	@	5%					£ 1,439,627
CAPEX total							£ 28,792,532
OPEX total							£ 34,180,000
						Subtotal	**£ 64,412,159**
Supervision costs	@	5%	of CAPEX total				£ 1,439,627
Engineering costs	@	5%	of CAPEX total				£ 1,439,627
						Subtotal	**£ 67,291,412**
Profit and contingency	@	20%	of CAPEX total				£ 5,758,506
						Total	**£ 73,049,919**
Optimism bias	@	0%					£ -
		60%					£ 43,829,951
GRAND TOTALS				incl.	**0%**	**O.B.**	**£ 73,049,919**
				incl.	**60%**	**O.B.**	**£ 116,879,870**

The total cost for this option is estimated to be approximately £116.9M including optimism bias at 60% which is consistent with estimates made for the wider FPS. Before optimism bias, preliminaries or costs relating to engineering, supervision and profit are applied, the cost of the scheme is approximately £28.8M, of which £10.4M relates to the provision of the caisson gate and a further outlay of £10.4M for the second caisson assumed to come into service 50 years into the service life of the defences. The balance of approximately £8.0M relates to the construction of the supporting structures.

The operational expenditure (OPEX) is based on deployment costs of half a day of time for 2x tugs per deployment, with 8,420 deployments over the service life of the structure. At £34.2M before application of costs, it eclipses the capital expenditure for this gate option. It should be noted that the estimated number of deployments should be regarded as an 'order of magnitude' estimate as it depends on many variables including the port's selected action level for defence deployment, the forecasting error of SEPA flood warnings the frequency of storm surges and the proportion of spring tides triggering defence deployment in future. See 2.5 for further details. Annual inspections and maintenance of the MEICA as well as 5-yearly inspections of the caisson structure form part of the OPEX cost.

9. Quayside flood defences

9.1 Overview

The alignment of the quayside defences is discussed in detail in the optioneering report for the port study (B2386100-JEC-S4-C03-ZZZ-RE-C-0001). Because the provision of such defences has an effect on the accessibility of facilities from the quayside (the pumphouse, stilling basin, machinery houses and approach structures, for example), their alignment will have to be developed in close collaboration with Forth Ports to ensure workability for port operations. For pricing purposes, it is envisaged that the quayside defences will comprise three different types:

1. Permanent concrete walls: these walls will be cantilever in form and will be structurally tied into the existing quay deck to provide a seal against floodwater ingress. Coring of the concrete deck where the defences are to be placed is envisaged to enable placement of reinforcement.

2. Stoplog system: this barrier system comprises post and rail elements that can be lifted out in the event that access is required to a particular section of the quay deck. It is envisaged that this system would be used either where access is required infrequently enough to warrant demounting a section of barrier, or where the barrier can be replaced quickly and at short notice following issuance of a flood warning. The posts are placed into recesses formed in the quay deck.

3. Proprietary flood gates: this barrier system is envisaged to be used where access is frequently required, e.g. the entrance to the machinery houses.

9.2 Design and layout

The quayside flood defences must connect the flood defences being provided for the wider GFPS project with the gate option adopted for the lock channel. Due to the critical nature of much of the infrastructure along the lock channel (e.g. the pumphouse and the machinery houses), the quayside defences will need to run from the gate option seawards to the outer end of the lock channel. This is shown for the middle (options C & D) and inner (option F) barrier positions in Figure 26 and Figure 27 respectively.

Note that the line of the quayside defences is taken around levelling culvert sluice access covers, as it will be very difficult to prevent floodwater ingress via these chambers if they were to fall within the line of defence. It is proposed to protect the pumphouse by bringing it within the defence alignment, but work will have to be undertaken to determine the viability of floodwater ingress from the impoundment water inlets via the pump seating rings or the pump body itself.

Where the quayside defences interface with the gate in each case, the section of barrier that falls within the line of bollards is designed to be demountable and as such, is currently shown as a stoplog wall. This is to allow the transit of overhanging cargo to take place. For options C and D, the section of defence closest to the gate on each side is designed to be a specially shaped panel that is flared to minimise collision risk whilst providing a sealing surface for the demountable barrier on top of each gate leaf.

Sections of the concrete walls and the stoplog walls are shown in drawings B2386100-DR-403 in (Appendix D). The layouts for each set of quayside defences are option dependent (middle gate or caisson gate locations) and an example layout for each barrier position considered is shown on drawings B2386100-DR-401 and B2386100-DR-402 in Appendix D. This will need to be developed at detailed design stage in collaboration with Forth Ports.

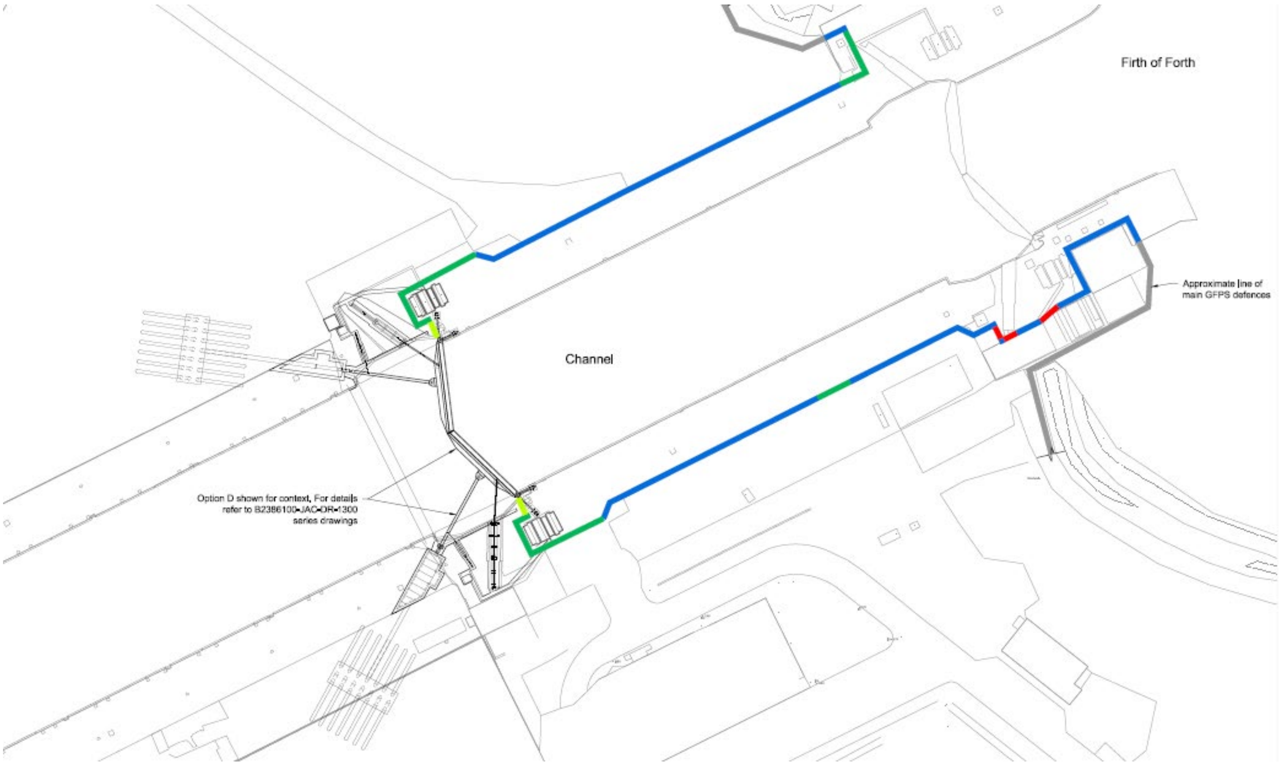


Figure 26: potential quayside flood defence alignment for options C and D

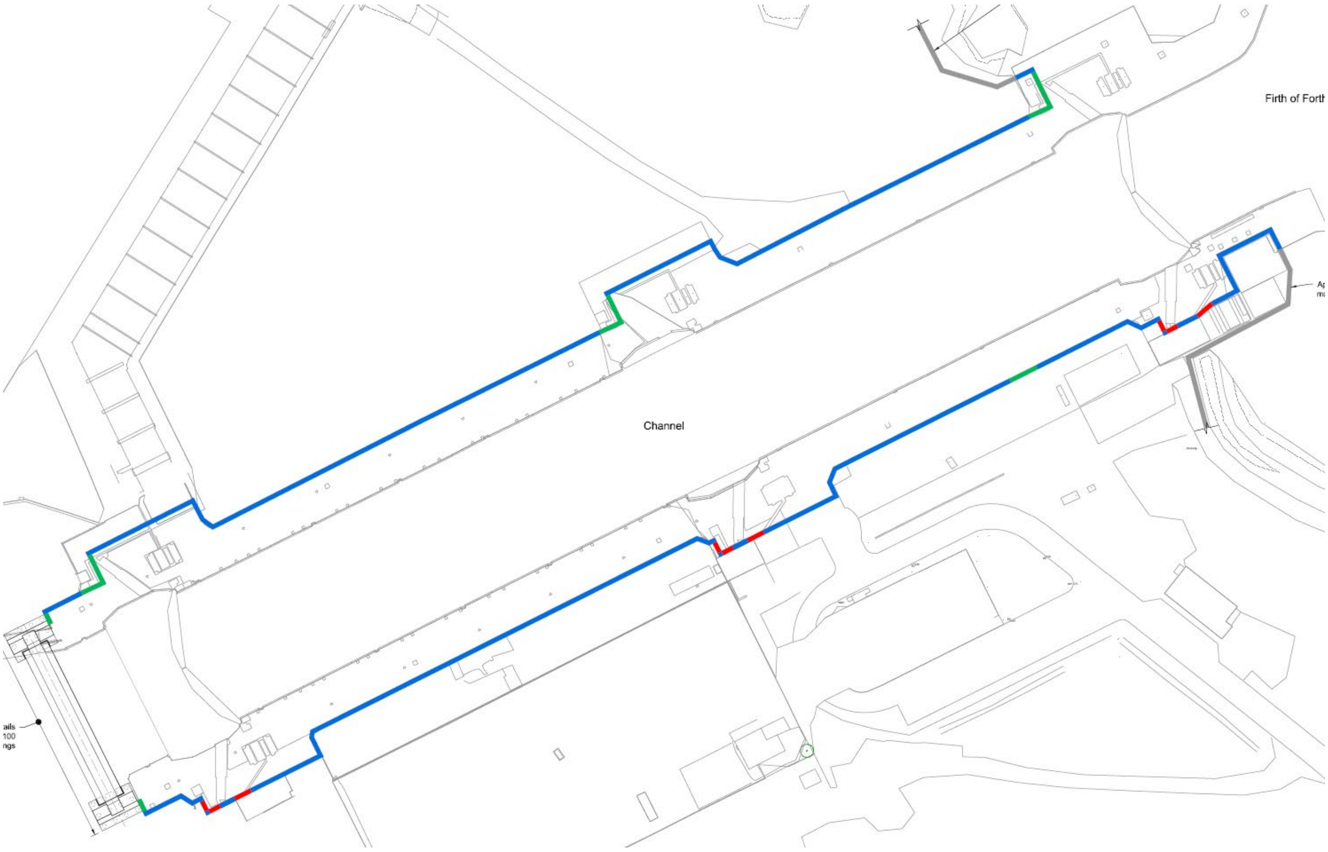


Figure 27: potential quayside flood defence alignment for option F

9.3 Cost

Outline costs for the provision of the quayside defences are provided in Appendix E. A summary is provided below.

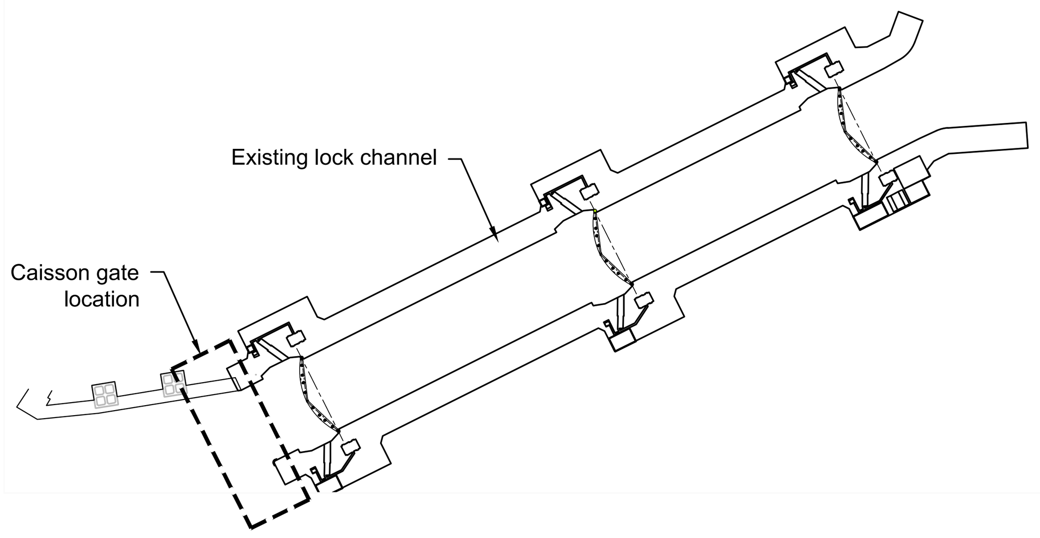
Options C and D:

Preliminaries	@	10%					£ 30,072
CAPEX total							£ 300,717
OPEX total							£ 634,269
					Subtotal		**£ 965,058**
Supervision costs	@	5%	of CAPEX total				£ 15,036
Engineering costs	@	5%	of CAPEX total				£ 15,036
					Subtotal		**£ 995,130**
Profit and contingency	@	20%	of CAPEX total				£ 60,143
					Total		**£ 1,055,273**
Optimism bias	@	0%				£	-
		60%					£ 633,164
GRAND TOTALS			incl.	**0%**	**O.B.**		**£ 1,055,273**
			incl.	**60%**	**O.B.**		**£ 1,688,437**

Option F:

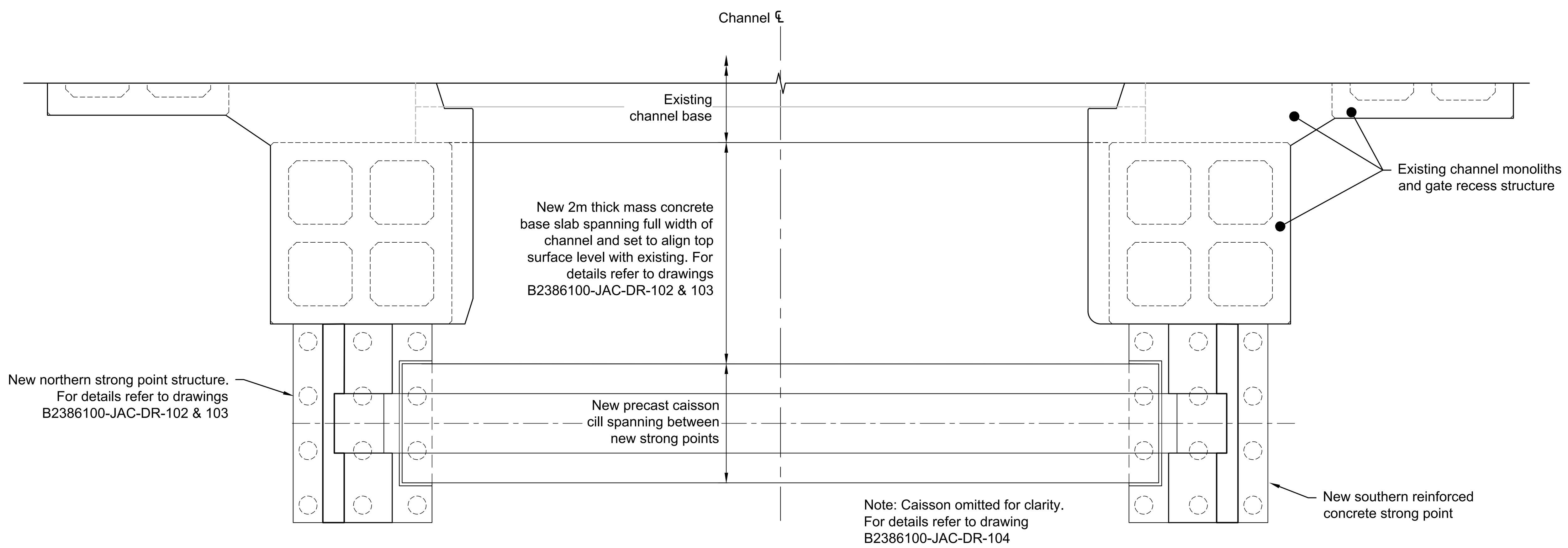
Preliminaries	@	10%					£ 54,863
CAPEX total							£ 548,629
OPEX total							£ 584,763
					Subtotal		**£ 1,188,255**
Supervision costs	@	5%	of CAPEX total				£ 27,431
Engineering costs	@	5%	of CAPEX total				£ 27,431
					Subtotal		**£ 1,243,118**
Profit and contingency	@	20%	of CAPEX total				£ 109,726
					Total		**£ 1,352,843**
Optimism bias	@	0%				£	-
		60%					£ 811,706
GRAND TOTALS			incl.	**0%**	**O.B.**		**£ 1,352,843**
			incl.	**60%**	**O.B.**		**£ 2,164,549**

Appendix A. Option C drawings



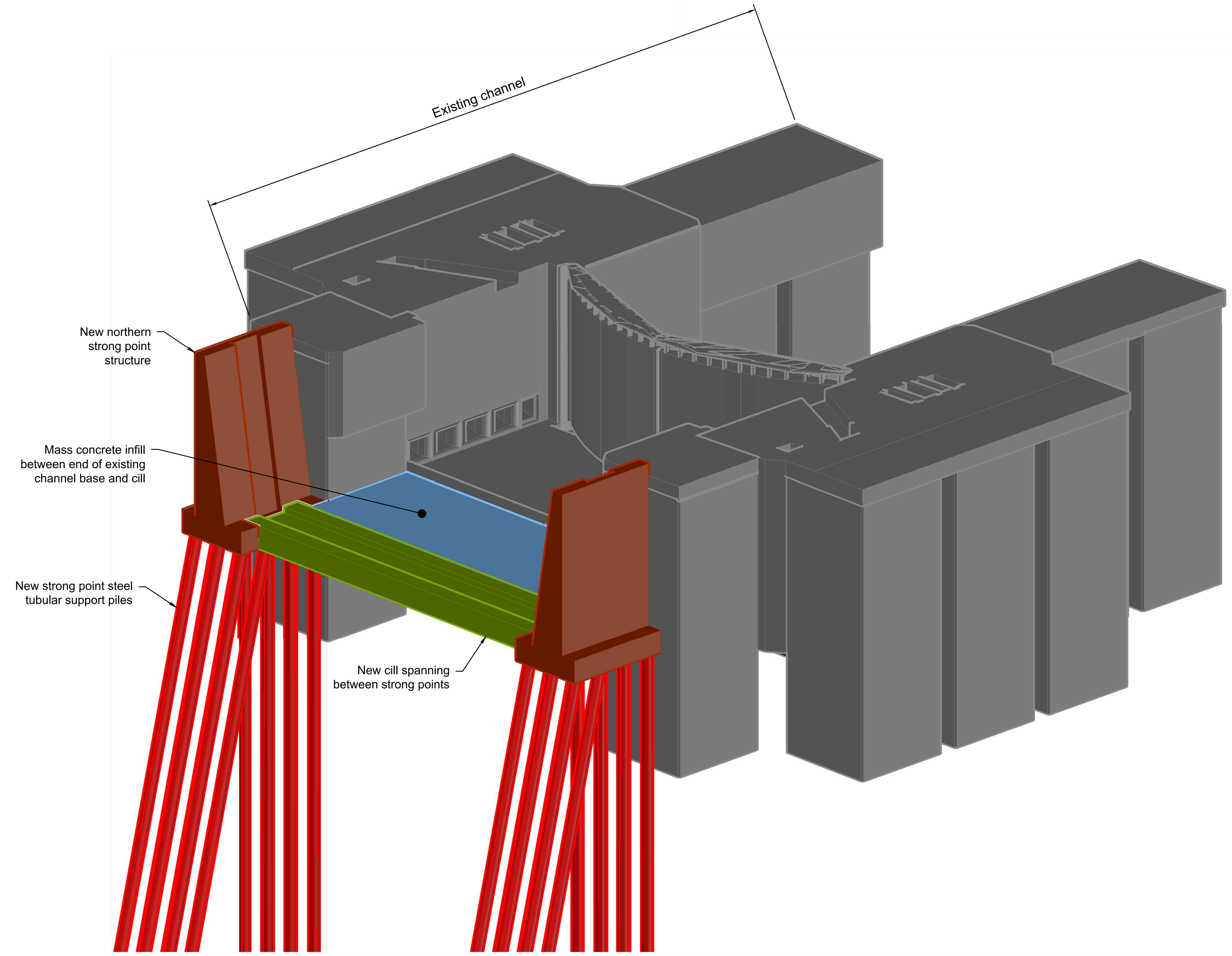
KEY PLAN

Scale 1:2500



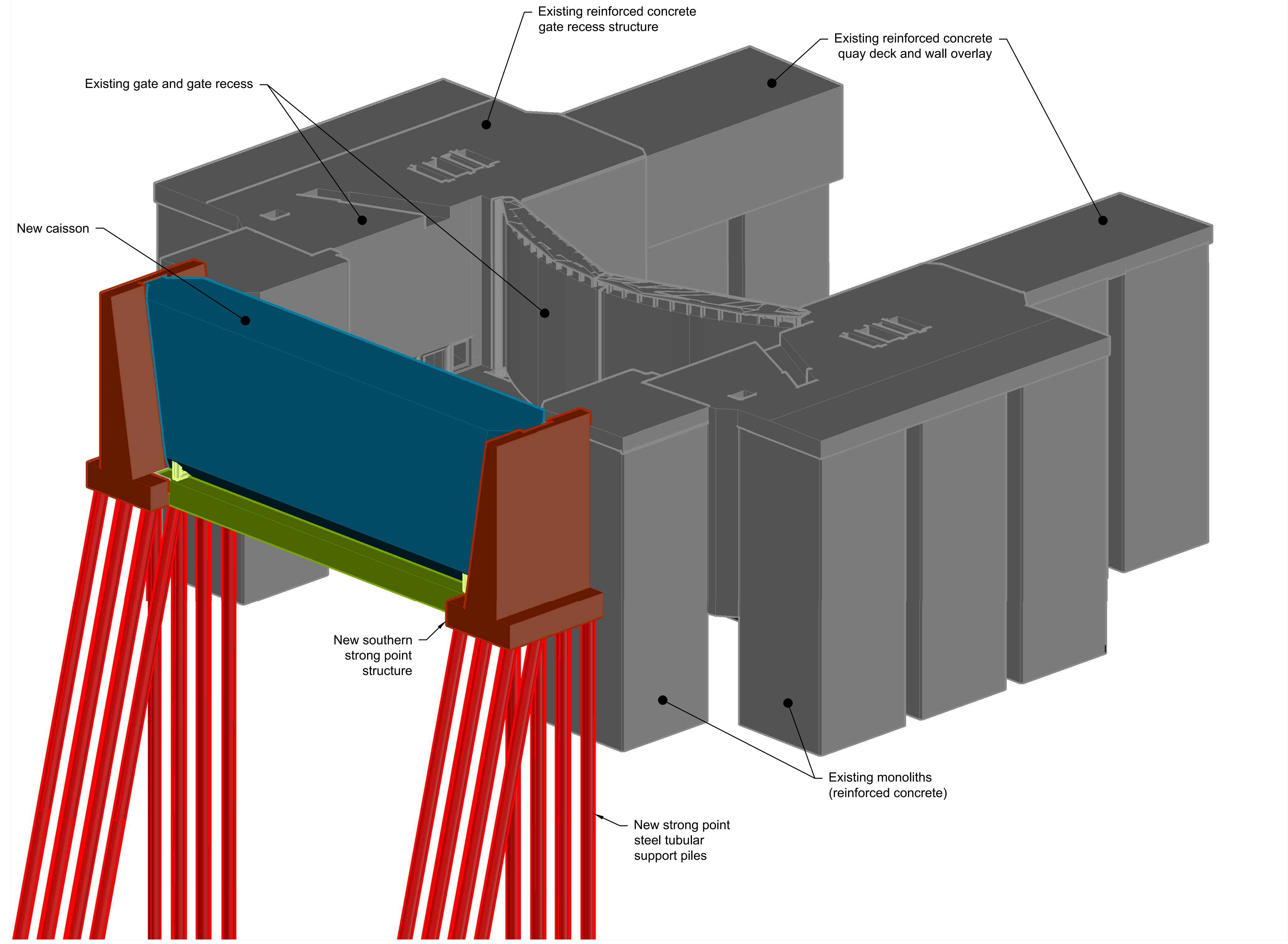
PLAN

SCALE 1:200



STRONG POINT 3D VIEW

Not to Scale



STRONG POINT 3D VIEW WITH CAISSON

Not to Scale

Notes:

1. Do not scale from this drawing.

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P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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www.jacobs.com

Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

Drawing title: TOWED CAISSON OPTION LOCATION, PLAN AND 3D VIEWS

Drawing status: FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			
Drawing number	B2386100-JAC-DR-101		

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. All concrete is grade C40/50, suitable for exposure class XS3 with c_{min} = 65mm, c_{dev} = 15mm, and c_{nom} = 80mm.
5. All hidden concrete surfaces are finish class F1, U1. All exposed surfaces are F4, U3.
6. All structural steel is grade S355 J2 delivered to EN 10025 unless noted otherwise.

Rev	Rev. Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

Drawing title: TOWED CAISSON OPTION SUPPORT STRUCTURES PLAN AND SECTIONS

Drawing status: FOR INFORMATION

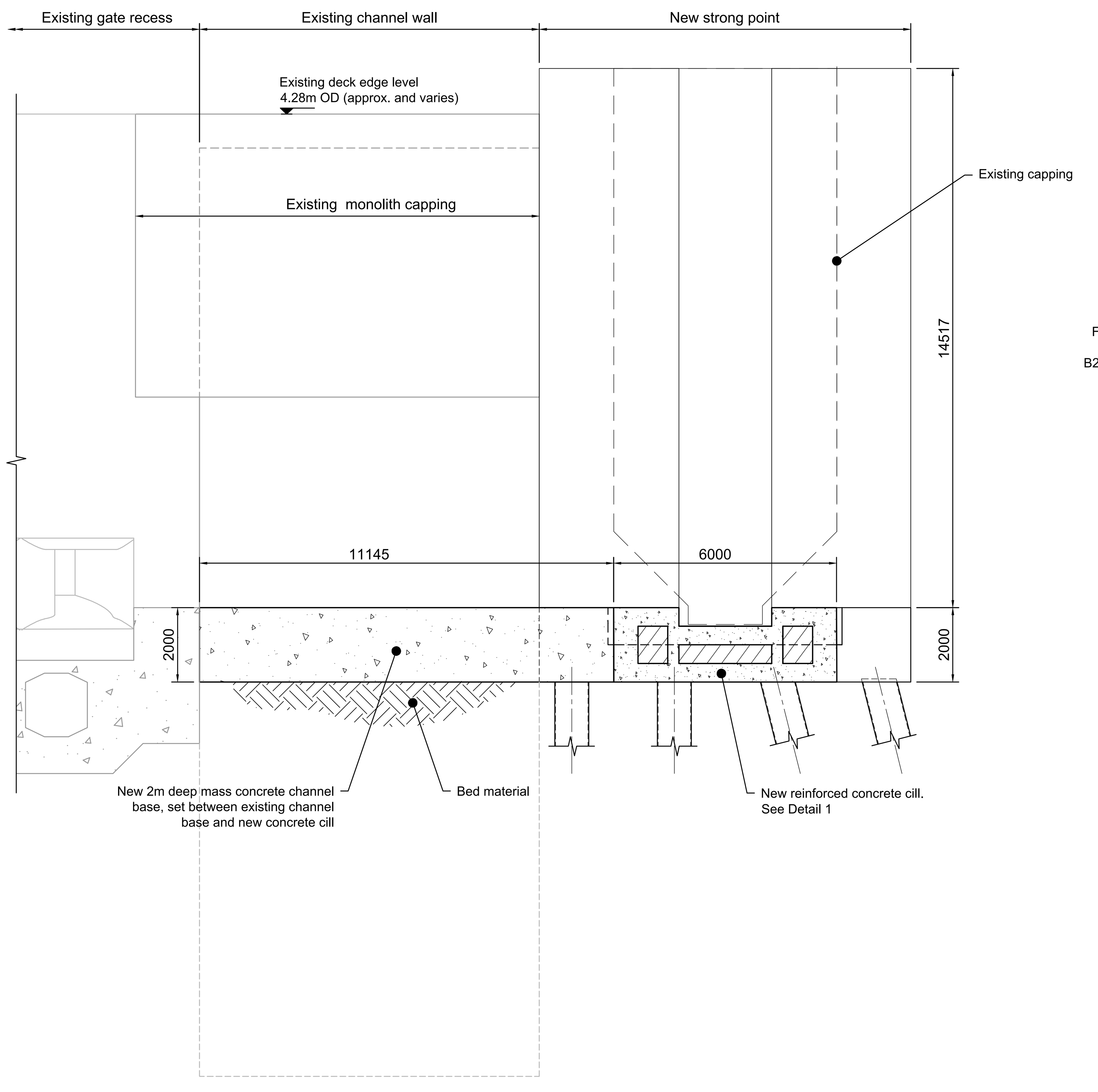
Scale: 1:100 @ A1 — DO NOT SCALE

Jacobs No.: B2386100

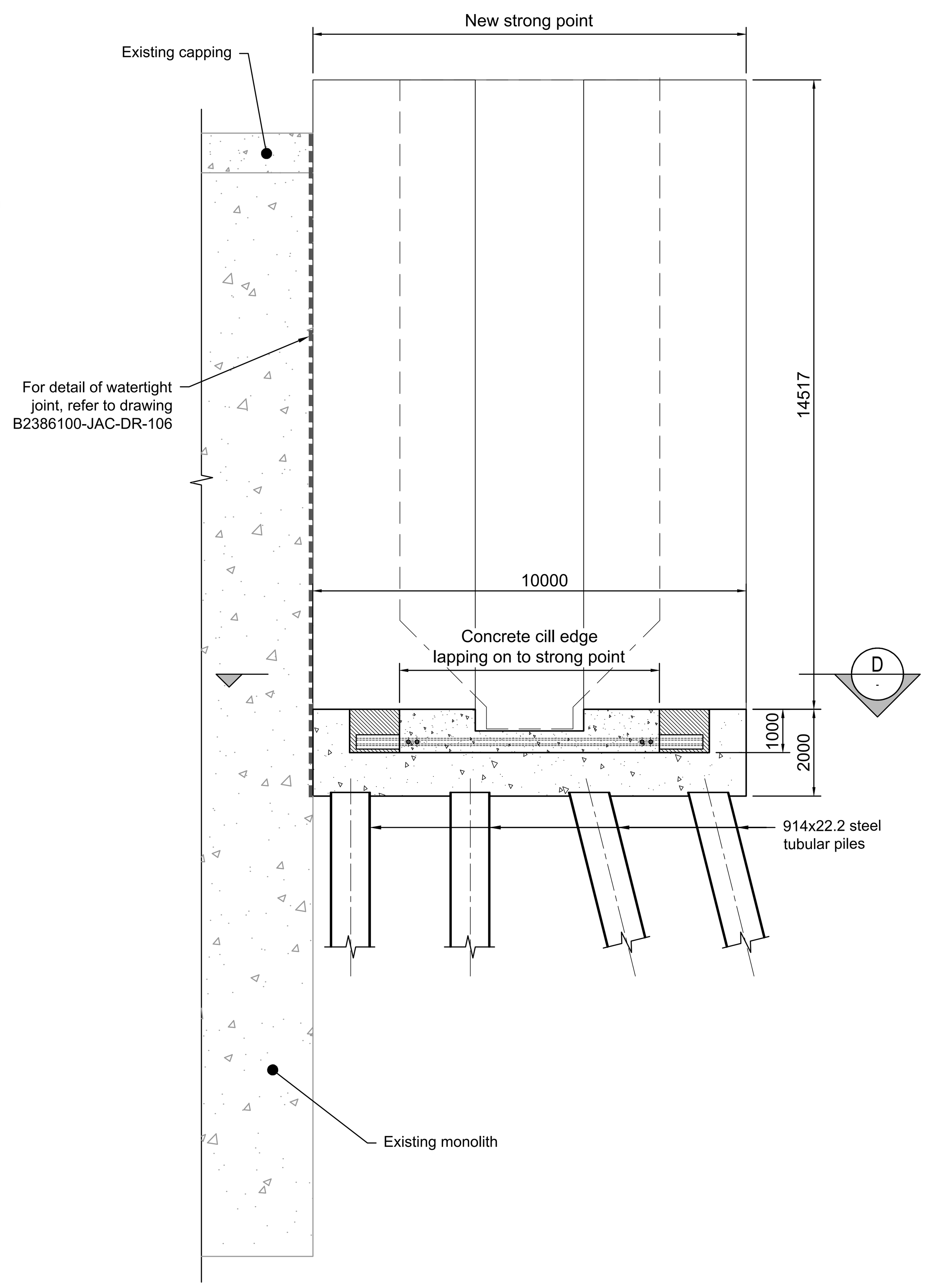
Rev: P0

Client no.:

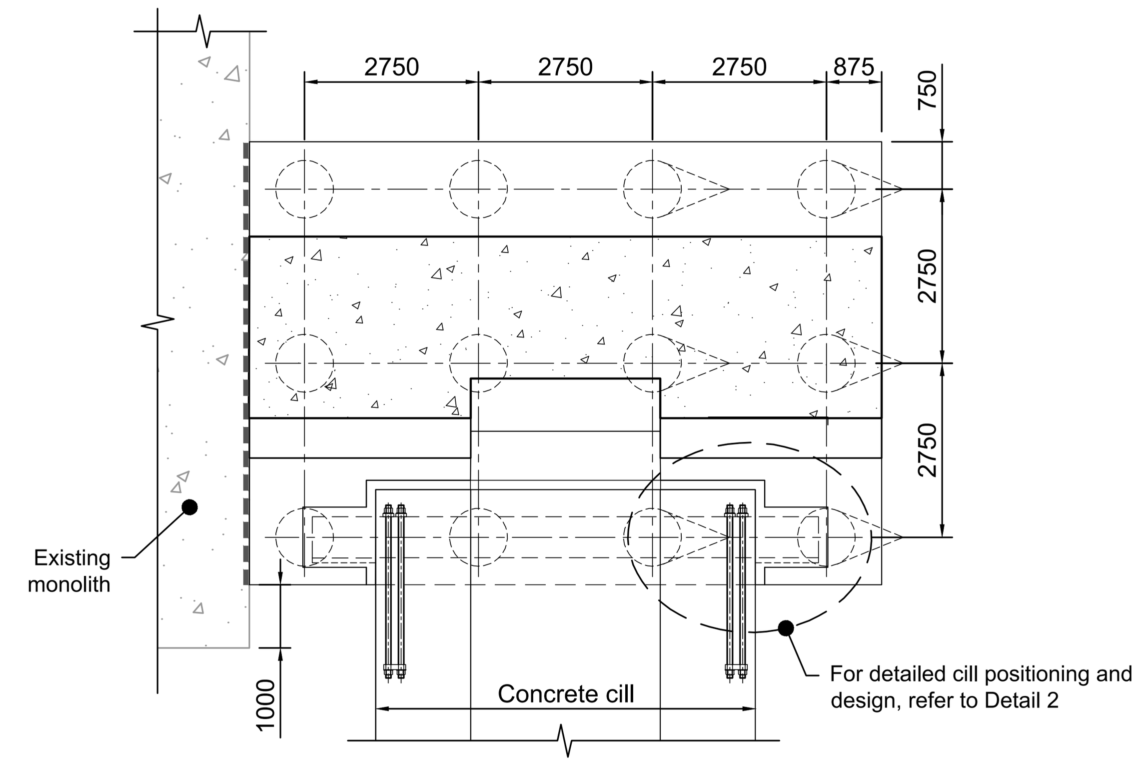
Drawing number: B2386100-JAC-DR-102



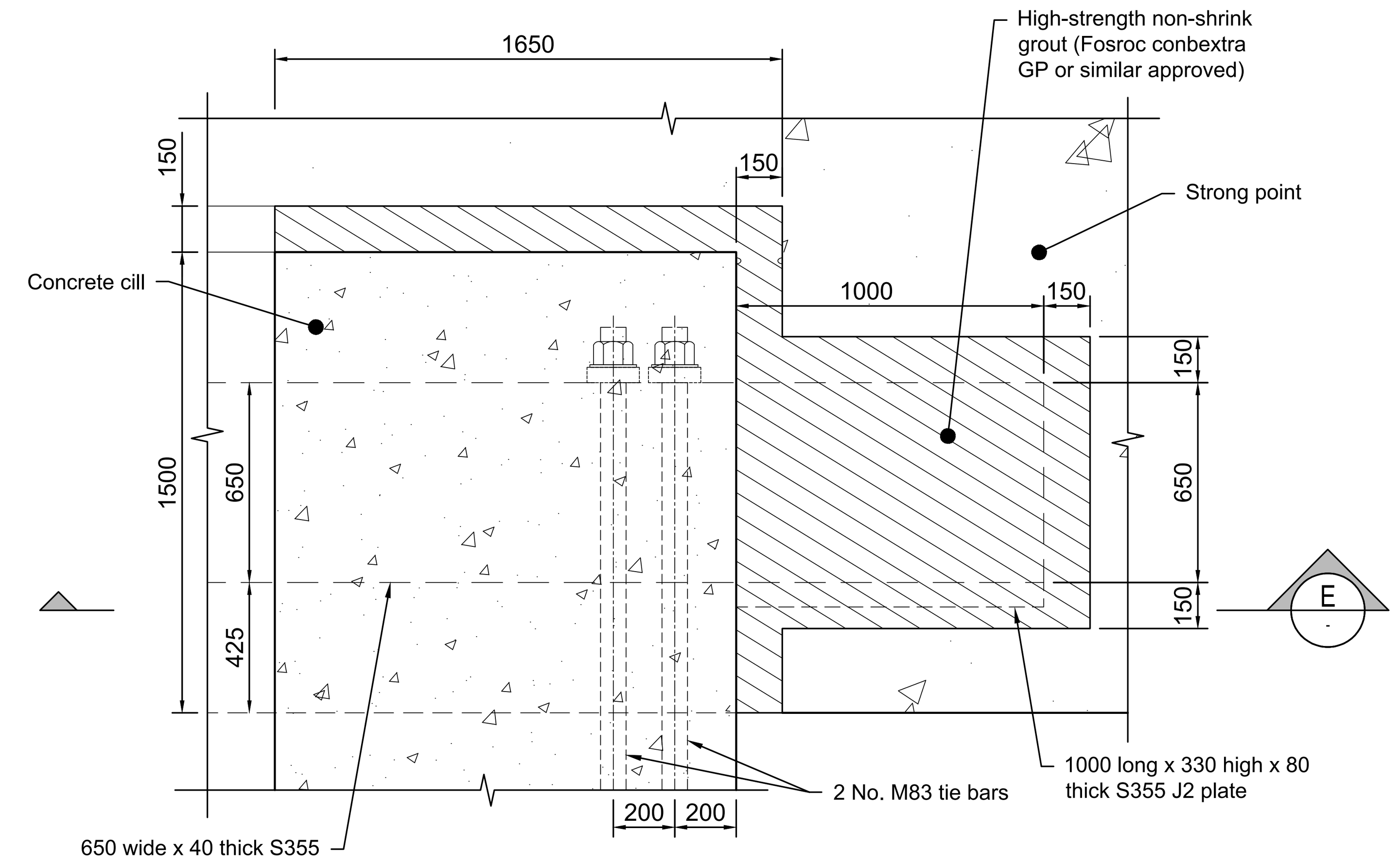
SECTION B
SCALE 1:100



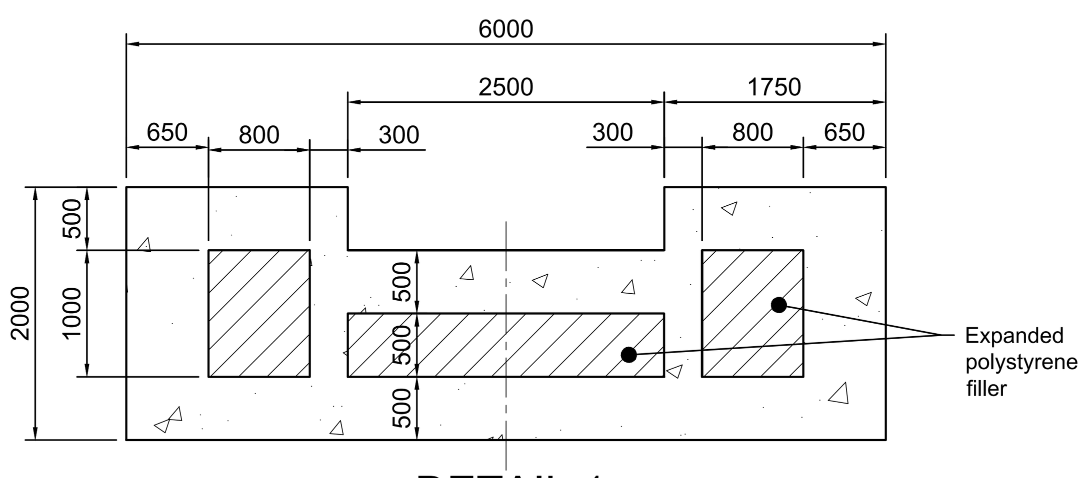
SECTION C
SCALE 1:100



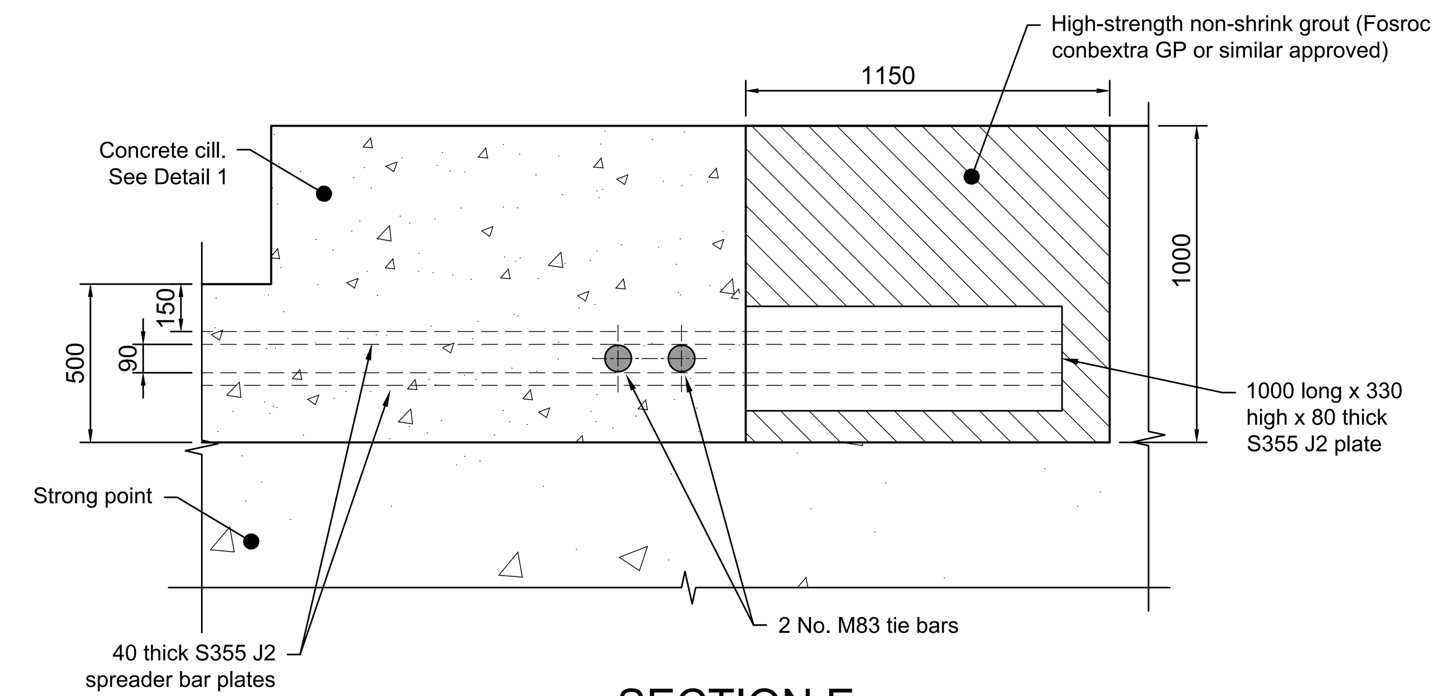
SECTION D
SCALE 1:100



DETAIL 2
SCALE 1:20



DETAIL 1
CONCRETE CILL CROSS SECTION
SCALE 1:50



SECTION E
SCALE 1:20

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. All concrete is grade C40/50, suitable for exposure class XS3 with c_{min} = 65mm, c_{dev} = 15mm, and c_{nom} = 80mm.
5. All hidden concrete surfaces are finish class F1, U1. All exposed surfaces are F4, U3.
6. All structural steel is grade S355 J2 delivered to EN 10025 unless noted otherwise.

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

Drawing title: TOWED CAISSON OPTION SUPPORT STRUCTURES DETAILS

Drawing status: FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			
Drawing number	B2386100-JAC-DR-103		

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. All hidden concrete surfaces are finish class F1, U1. All exposed surfaces are F4, U3.
5. All structural steel is grade S355 J2 delivered to EN 10025 unless noted otherwise.

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

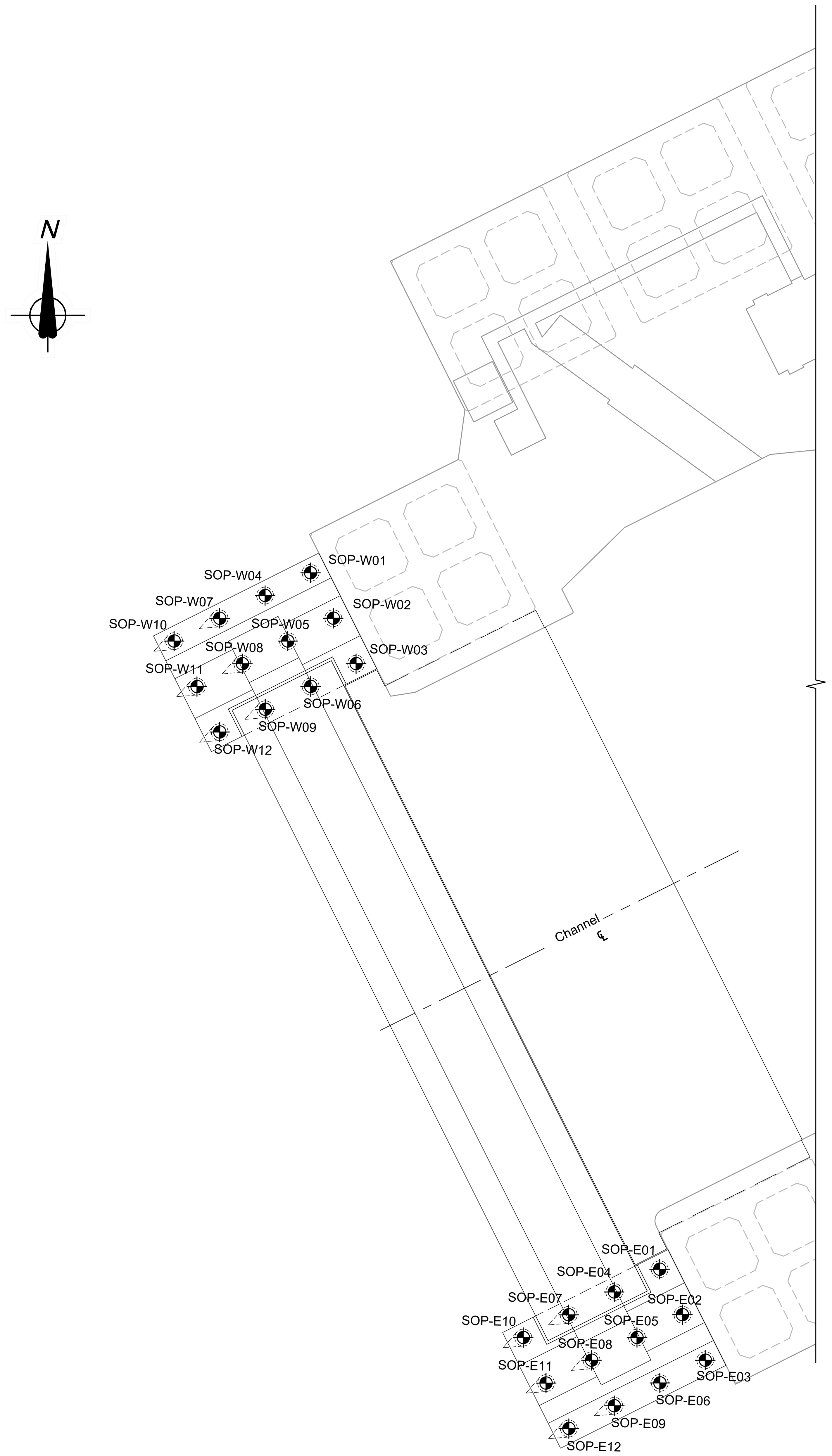
Project: GRANGEMOUTH FPS

Drawing title: TOWED CAISSON OPTION CAISSON PLAN, ELEVATION & CROSS SECTION

Drawing status: FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE
Jacobs No.	B2386100	Rev P0
Client no.		

Drawing number: B2386100-JAC-DR-104



PLAN
SCALE 1:200

TABLE 1
PILE SCHEDULE

PILE REF	DIAMETER (mm)	WALL THICKNESS (mm)	GRADE	CUT OFF LEVEL (mOD)	TOE LEVEL (mOD)	PILE RAKE	ADDITIONAL PILE LENGTH (m)	TOTAL PILE LENGTH (m)
SOP-E01	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-E02	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-E03	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-E04	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-E05	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-E06	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-E07	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-E08	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-E09	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-E10	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-E11	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-E12	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-W01	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-W02	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-W03	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-W04	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-W05	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-W06	914	22.2	S355J2N	-10.630	-48.130	Vertical	17.500	55
SOP-W07	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-W08	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-W09	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-W10	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-W11	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55
SOP-W12	914	22.2	S355J2N	-10.630	-47.010	1 in 4	17.500	55

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

Notes:
1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. Pile setting out coordinates are relative to OSGB36.
5. Additional pile length includes 2.5m allowance for achieving set and 15m allowance for cut off to accommodate piling through gate from quayside.
6. All piles are unpainted.
7. Pile installation tolerance as follows:
   - Pile position at cut-off level: +/- 75mm
   - Pile rake: 1 in 75 for vertical piles; 1 in 15 for raking piles
   - Cut-off level: +/- 10mm

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Client
FALKIRK COUNCIL

Project
GRANGEMOUTH FPS

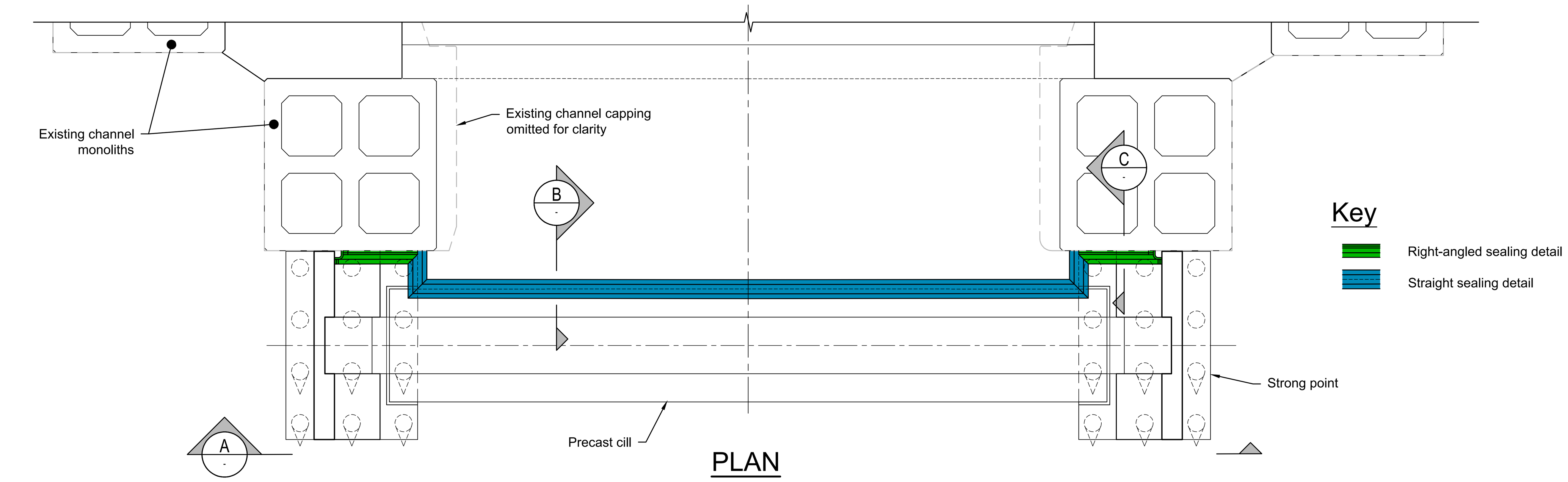
Drawing title
TOWED CAISSON OPTION
PILE SETTING OUT POINTS

Drawing status
FOR INFORMATION

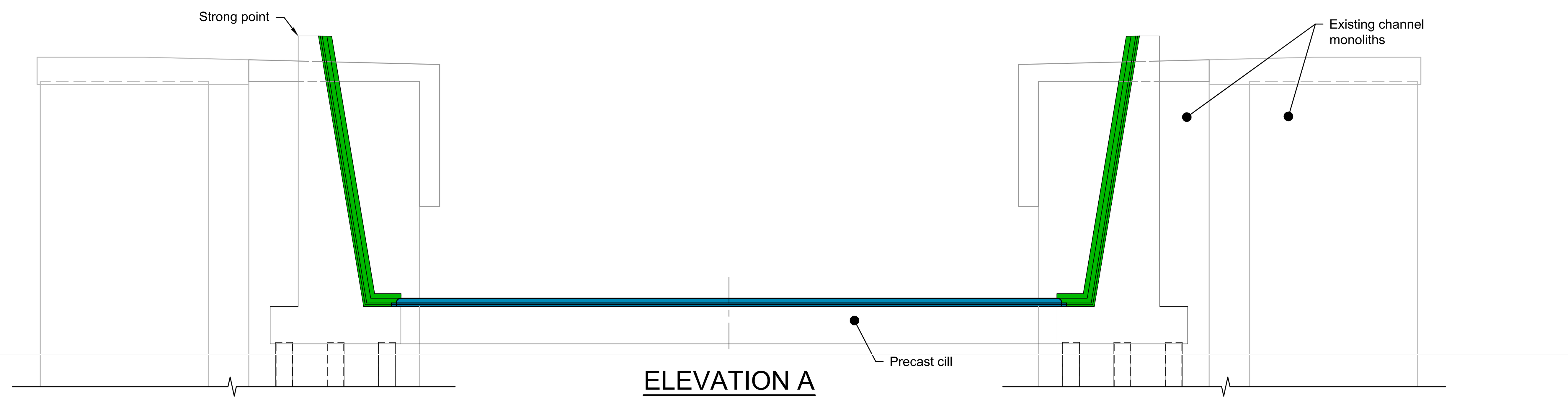
Scale	1:200 @ A1	DO NOT SCALE
Jacobs No.	B2386100	Rev P0
Client no.		

Drawing number
B2386100-JAC-DR-105

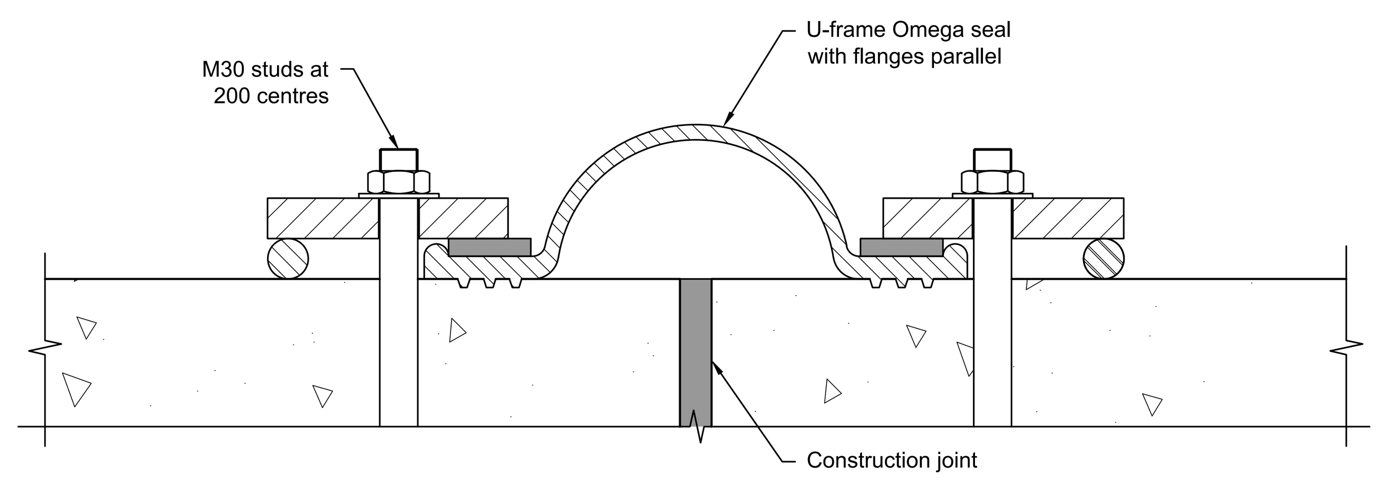
DRAFT - 16/09/2021



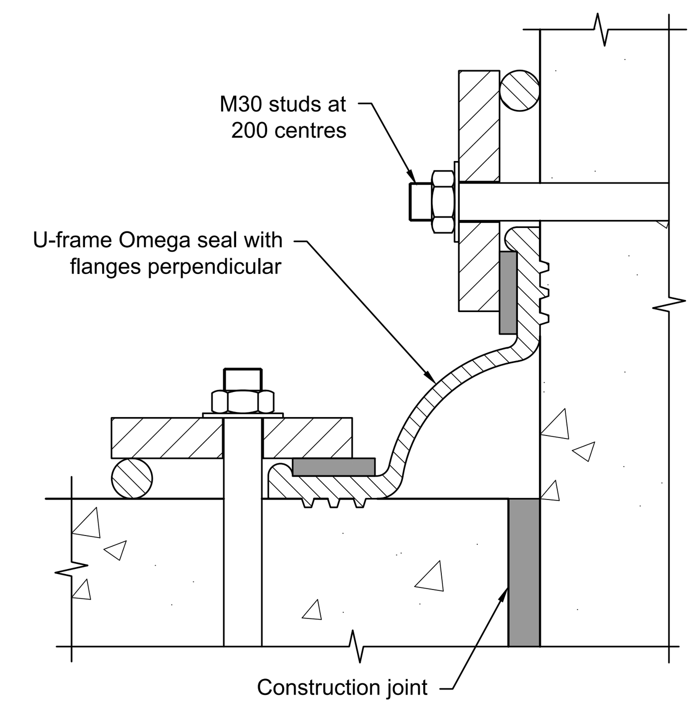
PLAN
SCALE 1:200



ELEVATION A
SCALE 1:200



SECTION B
SCALE 1:5



SECTION C
SCALE 1:5

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

Drawing title: TOWED CAISSON OPTION SUPPORT STRUCTURES SEALANT ARRANGEMENT AND DETAILS

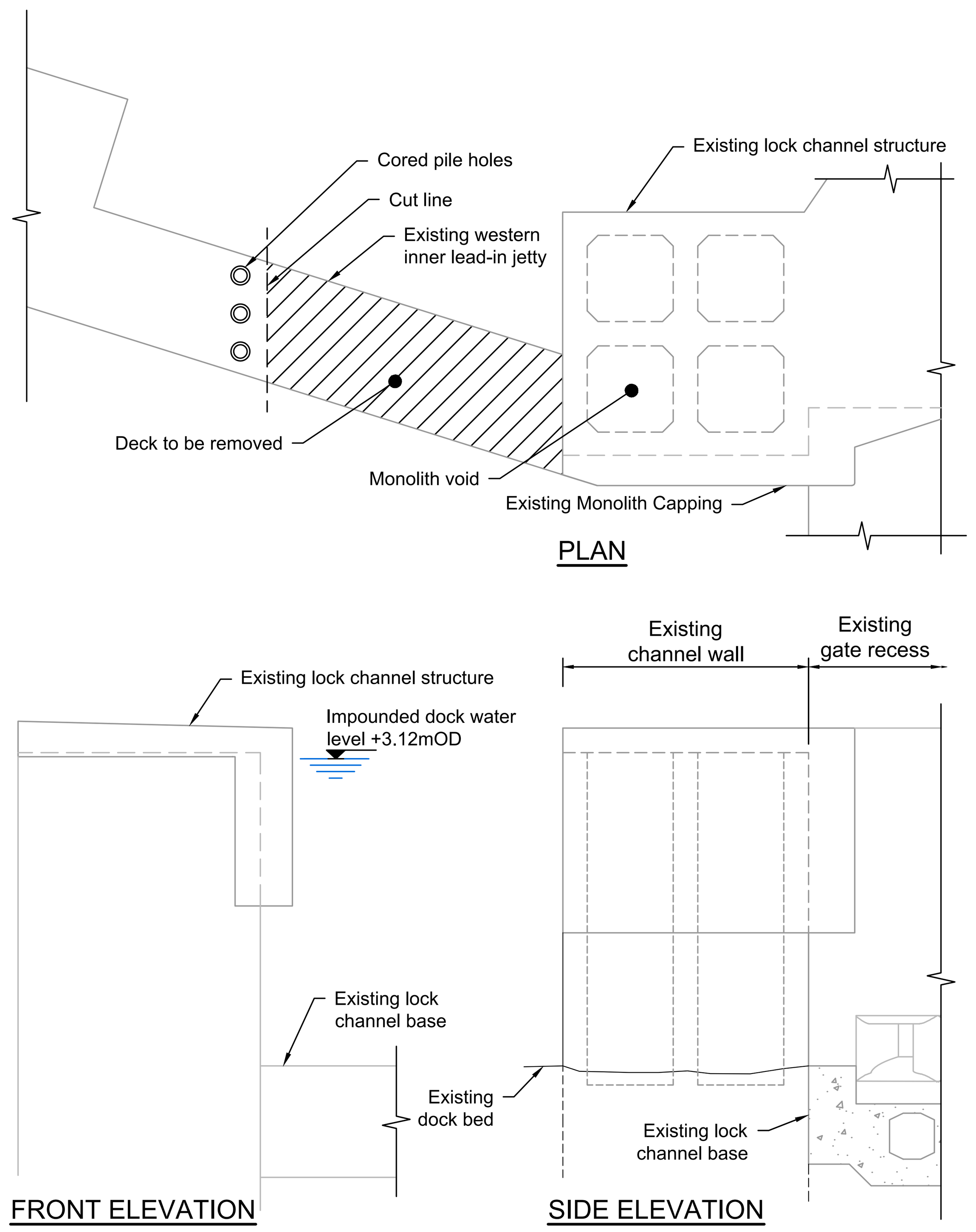
Drawing status: FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE
Jacobs No.	B2386100	Rev P0
Client no.		

Drawing number: B2386100-JAC-DR-106

Steps:

1.1 Core 3No. holes through western inner lead-in jetty.
1.2 Drive piles through cored holes.
1.3 Cast pile heads to support deck slab.
1.4 Cut deck slab at lock structure interface and at cut line.
1.5 Lift out deck section to facilitate strong point construction.



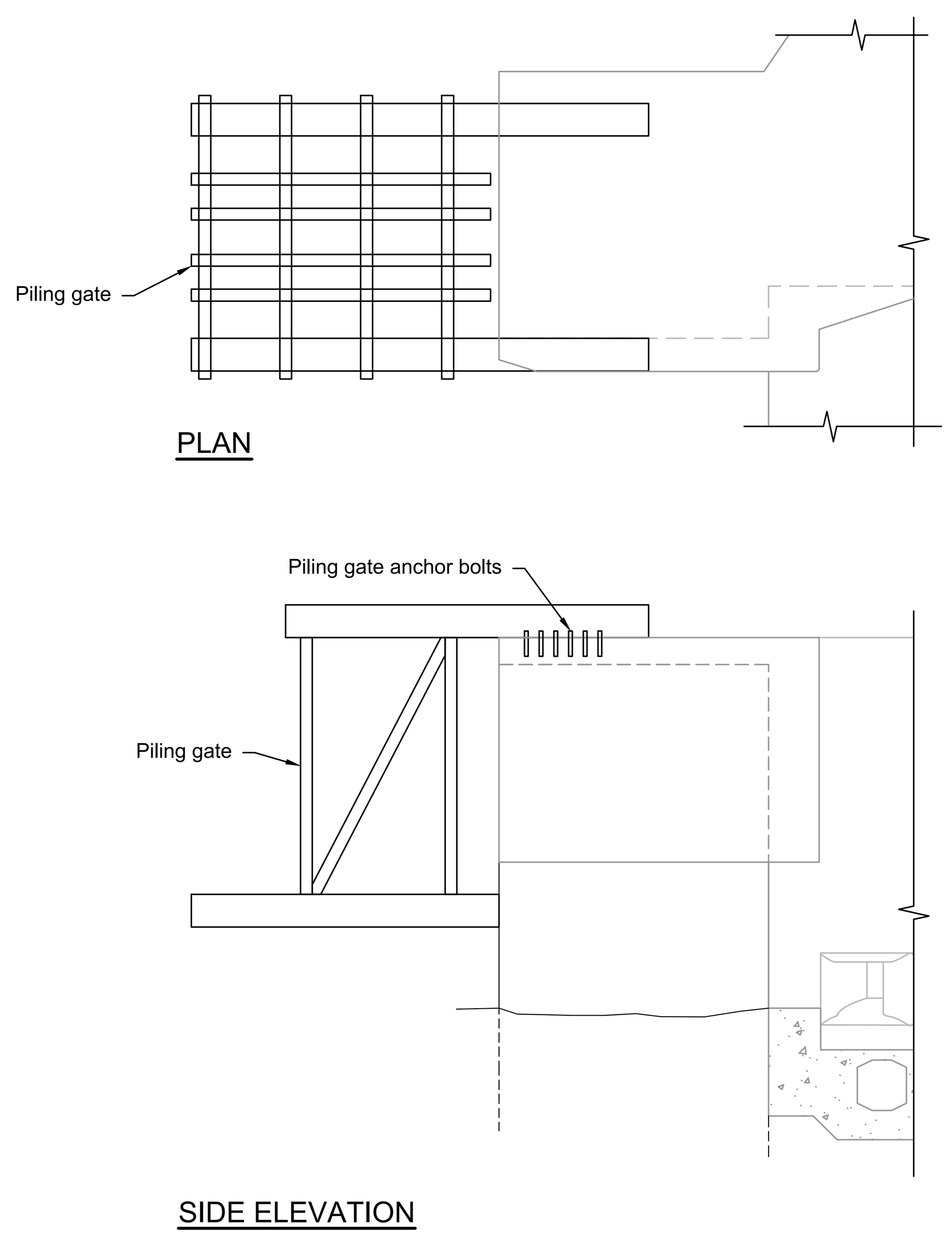
STAGE 1
ENABLING WORKS

Steps:

2.1 Construct piling gate at end of existing lock channel structure.
2.2 Anchor piling gate into existing structure.
2.3 Mobilise piling rig consisting of crawler crane supporting piling hammer.
2.4 Position piling rig towards end of existing structure.

STAGE 2 (Alternative)

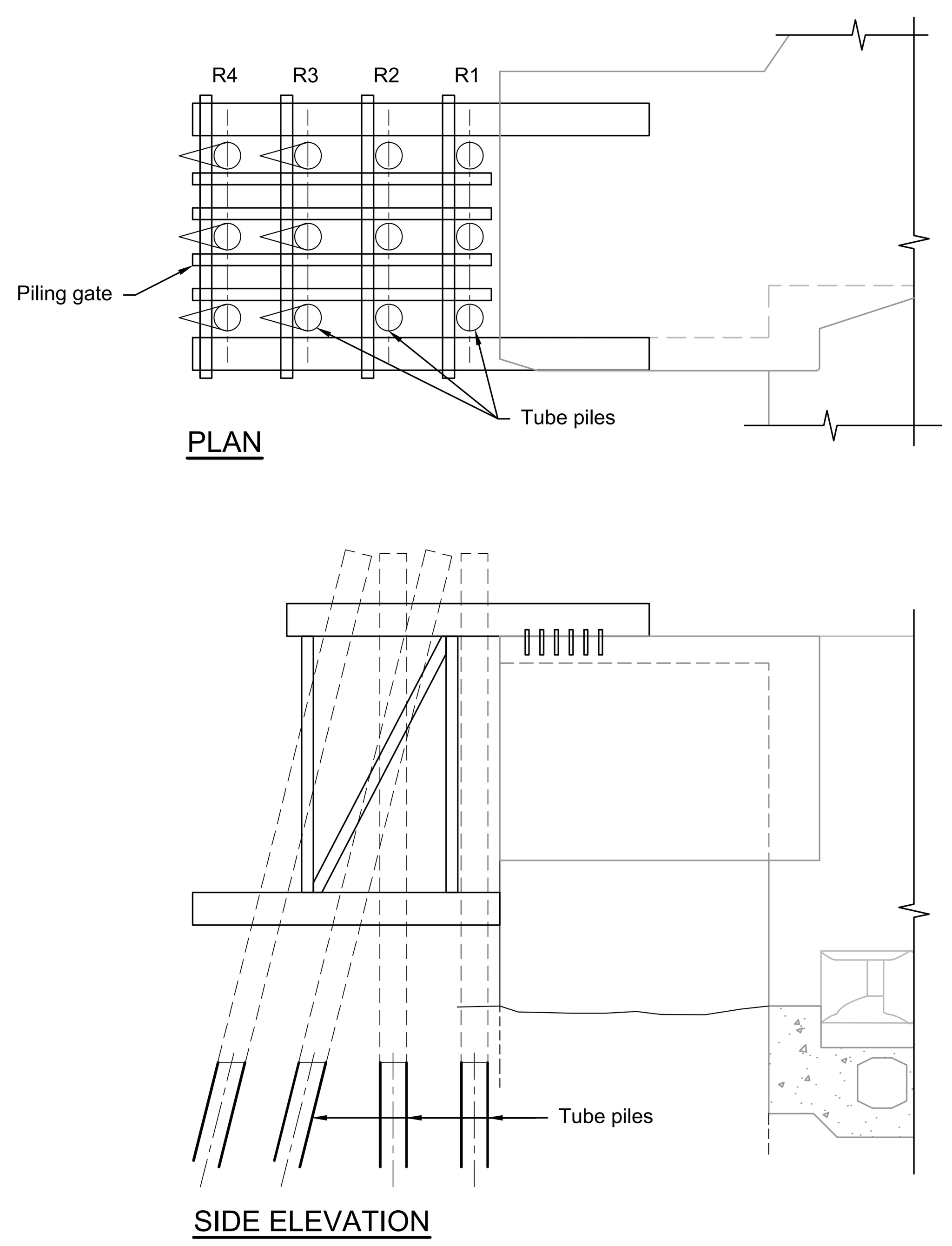
2.1 Mobilise piling rig consisting of crawler crawler crane with fixed or swinging leaders, sized to cater for driving all piles in group from existing lock channel structure.
2.2 Position piling rig towards end of existing structure.



STAGE 2
POSITION PILING EQUIPMENT

Steps:

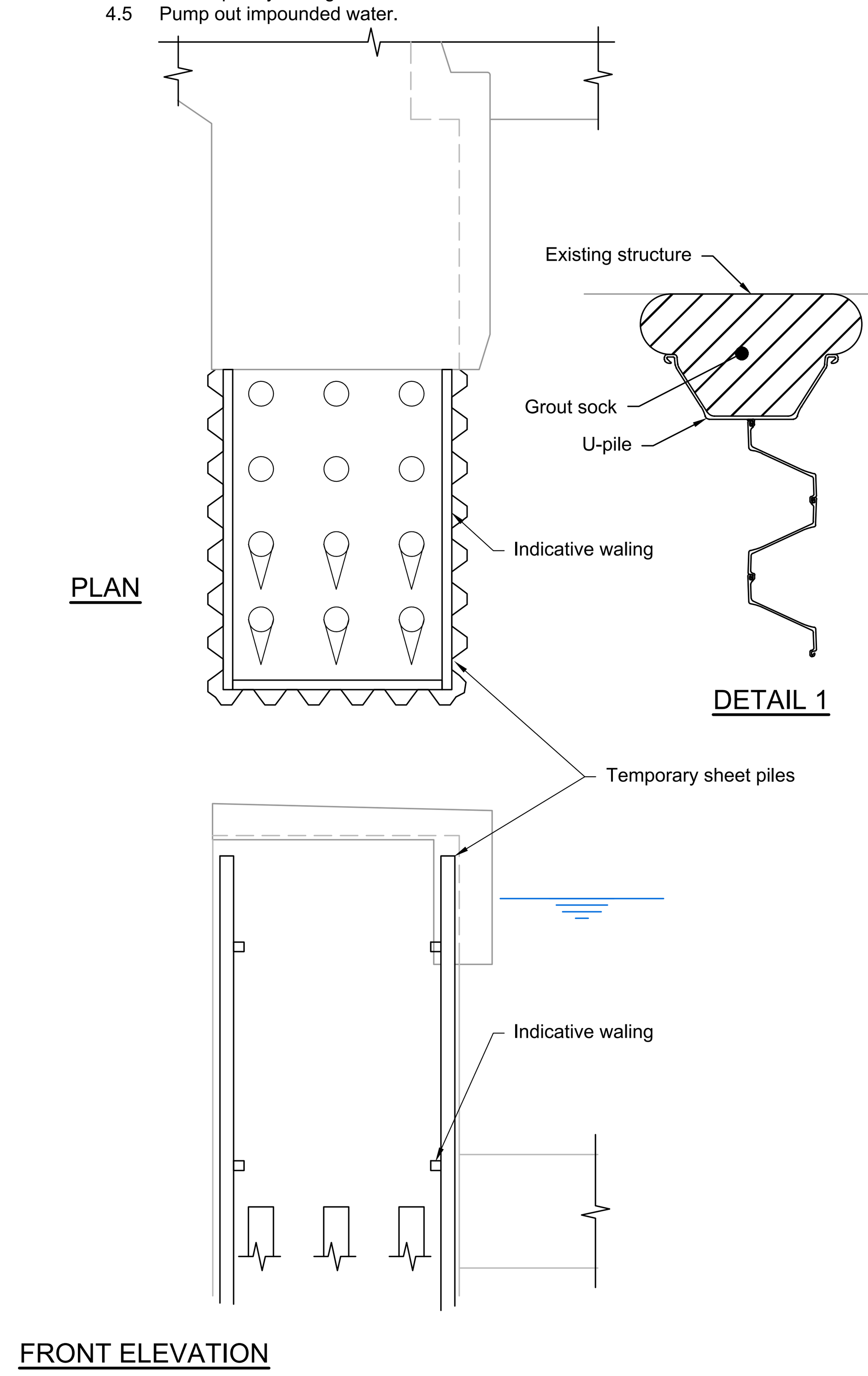
3.1 Drive pile row 1 by pitching pile into piling gate, driving initial length and welding additional sections in-situ as required.
3.2 Repeat for pile rows 3 and 4.
3.3 Cut off pile rows 1, 3 and 4.
3.4 Drive pile row 2.
3.5 Cut off pile row 2



STAGE 3
DRIVE PILES

Steps:

4.1 Drive regular cofferdam piles.
4.2 Drive end U-pile seal arrangement (see Detail 1).
4.3 Place grout sock and fill.
4.4 Fix temporary waling.
4.5 Pump out impounded water.



STAGE 4
CONSTRUCT COFFERDAM

Notes:
1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.

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P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

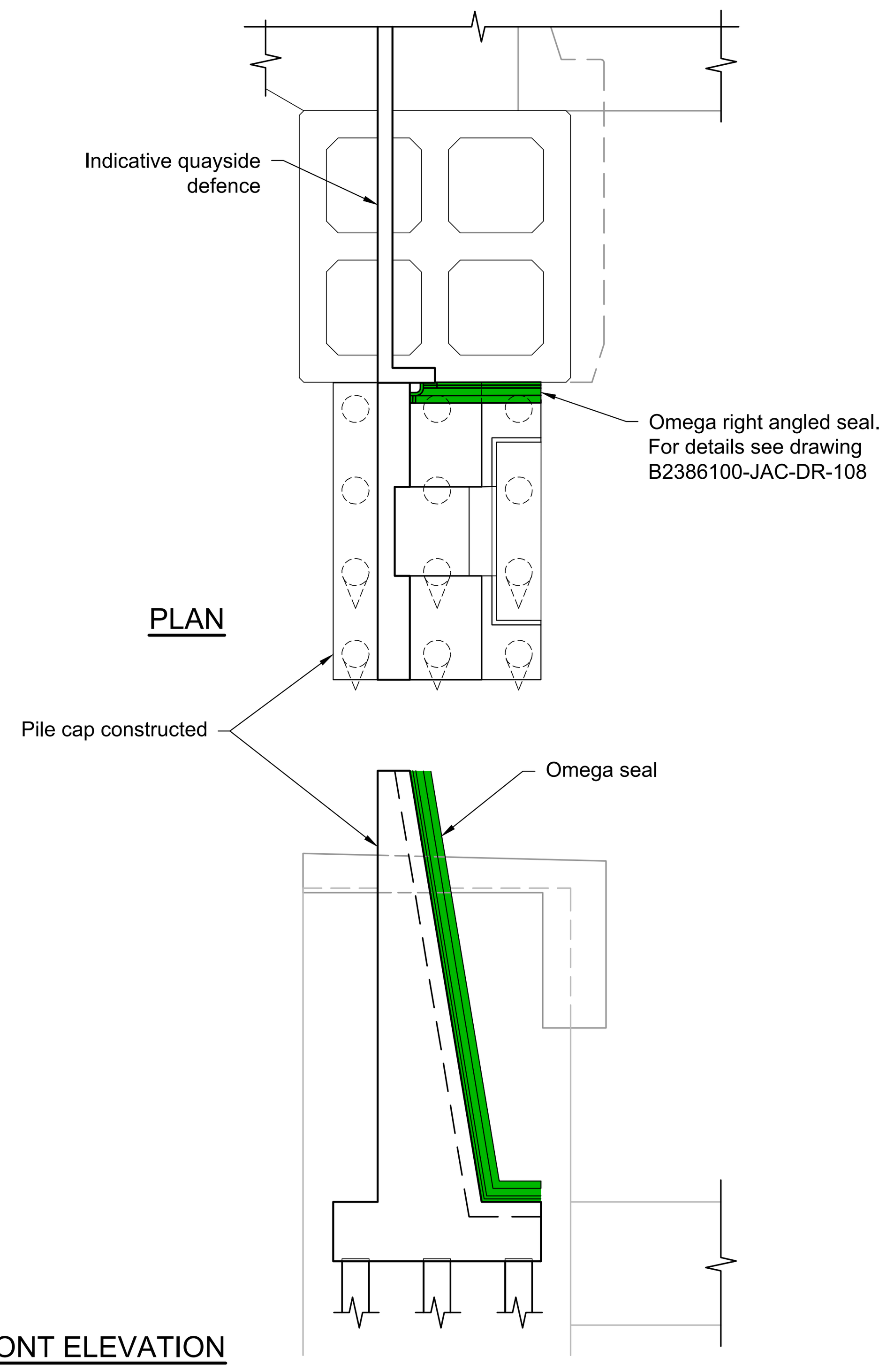
Drawing title: TOWED CAISSON OPTION GATE SUPPORT CONSTRUCTION SEQUENCE (SHEET 1 OF 2)

Drawing status: FOR INFORMATION

Scale	NTS
	DO NOT SCALE
Jacobs No.	B2386100
Client no.	
Rev	P0
Drawing number	B2386100-JAC-DR-107

Steps:

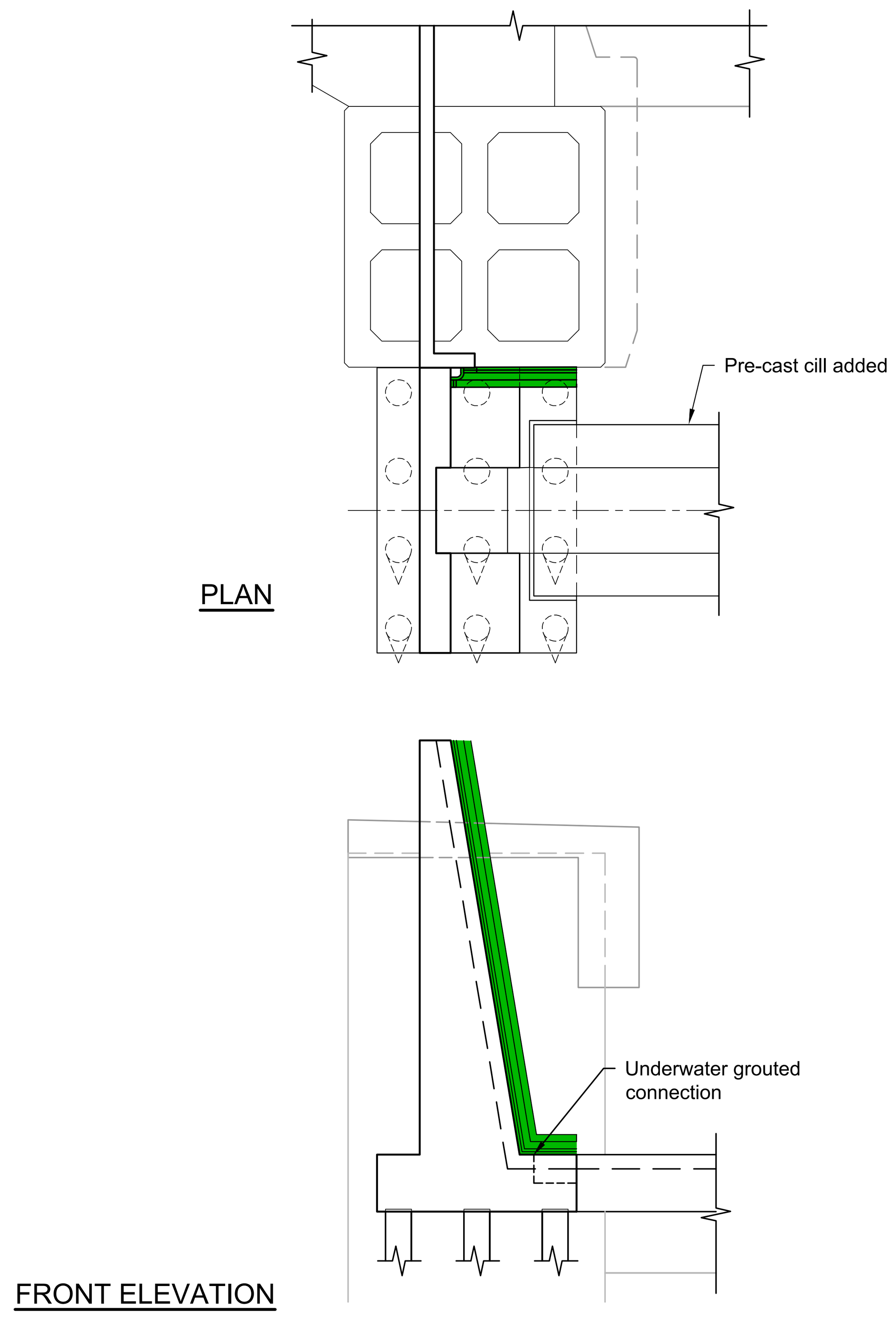
5.1 Prepare formwork and fix reinforcement for base.
5.2 Cast base.
5.3 Prepare formwork and fix reinforcement for upstand.
5.4 Cast upstand.
5.5 Remove formwork.
5.6 Tie in with proposed quayside defences.
5.7 Fix omega seal between strong point and existing structure.
5.8 Remove cofferdam.



STAGE 5
CAST PILE CAP

Steps:

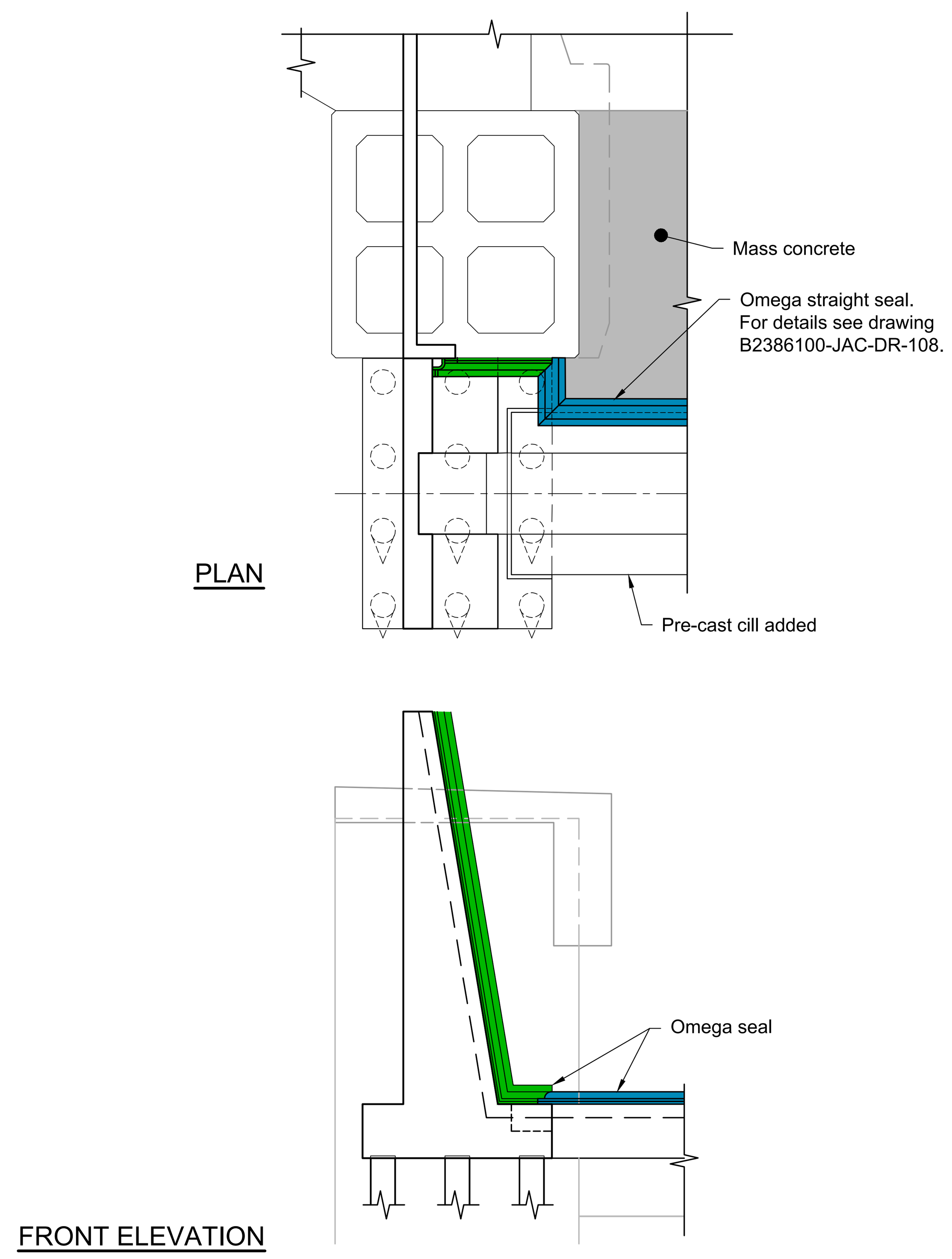
6.1 Cast cill element either on a submersible barge or within a dry dock and transport to site.
6.2 Using crane assistance (and buoyancy aids, if required) lower cill into position on the strong points.
6.3 Complete grouted cill to strong point connection.



STAGE 6
INSTALL PRE-CAST CILL

Steps:

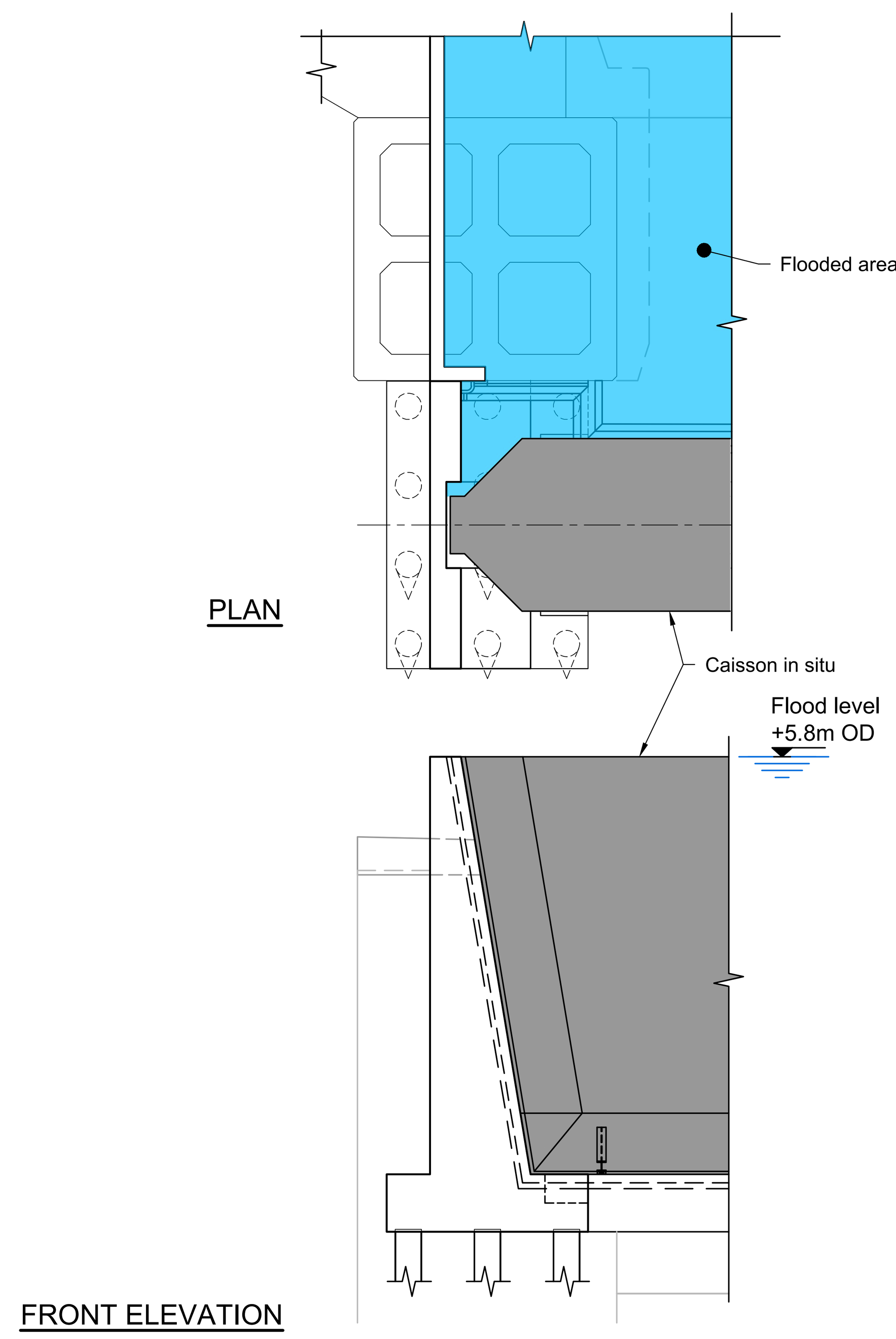
7.1 Cast mass concrete between cill and existing lock channel base.
7.2 Check the installation of the omega seal between the mass concrete pour and the cill and strong point elements. These seals may be pre-installed on the pre-cast cill unit and on the strong point base, and propped to leave the free half of the joint to be cast into the mass concrete pour.



STAGE 7
CAST MASS CONCRETE

Steps:

8.1 Fabricate caisson off-site at specialist sub-contractor.
8.2 Transport to site via barge
8.3 Lower into slot by filling buoyancy tanks while using tugs for positioning
8.4 Pump water into lock channel to form a positive head and seat seals against side of channel.
8.5 Following storm event, equalise head by pumping before raising caisson and towing to mooring position within impounded dock.



STAGE 8
DEPLOY CAISSON

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.

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P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client
FALKIRK COUNCIL

Project
GRANGEMOUTH FPS

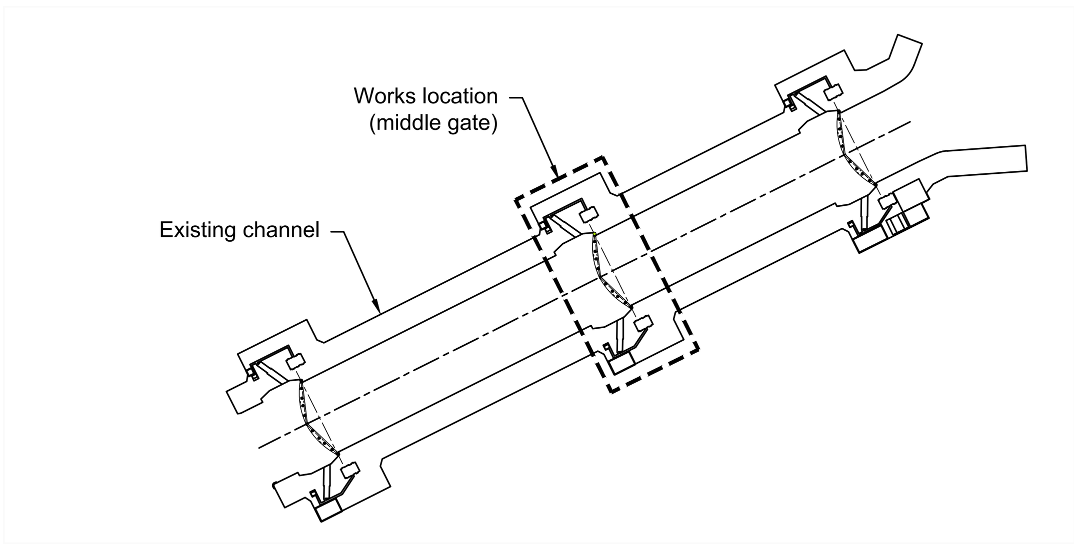
Drawing title
TOWED CAISSON OPTION
GATE SUPPORT
CONSTRUCTION SEQUENCE
(SHEET 2 OF 2)

Drawing status
FOR INFORMATION

Scale	NTS	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

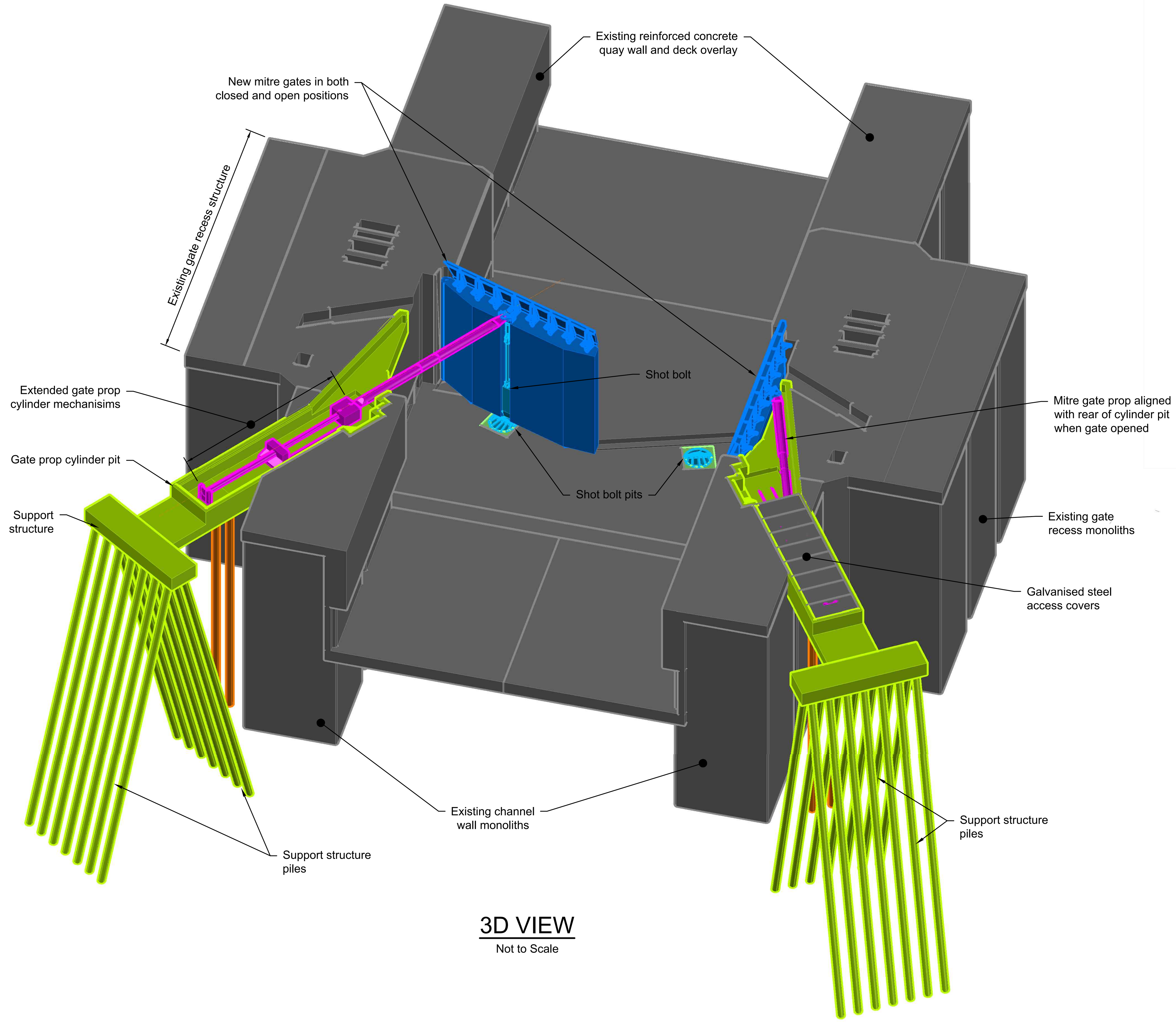
Drawing number
B2386100-JAC-DR-108

Appendix B. Option D drawings



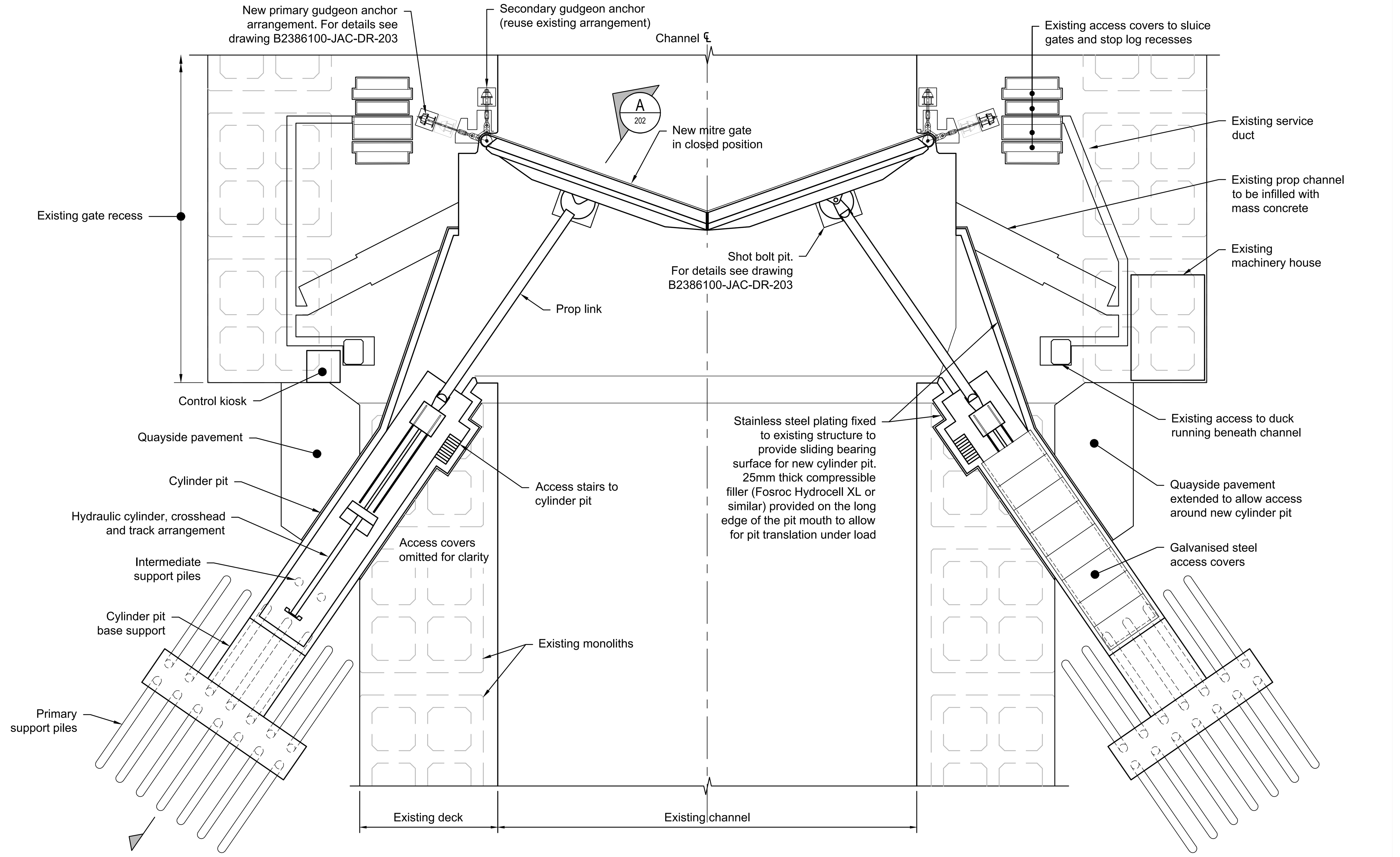
KEY PLAN

Not to Scale



3D VIEW

Not to Scale



MITRE GATE PLAN

SCALE 1:250

Notes:

1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.
4. Safety-related infrastructure such as separated walkways and handrailing not shown.

0 5 10 15 20
SCALE 1:250 (A1) METRES

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Appr'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

Drawing title: FOR MITRE GATES SHOT BOLT OPTION GA PLAN & 3D MODEL

Drawing status: FOR INFORMATION

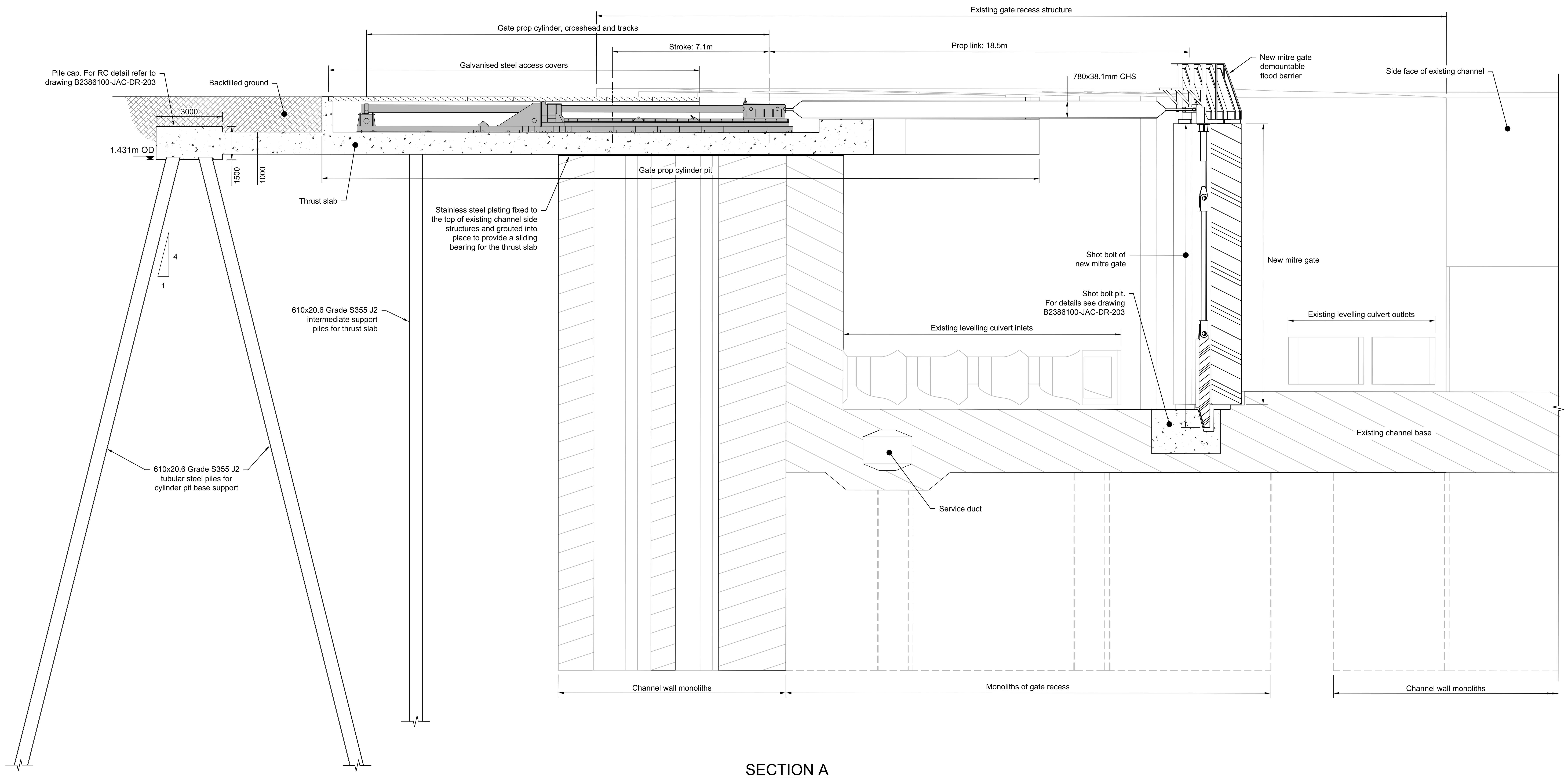
Scale: AS SHOWN @ A1 — DO NOT SCALE

Jacobs No.: B2386100

Client no.:

Rev: P0

Drawing number: B2386100-JAC-DR-201



SECTION A

SCALE 1:100

Notes:

1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.
4. The levels shown on this drawing have been deduced based on quayside levels taken by Malcolm Hughes (Chartered Land Surveyors) in November 2020 and the as-built drawings on the lock channel. The levels suggest that settlement of the lock channel and associated infrastructure of approximately 300mm has taken place since its construction. These levels require verification prior to detailed design.

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

0 5 10
SCALE 1:100 (A1) METRES

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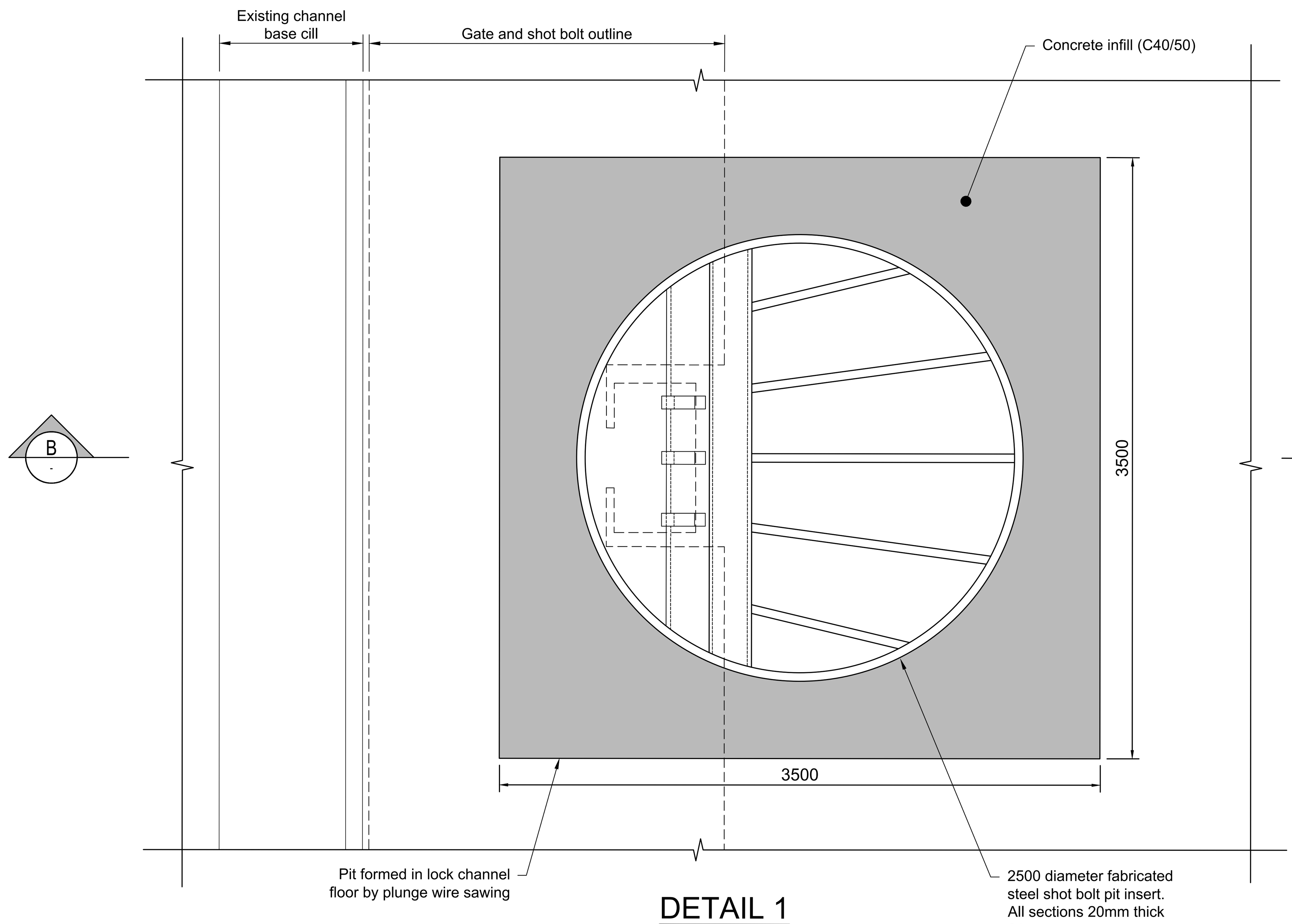
Client: FALKIRK COUNCIL

Project: GRANGEMOUTH FPS

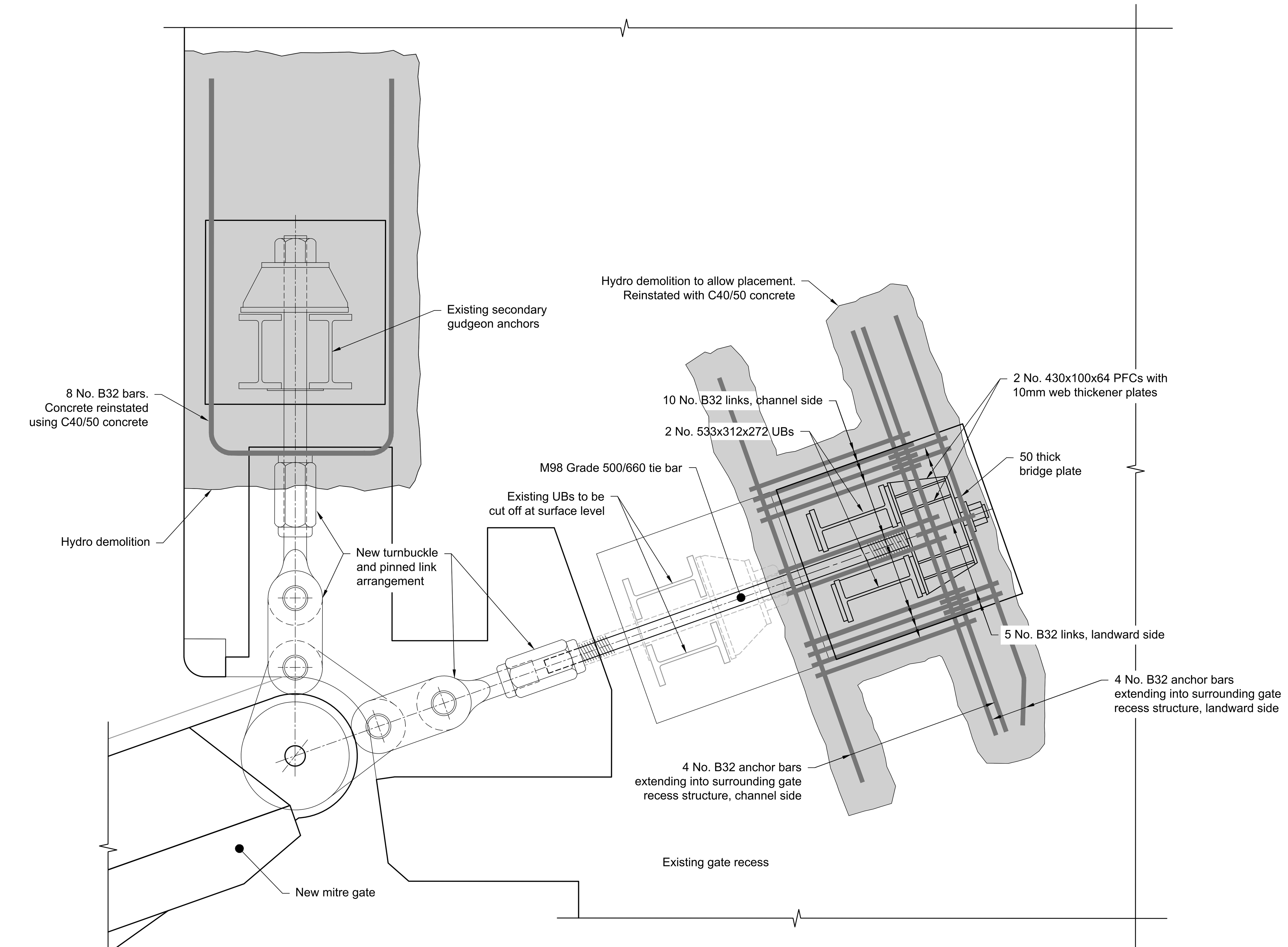
Drawing title: FOR MITRE GATES SHOT BOLT OPTION LONG SECTION

Drawing status: FOR INFORMATION

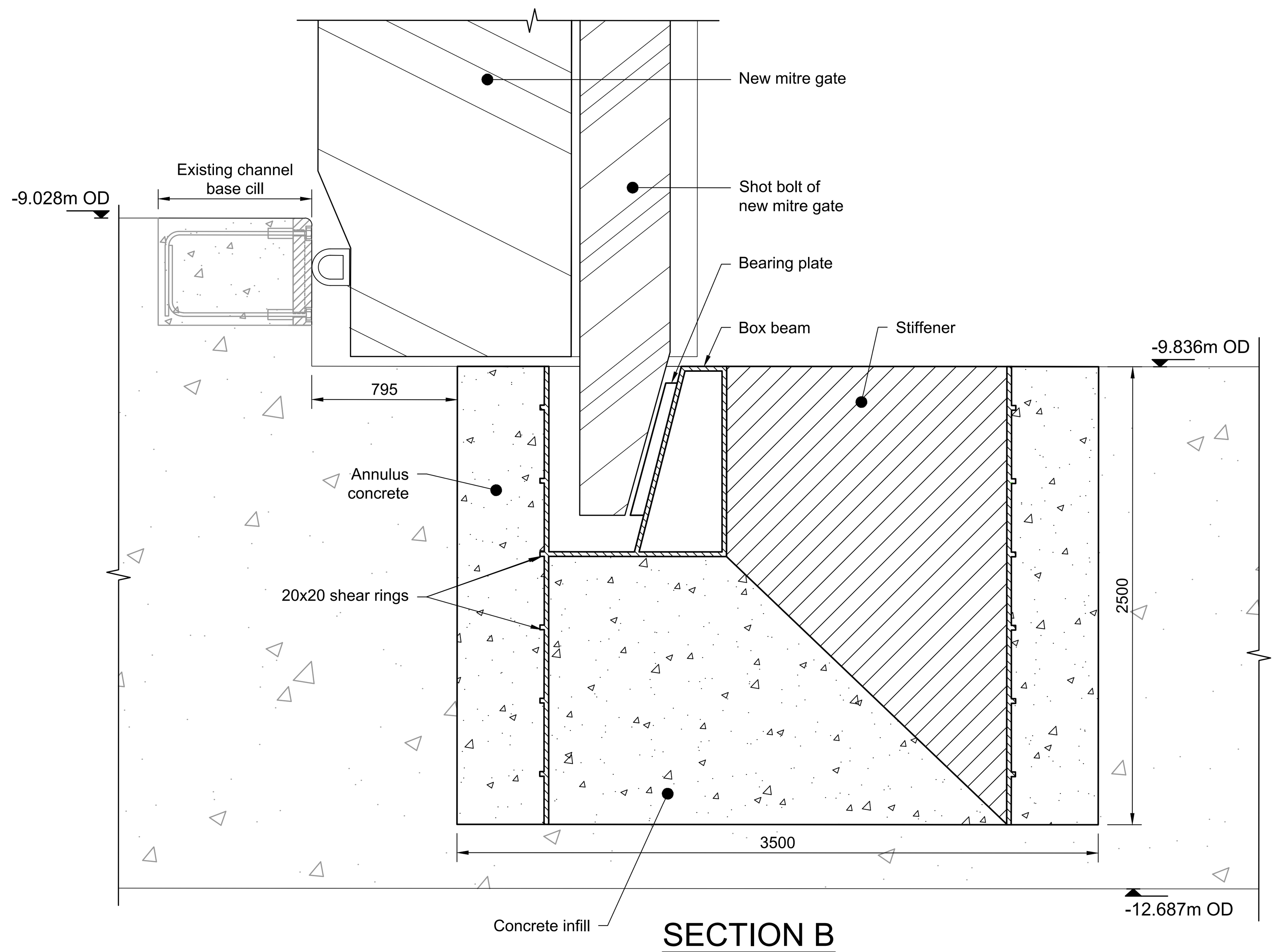
Scale	1:100 @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			
Drawing number	B2386100-JAC-DR-202		



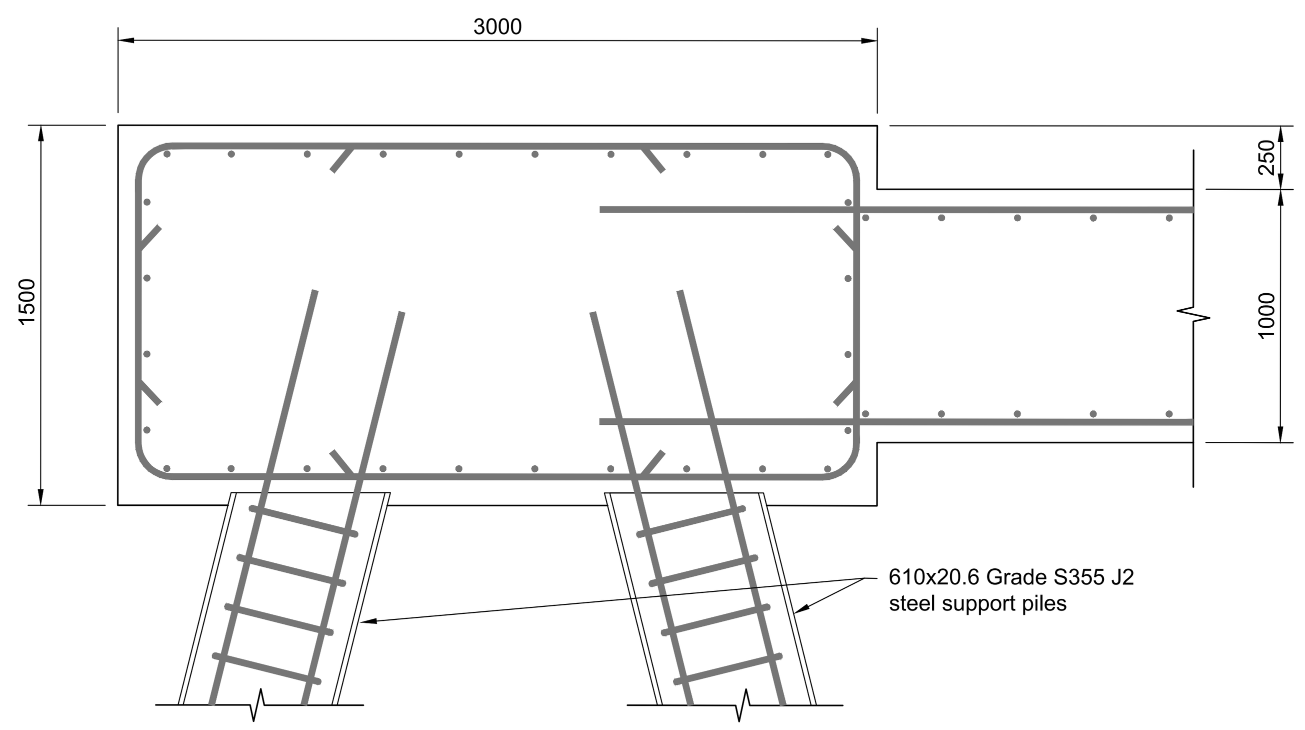
DETAIL 1
SHOT BOLT PIT PLAN
SCALE 1:25



DETAIL 2
GUDGEON ANCHOR ARRANGEMENT PLAN
SCALE 1:25



SECTION B
SCALE 1:25

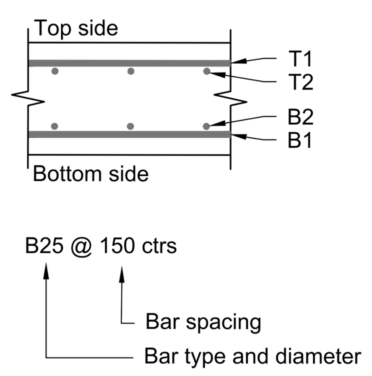


DETAIL 3
PILE CAP AND THRUST SLAB REINFORCEMENT
SCALE 1:25

TABLE 1 - REINFORCEMENT DATA

REFERENCE	PILE CAP (mm)	THRUST SLAB (mm)	PILE PLUG (mm)
T1	B25 @ 150 ctrs	B32 @ 150 ctrs	-
T2	B25 @ 150 ctrs	B32 @ 150 ctrs	-
B1	B25 @ 150 ctrs	B32 @ 150 ctrs	-
B2	B25 @ 150 ctrs	B32 @ 150 ctrs	-
Main bars	-	-	B32 - 14 No.
Links	-	-	B16 @ 150 ctrs

Pile plug details refer to both primary support piles and intermediate support piles



Notes:
1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.
4. The levels shown on this drawing have been deduced based on quayside levels taken by Malcolm Hughes (Chartered Land Surveyors) in November 2020 and the as-built drawings on the lock channel. The levels suggest that settlement of the lock channel and associated infrastructure of approximately 300mm has taken place since its construction. These levels require verification prior to detailed design.

0 0.5 1 1.5 2
SCALE 1:25 (A1) METRES

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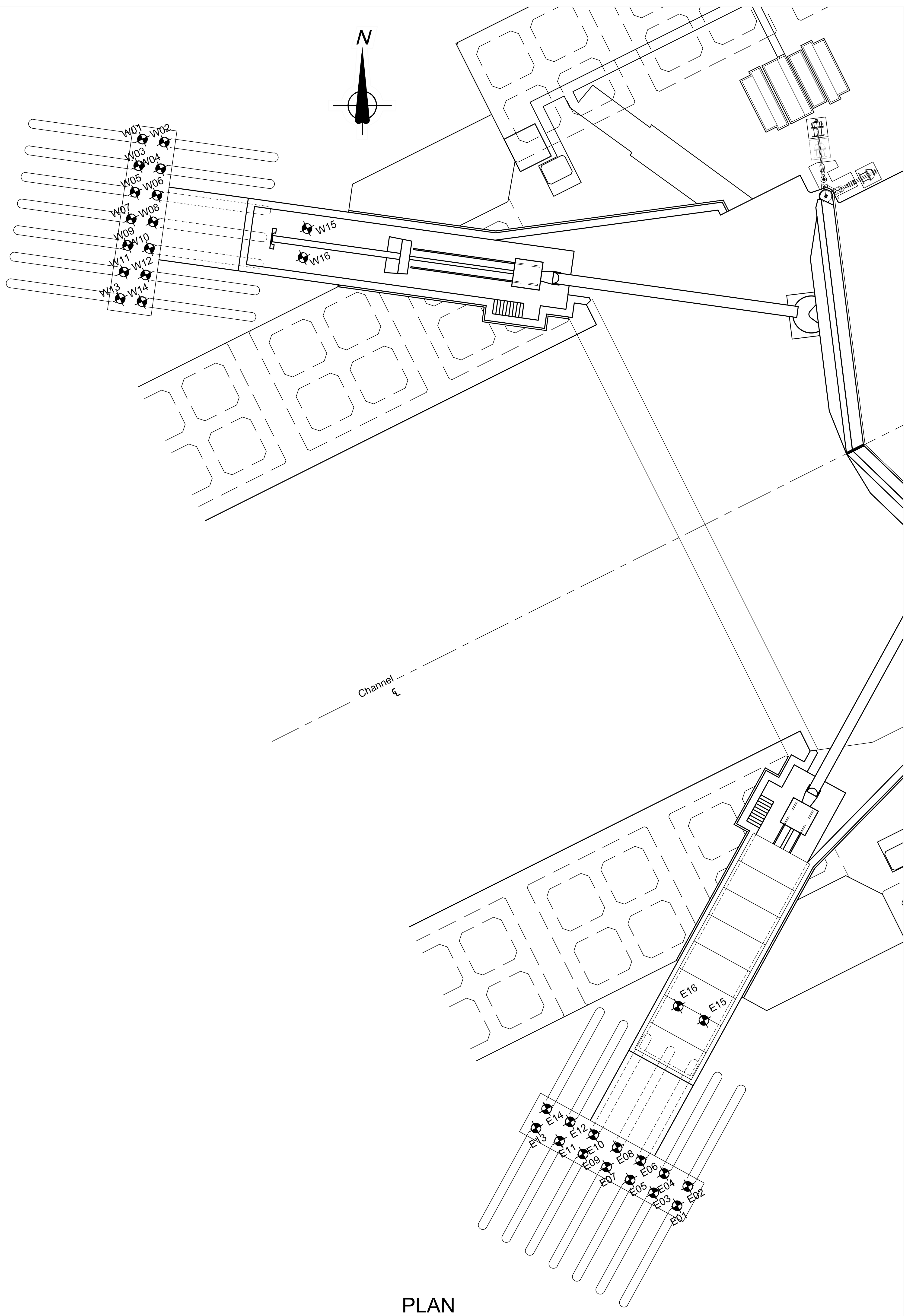
Drawing title
FOR MITRE GATES SHOT BOLT OPTION DETAILS

Drawing status
FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

Drawing number
B2386100-JAC-DR-203



PLAN
SCALE 1:200

TABLE 1
PILE SCHEDULE

PILE REF	DIAMETER (mm)	WALL THICKNESS (mm)	GRADE	CUT OFF LEVEL (mOD)	TOE LEVEL (mOD)	PILE RAKE	ADDITIONAL PILE LENGTH (m)	TOTAL PILE LENGTH (m)
E01	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E02	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E03	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E04	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E05	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E06	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E07	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E08	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E09	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E10	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E11	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E12	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E13	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E14	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
E15	610	20.6	S355J2N	1.800	-35.950	Vertical	17.5	55
E16	610	20.6	S355J2N	1.800	-35.950	Vertical	17.5	55
W01	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W02	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W03	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W04	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W05	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W06	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W07	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W08	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W09	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W10	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W11	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W12	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W13	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W14	610	20.6	S355J2N	1.550	-34.830	1 in 4	17.5	55
W15	610	20.6	S355J2N	1.800	-35.950	Vertical	17.5	55
W16	610	20.6	S355J2N	1.800	-35.950	Vertical	17.5	55

Notes:
1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. Pile setting out coordinates are relative to OSGB36.
5. Additional pile length includes 2.5m allowance for achieving set and 15m allowance for cut off to accommodate piling through gate from quayside.
6. All piles are unpainted.
7. Pile installation tolerance as follows:
   - Pile position at cut-off level: +/- 75mm
   - Pile rake: 1 in 75 for vertical piles; 1 in 15 for raking piles
   - Cut-off level: +/- 10mm

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P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Drawing title: MITRE GATES SHOT BOLT OPTION PILE SETTING OUT POINTS

Drawing status: FOR INFORMATION

Scale	1:200 @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

Drawing number: B2386100-JAC-DR-204

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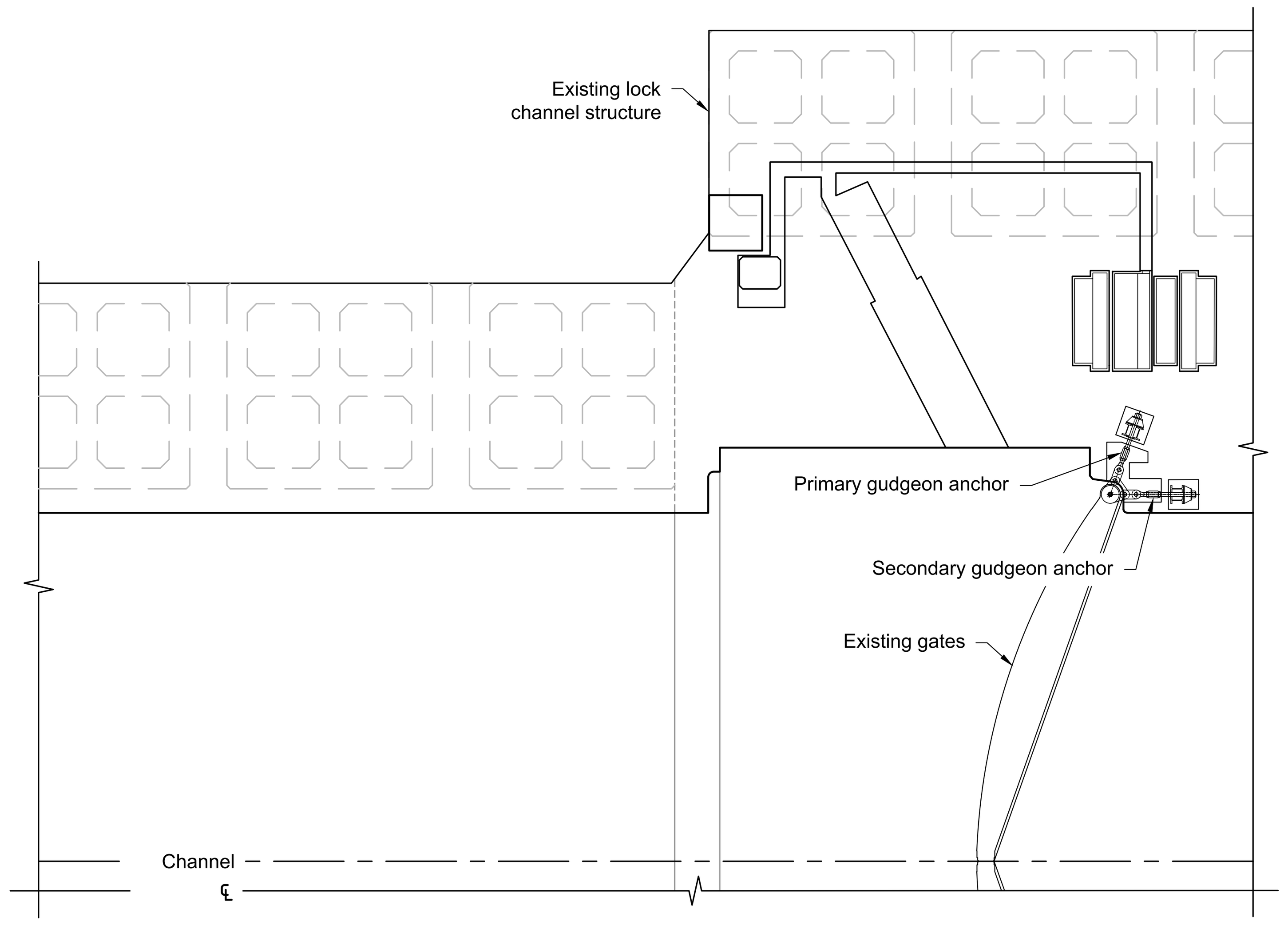
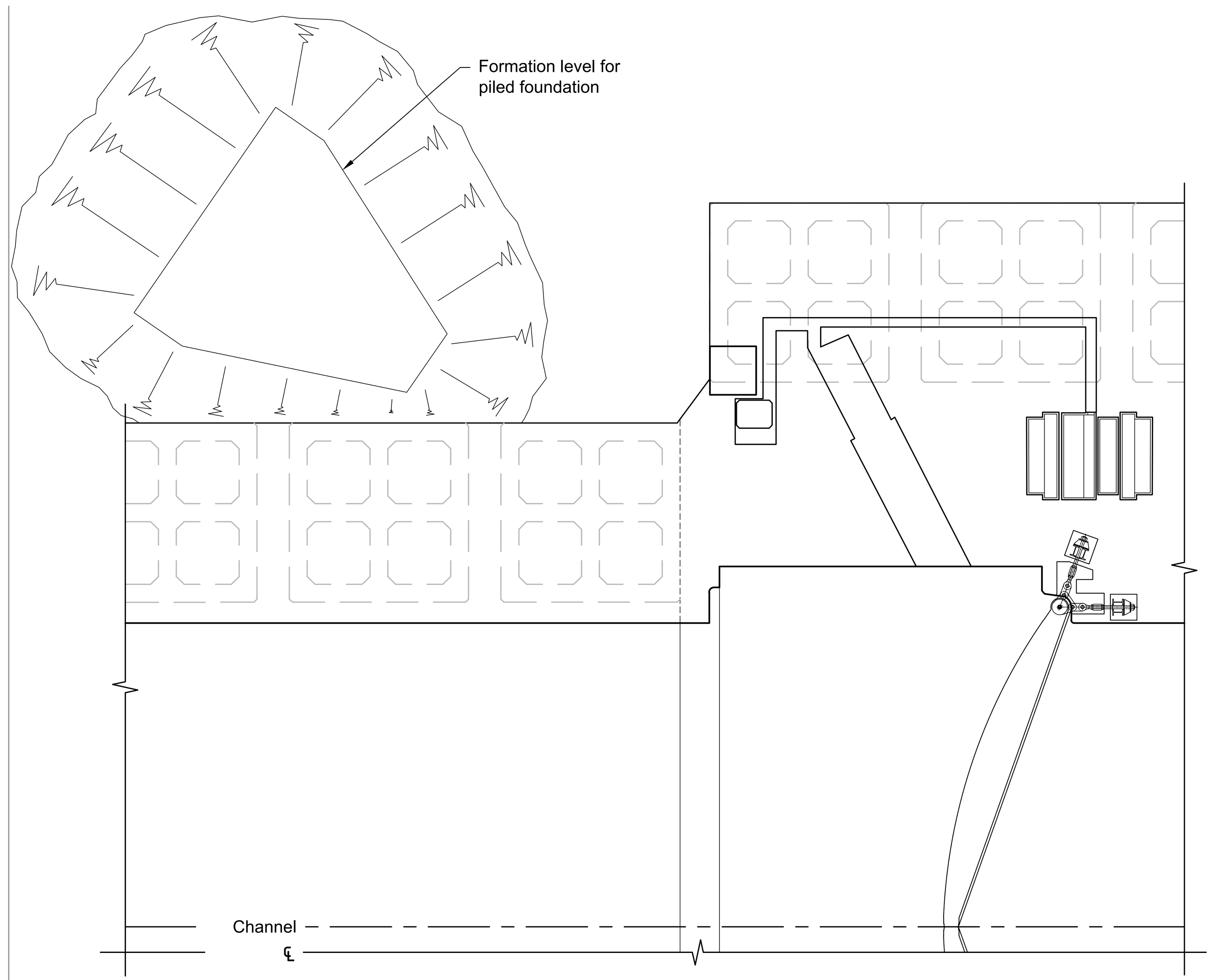


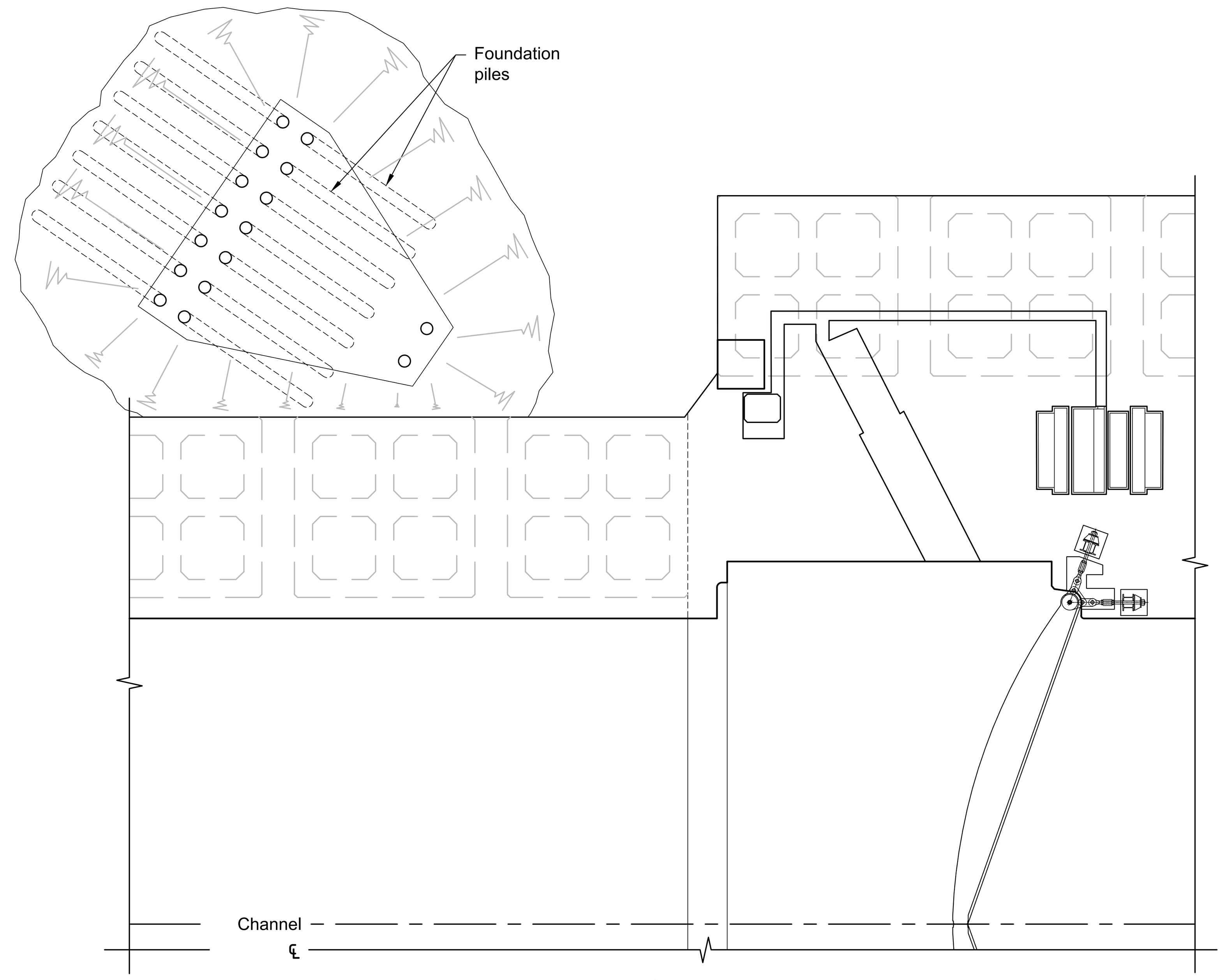
STAGE 1

1.1 Mobilise and establish site



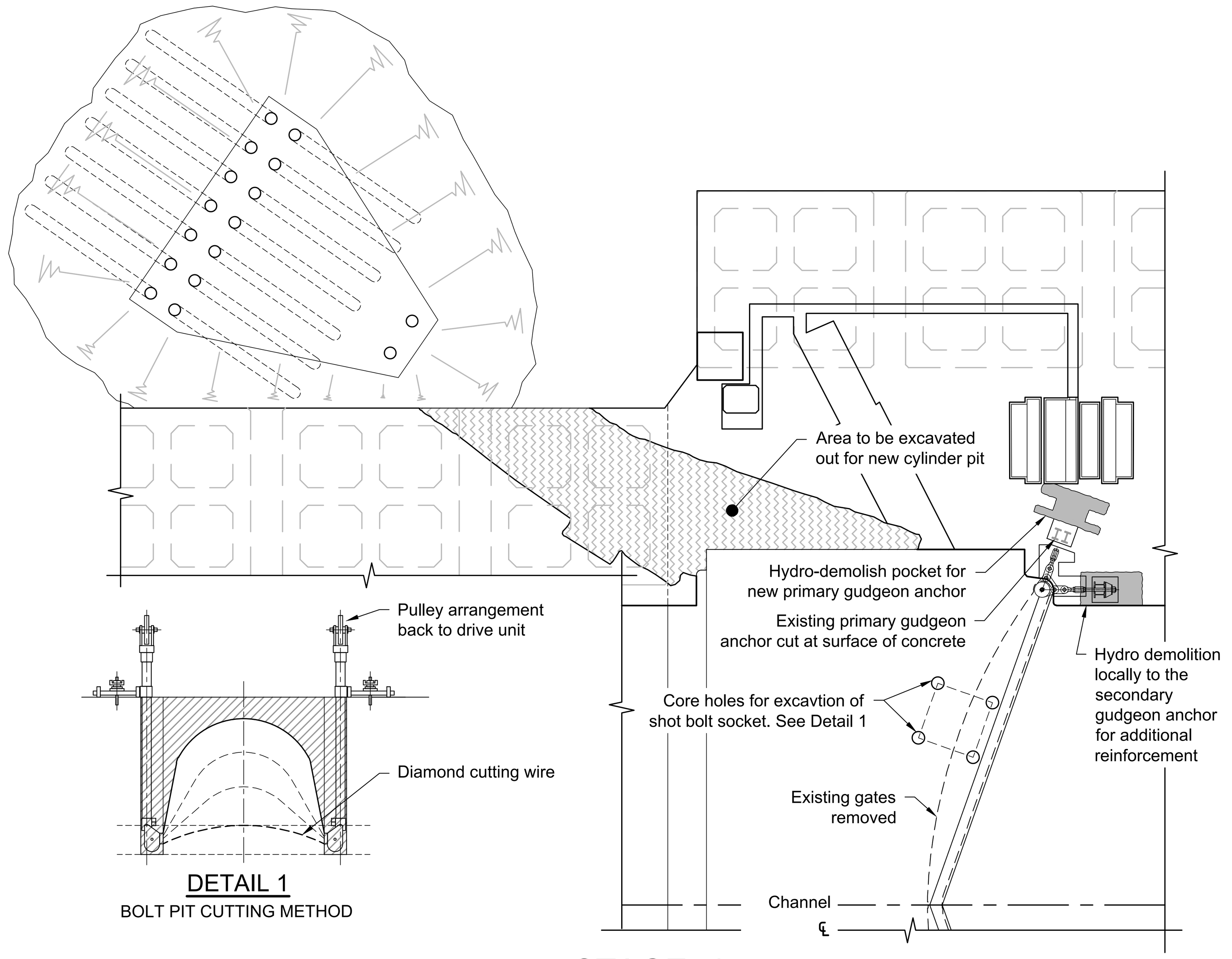
STAGE 2

2.1 Excavate to soffit level of piled foundation



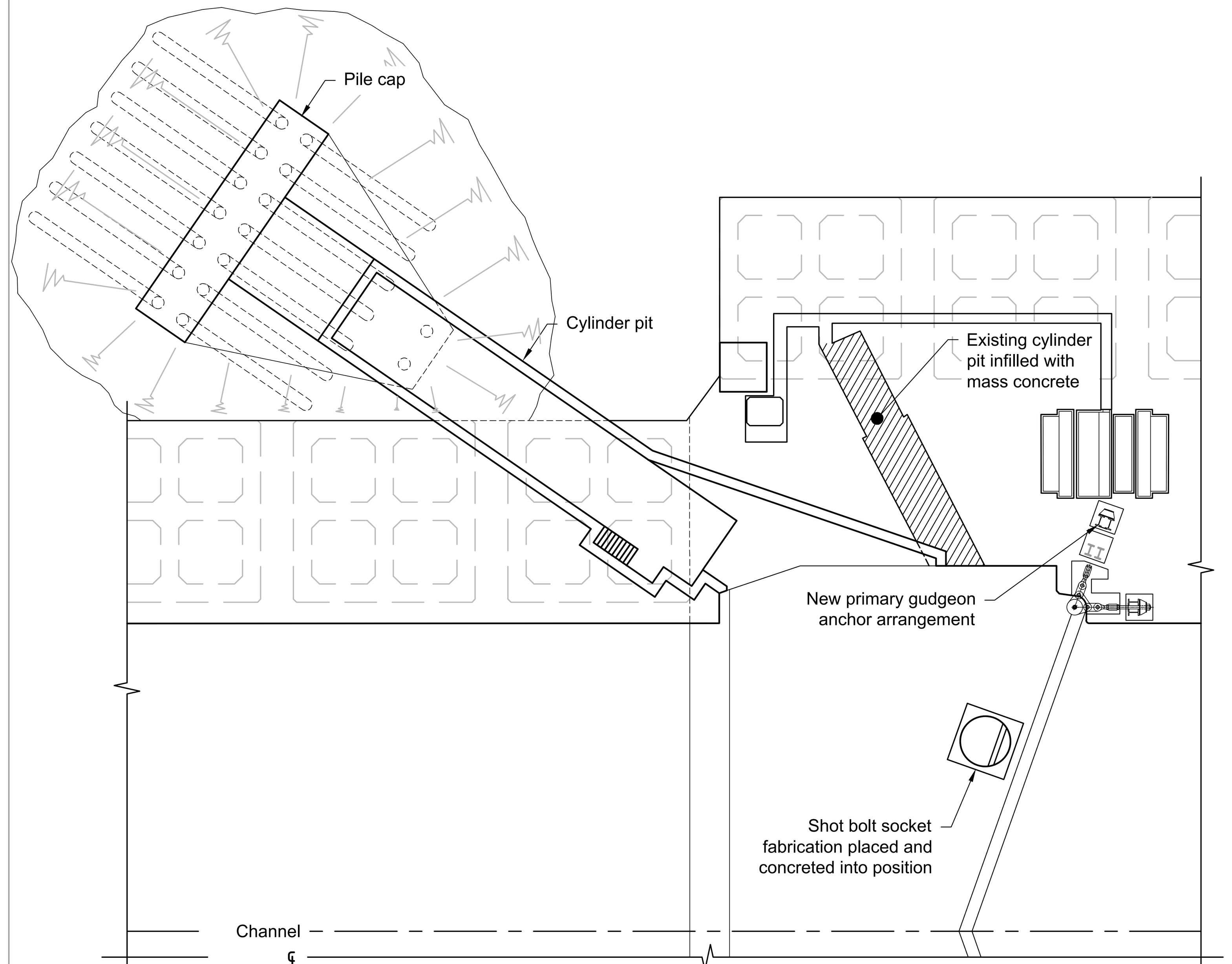
STAGE 3

3.1 Drive foundation piles.



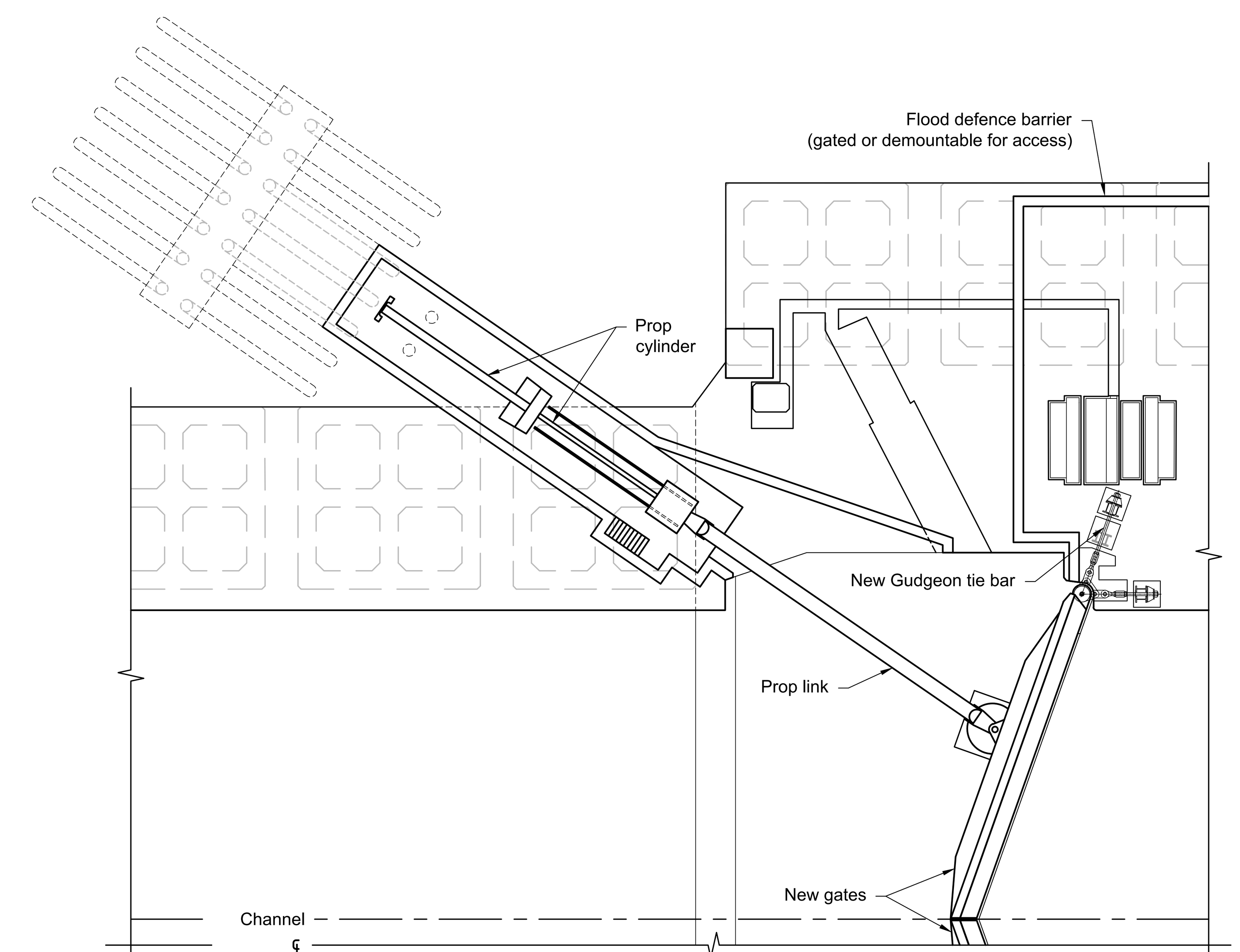
STAGE 4

4.1 Remove existing gates.
4.2 Cut existing primary gudgeon anchor sections.
4.3 Excavate pocket for new primary gudgeon arrangement and remove concrete locally to secondary gudgeon anchor by hydro-demolition.
4.4 Excavate pocket for new cylinder pit.
4.5 Wire cutting rig lowered to channel bottom and positioned using divers. Corners blind cored to required depth. Sides of the void cut using diamond wire plunge saw technique. Once sides have been cut, the cut across the bottom of the pit will be made using the same method. Lifting points fixed to the concrete block for removal by crane.



STAGE 5

5.1 Cast pile cap and thrust slab.
5.2 Cast cylinder pit and make good the excavation sides to the existing gate recess structure.
5.3 Install new primary gudgeon anchor and reinforcement then reinstate concrete.
5.4 At secondary gudgeon anchor install U-bars then reinstate concrete.
5.5 Infill existing cylinder pit with mass concrete.
5.6 Shot bolt socket placed and concreted into position.



STAGE 6

6.1 Backfill around new cylinder pit foundaton structure.
6.2 Install new gates, gudgeon tie bar, prop link, cylinder and associated M&E.
6.2 Quayside flood defences and mating demountable barrier sections installed to interface with gate barriers.
6.4 Covers installed new cylinder pit arrangement.

Notes:
1. Do not scale from this drawing.

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P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Project: GRANGEMOUTH FPS

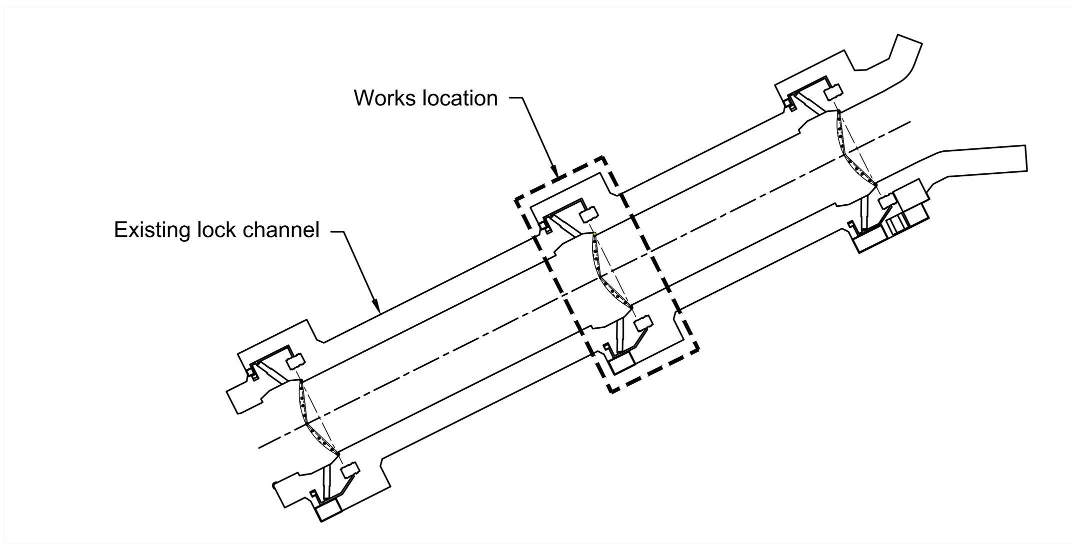
Drawing title: CONSTRUCTION SEQUENCE FOR MITRE GATES SHOT BOLT OPTION

Drawing status: FOR INFORMATION

Scale	Not to scale	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

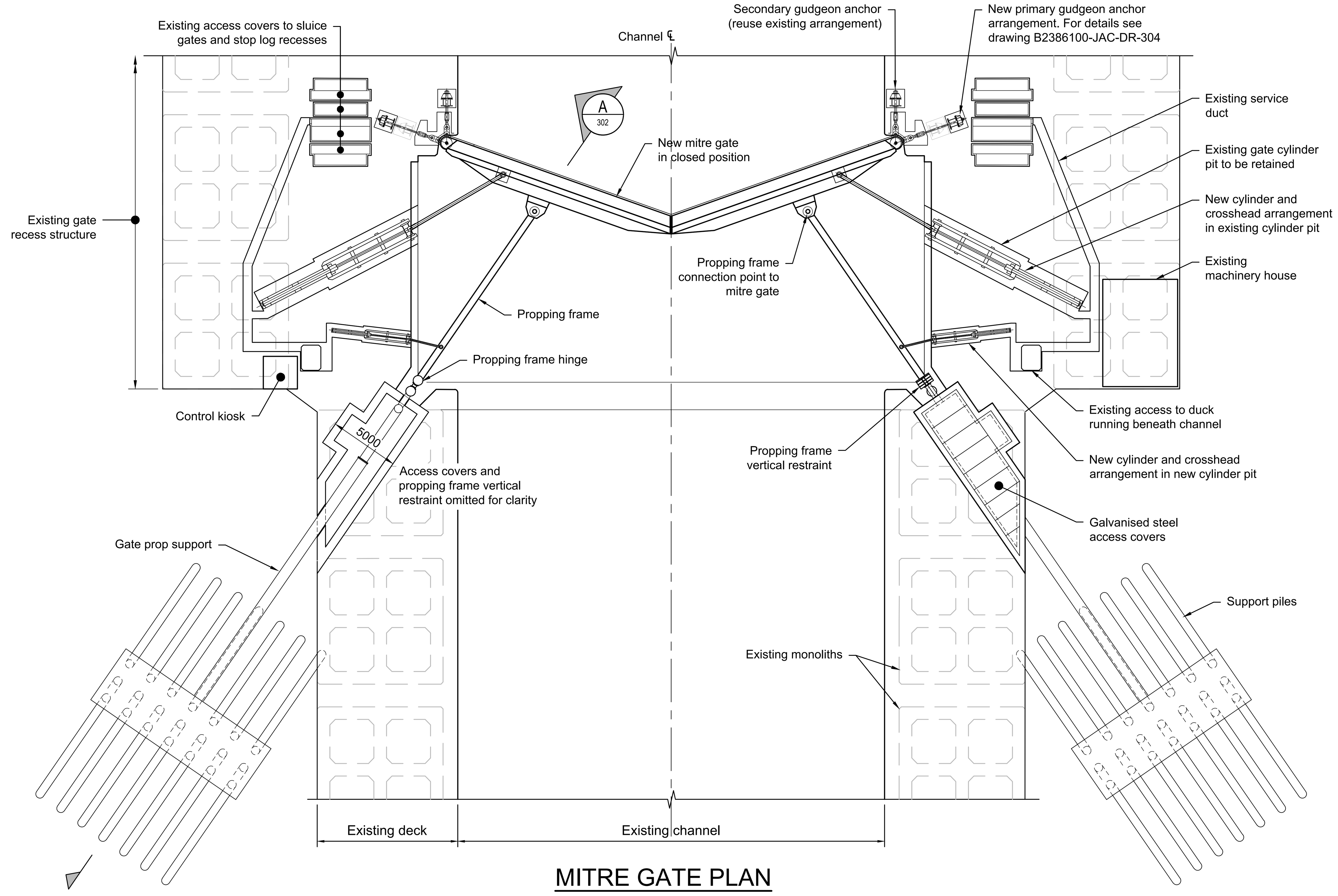
Drawing number: B2386100-JAC-DR-205

Appendix C. Option F drawings



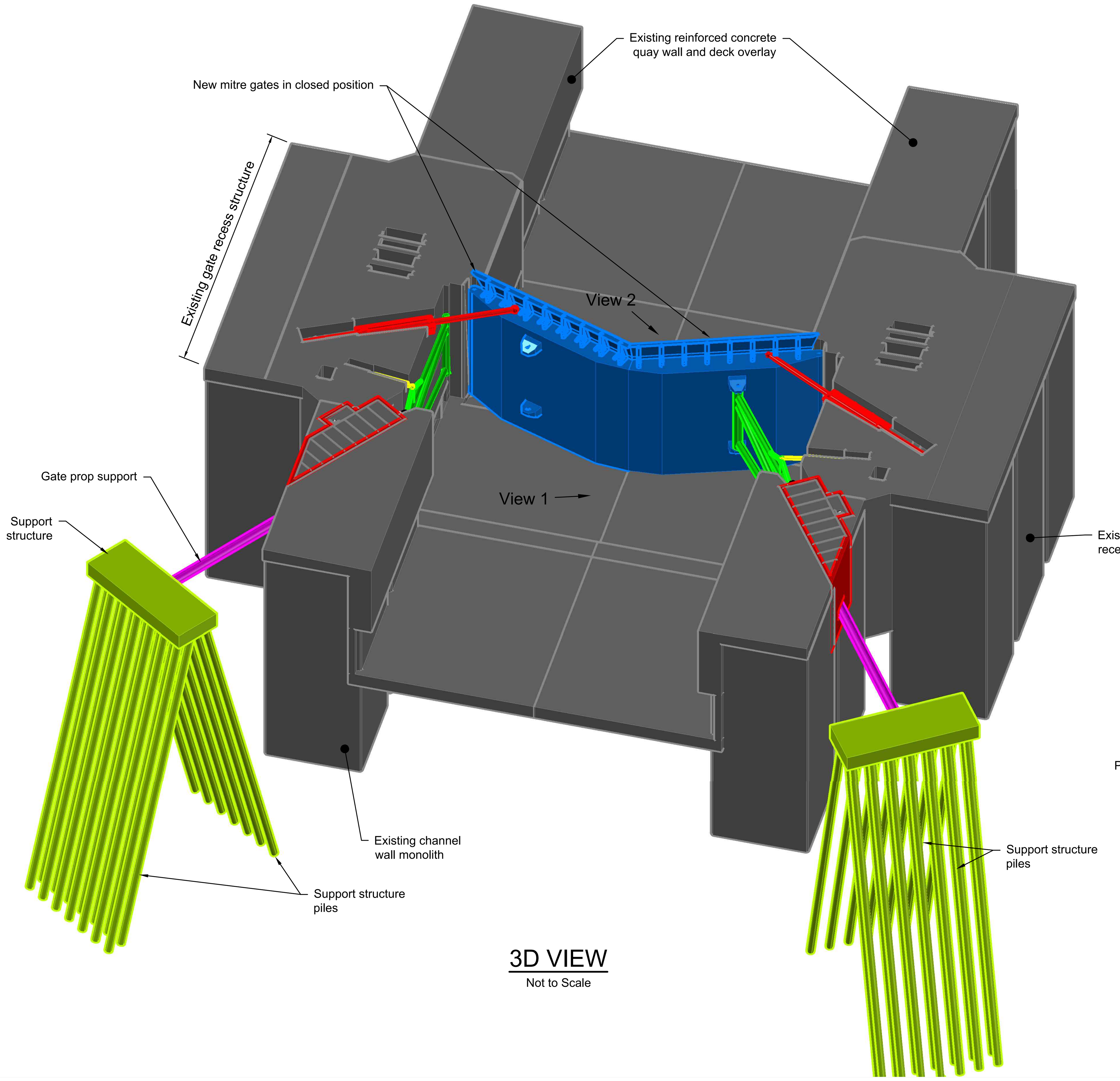
KEY PLAN

Not to Scale



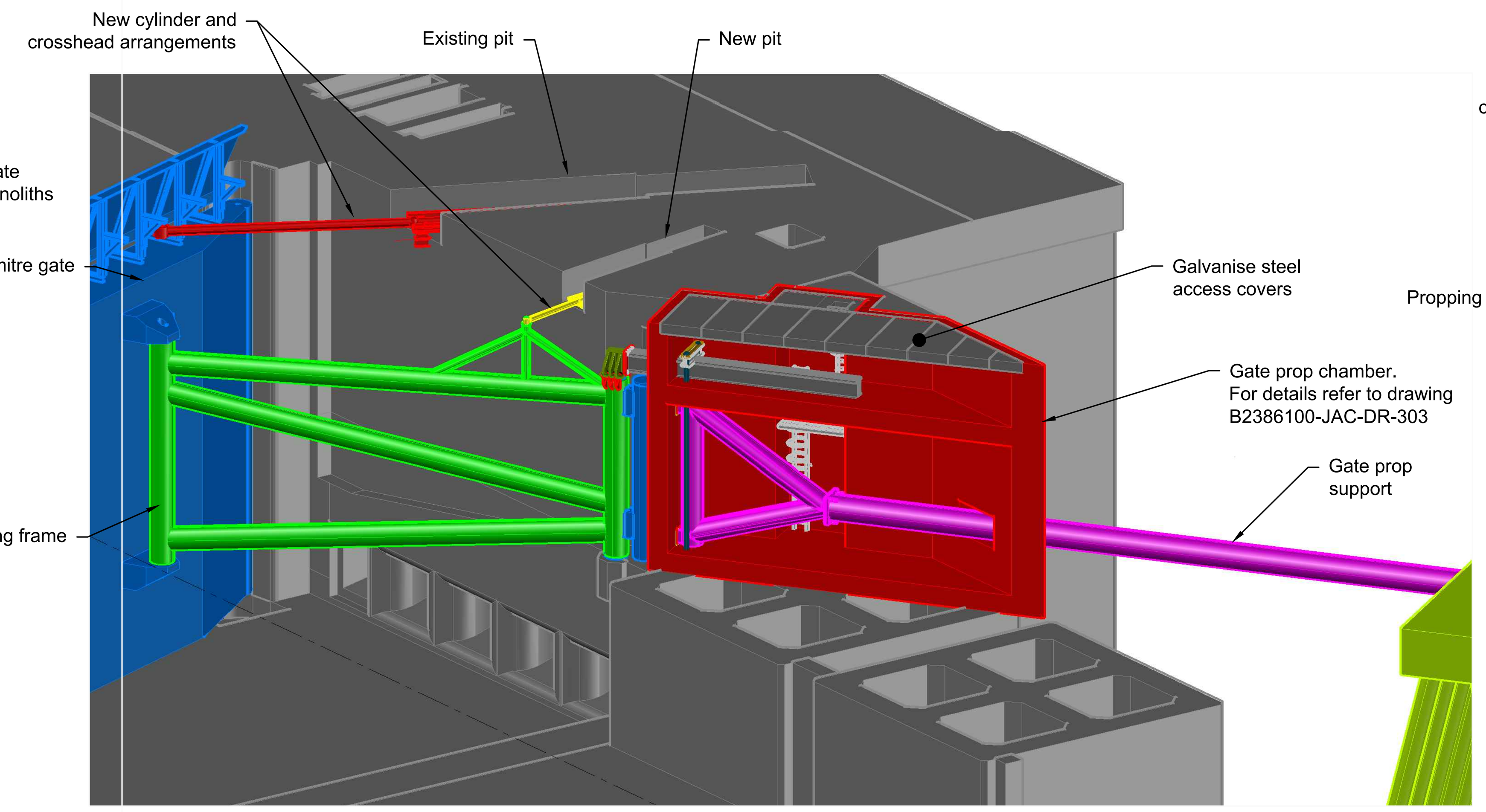
MITRE GATE PLAN

SCALE 1:250



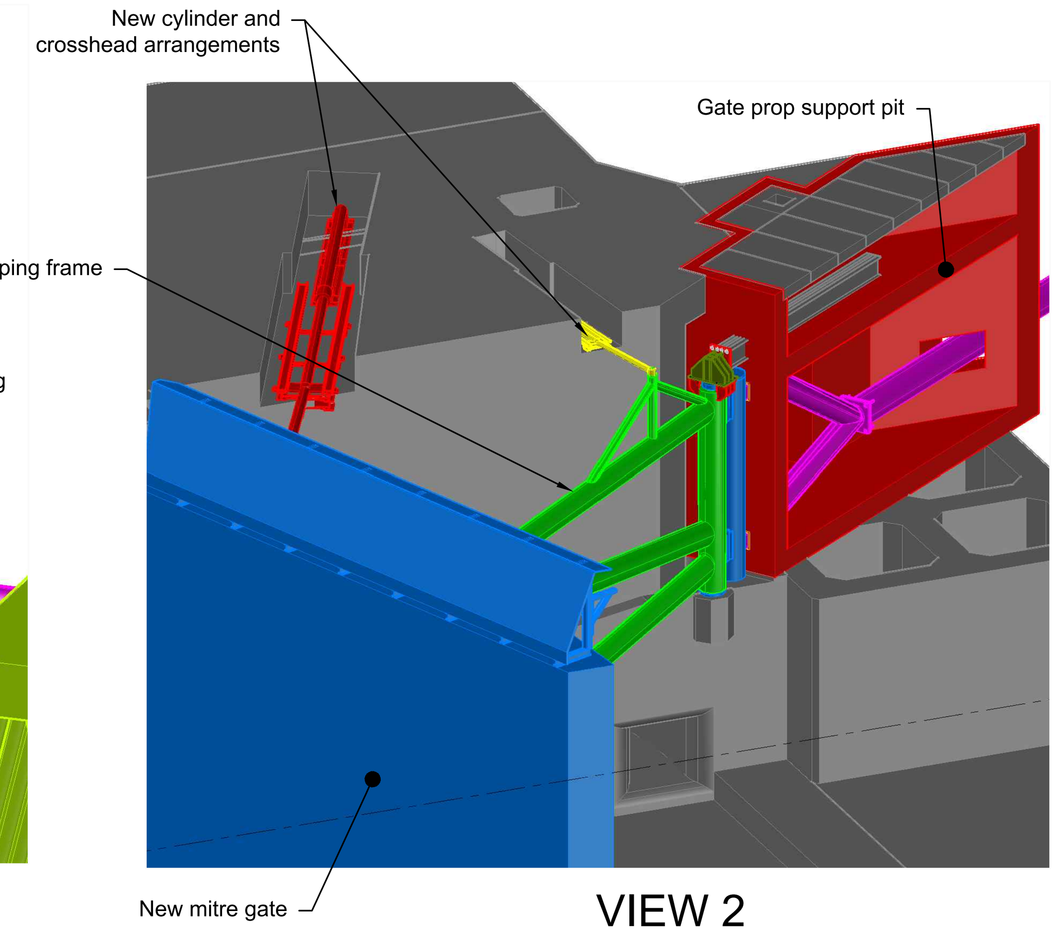
3D VIEW

Not to Scale



VIEW 1

Not to scale



VIEW 2

Not to scale

Notes:

1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.

0 5 10 15 20
SCALE 1:250 (A1) METRES

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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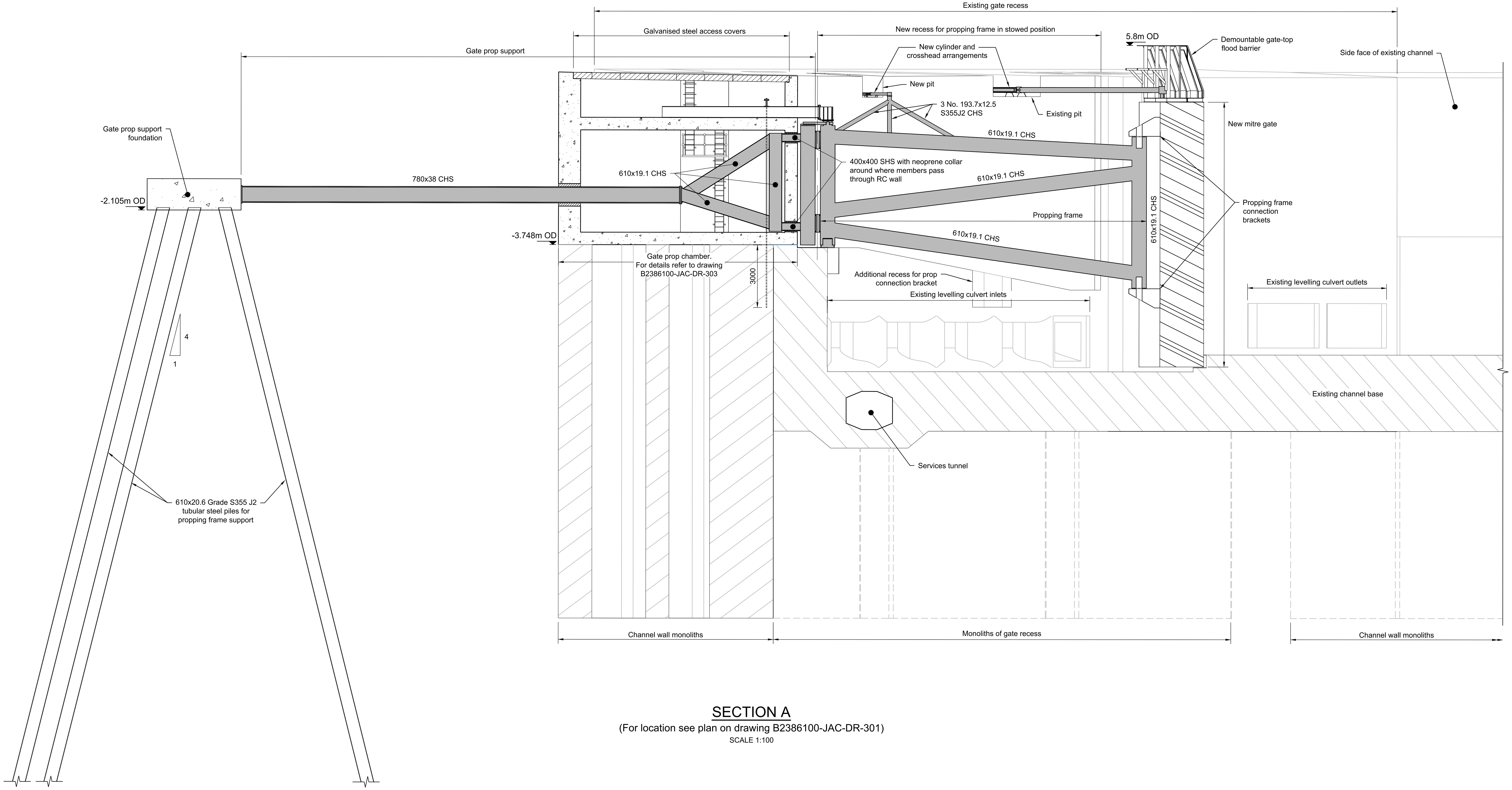
Project: GRANGEMOUTH FPS

Drawing title: OPTION C FOR MITRE GATES PROP FRAME OPTION

Drawing status: FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			
Drawing number	B2386100-JAC-DR-301		



SECTION A

(For location see plan on drawing B2386100-JAC-DR-301)

SCALE 1:100

Notes:

1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.
4. The levels shown on this drawing have been deduced based on quayside levels taken by Malcolm Hughes (Chartered Land Surveyors) in November 2020 and the as-built drawings on the lock channel. The levels suggest that settlement of the lock channel and associated infrastructure of approximately 300mm has taken place since it's construction. These levels require verification prior to detailed design.

0 5 10
SCALE 1:100 (A1) METRES

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
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Project: GRANGEMOUTH FPS

Drawing title: MITRE GATES PROP OPTION

Drawing status: FOR INFORMATION

Scale	1:100 @ A1	DO NOT SCALE
Jacobs No.	B2386100	Rev P0
Client no.		

Drawing number: B2386100-JAC-DR-302

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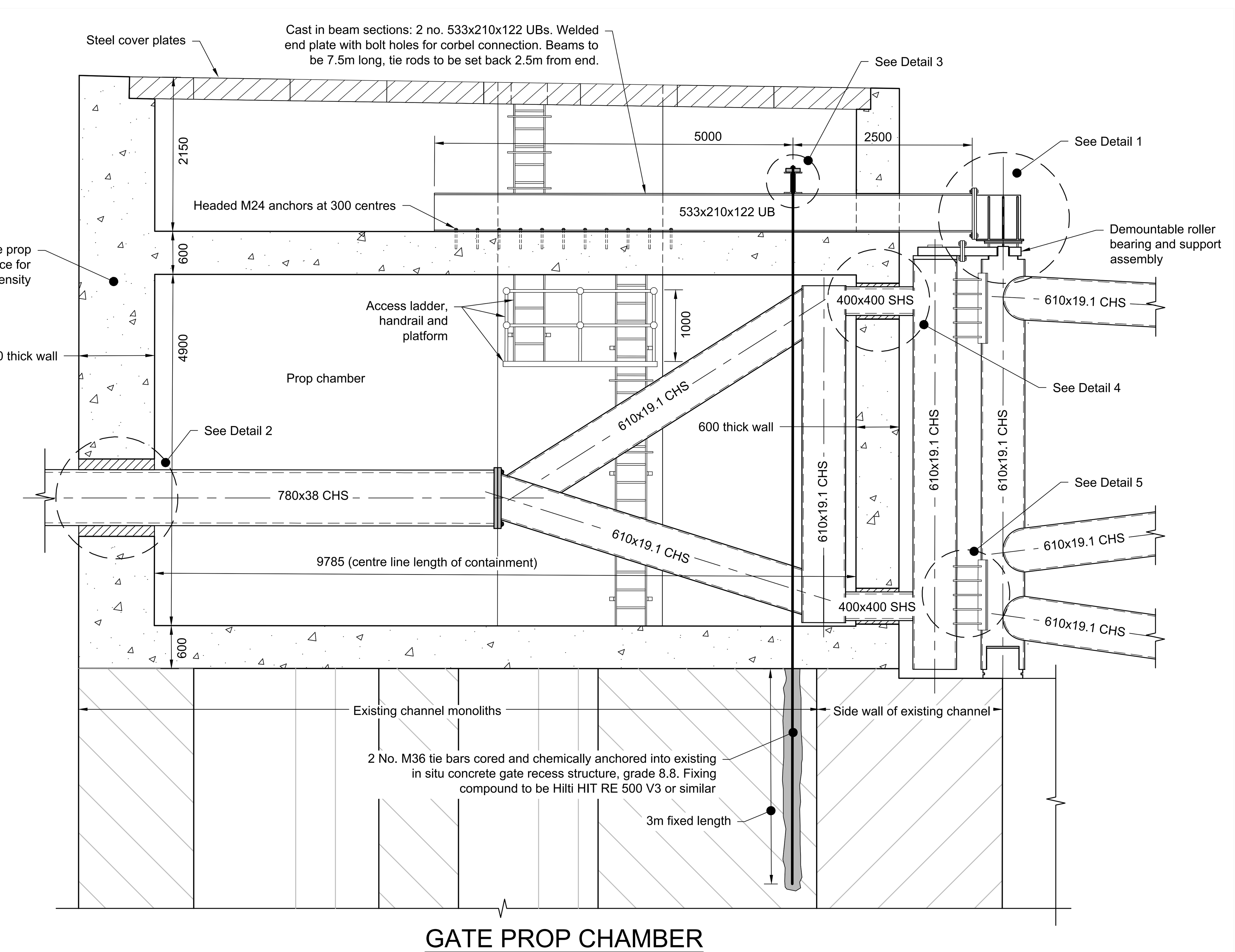
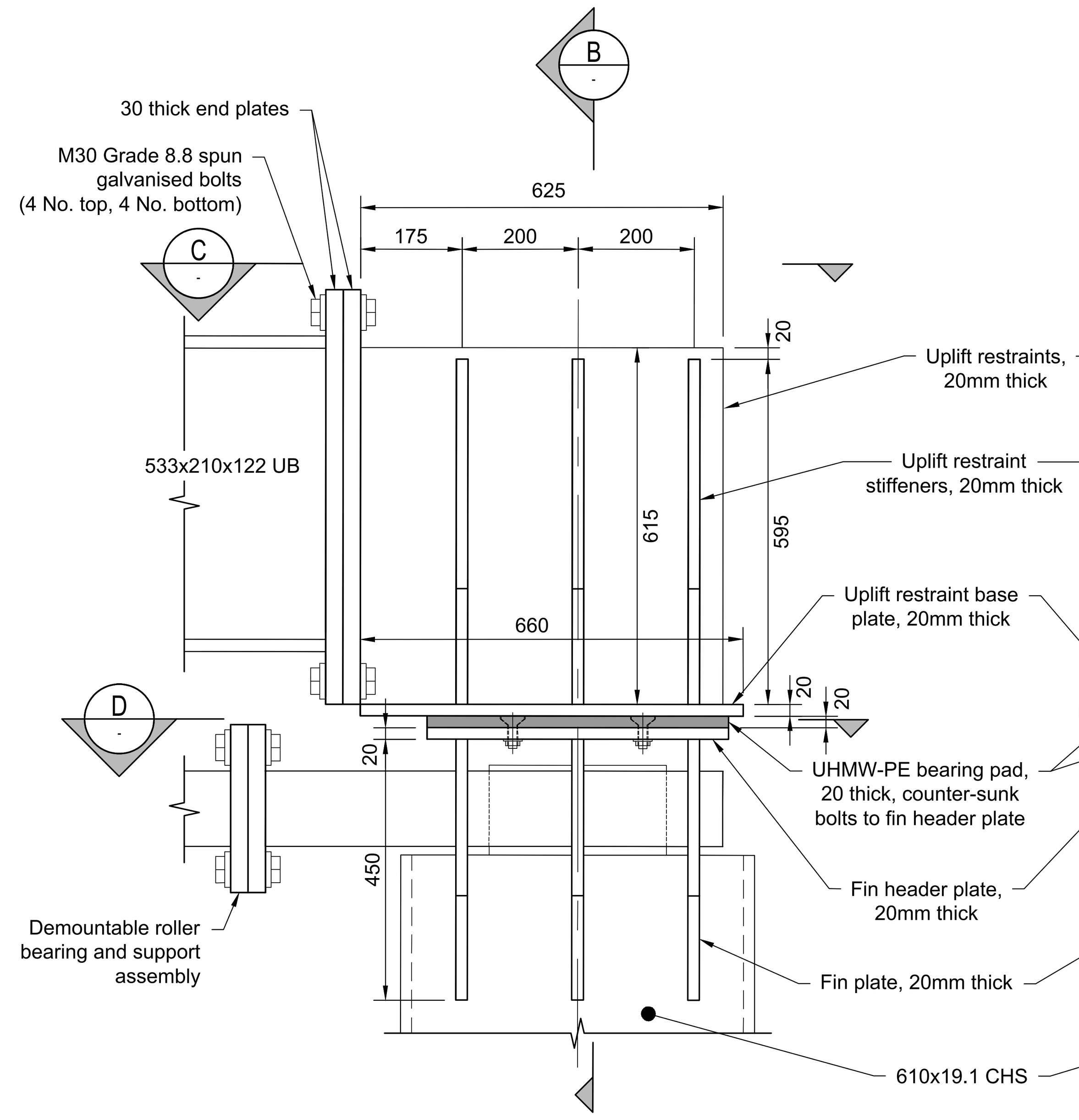
AUTOCAD DRAWING

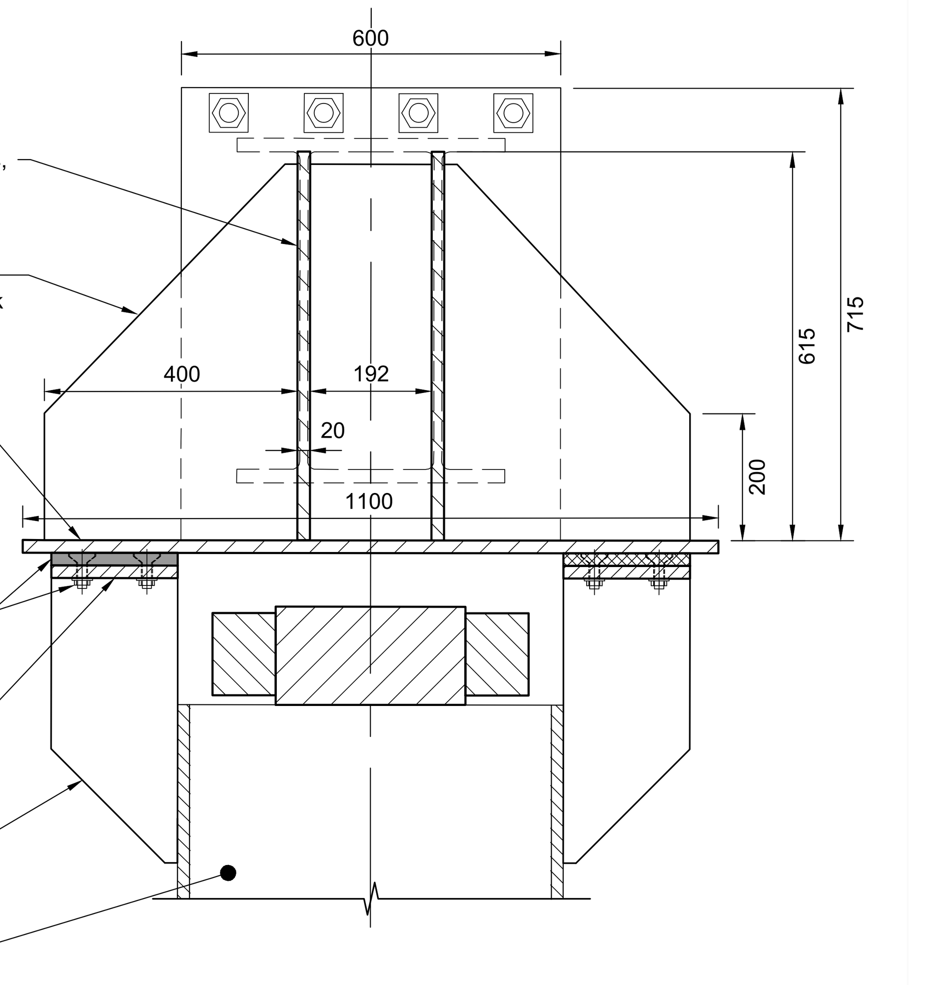
\\glafpp02\Water\Projects\ALL_FC_PROJECTS\B2386100 Grangemouth FPS\60_Deliverables\Drawings\Port study\01 Preliminary\B2386100-JAC-DR-301 to 303 Rev P0.dwg - 16/09/2021 17:12:36 - 302 - McgilliganJA



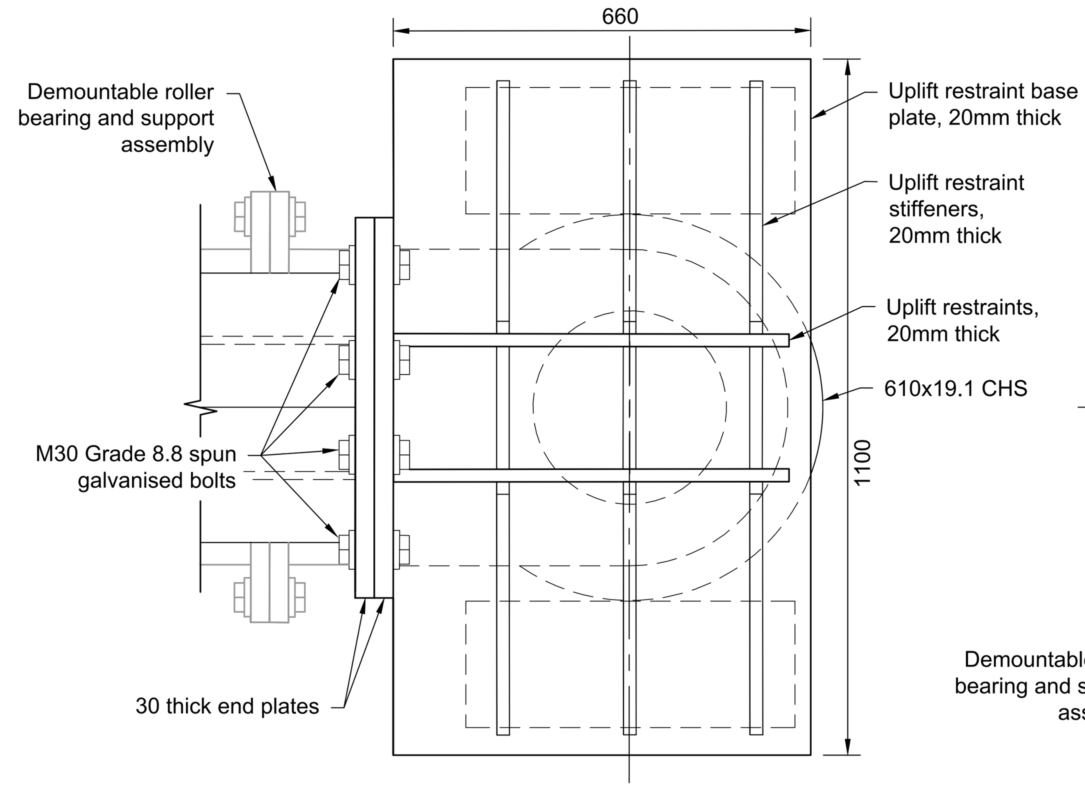
GATE PROP CHAMBER
TYPICAL LONG SECTION
SCALE 1:50



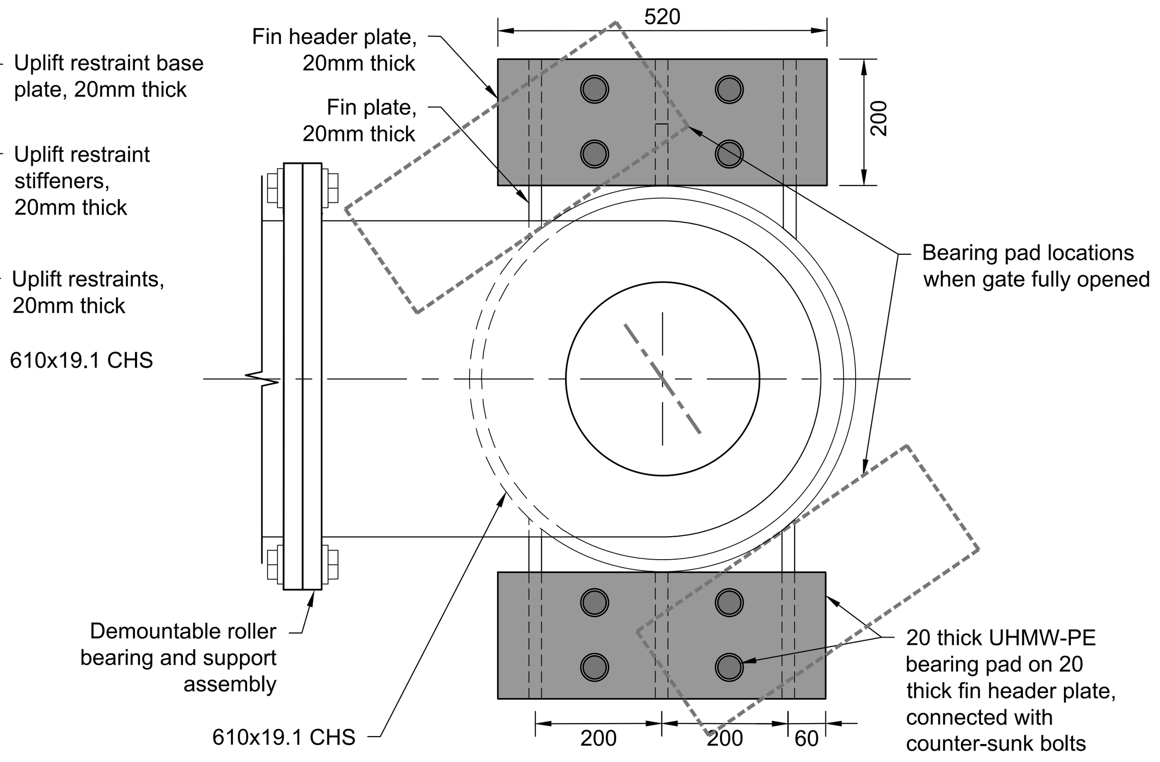
DETAIL 1
SCALE 1:10



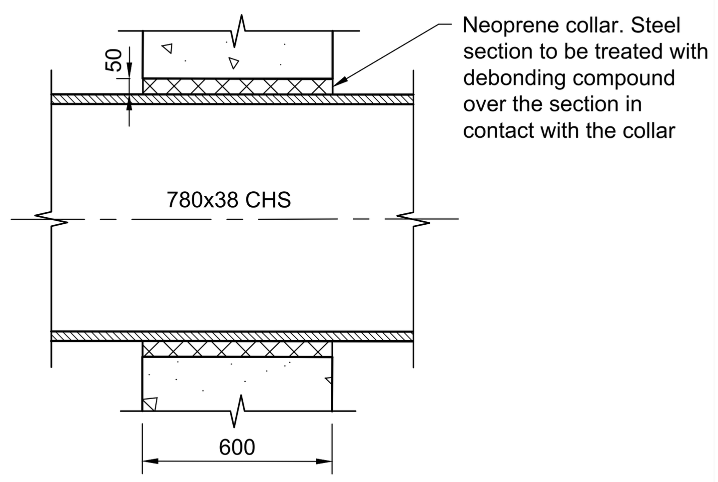
SECTION B
SCALE 1:10



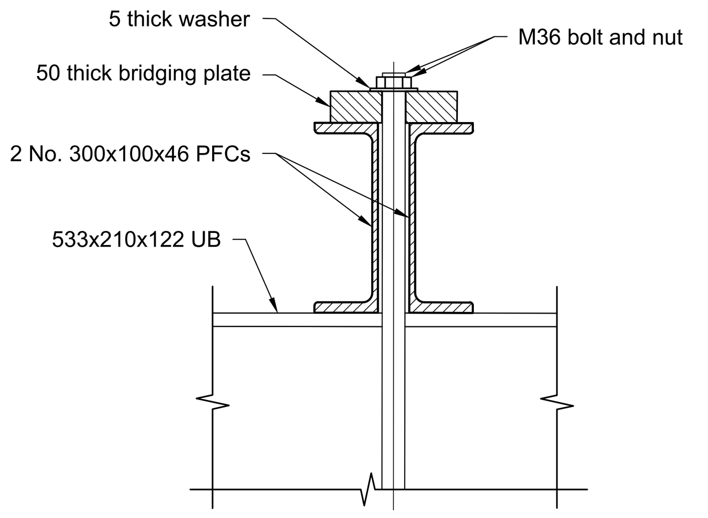
PLAN C
SCALE 1:10



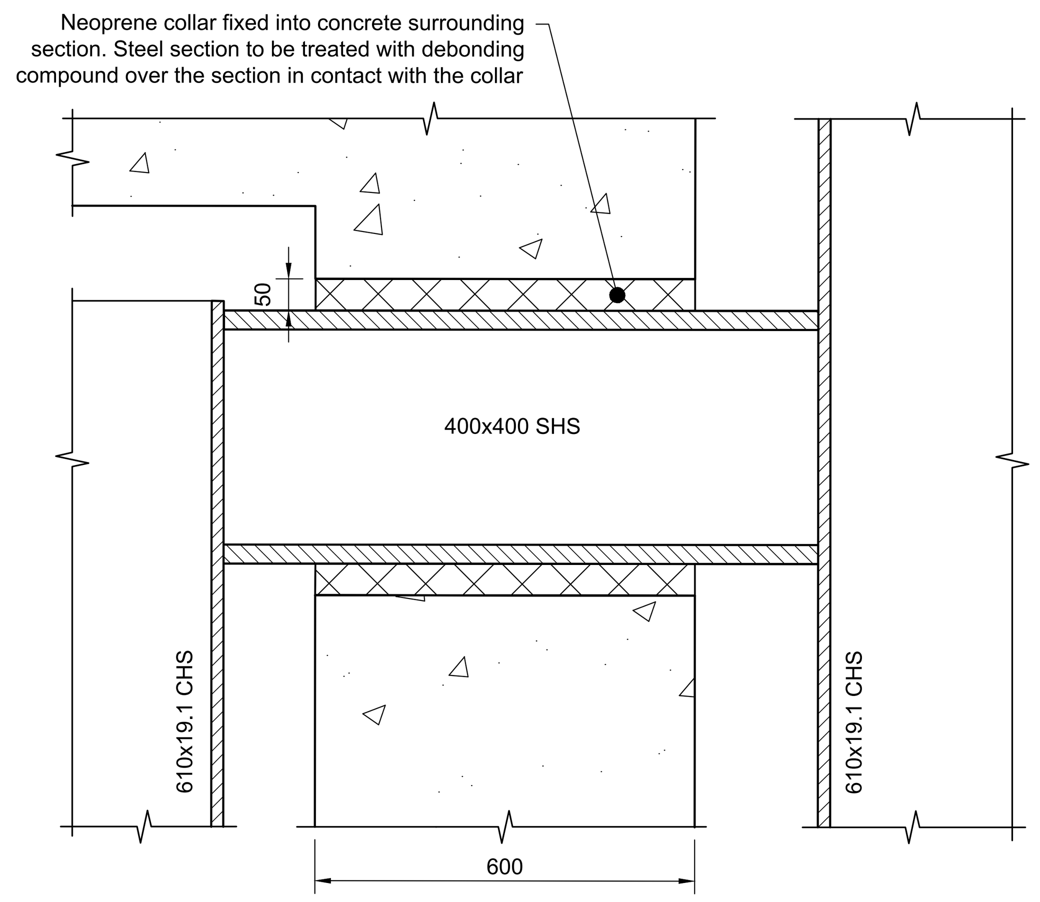
SECTION D
SCALE 1:10



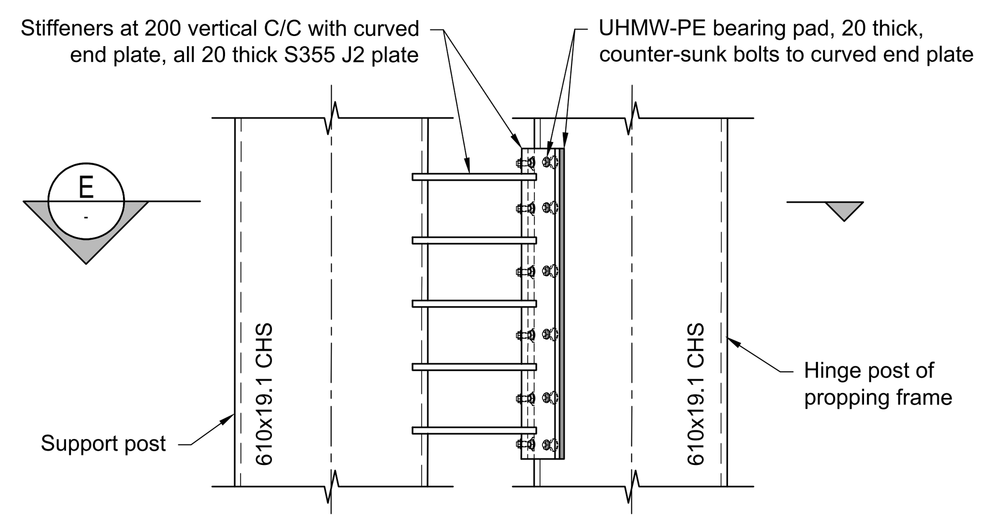
DETAIL 2
SCALE 1:20



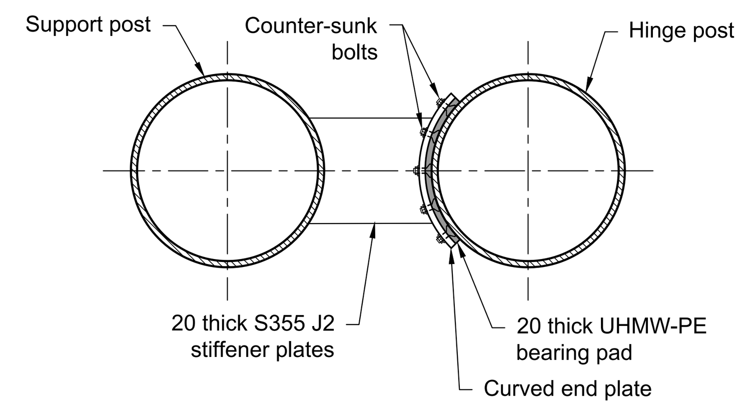
DETAIL 3
SCALE 1:10



DETAIL 4
SCALE 1:10



DETAIL 5
SCALE 1:20



SECTION E
SCALE 1:20

Notes:

1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.
4. All steelwork S355 J2 to EN 10025 unless otherwise stated.

0 100 200 300 400 500 1000
SCALE 1:10 (A1) MILLIMETRES

0 0.5 1 2
SCALE 1:20 (A1) METRES

0 1000 2000 3000 4000 5000
SCALE 1:50 (A1) MILLIMETRES

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Project: GRANGEMOUTH FPS

Drawing title: FOR MITRE GATES PROP OPTION DETAILS

Drawing status: FOR INFORMATION

Scale	AS SHOWN @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

Drawing number: B2386100-JAC-DR-303

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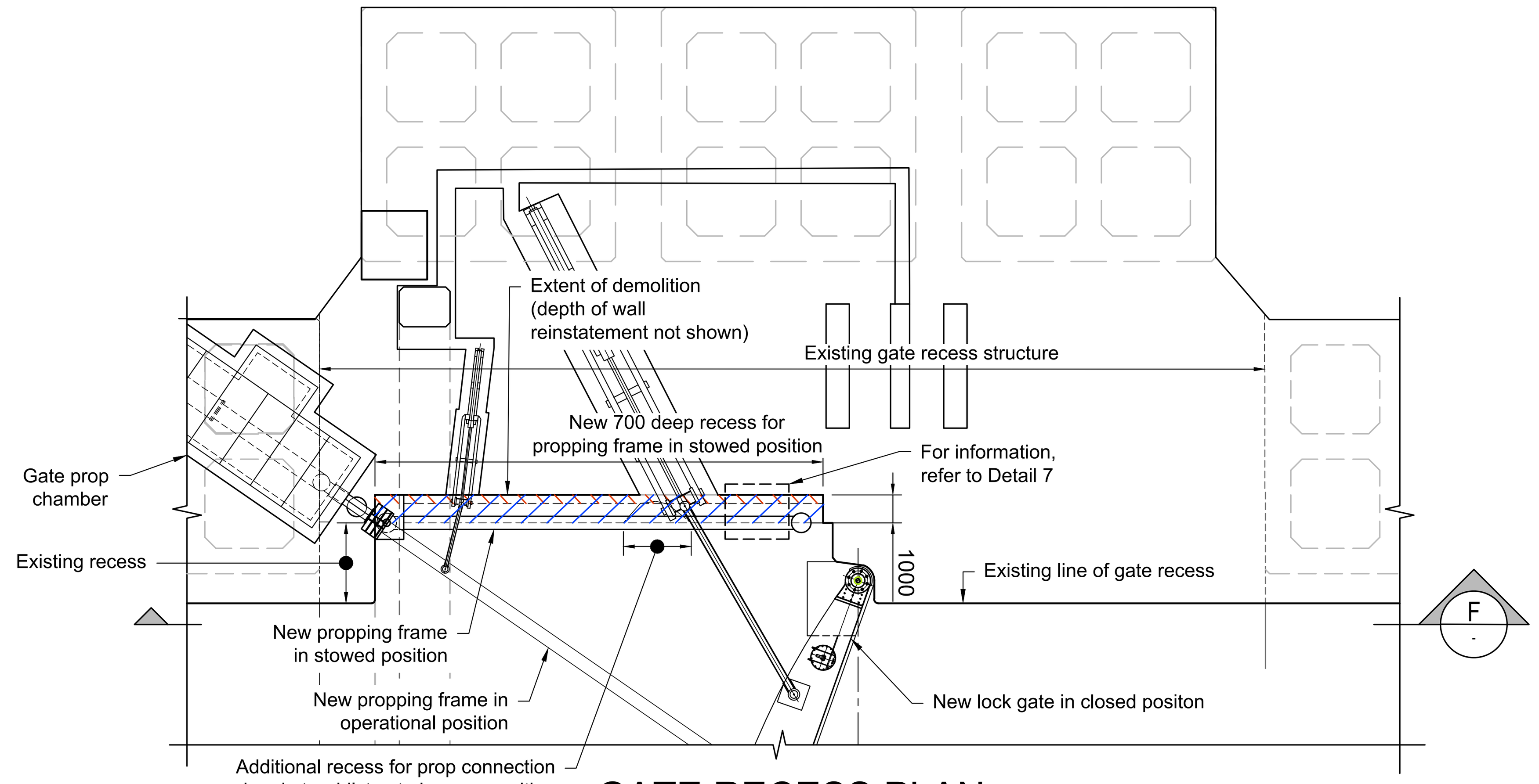
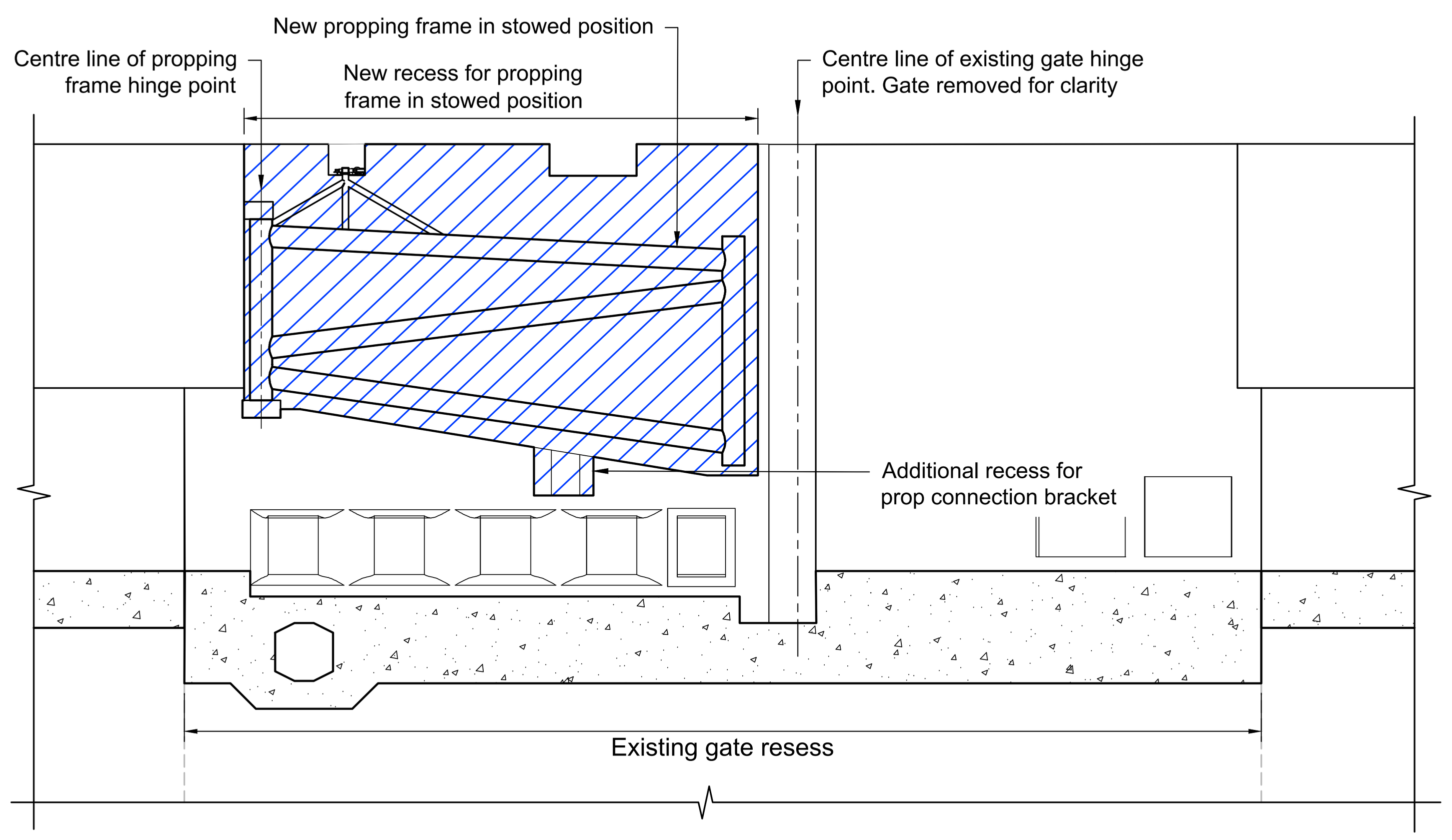


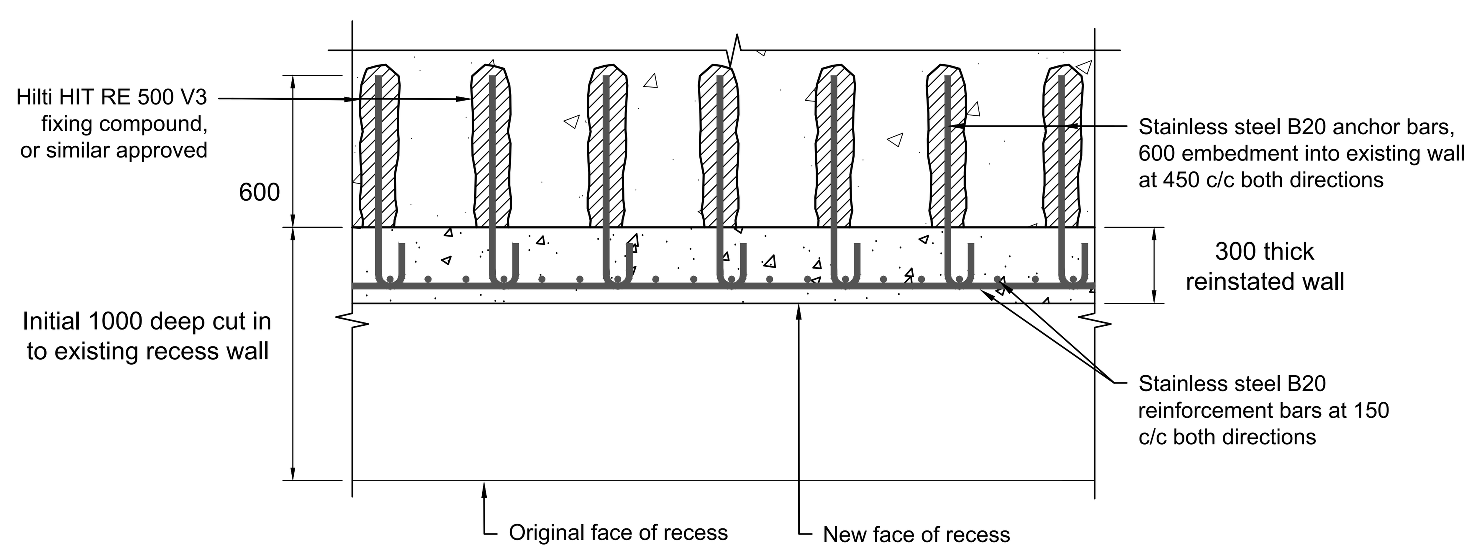
GATE RECESS PLAN

SCALE 1:200



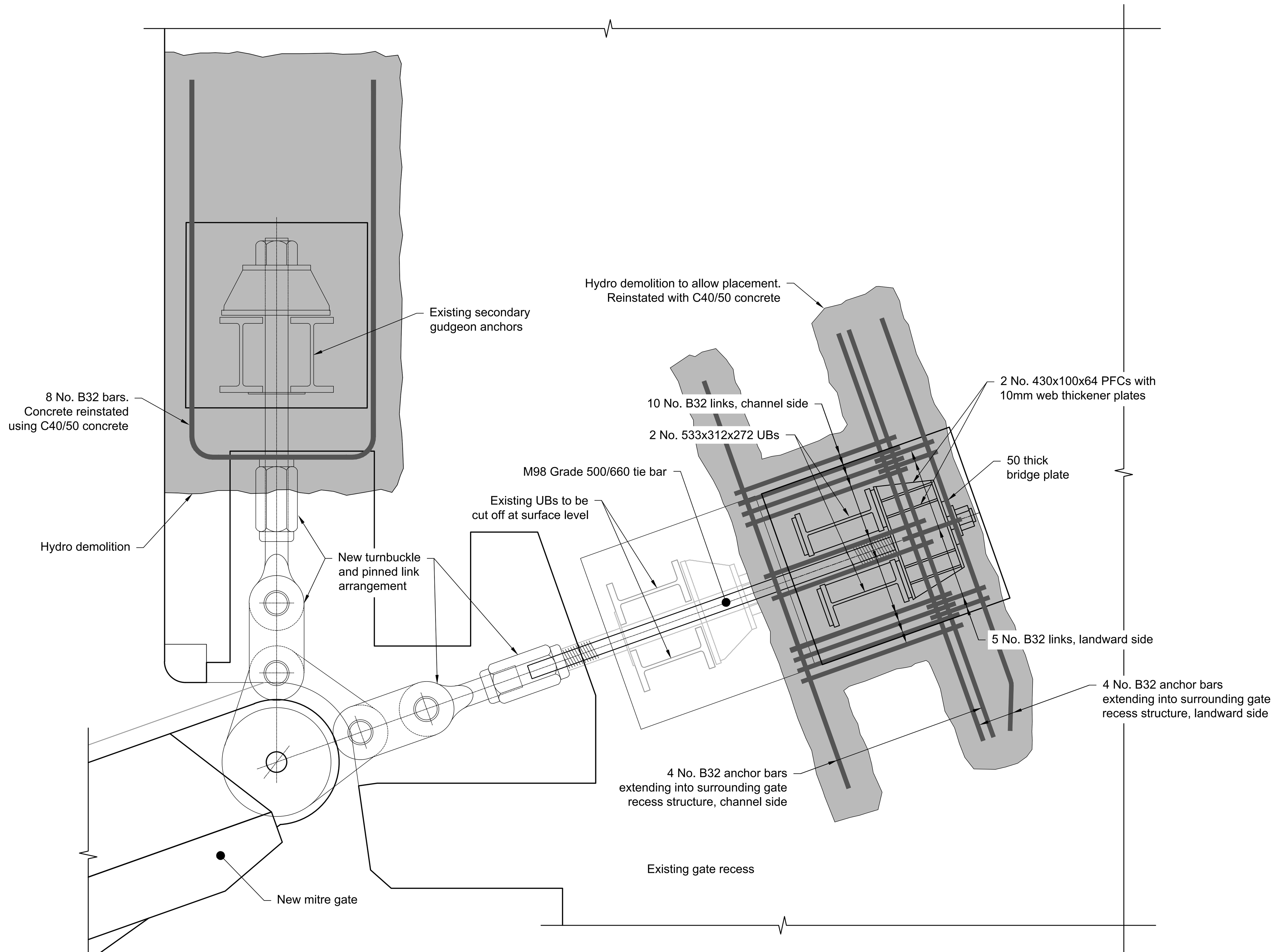
SECTION F - GATE RECESS DEMOLITION EXTENT

SCALE 1:200



DETAIL 7
RECESSED WALL DETAIL

SCALE 1:25



DETAIL 6
GUDGEON ANCHOR ARRANGEMENT PLAN

SCALE 1:25

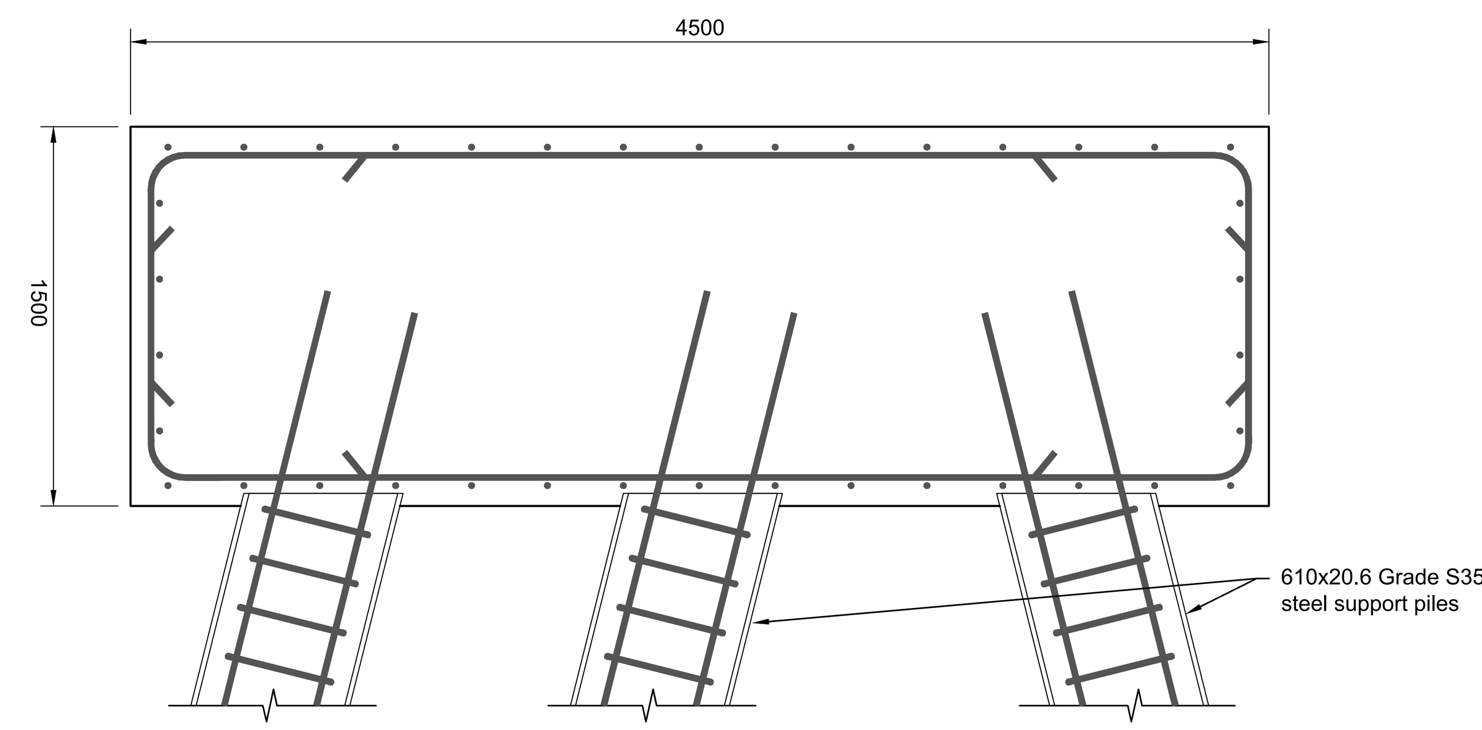
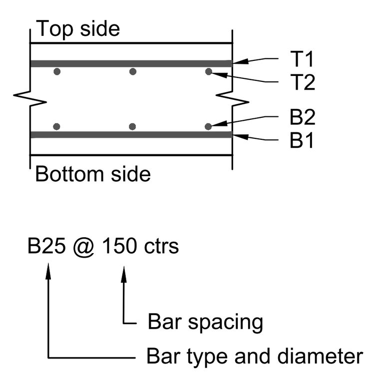


TABLE 1 - REINFORCEMENT DATA

REFERENCE	PILE CAP (mm)	PILE PLUG (mm)
T1	B25 @ 150 ctrs	-
T2	B25 @ 150 ctrs	-
B1	B25 @ 150 ctrs	-
B2	B25 @ 150 ctrs	-
Main bars	-	B40 - 11 No.
Links	-	B16 @ 150 ctrs



DETAIL 8
PILE CAP AND THRUST SLAB REINFORCEMENT

SCALE 1:25

Notes:
1. Do note scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres to Ordnance Datum unless noted otherwise.

0 0.5 1 1.5 2
SCALE 1:25 (A1) METRES

0 5 10 20
SCALE 1:200 (A1) METRES

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

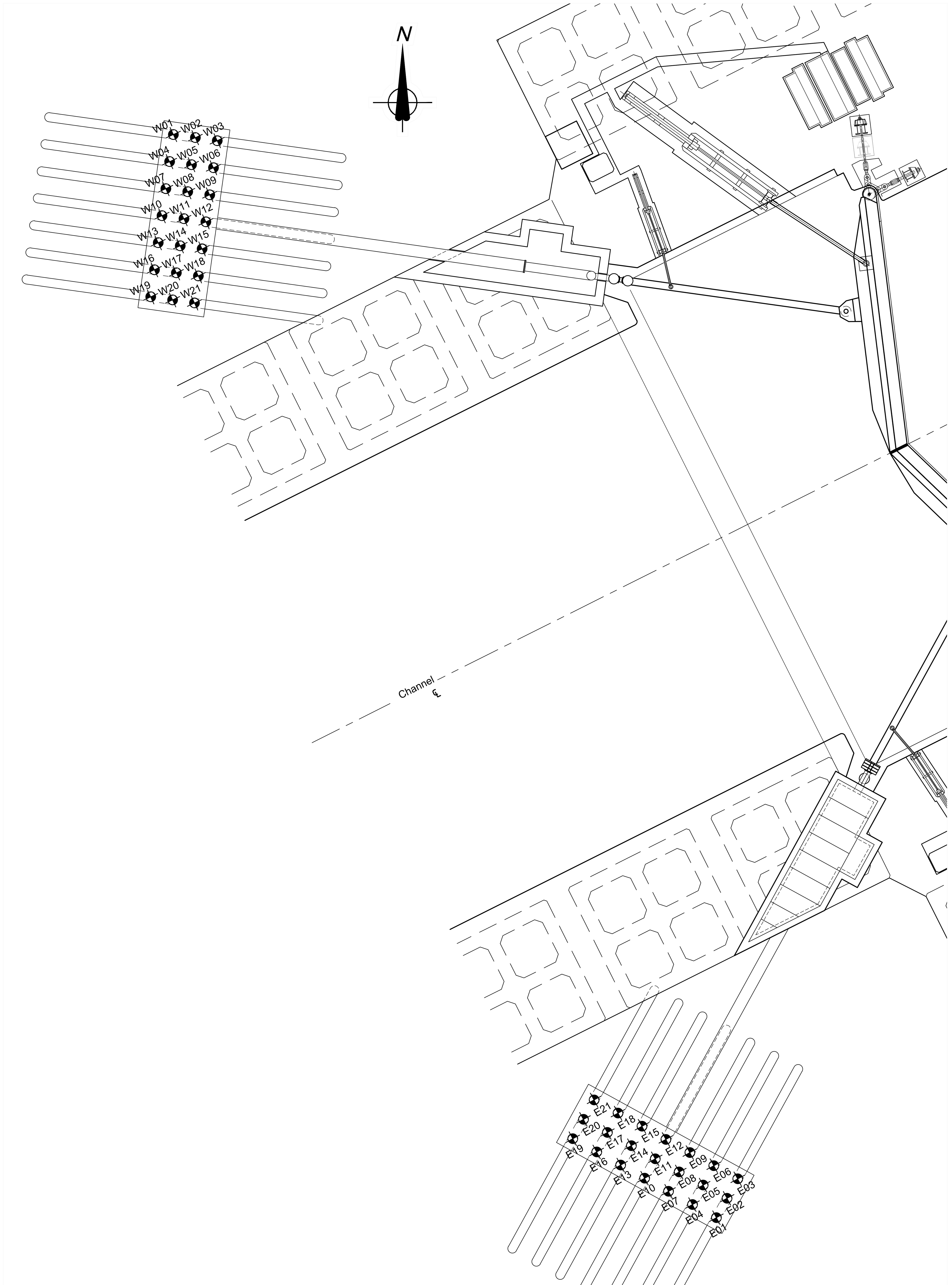
Project: GRANGEMOUTH FPS

Drawing title: GATE PROP DESIGN OPTION

Drawing status: FOR INFORMATION

Scale	AS SHOWN	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

Drawing number: B2386100-JAC-DR-304



PLAN

SCALE 1:200

TABLE 1
PILE SCHEDULE

PILE REF	DIAMETER (mm)	WALL THICKNESS (mm)	GRADE	CUT OFF LEVEL (mOD)	TOE LEVEL (mOD)	PILE RAKE	ADDITIONAL PILE LENGTH (m)	TOTAL PILE LENGTH (m)
E01	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E02	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E03	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
E04	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E05	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E06	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
E07	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E08	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E09	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
E10	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E11	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E12	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
E13	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E14	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E15	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
E16	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E17	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E18	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
E19	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E20	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
E21	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W01	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W02	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W03	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W04	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W05	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W06	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W07	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W08	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W09	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W10	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W11	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W12	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W13	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W14	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W15	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W16	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W17	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W18	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63
W19	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W20	610	20.6	S355J2N	-2.025	-36.950	1 in 4	17	53
W21	610	20.6	S355J2N	-2.025	-43.741	1 in 4	20	63

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. Pile setting out coordinates are relative to OSGB36.
5. Additional pile length includes 2.5m allowance for achieving set and 15m allowance for cut off to accommodate piling through gate from quayside.
6. All piles are unpainted.
7. Pile installation tolerance as follows:
   - Pile position at cut-off level: +/- 75mm
   - Pile rake: 1 in 75 for vertical piles; 1 in 15 for raking piles
   - Cut-off level: +/- 10mm

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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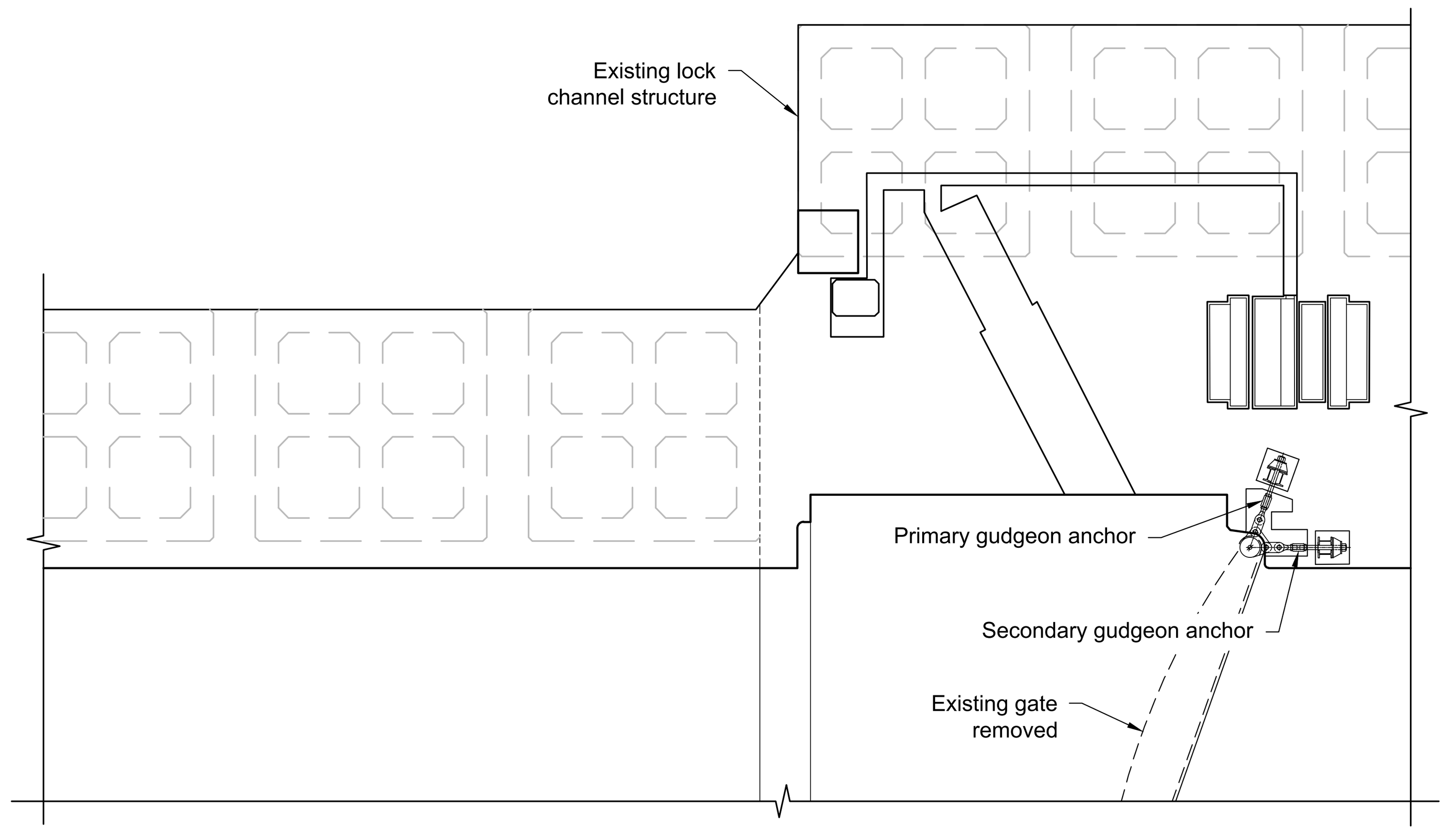
Project: GRANGEMOUTH FPS

Drawing title: MITRE GATES PROP OPTION PILE SETTING OUT POINTS

Drawing status: FOR INFORMATION

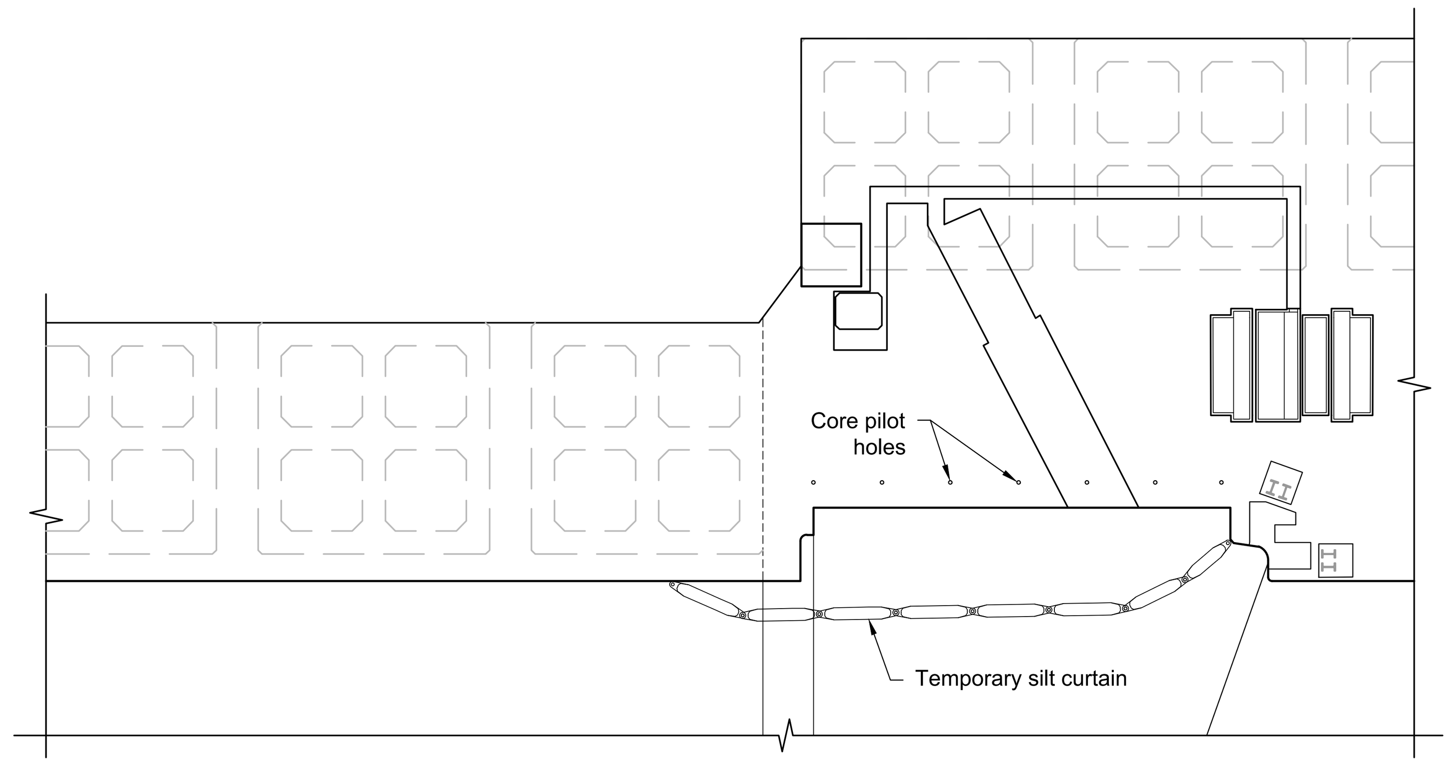
Scale	1:200 @ A1	DO NOT SCALE
Jacobs No.	B2386100	Rev P0
Client no.		

Drawing number: B2386100-JAC-DR-305



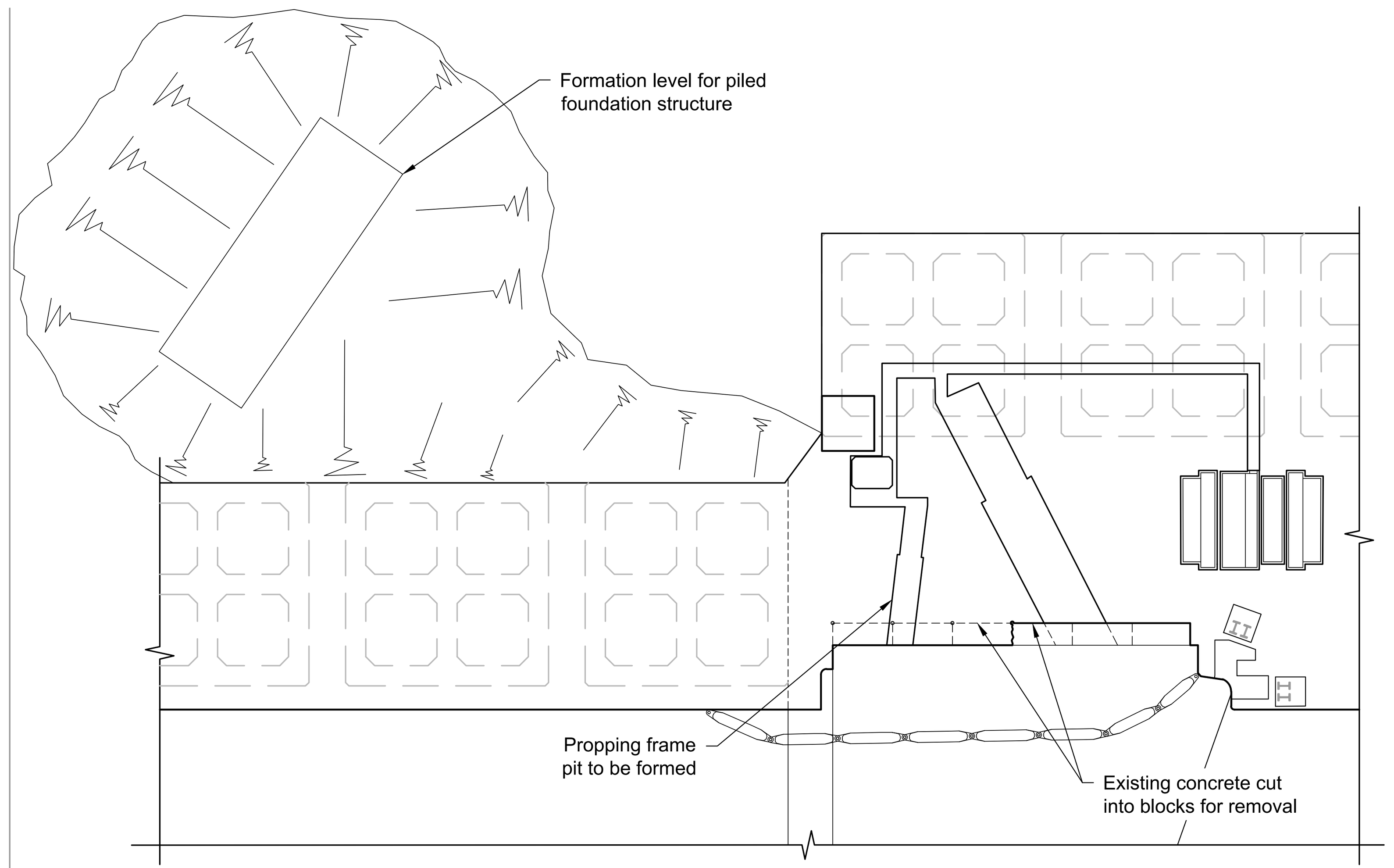
STAGE 1

1.1 Gates removed
1.2 Primary and secondary gudgeon anchors removed



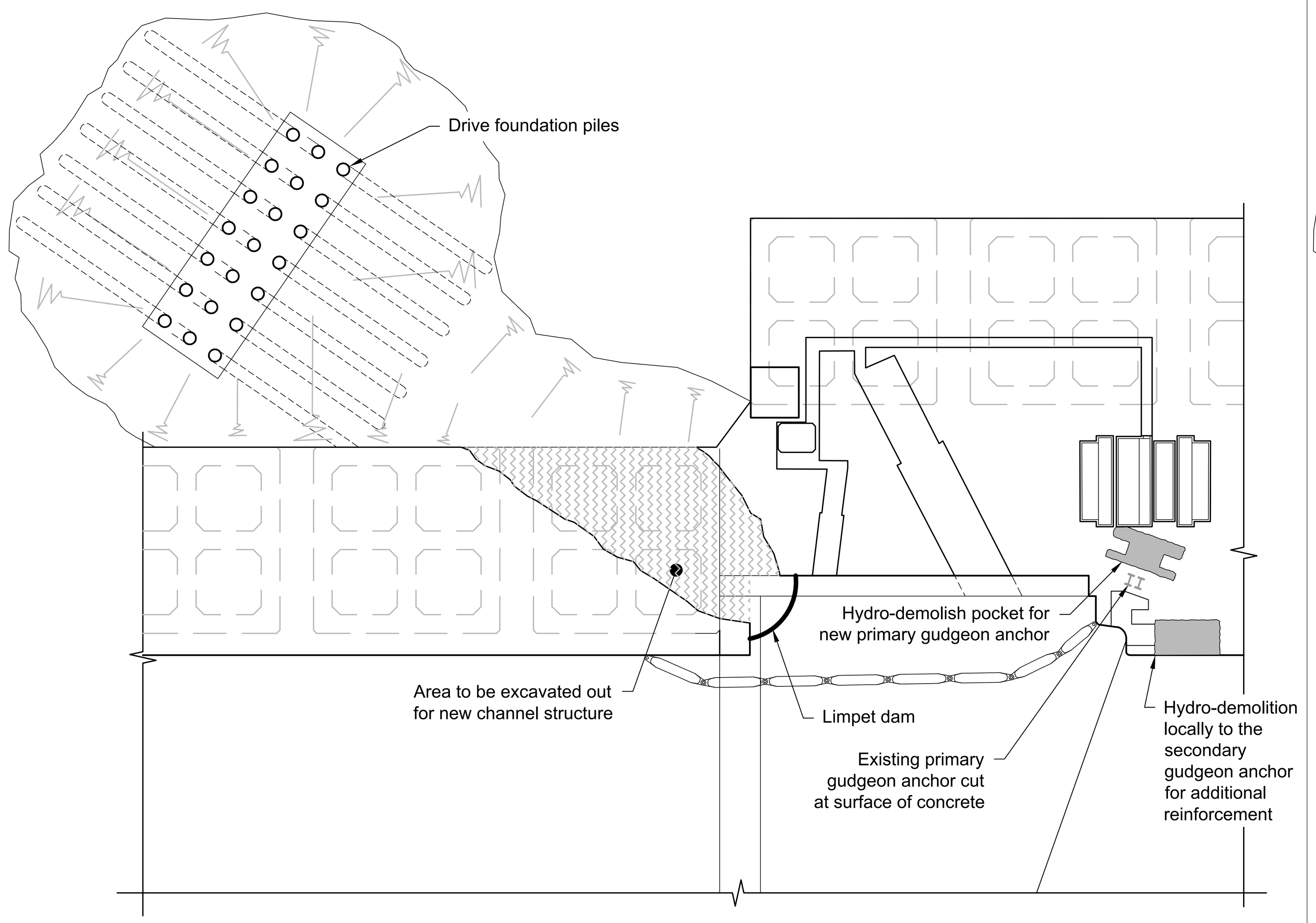
STAGE 2

2.1 Install silt curtain.
2.2 Core pilot holes for recess deepening. Core holes to be formed on vertical recess face also



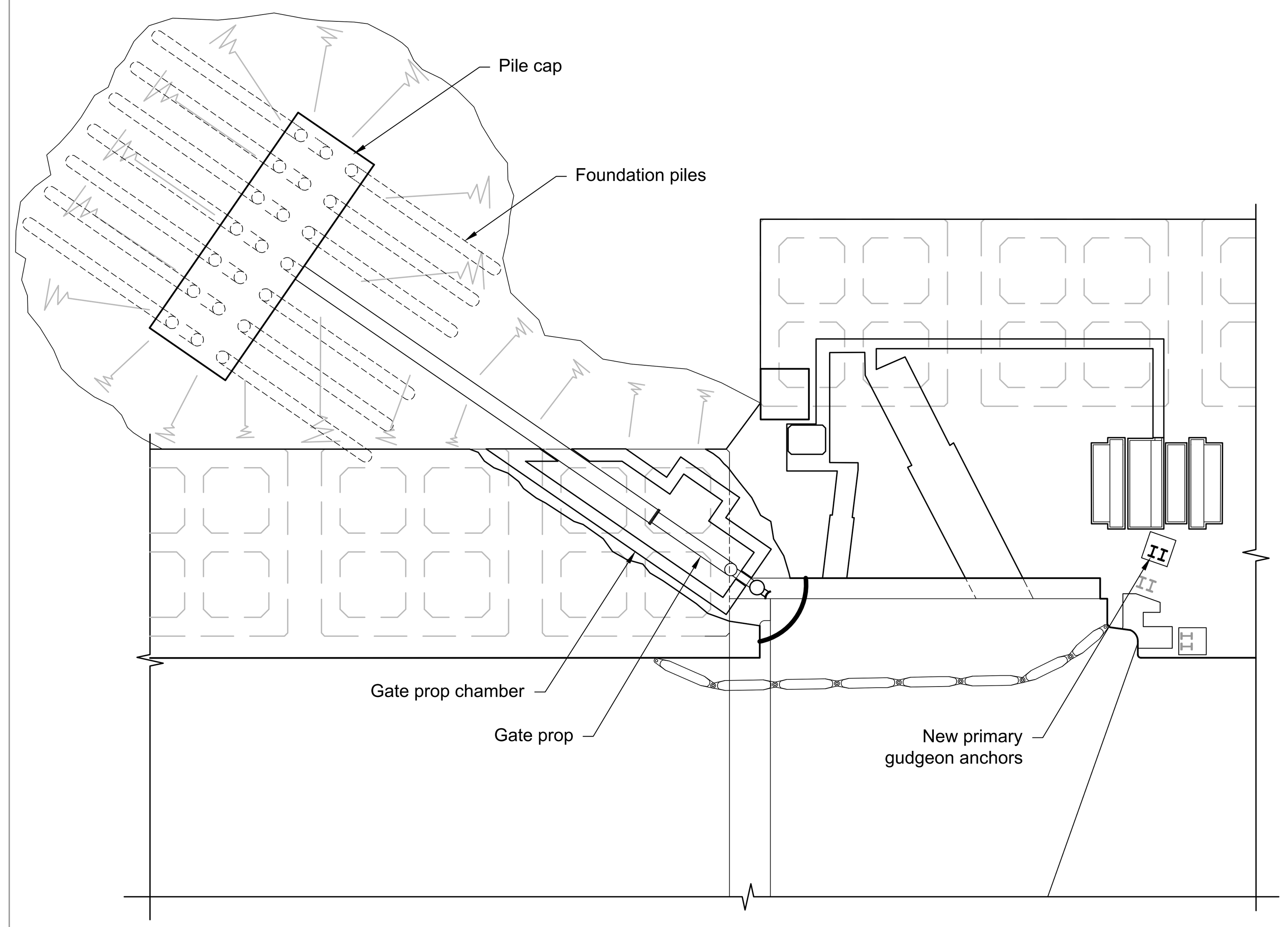
STAGE 3

3.1 Plunge wire saw to the back of the recess into blocks and lift out sequentially.
3.2 Repeat for full depth of required recess.
3.3 Form propping frame cylinder pit and service duct in lock channel quayside slab.
3.4 Excavate pit for the foundation structure.



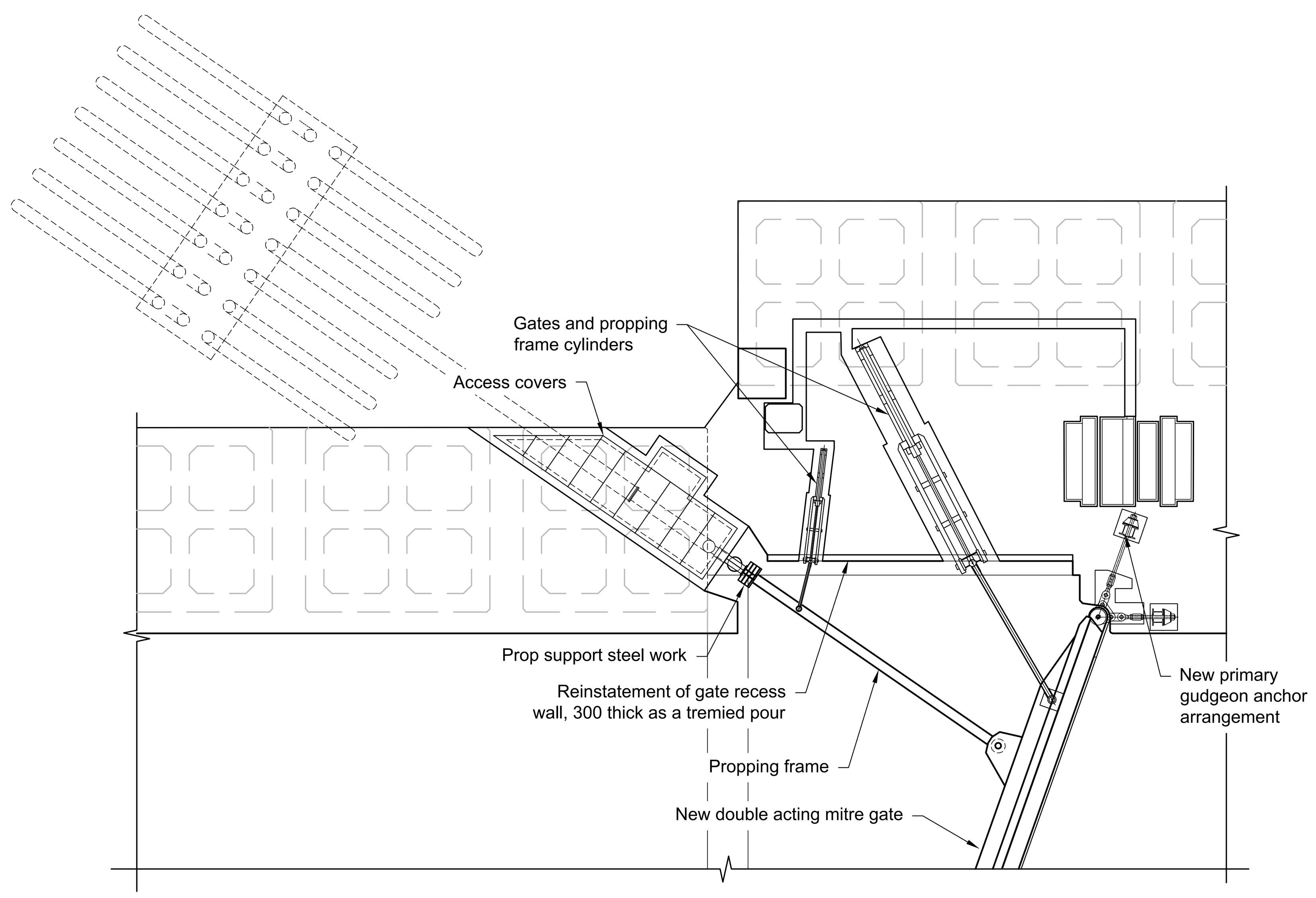
STAGE 4

4.1 Cut existing gudgeon anchors as required.
4.2 Excavate pocket for new primary gudgeon arrangement and remove concrete locally to secondary gudgeon anchor by hydro-demolition.
4.3 Excavate pocket for new channel structure.
4.4 Using limpet dam, break out the recess wall and part of the underlying channel structure.
4.5 Drive foundation piles.



STAGE 5

5.1 Cast pile cap.
5.2 Cast gate prop chamber and gate prop.
5.3 Install new primary gudgeon anchor. Set anchors and reinforcement then reinstate concrete.
5.4 At secondary gudgeon anchor install U-bars then reinstate concrete.



STAGE 6

6.1 Reinstate gate recess wall.
6.2 Install propping frame.
6.3 Install new double acting mitre gates and anchor arrangements.
6.4 Install access covers.

Notes:
1. Do not scale from this drawing.

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Project: GRANGEMOUTH FPS

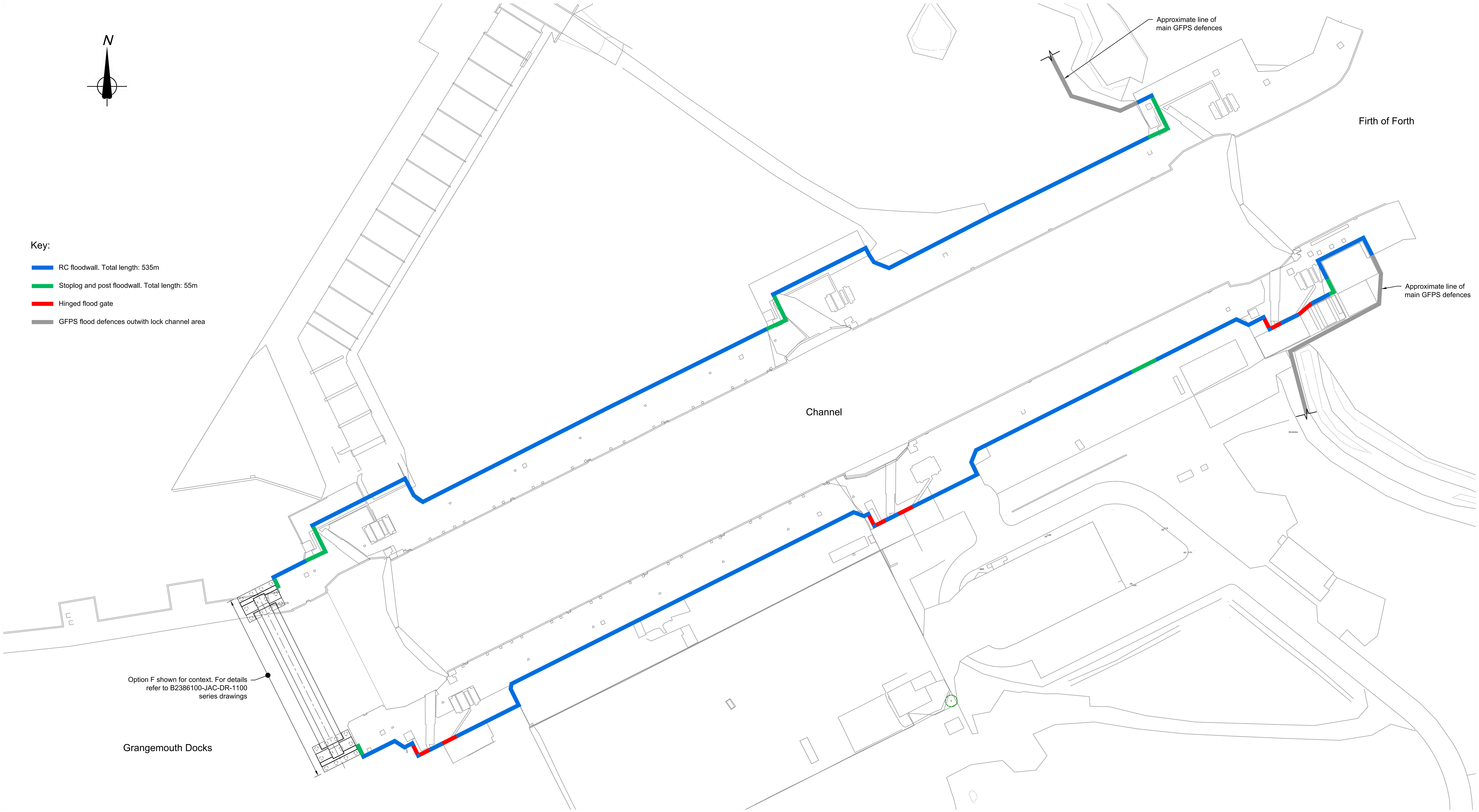
Drawing title: CONSTRUCTION SEQUENCE FOR MITRE GATES PROPPING FRAME OPTION

Drawing status: FOR INFORMATION

Scale	Not to scale	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

Drawing number: B2386100-JAC-DR-306

Appendix D. Quayside defence drawings



SITE PLAN

Scale 1:500

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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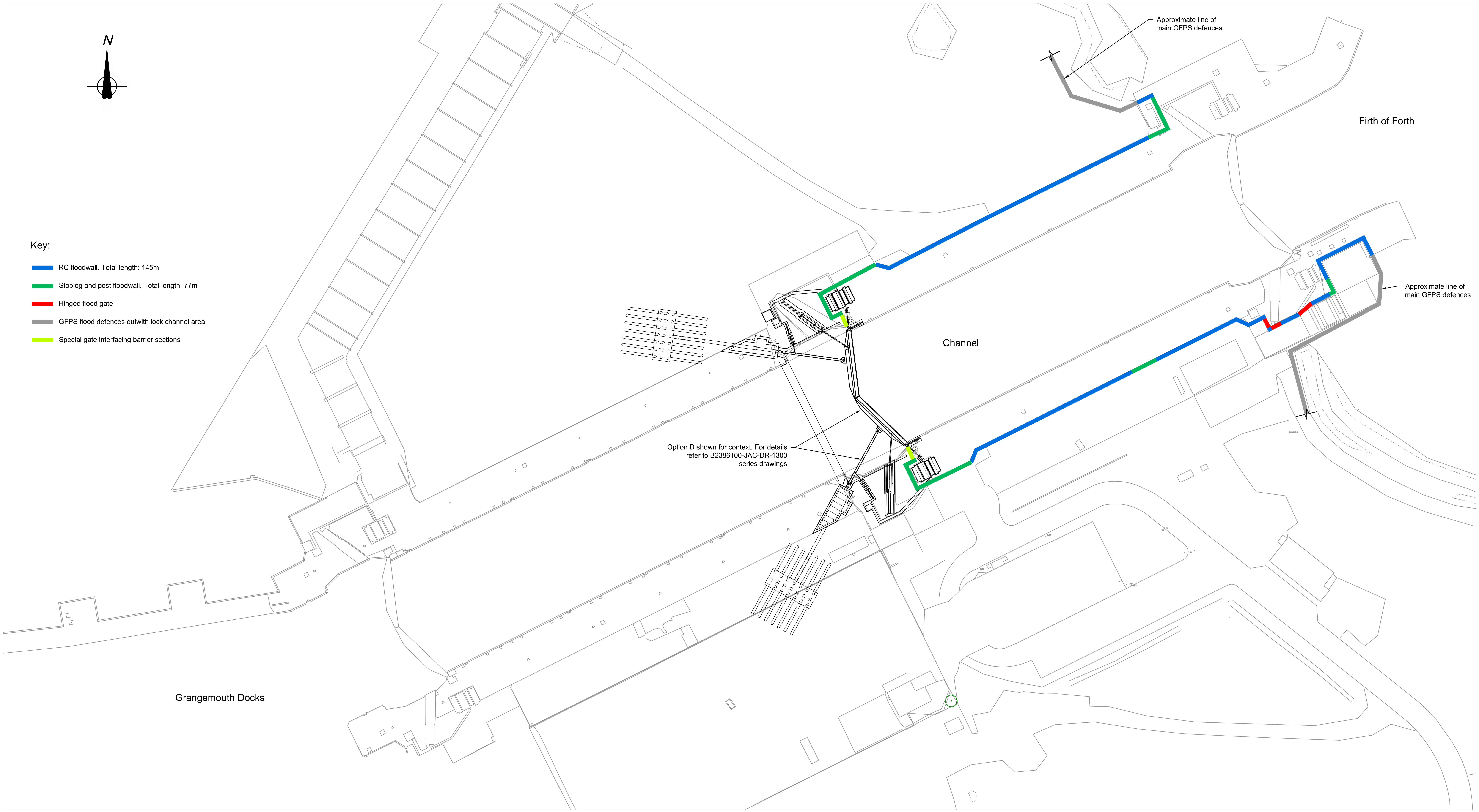
Client
FALKIRK COUNCIL

Project
GRANGEMOUTH FPS

Drawing title
LOCK CHANNEL DEFENCES
OPTION F
(INNER GATE)
SITE PLAN

Drawing status
FOR INFORMATION

Scale	1:500 @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			
Drawing number	B2386100-JAC-DR-401		



SITE PLAN
Scale 1:500

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
P0	17/09/2021	Draft for comment	GM	JM	RM	AM

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Client: FALKIRK COUNCIL

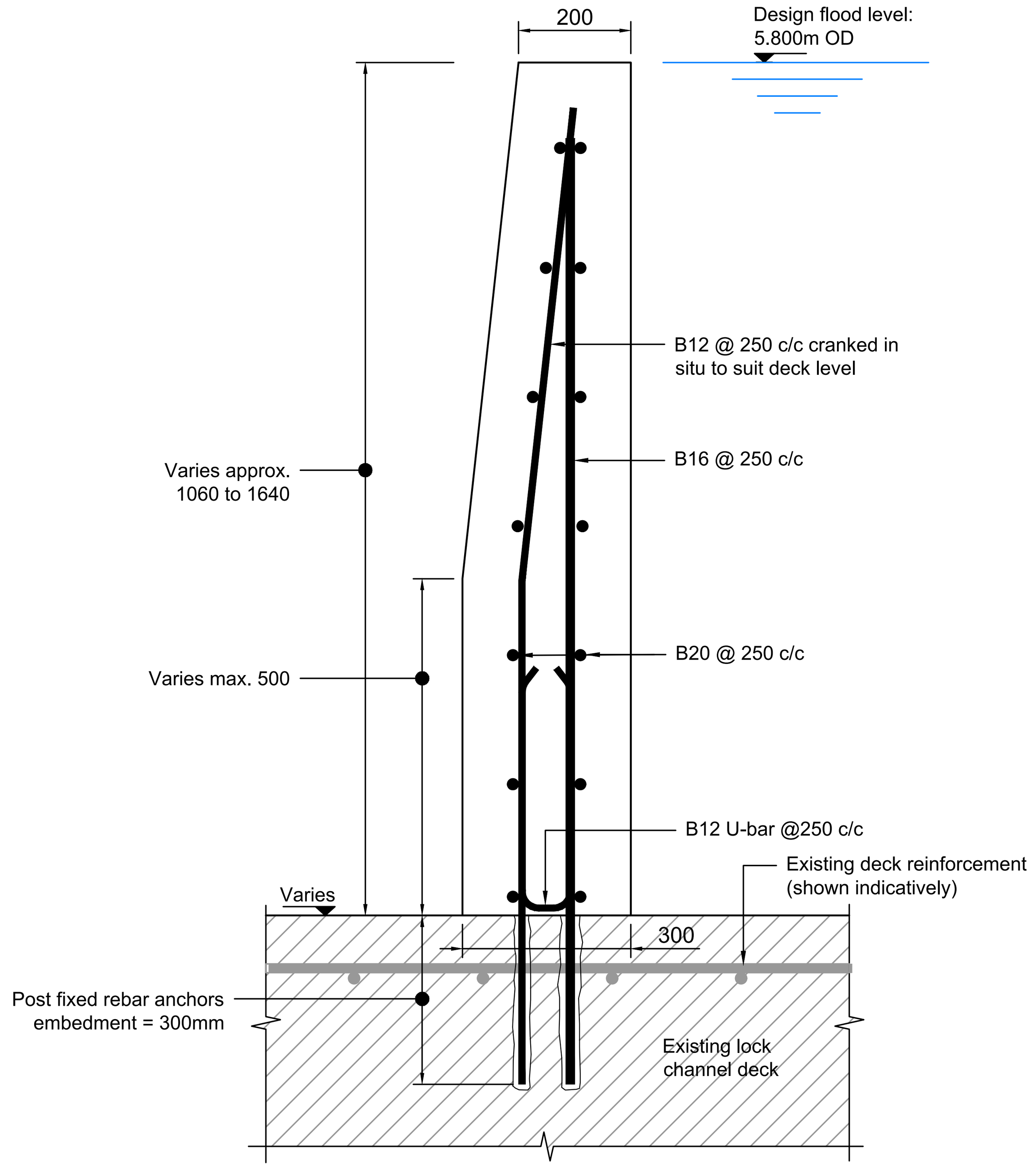
Project: GRANGEMOUTH FPS

Drawing title: LOCK CHANNEL DEFENCES OPTION C & D (MIDDLE GATE) SITE PLAN

Drawing status: FOR INFORMATION

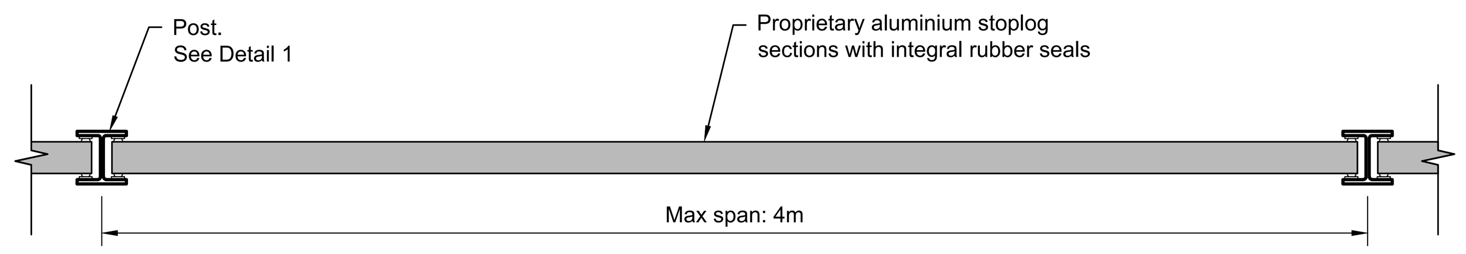
Scale	1:500 @ A1	DO NOT SCALE
Jacobs No.	B2386100	Rev P0
Client no.		

Drawing number: B2386100-JAC-DR-402



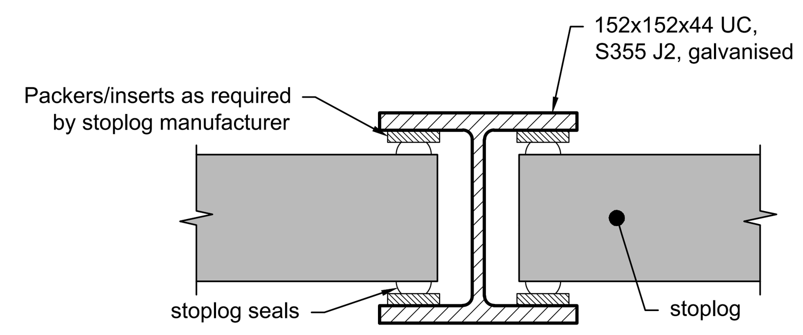
TYPICAL SECTION
THROUGH CONCRETE FLOOD WALL

SCALE 1:10



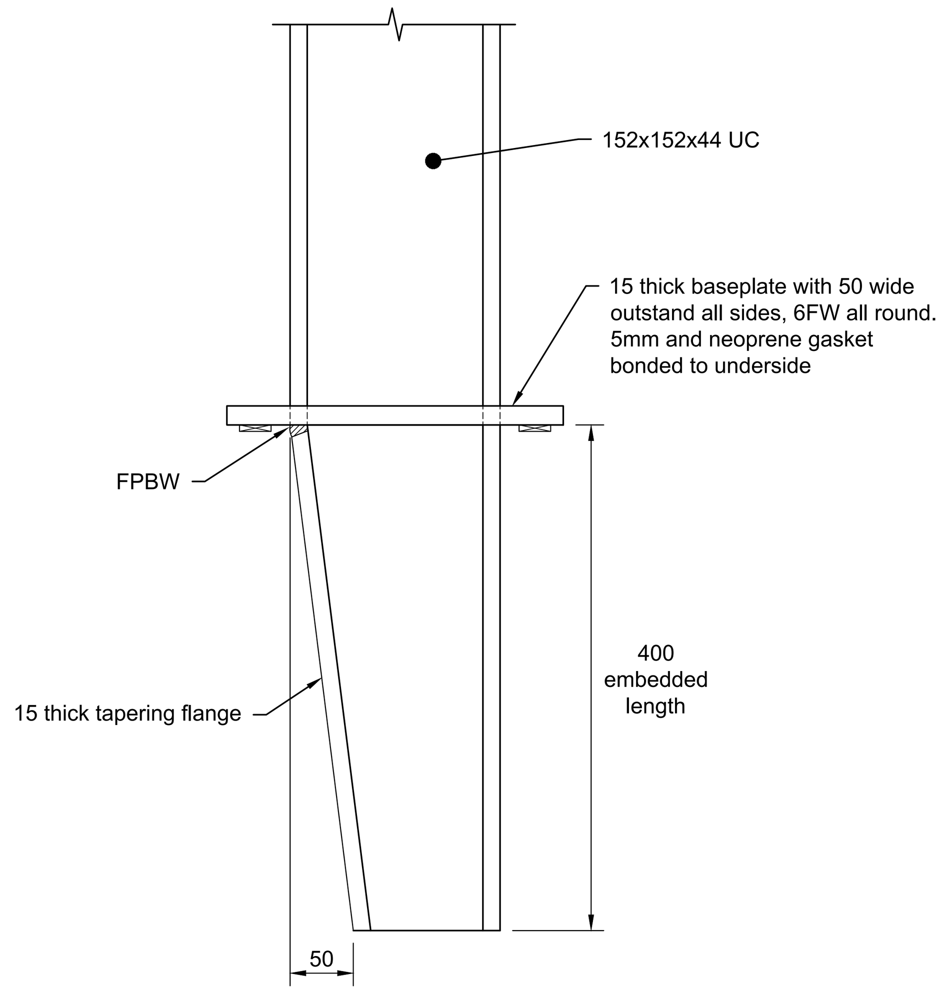
PLAN
STOPLOG FLOOD DEFENCE WALL

SCALE 1:20



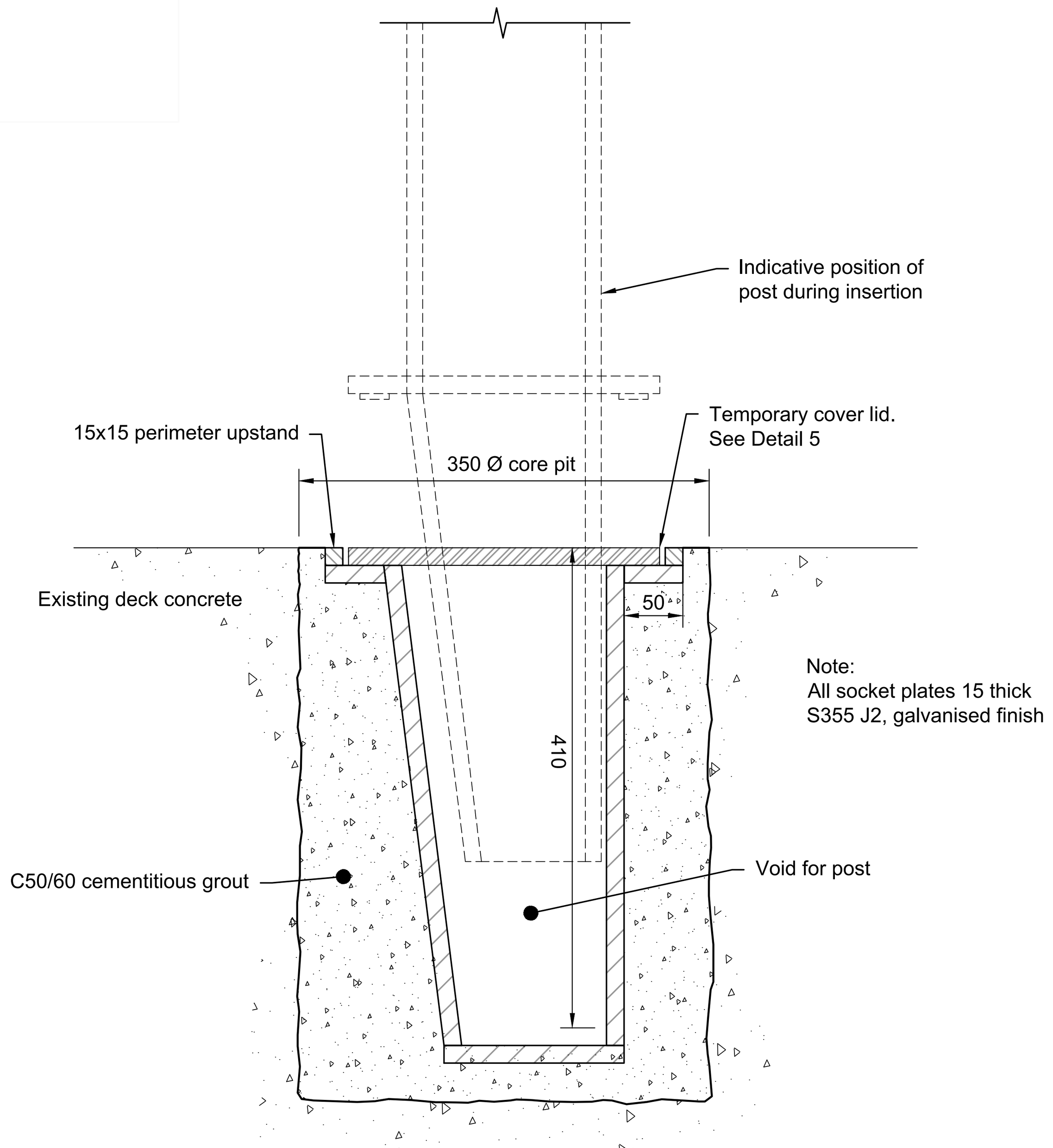
DETAIL 1
PLAN OF POST

SCALE 1:5



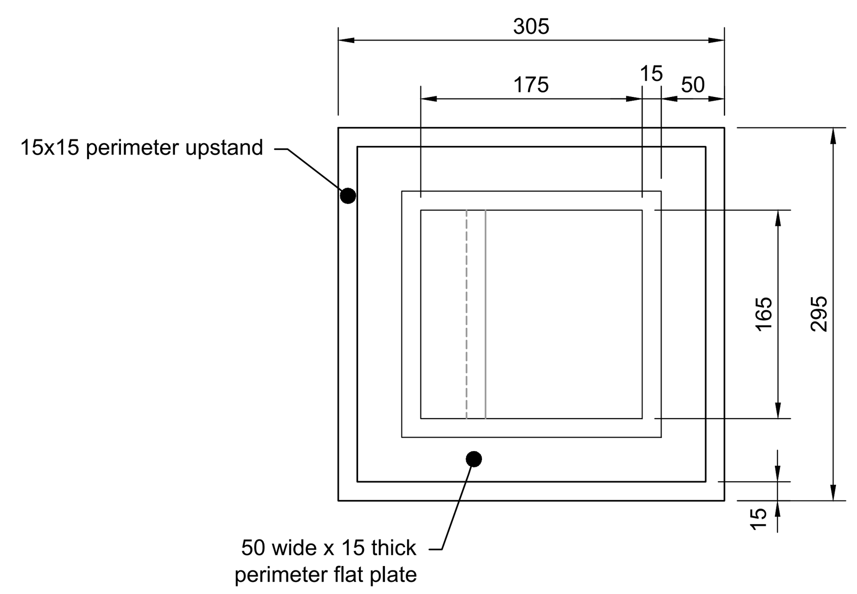
DETAIL 2
TOE OF POST

SCALE 1:5



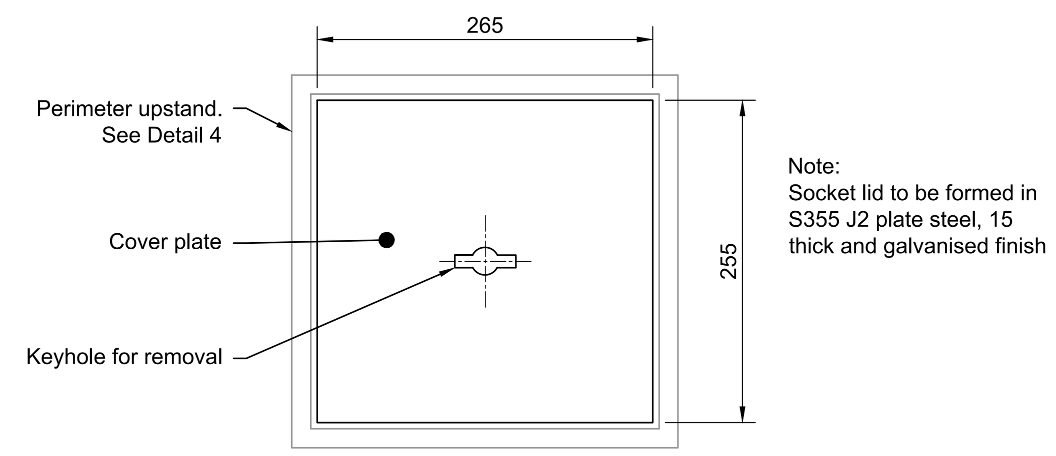
DETAIL 3
SECTION THROUGH DECK SOCKET INSERT

SCALE 1:5



DETAIL 4
DECK SOCKET PLAN

SCALE 1:5



DETAIL 5
PLAN ON LID

SCALE 1:5

Notes:

1. Do not scale from this drawing.
2. All dimensions are in millimetres unless noted otherwise.
3. All levels are in metres above ordnance datum unless noted otherwise.
4. All concrete is grade C40/50, suitable for exposure class XS3 with c_{min} = 65mm, c_{dev} = 15mm, and c_{nom} = 80mm.
5. All hidden concrete surfaces are finish class F1, U1. All exposed surfaces are F4, U3.
6. All structural steel is grade S355 J2 delivered to EN 10025 unless noted otherwise.

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Project: GRANGEMOUTH FPS

Drawing title: LOCK CHANNEL DEFENCE BARRIER DETAILS

Drawing status: FOR INFORMATION

Scale	1:100 @ A1	DO NOT SCALE	
Jacobs No.	B2386100	Rev	P0
Client no.			

Drawing number: B2386100-JAC-DR-403

Appendix E. Cost estimates

Reference/Output

1.0 Introduction

This calculation has been prepared to determine an approximate cost estimate for Option C as part of the Grangemouth FPS Port Study.

Option C relies on new mitre gates which during a flood event are supported by a hydraulic cylinder and shot bolt.

Reference should be made to drawings B2386100-DR-201 to 206 for details of Option C.

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	10/08/2021	Serial no:	PS-C-12
Subject:	Option C - Cost Estimate	Verified by:	JM	Sheet no:	2
		Date:	16/09/2021	Revision:	0

Reference/Output

3.0 Summary of Costs

Preliminaries	@	5%	(partially covered by site costs etc so lower % than normal)	£915,737	
CAPEX total				£18,314,741	
OPEX total				£1,050,000	
Subtotal					**£20,280,478**
Supervision costs	@	5%	of CAPEX total	£915,737	
Engineering costs	@	5%	of CAPEX total	£915,737	
Subtotal					**£22,111,952**
Profit and contingency	@	20%	of CAPEX total	£3,662,948	
Total					**£25,774,900**
Optimism bias	@	0%			£0
		60%	(consistent with wider project, less than Treasury Green Book of 66% for non-standard civil engineering)		£15,464,940
GRAND TOTALS			***(incl.) 0% O.B.***		***£25,774,900***
			(incl.) 60% O.B.		***£41,239,840***

Jacobs	CALCULATION SHEET					Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100	
		Date:	10/08/2021	Serial no:	PS-C-12	
Subject:	Option C - Cost Estimate	Verified by:	JM	Sheet no:	3	
		Date:	16/09/2021	Revision:	0	

4.0 CAPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**		**Total (£)**		**Reference/Output**	
PLEASE REFER TO QTY CALCS AND SCHEDULE OF RATES FOR CALCULATIONS/SOURCES								
4.1 Mobilisation								
General contractor mobilisation	1	No.	£	100,000	£	100,000	Estimation	
Mobilisation of cranes (for piling)	1	No.	£	20,000	£	20,000		
Mobilisation/demob of crane barge (gate removal)	2	No.	£	32,500	£	65,000		
						Subtotal	£	185,000
4.2 Site Costs								
Telehandler	84	week	£	905	£	75,993		
Flatbed work vans	252	week	£	400	£	100,800	Allows 3No. for duration	
Office cabins	4	No.	£	11,692	£	46,768	(rates includes transport	
Mess cabins	1	No.	£	7,576	£	7,576		
Toilet unit	1	No.	£	22,780	£	22,780		
Fencing	300	m	£	18	£	5,250		
						Subtotal	£	259,167
4.3 Plant and Equipment								
Concrete skip	36	week	£	250	£	9,000		
Concrete tremies for grout/mass concrete	5	week	£	800	£	4,000		
Safety boat	84	week	£	1,000	£	84,000		
Crane barge	1	week	£	63,750	£	63,750		
						Subtotal	£	160,750
4.4 Piling								
Crawler crane hire	420	day	£	2,461	£	1,033,776	Based on programme tab	
Vibrator and hammer hire	126	day	£	1,000	£	126,000		
Steel tubular piles (material cost)	1761	m	£	325	£	571,554		
Delivery of piles (assume 2No. deliveries)	2	No.	£	14,000	£	28,000	Based on week barge hire	
Welding piles together (assume 3 welds per pile)	96	No.	£	1,916	£	183,972		
Dynamic pile testing (CAPWAP)	64	No.	£	500	£	32,000	Allows retest after 7 days	
Cut off piles	32	No.	£	200	£	6,400		
						Subtotal	£	1,981,701
4.5 In-Situ Reinforced Concrete								
Strong points reinforced concrete	115.2	m3	£	650	£	74,880		
Vertical formwork for strong points	189.6	m2	Included in RC rate					
Horizontal formwork for strong points	153.6	m2	Included in RC rate					
Main Slab reinforced concrete	242.677	m3	£	650	£	157,740		
Vertical formwork for main slabs	118.652	m2	Included in RC rate					
Horizontal formwork for main slabs	242.677	m2	Included in RC rate					
Walls reinforced concrete	0	m3	£	650	£	-		
Vertical formwork for walls	94.8	m2	Included in RC rate					
Horizontal formwork for walls	0	m2	Included in RC rate					
Access scaffolding for strongpoint construction	94.8	m2	£	30	£	2,844		
						Subtotal	£	235,464
4.5 Shot Bolt Pit Formation								
Specialist subcontractor cost for coring and diamor	1	No.	£	300,000	£	300,000	Estimate	
Diver time	18	day	£	2,500	£	45,000		
Shot bolt insert (steelwork)	10.2	te	£	1,933	£	19,763		
Tremied concrete/grout	43.75	m3	£	200	£	8,750		
Concrete pump hire	18	Day	£	1,500	£	27,000		
						Subtotal	£	400,513

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	10/08/2021	Serial no:	PS-C-12
Subject:	Option C - Cost Estimate	Verified by:	JM	Sheet no:	4
		Date:	16/09/2021	Revision:	0

4.0 CAPEX Cost Breakdown (Cont.)	**Qty**	**Unit**	**Rate (£)**		**Total (£)**		**Reference/Output**	
4.6 Steel Mitre Gate (original install at 2030)								
Gate leafs	402	te	£	7,500	£	3,015,000	Based on other projects	
Hydraulic system	1	No.	£	650,000	£	650,000	Based on other projects	
Hydraulic cylinders	1	No.	£	300,000	£	300,000	Based on other projects	
Control System	1	No.	£	500,000	£	500,000	Based on other projects	
Allowance for spare parts	1	No.	£	200,000	£	200,000	Based on other projects	
Spare gate leaves	402	te	£	7,500	£	3,015,000	Based on other projects	
Transportation and installation	1	No.	£	1,350,000	£	1,350,000	Based on other projects	
						Subtotal	£	9,030,000
4.7 Steel Mitre Gate (replacement of original at 2080)								
Gate leafs	402	te	£	7,500	£	3,015,000	Based on other projects	
Hydraulic system	1	No.	£	650,000	£	650,000	Based on other projects	
Hydraulic cylinders	1	No.	£	300,000	£	300,000	Based on other projects	
Control system	1	No.	£	500,000	£	500,000	Based on other projects	
Allowance for spare parts	1	No.	£	200,000	£	200,000	Based on other projects	
Transportation and installation	1	No.	£	1,350,000	£	1,350,000	Based on other projects	
						Subtotal	£	6,015,000
4.8 Temporary and Enabling Works								
Channel wall breakout for cylinder pit	320	m3	£	16	£	5,232		
Excavation for piled foundation	1429.12	m3	£	16	£	23,366		
Filling existing cylinder pit with mass concrete	43	m3	£	200	£	8,547		
Localised hydro-demolition	1	No.	£	10,000	£	10,000		
						Subtotal	£	47,145
		CAPEX total	**£**			**18,314,741**		

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	10/08/2021	Serial no:	PS-C-12
Subject:	Option C - Cost Estimate	Verified by:	JM	Sheet no:	5
		Date:	16/09/2021	Revision:	0

5.0 OPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
5.2 Inspections and maintenance					
Annual inspection of M+E	100	No.	£ 1,000	£ 100,000	
Annual maintenance of M+E	100	No.	£ 5,000	£ 500,000	
5-yearly inspection of mitre gates	20		£ 10,000	£ 200,000	Includes dive survey
5-yearly clear out of shot bolt recess	20		£ 12,500	£ 250,000	Diver time
					Subtotal
					£ 1,050,000
5.2 Deployment Costs					
None					**Subtotal**
					£ -
		OPEX total	**£**	**1,050,000**	

Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	16/09/2021	Serial no:	PS-D-08
Subject:	Option D - Cost Estimate	Verified by:	JM	Sheet no:	1
		Date:	16/09/2021	Revision:	0

Reference/Output

1.0 Introduction

This calculation has been prepared to determine an approximate cost estimate for Option D as part of the Grangemouth FPS Port Study.

Option D relies on new mitre gates with a propping frame installed in a recess of the lock channel walls. This frame resists the loads experienced during a flood event.

Reference should be made to drawings B2386100-DR-301 to 306 for details of Option D.

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	16/09/2021	Serial no:	PS-D-08
Subject:	Option D - Cost Estimate	Verified by:	JM	Sheet no:	2
		Date:	16/09/2021	Revision:	0

Reference/Output

<u>3.0 Summary of Costs</u>

Preliminaries	@	5%	(partially covered by site costs etc so lower % than normal)	£921,628	
CAPEX total				£18,432,553	
OPEX total				£820,000	
Subtotal					**£20,174,180**
Supervision costs	@	5%	of CAPEX total	£921,628	
Engineering costs	@	5%	of CAPEX total	£921,628	
Subtotal					**£22,017,436**
Profit and contingency	@	20%	of CAPEX total	£3,686,511	
Total					**£25,703,946**
Optimism bias	@	0%			£0
		60%	(consistent with wider project, less than Treasury Green Book of 66% for non-standard civil engineering)		£15,422,368
GRAND TOTALS			***(incl.) 0% O.B.***		***£25,703,946***
			(incl.) 60% O.B.		***£41,126,314***

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	16/09/2021	Serial no:	PS-D-08
Subject:	Option D - Cost Estimate	Verified by:	JM	Sheet no:	3
		Date:	16/09/2021	Revision:	0

4.0 CAPEX Cost Breakdown	**Qty**	**Unit**		**Rate (£)**		**Total (£)**	**Reference/Output**	
PLEASE REFER TO QTY CALCS AND SCHEDULE OF RATES FOR CALCULATIONS/SOURCES								
4.1 Mobilisation								
General contractor mobilisation	1	No.	£	100,000	£	100,000	Estimation	
Mobilisation of cranes (for piling)	1	No.	£	20,000	£	20,000		
Mobilisation/demob of crane barge (gate removal)	2	No.	£	32,500	£	65,000		
						Subtotal		
4.2 Site Costs								
Telehandler	57	week	£	905	£	51,567		
Flatbed work vans	171	week	£	400	£	68,400	Allows 3No. for duration	
Office cabins	4	No.	£	9,316	£	37,264	(rates includes transport	
Mess cabins	1	No.	£	6,523	£	6,523		
Toilet unit	1	No.	£	16,840	£	16,840		
Fencing	300	m	£	18	£	5,250		
						Subtotal	£	185,844
4.3 Plant and Equipment								
Concrete skip	19	week	£	250	£	4,750		
Concrete tremies for grout/mass concrete	6	week	£	800	£	4,800		
Safety boat	57	week	£	1,000	£	57,000		
Crane barge	1	week	£	63,750	£	63,750		
						Subtotal	£	130,300
4.4 Piling								
Crawler crane hire	588	day	£	2,461	£	1,447,286	Based on programme tab	
Vibrator and hammer hire	126	day	£	1,000	£	126,000		
Steel tubular piles (material cost)	1183.0	m	£	325	£	383,957		
Delivery of piles (assume 2No. deliveries)	2	No.	£	14,000	£	28,000	Based on week barge hire	
Welding piles together (assume 3 welds per pile)	63	No.	£	1,916	£	120,731		
Dynamic pile testing (CAPWAP)	42	No.	£	500	£	21,000	Allows retest after 7 days	
Cut off piles	21	No.	£	200	£	4,200		
						Subtotal	£	2,131,175
4.5 In-Situ Reinforced Concrete								
Strong points reinforced concrete	172.8	m3	£	650	£	112,320		
Vertical formwork for strong points	207.6	m2	Included in RC rate					
Horizontal formwork for strong points	230.4	m2	Included in RC rate					
Chamber reinforced concrete	613.1	m3	£	650	£	398,539		
Access scaffolding for strongpoint construction	103.8	m2	£	30	£	3,114		
Environmental containment for concreting	35	week	£	2,000	£	70,000		
Reinstatement of recess walls	91.2	m3	£	650	£	59,280		
						Subtotal	£	643,253

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	16/09/2021	Serial no:	PS-D-08
Subject:	Option D - Cost Estimate	Verified by:	JM	Sheet no:	4
		Date:	16/09/2021	Revision:	0

4.0 CAPEX Cost Breakdown (Cont.)	Qty	Unit	Rate (£)	Total (£)	Reference/Output
4.6 Steel Mitre Gate (original install at 2030)					
Gate leafs	402	te	£ 7,500	£ 3,015,000	Based on other projects
Hydraulic system	1	No.	£ 455,000	£ 455,000	Based on other projects
Hydraulic cylinders	1	No.	£ 150,000	£ 150,000	Based on other projects
Control System	1	No.	£ 500,000	£ 500,000	Based on other projects
Allowance for spare parts	1	No.	£ 200,000	£ 200,000	Based on other projects
Spare Gate leafs	402	te	£ 7,500	£ 3,015,000	Based on other projects
Transportation and installation	1	No.	£ 1,350,000	£ 1,350,000	Based on other projects
				Subtotal	£ 8,685,000
4.7 Steel Mitre Gate (replacement of original at 2080)					
Gate leafs	402	te	£ 7,500	£ 3,015,000	Based on other projects
Hydraulic system	1	No.	£ 455,000	£ 455,000	Based on other projects
Hydraulic cylinders	1	No.	£ 150,000	£ 150,000	Based on other projects
Control System	1	No.	£ 500,000	£ 500,000	Based on other projects
Allowance for spare parts	1	No.	£ 200,000	£ 200,000	Based on other projects
Transportation and installation	1	No.	£ 1,350,000	£ 1,350,000	Based on other projects
				Subtotal	£ 5,670,000
4.8 Propping Frame Steelwork					
Steel sections	75.5	te	£ 1,933	£ 145,943	
External painting of steelwork	428.2	m2	£ 110.00	£ 47,105	
				Subtotal	£ 193,048
4.8 Temporary and Enabling Works					
Recess wall diamond wire cutting	20.0	weeks	£ 5,000	£ 100,000	Estimated rate for 2x wire
Break out existing lock channel structure for chamb	1660.0	m3	£ 61	£ 101,559	
Excavation for piled foundation	5802.7	m3	£ 16	£ 94,874	
Localised hydro-demolition	1	No.	£ 10,000	£ 10,000	
Limpet dams	2	No.	£ 100,000	£ 200,000	
				Subtotal	£ 506,433
4.10 Miscellaneous					
Silt Curtain	2	No.	£ 50,000	£ 100,000	
Diver installation of above	1	weeks	£ 2,500	£ 2,500	
				Subtotal	£ 102,500
		CAPEX total	**£**	**18,432,553**	

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	16/09/2021	Serial no:	PS-D-08
Subject:	Option D - Cost Estimate	Verified by:	JM	Sheet no:	5
		Date:	16/09/2021	Revision:	0

5.0 OPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
5.2 Inspections					
Annual inspection of M+E	100	No.	£ 1,000	£ 100,000	
Annual maintenance of M+E	100	No.	£ 5,000	£ 500,000	
5-yearly inspection of mitre gates	20		£ 10,000	£ 200,000	Includes dive survey
5-yearly inspection of gate prop support pits	20		£ 1,000	£ 20,000	
					Subtotal
					£ 820,000
5.2 Deployment Costs					
None					
					Subtotal
					£ -
		OPEX total	**£**	**820,000**	

Calculation title:	Grangemouth Flood Protection Scheme	Created by:	AAG	Project code:	B2386100
		Date:	12/07/2021	Serial no:	PS-F-10
Subject:	Option F - Towed Caisson Cost Estimate	Verified by:	JM	Sheet no:	1
		Date:	12/07/2021	Revision:	1

Reference/Output

1.0 Introduction

This calculation has been prepared to determine an approximate cost estimate for Option as part of the Grangemouth FPS Port Study.

Option F relies on a towed steel caisson together with associated support structures to provide the flood defence barrier.

Reference should be made to drawings B2386100-DR-101 to 108 for details of Option F.

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	Andrew Gibb	Project code:	B2386100
		Date:	12/07/2021	Serial no:	PS-F-10
Subject:	Option F - Towed Caisson Cost Estimate	Verified by:	JM	Sheet no:	2
		Date:	12/07/2021	Revision:	1

Reference/Output

3.0 Summary of Costs

Preliminaries	@	5%	(partially covered by site costs etc so lower % than normal)	£1,439,627	
CAPEX total				£28,792,532	
OPEX total				£34,180,000	
Subtotal					**£64,412,159**
Supervision costs	@	5%	of CAPEX total	£1,439,627	
Engineering costs	@	5%	of CAPEX total	£1,439,627	
Subtotal					**£67,291,412**
Profit and contingency	@	20%	of CAPEX total	£5,758,506	
Total					**£73,049,919**
Optimism bias	@	0%			£0
		60%	(consistent with wider project, less than Treasury Green Book of 66% for non-standard civil engineering)		£43,829,951
GRAND TOTALS			***(incl.) 0% O.B.***		***£73,049,919***
			(incl.) 60% O.B.		***£116,879,870***

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	Andrew Gibb	Project code:	B2386100
		Date:	12/07/2021	Serial no:	PS-F-10
Subject:	Option F - Towed Caisson Cost Estimate	Verified by:	JM	Sheet no:	3
		Date:	12/07/2021	Revision:	1

4.0 CAPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**		**Total (£)**		**Reference/Output**	
PLEASE REFER TO QTY CALCS AND SCHEDULE OF RATES FOR CALCULATIONS/SOURCES								
4.1 Mobilisation								
General contractor mobilisation	1	No.	£	100,000	£	100,000	Estimation	
Mobilisation of cranes (for piling then cill placemen	2	No.	£	20,000	£	40,000		
						Subtotal	£	140,000
4.2 Site Costs								
Telehandler	65	week	£	905	£	58,804		
Flatbed work vans	195	week	£	400	£	78,000	Allows 3No. for duration	
Office cabins	4	No.	£	10,020	£	40,080	(rates includes transport	
Mess cabins	1	No.	£	6,835	£	6,835		
Toilet unit	1	No.	£	18,600	£	18,600		
Fencing	300	m	£	18	£	5,250		
						Subtotal	£	207,569
4.3 Plant and Equipment								
Concrete skip	25	week	£	250	£	6,250		
Concrete tremies for grout/mass concrete	25	week	£	800	£	20,000		
Safety boat	65	week	£	1,000	£	65,000		
						Subtotal	£	91,250
4.4 Piling								
Crawler crane hire	714	day	£	2,461	£	1,757,419	Based on programme tab	
Vibrator and hammer hire	714	day	£	1,000	£	714,000		
Construction of piling gate	30.6	te	£	1,850	£	56,654		
Steel tubular piles (material cost)	1320	m	£	534	£	704,310		
Delivery of piles (assume 2No. deliveries)	2	No.	£	14,000	£	28,000	Based on week barge hire	
Welding piles together (assume 3 welds per pile)	72	No.	£	2,871	£	206,742		
Dynamic pile testing (CAPWAP)	48	No.	£	500	£	24,000	Allows retest after 7 days	
Cut off piles	24	No.	£	200	£	4,800		
						Subtotal	£	3,495,925
4.5 Pre-Cast Concrete (cill)								
Hire of submersible barge	84	day	£	2,000	£	168,000	Based on programme tab	
Concrete material	276.5	m3	£	650	£	179,725		
Reinforcing steel			Included in RC rate					
Formwork			Included in RC rate					
Polystyrene	91	m3	£	69	£	6,279		
Grouting cill to strong point connection	2	No.	£	5,000	£	10,000		
Crane assistance for placing cill (2No.)	6	day	£	2,461	£	14,768		
Diver assistance for placing cill	3	day	£	2,500	£	7,500		
Diver assistance for grouting connections	5	day	£	2,500	£	12,500		
						Subtotal	£	398,772
4.6 In-Situ Reinforced and Mass Concrete								
Strong points reinforced concrete	944.879	m3	£	650	£	614,171		
Vertical formwork for strong points	849.656	m2	Included in RC rate					
Horizontal formwork for strong points	140	m2	Included in RC rate					
Access scaffolding for strongpoint construction	1020	m2	£	30	£	30,600		
Insitu mass concrete base	738.557	m3	£	200	£	147,711		
Diver assitance for above	8	day	£	2,500	£	20,000		
Environmental containment for concreting	25	week	£	2,000	£	50,000		
						Subtotal	£	862,482

Jacobs	CALCULATION SHEET			Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by: Andrew Gibb	Project code:	B2386100
		Date: 12/07/2021	Serial no:	PS-F-10
Subject:	Option F - Towed Caisson Cost Estimate	Verified by: JM	Sheet no:	4
		Date: 12/07/2021	Revision:	1

4.0 CAPEX Cost Breakdown (Cont.)	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
4.7 Steel Caisson (original install at 2030)					
Steel structure	995	t	£ 6,000	£ 5,970,642	
External paint coating	2520	m2	£ 110	£ 277,200	
Internal paint coating	5796	m2	£ 70	£ 405,720	
Concrete ballast	250	te	£ 4,000	£ 1,000,000	Based on other projects
Bollards/fairleads	4	No.	£ 3,000	£ 12,000	
Winch machinery	2	No.	£ 500,000	£ 1,000,000	Based on other projects
M&E, valves, pumps, lighting, controls	1	No.	£ 500,000	£ 500,000	Based on other projects
Fendering - D-profile seal	110	m3	£ 128	£ 14,080	
Fendering - general	168	m	£ 128	£ 21,504	
Allowance for spare parts	1	No.	£ 200,000	£ 200,000	Based on other projects
Transport and installation	1	No.	£ 1,000,000	£ 1,000,000	Based on other projects
				Subtotal	£ 10,401,146
4.8 Steel Caisson (replacement of original at 2080)					
Steel structure	995	t	£ 6,000	£ 5,970,642	
External paint coating	2520	m2	£ 110	£ 277,200	
Internal paint coating	5796	m2	£ 70	£ 405,720	
Concrete ballast	250	te	£ 4,000	£ 1,000,000	Based on other projects
Bollards/fairleads	4	No.	£ 3,000	£ 12,000	
Winch machinery	2	No.	£ 500,000	£ 1,000,000	Based on other projects
M&E, valves, pumps, lighting, controls	1	No.	£ 500,000	£ 500,000	Based on other projects
Fendering - D-profile seal	110	m3	£ 128	£ 14,080	
Fendering - general	168	m	£ 128	£ 21,504	
Allowance for spare parts	1	No.	£ 200,000	£ 200,000	Based on other projects
Transport and installation	1	No.	£ 1,000,000	£ 1,000,000	Based on other projects
				Subtotal	£ 10,401,146
4.9 Temporary and Enabling Works					
Cofferdam for strong point construction	2	No.	£ 240,000	£ 480,000	
Inner lead in jetty support piles	150	m	£ 14,534	£ 2,180,035	
Inner lead in jetty concrete breakout/removal	120	m3	£ 61	£ 7,342	
				Subtotal	£ 2,667,377
4.10 Miscellaneous					
Omega underwater seal	72	m	£ 512	£ 36,864	
Diver installation of above	36	day	£ 2,500	£ 90,000	
				Subtotal	£ 126,864
		CAPEX total	**£**	**28,792,532**	

Jacobs	CALCULATION SHEET				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	Andrew Gibb	Project code:	B2386100
		Date:	12/07/2021	Serial no:	PS-F-10
Subject:	Option F - Towed Caisson Cost Estimate	Verified by:	JM	Sheet no:	5
		Date:	12/07/2021	Revision:	1

5.0 OPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
5.2 Inspections					
Annual inspection of M+E	100	No.	£ 1,000	£ 100,000	
Annual maintenance of M+E	100	No.	£ 1,000	£ 100,000	
5-yearly inspection of caisson structure	20		£ 10,000	£ 200,000	Includes dive survey
Replacement of caisson seals every 25 years	2	No.	£ 50,000	£ 100,000	Includes diver time
					Subtotal
					£ 500,000
5.2 Deployment Costs					
Tugs used to deploy and remove caisson	8420	No.	£ 4,000	£ 33,680,000	1 tug day per deployment
					Subtotal
					£ 33,680,000
		OPEX total	**£**	**34,180,000**	

Reference/Output

1.0 Introduction

This calculation has been prepared to determine an approximate cost estimate for the flood defences to accompany Options C and D as part of the Grangemouth FPS Port Study.

Reference should be made to drawings B2386100-JAC-DR-1402 and 1403 for details of the quayside defences.

Jacobs					Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	15/09/2021	Serial no:	PS-XX-03
Subject:	Option C & D - Quayside Defences Cost Estimate	Verified by:	JM	Sheet no:	2
		Date:	17/09/2021	Revision:	0

Reference/Output

3.0 Summary of Costs

Preliminaries	@	10%		£30,072	
CAPEX total				£300,717	
OPEX total				£634,269	
Subtotal					**£965,058**
Supervision costs	@	5%	of CAPEX total	£15,036	
Engineering costs	@	5%	of CAPEX total	£15,036	
Subtotal					**£995,130**
Profit and contingency	@	20%	of CAPEX total	£60,143	
Total					**£1,055,273**
Optimism bias	@	0%			£0
		60%	(consistent with wider project, less than Treasury Green Book of 66% for non-standard civil engineering)		£633,164
GRAND TOTALS			***(incl.) 0% O.B.***		***£1,055,273***
			(incl.) 60% O.B.		***£1,688,437***

Jacobs	Calculation sheet				
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	15/09/2021	Serial no:	PS-XX-03
Subject:	Option C & D - Quayside Defences Cost Estimate	Verified by:	JM	Sheet no:	3
		Date:	17/09/2021	Revision:	0

4.0 CAPEX Cost Breakdown

PLEASE REFER TO QTY CALCS AND SCHEDULE OF RATES FOR CALCULATIONS/SOURCES

Item	Qty	Unit	Rate (£)		Total (£)		Reference/Output	
4.1 Mobilisation								
Covered in preliminaries								
						Subtotal	£	-
4.2 Site Costs								
Covered in preliminaries								
						Subtotal	£	-
4.3 Plant and Equipment								
Concrete skip	9.6	week	£	250	£	2,396		
						Subtotal	£	2,396
4.4 In-Situ Reinforced Concrete								
Flood Wall reinforced concrete	71.34	m3	£	650	£	46,371		
Vertical formwork for flood wall	475.6	m2	Included in RC rate					
Drill bits for anchor coring	29	No.	£	50	£	1,450		
Operative to install anchors	767	hr	£	35	£	26,839		
Tubes of epoxy mortar (20 pack)	6	No.	£	685	£	4,108		
						Subtotal	£	46,371
4.5 Stoplogs and gates								
Stoplogs	77	m	£	2,100	£	161,700	Quotation from supplier	
Stoplog posts	2.1	t	£	2,000	£	4,169		
Stoplog sockets	1.0	t	£	2,000	£	2,085		
Post sockets - operator time	64.9	hr	£	35	£	2,271		
Coring of post sockets - core bits	3	No.	£	1,000	£	3,000		
Coring of post sockets - grout	1.33	m3	£	1,000	£	1,328		
Large Gates	2	No.	£	20,000	£	40,000		
Small Gates	1	No.	£	5,000	£	5,000		
						Subtotal	£	170,226
		CAPEX total	**£**			**300,717**		

Jacobs

Calculation sheet

Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	15/09/2021	Serial no:	PS-XX-03
Subject:	Option C & D - Quayside Defences Cost Estimate	Verified by:	JM	Sheet no:	4
		Date:	17/09/2021	Revision:	0

5.0 OPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
5.2 Inspections and maintenance					
5-yearly inspection of walls, stoplogs and gates	20		£ 5,000	£ 100,000	
Replacement of stoplogs every 25 years	3		£ 161,700	£ 485,100	
Replacement of gates at 50 years	1		£ 45,000	£ 45,000	
Replacement of stoplog posts every 50 years	1		£ 4,169.44	£ 4,169.44	
				Subtotal	£ 634,269
		OPEX total	**£**	**634,269**	

Jacobs				Calculation sheet	
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	15/09/2021	Serial no:	PS-XX-03
Subject:	Option F - Quayside Defences Cost Estimate	Verified by:	JM	Sheet no:	1
		Date:	17/09/2021	Revision:	0

Reference/Output

1.0 Introduction

This calculation has been prepared to determine an approximate cost estimate for the flood defences to accompany Options C and D as part of the Grangemouth FPS Port Study.

Reference should be made to drawings B2386100-JAC-DR-1402 and 1403 for details of the quayside defences.

Jacobs	Calculation sheet				
Calculation title:	Grangemouth Flood Protection Scheme	Created by:	ID	Project code:	B2386100
		Date:	15/09/2021	Serial no:	PS-XX-03
Subject:	Option F - Quayside Defences Cost Estimate	Verified by:	JM	Sheet no:	2
		Date:	17/09/2021	Revision:	0

Reference/Output

3.0 Summary of Costs

				Reference/Output	
Preliminaries	@	10%		£54,863	
CAPEX total				£548,629	
OPEX total				£584,763	
Subtotal					**£1,188,255**
Supervision costs	@	5%	of CAPEX total	£27,431	
Engineering costs	@	5%	of CAPEX total	£27,431	
Subtotal					**£1,243,118**
Profit and contingency	@	20%	of CAPEX total	£109,726	
Total					**£1,352,843**
Optimism bias	@	0%			£0
		60%	(consistent with wider project, less than Treasury Green Book of 66% for non-standard civil engineering)		£811,706
GRAND TOTALS			***(incl.) 0% O.B.***		***£1,352,843***
			(incl.) 60% O.B.		***£2,164,549***

Jacobs				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by: ID	Date: 15/09/2021	Project code: B2386100 / Serial no: PS-XX-03
Subject:	Option F - Quayside Defences Cost Estimate	Verified by: JM	Date: 17/09/2021	Sheet no: 3 / Revision: 0

4.0 CAPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
PLEASE REFER TO QTY CALCS AND SCHEDULE OF RATES FOR CALCULATIONS/SOURCES					
4.1 Mobilisation					
Covered in preliminaries					
				Subtotal	£ -
4.2 Site Costs					
Covered in preliminaries					
				Subtotal	£ -
4.3 Plant and Equipment					
Concrete skip	35.4	week	£ 250	£ 8,842	
				Subtotal	£ 8,842
4.4 In-Situ Reinforced Concrete					
Flood Wall reinforced concrete	263.22	m3	£ 650	£ 171,093	
Vertical formwork for flood wall	1754.8	m2	Included in RC rate		
Drill bits for anchor coring	107	No.	£ 50	£ 5,350	
Operative to install anchors	2829	hr	£ 35	£ 99,025	
Tubes of epoxy mortar (20 pack)	6	No.	£ 685	£ 4,108	
				Subtotal	£ 171,093
4.5 Stoplogs and gates					
Stoplogs	55	m	£ 2,100	£ 115,500	Quotation from supplier
Stoplog posts	1.6	t	£ 2,000	£ 3,263	
Stoplog sockets	0.8	t	£ 2,000	£ 1,632	
Post sockets - operator time	50.8	hr	£ 35	£ 1,777	
Coring of post sockets - core bits	2	No.	£ 1,000	£ 2,000	
Coring of post sockets - grout	1.04	m3	£ 1,000	£ 1,039	
Large Gates	6	No.	£ 20,000	£ 120,000	
Small Gates	3	No.	£ 5,000	£ 15,000	
				Subtotal	£ 122,172
		CAPEX total	**£**	**548,629**	

Jacobs				Calculation sheet
Calculation title:	Grangemouth Flood Protection Scheme	Created by: ID	Project code: B2386100	
		Date: 15/09/2021	Serial no: PS-XX-03	
Subject:	Option F - Quayside Defences Cost Estimate	Verified by: JM	Sheet no: 4	
		Date: 17/09/2021	Revision: 0	

5.0 OPEX Cost Breakdown	**Qty**	**Unit**	**Rate (£)**	**Total (£)**	**Reference/Output**
5.2 Inspections and maintenance					
5-yearly inspection of walls, stoplogs and gates	20		£ 5,000	£ 100,000	
Replacement of stoplogs every 25 years	3		£ 115,500	£ 346,500	
Replacement of gates at 50 years	1		£ 135,000	£ 135,000	
Replacement of stoplog posts every 50 years	1		£ 3,263	£ 3,263	
				Subtotal	£ 584,763
		OPEX total	**£**	**584,763**	

Appendix F. Designers' risk assessment (DHERR)

Jacobs

DESIGN HAZARD ELIMINATION AND RISK REDUCTION REGISTER

Latest Meeting Date	

Phase
C Construction
M Maintain / Clean
U Use as Workplace
D Demolish

Update Critical Risk Table

Project Name:	Grangemouth Flood Protection Scheme
Project Number:	B2386100
Client:	Falkirk Council

Probability	Worst Potential Severity (WPS) of Impact
1: Highly Unlikely 2: Unlikely 3: Possible 4: Likely 5: Highly Likely	1: Nil or slight injury / illness, property damage or environmental issue. 2: Minor injury / illness, property damage or environmental issue. 3: Moderate injury or illness, property damage or environmental issue. 4: Major injury or illness, property damage or environmental issue. 5: Fatal or long term disabling injury or illness. Significant property damage or environmental issu 10. Multiple fatalities and catastrophic event

RISK

LIKELIHOOD					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5

SEVERITY

1 Risk ID.	2 Formal Review Description	3 Phase	4 Activity	5 Potential Hazard	6 Person(s) Most at Risk	7 Prob	8 WPS	9 Initial Risk Rating	10 Discipline	11 Design Measures to Eliminate Hazards	12 Design Measures to Reduce Risk	13 Residual Prob	14 Residual WPS	15 Residual Risk Rating	16 Residual Risk Description
1	5: Design Stage Review	C	Option F	Various Hazards associated with piling from marine plant including stability and ease of access.	Construction	3	3	9	Civil / Structural	Several stages of refinement in pile arrangement undertaken at concept design to facilitate pile driving using land-based plant. Marine piling not required for final arrangement as designed.	N/A	1	1	1	No residual risks associated with marine piling as designed out.
2	5: Design Stage Review	C	Option F	Disturbing live existing buried, topside or overhead services during construction including piling.	Construction	3	5	15	Civil / Structural	N/A	Desk-based utilities mapping, together with intrusive utilities search if required to be carried out at subsequent design stage before this risk can be considered mitigated.	3	5	15	No mitigated at present until design measures are carried out.
3	5: Design Stage Review	C	Option F	Insufficient capacity of existing lock structure to support modifications including temporary plant required for piling and any long term actions.	Construction	2	3	6	Civil / Structural	N/A	Support structures are designed such that additional permanent actions are applied to the existing structure. This relies on a design assumption that at least 1No. lock gate is closed seaward of the caisson when in deployed condition. The additional temporary loading caused by the piling rig may require checking during subsequent design stage.	1	3	3	Partially mitigated by design development at concept stage, to be taken further at detailed design. If Option F is taken forward, verification of design assumption that at least one lock gate is operational required at detailed design.
4	5: Design Stage Review	C	Option F	Reduced structural capacity of existing lock channel caused by cutting or partial removal of structures to facilitate construction of proposed solution.	Construction	2	3	6	Civil / Structural	Hazard eliminated as support structures are self-supporting and do not require any modification of the existing lock channel.	N/A	1	1	1	Hazard eliminated.

Risk ID.	Formal Review Description	Phase	Activity	Potential Hazard	Person(s) Most at Risk	Prob	WPS	Initial Risk Rating	Discipline	Design Measures to Eliminate Hazards	Design Measures to Reduce Risk	Residual Prob	Residual WPS	Residual Risk Rating	Residual Risk Description
5	5: Design Stage Review	C	Option F	Requirement for underwater (diver assisted) operations including grouted connections, underwater concrete.	Construction	3	4	12	Civil / Structural	N/A	Pre-cast cill with in-situ grouted joints designed requiring minimal diver assistance in preference to other options considered.	2	4	8	Residual risk remains as some underwater working is still required but reduced during design. If Option F is taken forward to detailed design, careful design of the proprietary seal (Omega) is necessary to minimise diver time upon installation and at intervals through the design working life of the defence.
6	5: Design Stage Review	C	Option F	Working adjacent to operational lock channel with related potential for vessel collision.	Construction	3	5	15	Civil / Structural	N/A	Design of support structures developed so that strong points can be constructed 'offline' with cofferdam protection while lock channel remains operational. Cill is to be pre-cast remotely so that only cill installation and grouting/sealing the various interfaces requires to be completed in channel.	1	5	5	Residual risk remains as some channel working is required, although greatly reduced by design. If Option F is taken forward to detailed design, careful design of the proprietary seal (Omega) is necessary to minimise diver time upon installation and at intervals through the design working life of the defence.
7	5: Design Stage Review	C	Option F	Working within cofferdam with associated risk of water flooding into works and restricted access.	Construction	3	5	15	Civil / Structural	N/A	Although the risks associated with cofferdam working will be managed by the Contractor's health and safety planning, there remains a heightened risk compared to dry working. Only proof of concept design has been undertaken to date and detailed design should look to minimise cofferdam working further.	3	5	15	If Option F is taken forward to detailed design, options to reduce cofferdam working including using pre-cast shells with in-situ stitching should be considered. Related environmental benefits including better containment of fines to avoid pollution should be investigated.
8	5: Design Stage Review	C	Option F	Lifting operations - Potential instability of crane/plant during lifting. Failure of lifting arrangement leading to collapse or dropped objects.	Construction	3	4	12	Civil / Structural	N/A	Risk mitigated during concept design by considering alternative means of getting the largest pre-cast element into position. The cill is designed such that it can be pre-cast on a submersible barge and maneuverer into position using buoyancy aids with cranes being used to guide only.	2	3	6	Residual risks remain for other lifting operations.

Risk ID.	Formal Review Description	Phase	Activity	Potential Hazard	Person(s) Most at Risk	Prob	WPS	Initial Risk Rating	Discipline	Design Measures to Eliminate Hazards	Design Measures to Reduce Risk	Residual Prob	Residual WPS	Residual Risk Rating	Residual Risk Description
9	5: Design Stage Review	C	Option F	Removal of existing deck of western lead-in jetty to facilitate strong point construction and associated risks of manual handling, lifting, noise, dust and hazard exposure.	Construction	2	4	8	Civil / Structural	N/A	It is envisaged that the removal process can be carried out remotely using wire cutting technology and temporary supports. Intrusive investigations of the existing deck are likely to have been made to detail the new supports and any new deck provision behind the strong point such that the structural formation of the structures to be removed will be known	2	4	8	Residual risk remains for further mitigation during detailed design.
10	5: Design Stage Review	C	Option F	Note - risk rating not applied as not appropriate for this. The towed caisson option carries a heightened risk of the flood defence being unavailable at the time of need compared to alternative mitre gate options. The caisson requires to be manually towed and lowered into position using tugs in advance of a flood event whereas mitre gates can be deployed relatively quickly and at short notice using the controls mechanism.	Construction	1	1	1	Civil / Structural	N/A	Not mitigated during design, this is a fundamental difference between the available options. The operational limitations of the towed caisson option versus the alternatives, including tug available, notice to deploy, deployment time and potential weather risk in lead up to forecasted flood event should all be considered as part of the options appraisal and ultimately form the basis for the client's decision.	1	1	1	If Option F is taken forward to detailed design, availability of the defence should be studied in detail including estimated number of deployments, source of tugs and notice required, contingency planning. Consideration should also be given to who manages the forecast monitoring and deployment of the caisson and how conflicts with navigation of the lock are to be handled.
11	5: Design Stage Review	C	Option C and D	Disturbing live existing buried, topside or overhead services during construction including piling	Construction	3	5	15	Civil / Structural	N/A	Desk-based utilities mapping, together with intrusive utilities search if required to be carried out at subsequent design stage before this risk can	3	5	15	Not mitigated at present until design measures are carried out.
12	5: Design Stage Review	C	Option C and D	Insufficient capacity of existing lock structure to support modifications including temporary plant required for piling and any long term actions.	Construction	2	3	6	Civil / Structural	N/A	Additional loads taken by the gates during a flood event are put through the new support structures. Checks have been undertaken to confirm that the existing lock structure can accommodate the minor increase in loads under operational conditions.	1	3	3	Partially mitigated by design development at concept stage, to be taken further at detailed design. If Option F is taken forward, verification of design assumption that at least one lock gate is operational required at

Risk ID.	Formal Review Description	Phase	Activity	Potential Hazard	Person(s) Most at Risk	Prob	WPS	Initial Risk Rating	Discipline	Design Measures to Eliminate Hazards	Design Measures to Reduce Risk	Residual Prob	Residual WPS	Residual Risk Rating	Residual Risk Description
13	5: Design Stage Review	C	Option C and D	Reduced structural capacity of existing lock channel caused by cutting or partial removal of structures to facilitate construction of proposed solution.	Construction	2	3	6	Civil / Structural	Modifications to the existing lock channel structures has been minimised and designed to have minimal impact on existing capacity.	N/A	1	1	1	Hazard mitigated at outline design stage. To be revisited at detailed design.
14	5: Design Stage Review	C	Option C and D	Working adjacent to operational lock channel with related potential for vessel collision.	Construction	3	5	15	Civil / Structural	N/A	Design of support structures developed so that proximity to the channel is minimised, though due to the nature of the work required this cannot be completely removed, thus no in-channel working during vessel transits is envisaged at this stage. For the shot bolt pit there will need to be closures of the channel to allow the works to be undertaken.	1	5	5	Residual risk remains as some channel working is required, though this will not coincide with vessel transits.
20	5: Design Stage Review	C	Option D	Requirement for underwater (diver assisted) operations	Construction	3	4	12	Civil / Structural	N/A	A limpet dam will be used for the channel wall breakout that reduces the requirement of underwater working.	2	4	8	Residual risk remains as some underwater working is still required but reduced during design.
21	5: Design Stage Review	C	Option D	Suspended soils within the channel impacting the works on the channel wall	Construction	2	3	6	Civil / Structural	N/A	A silt curtain will be deployed for the duration of the works.	1	3	3	Risk mitigated. Arrangement to be revisited once a more detailed construction methodology developed.

Appendix G. Project risk register (port study)

GRANGEMOUTH FLOOD PROTECTION SCHEME

PORT STUDY RISK REGISTER

Project Code:	**B2386100**
Revision Date:	**3-Aug-21**
Completed By:	**James McGilligan**

Rev 1.1

NO.	RISK ID	RISK TITLE	DESCRIPTION OF RISK	INITIAL RISK			Owner	CATEGORISATION		IMPACTS					RESPONSE STRATEGY					MITIGATION MEASURES	RESIDUAL RISK		
12				Prob.	Cons.	Score		Category	Stage	Cost	Time	Quality	Env.	Opp.	Avoid	Transfer	Reduce	Share	Accept		Prob.	Cons.	Score
1	GFPS-PSRR-001	Encountering difficult ground conditions	Risk refers to adverse ground conditions being discovered during design stage ground investigation survey works (not on site during construction). May result in requirement for significantly adapted detailed design stage structures and more expensive construction techniques. Preliminary design is based on ground conditions at depth being similar to those found in BHFP15B, in particular the existance of a dense sand layer around -50mOD	H	VH	12	Client	Technical	Design	Yes	Yes						Yes	Yes		Impossible to avoid completely, although the extent of the ground conditions should be adequately determined in advance of issuing the tender drawings, which may include CPT testing at each pile location to give a high degree of confidence that design pile capacities are able to be achieved. GI data to be used to establish an adequate degree of additional pile length to ensure set is achieved.	H	M	6
1	GFPS-PSRR-002	Encountering obstructions within the ground	Each option considered for the port study relies upon piled foundations to resist hydrostatic flood loading. As the site is reclaimed land, the made ground has significant risk of containing obstructions to piling. Obstructions in the natural deposits may also be encountered.	H	H	9	Client	Technical	Construction	Yes	Yes						Yes			Impossible to avoid completely, although the extent of the ground conditions should be adequately determined in advance of issuing the tender drawings, which may include CPT testing at each pile location to give a high degree of confidence in the design. Depending onthe option, some redundancy may be allowed for in the design in the event that some piles are unable to be driven past an obstruction. Dealing with the risk of certain sections of difficult ground could be transferred to the contractor through contractor design.			
1	GFPS-PSRR-003	Managing ground water	Potential to require complex seepage reduction measures which could ultimately increase the overall cost of the project and cause delays to programme. Also consider ingress of water in excavations at design stage. Also consider inability of ground water to percolate to watercourse as a result of constructing the scheme.	H	H	9	Client	Technical	Design	Yes	Yes						Yes			Where possible, avoid designs that require complex seepage reduction measures and try to eliminate the potential for dealing with water during construction e.g. avoid need for deep excavations. Where these cannot be avoided, ensure groundwater information supplied to the contractor is complete and accurate such that dewatering measures can be adequately priced for.	H	M	6
1	GFPS-PSRR-004	Dealing with Services & utilities prior to construction	Unreliable service records from providers leading to unsuitable designs and unforeseen design changes. Diversion and crossing of existing electricity, water, sewerage and telephone lines, requiring to be carried out or supervised by the service provider. Possibility of delay, financial burden and bad publicity to the project.	VH	H	12	Client	Technical	Design	Yes	Yes						Yes			Client / Design Consultant responsible for identification of all services, and to ensure that the information is as accurate as possible and included in the Contract Documents, such that appropriate diversion works can be included in design. Agree on Employer carrying out advance works such as GPR/ trial digs to provide greater confidence in location. However, ultimatly the ground confirmation of service and utility location will be the responsibility of the contractor.	H	H	9
1	GFPS-PSRR-005	Unforeseen Services & utilities during construction	The presence of existing services and utilities which are not charted on plans or are not recorded accurately on plans impact directly on construction.	H	VH	12	Client	Technical	Construction	Yes	Yes								Yes	Contractor will be responsible for dealing with those services and utilities which are known and not diverted as part of the advance service diversion contract. The presence of unforeseen services will always be a risk which can only be owned by the Client. Consequences of discovery of services could be costly in terms of programme and unforeseen diversion costs.	H	VH	12
1	GFPS-PSRR-006	Encountering built lock channel infrastructure different to that presented on as-builts.	As built records as supplied by Forth Ports are incomplete with respect to the channel construction. A risk of encountering lock channel infrastructure or enabling works unknown about at design stage could impact on the constructability of the designs put forward.	H	VH	12	Client	Technical	Construction	Yes	Yes						Yes			Carry out as thorough a GI campagin as possible in the areas requiring deep foundations. The risk of encountering infrastructure/obstructions cannot be removed completely.	H	VH	12
1	GFPS-PSRR-007	Encountering a greater or lesser density of reinforcement in reinforced concrete sections than that assumed at preliminary design stage.	Few as-built records have been provided that have any indication of the density of reinforcement within the RC sections of the channel construction. Due to the need to make assumptions during design, the existing infrastructure may not have the capacity to bear required loads or to remain self-supporting following the necessary modifications to the channel structure. Furthermore, the reinforcement density of the existing lock channel infrastructure affects the time taken to demolish sections that need to be removed in order to create space for the new arrangement. Greater densities of steel reinforcement may make the cutting process slower which may in turn have ramifications for undertaking the works within the channel closure windows identified.	H	VH	12	Client	Technical	Construction	Yes	Yes						Yes			Make estimates of the load envelopes the existing channel structure is subject to and where possible, design new structures to remain within these envelopes. Foundations for new loads such as thrust loads in propping cylinders to be resisted by entirely new structures unconnected to and isolated from the existing channel. Where designs rely heavily upon the integrity of an existing structure and a minimum reinfocement density, or the removal of such material by cutting, plan to carry out intrusive investigations to corroborate the assumptions made during the design.	M	VH	8
1	GFPS-PSRR-008	Changes to the design flood level and the impact on the supporting structures	As this option is being designed for a 100-year service life with an estimated operational date in 2030, by 2080 the predicted level of protection against a 1:200 year flood event will begin to diminish and the gate will be at increasing risk of facing flood stages higher than that designed for. The risk of facing such severe flood levels needs to be considered carefully, as deployment of the barrier under these conditions could lead to overloading of the support structures and potential failure of the gate.	H	VH	12	Client	Technical	Design	Yes	Yes				Yes					Strategy on the flood levels to be designed for, the design life of the structures and the performance requirements vs asset lifespan to be agreed with the GFPS PM team at detailed design stage. A range of flood levels will be required to be provided by the flood modelling team to allow for a detailed design to be carried out to Eurocode principles, i.e. it is envisaged characteristic and accidental design scenarios will be developed for analysis.	M	VH	8
1	GFPS-PSRR-009	Reverse loading of barrier structures	Some of the port study flood defences are designed to be reverse loaded (for example double-acting mitre gates), however the reverse loading of some solutions e.g. a towed caisson gate has structural implications for the existing lock channel structure which need to be planned for if these this design situation is to arise.	H	VH	12	Client	Technical	Design	Yes	Yes				Yes					The development of a reverse loading design situation for the caisson gate requires a particular sequence of events to take place to ensure that the gate is deployed and the lock channel drained to an onerously low level. The likelihood of this occurrence needs to be assessed in dialogue with the Forth Ports and if the risk is deemed high enough, provision for the strengthening of the existing lock channel structures may require to be made.	H	L	3

NO.	RISK ID	RISK TITLE	DESCRIPTION OF RISK	INITIAL RISK			Owner	CATEGORISATION		IMPACTS					RESPONSE STRATEGY					MITIGATION MEASURES	RESIDUAL RISK		
12				Prob.	Cons.	Score		Category	Stage	Cost	Time	Quality	Env.	Opp.	Avoid	Transfer	Reduce	Share	Accept		Prob.	Cons.	Score
1	GFPS-PSRR-010	Vessel collision with new barrier	Contact with the lock channel infrastructure by transiting vessels is not uncommon and the risk of a collision with the new gate solution needs to be fully understood for the option taken forward.	H	VH	12	Client	Technical	Design	Yes	Yes						Yes			The forces generated in the collision of a large vessel with a structure are often too large to be designed to be catered for and so thought needs to be given to providing replaceable elements, flaring any upstands to reduce the collision risk and to providing fused structural elements to fail preferentially in the event of overload. A full navigational study should be undertaken as part of the detailed design to highlight the areas and elements at risk so that the design make make the required allowances.	H	L	3
1	GFPS-PSRR-011	Gate design	Gate design did not form part of the scope of the port study. For each option, it is not envisaged that gate design outwith the 'norm' for such applications will need to be made to cater for each of the design situations. However, until the gate design is undertaken, a risk remains that considerations made in the design of the gates has an impact on the support structures or the operation of the lock channel.	H	H	9	Client	Technical	Design	Yes	Yes						Yes			The gate design should be prepared in tandem with the civils design at detailed design stage to enable any impacts arising from gate geometry and detailing to be dealt with at an early stage.	H	L	3
1	GFPS-PSRR-012	Pile installation tolerances	The design of the foundation structures for two of the gate options under the port study rely on closely spaced raking piles. Due to the large verticality tolerances inherent in driving raking piles and the length of the driven sections, a risk of pile clashes exists at depth.	H	H	9	Client	Technical	Design	Yes	Yes						Yes			A specialist piling contractor may be able to adopt a piling methodology to better the tolerance stated above. Early contractor involvement in the detailed design phase would act to mitigate this risk. Alternatively, a staggered layout for the raking piles would mitigate the clash risk, as would adopting a steeper design rake for the external row.	M	H	6