KGS GROUP
CONSULTING ENGINEERS

NORTH HURON

HOWSON DAM
DAM STABILITY ASSESSMENT REPORT

DRAFT REV C

KGS Group 17-3212-001
May 2018

PREPARED BY:

Yongbo Fu P. Eng.
Senior Structural Engineer

Fuad Curi P. Eng.
Water Resources Department Head

APPROVED BY:

Holly Hampton Ph.D. P.Eng.
Civil/Structural Department Head

EXECUTIVE SUMMARY

The Howson Dam, on the North Branch of the Maitland River (North Maitland River), is located north of Highway 86 in Wingham, in the Township of North Huron, Ontario. The available documentation suggests that the dam was originally built to prevent flooding and to create a reservoir for recreational use. It has two distinguishable components: the South Dam built approximately in the 1920's and the North Dam, built in 1966, to provide additional spill capacity.

The South Dam consists of four overflow weirs with a sill level of El. 309.3 m. Their crest lengths are, from North to South, 10.6 m, 11.5 m, 10.8 m and 10.7 m. The North Dam consists of three sluiceway bays of lengths: 3.8 m, 4.0 m and 3.8 m. They have a sill elevation of approximately El. 306.6 m and each has seven stop-logs that are operated to maintain the reservoir levels and removed to provide spill capacity in the spring. Historically, the dam was operated to maintain a reservoir level of approximately El. 310 m; but it has been operated at lower levels in recent years. There is an earth embankment section between the North and the South dams, of approximately 20 m of length. There is a bridge located on the deck of the dam, on Water Street in Wingham.

The concrete in the South Dam at the Howson Dam and in the bridge structure shows severe signs of deterioration. The bridge has been closed to vehicular traffic; but at the time of initiation of this project it was open to public use. Evaluations of the concrete were carried out by the firms BM Ross and Associates Ltd and Atkinson-Davies Inc. in the period from 1983 to 1985. At that time, attempts to obtain concrete cores on the South Dam were terminated at shallow depths due to the poor condition of the concrete. The two consultant firms concluded that the concrete in the dam and bridge did not provide a basis for satisfactory long-term repair works and that the only course of action available was removal and replacement of these structures.

The available documentation also indicates that through the history of the dam, works have been required to prevent or mitigate undermining of the foundation. Extension of the apron and sheet-piling were carried out in the downstream end of the South Dam, as early as the 1940's or 1950's. More recently, in 1963, additional sheet-piling was required for one section of the South Dam. Repairs for foundation undermining of the North Dam were also required in the 1980's.

It was indicated by the Township of North Huron that an Environmental Assessment (EA) was initiated in 2016 to evaluate alternatives for repairing the dam. Correspondence from that period by BM Ross and Associates Ltd refer to a plan to repair the dam that included re-facing and restoration of the upstream concrete sill and patch restoration on the piers, with a cost of approximately $485,000 plus HST. During this process the MNRF was consulted and it was concluded that it would most likely require application to obtain approval under Section 16 of the Lakes and Rivers Improvement Act (LRIA). For this application, a dam safety and structural stability assessment are required.

The Township of North Huron retained KGS Group to carry out a dam safety assessment of the dam, determine the Hazard Potential Classification (HPC) and the Inflow Design Flood (IDF), evaluate the adequacy of the discharge capacity at the site to convey the IDF, conduct site investigations and testing for the concrete and structural stability assessment on the South Dam. The assessment of the stability of the South Dam was to be performed considering the conditions with and without the bridge in place. These analyses were required to be conducted in accordance with the Bulletins and Guidelines issued by MNRF in 2011, associated to the

Lakes and Rivers Improvement Act (LRIA) and its Administrative Guide. The scope of the project did not include an assessment of the condition of the bridge or analyses of its strength.

KGS Group carried out hydrologic analysis to determine flood flow values for the site, based on data from Water Survey of Canada (WSC Station 02FE005). It was estimated that the 100-Year Flood had a peak flow value at the site of 415 m^3/s. This value is in the same range of previous estimates found in the available documentation. An order of magnitude of 1,400 m^3/s was obtained for the Maximum Probable Flood (PMF).

KGS Group also carried out simulations of a dam breach, using hydraulic models, to evaluate the potential consequences of a breach of the Howson Dam in two conditions: normal (sunny-day) and during a large flood. The dam break consequences were evaluated, in accordance with the 2011 LRIA associated bulletins, in terms of Incremental Loss of Lives (ILOL), and damages to third party assets, the environment and to cultural assets.

The analysis indicated ILOL values between 1 and 10 for a dam breach in normal (sunny-day) conditions, mainly associated to the recreational use of the areas downstream of the dam. It corresponded to an HPC of HIGH and a design ground motion with exceedance probability of 1 in 2,500 years. The analysis also indicated that a dam breach during a large flood would result in a small increase in water levels, attributable to the dam failure, in the downstream areas of permanent population. Recognizing the flooding in those areas, and from application of the “2x2 Rule” promoted by the 2011 LRIA associated bulletins, the dam was assigned an HPC of HIGH for a breach during a flood. Through incremental analysis the 100-Year Flood was proposed as IDF, because larger flood events would only cause a small increase in water levels (10 cm or less) in areas of hazard to population.

The analysis indicated that the dam could adequately pass the IDF (100-Year Flood with a peak flow of 415 m3/s) with all the bays open, and provide adequate freeboard. It requires, however, that provisions are taken to ensure that the sluiceway bays can be opened in advance of a flood. The analysis of energy dissipation downstream of the dam suggests that the conditions are adequate; but these need to be confirmed at the time of design of dam upgrades. This confirmation should include a more detailed determination of the tailwater rating curve than what was available during the study. It must be noted that previous studies have identified concerns with the management of ice and debris affecting spill capacity, as well as scour on the banks and downstream of the dam. These need to be also considered during the design of potential dam upgrades.

As part of the assessment, KGS Group engineers carried out a visual inspection of the structures and a reconnaissance of the site and surrounding area. A concrete coring program was carried out during the structural assessment of the dam (refer to 2018 Geotechnical Site Investigation Report by KGS Group). Three vertical core holes were completed from the top of the piers to depths between 1.6 and 1.9 m. The concrete in the cores was observed to be extensively deteriorated with fractures present throughout the core length. In those conditions, the load-carrying capacity and the water tightness of the concrete are expected to be significantly reduced.

The visual inspection revealed that the South Dam at the site is in very poor condition. Large areas of freeze/thaw spalling and delamination were visible in the concrete overflow weirs, piers and abutments. If the concrete condition within the body of the overflow weirs is similar to the concrete obtained from the core logs from the piers, it would mean that the integrity of the concrete in the weir may no longer be reliable and that the South Dam is required to be repaired as soon as possible.

The bridge deck is a reinforced concrete beam structure but a large portion of the reinforcing steel is exposed and corroded. Due to the corroded reinforcing steel, and potential horizontal fractures and extensive deterioration within the concrete at the girders and deck, the structural capacity of the girders and deck is compromised. Moreover, it is not possible to reasonably estimate the load-carrying capacity of the girders/ deck slabs based on the deteriorated concrete condition. Although an analysis of the bridge or its members was not within the scope and has not been conducted, the observations from the site visit suggest that the further use of the bridge may pose a risk to the public and that the safety of the bridge should be addressed.

The dam appears to be founded on soil, based on the report of the B.M. Ross and Associates Ltd. There have been undermining issues that have required repairs at different times during the life of the structure. As such, the foundation condition and potential scouring and undermining need to be assessed as part of any future alternatives for the dam.

The structural stability analyses for the South Dam were carried out in accordance with the criteria indicated in the 2011 LRIA associated bulletins. KGS Group computed stability factors for the six load-combination cases specified in 2011 LRIA:

- Load Case One: with maximum normal operation water level in summer.
- Load Case Two: winter operation water level plus “usual” ice loading condition.
- Load Case Three: flood condition (IDF).
- Load Case Four: winter operation water level plus “unusual” ice loading condition.
- Load Case Five: earthquake condition, and
- Load Case Six: post-earthquake condition.

Note that for the stability assessment, the concrete of the piers and weir was assumed to be intact.

The results of the stability analyses show that the piers under current condition (with the bridge deck) meet the 2011 LRIA stability criteria for all loading conditions. For the case with the bridge deck removed, the results of the stability analyses show that the piers do not meet the 2011 LRIA stability criteria for the sliding stability under normal summer, winter, IDF and earthquake loading conditions.

The results of stability analyses show that the overflow weirs of the South Dam do not meet the 2011 LRIA stability criteria for the sliding stability under all loading conditions except the IDF.

Under the current dam operation condition, the results of stability analyses show that the entire South Dam does not meet the 2011 LRIA stability criteria for the sliding stability under all loading conditions except the IDF and post-earthquake loadings.

It was concluded that the dam does not meet the 2011 LRIA sliding stability criteria. Remedial work is required to address the dam stability deficiency, required for the application to obtain approval from MNRF under Section 16 of the LRIA.

The following alternatives for addressing the stability deficiency of the South Dam at the Howson Dam were evaluated:

- Do nothing
- Dam Decommissioning
- Dam Rehabilitation
- Dam Replacement

For these alternatives, American Association of Cost Engineering (AACE) Class 4 estimates, with an accuracy of plus or minus 40 to 50%, were obtained and are provided in subsequent paragraphs.

The do nothing alternative was considered not feasible because it would not address the risk posed by the dam, since it does not satisfy the dam safety requirements indicated in the 2011 LRIA associated criteria for stability. The do nothing alternative also does not address the risk posed by the bridge at its present state of deterioration.

The alternative of dam decommissioning was not ruled unfeasible; but it would require an extensive process of consultation at various levels. It is anticipated, based on the input obtained during the 2016 EA, that it could be opposed by the public. A cost estimate of $ 436,000 was obtained for this option. This estimate does not include some costs that might be related to environmental controls and management of fish population or fish habitat. There are also considerations such as effect on species at risk and on the character of the area and public use of the site for which a monetary value is difficult to assign.

For the alternative of dam rehabilitation, two options were considered: installation of post-tension anchors and addition of concrete mass. Both options need to be confirmed with site investigations to assess the condition of the concrete in the weirs and of the foundation of the dam. The information available from the visual inspection and limited core sampling suggests that these options will likely be found not feasible after these site investigations are carried out. Nonetheless, a cost estimate was prepared assuming that the concrete in the weirs would be found to be sound and would only need removal of damaged concrete up to 0.5 m of depth from the surface. The cost estimate also was based on the assumption of a competent dam foundation. The rehabilitation options, if feasible, would ensure that the South Dam satisfies the stability requirements of the LRIA. The rehabilitated dam, in conjunction with the North Dam would allow safe passage of the IDF in accordance with the requirements by the LRIA. The estimated costs of the two rehabilitation options are:

- Installation of post-tensioned anchors at the overflow weirs: $ 2,869,000
- Addition of concrete mass to the overflow weirs: $ 4,581,000.

Additional evaluation is necessary to assess the structural stability of the North Dam. It is possible that, as the result of this assessment, the North Dam also requires rehabilitation works to satisfy the LRIA, which have not been included in the cost estimates presented above.

Two options were considered for rebuilding the dam: concrete weir and earth embankment with an additional sluiceway structure. These options would allow satisfying the requirements of the LRIA. As in the case of the rehabilitation alternative, the rebuilt dam would require the spill capacity from the North Dam to safely pass the IDF. The stability of the North Dam would need to be assessed and it could potentially need rehabilitation works to ensure that this dam also satisfies the requirement of the LRIA. The estimated costs of the two rebuilt options are:

- New concrete overflow weir $ 6,209,000
- Earth embankment and new sluiceway structure: $ 3,960,000.

Further consideration of these alternatives is required, including public consultation. It is recommended that these are included in the EA process initiated in 2016. A more detailed investigation program to determine the concrete condition of the overflow weir and its foundation condition are recommended prior to selecting the preferred alternative. These investigations and analyses will be required to confirm the feasibility of any of the rehabilitation options.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

The Howson Dam, located north of Highway 86 in the Township of North Huron, was built in approximately 1920 (South Section) and 1966 (North Section). The dam is located on the North Branch of the Maitland River (North Maitland River) and was originally built to prevent flooding and to create a reservoir for recreational use. Water levels at the reservoir are managed by operating stop-log sluices in the north section of the dam.

The Township of North Huron retained KGS Group to carry out a design services for the stability assessment on the South Dam of the Howson Dam. The stability assessment is one component of a dam safety management system which is developed in order to ensure safe management of the dam throughout its life cycle. The scope of work for this project includes the assessment of the stability of the South Dam considering two conditions: with and without the bridge at the site in place. It must be noted that the scope does not include an assessment of the condition of the bridge or analyses of its strength and stability.

As part of the assessment, KGS Group engineers carried out a visual inspection of the structures, features of geological significance, flow control equipment, and the hydrology of the site and surrounding area.

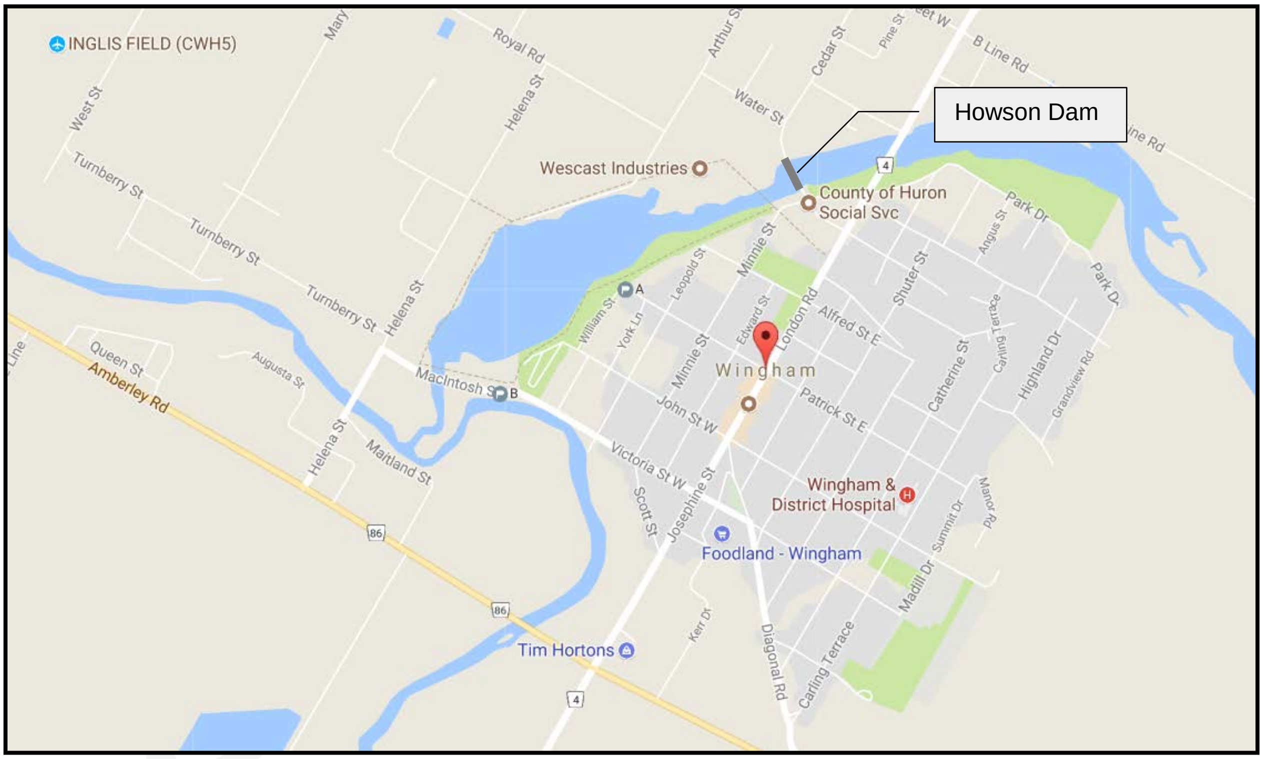
This report presents the findings and results of stability assessment on the South Dam and provides recommendations.

The dam stability assessment has been completed by KGS Group in accordance with the requirements of the MNRF 2011 Lakes and Rivers Improvement Act Dam Safety Technical Bulletins (hereafter referred to as 2011 LRIA).

The South Dam is approximately 54m long, 6.5 m high and has four sluice bays, each with a sill level at approximately El. 309.25 m. This elevation was obtained from the document "Proposed Repairs to the Howson Dam" prepared by BM Ross and Associates Limited in 2015 (BM Ross 2015). The top elevation of the deck of the structure is at El. 312.48 m (geodetic elevation provided by the Township of North Huron). A structure inspection report prepared by BM Ross and Associated Limited in 2013 – Report No. 010 (BM Ross 2013a) indicates that the four bays, from north to south, were 10.6 m, 11.5 m, 10.8 m, and 10.7 m in length.

Figure 1-1 shows the location of the Howson Dam

FIGURE 1-1
GENERAL LOCATION OF THE HOWSON DAM (GOOGLE MAPS IMAGE)



2.0 BACKGROUND INFORMATION

2.1 GENERAL

In the report submitted in May 1965 by Crysler, Davis & Jorgensen Ltd. Consulting Engineers, it was indicated that the ogee section of the sluiceway (South Dam) was spalled and spalling was observed in all piers, too, but they appeared to be structurally sound.

The deteriorated concrete condition of the south dam was further reported by B.M Ross and Associates including the inspection results and report carried out by Atkinson Davies Inc in December 1984. Nine concrete core samples were taken from superstructure and substructure of south sluiceway by Atkinson Davies. Given the conditions of the concrete, negligible or zero concrete compression strength was noted in the report of Atkinson Davies inc. Severe delaminated /spalled concrete areas were identified in the report of B.M Ross and Associates for both of the bridge and the south dam. Consequently, a 3-tonne live load limit on the bridge was proposed by B.M Ross and Associates. The reports also discussed alternatives of remedial measures to the structure, that were developed by B.M Ross and Associates in October 1985. These alternatives corresponded to options for reconstructing the dam.

A document provided by the Township of North Huron, referring to the 2013 Asset Management Plan and the status of the Howson Dam project indicates that the bridge over the dam was closed to vehicular traffic, approximately since 1999. The document refers to the poor condition of the dam and the previous recommendations for repairs. It mentions that the MNRF has suggested the potential need for application under Section 16 of the LRIA, before approval of the dam repairs. The document also discuss the head pond levels and the fact that flashboards cannot be installed in the present conditions, and mentions discussions that have taken place regarding hydro generation potential at the site.

The Township also provided correspondence from BM Ross Engineering that refer to a revised plan of the repairs to the dam. The letter refers to a cost of approximately $485,000 plus HST for re-facing and restoration of the upstream concrete sill and patch restoration on the piers. The letter does not provide details but refer to reports issued in 2015. These were not available for review. The letter does indicate that stability analyses had not been completed for the structure. Subsequent to this letter, there were other communications with MNRF and with BM Ross. In those it is suggested that the proposed works might exceed MNRF's definition of "minor works" and, therefore, require approval under the LRIA.

3.0 INSPECTION AND DEFICIENCIES

3.1 RECORD OF OBSERVATIONS

As part of this dam stability assessment, KGS Group engineers carried out a visual inspection of the south dam on November 22, 2017. The weather was sunny to partly cloudy, and the temperature was about 3° C. Photographic records of the inspection were made.

The detailed structural and geotechnical observations were recorded on Dam Safety General Inspection (DSGI) sheets provided in Appendix C.

3.2 DAM STRUCTURE CONDITION ASSESSMENT

3.2.1 General

The South Dam is made up of concrete overflow weirs and piers/abutments. A bridge deck is supported on the top of the piers/abutments. The various elements of the inspected structures are described below.

3.2.1.1 Concrete Overflow Weir

The concrete overflow weir is a concrete mass structure and is in poor to very poor condition. Large area of freeze/thaw spalling/erosion are found at upstream face, top and downstream side of the structure as shown in photos Photo 3.2.1 and Photo 3.2.2.

PHOTO 3.2.1
UPSTREAM VIEW OF OVERFLOW WEIR

PHOTO 3.2.2
TOP AND DOWNSTREAM VIEW OF OVERFLOW WEIR

3.2.1.2 Piers / Abutments

The piers/abutments are concrete mass structures and are in very poor condition. The pier noses were found to have large spalled concrete as shown in photo 3.2.3. The side face of the pier shows severe spalling / delamination (see photo 3.2.4). As shown in photo 3.2.5, the downstream sides of the piers are cracked. Large spalled concrete is also found at the abutments (see photo 3.2.6).

PHOTO 3.2.3
SPALLLED PIER NOSE

PHOTO 3.2.4
VIEW OF PIER SIDE FACE

PHOTO 3.2.5
VIEW OF PIER DOWMSTREAM SIDE

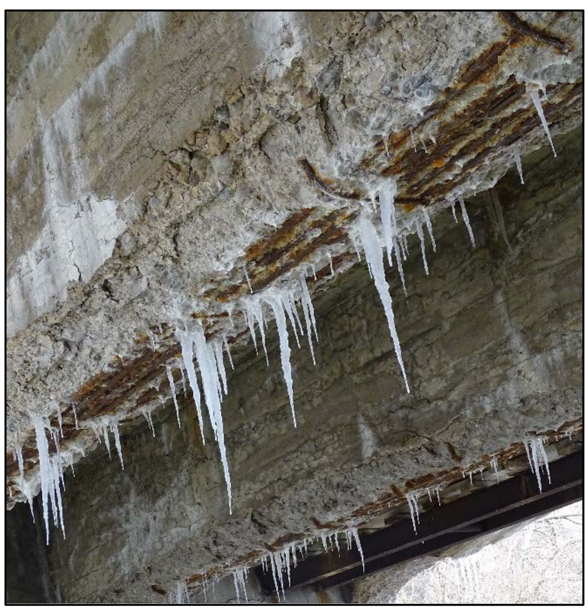
PHOTO 3.2.6
VIEW OF ABUTMENTS

3.2.1.3 Bridge Deck

The bridge deck consists of deck slab and concrete girders. They are structural beam elements and are in very poor condition. The concrete deck has leakage and exposed corroded reinforcing bars. The bottom reinforce bars of the girders are largely exposed and severely corroded. The girders also show large areas of spalling concrete. (See Photo 3.2.7 and Photo 3.2.8).

PHOTO 3.2.7
BOTTOM VIEW OF THE BRIDGE DECK AND GIRDERS

PHOTO 3.2.8
EXCESSIVE REBAR CORROSION AT GIRDERS



3.2.2 Field Inspection Conclusions

A concrete coring program was carried during the structural assessment of the dam (refer to 2018 Geotechnical Site Investigation Report by KGS Group). The core logs of the concrete at the top of piers indicate that the concrete is extensively deteriorated with horizontal fractures present throughout the core length. Therefore, the load-carrying capacity and the water tightness of the concrete are expected to be significantly reduced.

Based on the visual inspection, the south dam is in very poor condition. Large areas of freeze/thaw spalling and delamination are identified for concrete overflow weirs, piers and abutments. If the concrete condition within the body of the overflow weirs is similar to the concrete obtained from core logs, the integrity of the concrete dam may no more reliable. Therefore, the south dam is required to be repaired as soon as possible.

The bridge deck is a reinforced concrete beam structure and its strength is relied on the reinforced bars and the concrete. Since the reinforced bars for the girders are largely exposed to weather and experienced severe corrosion, the strength reduction of the reinforced bars is expected. Due to the potential horizontal fractures and extensively deterioration within the concrete at the girders and decks, the structural capacity of the girders and decks is compromised. Moreover, it is not possible reasonably to estimate the load-carrying capacity of the girders/ deck slabs based on the deteriorated concrete condition. Although an analysis of the bridge or its members has not been conducted, the observations from the site visit suggest that the further use of the bridge may pose a risk to the public. The safety of the bridge should be addressed.

The dam appears to be founded on the soil, based on the report of the B.M. Ross and Associates. Since the downstream apron and its cut-off wall was not visible during the presence of water, the condition of potential scour and undermining at the downstream of the overflow weir is unknown.

4.0 STRUCTURAL ANALYSIS

4.1 GENERAL

Assuming the concrete is intact for the south dam; calculations to check the stability of the south dam have been performed. The stability assessment of the south dam is based on the following:

- Drawings provided by the Township of North Huron. The drawings are listed in Appendix A.
- Field measurements taken as part of this dam safety assessment.
- Howson Dam - 2018 Geotechnical Site Investigation Report, KGS Group.
- Howson Dam – 2017 Dam Safety Assessment Report, KGS Group.

The structures were analyzed based on the 2011 LRIA Technical Bulletin “Structural Design and Factors of Safety”. KGS Group assessed the stability of the structures, and compared the results to the LRIA acceptance criteria. The structural sections examined were as follows:

- Overflow Weirs
- Piers with Bridge Deck
- Piers without Bridge Deck (Assuming The Bridge Deck Is Removed).

The stability of the structures was calculated using the “gravity method”. By this method, the dam is assumed to be a two dimensional rigid block. All loads are carried by gravity to the underlying soil, and the foundation pressure distribution is assumed linear. This is also known as rigid body analysis. The stability analysis was assessed at the concrete/soil interface, which is typically the weakest plane of failure.

4.2 GENERAL PARAMETERS

The load parameters and acceptance criteria for the stability assessment were based on 2011 LRIA. KGS Group used stability parameters with no cohesion based on the 2011 LRIA, our previous experience and overall industry practice. As per 2011 LRIA, “usual”, “unusual”, “earthquake” and “post-earthquake” loading combinations were analyzed.

The major parameters used for the dam stability analyses are provided in the following Table 4.2-1.

TABLE 4.2-1
GENERAL PARAMETERS USED FOR ANALYSES[/1/]

INCREMENTAL CONSEQUENCE CATEGORY	HIGH
Water Unit Weight	9.81 kN/m^3
Friction Angle at Concrete to Soil Interface	23°
Cohesion at Concrete to Soil Interface	0.0 kPa
Concrete Unit Weight (assumed)	23.5 kN/m^3
Concrete Compressive Strength	23 MPa
Factored Foundation Bearing Capacity at Service Limit State (SLS)	300 kPa.

[/1/] Material properties and shear strength parameters were estimated based on the original drawings and background information.

The south dam is founded on the native sandy silt to silty sand till. The recommended lower bound shear strength parameters at the interface concrete / soil is 23º internal friction angle with zero (0) cohesion.

The test results of the limited solid concrete cylinders show the compressive strength of the concrete to be 23 MPa.

4.3 LOADING

4.3.1 Earthquake

Since the Hazard Classification for the Howson Dam is HIGH, the Design Basis Earthquake (DBE) should have a probability of annual exceedance of 1 in 2,500 years for this dam as specified in Table 1 of the 2011 LRIA Technical Bulletin “Seismic Hazards”. The horizontal Peak Ground Acceleration (PGA) is estimated to be 8.34% g based on the 2015 National Building Code Seismic Hazard calculations provided by the National Research Council (NRC).

Pseudo-Static Analysis (Seismic Coefficient) was performed by using a seismic coefficient equal to the PGA expressed as a fraction of gravity in accordance with 2011 LRIA. Earthquake-induced horizontal and vertical inertia forces were simultaneously taken into account for the stability analysis of the concrete structures. The vertical seismic coefficient is scaled from the horizontal seismic coefficient using a scaling factor in the range of 1/2 to 2/3. Two thirds of the horizontal seismic coefficient was assumed for the vertical seismic coefficient in the calculations. The earthquake-induced hydrodynamic pressure of the reservoir was also considered in the analysis for the spillway and pier. For analysis of the retaining walls, the Mononobe-Okabe formula was used to determine the increase in earth pressure from the backfill.

4.3.2 Ice

The approach to determine the thermal ice load must consider site-specific characteristics and operating information.

For the usual load combination, a load of 75 kN/m was used. An unusual ice load of 83.5 kN/m was estimated for the stability analysis based on the database of the Centre for Energy Advancement through Technological Innovation. (CEATI). For the stability analyses, the ice load was considered to act at 305 mm below the maximum winter operating water level water level.

4.3.3 Water Pressure

The dam is required to resist the maximum normal operating headwater levels for summer and winter. Since there are no data recorded for the historical water levels at the headpond, the maximum summer normal operating water level is estimated to be 310.9 m based on the rating curve. This water level is corresponding to an annual exceedance probability of 10% (recommended by the 2011 LIRA). The winter water level is take at 310.26 m which equals to the top elevation of the overflow weir. The associated assumed tailwater level at the toe of the dam is dry. The estimated IDF water level is at an elevation of 311.9 m (refer to 2017 Dam Safety Assessment Report, KGS Group) for the headwater level and the associated tailwater level at the toe of dams is 310.3 m.

Full uplift, varying linearly from 100% headwater pressure at the upstream face to 100% tailwater pressure at the downstream face, was assumed. Once a cracked plane was determined based on the calculations, crack analysis was performed. The modified uplift was assumed to be full headwater pressure over the length of the crack, varying as a straight line from full headwater pressure at the end of the crack to full tailwater pressure at the toe. The stress distribution and shear-friction safety factor was calculated along the uncracked portion.

4.3.4 Force Due to Passive Rock Wedge

The dam base appears keyed into the soil as shown on the reference drawings provided in Appendix A. However, the sliding capacity of the possible passive wedge downstream of the key was not taking into account for the dam stability calculations. This is because the calculated passive pressure of the wedge is insignificant by using its gravitational sliding friction resistance in the absence of the cohesion. Note that the cohesion value of the soil cannot be confirmed based on available data.

4.4 ACCEPTANCE CRITERIA

For dam structures with cohesion assumed to be zero, 2011 LRIA outlines the following performance factors summarized in the Table 4.3-1.

TABLE 4.3-1
STABILITY PERFORMANCE FACTORS

LOADING CASE	LOAD COMBINATION			
	USUAL (Summer / Winter)	UNUSUAL (IDF)	EARTHQUAKE	POST-EARTHQUAKE
Sliding Stability Factor (SSF)	1.5	1.3	1.1	1.1
Location of the Resultant	Within Middle-third[1/]	Within Base	May be outside base	May be outside base

[1/] For existing dams, it may be acceptable to allow a small percentage of the base to not be in compression if all other performance factors, including the sliding factor of safety, are met and the resultant is within the base of the dam and allowable bearing stresses are not exceeded.

4.5 RESULTS OF STABILITY ANALYSIS

KGS Group has computed stability factors for the six load-combination cases specified in 2011 LRIA. Table 4.5-1 shows the six load cases that were considered for the stability analyses of the pier and rollway sections individually and for the entire dam as sensitivity analysis. Load Case One is related to the maximum normal operation water level in summer. Load Case Two represents the winter operation water level plus the usual ice loading condition. Load Case Three is for the flood condition (IDF). Load Case Four is the winter operation water level plus the unusual ice loading condition. Load Cases Five and Six are the loading cases for earthquake and post-earthquake condition, respectively.

The stability calculations for the piers were performed with the weight of the bridge deck. However, taking consideration of the potential removal of the existing bridge deck, the pier stability was also assessed without using the weight of the bridge deck. Since the original drawings don't provide the conclusive information for the connections between the piers and overflow weirs, KGS Group performed stability analyses for the individual sections of the weirs and piers as base case. In other words, it was assumed the each weir and pier worked independently to resist the applicable loads. In addition, sensitivity analyses were performed for the entire dam assuming that the piers and weirs worked together. Tables 4.5-2 through 4.5-6 show the summary of the results of the stability analyses. Detailed calculations are provided in Appendix B.

TABLE 4.5-1
PIER AND ROLLWAY LOADING DATA

DATA TYPE	LOADING CASES					
	USUAL		UNUSUAL		EXTREME	
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Head Water Level (H.W.L) (m)	310.9	309.26	311.90	309.26	310.9	310.9
Tail Water Level (T.W.L) (m)	0	0	310.30	0	0	0
Ice Load (kN/m)	---	75.0	---	83.5	---	---
Seismic Coefficient (horizontal)	---	---	---	---	8.34% g	---
Drag Force	---	---	---	---	---	---
Uplift	Full	Full	Full	Full	Full	Full

Legend:
Case 1: Summer Normal Maximum Operating Water Level
Case 2: Winter Normal Maximum Operating Water Level plus Usual Ice
Case 3: Inflow Design Flood (IDF)
Case 4: Winter Normal Maximum Operating Water Level plus Unusual Ice
Case 5: Earthquake Loads in Conjunction with Usual Loading Case 1
Case 6: Post-Earthquake to Consider Modified Uplift Pressures Applied to the Cracked Section

4.5.1 Dam Stability Calculations including Bridge Deck

Table 4.5-2 and Table 4.5-3 show the summary of the results of the base case stability analyses for the pier and overflow weir including the bridge deck in place. Table 4.5-4 shows the results of sensitivity analysis for the entire dam by the combination of the pier and the weir.

TABLE 4.5-2
RESULTS OF STABILITY ANALYSIS - PIER INCLUDING BRIDGE DECK

LOADING CASE		USUAL		UNUSUAL		EXTREME	
		Case 1 (Summer Normal Water Level)	**Case 2** (Winter Normal Water Level + Usual Ice)	**Case 3** (IDF)	**Case 4** (Winter Normal Water Level + Unusual Ice)	**Case 5** (Normal Water Level plus EQ)	**Case 6** (Post EQ Condition)
Sliding Stability Factor (SSF)	LRIA Required	**1.5**	**1.5**	**1.3**	**1.3**	**1.1**	**1.1**
	Computed	2.52	2.38	2.53	2.23	1.41	2.52
Location of the Resultant	LRIA Required	**Within Mid-Third**	**Within Mid-Third**	**Within Base**	**Within Base**	**Outside Base**	**Outside Base**
	Computed	Within Mid-Third	Within Mid-Third	Within Base	Within Base	Within Base	Within Base
Location of the Resultant from Toe 'a' (m)		3.4	3.3	3.4	3.3	2.8	3.4
Maximum bearing stress (kPa)	Required	**300**	**300**	**300**	**300**	**300**	**300**
	Computed	235	255	191	261	282	235

Height of Section = 5.67 m
Base Length of Section = 7.95 m
Compressive Strength of Concrete f'c = 20 MPa
Tensile Strength of Concrete / Rock = 0.0 MPa
Internal Friction Angle Concrete / Rock = 23°
Cohesion Concrete / Rock, c = 0.0 kPa
Uplift = Varies linearly from 100% headwater pressure to 100% tailwater pressure.

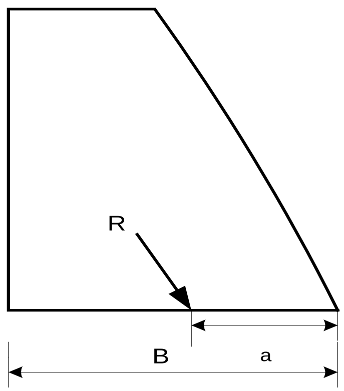


TABLE 4.5-3
RESULTS OF STABILITY ANALYSIS – OVERFLOW WEIR

LOADING CASE		USUAL		UNUSUAL		EXTREME	
		Case 1 (Summer Normal Water Level)	**Case 2** (Winter Normal Water Level + Usual Ice)	**Case 3** (IDF)	**Case 4** (Winter Normal Water Level + Unusual Ice)	**Case 5** (Normal Water Level plus EQ)	**Case 6** (Post EQ Condition)
Sliding Stability Factor (SSF)	LRIA Required	**1.5**	**1.5**	**1.3**	**1.3**	**1.1**	**1.1**
	Computed	0.85	0.57	1.31	0.53	0.59	0.85
Location of the Resultant	LRIA Required	**Within Mid-Third**	**Within Mid-Third**	**Within Base**	**Within Base**	**Outside Base**	**Outside Base**
	Computed	Within Mid-Third	Within Mid-Third	Within Base	Within Base	Within Base	Within Base
Location of the Resultant from Toe 'a' (m)		3.0	2.3	3.5	2.1	2.6	3.0
Maximum bearing stress (kPa)	Required	**300**	**300**	**300**	**300**	**300**	**300**
	Computed	35	48	34	52	43	35

Height of Section =	3.20 m
Base Length of Section =	6.20 m
Compressive Strength of Concrete f'c =	20 MPa
Tensile Strength of Concrete / Rock =	0.0 MPa
Internal Friction Angle Concrete / Rock =	23°
Cohesion Concrete / Rock, c =	0.0 kPa
Uplift =	Varies linearly from 100% headwater pressure to 100% tailwater pressure.

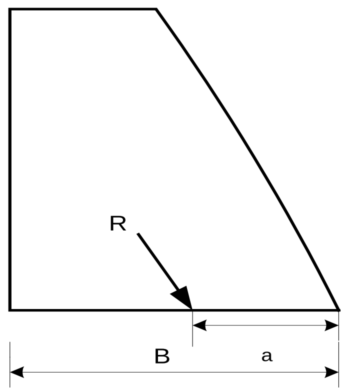
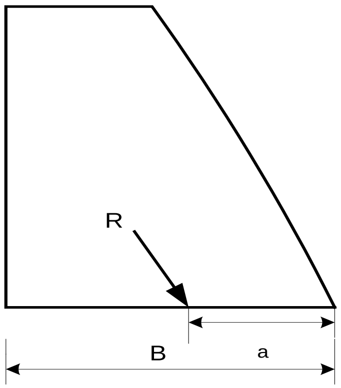


TABLE 4.5-4
RESULTS OF STABILITY ANALYSIS – ENTIRE DAM INCLUDING BRIDGE DECK

LOADING CASE		USUAL		UNUSUAL		EXTREME	
		Case 1 (Summer Normal Water Level)	**Case 2** (Winter Normal Water Level + Usual Ice)	**Case 3** (IDF)	**Case 4** (Winter Normal Water Level + Unusual Ice)	**Case 5** (Normal Water Level plus EQ)	**Case 6** (Post EQ Condition)
Sliding Stability Factor (SSF)	LRIA Required	**1.5**	**1.5**	**1.3**	**1.3**	**1.1**	**1.1**
	Computed	1.29	1.02	1.76	0.95	0.85	1.29
Location of the Resultant	LRIA Required	**Within Mid-Third**	**Within Mid-Third**	**Within Base**	**Within Base**	**Outside Base**	**Outside Base**
	Computed	Within Mid-Third	Within Mid-Third	Within Base	Within Base	Within Base	Within Base
Location of the Resultant from Toe 'a' (m)		3.2	2.9	3.4	2.8	2.7	3.2
Maximum bearing stress (kPa)	Required	**300**	**300**	**300**	**300**	**300**	**300**
	Computed	65	74	44	78	79	65

Height of Section = 5.67 m
Base Length of Section = 7.95 m
Compressive Strength of Concrete f'c = 20 MPa
Tensile Strength of Concrete / Rock = 0.0 MPa
Internal Friction Angle Concrete / Rock = 23°
Cohesion Concrete / Rock, c = 0.0 kPa
Uplift = Varies linearly from 100% headwater pressure to 100% tailwater pressure.



4.5.2 Dam Stability Calculations Assuming the Bridge Deck to be Removed

Table 4.5-2 and Table 4.5-3 show the summary of the results of the base case stability analyses for the pier and overflow weir including the bridge deck in place. Table 4.5-4 shows the results of the sensitivity analysis for the entire dam by the combination of the pier and the weir

TABLE 4.5-5
RESULTS OF STABILITY ANALYSIS - PIER (FOR BRIDGE DECK REMOVED)

LOADING CASE		USUAL		UNUSUAL		EXTREME	
		Case 1 (Summer Normal Water Level)	**Case 2** (Winter Normal Water Level + Usual Ice)	**Case 3** (IDF)	**Case 4** (Winter Normal Water Level + Unusual Ice)	**Case 5** (Normal Water Level plus EQ)	**Case 6** (Post EQ Condition)
Sliding Stability Factor (SSF)	LRIA Required	**1.5**	**1.5**	**1.3**	**1.3**	**1.1**	**1.1**
	Computed	1.40	1.37	1.16	1.28	0.90	1.36
Location of the Resultant	LRIA Required	**Within Mid-Third**	**Within Mid-Third**	**Within Base**	**Within Base**	**Outside Base**	**Outside Base**
	Computed	Within Mid-Third	Within Mid-Third	Within Base	Within Base	Within Base	Within Base
Location of the Resultant from Toe 'a' (m)		2.9	2.8	2.7	2.8	2.4	2.8
Maximum bearing stress (kPa)	Required	**300**	**300**	**300**	**300**	**300**	**300**
	Computed	163	188	118	188	184	163

Height of Section = 5.67 m
Base Length of Section = 7.95 m
Compressive Strength of Concrete f'c = 20 MPa
Tensile Strength of Concrete / Rock = 0.0 MPa
Internal Friction Angle Concrete / Rock = 23°
Cohesion Concrete / Rock, c = 0.0 kPa
Uplift = Varies linearly from 100% headwater pressure to 100% tailwater pressure.

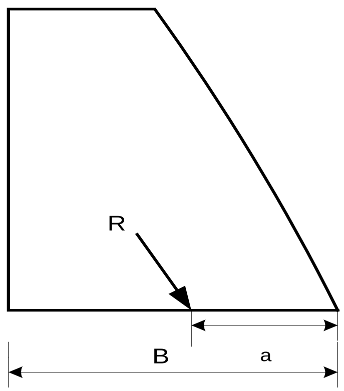
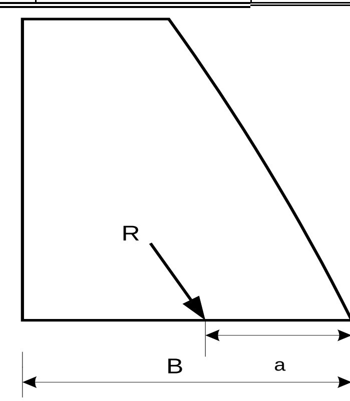


TABLE 4.5-6
RESULTS OF STABILITY ANALYSIS – ENTIRE DAM (FOR BRIDGE DECK REMOVED)

LOADING CASE		USUAL		UNUSUAL		EXTREME	
		Case 1 (Summer Normal Water Level)	**Case 2** (Winter Normal Water Level + Usual Ice)	**Case 3** (IDF)	**Case 4** (Winter Normal Water Level + Unusual Ice)	**Case 5** (Normal Water Level plus EQ)	**Case 6** (Post EQ Condition)
Sliding Stability Factor (SSF)	LRIA Required	**1.5**	**1.5**	**1.3**	**1.3**	**1.1**	**1.1**
	Computed	0.99	0.77	1.25	0.72	0.68	0.98
Location of the Resultant	LRIA Required	**Within Mid-Third**	**Within Mid-Third**	**Within Base**	**Within Base**	**Outside Base**	**Outside Base**
	Computed	Within Mid-Third	Within Mid-Third	Within Base	Within Base	Within Base	Within Base
Location of the Resultant from Toe 'a' (m)		3.0	2.5	3.2	2.4	2.5	3.0
Maximum bearing stress (kPa)	Required	**300**	**300**	**300**	**300**	**300**	**300**
	Computed	58	67	36	71	66	58

Height of Section = 5.67 m
Base Length of Section = 7.95 m
Compressive Strength of Concrete f'c = 20 MPa
Tensile Strength of Concrete / Rock = 0.0 MPa
Internal Friction Angle Concrete / Rock = 23°
Cohesion Concrete / Rock, c = 0.0 kPa
Uplift = Varies linearly from 100% headwater pressure to 100% tailwater pressure.



4.6 DISCUSSION OF RESULTS

4.6.1 Piers

The results of stability analyses show that the piers under current dam operation condition meet the 2011 LRIA stability criteria for the sliding stability under all loading conditions. Note that for the assessment the concrete of the piers was assumed to be intact.

For the case with the bridge deck removed, the results of the stability analyses show that the piers do not meet the 2011 LRIA stability criteria for the sliding stability under normal summer, winter, IDF and earthquake loading conditions.

4.6.2 Overflow Weirs

The results of stability analyses show that the weirs do not meet the 2011 LRIA stability criteria for the sliding stability under all loading conditions except the IDF.

4.6.3 Entire Dam – Combination of Piers and Overflow Weirs

Under current dam operation condition, the results of stability analyses show that the entire dam does not meet the 2011 LRIA stability criteria for the sliding stability under all loading conditions except the IDF and post-earthquake loadings.

5.0 ALTERNATIVES TO THE PROJECT

KGS Group conducted a Dam Safety Assessment for the Howson Dam (KGS Group, 2017) and concluded that, in accordance with the 2011 LRIA, the Hazard Potential Classification (HPC) for the dam corresponds to the category of HIGH. This was based on the evaluation of incremental consequences of a dam breach, and applied to both normal or “sunny-day” conditions and flood conditions. The Dam Safety Assessment concluded that the Inflow Design Flood (IDF) for the dam should be the 100-Year Flood, since a breach during a greater flood would not pose significant additional threat to lives, property or environmental or cultural assets. The corresponding peak flow of the IDF is 415 m^3/s, and it could be safely passed through the dam in its present condition. However, the stability analysis documented in this report indicates that the dam does not meet the 2011 LRIA sliding stability criteria, and that remedial work would be required to address the dam stability deficiency, required for the application to obtain approval from MNRF under Section 16 of the LRIA.

Two aspects have not been included in the assessment and would need to be considered, depending on the alternative selected. The first one is the stability of the sluiceway structure that constitutes the North Dam. This was not investigated as part of the scope of this study, and would need to be evaluated as this structure is part of some of the alternatives discussed in this section. The second aspect is the stability of the earth embankment between the North Dam and the South Dam. Depending on the alternative selected, if this embankment is part of the preferred solution, its stability would need to be evaluated. An allowance to cover those costs have been included in those cases.

The alternatives evaluated to address the stability deficiency of the South Dam at the Howson Dam are the following:

- Do nothing
- Dam Decommissioning
- Dam Rehabilitation
- Dam Replacement.

Considerations and cost estimates for each of these alternatives are presented in the following sections. These are based on the information available for the site and costs of similar projects. These cost estimates correspond to American Association of Cost Engineering (AACE) Class 4 estimates, with an accuracy of plus or minus 40 to 50%. The feasibility and costs of these alternatives should be confirmed with further studies.

5.1 DO NOTHING

This alternative consists of continuing with the status quo, allowing the structure to continue to deteriorate. The Do Nothing alternative is not considered feasible, as the existing dam does not meet current standards and deficiencies have been identified which need to be addressed. Furthermore, the bridge at the site, although not specifically evaluated as part of this project, shows major signs of deterioration. It is the opinion of KGS Group that the further use of the bridge may pose a risk to the public and that the safety of the bridge should be addressed.

5.2 DAM DECOMMISSIONING

This alternative involves the demolition and removal of the dam structure or part of it, including the bridge deck, and draining the reservoir. Any components of the dam left in place would need to be in a condition that do not pose further risk or require maintenance.

This alternative would require studies, consultations, approvals and permits, including an Environmental Assessment (EA) and approval under Section 16 of the LRIA. It is expected that this option would not be favored by the public, since the EA conducted in 2016 demonstrated that there is strong support from the public for the rehabilitating or repairing the dam. However, it must be noted that the options presented at the time of the 2016 EA did not consider the findings that the stability assessment subsequently revealed.

The decommission alternative would address the deficiencies identified in the structural stability analysis of the dam, and would remove the perceived risk posed by the bridge; but it would also have significant effect on the character of the area and the use of the reservoir by the community. The reservoir would be lost and the exposed area as well as the shoreline would need to be restored. Its aesthetic and recreational importance would need to be considered as part of the evaluation of this alternative.

The removal of the dam would include demolition, river flow diversion and sediment management. An estimate of these construction costs is included in Appendix D. Additional costs, such as design, engineering and permitting, administration and contingency, which have been estimated as a percentage of the construction cost, are also included in Appendix D. The total estimated cost for this alternative is $ 436,000. It is estimated that the demolition work would have a duration of 6 months.

The dam decommissioning would require management and monitoring of sediment, to ensure that the sediment is not mobilized and transported to downstream reaches. It would also have environmental effects that need to be evaluated and for which it can be difficult to assign a monetary value. The Township of North Huron has noted that the EA identified two species at risk in the areas upstream and downstream of the dam. This alternative would require follow up monitoring and adaptive management of the area of influence of the dam. It would also require permits and approvals from federal and provincial government agencies. There could be requirements issued by the Department of Fisheries and Oceans (DFO) as part of their review and/or authorization process, which could include water and sediment management, considerations for disposal of material, work restrictions for areas and timing of the works, fish salvage operations, management of fish habitat.

The decision to proceed with this alternative would require careful examination of the multiple aspects described above and would involve an EA process.

5.3 DAM REHABILITATION

This alternative involves applying remedial measures to the dam to establish structural integrity and provide for the safe operation and passage of flows up to and including the IDF.

Two options were considered for the dam rehabilitation alternative:

1. Installation of post-tensioned anchors at the overflow weirs
2. Addition of concrete mass to the overflow weirs.

The feasibility of any of these options requires that the concrete in the overflow weirs be in sound condition and that the foundation of the dam is compact and with no leakage. The compliance with these two requirements could not be confirmed or refuted with the information available for this study. The external signs and appearance of the concrete and the limited concrete core samples obtained on the piers, as part of this study, suggest that it is likely that the condition of the concrete in the weirs will not be adequate for the rehabilitation options. That, however, would need confirmation with core samples taken on the weirs. Likewise, the type of foundation and the overall condition at the site suggest that the dam foundation might not be completely sound, since there are reports of previous undermining issues being addressed on both the North Dam and the South Dam; but that needs to be confirmed. If those concerns are confirmed, and the dam is in such a state that it is beyond repair, the rehabilitation alternative would not be feasible as it would essentially become a rebuild or replacement of the dam.

For the purpose of estimating a cost for the rehabilitation options, it has been assumed that the foundation is adequate and that the concrete core of the weirs is sound, and only requires removal and replacement of the concrete surface up to a 0.5 m depth. Site investigations, on the weir concrete and the dam foundation, beyond those conducted in this study, are required to confirm the viability of the two potential rehabilitation options. These site investigations have been included in the cost estimate for this alternative.

Another element included in both options for the rehabilitation alternative, and in the corresponding cost estimates, is the removal of the bridge deck and the upper portion of the piers. KGS Group is of the opinion that the bridge in its present condition would be a safety hazard for the works included in the rehabilitation alternative.

In both options for the dam rehabilitation alternative, the North Dam is maintained, to provide spill capacity. This capacity, supplemented by the discharge provided by the overtopping of the rehabilitated portion of the dam, would allow safe passage of the IDF with a minimum of 0.5 m of freeboard with respect to the top of the North Dam (El. 311.9 m). Stability requirements for the North Dam, with respect to 2011 LRIA, have not been evaluated. It is possible that this dam requires some remedial measures to satisfy these requirements; but these have not been included in this analysis.

The first option evaluated for rehabilitating the dam is the installation of post-tensioned anchors at the weirs to improve the dam stability. The dam would be a similar structure to the present one, without the bridge deck and the upper portion of the piers. The top level of the weir would be El. 310.0 m. This alternative is, in general, cost effective, easy to construct and requires minor maintenance. As previously indicated, for it to be feasible, the concrete body of the existing weirs must be reasonably intact and the soil foundation to approximately 15 m below the ground must be able to carry the post-tensioning design force. If the concrete in the weirs is similar to that revealed by the limited concrete coring obtained at the piers, its condition is deteriorated and is not appropriate for the installation of the post-tensioned anchors.

Appendix D shows a cost estimate for this rehabilitation option with a total value of $2,869,000. It includes construction costs for removal of damage concrete in the weirs (up to 0.5 m from the surface), installation of post-tensioned anchors, cofferdam and works to divert water from the area of work, using the North Dam, and demolition of the bridge deck and part of the piers. General costs, such as mobilization, demobilization, site investigations, environmental program, material quality control, site restoration are included, as a percentage of the work activities previously listed. The estimate also includes costs for design, engineering and permitting, overhead and administration as well as a cost contingency, which were estimated as percentages of the construction cost.

The second rehabilitation option is the addition of mass to the overflow weir. This can be achieved by removing the deteriorated concrete at the surface of the weir (up to 0.5 m from the surface) and placing new concrete around the cross-section of the existing weir. The new concrete would result in a bigger structure than the present one, with sufficient mass to satisfy the stability requirements. The top of the weir would be El. 310.0 m. For this option to be feasible, the concrete body of the existing weir must be reasonably intact. Otherwise, the removal of the deteriorated concrete could result in demolishing the entire weir. Similarly, if the foundation is not sound, the repair works could require removal of an extensive part of the structure. In both cases, this option would change to removal of the dam and/or dam replacement.

The dam rehabilitation by addition of mass, if feasible, will in general involve more construction activities than the installation of post-tension anchors. This reflects in greater construction costs, as well as increased cost of the activities estimated as a percentage of it. The estimated cost for this option is $4,581,000 and it is provided in Appendix D.

5.4 DAM REPLACEMENT

This alternative consists of replacing the existing dam with a new dam constructed at the same location. It would involve water diversion, demolition of the existing bridge and dam, investigation of the foundation condition and properties, and building of the new structure. The new dam would satisfy the stability requirements, in accordance with the 2011 LRIA. It also will, in conjunction with the North Dam, provide adequate spill capacity to safely pass the IDF with a minimum of 0.5 m freeboard with respect to the top of the North Dam (El. 311.9 m). As indicated in Section 5.3, the stability requirements for the North Dam have not been assessed and it is possible that further work is required to ensure that this structure satisfy the requirements of 2011 LRIA.

Two options were considered for the Dam Replacement alternative:

1. Concrete weir
2. Earth embankment with an additional sluiceway structure

The first dam replacement option consists of maintaining the North Dam and replacing the South Dam with a concrete weir across the river. The weir would extend from the south bank to the abutment of the North Dam. It would be built up to El. 310.0 m, to maintain historical water levels in the reservoir. The cost estimates for this option are shown in Appendix D and amount to $6,209,000. They include construction costs as well as design, engineering, permitting, overhead and project management by the Township and contingency costs, which were estimated as percentages of the construction cost.

The second dam replacement option consists of maintaining the North Dam and replacing the South Dam with an earth embankment and a new sluiceway structure, of a similar size to the North Dam. The new sluiceway structure would provide the required additional spill capacity to ensure safe passage of the IDF with a minimum 0.5 m of freeboard with respect to the top of the North Dam. It includes provision of a winch mechanism to allow operation of the sluiceway structure in response to floods. The crest of the proposed new dam would be at the same level as the North Dam (El. 311.9 m). Since the new dam would consist of an earth embankment, it will be vulnerable to a failure if it is overtopped. The estimated cost of this alternative is included in Appendix D and amounts to $3,960,000.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the stability analyses, the entire dam does not meet the 2011 LRIA sliding stability criteria. Remedial work is required to address the dam stability deficiency.

The bridge at the Howson Dam is currently closed to vehicle traffic; but it is accessible to pedestrian use. Although an analysis of the bridge or its elements was not part of the scope of work, and has not been completed, the information obtained from the limited concrete cores, and the site observations, suggest the bridge being structurally deficient. It is our opinion that the further use of the bridge may pose a risk to the public and that the safety of the bridge should be addressed.

The following alternatives for addressing the stability deficiency of the South Dam at the Howson Dam were evaluated:

- Do nothing
- Dam Decommissioning
- Dam Rehabilitation
- Dam Replacement

AACE Class 4 estimates, with an accuracy of plus or minus 40 to 50%, were obtained for these alternatives and are provided in the report.

The do nothing alternative was considered not feasible because it would not address the risk posed by the dam, which does not satisfy the dam safety requirements indicated in the 2011 MNRF for stability, or that of the bridge at its present state of deterioration.

The alternative of dam decommissioning was not ruled unfeasible; but it would require an extensive process of consultation at various levels. It is anticipated, based on the input obtained during the 2016 EA, that it could be opposed by the public. A cost estimate of $ 436,000 was obtained for this option. This cost does not include some costs that might be related to environmental controls and management of fish population or fish habitat. There are also considerations such as effect on species at risk and on the character of the area and public use of the site for which a monetary value is difficult to assign.

Two options were considered for dam rehabilitation: installation of post-tension anchors and addition of concrete mass. Both alternatives need to be confirmed with site investigations to assess the condition of the concrete in the weirs and the foundation of the dam. The information available suggests that these options will likely be found not feasible after these site investigations. Nonetheless, a cost estimate was prepared assuming that the concrete in the weirs would be found to be sound and would only need removal of damaged concrete up to 0.5 m of depth from the surface. The cost estimate also was based on the assumption of a competent dam foundation. The rehabilitation options, if feasible, would ensure that the South Dam satisfies the stability requirements of the LRIA. The rehabilitated dam, in conjunction with the North Dam would allow safe passage of the IDF in accordance with the requirements by the LRIA. The estimated costs of the two rehabilitation options are:

- Installation of post-tensioned anchors at the overflow weirs: $ 2,869,000
- Addition of concrete mass to the overflow weirs: $ 4,581,000

Additional evaluation is necessary to assess the structural stability of the North Dam. It is possible that, as the result of this assessment, the North Dam also requires rehabilitation works to satisfy the LRIA, which have not been included in the cost estimates presented above.

Two options were considered for rebuilding the dam: concrete weir and earth embankment with an additional sluiceway structure. These options would allow satisfying the requirements of the LRIA. As in the case of the rehabilitation options, the rebuilt dam would require the spill capacity from the North Dam to safely pass the IDF. The stability of the North Dam would need to be assessed and it could potentially need rehabilitation works to ensure that this dam also satisfies the requirement of the LRIA. The estimated costs of the two rebuilt options are:

- New concrete overflow weir $ 6,209,000
- Earth embankment and new sluiceway structure: $ 3,960,000

Further consideration of these alternatives is required, including public consultation. It is recommended that these are included in the EA process initiated in 2016. A more detailed investigation program to determine the concrete condition of the overflow weir and its foundation condition are recommended prior to selecting the preferred alternative. These investigations and analyses will be required to confirm the feasibility of any of the rehabilitation options.

7.0 STATEMENT OF LIMITATIONS

7.1 THIRD PARTY USE OF REPORT

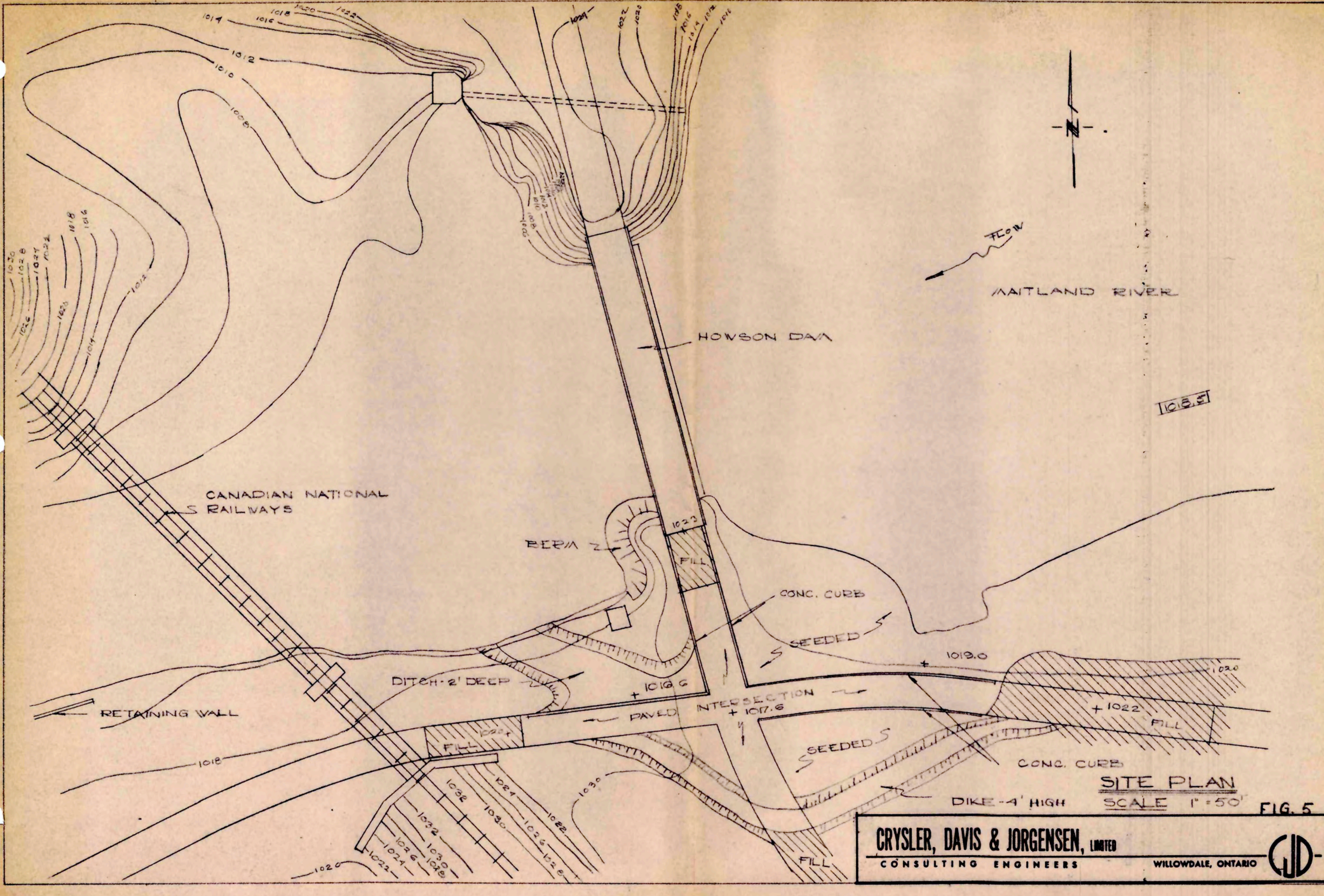
This report has been prepared for the Township of North Huron to whom this report has been addressed and any use a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this report. This report has been prepared for the Client to whom this report has been addressed and any use a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this report.

8.0 REFERENCE

1. Ontario Ministry of Natural Resources (MNR), 2011, Lakes And Rivers Improvement Act-Administrative Guide, Technical Bulletins and Best Management Practices
2. Request for Proposals for the Provision of Consulting Services for the Howson Dam – Dam Safety Assessment, 2017, Township of North Huron
3. Howson Dam Safety Assessment Proposal for Engineering Services, April 2017, KGS Group Consulting Engineers
4. Proposed Repairs To Howson Dam, March 2015, BM Ross and Associates Limited.
5. Inspection Report No. 009, November 2013 BM (Ross 2013a), BM Ross and Associates Limited.
6. Inspection Report No. 010, November 2013 BM (Ross 2013b), BM Ross and Associates Limited.
7. Preliminary Engineering Report, October 1985, BM Ross and Associates Limited.
8. Evaluation of Existing Main Howson Dam Bridge Structure, December 1984, BM Ross and Associates Limited.
9. Report On Howson Dam, May 1965, Maitland Valley Conservation Authority

APPENDIX A

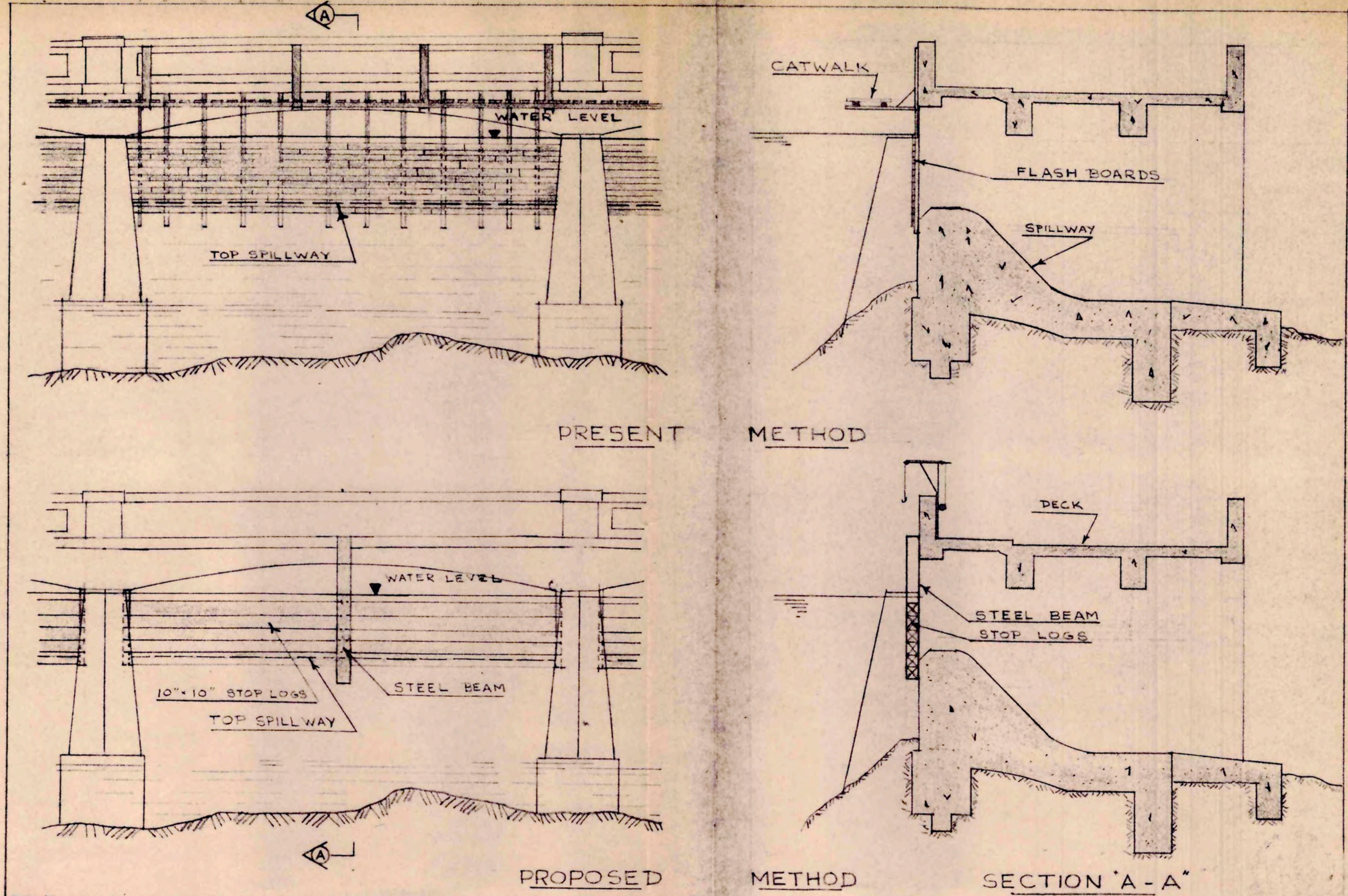
CONSTRUCTION DRAWINGS



SITE PLAN
SCALE 1" = 50'

FIG. 5

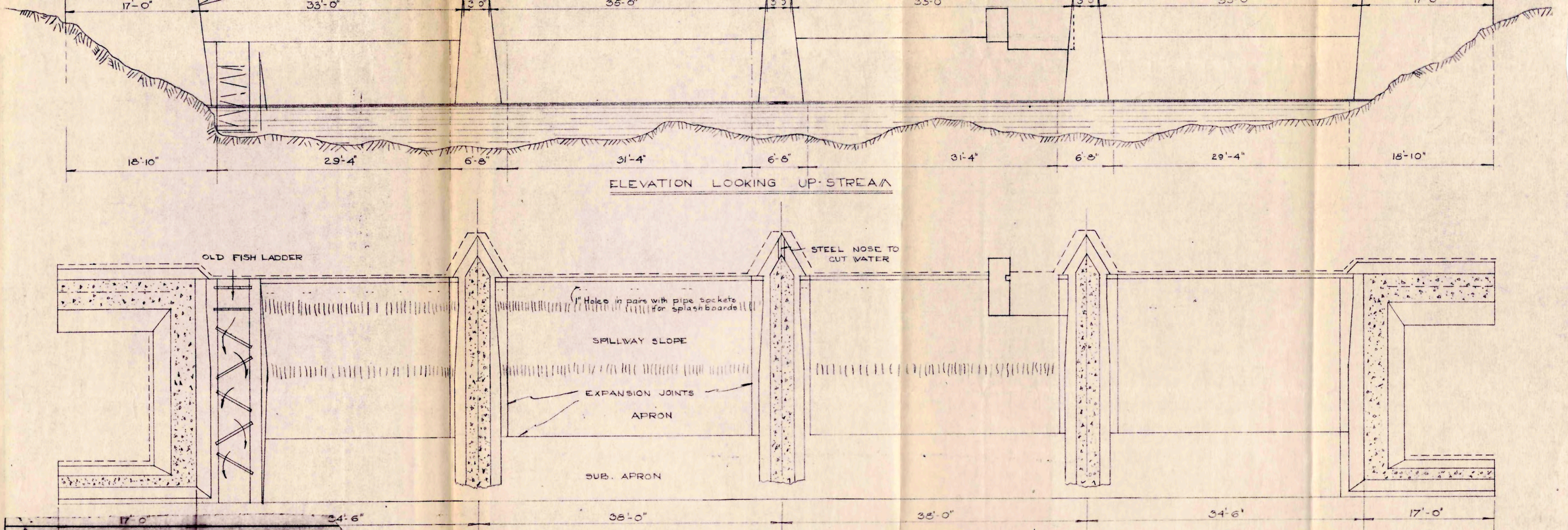
CRYSLER, DAVIS & JORGENSEN, LIMITED
CONSULTING ENGINEERS
WILLOWDALE, ONTARIO



CRYSLER, DAVIS & JORGENSEN, LIMITED
CONSULTING ENGINEERS
WILLOWDALE, ONTARIO

NOTE - DRAWING OF HOWSON DAM WAS COPIED FROM PLANS DRAWN BY FRED B. JAMES AMEIC. JUNE 26, 19[illegible].

FIGURE 6



CRYSLER, DAVIS & JORGENSEN, LIMITED
CONSULTING ENGINEERS
WILLOWDALE, ONTARIO

NOTE :- THE HOWSON DAM DRAWING WAS COPIED FROM PLANS DRAWN BY FRED B. JAMES A.M.E.I.C. JUNE 26, 1930

PLAN BELOW BRIDGE FLOOR

HOWSON DAM

FIGURE 2

ELEVATION - LOOKING DOWNSTREAM
SCALE 1/8" = 1'-0"
FOR BRACKET DETAIL SEE A
FOR UPRIGHT DETAIL SEE B
SEE DETAIL 'E'
SEE DETAIL 'C' FOR BOT. SOCKET
3 OPENINGS
2 UPRIGHTS 7'-0" LONG
17'-0"
ELEVATION OF UPRIGHT
12 W 40
VARIES
12"
TEE SECTION TAKEN FROM A 12 W 40
WELDED
SIDE ELEVATION
TOP ELEVATION
UPRIGHT DETAILS
SCALE 1 1/2" = 1'-0"
DETAIL B
ANCHOR TO FORM MECHANICAL BOND
GROUTING
METAL LINER 1/4" PL
PLAN
GROUTED WITH EMBECCO PREMIX GROUT
TOP OF SILL
ELEVATION
BOTTOM SOCKET DETAILS - DETAIL C
SCALE 1 1/2" = 1'-0"
1" Ø LIFTING PIN COUNTERSUNK & GROUND FLUSH
PLAN
SIDE ELEVATION
3" Ø WASHER COUNTERSUNK (EACH SIDE)
END ELEVATION
STOP LOG END DETAILS
LOGS 10'7" LONG
SCALE 1 1/2" = 1'-0"
ELEVATION - STOP LOG GUIDE ON ABUTMENT - DETAIL D
ST 5 W 24.5 #/ft MADE BY CUTTING A 10 W 49 5'-4" LONG
TOP ELEVATION
CONCRETE FILL
STOP LOG GUIDE - SEE DETAIL 'D'
EXISTING ABUTMENT
CHIPPED TO PLUMB STOP LOG GUIDE
TOP OF SILL
N.T.S.
DETAIL 'E' (TYPICAL)
SHOWING SETTING OF STOP LOG GUIDE AT ABUTMENT
NOTE
CONCRETE FILL BEHIND STOP LOG GUIDE AT ABUTMENTS TO CONTAIN SIKA COLMA DUR IN ACCORDANCE TO MANUFACTURER'S SPECIFICATION
UPRIGHT SHOWN IN PLACE
TOP ELEVATION
WELD
ELEVATION
TOP BRACKET - DETAIL A
SCALE 1 1/2" = 1'-0"
BRACKET CLIP
TOP BRACKET TO HOLD BRACKET CLIP
12 W 40
METAL LINER
ISOMETRIC OF UPRIGHT
1/2 PLATE
WELD
BRACKET CLIPS
ONE PAIR REQUIRED ON EACH UPRIGHT
STOP LOG GUIDE 41" LONG
EXISTING BLOCK
EXISTING ANGLE
AT LOW LEVEL OPENING
53 plates
22 pins
Master
1 NOV 15/66 CHANGED TOP BRACKET & DIMENSIONS IN ELEV. - ADDITION OF NEW DETAILS C.S.Z.
ISSUE OR REVISION
DATE
BY
MAITLAND VALLEY CONSERVATION AUTHORITY
HOWSON DAM REVISION
DETAILS OF STOP LOG GUIDES
DATE FEB. 2/66
DRAWN C.S.Z.
SCALE AS NOTED
DWG. NO. 6522
CRYSLER, DAVIS & JORGENSEN, LIMITED
CONSULTING ENGINEERS
WILLOWDALE, ONTARIO
APPD.
CHKD.

ELEVATION - LOOKING DOWNSTREAM
FOR BRACKET DETAIL SEE A
FOR UPRIGHT DETAIL SEE B
SEE DETAIL 'E'
SEE DETAIL 'C' FOR BOT. SOCKET
17'-0"
32'-9"
32'-0"
32'-6"
32'-1"
32'-8"
10'9"
ELEVATION OF UPRIGHT
(8 Req'd)
12 W 40
TEE SECTION TAKEN FROM A 12 W 40
WELDED
SIDE ELEVATION
TOP ELEVATION
UPRIGHT DETAILS
SCALE 1½"=1'-0"
DETAIL B
ANCHOR TO FORM MECHANICAL BOND
GROUTING
METAL LINER ¼" PL
PLAN
GROUTED WITH EMBECCO PREMIX GROUT
TOP OF SILL
ELEVATION
BOTTOM SOCKET DETAILS - DETAIL C
SCALE: 1½"=1'-0"
10"x8"
1" Ø LIFTING PIN COUNTERSUNK & GROUND FLUSH
PLAN
SIDE ELEVATION
END ELEVATION
3" Ø WASHER COUNTERSUNK (EACH SIDE)
STOP LOG END DETAILS
LOGS 10'7" LONG
~~(48 Req'd)~~
56
ST 6 W 24.5 #/ft MADE BY CUTTING A 10 W 49 5'-4" LONG
TOP ELEVATION
ELEVATION - STOP LOG GUIDE ON ABUTMENT - DETAIL D
(8 Req'd)
STOP LOG GUIDE - SEE DETAIL 'D'
CONCRETE FILL
EXISTING ABUTMENT
CHIPPED TO PLUMB STOP LOG GUIDE
TOP OF SILL
N.T.S.
DETAIL E' (TYPICAL)
TOP BRACKET
12 W 40
METAL LINER
ISOMETRIC OF UPRIGHT
3/8" PL
NOTE
BRACKET SHIMMED TO ALLOW CLEARANCE FOR PLACEMENT OF UPRIGHTS
TOP ELEVATION
5/8" Ø BOLTS
20"
ELEVATION
TOP BRACKET - DETAIL A
(8 Req'd)
ISSUE OR REVISION
DATE
Do Not Use - Refer to Master
BY
MAITLAND VALLEY CONSERVATION AUTHORITY
HOWSON DAM REVISION
DETAILS OF STOP LOG GUIDES
ISSUED
DATE FEB. 2/66
DRAWN C.S.Z.
SCALE AS NOTED
DWG. NO. 6522-9
REGISTERED PROFESSIONAL ENGINEER
K. W. LATHEM
PROVINCE OF ONTARIO
APP'D.
CHK'D.
CRYSLER, DAVIS & JORGENSEN, LIMITED
CONSULTING ENGINEERS
WILLOWDALE, ONTARIO

APPENDIX B

STABILITY CALCULATIONS

KGS GROUP

DESIGN CALCULATIONS COVER SHEET

Project No. :	17-3212-001	**Project Name :**	Howson Dam (South Structure)		
File No. :		**Discipline :**	Structural Engineering		
Calculation Title :	**Pier and abutment Stability Analysis Sheet (LRIA - v3.3)**				
Calculation No. :	CIV-001	**Prepared by :**	HS	**Date :**	Feb. 23, 2018
No. of Sheets :		**Checked by :**	YF	**Date :**	April 20, 2018
Supersedes Calc. No. :		**Approved by :**		**Date :**	

Calculation Description :

The dam has been reviewed against LRIA technical bulletins

Related Design Concept :

Stability analysis for the structures is carried out using the "Gravity Method".
Six loading cases are utilized in the analyses based on the LRIA Technical Bulletin "Structural Design and Factors of Safety (August 2011).

Reference Codes and Standards :
1. *Design of Small Dams,* Third Edition, U.S. Government Printing Office, Washington, D.C. 1987.
2. Structural Design and Factors of Safety – Technical Bulletin Ontario Ministry of Natural Resources (August 2011)

ENGINEER'S SEAL

Rev. #	**Rev. Description**	**Rev. Author**	**Date Revised**	**Checked by**	**Approved by**	**Approved Date**

Notes and Figures

Properties of Materials

$\gamma_w := 9.81 \frac{kN}{m^3}$ *Water density*

$\gamma_{conc} := 23.5 \cdot \frac{kN}{m^3}$ *Concrete density adjusted due to combination of the pier and abutment sections.*

$\phi_{cf} := 23 \cdot deg$ *Friction angle of concrete/foundation interface*

$c := 0MPa$ *Cohesion at concrete/foundation interface (generally set to 0)*

$f_{t.cf} := \frac{-c}{2} = 0$ *Tensile strength at concrete/rock interface (generally set to 0, or 0.5 x cohesion). This is a negative number.*

$\gamma_{silt} := 7.7 \cdot \frac{kN}{m^3}$ *Silt density*

$\phi'_{silt} := 20 \cdot deg$ *Angle of internal friction for silt at rest condition*

$\gamma_{fill} := 7.7 \cdot \frac{kN}{m^3}$ *Backfill density*

$\phi'_{fill} := 30 \cdot deg$ *Angle of internal friction for backfill at rest condition*

$\gamma_{timber} := 10 \cdot \frac{kN}{m^3}$ *Timber density (for stoplogs)*

$\gamma_{Granular} := 15 \frac{kN}{m^3}$ *Weight of granular material or rip rap on top of section*

Water Levels

Usual Summer Operating Levels

Used in LC 1,4,5

$WL_{US.Sum} := 310.9m$ *Upstream water level (left side)*

$WL_{DS.Sum} := 305.27m$ *Downstream water level (right side)*

Usual Winter Operating Levels

Used in LC 2

$WL_{US.Win} := 309.26m$

$WL_{DS.Win} := 305.27m$

Unusual Flood Discharge Levels

Used in LC 3

$WL_{US.IDF} := 311.9m$

$WL_{DS.IDF} := 310.3m$

Seismic Accelerations

$\lambda_{Hor} := 0.0834$ *Horizontal component of earthquake intensity = ratio of earthquake acceleration to acceleration due to gravity (unitless number)*

$\lambda_{Ver} := \frac{2}{3} \cdot \lambda_{Hor} = 0.056$

Vertical component of earthquake intensity. CDA recommends a factor between 1/2 and 2/3 of the horizontal acceleration (pg 15 of Seismic Hazard Considerations Technical Bulletin)

Structure Geometry

Input

Note: Enter structure geometry as series of points on X-Y grid. Align structure so that upstream is on the left side. Structure outline is "closed" automatically (last point is assigned same values as first). Ensure that values of ELE.Base.L and ELE.Base.R are adjusted to correspond with the lowest upstream and downstream elevations.

Input X & Y coordinates

$X := \begin{pmatrix} 0 \\ 7.95 \\ 7.95 \\ 0 \end{pmatrix} \cdot m$ $Y := \begin{pmatrix} 305.27 \\ 305.27 \\ 310.94 \\ 310.94 \end{pmatrix} \cdot m$

$ELE_{Base.L} := 305.27m$ *Elevation of left side of base (lowest point)*

$ELE_{Base.R} := 305.27m$ *Elevation of right side of base (lowest point)*

$ELE_{Top} := 310.94m$ *Elevation of top of dam (for hydrostatic, hydrodynamic forces)*

$B := \frac{2.03 + 1.32}{2} \cdot m = 1.67\,m$ *Set unit width of structure (1m if using metric, 1ft if using imperial units)*

$\omega_{US} := 0deg$ *Incline of upstream face from vertical (positive number in degrees)*

$\omega_{DS} := 0deg$ *Incline of downstream face from vertical (positive number in degrees)*

$L_{hor} := max(X) - min(X) = 7.95\,m$ *Horizontal projection of base*

$\alpha := atan\left(\frac{ELE_{Base.R} - ELE_{Base.L}}{L_{hor}}\right) = 0 \cdot deg$ *Angle of inclination of base. Positive is counter clockwise from the horizontal in the downstream direction*

$L_{incl} := \frac{L_{hor}}{cos(\alpha)} = 7.95\,m$ *Inclined length of concrete-foundation interface*

Variables for Combines Structure Model

$B_{pier} := B = 1.67\,m$

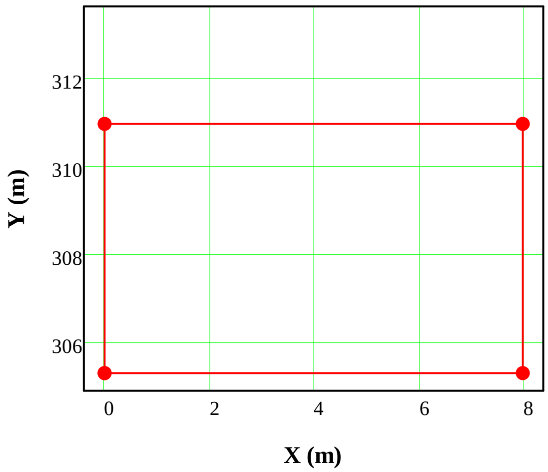
$L_{incl.pier} := L_{incl} = 7.95\,m$

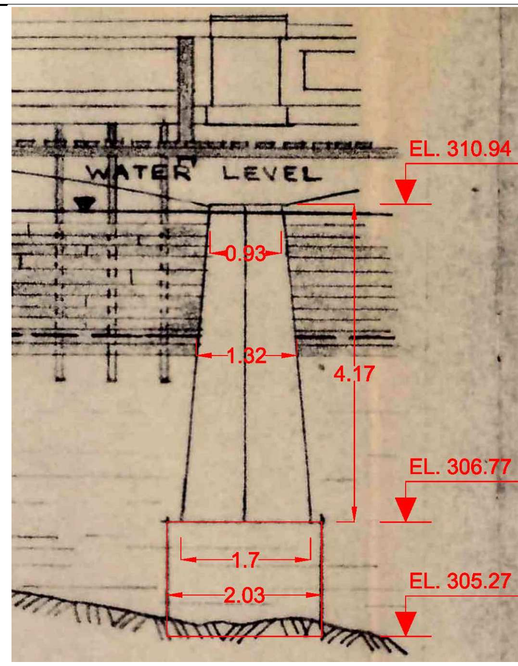
$\alpha_{pier} := \alpha$

Input

Plot Functions

Graphical Representation of Structure





Computation of Area and Center of Gravity

Gate/Stoplog Geometry

$X_{log} := 0 \cdot m$ — *Horizontal distance from left side (x=0) to location of gate/stoplogs*

$ELE_{sill} := 307.13m$ — *Elevation of the bottom of the gate/stoplogs*

$ELE_{gate.top} := 310.28m$ — *Elevation of top of gate/stoplogs*

$Trib_{gate} := \frac{10 \cdot ft}{2} = 1.52\,m$ — *Tributary width of gates/logs experiencing hydrostatic/hydrodynamic/ice forces*

$Wi_{gate} := 0m$ — *Total width of gate/stoplogs (for calculating weight on slab/rollway)*

Forces on Gates/Stoplogs Transferred into Piers

$Gates_{Sum.Hyd} := 1$ — *If gates are present during summer operation (and earthquake), set = 1, otherwise set to 0*

$Gates_{Win.Hyd} := 1$ — *If gates are present during winter operation, set = 1, otherwise set to 0*

$Gates_{IDF.Hyd} := 1$ — *If gates are present during IDF, set = 1, otherwise set to 0*

Weight of Gates/Stoplogs bearing on rollway/slab

$Gates_{Sum.Weight} := 0$ — *If gates are present during summer operation (and earthquake), set = 1, otherwise set to 0*

$Gates_{Win.Weight} := 0$ — *If gates are present during winter operation, set = 1, otherwise set to 0*

$Gates_{IDF.Weight} := 0$ — *If gates are present during IDF, set = 1, otherwise set to 0*

Weight of Main Structure (D)

$B_{ave} := \frac{2.03 + 0.93}{2} \cdot m = 1.48m$ — *Average width of the structure for calculating the pier weight*

$Vol\_conc := Area \cdot B_{ave} = 66.7 \cdot m^3$ — *Volume of concrete per unit width of structure*

$W_{conc} := Vol\_conc \cdot \gamma_{conc} = 1568 \cdot kN$ — *Dead load of concrete in structure*

$MA := L_{hor} - Xg = 3.975m$ — *Moment arm is the horizontal distance from right side of base to C.G.*

$M_{conc} := W_{conc} \cdot MA = 6231.8 \cdot kN \cdot m$ — *Moment from structure self weight*

$\gamma_{conc} = 23.5 \cdot \frac{kN}{m^3}$

$Area = 45.1m^2$

$B = 1.7m$

$L_{hor} = 7.95m$

$Xg = 3.975m$

$Yg = 308.105m$

Weight of Stoplogs (D) - NOT APPLICABLE

Weight of Slab (D)

$Wi_{slab} := 11.58 \cdot m$ — *Slab width*

$L_{slab} := 7.95 \cdot m$ — *Total length of slab*

$S_{thk} := 0.25m$ — *Equivalent slab thickness*

$\gamma_{conc} = 23.5 \cdot \frac{kN}{m^3}$

$B = 1.67m$

$L_{hor} = 7.95m$

$Wi_{Gir} := 0.55 \cdot m$ — *Girder width*

$L_{Gir} := 11.58 \cdot m$ — *Total length of girder*

$Gir_{thk} := \frac{1 + 0.4}{2} \cdot m = 0.7m$ — *Equivalent girder thickness (conservative assumption)*

$Gir_{No} := 4$ — *Number of girders in each span*

$$ELE_{slab} := 312.48 \cdot m - \frac{\left[L_{slab} \cdot Wi_{slab} \cdot S_{thk} \cdot \frac{S_{thk}}{2} + Gir_{No} \cdot L_{Gir} \cdot Wi_{Gir} \cdot Gir_{thk} \cdot \left(\frac{Gir_{thk}}{2} + S_{thk}\right)\right]}{L_{slab} \cdot Wi_{slab} \cdot S_{thk} + Gir_{No} \cdot L_{Gir} \cdot Wi_{Gir} \cdot Gir_{thk}} = 312.15m$$

Elevation of centre of gravity of slab

$X_{slab} := \frac{L_{slab}}{2} = 3.98m$ — *Horizontal distance from left side (x=0) to centre of slab*

$Wi_{opening} := 0m$ — *Width of stoplog opening*

$L_{opening} := 8.23m$ — *Length of stoplog opening*

$X_{opening} := 2.12m$ — *Horizontal distance from left side (x=0) to centre of slab*

$W_{slab1} := \gamma_{conc} \cdot (L_{slab} \cdot Wi_{slab} \cdot S_{thk} + Gir_{No} \cdot L_{Gir} \cdot Wi_{Gir} \cdot Gir_{thk}) = 959.9 \cdot kN$ — *Dead load from slab (not considering opening)*

$MA_{slab1} := L_{hor} - X_{slab} = 3.975m$ — *Moment arm measured as horizontal distance from centre of slab to right side of base*

$W_{opening} := \gamma_{conc} \cdot L_{opening} \cdot Wi_{opening} \cdot S_{thk} = 0$ — *Weight to be removed from slab due to opening*

$MA_{opening} := L_{hor} - X_{opening} = 5.830m$ — *Moment arm measured as horizontal distance from centre of opening to right side of base*

$W_{slab} := W_{slab1} - W_{opening} = 959.9kN$ — *Net dead load from slab*

$M_{slab} := W_{slab1} \cdot MA_{slab1} - W_{opening} \cdot MA_{opening} = 3815.8 \cdot kN \cdot m$ *Moment from weight of slab*

Weight of Tower(D) - NOT APPLICABLE

Weight of Riprap / Granular Material on Top of Section - NOT APPLICALBE

Input coordinates

Calculations

Results

Upstream Hydrostatic Force (H)

Figures

Calculations

Note: If inclined face is present, it is assumed to be linear from heel to water level.

$WL_{US.Sum} = 310.900\,m$
$ELE_{Top} = 310.940\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$\omega_{US} = 0.0$
$L_{hor} = 7.95\,m$
$B = 1.67\,m$

Case 1: Summer Operating Level

$$H := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{Base.L} \\ WL_{US.Sum} - ELE_{Base.L} & \text{otherwise} \end{cases} = 5.630$$ *Height of water in front of section*

$$\boxed{P_{US.Sum} := H \cdot \gamma_w = 55.2\,kPa}$$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{Top} \\ WL_{US.Sum} - ELE_{Top} & \text{otherwise} \end{cases} = 0.000$$ *Height of water above top of section*

$$L_{below} := \frac{H - H_{above}}{\cos(\omega_{US})} = 5.630\,m$$ *Inclined length of face under water*

$$F1 := \frac{(H - H_{above}) \cdot \gamma_w \cdot L_{below}}{2} \cdot B = 260.4\,kN$$ *Force due to triangular portion of pressure diagram*

$$F1_{Hor} := F1 \cdot \cos(\omega_{US}) = 260.4\,kN$$ *Horizontal component of F1*

$$F1_{Ver} := F1 \cdot \sin(\omega_{US}) = 0\,kN$$ *Vertical component of F1*

$$ELE_{F1} := ELE_{Base.L} + \left(\frac{L_{below}}{3}\right) \cdot \cos(\omega_{US}) = 307.147\,m$$ *Elevation of F1*

$$MA_{F1.Hor} := ELE_{F1} - ELE_{Base.R} = 1.877\,m$$ *Moment arm of horizontal component of F1*

$$MA_{F1.Ver} := L_{hor} - (ELE_{F1} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$$ *Moment arm of vertical component of F1*

$$F2 := H_{above} \cdot \gamma_w \cdot L_{below} \cdot B = 0.0\,kN$$ *Force due to rectangular portion of pressure diagram*

$$F2_{Hor} := F2 \cdot \cos(\omega_{US}) = 0\,kN$$

$$F2_{Ver} := F2 \cdot \sin(\omega_{US}) = 0\,kN$$

$$ELE_{F2} := ELE_{Base.L} + \left(\frac{L_{below}}{2}\right) \cdot \cos(\omega_{US}) = 308.085\,m$$

$MA_{F2.Hor} := ELE_{F2} - ELE_{Base.R} = 2.815\,m$

$MA_{F2.Ver} := L_{hor} - (ELE_{F2} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F_{US.Sum.Hor} := F1_{Hor} + F2_{Hor} = 260.4\,kN$ *Horizontal hydrostatic force*

$F_{US.Sum.Ver} := F1_{Ver} + F2_{Ver} = 0\,kN$ *Vertical hydrostatic force*

$M_{US.Sum.Hor} := F1_{Hor} \cdot MA_{F1.Hor} + F2_{Hor} \cdot MA_{F2.Hor} = 488.7\,kN \cdot m$ *Moment due to horizontal component of hydrostatic force*

$M_{US.Sum.Ver} := F1_{Ver} \cdot MA_{F1.Ver} + F2_{Ver} \cdot MA_{F2.Ver} = 0\,kN \cdot m$ *Moment due to vertical component of hydrostatic force*

Case 2: Winter Operating Level

$WL_{US.Win} = 309.260\,m$
$ELE_{Top} = 310.940\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$\omega_{US} = 0.0$
$L_{hor} = 7.95\,m$
$B = 1.67\,m$

$$H := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{Base.L} \\ WL_{US.Win} - ELE_{Base.L} & \text{otherwise} \end{cases} = 3.990$$

$P_{US.Win} := H \cdot \gamma_w = 39.1\,kPa$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{Top} \\ WL_{US.Win} - ELE_{Top} & \text{otherwise} \end{cases} = 0.000$$

$$L_{below} := \frac{H - H_{above}}{\cos(\omega_{US})} = 3.990\,m$$

$$F1 := \frac{(H - H_{above}) \cdot \gamma_w \cdot L_{below}}{2} \cdot B = 130.8\,kN$$

$F1_{Hor} := F1 \cdot \cos(\omega_{US}) = 130.8\,kN$

$F1_{Ver} := F1 \cdot \sin(\omega_{US}) = 0\,kN$

$$ELE_{F1} := ELE_{Base.L} + \left(\frac{L_{below}}{3}\right) \cdot \cos(\omega_{US}) = 306.600\,m$$

$MA_{F1.Hor} := ELE_{F1} - ELE_{Base.R} = 1.330\,m$

$MA_{F1.Ver} := L_{hor} - (ELE_{F1} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F2 := H_{above} \cdot \gamma_w \cdot L_{below} \cdot B = 0.0\,kN$

$F2_{Hor} := F2 \cdot \cos(\omega_{US}) = 0\,kN$

$F2_{Ver} := F2 \cdot \sin(\omega_{US}) = 0\,kN$

$$ELE_{F2} := ELE_{Base.L} + \left(\frac{L_{below}}{2}\right) \cdot \cos(\omega_{US}) = 307.265\,m$$

$MA_{F2.Hor} := ELE_{F2} - ELE_{Base.R} = 1.995\,m$

$MA_{F2.Ver} := L_{hor} - (ELE_{F2} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F_{US.Win.Hor} := F1_{Hor} + F2_{Hor} = 130.8\,kN$

$F_{US.Win.Ver} := F1_{Ver} + F2_{Ver} = 0\,kN$

$M_{US.Win.Hor} := F1_{Hor} \cdot MA_{F1.Hor} + F2_{Hor} \cdot MA_{F2.Hor} = 174\,kN \cdot m$

$M_{US.Win.Ver} := F1_{Ver} \cdot MA_{F1.Ver} + F2_{Ver} \cdot MA_{F2.Ver} = 0\,kN \cdot m$

Case 3: IDF Level

$WL_{US.IDF} = 311.900\,m$
$ELE_{Top} = 310.940\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$\omega_{US} = 0.0$
$L_{hor} = 7.95\,m$
$B = 1.67\,m$

$$H := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{Base.L} \\ WL_{US.IDF} - ELE_{Base.L} & \text{otherwise} \end{cases} = 6.630$$

$P_{US.IDF} := H \cdot \gamma_w = 65\,kPa$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{Top} \\ WL_{US.IDF} - ELE_{Top} & \text{otherwise} \end{cases} = 0.960$$

$$L_{below} := \frac{H - H_{above}}{\cos(\omega_{US})} = 5.670\,m$$

$$F1 := \frac{(H - H_{above}) \cdot \gamma_w \cdot L_{below}}{2} \cdot B = 264.1\,kN$$

$F1_{Hor} := F1 \cdot \cos(\omega_{US}) = 264.1\,kN$

$F1_{Ver} := F1 \cdot \sin(\omega_{US}) = 0\,kN$

$ELE_{F1} := ELE_{Base.L} + \left(\frac{L_{below}}{3}\right) \cdot \cos(\omega_{US}) = 307.160\,m$

$MA_{F1.Hor} := ELE_{F1} - ELE_{Base.R} = 1.890\,m$

$MA_{F1.Ver} := L_{hor} - (ELE_{F1} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F2 := H_{above} \cdot \gamma_w \cdot L_{below} \cdot B = 89.4\,kN$

$F2_{Hor} := F2 \cdot \cos(\omega_{US}) = 89.4\,kN$

$F2_{Ver} := F2 \cdot \sin(\omega_{US}) = 0\,kN$

$ELE_{F2} := ELE_{Base.L} + \left(\frac{L_{below}}{2}\right) \cdot \cos(\omega_{US}) = 308.105\,m$

$MA_{F2.Hor} := ELE_{F2} - ELE_{Base.R} = 2.835\,m$

$MA_{F2.Ver} := L_{hor} - (ELE_{F2} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F_{US.IDF.Hor} := F1_{Hor} + F2_{Hor} = 353.6\,kN$

$F_{US.IDF.Ver} := F1_{Ver} + F2_{Ver} = 0\,kN$

$M_{US.IDF.Hor} := F1_{Hor} \cdot MA_{F1.Hor} + F2_{Hor} \cdot MA_{F2.Hor} = 752.8\,kN \cdot m$

$M_{US.IDF.Ver} := F1_{Ver} \cdot MA_{F1.Ver} + F2_{Ver} \cdot MA_{F2.Ver} = 0\,kN \cdot m$

Calculations

Downstream Hydrostatic Force (H)

Hydrostatic Force on Gates (H)

Calculations

Note: Pressure from tailwater not considered. Calculations assume a flat vertical face

$Gates_{Sum.Hyd} = 1$
$Gates_{Win.Hyd} = 1$
$Gates_{IDF.Hyd} = 1$
$WL_{US.Sum} = 310.900\,m$
$WL_{US.Win} = 309.260\,m$
$WL_{US.IDF} = 311.900\,m$
$ELE_{sill} = 307.130\,m$
$ELE_{gate.top} = 310.280\,m$
$ELE_{Base.R} = 305.270\,m$
$Trib_{gate} = 1.524\,m$
$L_{hor} = 7.95\,m$

Case 1: Summer operating level

$H := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{sill} \\ WL_{US.Sum} - ELE_{sill} & \text{otherwise} \end{cases} = 3.770$ *Height of water in front of gate/stoplogs*

$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{gate.top} \\ WL_{US.Sum} - ELE_{gate.top} & \text{otherwise} \end{cases} = 0.620$ *Height of water above top of gate/stoplogs*

$F1 := \frac{(H - H_{above})^2 \cdot \gamma_w}{2} \cdot Trib_{gate} = 74.2\,kN$ *Force due to triangular portion of pressure diagram*

$MA1 := \left(ELE_{sill} + \frac{H - H_{above}}{3} - ELE_{Base.R}\right) = 2.910\,m$ *Moment arm*

$F2 := H_{above} \cdot (H - H_{above}) \cdot \gamma_w \cdot Trib_{gate} = 29.2\,kN$ *Force due to rectangular portion of pressure diagram*

$MA2 := \left(ELE_{sill} + \frac{H - H_{above}}{2} - ELE_{Base.R}\right) = 3.435\,m$ *Moment arm*

$F_{gateH.Sum} := \begin{cases} (F1 + F2) & \text{if } Gates_{Sum.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 103.4 \cdot kN$ *Total hydrostatic force on gate/stoplogs*

$M_{gateH.Sum} := \begin{cases} (F1 \cdot MA1 + F2 \cdot MA2) & \text{if } Gates_{Sum.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 316.1 \cdot kN \cdot m$ *Moment due to hydrostatic force on gate/stoplogs*

Case 2: Winter operating level

$$H := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{sill} \\ WL_{US.Win} - ELE_{sill} & \text{otherwise} \end{cases} = 2.130$$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{gate.top} \\ WL_{US.Win} - ELE_{gate.top} & \text{otherwise} \end{cases} = 0.000$$

$$F1 := \frac{\left(H - H_{above}\right)^2 \cdot \gamma_w}{2} \cdot Trib_{gate} = 33.9\,kN$$

$$MA1 := \left(ELE_{sill} + \frac{H - H_{above}}{3} - ELE_{Base.R}\right) = 2.570\,m$$

$$F2 := H_{above} \cdot \left(H - H_{above}\right) \cdot \gamma_w \cdot Trib_{gate} = 0.0\,kN$$

$$MA2 := \left(ELE_{sill} + \frac{H - H_{above}}{2} - ELE_{Base.R}\right) = 2.925\,m$$

$$F_{gateH.Win} := \begin{cases} (F1 + F2) & \text{if } Gates_{Win.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 33914.3$$

$$M_{gateH.Win} := \begin{cases} (F1 \cdot MA1 + F2 \cdot MA2) & \text{if } Gates_{Win.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 87159.8$$

Case 3: IDF level

$$H := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{sill} \\ WL_{US.IDF} - ELE_{sill} & \text{otherwise} \end{cases} = 4.770$$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{gate.top} \\ WL_{US.IDF} - ELE_{gate.top} & \text{otherwise} \end{cases} = 1.620$$

$$F1 := \frac{\left(H - H_{above}\right)^2 \cdot \gamma_w}{2} \cdot Trib_{gate} = 74.2\,kN$$

$$MA1 := \left(ELE_{sill} + \frac{H - H_{above}}{3} - ELE_{Base.R}\right) = 2.910\,m$$

$$F2 := H_{above} \cdot \left(H - H_{above}\right) \cdot \gamma_w \cdot Trib_{gate} = 76.3\,kN$$

$$MA2 := \left(ELE_{sill} + \frac{H - H_{above}}{2} - ELE_{Base.R}\right) = 3.435\,m$$

$$F_{gateH.IDF} := \begin{cases} (F1 + F2) & \text{if } Gates_{IDF.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 150.5 \cdot kN$$

$$M_{gateH.IDF} := \begin{cases} (F1 \cdot MA1 + F2 \cdot MA2) & \text{if } Gates_{IDF.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 477.9 \cdot kN \cdot m$$

Calculations

Hydraulic Drag Force (H)

Weight of Water Above Section (H) - NOT APPLICABLE

Input coordinates

Calculations

Results

Initial Uplift Forces (U)

Figures

Uplift Function Definition

Input and Calculation

Note: Analysis assumes uplift pressure acts perpendicular to the concrete-foundation interface. Uplift pressure is considered positive, but the actual forces are negative when vertically upwards and positive in downstream (right) direction. Crack length is initially set to 0 but may change in subsequent cracked base analysis. Uplift is calculated again in the cracked section analysis and in the post-earthquake load combination.

$Factor_{UL} := 1.00$ — *Factor to reduce uplift pressure if required. Set to 1.00 for 100%.*

$L_{crack0} := 0 \cdot m$ — *Set initial crack length. Measured from left side, parallel to base*

$L_{incl} = 7.95\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$WL_{US.Sum} = 310.900\,m$
$WL_{US.Win} = 309.260\,m$
$WL_{US.IDF} = 311.900\,m$
$WL_{DS.Sum} = 305.270\,m$
$WL_{DS.Win} = 305.270\,m$
$WL_{DS.IDF} = 310.300\,m$
$P_{US.Sum} = 55.2 \cdot kPa$
$P_{DS.Sum} = 0.0 \cdot kPa$

$P_{USUL.Sum} := Factor_{UL} \cdot P_{US.Sum} = 55.2 \cdot kPa$ — *Uplift pressure at upstream (left) side*

$P_{DSUL.Sum} := Factor_{UL} \cdot P_{DS.Sum} = 0 \cdot kPa$ — *Uplift pressure at downstream (right) side*

$P_{USUL.Win} := Factor_{UL} \cdot P_{US.Win} = 39.1 \cdot kPa$

$P_{DSUL.Win} := Factor_{UL} \cdot P_{DS.Win} = 0 \cdot kPa$

$P_{USUL.IDF} := Factor_{UL} \cdot P_{US.IDF} = 65 \cdot kPa$

$P_{DSUL.IDF} := Factor_{UL} \cdot P_{DS.IDF} = 49.3 \cdot kPa$

Case 1: Water at summer operating levels

$P_{U.Sum}(x) := P_{UL}(x, L_{crack0}, P_{USUL.Sum}, P_{DSUL.Sum})$ — *Creates the pressure function*

$$F_{U0.Sum} := \int_0^{L_{incl}} P_{U.Sum}(x) \cdot B\,dx = 367.7 \cdot kN$$

Total uplift force. Calculated as the area under the uplift pressure diagram.

$$MA := L_{incl} - \frac{1}{F_{U0.Sum}} \left(\int_0^{L_{incl}} P_{U.Sum}(x) \cdot x \cdot B\,dx \right) = 5.3\,m$$

Moment arm of uplift force about the right side of base. Measured parallel to base.

$M_{U0.Sum} := F_{U0.Sum} \cdot MA = 1949 \cdot kN \cdot m$ — *Moment from uplift on uncracked section*

$F_{U0.Sum.Hor} := -F_{U0.Sum} \cdot \sin(\alpha) = 0 \cdot kN$ — *Uplift resolved into horizontal and vertical forces for subsequent calculations*

$F_{U0.Sum.Ver} := -F_{U0.Sum} \cdot \cos(\alpha) = -367.7 \cdot kN$

Case 2: Water at winter operating levels

$P_{U.Win}(x) := P_{UL}(x, L_{crack0}, P_{USUL.Win}, P_{DSUL.Win})$

$$F_{U0.Win} := \int_0^{L_{incl}} P_{U.Win}(x) \cdot B\,dx = 260.6 \cdot kN$$

$$MA := L_{incl} - \frac{1}{F_{U0.Win}} \left(\int_0^{L_{incl}} P_{U.Win}(x) \cdot x \cdot B\,dx \right) = 5.3\,m$$

$M_{U0.Win} := F_{U0.Win} \cdot MA = 1381.2 \cdot kN \cdot m$

$F_{U0.Win.Hor} := -F_{U0.Win} \cdot \sin(\alpha) = 0 \cdot kN$

$F_{U0.Win.Ver} := -F_{U0.Win} \cdot \cos(\alpha) = -260.6 \cdot kN$

Case 3: Water at IDF levels

$P_{U.IDF}(x) := P_{UL}(x, L_{crack0}, P_{USUL.IDF}, P_{DSUL.IDF})$

$$F_{U0.IDF} := \int_0^{L_{incl}} P_{U.IDF}(x) \cdot B\,dx = 761.6 \cdot kN$$

$$MA := L_{incl} - \frac{1}{F_{U0.IDF}}\left(\int_0^{L_{incl}} P_{U.IDF}(x) \cdot x \cdot B\,dx\right) = 4.16\,m$$

$M_{U0.IDF} := F_{U0.IDF} \cdot MA = 3165.8 \cdot kN \cdot m$

$F_{U0.IDF.Hor} := -F_{U0.IDF} \cdot \sin(\alpha) = 0 \cdot kN$

$F_{U0.IDF.Ver} := -F_{U0.IDF} \cdot \cos(\alpha) = -761.6 \cdot kN$

Input and Calculation

Plot of Results

Upstream Silt Buildup (S)

Downstream Backfill (S)

Ice Loading (I)

USUAL LOAD CASE

Direct ice load on structure

$Wi_{gate} = 0.00$
$Trib_{gate} = 1.52\,m$
$ELE_{Base.R} = 305.270\,m$
$WL_{US.Win} = 309.260\,m$
$B = 1.67\,m$
$Gates_{Win.Hyd} = 1$

$IceLoad_{usual} := 75 \frac{kN}{m}$ — *Ice loading on structure (enter as kN/m)*

$F_{ice.1.usual} := IceLoad_{usual} B = 125.6 \cdot kN$ — *Force acting on the structure*

$ELE_{ice} := WL_{US.Win} - 0.3m = 308.96\,m$ — *Elevation of force (assumed to act at 0.3m below water level)*

$MA := ELE_{ice} - ELE_{Base.R} = 3.7\,m$ — *Moment arm is vertical distance from force to right side of base*

$M_{ice.1.usual} := F_{ice.1.usual} \cdot MA = 463.6 \cdot kN \cdot m$ — *Moment about right side of base*

Ice load on adjacent gates/stop logs

Note: Ice load in this section acts on the tributary gate width to be transferred into gate slots

$$F_{ice.gate.usual} := \begin{vmatrix} 0 \ \text{if}\ Gates_{Win.Hyd} = 0 \\ IceLoad_{usual} \cdot Trib_{gate} \ \text{otherwise} \end{vmatrix} = 114.3 \cdot kN$$

$M_{ice.gate.usual} := F_{ice.gate.usual} \cdot MA = 421.8\,kN \cdot m$

$F_{ice.usual} := F_{ice.1.usual} + F_{ice.gate.usual} = 239.9\,kN$

$M_{ice.usual} := M_{ice.1.usual} + M_{ice.gate.usual} = 885.3\,kN \cdot m$

UNUSUAL LOAD CASE

Direct ice load on structure

$IceLoad := 83.5\,\frac{kN}{m}$ — *Ice loading on structure (enter as kN/m)*

$F_{ice.1} := IceLoad\,B = 139.9 \cdot kN$ — *Force acting on the structure*

$M_{ice.1} := F_{ice.1} \cdot MA = 516.1 \cdot kN \cdot m$ — *Moment about right side of base*

Ice load on adjacent gates/stop logs

Note: *Ice load in this section acts on the tributary gate width to be transferred into gate slots*

$$F_{ice.gate} := \begin{vmatrix} 0 \text{ if } Gates_{Win.Hyd} = 0 \\ IceLoad \cdot Trib_{gate} \text{ otherwise} \end{vmatrix} = 127.3 \cdot kN$$

$M_{ice.gate} := F_{ice.gate} \cdot MA = 469.6\,kN \cdot m$

$F_{ice} := F_{ice.1} + F_{ice.gate} = 267.1\,kN$

$M_{ice} := M_{ice.1} + M_{ice.gate} = 985.7\,kN \cdot m$

Seismic Forces - Inertia of Structure Dead Load (Q)

Seismic Forces - Hydrodynamic Forces (Q)

Figures

Calculations

Seismic Forces - Dynamic Soil Pressures (Q)

Tensioned Anchors - NOT APPLICABLE

Other Forces - NOT APPLICABLE

Load Case 1. Usual Loading Summer Case (D+H+S+U)

LC.1 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ $\quad$ $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Sum} = 0$ $\quad$ $M_{log.Sum} = 0$

$W_{slab} = 959.9\,kN$ $\quad$ $M_{slab} = 3815.8\,kN \cdot m$

$W_{tower} = 0$ $\quad$ $M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 260.4 \cdot kN$ $\quad$ $M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$

$F_{US.Sum.Ver} = 0 \cdot kN$ $\quad$ $M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Sum.Hor} = 0\,kN$ $\quad$ $M_{DS.Sum.Hor} = 0\,kN \cdot m$

$F_{DS.Sum.Ver} = 0\,kN$ $\quad$ $M_{DS.Sum.Ver} = 0\,kN \cdot m$

$F_{gateH.Sum} = 103.4\,kN$ $\quad$ $M_{gateH.Sum} = 316.1\,kN \cdot m$

$W_{Water.Above.Sum} = 0$ $\quad$ $M_{Water.Above.Sum} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ $\quad$ $M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$ $\quad$ $M_{US.silt.Ver} = 0\,kN \cdot m$

$F_{DS.fill.Hor} = 0$ $\quad$ $M_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$ $\quad$ $M_{DS.fill.Ver} = 0$

$W_{Granular.Sum} = 0\,kN$ $\quad$ $M_{Granular.Sum} = 0\,kN \cdot m$

Uplift (U):

$F_{U0.Sum.Hor} = 0 \cdot kN$ $\quad$ $M_{U0.Sum} = 1949 \cdot kN \cdot m$

$F_{U0.Sum.Ver} = -367.7 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ $\quad$ $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ $\quad$ $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ $\quad$ $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ $\quad$ $M_{other.Ver.1} = 0$

LC.1 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.Sum.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) = 363.8\,kN$$

Sum of horizontal forces

$$F_{ver0} := \left(W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}\right) + \left(F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Sum}\right) + \left(F_{U0.Sum.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 2160\,kN$$

Sum of vertical forces

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 363.8 \cdot kN$$

Forces acting parallel to uncracked base

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2160.0 \cdot kN$$

Forces acting perpendicular to uncracked base

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \ldots + \left(M_{US.silt.Ver} + M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{Granular.Sum}\right) \ldots + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 10047.6\,kN \cdot m$$

Sum of stabilizing moments

$$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Sum}\right) = 2753.8\,kN \cdot m$$

Sum of overturning moments

$$M_{net0} := M_{stab0} - M_{overturn0} = 7293.8\,kN \cdot m$$

Net resisting moment

LC.1 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 3.38\,m$ — *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.6\,m$ — *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 7.95\,m$
$M_{net0} = 7293.8\,kN \cdot m$
$F_{perp0} = 2160.0\,kN$

Stress Calculations

$q_{max0} = 235.4\,kPa$ $\quad q_{min0} = 89\,kPa$ — *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp0} = 7.95\,m$ — *Length of base in compression before iterative cracked base analysis*

$L_{tens0} = 0.00\,m$ — *Length of base in tension before iterative cracked base analysis*

$L_{crack0} = 0.00\,m$ — *Length of crack between concrete and base before iterative cracked base analysis*

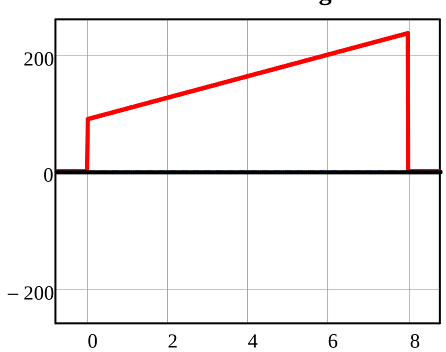
$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2159969$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

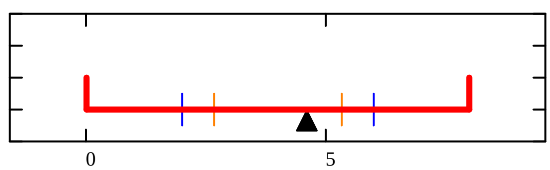
Compression and tension forces in foundation

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\quad \frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\quad \frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

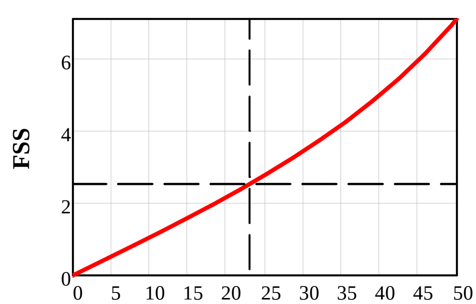
LC.1 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 2.52$ — *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$



Friction Angle

LC.1 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{vmatrix} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{vmatrix} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 2. Usual Loading Winter Case (D+H+S+U+I)

LC.2 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Win} = 0$ $M_{log.Win} = 0$

$W_{slab} = 959.9 kN$ $M_{slab} = 3815.8 kN \cdot m$

$W_{tower} = 0$ $M_{tower} = 0$

Hydraulic (H):

$F_{US.Win.Hor} = 130.8 \cdot kN$ $M_{US.Win.Hor} = 174 \cdot kN \cdot m$

$F_{US.Win.Ver} = 0 \cdot kN$ $M_{US.Win.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Win.Hor} = 0 kN$ $M_{DS.Win.Hor} = 0 kN \cdot m$

$F_{DS.Win.Ver} = 0 kN$ $M_{DS.Win.Ver} = 0 kN \cdot m$

$F_{gateH.Win} = 33.9 kN$ $M_{gateH.Win} = 87.2 kN \cdot m$

$W_{Water.Above.Win} = 0$ $M_{Water.Above.Win} = 0$

Soil (S):

$F_{US.silt.Hor} = 0 kN$ $M_{US.silt.Hor} = 0 kN \cdot m$

$W_{US.silt} = 0 kN$ $M_{US.silt.Ver} = 0 kN \cdot m$

$F_{DS.fill.Hor} = 0$ $M_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$ $M_{DS.fill.Ver} = 0$

$W_{Granular.Win} = 0 kN$ $M_{Granular.Win} = 0 kN \cdot m$

Uplift (U):

$M_{U0.Win} = 1381.2 \cdot kN \cdot m$

$F_{U0.Win.Hor} = 0 \cdot kN$

$F_{U0.Win.Ver} = -260.6 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ $M_{other.Ver.1} = 0$

Ice (I):

$F_{ice.usual} = 239.9 \cdot kN$ $M_{ice.usual} = 885.3 \cdot kN \cdot m$

LC.2 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Win.Hor} - F_{DS.Win.Hor} + F_{gateH.Win}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.Win.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) + \left(F_{ice.usual}\right) = 404.6 kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Win} + W_{slab} + W_{tower}\right) + \left(F_{US.Win.Ver} + F_{DS.Win.Ver} + W_{Water.Above.Win}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Win}\right) + \left(F_{U0.Win.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 2267.1 kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 404.6 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2267.1 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Win.Ver} + M_{DS.Win.Hor} + M_{DS.Win.Ver} + M_{Water.Above.Win}\right) \ldots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Win}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 10047.6 kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Win.Hor} + M_{gateH.Win}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Win}\right) + \left(M_{ice.usual}\right) = 2527.7 kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 7519.9 kN \cdot m$$

LC.2 - Resultant and Bearing Stresses

$x_0 := \dfrac{M_{net0}}{F_{perp0}} = 3.32\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \dfrac{L_{incl}}{2} - x_0 = 0.66\,m$ *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 7.95\,m$
$M_{net0} = 7519.9\,kN \cdot m$
$F_{perp0} = 2267.1\,kN$

Stress Calculations

$q_{max0} = 254.8\,kPa$ $q_{min0} = 85.7\,kPa$

$L_{comp0} = 7.95\,m$

$L_{tens0} = 0.00\,m$

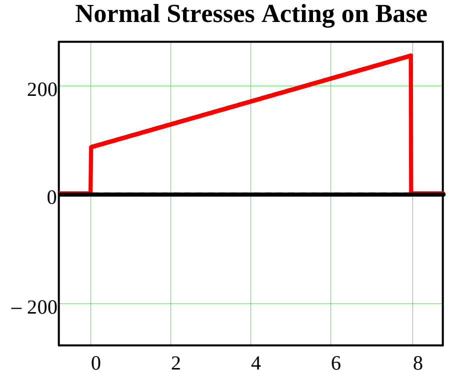
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \dfrac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2267087.6$$

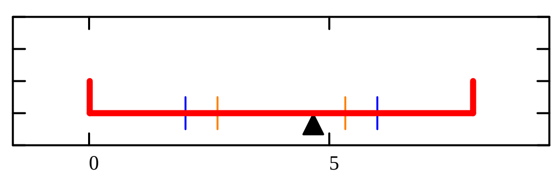
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\dfrac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\dfrac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\dfrac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

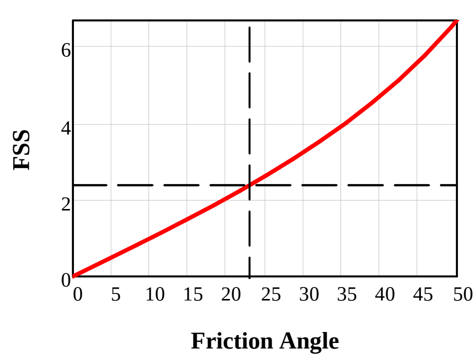
LC.2 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \dfrac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 2.38$ *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$



LC.2 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 3. Unusual Loading IDF (D+H_{IDF}+S+U_{IDF})

LC.3 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ $\quad$ $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.IDF} = 0$ $\quad$ $M_{log.IDF} = 0$

$W_{slab} = 959.9\,kN$ $\quad$ $M_{slab} = 3815.8\,kN \cdot m$

$W_{tower} = 0$ $\quad$ $M_{tower} = 0$

Hydraulic (H):

$F_{US.IDF.Hor} = 353.6 \cdot kN$ $\quad$ $M_{US.IDF.Hor} = 752.8 \cdot kN \cdot m$

$F_{US.IDF.Ver} = 0 \cdot kN$ $\quad$ $M_{US.IDF.Ver} = 0 \cdot kN \cdot m$

$F_{DS.IDF.Hor} = 207.9\,kN$ $\quad$ $M_{DS.IDF.Hor} = 348.5\,kN \cdot m$

$F_{DS.IDF.Ver} = 0\,kN$ $\quad$ $M_{DS.IDF.Ver} = 0\,kN \cdot m$

$F_{gateH.IDF} = 150.5\,kN$ $\quad$ $M_{gateH.IDF} = 477.9\,kN \cdot m$

$F_{drag} = 0$ $\quad$ $M_{drag} = 0$

$W_{Water.Above.IDF} = 0$ $\quad$ $M_{Water.Above.IDF} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ $\quad$ $M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$ $\quad$ $M_{US.silt.Ver} = 0\,kN \cdot m$

$F_{DS.fill.IDF.Hor} = 0$ $\quad$ $M_{DS.fill.IDF.Hor} = 0$

$W_{DS.fill.IDF} = 0$ $\quad$ $M_{DS.fill.IDF.Ver} = 0$

$W_{Granular.IDF} = 0\,kN$ $\quad$ $M_{Granular.IDF} = 0\,kN \cdot m$

Uplift (U):

$M_{U0.IDF} = 3165.8 \cdot kN \cdot m$

$F_{U0.IDF.Hor} = 0 \cdot kN$

$F_{U0.IDF.Ver} = -761.6 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ $\quad$ $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ $\quad$ $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ $\quad$ $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ $\quad$ $M_{other.Ver.1} = 0$

LC.3 - Combine Forces and Moments

$$F_{hor0} := (F_{US.IDF.Hor} - F_{DS.IDF.Hor} + F_{gateH.IDF} + F_{drag}) + (F_{US.silt.Hor} - F_{DS.fill.IDF.Hor}) \ldots + (F_{U0.IDF.Hor}) + (F_{anchor.Hor} + F_{other.Hor.1}) = 296.2\,kN$$

$$F_{ver0} := (W_{conc} + W_{log.IDF} + W_{slab} + W_{tower}) + (F_{US.IDF.Ver} + F_{DS.IDF.Ver} + W_{Water.Above.IDF}) \ldots + (W_{US.silt} + W_{DS.fill.IDF} + W_{Granular.IDF}) + (F_{U0.IDF.Ver}) + (F_{anchor.Ver} + F_{other.Ver.1}) = 1766.1\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 296.2 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1766.1 \cdot kN$$

$$M_{stab0} := (M_{conc} + M_{log.IDF} + M_{slab} + M_{tower}) + (M_{US.IDF.Ver} + M_{DS.IDF.Hor} + M_{DS.IDF.Ver} + M_{Water.Above.IDF}) \ldots + (M_{US.silt.Ver} + M_{DS.fill.IDF.Hor} + M_{DS.fill.IDF.Ver} + M_{Granular.IDF}) \ldots + (M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}) = 10396.1\,kN \cdot m$$

$$M_{overturn0} := (M_{US.IDF.Hor} + M_{gateH.IDF} + M_{drag}) + (M_{US.silt.Hor}) + (M_{U0.IDF}) = 4396.5\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 5999.7\,kN \cdot m$$

LC.3 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 3.40\,m$

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.58\,m$

$L_{incl} = 7.95\,m$
$M_{net0} = 5999.7\,kN \cdot m$
$F_{perp0} = 1766.1\,kN$

Stress Calculations

$q_{max0} = 190.5\,kPa$ $q_{min0} = 74.8\,kPa$

$L_{comp0} = 7.95\,m$

$L_{tens0} = 0.00\,m$

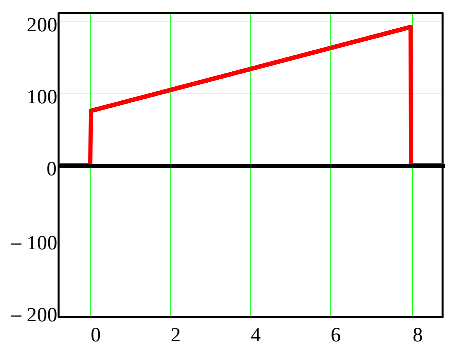
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1766112.3$$

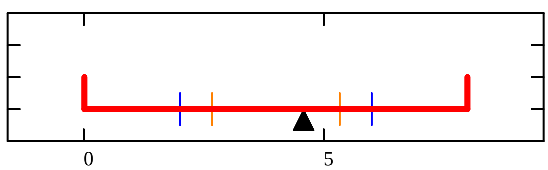
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.3 - Sliding

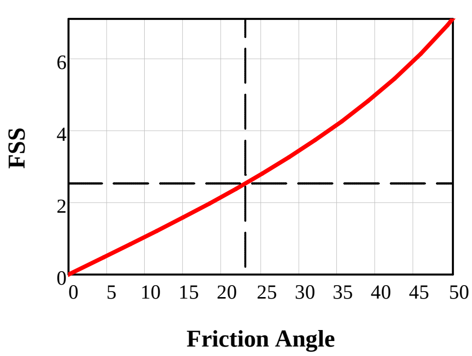
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$

$FSS_0(\phi_{cf}) = 2.53$

Factor of safety against sliding for specified friction angle



LC.3 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 4. Unusual Loading Winter Case (D+H+S+U+I)

LC.4 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ — $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Win} = 0$ — $M_{log.Win} = 0$

$W_{slab} = 959.9 kN$ — $M_{slab} = 3815.8 kN \cdot m$

$W_{tower} = 0$ — $M_{tower} = 0$

Hydraulic (H):

$F_{US.Win.Hor} = 130.8 \cdot kN$ — $M_{US.Win.Hor} = 174 \cdot kN \cdot m$

$F_{US.Win.Ver} = 0 \cdot kN$ — $M_{US.Win.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Win.Hor} = 0 kN$ — $M_{DS.Win.Hor} = 0 kN \cdot m$

$F_{DS.Win.Ver} = 0 kN$ — $M_{DS.Win.Ver} = 0 kN \cdot m$

$F_{gateH.Win} = 33.9 kN$ — $M_{gateH.Win} = 87.2 kN \cdot m$

$W_{Water.Above.Win} = 0$ — $M_{Water.Above.Win} = 0$

Soil (S):

$F_{US.silt.Hor} = 0 kN$ — $M_{US.silt.Hor} = 0 kN \cdot m$

$W_{US.silt} = 0 kN$ — $M_{US.silt.Ver} = 0 kN \cdot m$

$F_{DS.fill.Hor} = 0$ — $M_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$ — $M_{DS.fill.Ver} = 0$

$W_{Granular.Win} = 0 kN$ — $M_{Granular.Win} = 0 kN \cdot m$

Uplift (U):

$M_{U0.Win} = 1381.2 \cdot kN \cdot m$

$F_{U0.Win.Hor} = 0 \cdot kN$

$F_{U0.Win.Ver} = -260.6 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ — $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ — $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ — $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ — $M_{other.Ver.1} = 0$

Ice (I):

$F_{ice} = 267.1 \cdot kN$ — $M_{ice} = 985.7 \cdot kN \cdot m$

LC.4 - Combine Forces and Moments

$$F_{hor0} := (F_{US.Win.Hor} - F_{DS.Win.Hor} + F_{gateH.Win}) + (F_{US.silt.Hor} - F_{DS.fill.Hor}) \dots + (F_{U0.Win.Hor}) + (F_{anchor.Hor} + F_{other.Hor.1}) + (F_{ice}) = 431.8 kN$$

$$F_{ver0} := (W_{conc} + W_{log.Win} + W_{slab} + W_{tower}) + (F_{US.Win.Ver} + F_{DS.Win.Ver} + W_{Water.Above.Win}) \dots + (W_{US.silt} + W_{DS.fill} + W_{Granular.Win}) + (F_{U0.Win.Ver}) + (F_{anchor.Ver} + F_{other.Ver.1}) = 2267.1 kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 431.8 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2267.1 \cdot kN$$

$$M_{stab0} := (M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}) + (M_{US.Win.Ver} + M_{DS.Win.Hor} + M_{DS.Win.Ver} + M_{Water.Above.Win}) \dots + (M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Win}) + (M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}) = 10047.6 kN \cdot m$$

$$M_{overturn0} := (M_{US.Win.Hor} + M_{gateH.Win}) + (M_{US.silt.Hor}) + (M_{U0.Win}) + (M_{ice}) = 2628 kN \cdot m$$

$M_{net0} := M_{stab0} - M_{overturn0} = 7419.6 kN \cdot m$

LC.4 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 3.27 m$

Distance of resulant from right side of base (measured parallel to base)

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.70 m$

Ecentricity of resultant (positive is to the right)

$L_{incl} = 7.95 m$
$M_{net0} = 7419.6 kN \cdot m$
$F_{perp0} = 2267.1 kN$

Stress Calculations

$q_{max0} = 260.5 kPa$

$q_{min0} = 80.0 kPa$

$L_{comp0} = 7.95 m$

$L_{tens0} = 0.00 m$

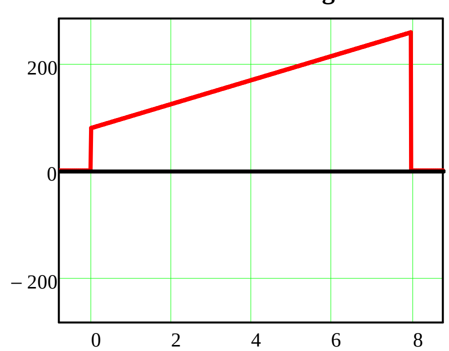
$L_{crack0} = 0.00 m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2267087.6$$

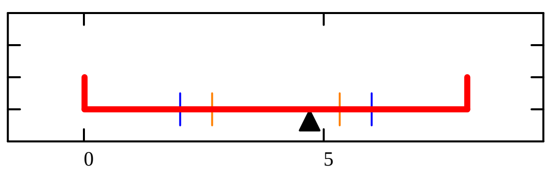
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0 kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.4 - Sliding

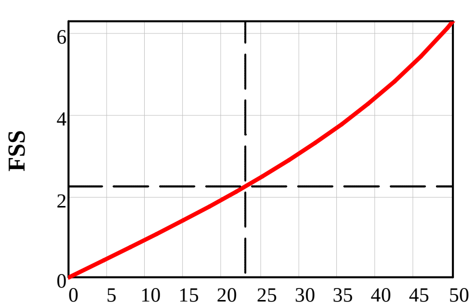
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 2.23$

Factor of safety against sliding for specified friction angle

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95 m$
$\alpha = 0 \cdot deg$
$B = 1.67 m$



LC.4 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 5. Extreme Loading Earthquake (D+H+S+Q+U_Q)

LC.5 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ | $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Sum} = 0$ | $M_{log.Sum} = 0$

$W_{slab} = 959.9\,kN$ | $M_{slab} = 3815.8\,kN \cdot m$

$W_{tower} = 0$ | $M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 260.4 \cdot kN$ | $M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$

$F_{US.Sum.Ver} = 0 \cdot kN$ | $M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Sum.Hor} = 0\,kN$ | $M_{DS.Sum.Hor} = 0\,kN \cdot m$

$F_{DS.Sum.Ver} = 0\,kN$ | $M_{DS.Sum.Ver} = 0\,kN \cdot m$

$F_{gateH.Sum} = 103.4\,kN$ | $M_{gateH.Sum} = 316.1\,kN \cdot m$

$W_{Water.Above.Sum} = 0$ | $M_{Water.Above.Sum} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ | $M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$ | $M_{US.silt.Ver} = 0\,kN \cdot m$

$F_{DS.fill.Hor} = 0$ | $M_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$ | $M_{DS.fill.Ver} = 0$

$W_{Granular.EQ} = 0\,kN$ | $M_{Granular.EQ} = 0\,kN \cdot m$

Uplift (U):

$F_{U0.Sum.Hor} = 0 \cdot kN$ | $M_{U0.Sum} = 1949 \cdot kN \cdot m$

$F_{U0.Sum.Ver} = -367.7 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ | $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ | $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ | $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ | $M_{other.Ver.1} = 0$

Seismic (Q):

$F_{eq.conc.Hor} = 130.8\,kN$ | $M_{eq.conc.Hor} = 370.7\,kN \cdot m$

$F_{eq.conc.Ver} = 87.2\,kN$	$M_{eq.conc.Ver} = 346.5\,kN\cdot m$
$F_{eq.log.Hor} = 0$	$M_{eq.log.Hor} = 0$
$F_{eq.log.Ver} = 0$	$M_{eq.log.Ver} = 0$
$F_{eq.slab.Hor} = 80.1\,kN$	$M_{eq.slab.Hor} = 550.6\,kN\cdot m$
$F_{eq.slab.Ver} = 53.4\,kN$	$M_{eq.slab.Ver} = 212.2\,kN\cdot m$
$F_{eq.tower.Hor} = 0$	$M_{eq.tower.Hor} = 0$
$F_{eq.tower.Ver} = 0$	$M_{eq.tower.Ver} = 0$
$F_{eq.HD.US} = 23.3\,kN$	$M_{eq.HD.US} = 52.8\,kN\cdot m$
$F_{eq.HD.gate} = 9\,kN$	$M_{eq.HD.gate} = 32.1\,kN\cdot m$
$F_{eq.silt.Hor} = 0\,kN$	$M_{eq.silt.Hor} = 0\,kN\cdot m$
$F_{eq.silt.Ver} = 0\,kN$	$M_{eq.silt.Ver} = 0\,kN\cdot m$
$F_{eq.fill.Hor} = 0$	$M_{eq.fill.Hor} = 0$
$F_{eq.fill.Ver} = 0$	$M_{eq.fill.Ver} = 0$
$F_{eq.Granular.Ver} = 0\,kN$	$M_{eq.Granular.Ver} = 0\,kN\cdot m$
$F_{eq.Granular.Hor} = 0\,kN$	$M_{eq.Granular.Hor} = 0\,kN\cdot m$
$F_{eq.Water.Above.Ver} = 0$	$M_{eq.Water.Above.Ver} = 0$
$F_{eq.Water.Above.Hor} = 0$	$M_{eq.Water.Above.Hor} = 0$

LC.5 - Combine Forces and Moments

$$F_{hor0} := (F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}) + (F_{US.silt.Hor} - F_{DS.fill.Hor}) \cdots + (F_{U0.Sum.Hor}) + (F_{anchor.Hor} + F_{other.Hor.1}) \cdots + (F_{eq.conc.Hor} + F_{eq.log.Hor} + F_{eq.slab.Hor} + F_{eq.tower.Hor} + F_{eq.HD.US} + F_{eq.HD.gate} + F_{eq.silt.Hor} + F_{eq.fill.Hor} + F_{eq.Granular.Hor}) = 606.9\,kN$$

$$F_{ver0} := (W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}) + (F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}) \cdots + (W_{US.silt} + W_{DS.fill} + W_{Granular.EQ}) + (F_{U0.Sum.Ver}) + (F_{anchor.Ver} + F_{other.Ver.1}) \cdots + (-F_{eq.conc.Ver} - F_{eq.log.Ver} - F_{eq.slab.Ver} - F_{eq.tower.Ver} - F_{eq.silt.Ver} - F_{eq.fill.Ver} - F_{eq.Granular.Ver} - F_{eq.Water.Above.Ver}) = 2019.4\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 606.9 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2019.4 \cdot kN$$

$$M_{stab0} := (M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}) + (M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}) \cdots + (M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.EQ}) + (M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}) = 10047.6\,kN \cdot m$$

$$M_{overturn0} := (M_{US.Sum.Hor} + M_{gateH.Sum}) + (M_{US.silt.Hor}) + (M_{U0.Sum}) \cdots + \begin{pmatrix} M_{eq.conc.Hor} + M_{eq.conc.Ver} + M_{eq.log.Hor} + M_{eq.log.Ver} + M_{eq.slab.Hor} \cdots \\ + M_{eq.slab.Ver} + M_{eq.tower.Hor} + M_{eq.tower.Ver} + M_{eq.HD.US} + M_{eq.HD.gate} \cdots \\ + M_{eq.silt.Hor} + M_{eq.silt.Ver} + M_{eq.fill.Hor} + M_{eq.fill.Ver} + M_{eq.Granular.Ver} \cdots \\ + M_{eq.Granular.Hor} + M_{eq.Water.Above.Ver} + M_{eq.Water.Above.Hor} \end{pmatrix} = 4318.7\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 5728.9\,kN \cdot m$$

LC.5 - Resultant and Bearing Stresses

$$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.84\,m$$

$$E_0 := \frac{L_{incl}}{2} - x_0 = 1.14\,m$$

$L_{incl} = 7.95\,m$
$M_{net0} = 5728.9\,kN \cdot m$
$F_{perp0} = 2019.4\,kN$

Stress Calculations

$q_{max0} = 281.9\,kPa$ $\quad$ $q_{min0} = 21.4\,kPa$

$L_{comp0} = 7.95\,m$

$L_{tens0} = 0.00\,m$

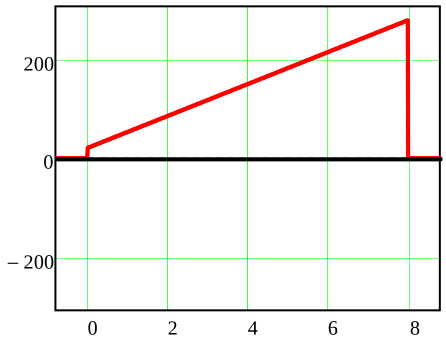
$L_{crack.eq} := L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \dfrac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2019428.9$$

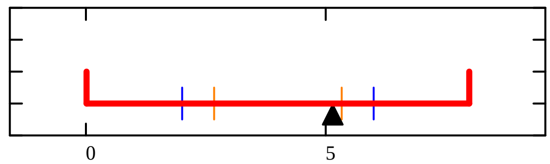
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \% \qquad \frac{L_{tens0}}{L_{incl}} = 0 \cdot \% \qquad \frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.5 - Sliding

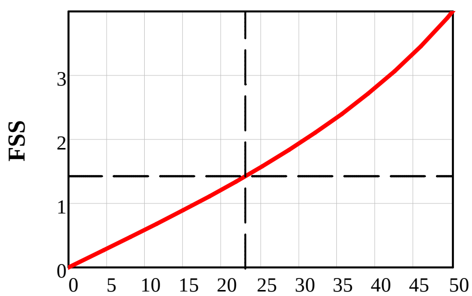
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS_0(\phi_{cf}) = 1.41}$

Factor of safety against sliding for specified friction angle

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$



Friction Angle

LC.5 - Cracked Base Analysis

Note: Iterative cracked base analysis does not occur during seismic conditions. Initial uplift pressures are assumed to be maintained even if cracking occurs, as per CDA guidelines.

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 6. Post-Earthquake (D+H+S+U$_{PQ}$)

LC.6(U) - Uplift

Updated uplift calculations

$L_{crack0} := L_{crack.eq} = 0.00\,m$

Crack length is set to the resulting crack length from LC.4.

$P_{U.eq}(x) := P_{UL}(x, L_{crack0}, P_{USUL.Sum}, P_{DSUL.Sum})$

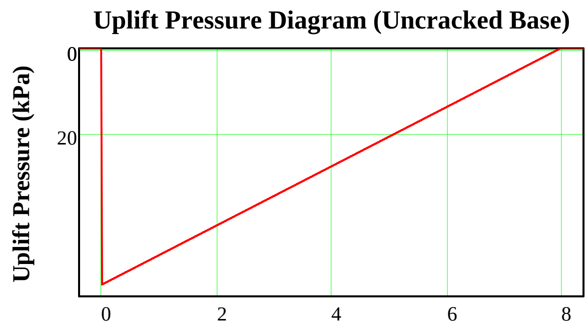
$$F_{U0.eq} := \int_0^{L_{incl}} P_{U.eq}(x) \cdot B\,dx = 367.7 \cdot kN$$

$$MA := L_{incl} - \frac{1}{F_{U0.eq}} \left(\int_0^{L_{incl}} P_{U.eq}(x) \cdot x \cdot B\,dx \right) = 5.3\,m$$

$M_{U0.eq} := F_{U0.eq} \cdot MA = 1949 \cdot kN \cdot m$

$F_{U0.eq.Hor} := -F_{U0.eq} \cdot \sin(\alpha) = 0 \cdot kN$

$F_{U0.eq.Ver} := -F_{U0.eq} \cdot \cos(\alpha) = -367.7 \cdot kN$



Updated uplift calculations

LC.6 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Sum} = 0$ $M_{log.Sum} = 0$

$W_{slab} = 959.9\,kN$ $M_{slab} = 3815.8\,kN \cdot m$

$W_{tower} = 0$ $M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 260.4 \cdot kN$ $M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$

$F_{US.Sum.Ver} = 0 \cdot kN$ $M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Sum.Hor} = 0\,kN$ $M_{DS.Sum.Hor} = 0\,kN \cdot m$

$F_{DS.Sum.Ver} = 0\,kN$ $M_{DS.Sum.Ver} = 0\,kN \cdot m$

$F_{gateH.Sum} = 103.4\,kN$ $M_{gateH.Sum} = 316.1\,kN \cdot m$

$W_{Water.Above.Sum} = 0$ $M_{Water.Above.Sum} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ $M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$

$F_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$

$W_{Granular.Post.EQ} = 0\,kN$

$M_{US.silt.Ver} = 0\,kN \cdot m$

$M_{DS.fill.Hor} = 0$

$M_{DS.fill.Ver} = 0$

$M_{Granular.Post.EQ} = 0\,kN \cdot m$

Uplift (U):

$F_{U0.eq.Hor} = 0 \cdot kN$

$F_{U0.eq.Ver} = -367.7 \cdot kN$

$M_{U0.eq} = 1949 \cdot kN \cdot m$

Other Forces:

$F_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$

$M_{anchor.Hor} = 0$

$M_{anchor.Ver} = 0$

$M_{other.Hor.1} = 0$

$M_{other.Ver.1} = 0$

LC.6 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.eq.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) = 363.8\,kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}\right) + \left(F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Post.EQ}\right) + \left(F_{U0.eq.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 2160\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 363.8 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2160.0 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \ldots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Post.EQ}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 10047.6\,kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.eq}\right) = 2753.8\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 7293.8\,kN \cdot m$$

LC.6 - Resultant and Bearing Stresses

$x_0 := \dfrac{M_{net0}}{F_{perp0}} = 3.38\,m$

$E_0 := \dfrac{L_{incl}}{2} - x_0 = 0.60\,m$

$L_{incl} = 7.95\,m$
$M_{net0} = 7293.8\,kN \cdot m$
$F_{perp0} = 2160.0\,kN$

Stress Calculations

$q_{max0} = 235.4\,kPa$ $q_{min0} = 89.0\,kPa$

$L_{comp0} = 7.95\,m$

$L_{tens0} = 0.00\,m$

$L_{crack0} = 0.00\,m$

$L_{crack0} := \begin{cases} L_{crack.eq} & \text{if } L_{crack.eq} > L_{crack0} \\ L_{crack0} & \text{otherwise} \end{cases} = 0.00$

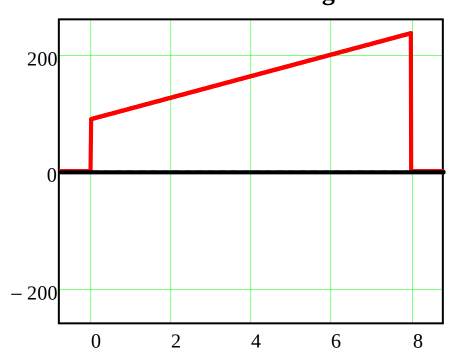
Adjust the crack length to be larger of eq, or post-eq load case.

$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \dfrac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2159969$

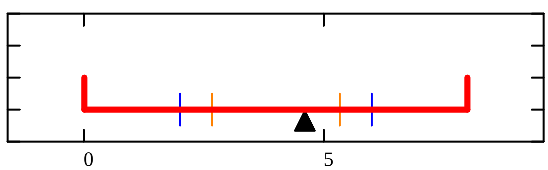
$F_{tens0} := \dfrac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$

$\dfrac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\dfrac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\dfrac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.6 - Sliding

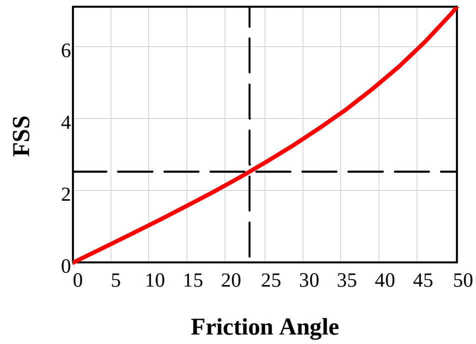
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$

$FSS_0(\phi_{cf}) = 2.52$

Factor of safety against sliding for specified friction angle



LC.6 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 1 & \text{if } L_{crack0} > L_{crack.eq} \\ 0 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

Cracked Base Analysis

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Summary of Forces/Moments

Dead Loads (and related seismic)

$W_{conc} = 1567.8 \cdot kN$ $M_{conc} = 6231.8 \cdot kN \cdot m$
$F_{eq.conc.Hor} = 130.8\,kN$ $M_{eq.conc.Hor} = 370.7\,kN \cdot m$
$F_{eq.conc.Ver} = 87.2\,kN$ $M_{eq.conc.Ver} = 346.5\,kN \cdot m$

$W_{log.Sum} = 0$ $M_{log.Sum} = 0$
$W_{log.Win} = 0$ $M_{log.Win} = 0$
$W_{log.IDF} = 0$ $M_{log.Win} = 0$

$F_{eq.log.Hor} = 0$ $M_{eq.log.Hor} = 0$
$F_{eq.log.Ver} = 0$ $M_{eq.log.Ver} = 0$

$W_{slab} = 959.9\,kN$ $M_{slab} = 3815.8\,kN \cdot m$
$F_{eq.slab.Hor} = 80.1\,kN$ $M_{eq.slab.Hor} = 550.6\,kN \cdot m$
$F_{eq.slab.Ver} = 53.4\,kN$ $M_{eq.slab.Ver} = 212.2\,kN \cdot m$

$W_{tower} = 0$ $M_{tower} = 0$
$F_{eq.tower.Hor} = 0$ $M_{eq.tower.Hor} = 0$
$F_{eq.tower.Ver} = 0$ $M_{eq.tower.Ver} = 0$

Soil Loads (and related seismic)

$F_{US.silt.Hor} = 0\,kN$ $M_{US.silt.Hor} = 0\,kN \cdot m$
$F_{eq.silt.Hor} = 0\,kN$ $M_{eq.silt.Hor} = 0\,kN \cdot m$
$W_{US.silt} = 0\,kN$ $M_{US.silt.Ver} = 0\,kN \cdot m$
$F_{eq.silt.Ver} = 0\,kN$ $M_{eq.silt.Ver} = 0\,kN \cdot m$

$F_{DS.fill.Hor} = 0$ $M_{DS.fill.Hor} = 0$
$F_{eq.fill.Hor} = 0$ $M_{eq.fill.Hor} = 0$
$F_{eq.fill.Ver} = 0$ $M_{eq.fill.Ver} = 0$
$W_{DS.fill} = 0$ $M_{DS.fill.Ver} = 0$
$W_{Granular.Sum} = 0\,kN$ $M_{Granular.Sum} = 0\,kN \cdot m$
$F_{eq.Granular.Ver} = 0\,kN$ $M_{eq.Granular.Ver} = 0\,kN \cdot m$
$F_{eq.Granular.Hor} = 0\,kN$ $M_{eq.Granular.Hor} = 0\,kN \cdot m$

Uplift Forces

$F_{U0.Sum} = 367.7\,kN$ $M_{U0.Sum} = 1949 \cdot kN \cdot m$
$F_{U0.Sum.Hor} = 0 \cdot kN$
$F_{U0.Sum.Ver} = -367.7 \cdot kN$

$F_{U0.Win} = 260.6\,kN$ $M_{U0.Win} = 1381.2 \cdot kN \cdot m$
$F_{U0.Win.Hor} = 0 \cdot kN$
$F_{U0.Win.Ver} = -260.6 \cdot kN$

$F_{U0.IDF} = 761.6\,kN$ $M_{U0.IDF} = 3165.8 \cdot kN \cdot m$
$F_{U0.IDF.Hor} = 0 \cdot kN$
$F_{U0.IDF.Ver} = -761.6 \cdot kN$

$F_{U0.eq} = 367.7\,kN$ $M_{U0.eq} = 1949 \cdot kN \cdot m$
$F_{U0.eq.Hor} = 0 \cdot kN$
$F_{U0.eq.Ver} = -367.7 \cdot kN$

Hydraulic Forces (and related seismic)

$F_{US.Sum.Hor} = 260.4 \cdot kN$ $M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$
$F_{eq.HD.US} = 23.3\,kN$ $M_{eq.HD.US} = 52.8\,kN \cdot m$
$F_{US.Sum.Ver} = 0 \cdot kN$ $M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$W_{Water.Above.Sum} = 0$ $M_{Water.Above.Sum} = 0$
$F_{eq.Water.Above.Ver} = 0$ $M_{eq.Water.Above.Ver} = 0$
$F_{eq.Water.Above.Hor} = 0$ $M_{eq.Water.Above.Hor} = 0$

$F_{US.Win.Hor} = 130.8 \cdot kN$ $M_{US.Win.Hor} = 174 \cdot kN \cdot m$
$F_{US.Win.Ver} = 0 \cdot kN$ $M_{US.Win.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.Win} = 0$ $M_{Water.Above.Win} = 0$

$F_{US.IDF.Hor} = 353.6 \cdot kN$ $M_{US.IDF.Hor} = 752.8 \cdot kN \cdot m$
$F_{US.IDF.Ver} = 0 \cdot kN$ $M_{US.IDF.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.IDF} = 0$ $M_{Water.Above.IDF} = 0$

$F_{DS.Sum.Hor} = 0\,kN$ $M_{DS.Sum.Hor} = 0\,kN \cdot m$
$F_{DS.Sum.Ver} = 0\,kN$ $M_{DS.Sum.Ver} = 0\,kN \cdot m$

$F_{DS.Win.Hor} = 0\,kN$ $M_{DS.Win.Hor} = 0\,kN \cdot m$
$F_{DS.Win.Ver} = 0\,kN$ $M_{DS.Win.Ver} = 0\,kN \cdot m$

$F_{DS.IDF.Hor} = 207.9\,kN$ $M_{DS.IDF.Hor} = 348.5\,kN \cdot m$
$F_{DS.IDF.Ver} = 0\,kN$ $M_{DS.IDF.Ver} = 0\,kN \cdot m$

$F_{gateH.Sum} = 103.4\,kN$ $M_{gateH.Sum} = 316.1\,kN \cdot m$
$F_{eq.HD.gate} = 9\,kN$ $M_{eq.HD.gate} = 32.1\,kN \cdot m$
$F_{gateH.Win} = 33.9\,kN$ $M_{gateH.Win} = 87.2\,kN \cdot m$
$F_{gateH.IDF} = 150.5\,kN$ $M_{gateH.IDF} = 477.9\,kN \cdot m$
$F_{drag} = 0$ $M_{drag} = 0$

Ice Loads

$F_{ice.1} = 139.9\,kN$ $M_{ice.1} = 516.1\,kN \cdot m$
$F_{ice.gate} = 127.3\,kN$ $M_{ice.gate} = 469.6\,kN \cdot m$
$F_{ice} = 267.1\,kN$ $M_{ice} = 985.7\,kN \cdot m$

$F_{ice.1.usual} = 125.6\,kN$ $M_{ice.1.usual} = 463.6\,kN \cdot m$
$F_{ice.gate.usual} = 114.3\,kN$ $M_{ice.gate.usual} = 421.8\,kN \cdot m$
$F_{ice.usual} = 239.9\,kN$ $M_{ice.usual} = 885.3\,kN \cdot m$

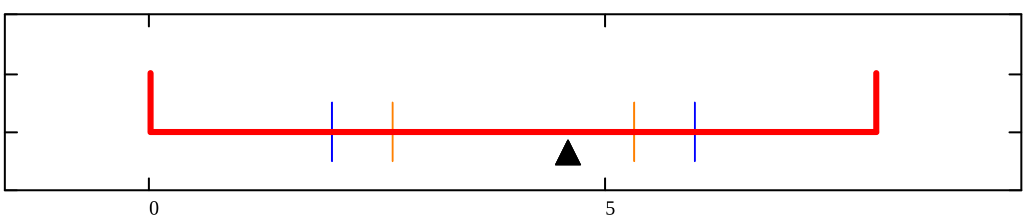
Other Forces:

$F_{anchor.Hor} = 0$ $M_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$ $M_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$ $M_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$ $M_{other.Ver.1} = 0$

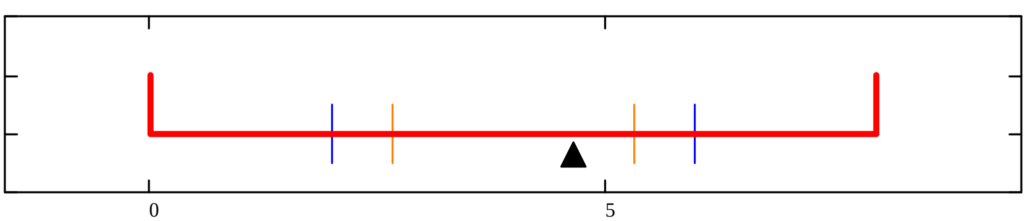
Results of Analysis

	FSS (Φ.cf)	E (m)	x.o (m)	L.comp (m)	% of Base in Compression	L.crack (m)	F.hor (kN)	F.ver (kN)	F.parallel (kN)	F.Perp (kN)	q.max (kPa)
LC.1 - Summer	2.52	0.60	3.38	7.95	100%	0.00	363.8	2,160.0	363.8	2,160.0	235.4
LC.2 - Winter (Usual)	2.38	0.66	3.32	7.95	100%	0.00	404.6	2,267.1	404.6	2,267.1	254.8
LC.3 - IDF	2.53	0.58	3.40	7.95	100%	0.00	296.2	1,766.1	296.2	1,766.1	190.5
LC.4 - Winter (Unusual)	2.23	0.70	3.27	7.95	100%	0.00	431.8	2,267.1	431.8	2,267.1	260.5
LC.5 - EQ	1.41	1.14	2.84	7.95	100%	0.00	606.9	2,019.4	606.9	2,019.4	281.9
LC.6 - Post - EQ	2.52	0.60	3.38	7.95	100%	0.00	363.8	2,160.0	363.8	2,160.0	235.4

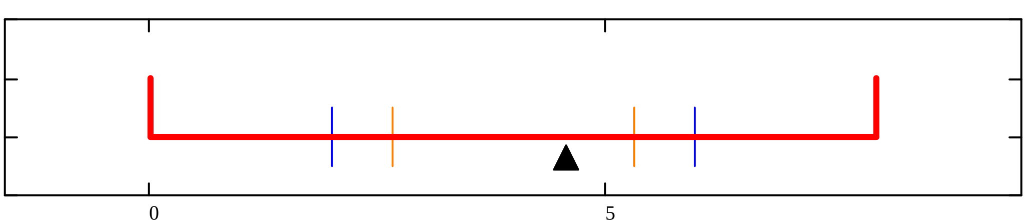
Location of Resultant



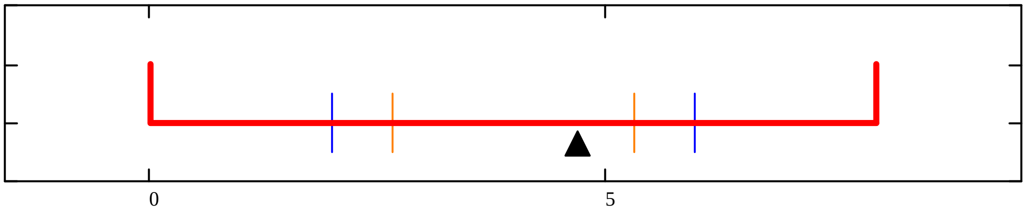
LC 1



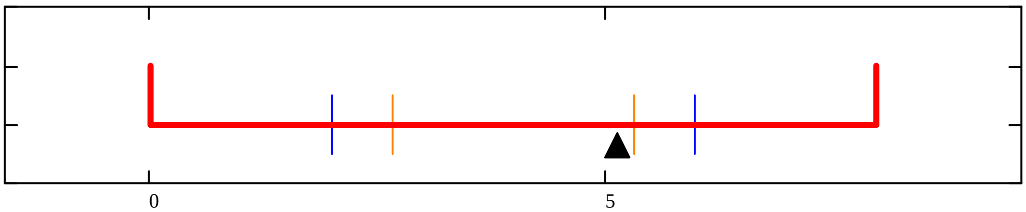
LC 2



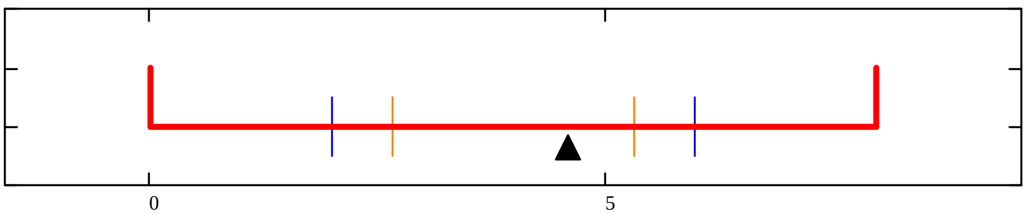
LC 3



LC 4



LC 5



LC 6

KGS GROUP

DESIGN CALCULATIONS COVER SHEET

Project No. :	17-3212-001	**Project Name :**	Howson Dam (South Structure)		
File No. :		**Discipline :**	Structural Engineering		
Calculation Title :	**Spillway Stability Analysis Sheet (LRIA - v3.3)**				
Calculation No. :	CIV-002	**Prepared by :**	HS	**Date :**	Feb. 23, 2018
No. of Sheets :		**Checked by :**	YF	**Date :**	April 20,2018
Supersedes Calc. No. :		**Approved by :**		**Date :**	

Calculation Description :

The dam has been reviewed against LRIA technical bulletins

Related Design Concept :

Stability analysis for the structures is carried out using the "Gravity Method".
Six loading cases are utilized in the analyses based on the LRIA Technical Bulletin "Structural Design and Factors of Safety (August 2011).

Reference Codes and Standards :

1. *Design of Small Dams,* Third Edition, U.S. Government Printing Office, Washington, D.C. 1987.
2. Structural Design and Factors of Safety – Technical Bulletin Ontario Ministry of Natural Resources (August 2011)
3. 2009 Parks Canada Directive for Dam Safety Program of Dams and Water-Retaining Structures

ENGINEER'S SEAL

Rev. #	**Rev. Description**	**Rev. Author**	**Date Revised**	**Checked by**	**Approved by**	**Approved Date**

Notes and Figures

Properties of Materials

$\gamma_w := 9.81 \frac{kN}{m^3}$ *Water density*

$\gamma_{conc} := 23.5 \cdot \frac{kN}{m^3}$ *Concrete density*

$\phi_{cf} := 23 \cdot deg$ *Friction angle of concrete/foundation interface*

$c := 0MPa$ *Cohesion at concrete/foundation interface (generally set to 0)*

$f_{t.cf} := \frac{-c}{2} = 0$ *Tensile strength at concrete/rock interface (generally set to 0, or 0.5 x cohesion). This is a negative number.*

$\gamma_{silt} := 7.7 \cdot \frac{kN}{m^3}$ *Silt density*

$\phi'_{silt} := 20 \cdot deg$ *Angle of internal friction for silt at rest condition*

$\gamma_{fill} := 7.7 \cdot \frac{kN}{m^3}$ *Backfill density*

$\phi'_{fill} := 30 \cdot deg$ *Angle of internal friction for backfill at rest condition*

$\gamma_{timber} := 10 \cdot \frac{kN}{m^3}$ *Timber density (for stoplogs)*

$\gamma_{Granular} := 0 \frac{kN}{m^3}$ *Weight of granular material or rip rap on top of section*

Water Levels

Usual Summer Operating Levels

Used in LC 1,4,5

$WL_{US.Sum} := 310.9m$ *Upstream water level (left side)*

$WL_{DS.Sum} := 306.06m$ *Downstream water level (right side)*

Usual Winter Operating Levels

Used in LC 2

$WL_{US.Win} := 309.26m$

$WL_{DS.Win} := 306.06m$

Unusual Flood Discharge Levels

Used in LC 3

$WL_{US.IDF} := 311.9m$

$WL_{DS.IDF} := 310.3m$

Seismic Accelerations

$\lambda_{Hor} := 0.0834$ *Horizontal component of earthquake intensity = ratio of earthquake acceleration to acceleration due to gravity (unitless number)*

$\lambda_{Ver} := \frac{2}{3} \cdot \lambda_{Hor} = 0.056$

Vertical component of earthquake intensity. CDA recommends a factor between 1/2 and 2/3 of the horizontal acceleration (pg 15 of Seismic Hazard Considerations Technical Bulletin)

Structure Geometry

Input

Note: Enter structure geometry as series of points on X-Y grid. Align structure so that upstream is on the left side. Structure outline is "closed" automatically (last point is assigned same values as first). Ensure that values of ELE.Base.L and ELE.Base.R are adjusted to correspond with the lowest upstream and downstream elevations.

Input X & Y coordinates

$X := \begin{pmatrix} 0 \\ 6.20 \\ 6.20 \\ 3.59 \\ 1.39 \\ 0 \end{pmatrix} \cdot m$ $\quad Y := \begin{pmatrix} 306.06 \\ 306.06 \\ 306.96 \\ 306.96 \\ 309.26 \\ 309.26 \end{pmatrix} \cdot m$

$ELE_{Base.L} := 306.06m$ *Elevation of left side of base (lowest point)*

$ELE_{Base.R} := 306.06m$ *Elevation of right side of base (lowest point)*

$ELE_{Top} := 309.26m$ *Elevation of top of dam (for hydrostatic, hydrodynamic forces)*

$B := 11.58 \cdot m - \frac{2.03 + 1.32}{2} \cdot m = 9.91\,m$ *Set unit width of structure (1m if using metric, 1ft if using imperial units)*

$\omega_{US} := 0deg$ *Incline of upstream face from vertical (positive number in degrees)*

$\omega_{DS} := 0deg$ *Incline of downstream face from vertical (positive number in degrees)*

$L_{hor} := \max(X) - \min(X) = 6.2\,m$ *Horizontal projection of base*

$\alpha := \operatorname{atan}\left(\frac{ELE_{Base.R} - ELE_{Base.L}}{L_{hor}}\right) = 0 \cdot deg$ *Angle of inclination of base. Positive is counter clockwise from the horizontal in the downstream direction*

$L_{incl} := \frac{L_{hor}}{\cos(\alpha)} = 6.2\,m$ *Inclined length of concrete-foundation interface*

Variables for Combines Structure Model

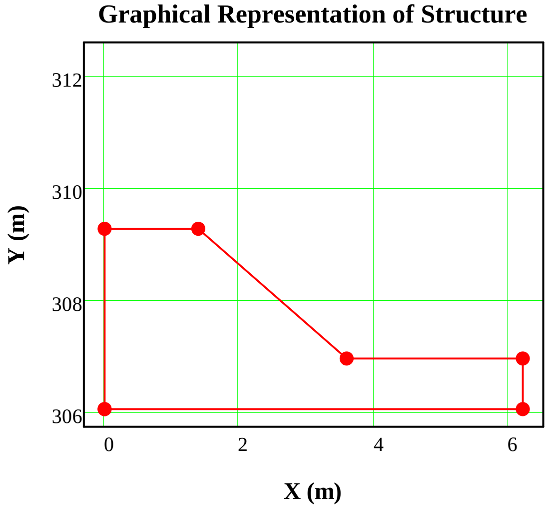
$B_{roll} := B = 9.91\,m$

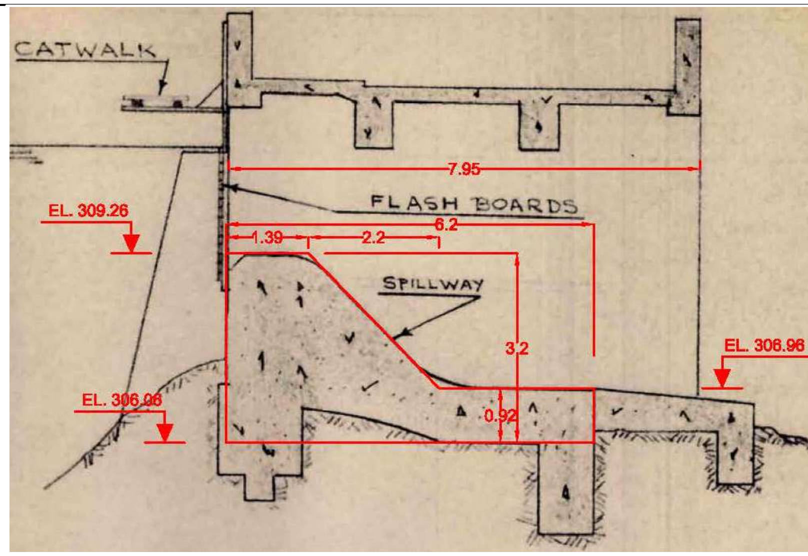
$L_{incl.roll} := L_{incl} = 6.2\,m$

$\alpha_{roll} := \alpha$

Input

Plot Functions





Computation of Area and Center of Gravity

Gate/Stoplog Geometry

$X_{log} := 0 \cdot m$ *Horizontal distance from left side (x=0) to location of gate/stoplogs*

$ELE_{sill} := 309.26m$ *Elevation of the bottom of the gate/stoplogs*

$ELE_{gate.top} := 309.26m$ *Elevation of top of gate/stoplogs*

$Trib_{gate} := 0 \cdot m$ *Tributary width of gates/logs experiencing hydrostatic/hydrodynamic/ice forces*

$Wi_{gate} := 11.58 \cdot m - \frac{2.03 + 1.32}{2} \cdot m = 9.91\,m$ *Total width of gate/stoplogs (for calculating weight on slab/rollway)*

Forces on Gates/Stoplogs Transferred into Piers

$Gates_{Sum.Hyd} := 0$ *If gates are present during summer operation (and earthquake), set = 1, otherwise set to 0*

$Gates_{Win.Hyd} := 0$ *If gates are present during winter operation, set = 1, otherwise set to 0*

$Gates_{IDF.Hyd} := 0$ *If gates are present during IDF, set = 1, otherwise set to 0*

Weight of Gates/Stoplogs bearing on rollway/slab

$Gates_{Sum.Weight} := 1$ *If gates are present during summer operation (and earthquake), set = 1, otherwise set to 0*

$Gates_{Win.Weight} := 1$ *If gates are present during winter operation, set = 1, otherwise set to 0*

$Gates_{IDF.Weight} := 1$ *If gates are present during IDF, set = 1, otherwise set to 0*

Weight of Main Structure (D)

Weight of Stoplogs (D)

Weight of Slab (D) - NOT APPLICABLE

Weight of Tower(D) - NOT APPLICABLE

Weight of Riprap / Granular Material on Top of Section - NOT APPLICABLE

Input coordinates

Calculations

Results

Upstream Hydrostatic Force (H)

Figures

Calculations

Downstream Hydrostatic Force (H)

Hydrostatic Force on Gates (H)

Calculations

Hydraulic Drag Force (H)

Weight of Water Above Section (H)

Input coordinates

Reference Coordinates of Structure

$$X_{struct} = \begin{pmatrix} 0.000 \\ 6.200 \\ 6.200 \\ 3.590 \\ 1.390 \\ 0.000 \\ 0.000 \end{pmatrix} m \qquad Y_{struct} = \begin{pmatrix} 306.060 \\ 306.060 \\ 306.960 \\ 306.960 \\ 309.260 \\ 309.260 \\ 306.060 \end{pmatrix} m$$

$WL_{US.Sum} - ELE_{Top} = 1.6\,m$

$WL_{US.Win} - ELE_{Top} = 0\,m$

$WL_{US.IDF} - ELE_{Top} = 2.6\,m$

$WL_{US.Sum} = 310.900\,m$
$WL_{DS.Sum} = 306.060\,m$
$WL_{US.Win} = 309.260\,m$
$WL_{DS.Win} = 306.060\,m$
$WL_{US.IDF} = 311.900\,m$
$WL_{DS.IDF} = 310.300\,m$
$ELE_{Base.L} = 306.060\,m$
$ELE_{Base.R} = 306.060\,m$
$ELE_{Top} = 309.260\,m$
$L_{hor} = 6.200\,m$
$B = 9.905\,m$

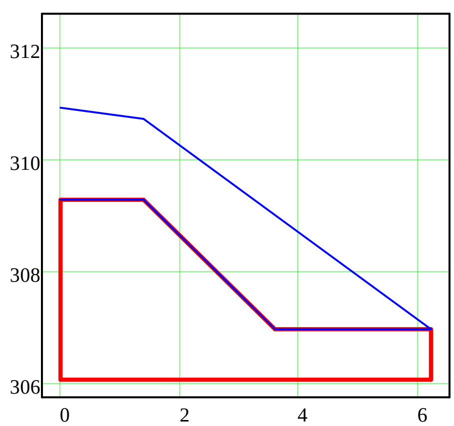
Insert coordinates of shape of water above structure

Note: if the water level is below the elevation of the top of the structure, then the arrays below will automatically be set 0 and will not factor into the calculations

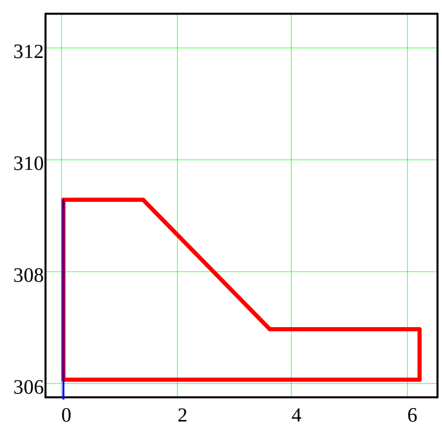
$B_{water.Sum} := B$ $\qquad$ $B_{water.Win} := B$

$$X_{water.Sum} := \begin{pmatrix} 0 \\ 1.39 \\ 6.20 \\ 3.59 \\ 1.39 \\ 0 \\ 0 \end{pmatrix} m \qquad Y_{water.Sum} := \begin{pmatrix} 310.9 \\ 310.7 \\ 306.96 \\ 306.96 \\ 309.26 \\ 309.26 \\ 309.26 \end{pmatrix} m \qquad X_{water.Win} := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} m \qquad Y_{water.Win} := \begin{pmatrix} 309.26 \\ 309.26 \\ 307.15 \\ 307.15 \\ 0 \\ 0 \\ 0 \end{pmatrix} m$$

Water Above Structure (Summer)



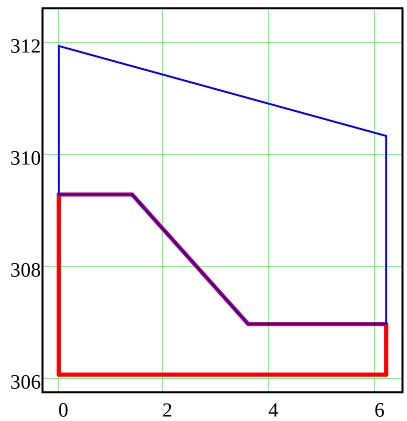
Water Above Structure (Winter)



$B_{water.IDF} := B$

$$X_{water.IDF} := \begin{pmatrix} 0 \\ 1.39 \\ 3.59 \\ 6.2 \\ 6.2 \\ 0 \\ 0 \end{pmatrix} m \qquad Y_{water.IDF} := \begin{pmatrix} 309.26 \\ 309.26 \\ 306.96 \\ 306.96 \\ \frac{WL_{DS.IDF}}{m} \\ \frac{WL_{US.IDF}}{m} \\ 309.26 \end{pmatrix} m$$

Water Above Structure (IDF)



Input coordinates

Calculations

Results

Initial Uplift Forces (U)

Figures

Uplift Function Definition

Input and Calculation

Plot of Results

Upstream Silt Buildup (S)

Downstream Backfill (S) - NOT APPLICABLE

Ice Loading (I)

USUAL LOAD CASE

Direct ice load on structure

$IceLoad_{usual} := 75 \frac{kN}{m}$ — *Ice loading on structure (enter as kN/m)*

$W_{igate} = 9.91\,m$
$Trib_{gate} = 0.00$
$ELE_{Base.R} = 306.060\,m$
$WL_{US.Win} = 309.260\,m$
$B = 9.91\,m$
$Gates_{Win.Hyd} = 0$

$F_{ice.1.usual} := IceLoad_{usual} B = 742.9 \cdot kN$ — *Force acting on the structure*

$ELE_{ice} := WL_{US.Win} - 0.3m = 308.96\,m$ — *Elevation of force (assumed to act at 0.3m below water level)*

$MA := ELE_{ice} - ELE_{Base.R} = 2.9\,m$ — *Moment arm is vertical distance from force to right side of base*

$M_{ice.1.usual} := F_{ice.1.usual} \cdot MA = 2154.3 \cdot kN \cdot m$ — *Moment about right side of base*

Ice load on adjacent gates/stop logs

Note: Ice load in this section acts on the tributary gate width to be transferred into gate slots

$$F_{ice.gate.usual} := \begin{cases} 0 & \text{if } Gates_{Win.Hyd} = 0 \\ IceLoad_{usual} \cdot Trib_{gate} & \text{otherwise} \end{cases} = 0 \cdot kN$$

$M_{ice.gate.usual} := F_{ice.gate.usual} \cdot MA = 0 \cdot kN \cdot m$

$F_{ice.usual} := F_{ice.1.usual} + F_{ice.gate.usual} = 742.9\,kN$

$M_{ice.usual} := M_{ice.1.usual} + M_{ice.gate.usual} = 2154.3 \cdot kN \cdot m$

UNUSUAL LOAD CASE

Direct ice load on structure

$IceLoad := 83.5 \frac{kN}{m}$ — *Ice loading on structure (enter as kN/m)*

$F_{ice.1} := IceLoad\,B = 827.1 \cdot kN$ — *Force acting on the structure*

$M_{ice.1} := F_{ice.1} \cdot MA = 2398.5 \cdot kN \cdot m$ — *Moment about right side of base*

Ice load on adjacent gates/stop logs

Note: Ice load in this section acts on the tributary gate width to be transferred into gate slots

$$F_{ice.gate} := \begin{cases} 0 & \text{if } Gates_{Win.Hyd} = 0 \\ IceLoad \cdot Trib_{gate} & \text{otherwise} \end{cases} = 0 \cdot kN$$

$M_{ice.gate} := F_{ice.gate} \cdot MA = 0 \cdot kN \cdot m$

$F_{ice} := F_{ice.1} + F_{ice.gate} = 827.1\,kN$

$M_{ice} := M_{ice.1} + M_{ice.gate} = 2398.5 \cdot kN \cdot m$

Seismic Forces - Inertia of Structure Dead Load (Q)

Seismic Forces - Hydrodynamic Forces (Q)

Figures

Calculations

Seismic Forces - Dynamic Soil Pressures (Q)

Tensioned Anchors - NOT APPLICABLE

Other Forces - NOT APPLICABLE

Load Case 1. Usual Loading Summer Case (D+H+S+U)

LC.1 - Summary of Forces

Deadloads (D):

$W_{conc} = 2631.9 \cdot kN$

$W_{log.Sum} = 0$

$W_{slab} = 0$

$W_{tower} = 0$

$M_{conc} = 10523.8 \cdot kN \cdot m$

$M_{log.Sum} = 0$

$M_{slab} = 0$

$M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 1007.4 \cdot kN$

$F_{US.Sum.Ver} = 0 \cdot kN$

$F_{DS.Sum.Hor} = 0\,kN$

$F_{DS.Sum.Ver} = 0\,kN$

$M_{US.Sum.Hor} = 1346.6 \cdot kN \cdot m$

$M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$M_{DS.Sum.Hor} = 0\,kN \cdot m$

$M_{DS.Sum.Ver} = 0\,kN \cdot m$

$F_{gateH.Sum} = 0$

$W_{Water.Above.Sum} = 836.2\,kN$

$M_{gateH.Sum} = 0$

$M_{Water.Above.Sum} = 2948.6\,kN \cdot m$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$

$W_{US.silt} = 0\,kN$

$F_{DS.fill.Hor} = 0\,kN$

$W_{DS.fill} = 0\,kN$

$M_{US.silt.Hor} = 0\,kN \cdot m$

$M_{US.silt.Ver} = 0\,kN \cdot m$

$M_{DS.fill.Hor} = 0\,kN \cdot m$

$M_{DS.fill.Ver} = 0\,kN \cdot m$

$W_{Granular.Sum} = 0$

$M_{Granular.Sum} = 0$

Uplift (U):

$F_{U0.Sum.Hor} = 0 \cdot kN$

$F_{U0.Sum.Ver} = -1457.9 \cdot kN$

$M_{U0.Sum} = 6026 \cdot kN \cdot m$

Other Forces:

$F_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$

$M_{anchor.Hor} = 0$

$M_{anchor.Ver} = 0$

$M_{other.Hor.1} = 0$

$M_{other.Ver.1} = 0$

LC.1 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.Sum.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) = 1007.4\,kN$$

Sum of horizontal forces

$$F_{ver0} := \left(W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}\right) + \left(F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Sum}\right) + \left(F_{U0.Sum.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 2010.2\,kN$$

Sum of vertical forces

$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 1007.4 \cdot kN$ *Forces acting parallel to uncracked base*

$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2010.2 \cdot kN$ *Forces acting perpendicular to uncracked base*

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \ldots + \left(M_{US.silt.Ver} + M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{Granular.Sum}\right) \ldots + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 13472.3 \cdot kN \cdot m$$

Sum of stabilizing moments

$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Sum}\right) = 7372.6 \cdot kN \cdot m$ *Sum of overturning moments*

$M_{net0} := M_{stab0} - M_{overturn0} = 6099.8 \cdot kN \cdot m$ *Net resisting moment*

LC.1 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 3.03\,m$ — *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.07\,m$ — *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 6.20\,m$
$M_{net0} = 6099.8 \cdot kN \cdot m$
$F_{perp0} = 2010.2\,kN$

Stress Calculations

$q_{max0} = 34.8\,kPa$ $q_{min0} = 30.7\,kPa$ — *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp0} = 6.20\,m$ — *Length of base in compression before iterative cracked base analysis*

$L_{tens0} = 0.00\,m$ — *Length of base in tension before iterative cracked base analysis*

$L_{crack0} = 0.00\,m$ — *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2010152.9$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

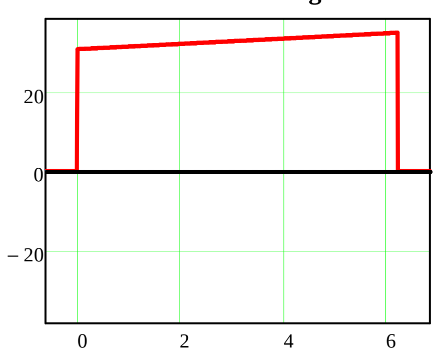
Compression and tension forces in foundation

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression*

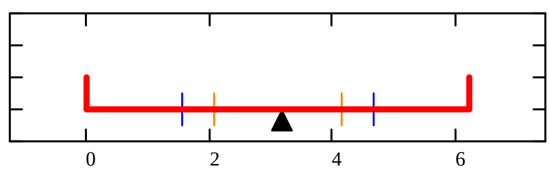
$\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension*

$\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

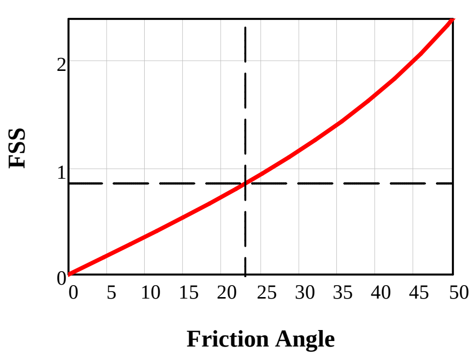
LC.1 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 0.85$ — *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 6.20\,m$
$\alpha = 0 \cdot deg$
$B = 9.91\,m$



LC.1 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

$crackactive := 0$

No crack due to combination of sections

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 2. Usual Loading Winter Case (D+H+S+U+I)

LC.2 - Summary of Forces

Deadloads (D):

$W_{conc} = 2631.9 \cdot kN$ $\quad M_{conc} = 10523.8 \cdot kN \cdot m$

$W_{log.Win} = 0$ $\quad M_{log.Win} = 0$

$W_{slab} = 0$ $\quad M_{slab} = 0$

$W_{tower} = 0$ $\quad M_{tower} = 0$

Hydraulic (H):

$F_{US.Win.Hor} = 497.5 \cdot kN$ $\quad M_{US.Win.Hor} = 530.7 \cdot kN \cdot m$

$F_{US.Win.Ver} = 0 \cdot kN$ $\quad M_{US.Win.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Win.Hor} = 0 kN$ $\quad M_{DS.Win.Hor} = 0 kN \cdot m$

$F_{DS.Win.Ver} = 0 kN$ $\quad M_{DS.Win.Ver} = 0 kN \cdot m$

$F_{gateH.Win} = 0$ $\quad M_{gateH.Win} = 0$

$W_{Water.Above.Win} = 0 kN$ $\quad M_{Water.Above.Win} = 0 kN \cdot m$

Soil (S):

$F_{US.silt.Hor} = 0 kN$ $\quad M_{US.silt.Hor} = 0 kN \cdot m$

$W_{US.silt} = 0 kN$ $\quad M_{US.silt.Ver} = 0 kN \cdot m$

$F_{DS.fill.Hor} = 0 kN$ $\quad M_{DS.fill.Hor} = 0 kN \cdot m$

$W_{DS.fill} = 0 kN$ $\quad M_{DS.fill.Ver} = 0 kN \cdot m$

$W_{Granular.Win} = 0$ $\quad M_{Granular.Win} = 0$

Uplift (U):

$M_{U0.Win} = 3984.1 \cdot kN \cdot m$

$F_{U0.Win.Hor} = 0 \cdot kN$

$F_{U0.Win.Ver} = -963.9 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ $\quad M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ $\quad M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ $\quad M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ $\quad M_{other.Ver.1} = 0$

Ice (I):

$F_{ice.usual} = 742.9 \cdot kN$ $\quad M_{ice.usual} = 2154.3 \cdot kN \cdot m$

LC.2 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Win.Hor} - F_{DS.Win.Hor} + F_{gateH.Win}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.Win.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) + \left(F_{ice.usual}\right) = 1240.4 kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Win} + W_{slab} + W_{tower}\right) + \left(F_{US.Win.Ver} + F_{DS.Win.Ver} + W_{Water.Above.Win}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Win}\right) + \left(F_{U0.Win.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1668 kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 1240.4 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1668.0 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Win.Ver} + M_{DS.Win.Hor} + M_{DS.Win.Ver} + M_{Water.Above.Win}\right) \ldots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Win}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 10523.8 \cdot kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Win.Hor} + M_{gateH.Win}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Win}\right) + \left(M_{ice.usual}\right) = 6669.2 \cdot kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 3854.6 \cdot kN \cdot m$$

LC.2 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.31\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.79\,m$ *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 6.20\,m$
$M_{net0} = 3854.6 \cdot kN \cdot m$
$F_{perp0} = 1668.0\,kN$

Stress Calculations

$q_{max0} = 47.9\,kPa$ $q_{min0} = 6.4\,kPa$

$L_{comp0} = 6.20\,m$

$L_{tens0} = 0.00\,m$

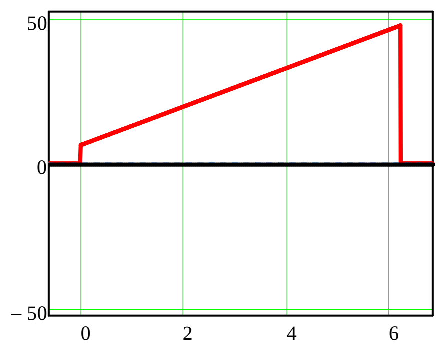
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1667995.1$$

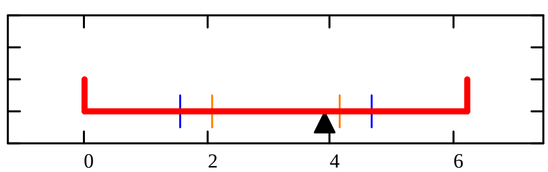
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



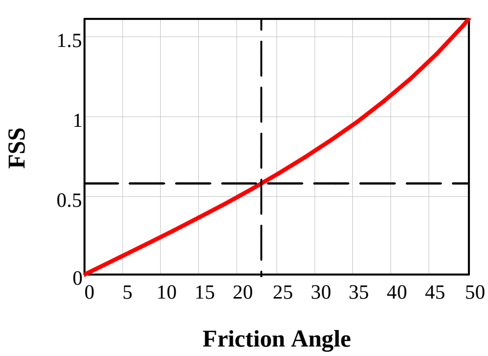
Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.2 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$ *Define function to evaluate sliding using a range of friction angles*

$FSS_0(\phi_{cf}) = 0.57$ *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 6.20\,m$
$\alpha = 0 \cdot deg$
$B = 9.91\,m$



LC.2 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

$crackactive := 0$

No crack due to combination of sections

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 3. Unusual Loading IDF ($D+H_{IDF}+S+U_{IDF}$)

LC.3 - Summary of Forces

Deadloads (D):

$W_{conc} = 2631.9 \cdot kN$ | $M_{conc} = 10523.8 \cdot kN \cdot m$

$W_{log.IDF} = 0$ | $M_{log.IDF} = 0$

$W_{slab} = 0$ | $M_{slab} = 0$

$W_{tower} = 0$ | $M_{tower} = 0$

Hydraulic (H):

$F_{US.IDF.Hor} = 1318.4 \cdot kN$ | $M_{US.IDF.Hor} = 1844.1 \cdot kN \cdot m$

$F_{US.IDF.Ver} = 0 \cdot kN$ | $M_{US.IDF.Ver} = 0 \cdot kN \cdot m$

$F_{DS.IDF.Hor} = 820.9 kN$ | $M_{DS.IDF.Hor} = 1048.1 kN \cdot m$

$F_{DS.IDF.Ver} = 0 kN$ | $M_{DS.IDF.Ver} = 0 kN \cdot m$

$F_{gateH.IDF} = 0$ | $M_{gateH.IDF} = 0$

$F_{drag} = 0$ | $M_{drag} = 0$

$W_{Water.Above.IDF} = 1937.6 kN$ | $M_{Water.Above.IDF} = 5517.5 kN \cdot m$

Soil (S):

$F_{US.silt.Hor} = 0 kN$ | $M_{US.silt.Hor} = 0 kN \cdot m$

$W_{US.silt} = 0 kN$ | $M_{US.silt.Ver} = 0 kN \cdot m$

$F_{DS.fill.IDF.Hor} = 0 kN$ | $M_{DS.fill.IDF.Hor} = 0 kN \cdot m$

$W_{DS.fill.IDF} = 0 kN$ | $M_{DS.fill.IDF.Ver} = 0 kN \cdot m$

$W_{Granular.IDF} = 0$ | $M_{Granular.IDF} = 0$

Uplift (U):

$M_{U0.IDF} = 9910.6 \cdot kN \cdot m$

$F_{U0.IDF.Hor} = 0 \cdot kN$

$F_{U0.IDF.Ver} = -3036.3 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ | $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ | $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ | $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ | $M_{other.Ver.1} = 0$

LC.3 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.IDF.Hor} - F_{DS.IDF.Hor} + F_{gateH.IDF} + F_{drag}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.IDF.Hor}\right) \dots + \left(F_{U0.IDF.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) = 497.5 kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.IDF} + W_{slab} + W_{tower}\right) + \left(F_{US.IDF.Ver} + F_{DS.IDF.Ver} + W_{Water.Above.IDF}\right) \dots + \left(W_{US.silt} + W_{DS.fill.IDF} + W_{Granular.IDF}\right) + \left(F_{U0.IDF.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1533.2 kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 497.5 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1533.2 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.IDF} + M_{slab} + M_{tower}\right) + \left(M_{US.IDF.Ver} + M_{DS.IDF.Hor} + M_{DS.IDF.Ver} + M_{Water.Above.IDF}\right) \dots + \left(M_{US.silt.Ver} + M_{DS.fill.IDF.Hor} + M_{DS.fill.IDF.Ver} + M_{Granular.IDF}\right) \dots + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 17089.3 kN \cdot m$$

$$M_{overturn0} := \left(M_{US.IDF.Hor} + M_{gateH.IDF} + M_{drag}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.IDF}\right) = 11754.6 kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 5334.6 kN \cdot m$$

LC.3 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 3.48\,m$

$E_0 := \frac{L_{incl}}{2} - x_0 = -0.38\,m$

$L_{incl} = 6.20\,m$
$M_{net0} = 5334.6\,kN \cdot m$
$F_{perp0} = 1533.2\,kN$

Stress Calculations

$q_{max0} = 34.1\,kPa$ $q_{min0} = 15.8\,kPa$

$L_{comp0} = 6.20\,m$

$L_{tens0} = 0.00\,m$

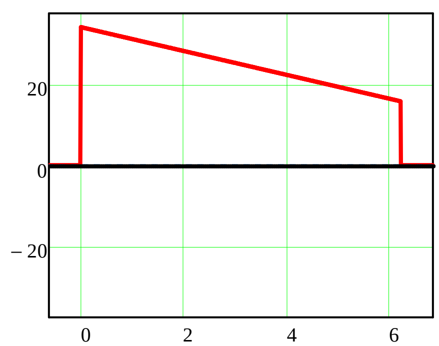
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1533223$$

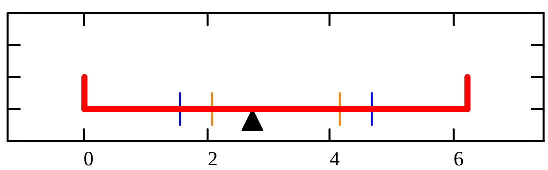
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.3 - Sliding

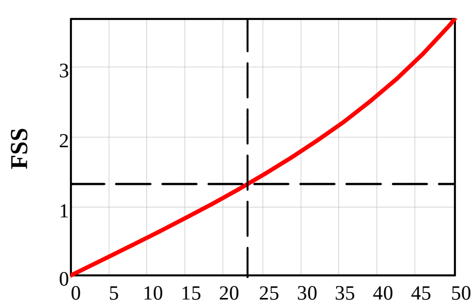
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 1.31$

Factor of safety against sliding for specified friction angle

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 6.20\,m$
$\alpha = 0 \cdot deg$
$B = 9.91\,m$



Friction Angle

LC.3 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{vmatrix} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{vmatrix} = 0$$

Determines if the cracked analysis should run.

$crackactive := 0$

No crack due to combination of sections

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 4. Unusual Loading Winter Case (D+H+S+U+I)

LC.4 - Summary of Forces

Deadloads (D):

$W_{conc} = 2631.9 \cdot kN$ — $M_{conc} = 10523.8 \cdot kN \cdot m$

$W_{log.Win} = 0$ — $M_{log.Win} = 0$

$W_{slab} = 0$ — $M_{slab} = 0$

$W_{tower} = 0$ — $M_{tower} = 0$

Hydraulic (H):

$F_{US.Win.Hor} = 497.5 \cdot kN$ — $M_{US.Win.Hor} = 530.7 \cdot kN \cdot m$

$F_{US.Win.Ver} = 0 \cdot kN$ — $M_{US.Win.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Win.Hor} = 0kN$ — $M_{DS.Win.Hor} = 0kN \cdot m$

$F_{DS.Win.Ver} = 0kN$ — $M_{DS.Win.Ver} = 0kN \cdot m$

$F_{gateH.Win} = 0$ — $M_{gateH.Win} = 0$

$W_{Water.Above.Win} = 0kN$ — $M_{Water.Above.Win} = 0kN \cdot m$

Soil (S):

$F_{US.silt.Hor} = 0kN$ — $M_{US.silt.Hor} = 0kN \cdot m$

$W_{US.silt} = 0kN$ — $M_{US.silt.Ver} = 0kN \cdot m$

$F_{DS.fill.Hor} = 0kN$ — $M_{DS.fill.Hor} = 0kN \cdot m$

$W_{DS.fill} = 0kN$ — $M_{DS.fill.Ver} = 0kN \cdot m$

$W_{Granular.Win} = 0$ — $M_{Granular.Win} = 0$

Uplift (U):

$M_{U0.Win} = 3984.1 \cdot kN \cdot m$

$F_{U0.Win.Hor} = 0 \cdot kN$

$F_{U0.Win.Ver} = -963.9 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ — $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ — $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ — $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ — $M_{other.Ver.1} = 0$

Ice (I):

$F_{ice} = 827.1 \cdot kN$ — $M_{ice} = 2398.5 \cdot kN \cdot m$

LC.4 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Win.Hor} - F_{DS.Win.Hor} + F_{gateH.Win}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.Win.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) + \left(F_{ice}\right) = 1324.6kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Win} + W_{slab} + W_{tower}\right) + \left(F_{US.Win.Ver} + F_{DS.Win.Ver} + W_{Water.Above.Win}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Win}\right) + \left(F_{U0.Win.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1668kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 1324.6 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1668.0 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Win.Ver} + M_{DS.Win.Hor} + M_{DS.Win.Ver} + M_{Water.Above.Win}\right) \ldots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Win}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 10523.8kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Win.Hor} + M_{gateH.Win}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Win}\right) + \left(M_{ice}\right) = 6913.3kN \cdot m$$

$M_{net0} := M_{stab0} - M_{overturn0} = 3610.4\,kN\cdot m$

LC.4 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.16\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.94\,m$ *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 6.20\,m$
$M_{net0} = 3610.4\,kN\cdot m$
$F_{perp0} = 1668.0\,kN$

Stress Calculations

$q_{max0} = 51.7\,kPa$ $q_{min0} = 2.6\,kPa$

$L_{comp0} = 6.20\,m$

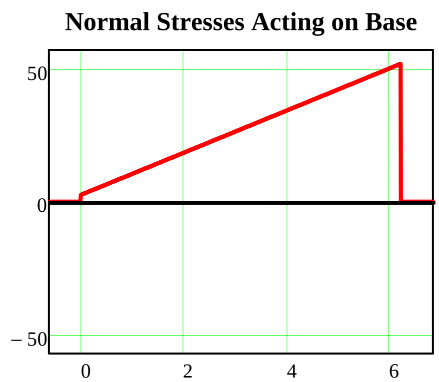
$L_{tens0} = 0.00\,m$

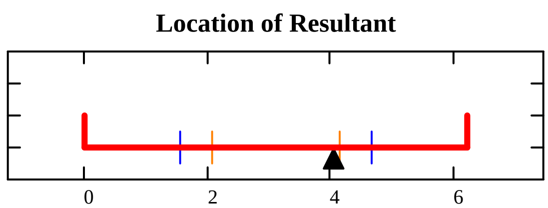
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1667995.1$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$





Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

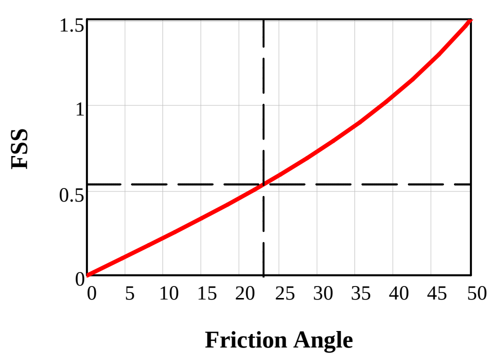
LC.4 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 0.53$ *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 6.20\,m$
$\alpha = 0 \cdot deg$
$B = 9.91\,m$



LC.4 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

$crackactive := 0$

No crack due to combination of sections

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 5. Extreme Loading Earthquake (D+H+S+Q+U_Q)

LC.5 - Summary of Forces

Deadloads (D):

$W_{conc} = 2631.9 \cdot kN$	$M_{conc} = 10523.8 \cdot kN \cdot m$
$W_{log.Sum} = 0$	$M_{log.Sum} = 0$
$W_{slab} = 0$	$M_{slab} = 0$
$W_{tower} = 0$	$M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 1007.4 \cdot kN$	$M_{US.Sum.Hor} = 1346.6 \cdot kN \cdot m$
$F_{US.Sum.Ver} = 0 \cdot kN$	$M_{US.Sum.Ver} = 0 \cdot kN \cdot m$
$F_{DS.Sum.Hor} = 0 kN$	$M_{DS.Sum.Hor} = 0 kN \cdot m$
$F_{DS.Sum.Ver} = 0 kN$	$M_{DS.Sum.Ver} = 0 kN \cdot m$
$F_{gateH.Sum} = 0$	$M_{gateH.Sum} = 0$
$W_{Water.Above.Sum} = 836.2 kN$	$M_{Water.Above.Sum} = 2948.6 kN \cdot m$

Soil (S):

$F_{US.silt.Hor} = 0 kN$	$M_{US.silt.Hor} = 0 kN \cdot m$
$W_{US.silt} = 0 kN$	$M_{US.silt.Ver} = 0 kN \cdot m$
$F_{DS.fill.Hor} = 0 kN$	$M_{DS.fill.Hor} = 0 kN \cdot m$
$W_{DS.fill} = 0 kN$	$M_{DS.fill.Ver} = 0 kN \cdot m$
$W_{Granular.EQ} = 0$	$M_{Granular.EQ} = 0$

Uplift (U):

$F_{U0.Sum.Hor} = 0 \cdot kN$	$M_{U0.Sum} = 6026 \cdot kN \cdot m$
$F_{U0.Sum.Ver} = -1457.9 \cdot kN$	

Other Forces:

$F_{anchor.Hor} = 0$	$M_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$	$M_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$	$M_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$	$M_{other.Ver.1} = 0$

Seismic (Q):

$F_{eq.conc.Hor} = 219.5\,kN$	$M_{eq.conc.Hor} = 257.8\,kN \cdot m$
$F_{eq.conc.Ver} = 146.3\,kN$	$M_{eq.conc.Ver} = 585.1\,kN \cdot m$
$F_{eq.log.Hor} = 0$	$M_{eq.log.Hor} = 0$
$F_{eq.log.Ver} = 0$	$M_{eq.log.Ver} = 0$
$F_{eq.slab.Hor} = 0$	$M_{eq.slab.Hor} = 0$
$F_{eq.slab.Ver} = 0$	$M_{eq.slab.Ver} = 0$
$F_{eq.tower.Hor} = 0$	$M_{eq.tower.Hor} = 0$
$F_{eq.tower.Ver} = 0$	$M_{eq.tower.Ver} = 0$
$F_{eq.HD.US} = 82.5\,kN$	$M_{eq.HD.US} = 123.5\,kN \cdot m$
$F_{eq.HD.gate} = 0$	$M_{eq.HD.gate} = 0$
$F_{eq.silt.Hor} = 0\,kN$	$M_{eq.silt.Hor} = 0\,kN \cdot m$
$F_{eq.silt.Ver} = 0\,kN$	$M_{eq.silt.Ver} = 0\,kN \cdot m$
$F_{eq.fill.Hor} = 0\,kN$	$M_{eq.fill.Hor} = 0\,kN \cdot m$
$F_{eq.fill.Ver} = 0\,kN$	$M_{eq.fill.Ver} = 0\,kN \cdot m$
$F_{eq.Granular.Ver} = 0$	$M_{eq.Granular.Ver} = 0$
$F_{eq.Granular.Hor} = 0$	$M_{eq.Granular.Hor} = 0$
$F_{eq.Water.Above.Ver} = 46.5\,kN$	$M_{eq.Water.Above.Ver} = 163.9\,kN \cdot m$
$F_{eq.Water.Above.Hor} = 69.7\,kN$	$M_{eq.Water.Above.Hor} = 191.2\,kN \cdot m$

LC.5 - Combine Forces and Moments

$$F_{hor0} := (F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}) + (F_{US.silt.Hor} - F_{DS.fill.Hor}) \cdots + (F_{U0.Sum.Hor}) + (F_{anchor.Hor} + F_{other.Hor.1}) \cdots + (F_{eq.conc.Hor} + F_{eq.log.Hor} + F_{eq.slab.Hor} + F_{eq.tower.Hor} + F_{eq.HD.US} + F_{eq.HD.gate} + F_{eq.silt.Hor} + F_{eq.fill.Hor} + F_{eq.Granular.Hor}) = 1309.4\,kN$$

$$F_{ver0} := (W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}) + (F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}) \cdots + (W_{US.silt} + W_{DS.fill} + W_{Granular.EQ}) + (F_{U0.Sum.Ver}) + (F_{anchor.Ver} + F_{other.Ver.1}) \cdots + (-F_{eq.conc.Ver} - F_{eq.log.Ver} - F_{eq.slab.Ver} - F_{eq.tower.Ver} - F_{eq.silt.Ver} - F_{eq.fill.Ver} - F_{eq.Granular.Ver} - F_{eq.Water.Above.Ver}) = 1817.3\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 1309.4 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1817.3 \cdot kN$$

$$M_{stab0} := (M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}) + (M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}) \cdots + (M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.EQ}) + (M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}) = 13472.3\,kN \cdot m$$

$$M_{overturn0} := (M_{US.Sum.Hor} + M_{gateH.Sum}) + (M_{US.silt.Hor}) + (M_{U0.Sum}) \cdots + \left(\begin{array}{l} M_{eq.conc.Hor} + M_{eq.conc.Ver} + M_{eq.log.Hor} + M_{eq.log.Ver} + M_{eq.slab.Hor} \cdots \\ + M_{eq.slab.Ver} + M_{eq.tower.Hor} + M_{eq.tower.Ver} + M_{eq.HD.US} + M_{eq.HD.gate} \cdots \\ + M_{eq.silt.Hor} + M_{eq.silt.Ver} + M_{eq.fill.Hor} + M_{eq.fill.Ver} + M_{eq.Granular.Ver} \cdots \\ + M_{eq.Granular.Hor} + M_{eq.Water.Above.Ver} + M_{eq.Water.Above.Hor} \end{array}\right) = 8694.2\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 4778.1\,kN \cdot m$$

LC.5 - Resultant and Bearing Stresses

$$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.63\,m$$

$$E_0 := \frac{L_{incl}}{2} - x_0 = 0.47\,m$$

$L_{incl} = 6.20\,m$

$M_{net0} = 4778.1\,kN \cdot m$

$F_{perp0} = 1817.3\,kN$

Stress Calculations

$q_{max0} = 43.1\,kPa$ $\quad q_{min0} = 16.1\,kPa$

$L_{comp0} = 6.20\,m$

$L_{tens0} = 0.00\,m$

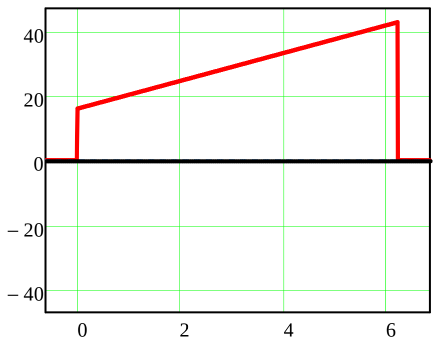
$L_{crack.eq} := L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \dfrac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1817328.7$$

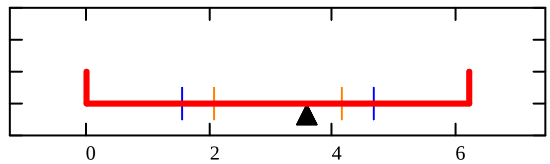
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \% \qquad \frac{L_{tens0}}{L_{incl}} = 0 \cdot \% \qquad \frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.5 - Sliding

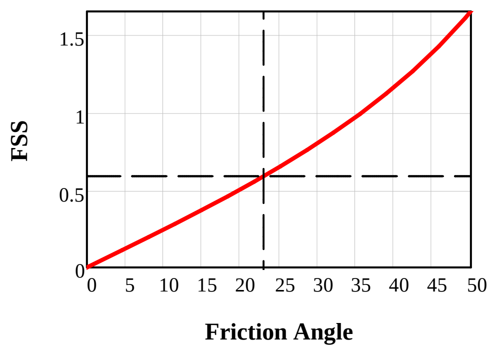
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS_0(\phi_{cf}) = 0.59}$

Factor of safety against sliding for specified friction angle

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 6.20\,m$
$\alpha = 0 \cdot deg$
$B = 9.91\,m$



LC.5 - Cracked Base Analysis

Note: Iterative cracked base analysis does not occur during seismic conditions. Initial uplift pressures are assumed to be maintained even if cracking occurs, as per CDA guidelines.

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 6. Post-Earthquake (D+H+S+U_{PQ})

LC.6(U) - Uplift

Updated uplift calculations

LC.6 - Summary of Forces

Deadloads (D):

$W_{conc} = 2631.9 \cdot kN$ — $M_{conc} = 10523.8 \cdot kN \cdot m$

$W_{log.Sum} = 0$ — $M_{log.Sum} = 0$

$W_{slab} = 0$ — $M_{slab} = 0$

$W_{tower} = 0$ — $M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 1007.4 \cdot kN$ — $M_{US.Sum.Hor} = 1346.6 \cdot kN \cdot m$

$F_{US.Sum.Ver} = 0 \cdot kN$ — $M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Sum.Hor} = 0 kN$ — $M_{DS.Sum.Hor} = 0 kN \cdot m$

$F_{DS.Sum.Ver} = 0 kN$ — $M_{DS.Sum.Ver} = 0 kN \cdot m$

$F_{gateH.Sum} = 0$ — $M_{gateH.Sum} = 0$

$W_{Water.Above.Sum} = 836.2 kN$ — $M_{Water.Above.Sum} = 2948.6 kN \cdot m$

Soil (S):

$F_{US.silt.Hor} = 0 kN$ — $M_{US.silt.Hor} = 0 kN \cdot m$

$W_{US.silt} = 0 kN$ — $M_{US.silt.Ver} = 0 kN \cdot m$

$F_{DS.fill.Hor} = 0 kN$ — $M_{DS.fill.Hor} = 0 kN \cdot m$

$W_{DS.fill} = 0 kN$ — $M_{DS.fill.Ver} = 0 kN \cdot m$

$W_{Granular.Post.EQ} = 0$ — $M_{Granular.Post.EQ} = 0$

Uplift (U):

$F_{U0.eq.Hor} = 0 \cdot kN$ — $M_{U0.eq} = 6026 \cdot kN \cdot m$

$F_{U0.eq.Ver} = -1457.9 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ — $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ — $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ — $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ — $M_{other.Ver.1} = 0$

LC.6 - Combine Forces and Moments

$$F_{hor0} := (F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}) + (F_{US.silt.Hor} - F_{DS.fill.Hor}) \dots + (F_{U0.eq.Hor}) + (F_{anchor.Hor} + F_{other.Hor.1}) = 1007.4 kN$$

$$F_{ver0} := (W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}) + (F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}) \dots + (W_{US.silt} + W_{DS.fill} + W_{Granular.Post.EQ}) + (F_{U0.eq.Ver}) + (F_{anchor.Ver} + F_{other.Ver.1}) = 2010.2 kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 1007.4 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 2010.2 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \cdots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Post.EQ}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 13472.3\,kN\cdot m$$

$$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.eq}\right) = 7372.6\,kN\cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 6099.8\,kN\cdot m$$

LC.6 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 3.03\,m$

$E_0 := \frac{L_{incl}}{2} - x_0 = 0.07\,m$

$L_{incl} = 6.20\,m$
$M_{net0} = 6099.8\,kN \cdot m$
$F_{perp0} = 2010.2\,kN$

Stress Calculations

$q_{max0} = 34.8\,kPa$ $q_{min0} = 30.7\,kPa$

$L_{comp0} = 6.20\,m$

$L_{tens0} = 0.00\,m$

$L_{crack0} = 0.00\,m$

$$L_{crack0} := \begin{cases} L_{crack.eq} & \text{if } L_{crack.eq} > L_{crack0} \\ L_{crack0} & \text{otherwise} \end{cases} = 0.00$$

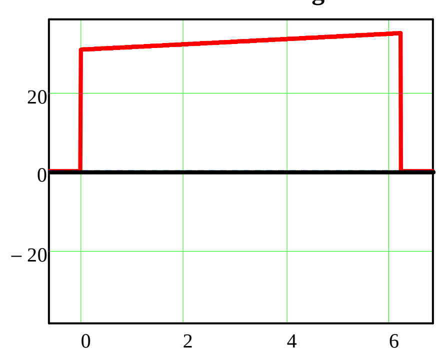
Adjust the crack length to be larger of eq, or post-eq load case.

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 2010152.9$$

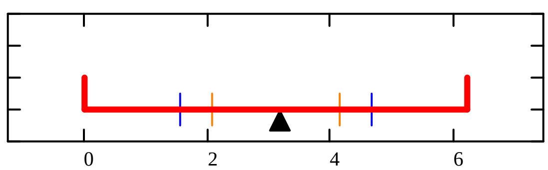
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.6 - Sliding

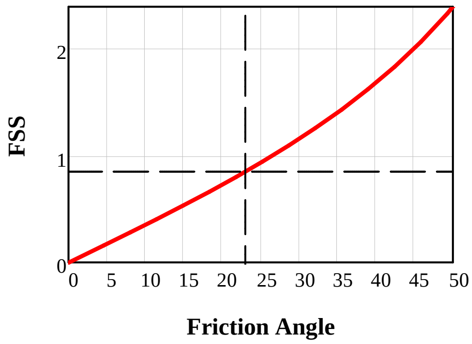
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 6.20\,m$
$\alpha = 0 \cdot deg$
$B = 9.91\,m$

$FSS_0(\phi_{cf}) = 0.85$

Factor of safety against sliding for specified friction angle



LC.6 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 1 & \text{if } L_{crack0} > L_{crack.eq} \\ 0 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

$crackactive := 0$

Cracked Base Analysis

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Summary of Forces/Moments

Dead Loads (and related seismic)

$W_{conc} = 2631.9 \cdot kN$	$M_{conc} = 10523.8 \cdot kN \cdot m$
$F_{eq.conc.Hor} = 219.5\,kN$	$M_{eq.conc.Hor} = 257.8\,kN \cdot m$
$F_{eq.conc.Ver} = 146.3\,kN$	$M_{eq.conc.Ver} = 585.1\,kN \cdot m$
$W_{log.Sum} = 0$	$M_{log.Sum} = 0$
$W_{log.Win} = 0$	$M_{log.Win} = 0$
$W_{log.IDF} = 0$	$M_{log.Win} = 0$
$F_{eq.log.Hor} = 0$	$M_{eq.log.Hor} = 0$
$F_{eq.log.Ver} = 0$	$M_{eq.log.Ver} = 0$
$W_{slab} = 0$	$M_{slab} = 0$
$F_{eq.slab.Hor} = 0$	$M_{eq.slab.Hor} = 0$
$F_{eq.slab.Ver} = 0$	$M_{eq.slab.Ver} = 0$
$W_{tower} = 0$	$M_{tower} = 0$
$F_{eq.tower.Hor} = 0$	$M_{eq.tower.Hor} = 0$
$F_{eq.tower.Ver} = 0$	$M_{eq.tower.Ver} = 0$

Soil Loads (and related seismic)

$F_{US.silt.Hor} = 0\,kN$	$M_{US.silt.Hor} = 0\,kN \cdot m$
$F_{eq.silt.Hor} = 0\,kN$	$M_{eq.silt.Hor} = 0\,kN \cdot m$
$W_{US.silt} = 0\,kN$	$M_{US.silt.Ver} = 0\,kN \cdot m$
$F_{eq.silt.Ver} = 0\,kN$	$M_{eq.silt.Ver} = 0\,kN \cdot m$
$F_{DS.fill.Hor} = 0\,kN$	$M_{DS.fill.Hor} = 0\,kN \cdot m$
$F_{eq.fill.Hor} = 0\,kN$	$M_{eq.fill.Hor} = 0\,kN \cdot m$
$F_{eq.fill.Ver} = 0\,kN$	$M_{eq.fill.Ver} = 0\,kN \cdot m$
$W_{DS.fill} = 0\,kN$	$M_{DS.fill.Ver} = 0\,kN \cdot m$
$W_{Granular.Sum} = 0$	$M_{Granular.Sum} = 0$
$F_{eq.Granular.Ver} = 0$	$M_{eq.Granular.Ver} = 0$
$F_{eq.Granular.Hor} = 0$	$M_{eq.Granular.Hor} = 0$

Uplift Forces

$F_{U0.Sum} = 1457.9\,kN$	$M_{U0.Sum} = 6026 \cdot kN \cdot m$
$F_{U0.Sum.Hor} = 0 \cdot kN$	
$F_{U0.Sum.Ver} = -1457.9 \cdot kN$	
$F_{U0.Win} = 963.9\,kN$	$M_{U0.Win} = 3984.1 \cdot kN \cdot m$
$F_{U0.Win.Hor} = 0 \cdot kN$	
$F_{U0.Win.Ver} = -963.9 \cdot kN$	
$F_{U0.IDF} = 3036.3\,kN$	$M_{U0.IDF} = 9910.6 \cdot kN \cdot m$
$F_{U0.IDF.Hor} = 0 \cdot kN$	
$F_{U0.IDF.Ver} = -3036.3 \cdot kN$	
$F_{U0.eq} = 1457.9\,kN$	$M_{U0.eq} = 6026 \cdot kN \cdot m$
$F_{U0.eq.Hor} = 0 \cdot kN$	
$F_{U0.eq.Ver} = -1457.9 \cdot kN$	

Hydraulic Forces (and related seismic)

$F_{US.Sum.Hor} = 1007.4 \cdot kN$	$M_{US.Sum.Hor} = 1346.6 \cdot kN \cdot m$
$F_{eq.HD.US} = 82.5\,kN$	$M_{eq.HD.US} = 123.5\,kN \cdot m$
$F_{US.Sum.Ver} = 0 \cdot kN$	$M_{US.Sum.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.Sum} = 836.2\,kN$	$M_{Water.Above.Sum} = 2948.6\,kN \cdot m$
$F_{eq.Water.Above.Ver} = 46.5\,kN$	$M_{eq.Water.Above.Ver} = 163.9\,kN \cdot m$
$F_{eq.Water.Above.Hor} = 69.7\,kN$	$M_{eq.Water.Above.Hor} = 191.2\,kN \cdot m$
$F_{US.Win.Hor} = 497.5 \cdot kN$	$M_{US.Win.Hor} = 530.7 \cdot kN \cdot m$
$F_{US.Win.Ver} = 0 \cdot kN$	$M_{US.Win.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.Win} = 0\,kN$	$M_{Water.Above.Win} = 0\,kN \cdot m$
$F_{US.IDF.Hor} = 1318.4 \cdot kN$	$M_{US.IDF.Hor} = 1844.1 \cdot kN \cdot m$
$F_{US.IDF.Ver} = 0 \cdot kN$	$M_{US.IDF.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.IDF} = 1937.6\,kN$	$M_{Water.Above.IDF} = 5517.5\,kN \cdot m$
$F_{DS.Sum.Hor} = 0\,kN$	$M_{DS.Sum.Hor} = 0\,kN \cdot m$
$F_{DS.Sum.Ver} = 0\,kN$	$M_{DS.Sum.Ver} = 0\,kN \cdot m$
$F_{DS.Win.Hor} = 0\,kN$	$M_{DS.Win.Hor} = 0\,kN \cdot m$
$F_{DS.Win.Ver} = 0\,kN$	$M_{DS.Win.Ver} = 0\,kN \cdot m$
$F_{DS.IDF.Hor} = 820.9\,kN$	$M_{DS.IDF.Hor} = 1048.1\,kN \cdot m$
$F_{DS.IDF.Ver} = 0\,kN$	$M_{DS.IDF.Ver} = 0\,kN \cdot m$
$F_{gateH.Sum} = 0$	$M_{gateH.Sum} = 0$
$F_{eq.HD.gate} = 0$	$M_{eq.HD.gate} = 0$
$F_{gateH.Win} = 0$	$M_{gateH.Win} = 0$
$F_{gateH.IDF} = 0$	$M_{gateH.IDF} = 0$
$F_{drag} = 0$	$M_{drag} = 0$

Ice Loads

$F_{ice.1} = 827.1\,kN$	$M_{ice.1} = 2398.5\,kN \cdot m$
$F_{ice.gate} = 0$	$M_{ice.gate} = 0$
$F_{ice} = 827.1\,kN$	$M_{ice} = 2398.5\,kN \cdot m$
$F_{ice.1.usual} = 742.9\,kN$	$M_{ice.1.usual} = 2154.3\,kN \cdot m$
$F_{ice.gate.usual} = 0$	$M_{ice.gate.usual} = 0$
$F_{ice.usual} = 742.9\,kN$	$M_{ice.usual} = 2154.3\,kN \cdot m$

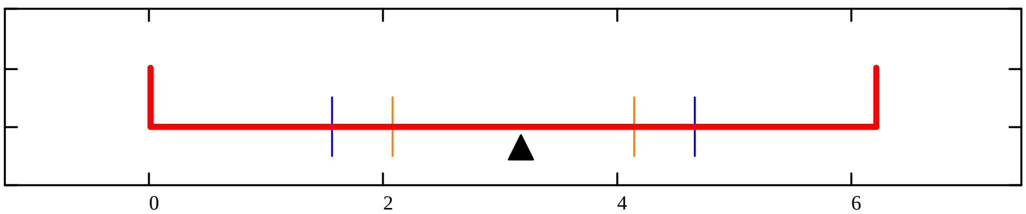
Other Forces:

$F_{anchor.Hor} = 0$	$M_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$	$M_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$	$M_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$	$M_{other.Ver.1} = 0$

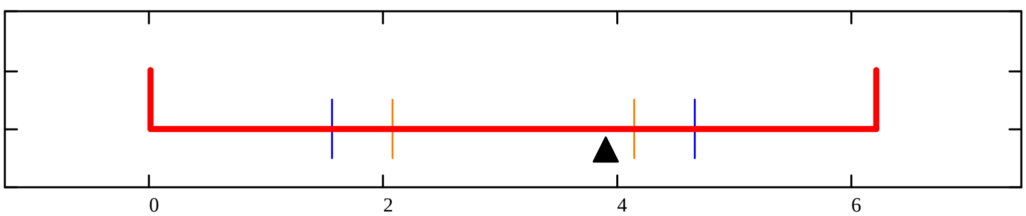
Results of Analysis

	FSS (Φ.cf)	E (m)	x.o (m)	L.comp (m)	% of Base in Compression	L.crack (m)	F.hor (kN)	F.ver (kN)	F.parallel (kN)	F.Perp (kN)	q.max (kPa)
LC.1 - Summer	0.85	0.07	3.03	6.20	100%	0.00	1,007.4	2,010.2	1,007.4	2,010.2	34.8
LC.2 - Winter (Usual)	0.57	0.79	2.31	6.20	100%	0.00	1,240.4	1,668.0	1,240.4	1,668.0	47.9
LC.3 - IDF	1.31	-0.38	3.48	6.20	100%	0.00	497.5	1,533.2	497.5	1,533.2	34.1
LC.4 - Winter (Unusual)	0.53	0.94	2.16	6.20	100%	0.00	1,324.6	1,668.0	1,324.6	1,668.0	51.7
LC.5 - EQ	0.59	0.47	2.63	6.20	100%	0.00	1,309.4	1,817.3	1,309.4	1,817.3	43.1
LC.6 - Post - EQ	0.85	0.07	3.03	6.20	100%	0.00	1,007.4	2,010.2	1,007.4	2,010.2	34.8

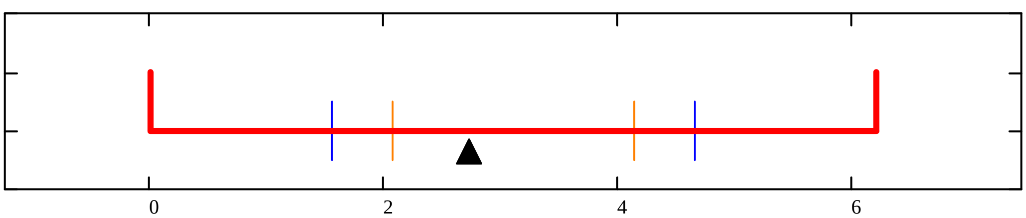
Location of Resultant



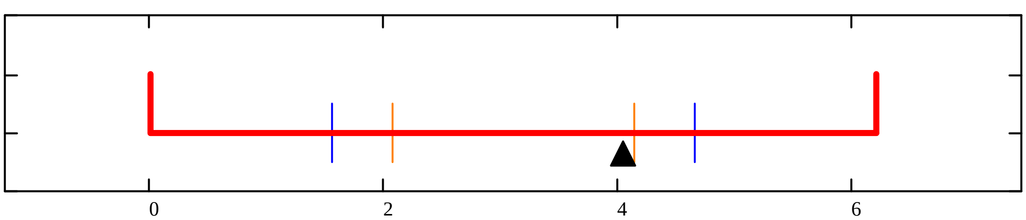
LC 1



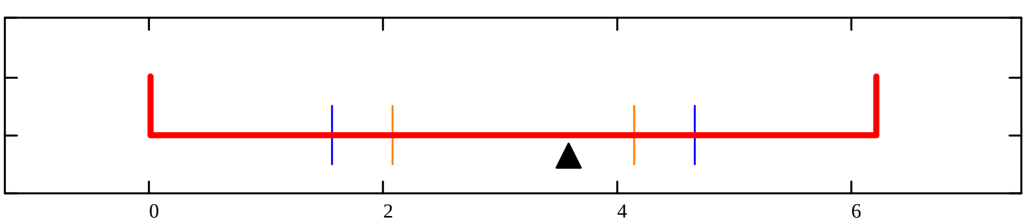
LC 2



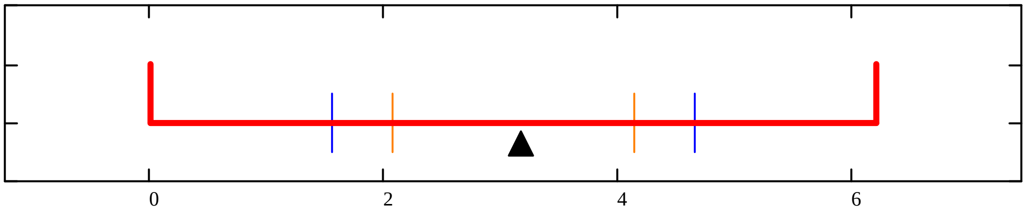
LC 3



LC 4



LC 5



LC 6

KGS GROUP	DESIGN CALCULATIONS COVER SHEET				
Project No. :	17-3212-001	**Project Name :**	Howson Dam (South Sluiceway)		
File No. :	CIV-003	**Discipline :**	Structural Engineering		
Calculation Title :	**Combined Rollway & Pier Stability Analysis**				
Calculation No. :	CIV-003	**Prepared by :**	HS	**Date :**	Feb. 23, 2018
No. of Sheets :		**Checked by :**	YF	**Date :**	April 20, 2018
Supersedes Calc. No. :		**Approved by :**		**Date :**	

Calculation Description :

The dam has been reviewed against LRIA technical bulletins

Related Design Concept :

Stability analysis for the structures is carried out using the "Gravity Method".
Six loading cases are utilized in the analyses based on the LRIA Technical Bulletin "Structural Design and Factors of Safety (August 2011).

Reference Codes and Standards :
1. *Design of Small Dams,* Third Edition, U.S. Government Printing Office, Washington, D.C. 1987.
2. Structural Design and Factors of Safety – Technical Bulletin Ontario Ministry of Natural Resources (August 2011)

ENGINEER'S SEAL

Rev. #	**Rev. Description**	**Rev. Author**	**Date Revised**	**Checked by**	**Approved by**	**Approved Date**

References

Pier

Reference:P:\Projects\2017\17-3212-001\Design\Struct\HS\MathCad\S Structure\CIV-001 Howson Dam S - Pier Section-HS YF.xmcd(R)

Rollway

Reference:P:\Projects\2017\17-3212-001\Design\Struct\HS\MathCad\S Structure\CIV-002 Howson Dam S - Sill Section HS YF.xmcd

Properties of Materials

$\phi_{cf} := 23 \cdot deg$ — *Friction angle of concrete/foundation interface*

$f_t := 0MPa$ — *Tensile strength at concrete/rock interface (generally set to 0). This is a negative number.*

$c := 0MPa$ — *Cohesion at concrete/foundation interface (generally set to 0)*

Geometry of Structures

Unit width of structure used in calculation sheet

$B_{pier} = 1.67m$ $\qquad$ $B_{roll} = 9.91m$

$L_{incl.pier} = 7.95m$ $\qquad$ $L_{incl.roll} = 6.2m$

$\alpha_{pier} = 0 \cdot deg$ $\qquad$ $\alpha_{roll} = 0 \cdot deg$

$B := B_{pier} + B_{roll} = 11.6m$

$$L_{incl} := \frac{L_{incl.pier} + L_{incl.roll}}{2} = 7.08m$$

$$\alpha_{avg} := \frac{\alpha_{pier} + \alpha_{roll}}{2} = 0 \cdot deg$$

Load Case 1. Usual Loading Summer Case (D+H+S+U)

$LC := 1$

LC. 1 - Forces from Structures

$F_{hor.pier_{LC}} = 363.8 \cdot kN$ | $F_{hor.roll_{LC}} = 1007.4 kN$ | *Force acting in horizontal direction on structure*

$F_{ver.pier_{LC}} = 2160 \cdot kN$ | $F_{ver.roll_{LC}} = 2010.2 \cdot kN$ | *Forces acting in vertical direction on structure*

$F_{perp.pier_{LC}} = 2160 \cdot kN$ | $F_{perp.roll_{LC}} = 2010.2 \cdot kN$ | *Force acting perpendicular to base from structure*

$F_{para.pier_{LC}} = 363.8 \cdot kN$ | $F_{para.roll_{LC}} = 1007.4 \cdot kN$ | *Force acting parallel to base from structure*

$L_{comp.pier_{LC}} = 8 m$ | $L_{comp.roll_{LC}} = 6.2 m$ | *Length of base in compression*

$M_{net.pier_{LC}} = 7293.8 \cdot kN \cdot m$ | $M_{net.roll_{LC}} = 6099.8 \cdot kN \cdot m$ | *Net resisting moment from structure*

LC.1 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1371.2 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 4170.1 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1371.2 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 4170.1 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 13393.5 \cdot kN \cdot m$

LC.1 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 3.21 m$ *Distance of resultant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.33 m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 65 kPa$ $q_{min} = 36.8 kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08 m$ *Length of base in compression before iterative cracked base analysis*

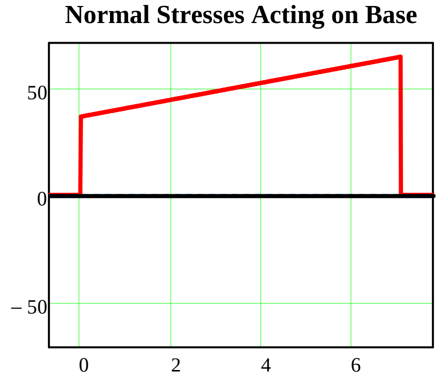
$L_{tens} = 0.00 m$ *Length of base in tension before iterative cracked base analysis*

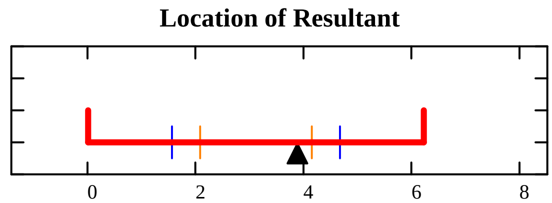
$L_{crack} = 0.00 m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \ge 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 4170.1 \cdot kN$$

$F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0 kN$ *Compression and tension forces in foundation*

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*





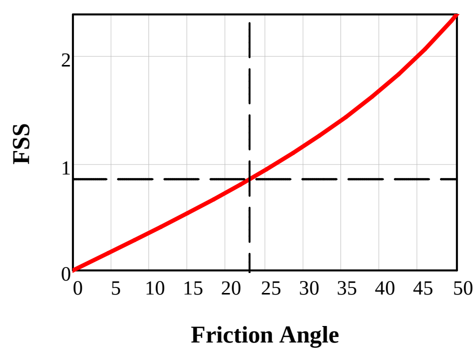
LC.1 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$FSS(\phi_{cf}) = 1.29$

Factor of safety against sliding for specified friction angle



Store results for summary

Load Case 2. Usual Loading Winter Case (D+H+S+U+I)

$LC := 2$

LC. 2 - Forces from Structures

$F_{hor.pier_{LC}} = 404.6 \cdot kN$	$F_{hor.roll_{LC}} = 1240.4 kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 2267.1 \cdot kN$	$F_{ver.roll_{LC}} = 1668 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 2267.1 \cdot kN$	$F_{perp.roll_{LC}} = 1668 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 404.6 \cdot kN$	$F_{para.roll_{LC}} = 1240.4 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8 m$	$L_{comp.roll_{LC}} = 6.2 m$	*Length of base in compression*
$M_{net.pier_{LC}} = 7519.9 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 3854.6 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.2 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1645 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 3935.1 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1645.0 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 3935.1 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 11374.5 \cdot kN \cdot m$

LC.2 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 2.89 m$ — *Distance of resulant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.65 m$ — *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 74.4 kPa$ $q_{min} = 21.7 kPa$ — *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08 m$ — *Length of base in compression before iterative cracked base analysis*

$L_{tens} = 0.00 m$ — *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00 m$ — *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 3935.1 \cdot kN$$

$$F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0 kN$$

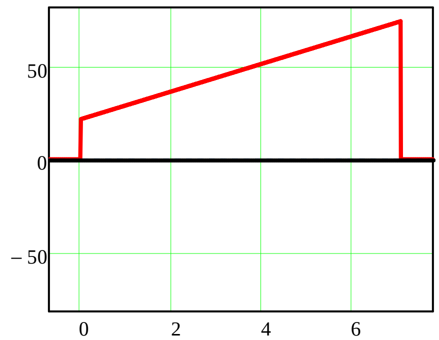
Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression*

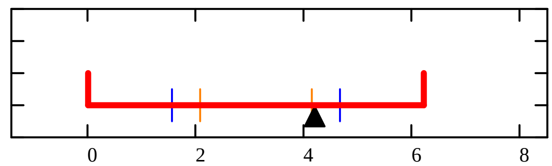
$\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension*

$\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



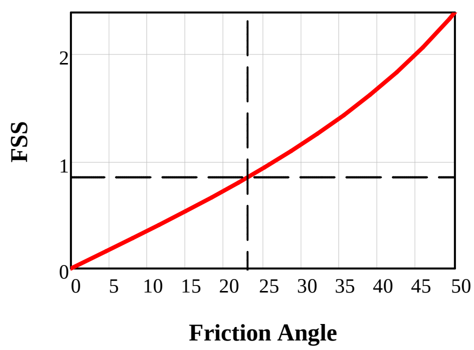
LC.2 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS(\phi_{cf}) = 1.02}$

Factor of safety against sliding for specified friction angle



▸ Store results for summary

Load Case 3. Unusual Loading IDF (D+H_{IDF}+S+U_{IDF})

$LC := 3$

LC. 3 - Forces from Structures

$F_{hor.pier_{LC}} = 296.2 \cdot kN$	$F_{hor.roll_{LC}} = 497.5\,kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 1766.1 \cdot kN$	$F_{ver.roll_{LC}} = 1533.2 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 1766.1 \cdot kN$	$F_{perp.roll_{LC}} = 1533.2 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 296.2 \cdot kN$	$F_{para.roll_{LC}} = 497.5 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8\,m$	$L_{comp.roll_{LC}} = 6.2\,m$	*Length of base in compression*
$M_{net.pier_{LC}} = 5999.7 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 5334.6 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.3 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 793.7 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 3299.3 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 793.7 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 3299.3 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 11334.3 \cdot kN \cdot m$

LC.3 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 3.44\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.1\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 43.8\,kPa$ $q_{min} = 36.8\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

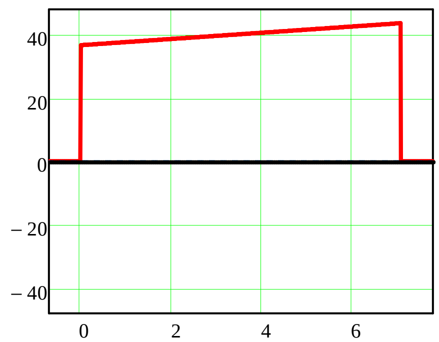
$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 3299.3 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$$

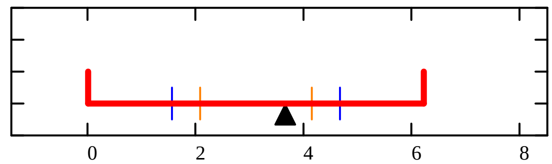
Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



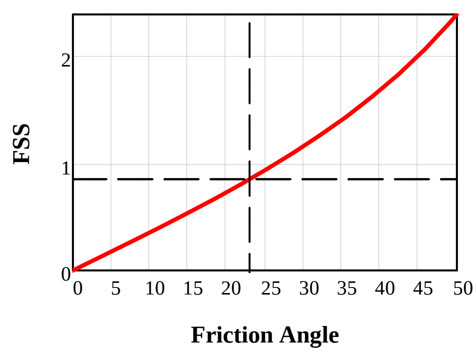
LC.3 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS(\phi_{cf}) = 1.76}$

Factor of safety against sliding for specified friction angle



▶ Store results for summary

Load Case 4. Unusual Loading Winter Case (D+H+S+U+I)

$LC := 4$

LC. 4 - Forces from Structures

$F_{hor.pier_{LC}} = 431.8 \cdot kN$	$F_{hor.roll_{LC}} = 1324.6\,kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 2267.1 \cdot kN$	$F_{ver.roll_{LC}} = 1668 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 2267.1 \cdot kN$	$F_{perp.roll_{LC}} = 1668 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 431.8 \cdot kN$	$F_{para.roll_{LC}} = 1324.6 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8\,m$	$L_{comp.roll_{LC}} = 6.2\,m$	*Length of base in compression*
$M_{net.pier_{LC}} = 7419.6 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 3610.4 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.4 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1756.4 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 3935.1 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1756.4 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 3935.1 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 11030 \cdot kN \cdot m$

LC.4 - Resultant and Bearing Stresses

$x_0 := \dfrac{M_{net}}{F_{perp}} = 2.8\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \dfrac{L_{incl}}{2} - x_0 = 0.73\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 77.9\,kPa$ $q_{min} = 18.1\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

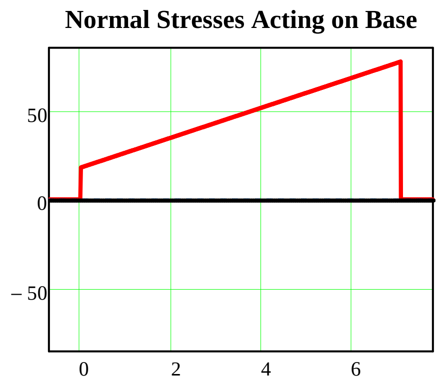
$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

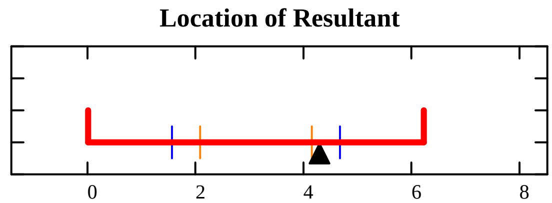
$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \dfrac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 3935.1 \cdot kN$ $F_{tens} := \dfrac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$ *Compression and tension forces in foundation*

$\dfrac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\dfrac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\dfrac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*





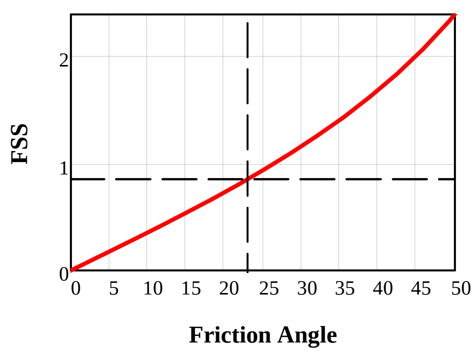
LC.4 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$FSS(\phi_{cf}) = 0.95$

Factor of safety against sliding for specified friction angle



Store results for summary

Load Case 5. Extreme Loading Earthquake (D+H+S+Q+U_Q)

$LC := 5$

LC. 5 - Forces from Structures

$F_{hor.pier_{LC}} = 606.9 \cdot kN$ $F_{hor.roll_{LC}} = 1309.4 kN$ *Force acting in horizontal direction on structure*

$F_{ver.pier_{LC}} = 2019.4 \cdot kN$ $F_{ver.roll_{LC}} = 1817.3 \cdot kN$ *Forces acting in vertical direction on structure*

$F_{perp.pier_{LC}} = 2019.4 \cdot kN$ $F_{perp.roll_{LC}} = 1817.3 \cdot kN$ *Force acting perpendicular to base from structure*

$F_{para.pier_{LC}} = 606.9 \cdot kN$ $F_{para.roll_{LC}} = 1309.4 \cdot kN$ *Force acting parallel to base from structure*

$L_{comp.pier_{LC}} = 8 m$ $L_{comp.roll_{LC}} = 6.2 m$ *Length of base in compression*

$M_{net.pier_{LC}} = 5728.9 \cdot kN \cdot m$ $M_{net.roll_{LC}} = 4778.1 \cdot kN \cdot m$ *Net resisting moment from structure*

LC.5 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1916.3 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 3836.8 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1916.3 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 3836.8 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 10507.1 \cdot kN \cdot m$

LC.5 - Resultant and Bearing Stresses

$x0 := \frac{M_{net}}{F_{perp}} = 2.74 m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.8 m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 78.6 kPa$ $q_{min} = 15.1 kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08 m$ *Length of base in compression before iterative cracked base analysis*

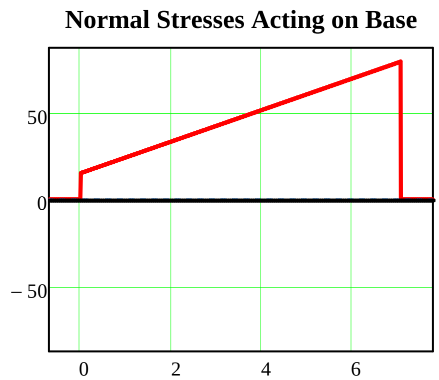
$L_{tens} = 0.00 m$ *Length of base in tension before iterative cracked base analysis*

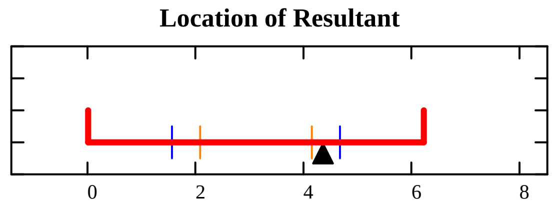
$L_{crack} = 0.00 m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \ge 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 3836.8 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0 kN$$

Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*





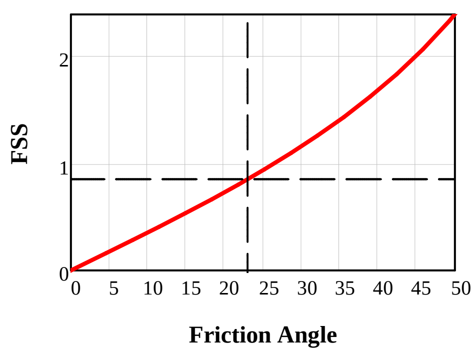
LC.5 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$FSS(\phi_{cf}) = 0.85$

Factor of safety against sliding for specified friction angle



Store results for summary

Load Case 6. Extreme Loading Earthquake (D+H+S+Q+U$_Q$)

$LC := 6$

LC. 6 - Forces from Structures

$F_{hor.pier_{LC}} = 363.8 \cdot kN$	$F_{hor.roll_{LC}} = 1007.4 kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 2160 \cdot kN$	$F_{ver.roll_{LC}} = 2010.2 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 2160 \cdot kN$	$F_{perp.roll_{LC}} = 2010.2 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 363.8 \cdot kN$	$F_{para.roll_{LC}} = 1007.4 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8 m$	$L_{comp.roll_{LC}} = 6.2 m$	*Length of base in compression*
$M_{net.pier_{LC}} = 7293.8 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 6099.8 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.6 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1371.2 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 4170.1 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1371.2 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 4170.1 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 13393.5 \cdot kN \cdot m$

LC.6 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 3.21\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.33\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 65\,kPa$ $q_{min} = 36.8\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

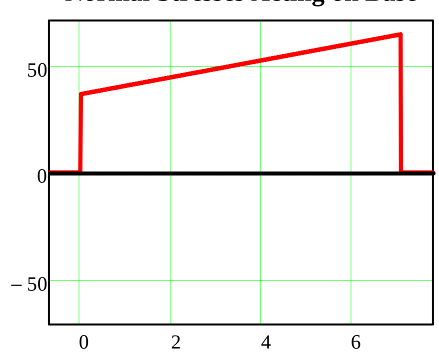
$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \ge 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 4170.1 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$$

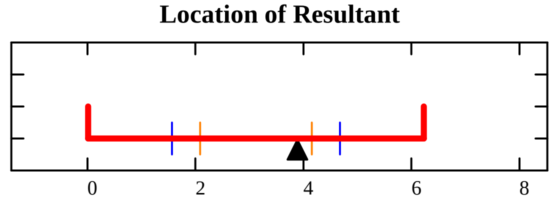
Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



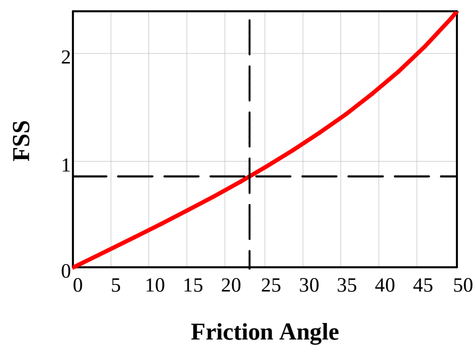
LC.6 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$FSS(\phi_{cf}) = 1.29$

Factor of safety against sliding for specified friction angle

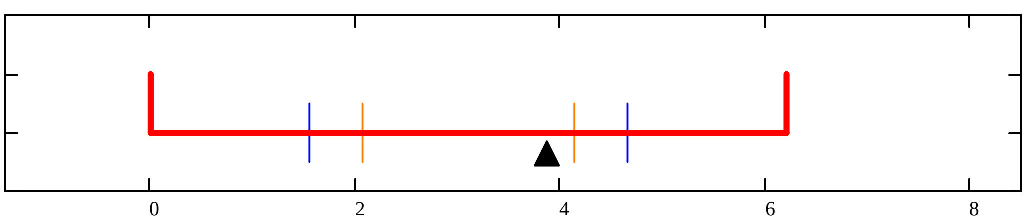


Store results for summary

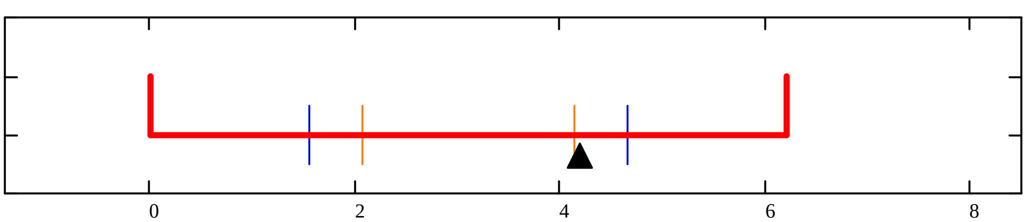
Results of Analysis

	FSS (Φ.cf)	E (m)	x.o (m)	L.comp (m)	% of Base in Compression	L.crack (m)	F.hor (kN)	F.ver (kN)	F.parallel (kN)	F.Perp (kN)	q.max (kPa)
LC.1 - Summer	1.29	0.33	3.21	7.08	100%	0.00	1,371.2	4,170.1	1,371.2	4,170.1	65.0
LC.2 - Winter (Usual)	1.02	0.65	2.89	7.08	100%	0.00	1,645.0	3,935.1	1,645.0	3,935.1	74.4
LC.3 - IDF	1.76	0.10	3.44	7.08	100%	0.00	793.7	3,299.3	793.7	3,299.3	43.8
LC.4 - Winter (Unusual)	0.95	0.73	2.80	7.08	100%	0.00	1,756.4	3,935.1	1,756.4	3,935.1	77.9
LC.5 - EQ	0.85	0.80	2.74	7.08	100%	0.00	1,916.3	3,836.8	1,916.3	3,836.8	78.6
LC.6 - Post - EQ	1.29	0.33	3.21	7.08	100%	0.00	1,371.2	4,170.1	1,371.2	4,170.1	65.0

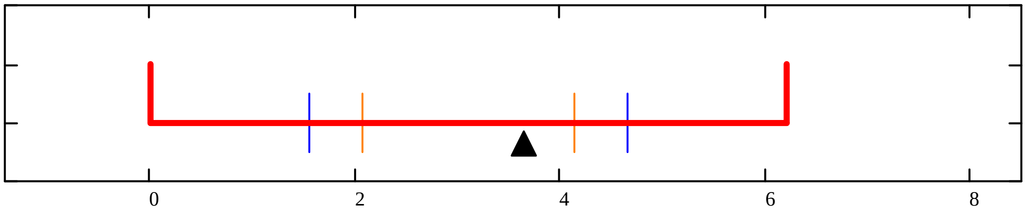
Location of Resultant



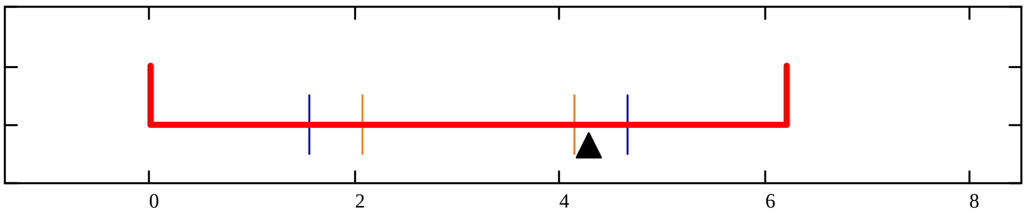
LC 1



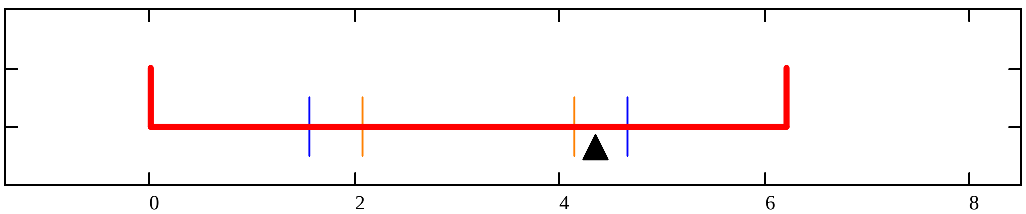
LC 2



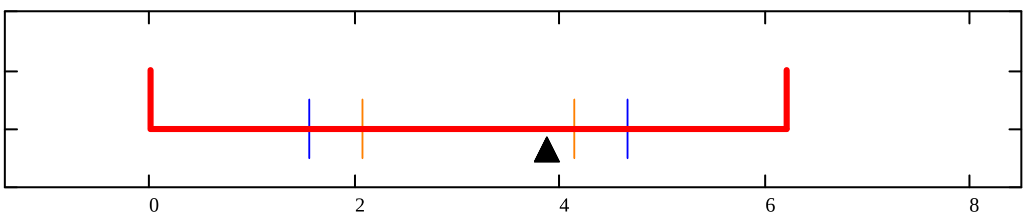
LC 3



LC 4



LC 5



LC 6

KGS GROUP	DESIGN CALCULATIONS COVER SHEET				
Project No. :	17-3212-001	**Project Name :**	Howson Dam (South Structure)		
File No. :		**Discipline :**	Structural Engineering		
Calculation Title :	**Pier Stability Analysis – Bridge deck to be removed**				
Calculation No. :	CIV-004	**Prepared by :**	HS	**Date :**	Feb. 23, 2018
No. of Sheets :		**Checked by :**	YF	**Date :**	April 20, 2018
Supersedes Calc. No. :		**Approved by :**		**Date :**	

Calculation Description :

The dam has been reviewed against LRIA technical bulletins

Related Design Concept :

Stability analysis for the structures is carried out using the "Gravity Method".
Six loading cases are utilized in the analyses based on the LRIA Technical Bulletin "Structural Design and Factors of Safety (August 2011).

Reference Codes and Standards :

1. *Design of Small Dams,* Third Edition, U.S. Government Printing Office, Washington, D.C. 1987.
2. Structural Design and Factors of Safety – Technical Bulletin Ontario Ministry of Natural Resources (August 2011)

ENGINEER'S SEAL

Rev. #	**Rev. Description**	**Rev. Author**	**Date Revised**	**Checked by**	**Approved by**	**Approved Date**

Notes and Figures

Properties of Materials

$\gamma_w := 9.81 \frac{kN}{m^3}$ *Water density*

$\gamma_{conc} := 23.5 \cdot \frac{kN}{m^3}$ *Concrete density adjusted due to combination of the pier and abutment sections.*

$\phi_{cf} := 23 \cdot deg$ *Friction angle of concrete/foundation interface*

$c := 0MPa$ *Cohesion at concrete/foundation interface (generally set to 0)*

$f_{t.cf} := \frac{-c}{2} = 0$ *Tensile strength at concrete/rock interface (generally set to 0, or 0.5 x cohesion). This is a negative number.*

$\gamma_{silt} := 7.7 \cdot \frac{kN}{m^3}$ *Silt density*

$\phi'_{silt} := 20 \cdot deg$ *Angle of internal friction for silt at rest condition*

$\gamma_{fill} := 7.7 \cdot \frac{kN}{m^3}$ *Backfill density*

$\phi'_{fill} := 30 \cdot deg$ *Angle of internal friction for backfill at rest condition*

$\gamma_{timber} := 10 \cdot \frac{kN}{m^3}$ *Timber density (for stoplogs)*

$\gamma_{Granular} := 15 \frac{kN}{m^3}$ *Weight of granular material or rip rap on top of section*

Water Levels

Usual Summer Operating Levels

Used in LC 1,4,5

$WL_{US.Sum} := 310.9m$ *Upstream water level (left side)*

$WL_{DS.Sum} := 305.27m$ *Downstream water level (right side)*

Usual Winter Operating Levels

Used in LC 2

$WL_{US.Win} := 309.26m$

$WL_{DS.Win} := 305.27m$

Unusual Flood Discharge Levels

Used in LC 3

$WL_{US.IDF} := 311.9m$

$WL_{DS.IDF} := 310.3m$

Seismic Accelerations

$\lambda_{Hor} := 0.0834$ *Horizontal component of earthquake intensity = ratio of earthquake acceleration to acceleration due to gravity (unitless number)*

$\lambda_{Ver} := \frac{2}{3} \cdot \lambda_{Hor} = 0.056$

Vertical component of earthquake intensity. CDA recommends a factor between 1/2 and 2/3 of the horizontal acceleration (pg 15 of Seismic Hazard Considerations Technical Bulletin)

Structure Geometry

Input

Note: Enter structure geometry as series of points on X-Y grid. Align structure so that upstream is on the left side. Structure outline is "closed" automatically (last point is assigned same values as first). Ensure that values of ELE.Base.L and ELE.Base.R are adjusted to correspond with the lowest upstream and downstream elevations.

Input X & Y coordinates

$X := \begin{pmatrix} 0 \\ 7.95 \\ 7.95 \\ 0 \end{pmatrix} \cdot m$ $\quad Y := \begin{pmatrix} 305.27 \\ 305.27 \\ 310.94 \\ 310.94 \end{pmatrix} \cdot m$

$ELE_{Base.L} := 305.27m$ *Elevation of left side of base (lowest point)*

$ELE_{Base.R} := 305.27m$ *Elevation of right side of base (lowest point)*

$ELE_{Top} := 310.94m$ *Elevation of top of dam (for hydrostatic, hydrodynamic forces)*

$B := \frac{2.03 + 1.32}{2} \cdot m = 1.67m$ *Set unit width of structure (1m if using metric, 1ft if using imperial units)*

$\omega_{US} := 0deg$ *Incline of upstream face from vertical (positive number in degrees)*

$\omega_{DS} := 0deg$ *Incline of downstream face from vertical (positive number in degrees)*

$L_{hor} := \max(X) - \min(X) = 7.95m$ *Horizontal projection of base*

$\alpha := \operatorname{atan}\left(\frac{ELE_{Base.R} - ELE_{Base.L}}{L_{hor}}\right) = 0 \cdot deg$ *Angle of inclination of base. Positive is counter clockwise from the horizontal in the downstream direction*

$L_{incl} := \frac{L_{hor}}{\cos(\alpha)} = 7.95m$ *Inclined length of concrete-foundation interface*

Variables for Combines Structure Model

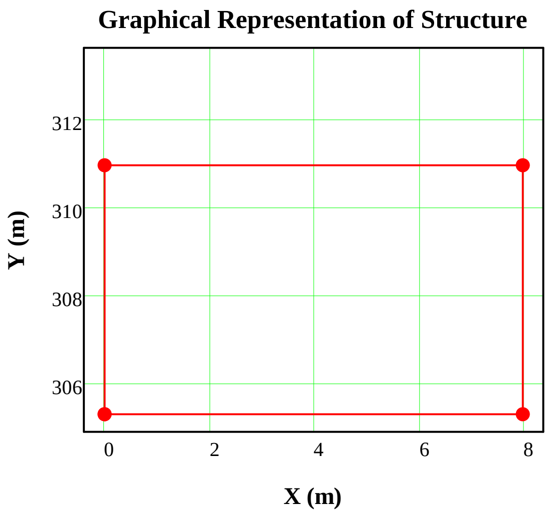
$B_{pier} := B = 1.67m$

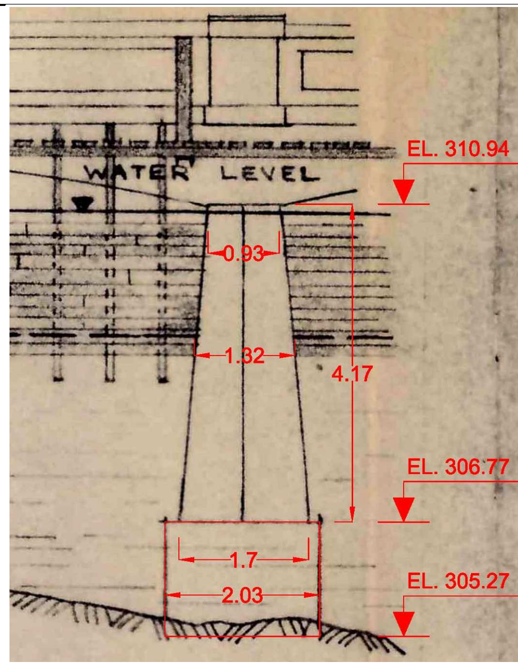
$L_{incl.pier} := L_{incl} = 7.95m$

$\alpha_{pier} := \alpha$

Input

Plot Functions





Computation of Area and Center of Gravity

Gate/Stoplog Geometry

$X_{log} := 0 \cdot m$ — *Horizontal distance from left side (x=0) to location of gate/stoplogs*

$ELE_{sill} := 307.13m$ — *Elevation of the bottom of the gate/stoplogs*

$ELE_{gate.top} := 310.28m$ — *Elevation of top of gate/stoplogs*

$Trib_{gate} := \frac{10.ft}{2} = 1.52\,m$ — *Tributary width of gates/logs experiencing hydrostatic/hydrodynamic/ice forces*

$Wi_{gate} := 0m$ — *Total width of gate/stoplogs (for calculating weight on slab/rollway)*

Forces on Gates/Stoplogs Transferred into Piers

$Gates_{Sum.Hyd} := 1$ — *If gates are present during summer operation (and earthquake), set = 1, otherwise set to 0*

$Gates_{Win.Hyd} := 1$ — *If gates are present during winter operation, set = 1, otherwise set to 0*

$Gates_{IDF.Hyd} := 1$ — *If gates are present during IDF, set = 1, otherwise set to 0*

Weight of Gates/Stoplogs bearing on rollway/slab

$Gates_{Sum.Weight} := 0$ — *If gates are present during summer operation (and earthquake), set = 1, otherwise set to 0*

$Gates_{Win.Weight} := 0$ — *If gates are present during winter operation, set = 1, otherwise set to 0*

$Gates_{IDF.Weight} := 0$ — *If gates are present during IDF, set = 1, otherwise set to 0*

Weight of Main Structure (D)

$B_{ave} := \frac{2.03 + 0.93}{2} \cdot m = 1.48m$ — *Average width of the structure for calculating the pier weight*

$Vol\_conc := Area \cdot B_{ave} = 66.7 \cdot m^3$ — *Volume of concrete per unit width of structure*

$W_{conc} := Vol\_conc \cdot \gamma_{conc} = 1568 \cdot kN$ — *Dead load of concrete in structure*

$MA := L_{hor} - Xg = 3.975m$ — *Moment arm is the horizontal distance from right side of base to C.G.*

$M_{conc} := W_{conc} \cdot MA = 6231.8 \cdot kN \cdot m$ — *Moment from structure self weight*

$\gamma_{conc} = 23.5 \cdot \frac{kN}{m^3}$

$Area = 45.1m^2$

$B = 1.7m$

$L_{hor} = 7.95m$

$Xg = 3.975m$

$Yg = 308.105m$

Weight of Stoplogs (D) - NOT APPLICABLE

Weight of Slab (D)

$Wi_{slab} := 0.001 \cdot m$ — *Slab width*

$L_{slab} := 0.001 \cdot m$ — *Total length of slab*

$S_{thk} := 0.001m$ — *Equivalent slab thickness*

$\gamma_{conc} = 23.5 \cdot \frac{kN}{m^3}$

$B = 1.67m$

$L_{hor} = 7.95m$

$Wi_{Gir} := 0 \cdot m$ — *Girder width*

$L_{Gir} := 0 \cdot m$ — *Total length of girder*

$Gir_{thk} := \frac{1 + 0.4}{2} \cdot m = 0.7m$ — *Equivalent girder thickness (conservative assumption)*

$Gir_{No} := 4$ — *Number of girders in each span*

$$ELE_{slab} := 312.48 \cdot m - \frac{\left[L_{slab} \cdot Wi_{slab} \cdot S_{thk} \cdot \frac{S_{thk}}{2} + Gir_{No} \cdot L_{Gir} \cdot Wi_{Gir} \cdot Gir_{thk} \cdot \left(\frac{Gir_{thk}}{2} + S_{thk}\right)\right]}{L_{slab} \cdot Wi_{slab} \cdot S_{thk} + Gir_{No} \cdot L_{Gir} \cdot Wi_{Gir} \cdot Gir_{thk}} = 312.48m$$

Elevation of centre of gravity of slab

$X_{slab} := \frac{L_{slab}}{2} = 0m$ — *Horizontal distance from left side (x=0) to centre of slab*

$Wi_{opening} := 0m$ — *Width of stoplog opening*

$L_{opening} := 8.23m$ — *Length of stoplog opening*

$X_{opening} := 2.12m$ — *Horizontal distance from left side (x=0) to centre of slab*

$W_{slab1} := \gamma_{conc} \cdot \left(L_{slab} \cdot Wi_{slab} \cdot S_{thk} + Gir_{No} \cdot L_{Gir} \cdot Wi_{Gir} \cdot Gir_{thk}\right) = 0 \cdot kN$ — *Dead load from slab (not considering opening)*

$MA_{slab1} := L_{hor} - X_{slab} = 7.950m$ — *Moment arm measured as horizontal distance from centre of slab to right side of base*

$W_{opening} := \gamma_{conc} \cdot L_{opening} \cdot Wi_{opening} \cdot S_{thk} = 0$ — *Weight to be removed from slab due to opening*

$MA_{opening} := L_{hor} - X_{opening} = 5.830m$ — *Moment arm measured as horizontal distance from centre of opening to right side of base*

$W_{slab} := W_{slab1} - W_{opening} = 0kN$ — *Net dead load from slab*

$M_{slab} := W_{slab1} \cdot MA_{slab1} - W_{opening} \cdot MA_{opening} = 0 \cdot kN \cdot m$ *Moment from weight of slab*

Weight of Tower(D) - NOT APPLICABLE

Weight of Riprap / Granular Material on Top of Section - NOT APPLICALBE

Input coordinates

Calculations

Results

Upstream Hydrostatic Force (H)

Figures

Calculations

Note: If inclined face is present, it is assumed to be linear from heel to water level.

$WL_{US.Sum} = 310.900\,m$
$ELE_{Top} = 310.940\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$\omega_{US} = 0.0$
$L_{hor} = 7.95\,m$
$B = 1.67\,m$

Case 1: Summer Operating Level

$$H := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{Base.L} \\ WL_{US.Sum} - ELE_{Base.L} & \text{otherwise} \end{cases} = 5.630$$ *Height of water in front of section*

$$\boxed{P_{US.Sum} := H \cdot \gamma_w = 55.2\,kPa}$$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{Top} \\ WL_{US.Sum} - ELE_{Top} & \text{otherwise} \end{cases} = 0.000$$ *Height of water above top of section*

$$L_{below} := \frac{H - H_{above}}{\cos(\omega_{US})} = 5.630\,m$$ *Inclined length of face under water*

$$F1 := \frac{(H - H_{above}) \cdot \gamma_w \cdot L_{below}}{2} \cdot B = 260.4\,kN$$ *Force due to triangular portion of pressure diagram*

$$F1_{Hor} := F1 \cdot \cos(\omega_{US}) = 260.4\,kN$$ *Horizontal component of F1*

$$F1_{Ver} := F1 \cdot \sin(\omega_{US}) = 0\,kN$$ *Vertical component of F1*

$$ELE_{F1} := ELE_{Base.L} + \left(\frac{L_{below}}{3}\right) \cdot \cos(\omega_{US}) = 307.147\,m$$ *Elevation of F1*

$MA_{F1.Hor} := ELE_{F1} - ELE_{Base.R} = 1.877\,m$ *Moment arm of horizontal component of F1*

$MA_{F1.Ver} := L_{hor} - (ELE_{F1} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$ *Moment arm of vertical component of F1*

$F2 := H_{above} \cdot \gamma_w \cdot L_{below} \cdot B = 0.0\,kN$ *Force due to rectangular portion of pressure diagram*

$F2_{Hor} := F2 \cdot \cos(\omega_{US}) = 0\,kN$

$F2_{Ver} := F2 \cdot \sin(\omega_{US}) = 0\,kN$

$$ELE_{F2} := ELE_{Base.L} + \left(\frac{L_{below}}{2}\right) \cdot \cos(\omega_{US}) = 308.085\,m$$

$MA_{F2.Hor} := ELE_{F2} - ELE_{Base.R} = 2.815\,m$

$MA_{F2.Ver} := L_{hor} - (ELE_{F2} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F_{US.Sum.Hor} := F1_{Hor} + F2_{Hor} = 260.4\,kN$ — *Horizontal hydrostatic force*

$F_{US.Sum.Ver} := F1_{Ver} + F2_{Ver} = 0\,kN$ — *Vertical hydrostatic force*

$M_{US.Sum.Hor} := F1_{Hor} \cdot MA_{F1.Hor} + F2_{Hor} \cdot MA_{F2.Hor} = 488.7\,kN \cdot m$ — *Moment due to horizontal component of hydrostatic force*

$M_{US.Sum.Ver} := F1_{Ver} \cdot MA_{F1.Ver} + F2_{Ver} \cdot MA_{F2.Ver} = 0\,kN \cdot m$ — *Moment due to vertical component of hydrostatic force*

Case 2: Winter Operating Level

$WL_{US.Win} = 309.260\,m$
$ELE_{Top} = 310.940\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$\omega_{US} = 0.0$
$L_{hor} = 7.95\,m$
$B = 1.67\,m$

$$H := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{Base.L} \\ WL_{US.Win} - ELE_{Base.L} & \text{otherwise} \end{cases} = 3.990$$

$\boxed{P_{US.Win} := H \cdot \gamma_w = 39.1\,kPa}$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{Top} \\ WL_{US.Win} - ELE_{Top} & \text{otherwise} \end{cases} = 0.000$$

$$L_{below} := \frac{H - H_{above}}{\cos(\omega_{US})} = 3.990\,m$$

$$F1 := \frac{(H - H_{above}) \cdot \gamma_w \cdot L_{below}}{2} \cdot B = 130.8\,kN$$

$F1_{Hor} := F1 \cdot \cos(\omega_{US}) = 130.8\,kN$

$F1_{Ver} := F1 \cdot \sin(\omega_{US}) = 0\,kN$

$$ELE_{F1} := ELE_{Base.L} + \left(\frac{L_{below}}{3}\right) \cdot \cos(\omega_{US}) = 306.600\,m$$

$MA_{F1.Hor} := ELE_{F1} - ELE_{Base.R} = 1.330\,m$

$MA_{F1.Ver} := L_{hor} - (ELE_{F1} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F2 := H_{above} \cdot \gamma_w \cdot L_{below} \cdot B = 0.0\,kN$

$F2_{Hor} := F2 \cdot \cos(\omega_{US}) = 0\,kN$

$F2_{Ver} := F2 \cdot \sin(\omega_{US}) = 0\,kN$

$$ELE_{F2} := ELE_{Base.L} + \left(\frac{L_{below}}{2}\right) \cdot \cos(\omega_{US}) = 307.265\,m$$

$MA_{F2.Hor} := ELE_{F2} - ELE_{Base.R} = 1.995\,m$

$MA_{F2.Ver} := L_{hor} - (ELE_{F2} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F_{US.Win.Hor} := F1_{Hor} + F2_{Hor} = 130.8\,kN$

$F_{US.Win.Ver} := F1_{Ver} + F2_{Ver} = 0\,kN$

$M_{US.Win.Hor} := F1_{Hor} \cdot MA_{F1.Hor} + F2_{Hor} \cdot MA_{F2.Hor} = 174\,kN \cdot m$

$M_{US.Win.Ver} := F1_{Ver} \cdot MA_{F1.Ver} + F2_{Ver} \cdot MA_{F2.Ver} = 0\,kN \cdot m$

Case 3: IDF Level

$WL_{US.IDF} = 311.900\,m$
$ELE_{Top} = 310.940\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$\omega_{US} = 0.0$
$L_{hor} = 7.95\,m$
$B = 1.67\,m$

$$H := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{Base.L} \\ WL_{US.IDF} - ELE_{Base.L} & \text{otherwise} \end{cases} = 6.630$$

$\boxed{P_{US.IDF} := H \cdot \gamma_w = 65\,kPa}$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{Top} \\ WL_{US.IDF} - ELE_{Top} & \text{otherwise} \end{cases} = 0.960$$

$$L_{below} := \frac{H - H_{above}}{\cos(\omega_{US})} = 5.670\,m$$

$$F1 := \frac{(H - H_{above}) \cdot \gamma_w \cdot L_{below}}{2} \cdot B = 264.1\,kN$$

$F1_{Hor} := F1 \cdot \cos(\omega_{US}) = 264.1\,kN$

$F1_{Ver} := F1 \cdot \sin(\omega_{US}) = 0\,kN$

$ELE_{F1} := ELE_{Base.L} + \left(\frac{L_{below}}{3}\right) \cdot \cos(\omega_{US}) = 307.160\,m$

$MA_{F1.Hor} := ELE_{F1} - ELE_{Base.R} = 1.890\,m$

$MA_{F1.Ver} := L_{hor} - (ELE_{F1} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F2 := H_{above} \cdot \gamma_w \cdot L_{below} \cdot B = 89.4\,kN$

$F2_{Hor} := F2 \cdot \cos(\omega_{US}) = 89.4\,kN$

$F2_{Ver} := F2 \cdot \sin(\omega_{US}) = 0\,kN$

$ELE_{F2} := ELE_{Base.L} + \left(\frac{L_{below}}{2}\right) \cdot \cos(\omega_{US}) = 308.105\,m$

$MA_{F2.Hor} := ELE_{F2} - ELE_{Base.R} = 2.835\,m$

$MA_{F2.Ver} := L_{hor} - (ELE_{F2} - ELE_{Base.L})\tan(\omega_{US}) = 7.950\,m$

$F_{US.IDF.Hor} := F1_{Hor} + F2_{Hor} = 353.6\,kN$

$F_{US.IDF.Ver} := F1_{Ver} + F2_{Ver} = 0\,kN$

$M_{US.IDF.Hor} := F1_{Hor} \cdot MA_{F1.Hor} + F2_{Hor} \cdot MA_{F2.Hor} = 752.8\,kN \cdot m$

$M_{US.IDF.Ver} := F1_{Ver} \cdot MA_{F1.Ver} + F2_{Ver} \cdot MA_{F2.Ver} = 0\,kN \cdot m$

Calculations

Downstream Hydrostatic Force (H)

Hydrostatic Force on Gates (H)

Calculations

Note: Pressure from tailwater not considered. Calculations assume a flat vertical face

$Gates_{Sum.Hyd} = 1$
$Gates_{Win.Hyd} = 1$
$Gates_{IDF.Hyd} = 1$
$WL_{US.Sum} = 310.900\,m$
$WL_{US.Win} = 309.260\,m$
$WL_{US.IDF} = 311.900\,m$
$ELE_{sill} = 307.130\,m$
$ELE_{gate.top} = 310.280\,m$
$ELE_{Base.R} = 305.270\,m$
$Trib_{gate} = 1.524\,m$
$L_{hor} = 7.95\,m$

Case 1: Summer operating level

$H := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{sill} \\ WL_{US.Sum} - ELE_{sill} & \text{otherwise} \end{cases} = 3.770$ *Height of water in front of gate/stoplogs*

$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Sum} \le ELE_{gate.top} \\ WL_{US.Sum} - ELE_{gate.top} & \text{otherwise} \end{cases} = 0.620$ *Height of water above top of gate/stoplogs*

$F1 := \frac{(H - H_{above})^2 \cdot \gamma_w}{2} \cdot Trib_{gate} = 74.2\,kN$ *Force due to triangular portion of pressure diagram*

$MA1 := \left(ELE_{sill} + \frac{H - H_{above}}{3} - ELE_{Base.R}\right) = 2.910\,m$ *Moment arm*

$F2 := H_{above} \cdot (H - H_{above}) \cdot \gamma_w \cdot Trib_{gate} = 29.2\,kN$ *Force due to rectangular portion of pressure diagram*

$MA2 := \left(ELE_{sill} + \frac{H - H_{above}}{2} - ELE_{Base.R}\right) = 3.435\,m$ *Moment arm*

$F_{gateH.Sum} := \begin{cases} (F1 + F2) & \text{if } Gates_{Sum.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 103.4 \cdot kN$ *Total hydrostatic force on gate/stoplogs*

$M_{gateH.Sum} := \begin{cases} (F1 \cdot MA1 + F2 \cdot MA2) & \text{if } Gates_{Sum.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 316.1 \cdot kN \cdot m$ *Moment due to hydrostatic force on gate/stoplogs*

Case 2: Winter operating level

$$H := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{sill} \\ WL_{US.Win} - ELE_{sill} & \text{otherwise} \end{cases} = 2.130$$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.Win} \le ELE_{gate.top} \\ WL_{US.Win} - ELE_{gate.top} & \text{otherwise} \end{cases} = 0.000$$

$$F1 := \frac{(H - H_{above})^2 \cdot \gamma_w}{2} \cdot Trib_{gate} = 33.9\,kN$$

$$MA1 := \left(ELE_{sill} + \frac{H - H_{above}}{3} - ELE_{Base.R}\right) = 2.570\,m$$

$$F2 := H_{above} \cdot (H - H_{above}) \cdot \gamma_w \cdot Trib_{gate} = 0.0\,kN$$

$$MA2 := \left(ELE_{sill} + \frac{H - H_{above}}{2} - ELE_{Base.R}\right) = 2.925\,m$$

$$F_{gateH.Win} := \begin{cases} (F1 + F2) & \text{if } Gates_{Win.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 33914.3$$

$$M_{gateH.Win} := \begin{cases} (F1 \cdot MA1 + F2 \cdot MA2) & \text{if } Gates_{Win.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 87159.8$$

Case 3: IDF level

$$H := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{sill} \\ WL_{US.IDF} - ELE_{sill} & \text{otherwise} \end{cases} = 4.770$$

$$H_{above} := \begin{cases} 0 & \text{if } WL_{US.IDF} \le ELE_{gate.top} \\ WL_{US.IDF} - ELE_{gate.top} & \text{otherwise} \end{cases} = 1.620$$

$$F1 := \frac{(H - H_{above})^2 \cdot \gamma_w}{2} \cdot Trib_{gate} = 74.2\,kN$$

$$MA1 := \left(ELE_{sill} + \frac{H - H_{above}}{3} - ELE_{Base.R}\right) = 2.910\,m$$

$$F2 := H_{above} \cdot (H - H_{above}) \cdot \gamma_w \cdot Trib_{gate} = 76.3\,kN$$

$$MA2 := \left(ELE_{sill} + \frac{H - H_{above}}{2} - ELE_{Base.R}\right) = 3.435\,m$$

$$F_{gateH.IDF} := \begin{cases} (F1 + F2) & \text{if } Gates_{IDF.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 150.5 \cdot kN$$

$$M_{gateH.IDF} := \begin{cases} (F1 \cdot MA1 + F2 \cdot MA2) & \text{if } Gates_{IDF.Hyd} = 1 \\ 0 & \text{otherwise} \end{cases} = 477.9 \cdot kN \cdot m$$

Calculations

Hydraulic Drag Force (H)

Weight of Water Above Section (H) - NOT APPLICABLE

Input coordinates

Calculations

Results

Initial Uplift Forces (U)

Figures

Uplift Function Definition

Input and Calculation

Note: Analysis assumes uplift pressure acts perpendicular to the concrete-foundation interface. Uplift pressure is considered positive, but the actual forces are negative when vertically upwards and positive in downstream (right) direction. Crack length is initially set to 0 but may change in subsequent cracked base analysis. Uplift is calculated again in the cracked section analysis and in the post-earthquake load combination.

$Factor_{UL} := 1.00$ — *Factor to reduce uplift pressure if required. Set to 1.00 for 100%.*

$L_{crack0} := 0 \cdot m$ — *Set initial crack length. Measured from left side, parallel to base*

$L_{incl} = 7.95\,m$
$ELE_{Base.L} = 305.270\,m$
$ELE_{Base.R} = 305.270\,m$
$WL_{US.Sum} = 310.900\,m$
$WL_{US.Win} = 309.260\,m$
$WL_{US.IDF} = 311.900\,m$
$WL_{DS.Sum} = 305.270\,m$
$WL_{DS.Win} = 305.270\,m$
$WL_{DS.IDF} = 310.300\,m$
$P_{US.Sum} = 55.2 \cdot kPa$
$P_{DS.Sum} = 0.0 \cdot kPa$

$P_{USUL.Sum} := Factor_{UL} \cdot P_{US.Sum} = 55.2 \cdot kPa$ — *Uplift pressure at upstream (left) side*

$P_{DSUL.Sum} := Factor_{UL} \cdot P_{DS.Sum} = 0 \cdot kPa$ — *Uplift pressure at downstream (right) side*

$P_{USUL.Win} := Factor_{UL} \cdot P_{US.Win} = 39.1 \cdot kPa$

$P_{DSUL.Win} := Factor_{UL} \cdot P_{DS.Win} = 0 \cdot kPa$

$P_{USUL.IDF} := Factor_{UL} \cdot P_{US.IDF} = 65 \cdot kPa$

$P_{DSUL.IDF} := Factor_{UL} \cdot P_{DS.IDF} = 49.3 \cdot kPa$

Case 1: Water at summer operating levels

$P_{U.Sum}(x) := P_{UL}(x, L_{crack0}, P_{USUL.Sum}, P_{DSUL.Sum})$ — *Creates the pressure function*

$$F_{U0.Sum} := \int_0^{L_{incl}} P_{U.Sum}(x) \cdot B\,dx = 367.7 \cdot kN$$

Total uplift force. Calculated as the area under the uplift pressure diagram.

$$MA := L_{incl} - \frac{1}{F_{U0.Sum}} \left(\int_0^{L_{incl}} P_{U.Sum}(x) \cdot x \cdot B\,dx \right) = 5.3\,m$$

Moment arm of uplift force about the right side of base. Measured parallel to base.

$M_{U0.Sum} := F_{U0.Sum} \cdot MA = 1949 \cdot kN \cdot m$ — *Moment from uplift on uncracked section*

$F_{U0.Sum.Hor} := -F_{U0.Sum} \cdot \sin(\alpha) = 0 \cdot kN$ — *Uplift resolved into horizontal and vertical forces for subsequent calculations*

$F_{U0.Sum.Ver} := -F_{U0.Sum} \cdot \cos(\alpha) = -367.7 \cdot kN$

Case 2: Water at winter operating levels

$P_{U.Win}(x) := P_{UL}(x, L_{crack0}, P_{USUL.Win}, P_{DSUL.Win})$

$$F_{U0.Win} := \int_0^{L_{incl}} P_{U.Win}(x) \cdot B\,dx = 260.6 \cdot kN$$

$$MA := L_{incl} - \frac{1}{F_{U0.Win}} \left(\int_0^{L_{incl}} P_{U.Win}(x) \cdot x \cdot B\,dx \right) = 5.3\,m$$

$M_{U0.Win} := F_{U0.Win} \cdot MA = 1381.2 \cdot kN \cdot m$
$F_{U0.Win.Hor} := -F_{U0.Win} \cdot \sin(\alpha) = 0 \cdot kN$
$F_{U0.Win.Ver} := -F_{U0.Win} \cdot \cos(\alpha) = -260.6 \cdot kN$

Case 3: Water at IDF levels

$P_{U.IDF}(x) := P_{UL}(x, L_{crack0}, P_{USUL.IDF}, P_{DSUL.IDF})$

$$F_{U0.IDF} := \int_0^{L_{incl}} P_{U.IDF}(x) \cdot B\,dx = 761.6 \cdot kN$$

$$MA := L_{incl} - \frac{1}{F_{U0.IDF}} \left(\int_0^{L_{incl}} P_{U.IDF}(x) \cdot x \cdot B\,dx \right) = 4.16\,m$$

$M_{U0.IDF} := F_{U0.IDF} \cdot MA = 3165.8 \cdot kN \cdot m$
$F_{U0.IDF.Hor} := -F_{U0.IDF} \cdot \sin(\alpha) = 0 \cdot kN$
$F_{U0.IDF.Ver} := -F_{U0.IDF} \cdot \cos(\alpha) = -761.6 \cdot kN$

Input and Calculation

Plot of Results

Upstream Silt Buildup (S)

Downstream Backfill (S)

Ice Loading (I)

USUAL LOAD CASE

Direct ice load on structure

$Wi_{gate} = 0.00$
$Trib_{gate} = 1.52\,m$
$ELE_{Base.R} = 305.270\,m$
$WL_{US.Win} = 309.260\,m$
$B = 1.67\,m$
$Gates_{Win.Hyd} = 1$

$IceLoad_{usual} := 75 \frac{kN}{m}$ — *Ice loading on structure (enter as kN/m)*

$F_{ice.1.usual} := IceLoad_{usual} B = 125.6 \cdot kN$ — *Force acting on the structure*
$ELE_{ice} := WL_{US.Win} - 0.3m = 308.96\,m$ — *Elevation of force (assumed to act at 0.3m below water level)*
$MA := ELE_{ice} - ELE_{Base.R} = 3.7\,m$ — *Moment arm is vertical distance from force to right side of base*
$M_{ice.1.usual} := F_{ice.1.usual} \cdot MA = 463.6 \cdot kN \cdot m$ — *Moment about right side of base*

Ice load on adjacent gates/stop logs

Note: Ice load in this section acts on the tributary gate width to be transferred into gate slots

$$F_{ice.gate.usual} := \begin{cases} 0 & \text{if } Gates_{Win.Hyd} = 0 \\ IceLoad_{usual} \cdot Trib_{gate} & \text{otherwise} \end{cases} = 114.3 \cdot kN$$

$M_{ice.gate.usual} := F_{ice.gate.usual} \cdot MA = 421.8\,kN \cdot m$

$F_{ice.usual} := F_{ice.1.usual} + F_{ice.gate.usual} = 239.9\,kN$

$M_{ice.usual} := M_{ice.1.usual} + M_{ice.gate.usual} = 885.3\,kN \cdot m$

UNUSUAL LOAD CASE

Direct ice load on structure

$IceLoad := 83.5\,\frac{kN}{m}$ — *Ice loading on structure (enter as kN/m)*

$F_{ice.1} := IceLoad\,B = 139.9 \cdot kN$ — *Force acting on the structure*

$M_{ice.1} := F_{ice.1} \cdot MA = 516.1 \cdot kN \cdot m$ — *Moment about right side of base*

Ice load on adjacent gates/stop logs

Note: Ice load in this section acts on the tributary gate width to be transferred into gate slots

$$F_{ice.gate} := \begin{cases} 0 & \text{if } Gates_{Win.Hyd} = 0 \\ IceLoad \cdot Trib_{gate} & \text{otherwise} \end{cases} = 127.3 \cdot kN$$

$M_{ice.gate} := F_{ice.gate} \cdot MA = 469.6\,kN \cdot m$

$F_{ice} := F_{ice.1} + F_{ice.gate} = 267.1\,kN$

$M_{ice} := M_{ice.1} + M_{ice.gate} = 985.7\,kN \cdot m$

Seismic Forces - Inertia of Structure Dead Load (Q)

Seismic Forces - Hydrodynamic Forces (Q)

Figures

Calculations

Seismic Forces - Dynamic Soil Pressures (Q)

Tensioned Anchors - NOT APPLICABLE

Other Forces - NOT APPLICABLE

Load Case 1. Usual Loading Summer Case (D+H+S+U)

LC.1 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$
$W_{log.Sum} = 0$
$W_{slab} = 0\,kN$
$W_{tower} = 0$

$M_{conc} = 6231.8 \cdot kN \cdot m$
$M_{log.Sum} = 0$
$M_{slab} = 0\,kN \cdot m$
$M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 260.4 \cdot kN$
$F_{US.Sum.Ver} = 0 \cdot kN$
$F_{DS.Sum.Hor} = 0\,kN$
$F_{DS.Sum.Ver} = 0\,kN$

$F_{gateH.Sum} = 103.4\,kN$
$W_{Water.Above.Sum} = 0$

$M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$
$M_{US.Sum.Ver} = 0 \cdot kN \cdot m$
$M_{DS.Sum.Hor} = 0\,kN \cdot m$
$M_{DS.Sum.Ver} = 0\,kN \cdot m$

$M_{gateH.Sum} = 316.1\,kN \cdot m$
$M_{Water.Above.Sum} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$
$W_{US.silt} = 0\,kN$
$F_{DS.fill.Hor} = 0$
$W_{DS.fill} = 0$

$W_{Granular.Sum} = 0\,kN$

$M_{US.silt.Hor} = 0\,kN \cdot m$
$M_{US.silt.Ver} = 0\,kN \cdot m$
$M_{DS.fill.Hor} = 0$
$M_{DS.fill.Ver} = 0$

$M_{Granular.Sum} = 0\,kN \cdot m$

Uplift (U):

$F_{U0.Sum.Hor} = 0 \cdot kN$
$F_{U0.Sum.Ver} = -367.7 \cdot kN$

$M_{U0.Sum} = 1949 \cdot kN \cdot m$

Other Forces:

$F_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$

$M_{anchor.Hor} = 0$
$M_{anchor.Ver} = 0$
$M_{other.Hor.1} = 0$
$M_{other.Ver.1} = 0$

LC.1 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \ldots + \left(F_{U0.Sum.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) = 363.8\,kN$$

Sum of horizontal forces

$$F_{ver0} := \left(W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}\right) + \left(F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}\right) \ldots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Sum}\right) + \left(F_{U0.Sum.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1200\,kN$$

Sum of vertical forces

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 363.8 \cdot kN$$

Forces acting parallel to uncracked base

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1200.0 \cdot kN$$

Forces acting perpendicular to uncracked base

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \ldots + \left(M_{US.silt.Ver} + M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{Granular.Sum}\right) \ldots + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 6231.8\,kN \cdot m$$

Sum of stabilizing moments

$$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Sum}\right) = 2753.8\,kN \cdot m$$

Sum of overturning moments

$$M_{net0} := M_{stab0} - M_{overturn0} = 3478\,kN \cdot m$$

Net resisting moment

LC.1 - Resultant and Bearing Stresses

$x_0 := \dfrac{M_{net0}}{F_{perp0}} = 2.9\,m$ — *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \dfrac{L_{incl}}{2} - x_0 = 1.08\,m$ — *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 7.95\,m$
$M_{net0} = 3478.0\,kN \cdot m$
$F_{perp0} = 1200.0\,kN$

Stress Calculations

$q_{max0} = 163.3\,kPa$ $\quad q_{min0} = 16.9\,kPa$ — *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp0} = 7.95\,m$ — *Length of base in compression before iterative cracked base analysis*

$L_{tens0} = 0.00\,m$ — *Length of base in tension before iterative cracked base analysis*

$L_{crack0} = 0.00\,m$ — *Length of crack between concrete and base before iterative cracked base analysis*

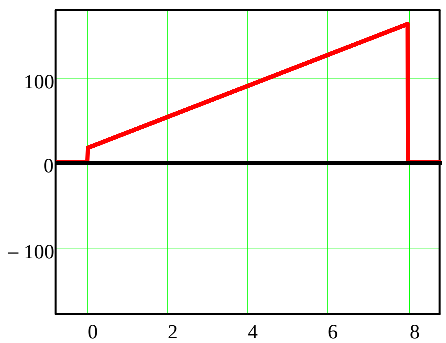
$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \dfrac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1200030.4$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

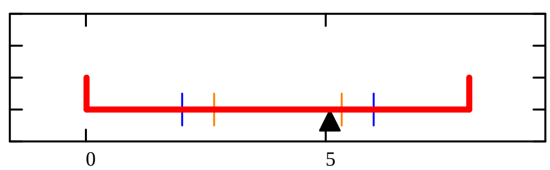
Compression and tension forces in foundation

$\dfrac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\quad \dfrac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\quad \dfrac{L_{crack0}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

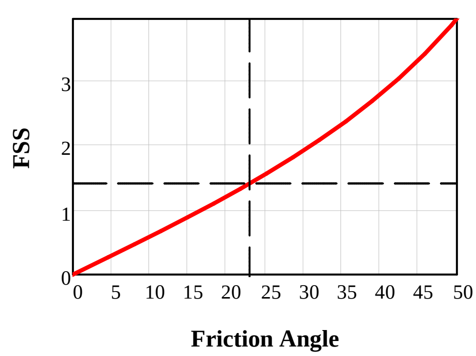
LC.1 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \dfrac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 1.40$ — *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$



LC.1 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 2. Usual Loading Winter Case (D+H+S+U+I)

LC.2 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ | $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Win} = 0$ | $M_{log.Win} = 0$

$W_{slab} = 0\,kN$ | $M_{slab} = 0\,kN \cdot m$

$W_{tower} = 0$ | $M_{tower} = 0$

Hydraulic (H):

$F_{US.Win.Hor} = 130.8 \cdot kN$ | $M_{US.Win.Hor} = 174 \cdot kN \cdot m$

$F_{US.Win.Ver} = 0 \cdot kN$ | $M_{US.Win.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Win.Hor} = 0\,kN$ | $M_{DS.Win.Hor} = 0\,kN \cdot m$

$F_{DS.Win.Ver} = 0\,kN$ | $M_{DS.Win.Ver} = 0\,kN \cdot m$

$F_{gateH.Win} = 33.9\,kN$ | $M_{gateH.Win} = 87.2\,kN \cdot m$

$W_{Water.Above.Win} = 0$ | $M_{Water.Above.Win} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ | $M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$ | $M_{US.silt.Ver} = 0\,kN \cdot m$

$F_{DS.fill.Hor} = 0$ | $M_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$ | $M_{DS.fill.Ver} = 0$

$W_{Granular.Win} = 0\,kN$ | $M_{Granular.Win} = 0\,kN \cdot m$

Uplift (U):

$M_{U0.Win} = 1381.2 \cdot kN \cdot m$

$F_{U0.Win.Hor} = 0 \cdot kN$

$F_{U0.Win.Ver} = -260.6 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ | $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ | $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ | $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ | $M_{other.Ver.1} = 0$

Ice (I):

$F_{ice.usual} = 239.9 \cdot kN$ | $M_{ice.usual} = 885.3 \cdot kN \cdot m$

LC.2 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Win.Hor} - F_{DS.Win.Hor} + F_{gateH.Win}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \dots + \left(F_{U0.Win.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) + \left(F_{ice.usual}\right) = 404.6\,kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Win} + W_{slab} + W_{tower}\right) + \left(F_{US.Win.Ver} + F_{DS.Win.Ver} + W_{Water.Above.Win}\right) \dots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Win}\right) + \left(F_{U0.Win.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1307.1\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 404.6 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1307.1 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Win.Ver} + M_{DS.Win.Hor} + M_{DS.Win.Ver} + M_{Water.Above.Win}\right) \dots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Win}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 6231.8\,kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Win.Hor} + M_{gateH.Win}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Win}\right) + \left(M_{ice.usual}\right) = 2527.7\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 3704.2\,kN \cdot m$$

LC.2 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.83\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \frac{L_{incl}}{2} - x_0 = 1.14\,m$ *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 7.95\,m$
$M_{net0} = 3704.2\,kN \cdot m$
$F_{perp0} = 1307.1\,kN$

Stress Calculations

$q_{max0} = 182.7\,kPa$ $q_{min0} = 13.6\,kPa$

$L_{comp0} = 7.95\,m$

$L_{tens0} = 0.00\,m$

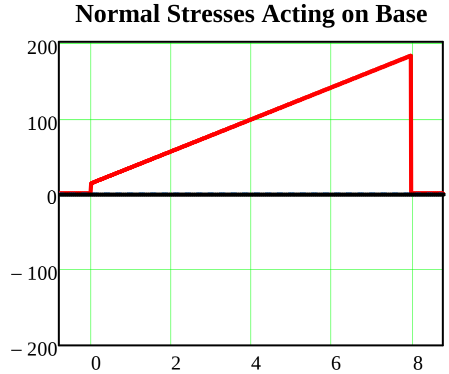
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1307149$$

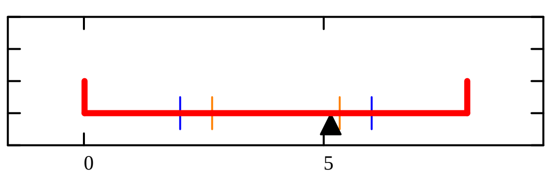
$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



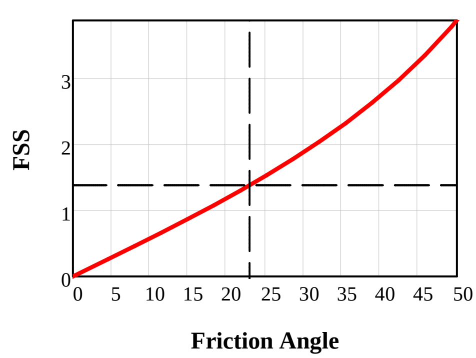
Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.2 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$ *Define function to evaluate sliding using a range of friction angles*

$FSS_0(\phi_{cf}) = 1.37$ *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$



LC.2 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$\text{crackactive} := \begin{vmatrix} 0 \text{ if } L_{crack0} = 0 \\ 1 \text{ otherwise} \end{vmatrix} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 3. Unusual Loading IDF ($D+H_{IDF}+S+U_{IDF}$)

LC.3 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ | $M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.IDF} = 0$ | $M_{log.IDF} = 0$

$W_{slab} = 0\,kN$ | $M_{slab} = 0\,kN \cdot m$

$W_{tower} = 0$ | $M_{tower} = 0$

Hydraulic (H):

$F_{US.IDF.Hor} = 353.6 \cdot kN$ | $M_{US.IDF.Hor} = 752.8 \cdot kN \cdot m$

$F_{US.IDF.Ver} = 0 \cdot kN$ | $M_{US.IDF.Ver} = 0 \cdot kN \cdot m$

$F_{DS.IDF.Hor} = 207.9\,kN$ | $M_{DS.IDF.Hor} = 348.5\,kN \cdot m$

$F_{DS.IDF.Ver} = 0\,kN$ | $M_{DS.IDF.Ver} = 0\,kN \cdot m$

$F_{gateH.IDF} = 150.5\,kN$ | $M_{gateH.IDF} = 477.9\,kN \cdot m$

$F_{drag} = 0$ | $M_{drag} = 0$

$W_{Water.Above.IDF} = 0$ | $M_{Water.Above.IDF} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ | $M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$ | $M_{US.silt.Ver} = 0\,kN \cdot m$

$F_{DS.fill.IDF.Hor} = 0$ | $M_{DS.fill.IDF.Hor} = 0$

$W_{DS.fill.IDF} = 0$ | $M_{DS.fill.IDF.Ver} = 0$

$W_{Granular.IDF} = 0\,kN$ | $M_{Granular.IDF} = 0\,kN \cdot m$

Uplift (U):

$M_{U0.IDF} = 3165.8 \cdot kN \cdot m$

$F_{U0.IDF.Hor} = 0 \cdot kN$

$F_{U0.IDF.Ver} = -761.6 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ | $M_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$ | $M_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$ | $M_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$ | $M_{other.Ver.1} = 0$

LC.3 - Combine Forces and Moments

$$F_{hor0} := (F_{US.IDF.Hor} - F_{DS.IDF.Hor} + F_{gateH.IDF} + F_{drag}) + (F_{US.silt.Hor} - F_{DS.fill.IDF.Hor}) \ldots + (F_{U0.IDF.Hor}) + (F_{anchor.Hor} + F_{other.Hor.1}) = 296.2\,kN$$

$$F_{ver0} := (W_{conc} + W_{log.IDF} + W_{slab} + W_{tower}) + (F_{US.IDF.Ver} + F_{DS.IDF.Ver} + W_{Water.Above.IDF}) \ldots + (W_{US.silt} + W_{DS.fill.IDF} + W_{Granular.IDF}) + (F_{U0.IDF.Ver}) + (F_{anchor.Ver} + F_{other.Ver.1}) = 806.2\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 296.2 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 806.2 \cdot kN$$

$$M_{stab0} := (M_{conc} + M_{log.IDF} + M_{slab} + M_{tower}) + (M_{US.IDF.Ver} + M_{DS.IDF.Hor} + M_{DS.IDF.Ver} + M_{Water.Above.IDF}) \ldots + (M_{US.silt.Ver} + M_{DS.fill.IDF.Hor} + M_{DS.fill.IDF.Ver} + M_{Granular.IDF}) \ldots + (M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}) = 6580.4\,kN \cdot m$$

$$M_{overturn0} := (M_{US.IDF.Hor} + M_{gateH.IDF} + M_{drag}) + (M_{US.silt.Hor}) + (M_{U0.IDF}) = 4396.5\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 2183.9\,kN \cdot m$$

LC.3 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.71\,m$

$E_0 := \frac{L_{incl}}{2} - x_0 = 1.27\,m$

$L_{incl} = 7.95\,m$
$M_{net0} = 2183.9\,kN \cdot m$
$F_{perp0} = 806.2\,kN$

Stress Calculations

$q_{max0} = 118.4\,kPa$ $q_{min0} = 2.7\,kPa$

$L_{comp0} = 7.95\,m$

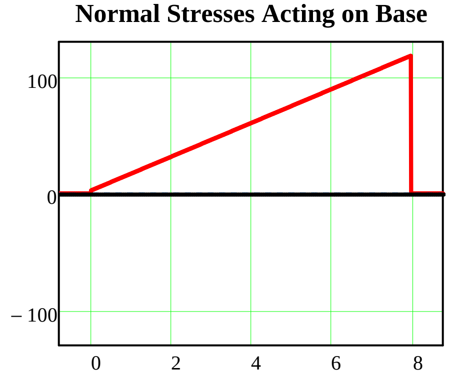
$L_{tens0} = 0.00\,m$

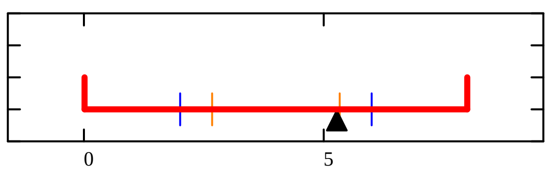
$L_{crack0} = 0.00\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 806173.7$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$





Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.3 - Sliding

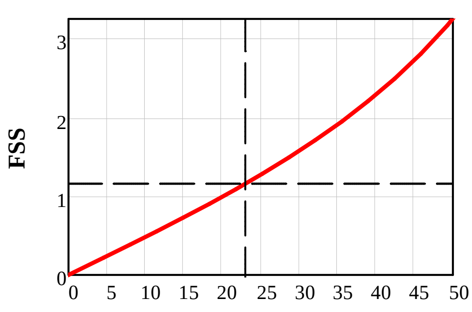
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$FSS_0(\phi_{cf}) = 1.16$

Factor of safety against sliding for specified friction angle

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$



LC.3 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

▶ Cracked Base Calculations

▶ Cracked Base Results

▶ Store results for summary

▶ Store (uncracked) results for Combined Analysis

Load Case 4. Unusual Loading Winter Case (D+H+S+U+I)

LC.4 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ | $M_{conc} = 6231.8 \cdot kN \cdot m$
$W_{log.Win} = 0$ | $M_{log.Win} = 0$
$W_{slab} = 0 kN$ | $M_{slab} = 0 kN \cdot m$
$W_{tower} = 0$ | $M_{tower} = 0$

Hydraulic (H):

$F_{US.Win.Hor} = 130.8 \cdot kN$ | $M_{US.Win.Hor} = 174 \cdot kN \cdot m$
$F_{US.Win.Ver} = 0 \cdot kN$ | $M_{US.Win.Ver} = 0 \cdot kN \cdot m$
$F_{DS.Win.Hor} = 0 kN$ | $M_{DS.Win.Hor} = 0 kN \cdot m$
$F_{DS.Win.Ver} = 0 kN$ | $M_{DS.Win.Ver} = 0 kN \cdot m$
$F_{gateH.Win} = 33.9 kN$ | $M_{gateH.Win} = 87.2 kN \cdot m$
$W_{Water.Above.Win} = 0$ | $M_{Water.Above.Win} = 0$

Soil (S):

$F_{US.silt.Hor} = 0 kN$ | $M_{US.silt.Hor} = 0 kN \cdot m$
$W_{US.silt} = 0 kN$ | $M_{US.silt.Ver} = 0 kN \cdot m$
$F_{DS.fill.Hor} = 0$ | $M_{DS.fill.Hor} = 0$
$W_{DS.fill} = 0$ | $M_{DS.fill.Ver} = 0$
$W_{Granular.Win} = 0 kN$ | $M_{Granular.Win} = 0 kN \cdot m$

Uplift (U):

$F_{U0.Win.Hor} = 0 \cdot kN$ | $M_{U0.Win} = 1381.2 \cdot kN \cdot m$
$F_{U0.Win.Ver} = -260.6 \cdot kN$

Other Forces:

$F_{anchor.Hor} = 0$ | $M_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$ | $M_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$ | $M_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$ | $M_{other.Ver.1} = 0$

Ice (I):

$F_{ice} = 267.1 \cdot kN$ | $M_{ice} = 985.7 \cdot kN \cdot m$

LC.4 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Win.Hor} - F_{DS.Win.Hor} + F_{gateH.Win}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \dots + \left(F_{U0.Win.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) + \left(F_{ice}\right) = 431.8 kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Win} + W_{slab} + W_{tower}\right) + \left(F_{US.Win.Ver} + F_{DS.Win.Ver} + W_{Water.Above.Win}\right) \dots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Win}\right) + \left(F_{U0.Win.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1307.1 kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 431.8 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1307.1 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Win.Ver} + M_{DS.Win.Hor} + M_{DS.Win.Ver} + M_{Water.Above.Win}\right) \dots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Win}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 6231.8 kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Win.Hor} + M_{gateH.Win}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Win}\right) + \left(M_{ice}\right) = 2628 kN \cdot m$$

$M_{net0} := M_{stab0} - M_{overturn0} = 3603.8 kN \cdot m$

LC.4 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.76 m$ *Distance of resulant from right side of base (measured parallel to base)*

$E_0 := \frac{L_{incl}}{2} - x_0 = 1.22 m$ *Ecentricity of resultant (positive is to the right)*

$L_{incl} = 7.95 m$
$M_{net0} = 3603.8 kN \cdot m$
$F_{perp0} = 1307.1 kN$

Stress Calculations

$q_{max0} = 188.4 kPa$ $q_{min0} = 7.9 kPa$

$L_{comp0} = 7.95 m$

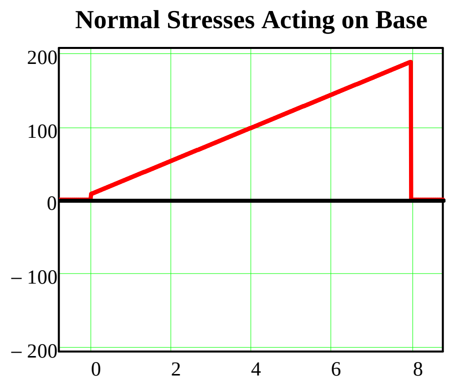
$L_{tens0} = 0.00 m$

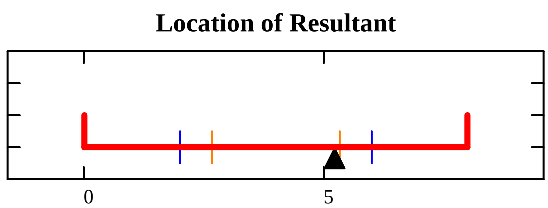
$L_{crack0} = 0.00 m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \ge 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1307149$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0 kN$$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 0 \cdot \%$





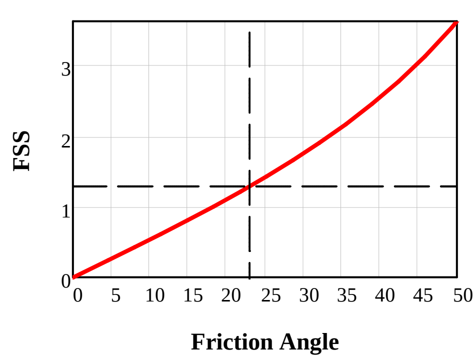
Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.4 - Sliding

$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$ *Define function to evaluate sliding using a range of friction angles*

$FSS_0(\phi_{cf}) = 1.28$ *Factor of safety against sliding for specified friction angle*

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95 m$
$\alpha = 0 \cdot deg$
$B = 1.67 m$



LC.4 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$crackactive := \begin{cases} 0 & \text{if } L_{crack0} = 0 \\ 1 & \text{otherwise} \end{cases} = 0$$

Determines if the cracked analysis should run.

Cracked Base Calculations

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 5. Extreme Loading Earthquake (D+H+S+Q+U_Q)

LC.5 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$	$M_{conc} = 6231.8 \cdot kN \cdot m$
$W_{log.Sum} = 0$	$M_{log.Sum} = 0$
$W_{slab} = 0 kN$	$M_{slab} = 0 kN \cdot m$
$W_{tower} = 0$	$M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 260.4 \cdot kN$	$M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$
$F_{US.Sum.Ver} = 0 \cdot kN$	$M_{US.Sum.Ver} = 0 \cdot kN \cdot m$
$F_{DS.Sum.Hor} = 0 kN$	$M_{DS.Sum.Hor} = 0 kN \cdot m$
$F_{DS.Sum.Ver} = 0 kN$	$M_{DS.Sum.Ver} = 0 kN \cdot m$
$F_{gateH.Sum} = 103.4 kN$	$M_{gateH.Sum} = 316.1 kN \cdot m$
$W_{Water.Above.Sum} = 0$	$M_{Water.Above.Sum} = 0$

Soil (S):

$F_{US.silt.Hor} = 0 kN$	$M_{US.silt.Hor} = 0 kN \cdot m$
$W_{US.silt} = 0 kN$	$M_{US.silt.Ver} = 0 kN \cdot m$
$F_{DS.fill.Hor} = 0$	$M_{DS.fill.Hor} = 0$
$W_{DS.fill} = 0$	$M_{DS.fill.Ver} = 0$
$W_{Granular.EQ} = 0 kN$	$M_{Granular.EQ} = 0 kN \cdot m$

Uplift (U):

$F_{U0.Sum.Hor} = 0 \cdot kN$	$M_{U0.Sum} = 1949 \cdot kN \cdot m$
$F_{U0.Sum.Ver} = -367.7 \cdot kN$	

Other Forces:

$F_{anchor.Hor} = 0$	$M_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$	$M_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$	$M_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$	$M_{other.Ver.1} = 0$

Seismic (Q):

$F_{eq.conc.Hor} = 130.8 kN$	$M_{eq.conc.Hor} = 370.7 kN \cdot m$

$F_{eq.conc.Ver} = 87.2\,kN$ $M_{eq.conc.Ver} = 346.5\,kN \cdot m$
$F_{eq.log.Hor} = 0$ $M_{eq.log.Hor} = 0$
$F_{eq.log.Ver} = 0$ $M_{eq.log.Ver} = 0$
$F_{eq.slab.Hor} = 0\,kN$ $M_{eq.slab.Hor} = 0\,kN \cdot m$
$F_{eq.slab.Ver} = 0\,kN$ $M_{eq.slab.Ver} = 0\,kN \cdot m$
$F_{eq.tower.Hor} = 0$ $M_{eq.tower.Hor} = 0$
$F_{eq.tower.Ver} = 0$ $M_{eq.tower.Ver} = 0$

$F_{eq.HD.US} = 23.3\,kN$ $M_{eq.HD.US} = 52.8\,kN \cdot m$
$F_{eq.HD.gate} = 9\,kN$ $M_{eq.HD.gate} = 32.1\,kN \cdot m$

$F_{eq.silt.Hor} = 0\,kN$ $M_{eq.silt.Hor} = 0\,kN \cdot m$
$F_{eq.silt.Ver} = 0\,kN$ $M_{eq.silt.Ver} = 0\,kN \cdot m$
$F_{eq.fill.Hor} = 0$ $M_{eq.fill.Hor} = 0$
$F_{eq.fill.Ver} = 0$ $M_{eq.fill.Ver} = 0$
$F_{eq.Granular.Ver} = 0\,kN$ $M_{eq.Granular.Ver} = 0\,kN \cdot m$
$F_{eq.Granular.Hor} = 0\,kN$ $M_{eq.Granular.Hor} = 0\,kN \cdot m$
$F_{eq.Water.Above.Ver} = 0$ $M_{eq.Water.Above.Ver} = 0$
$F_{eq.Water.Above.Hor} = 0$ $M_{eq.Water.Above.Hor} = 0$

LC.5 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \cdots + \left(F_{U0.Sum.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) \cdots + \left(F_{eq.conc.Hor} + F_{eq.log.Hor} + F_{eq.slab.Hor} + F_{eq.tower.Hor} + F_{eq.HD.US} + F_{eq.HD.gate} + F_{eq.silt.Hor} + F_{eq.fill.Hor} + F_{eq.Granular.Hor}\right) = 526.8\,kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}\right) + \left(F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}\right) \cdots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.EQ}\right) + \left(F_{U0.Sum.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) \cdots + \left(-F_{eq.conc.Ver} - F_{eq.log.Ver} - F_{eq.slab.Ver} - F_{eq.tower.Ver} - F_{eq.silt.Ver} - F_{eq.fill.Ver} - F_{eq.Granular.Ver} - F_{eq.Water.Above.Ver}\right) = 1112.9\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 526.8 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1112.9 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \cdots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.EQ}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 6231.8\,kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.Sum}\right) \cdots + \begin{pmatrix} M_{eq.conc.Hor} + M_{eq.conc.Ver} + M_{eq.log.Hor} + M_{eq.log.Ver} + M_{eq.slab.Hor} \cdots \\ + M_{eq.slab.Ver} + M_{eq.tower.Hor} + M_{eq.tower.Ver} + M_{eq.HD.US} + M_{eq.HD.gate} \cdots \\ + M_{eq.silt.Hor} + M_{eq.silt.Ver} + M_{eq.fill.Hor} + M_{eq.fill.Ver} + M_{eq.Granular.Ver} \cdots \\ + M_{eq.Granular.Hor} + M_{eq.Water.Above.Ver} + M_{eq.Water.Above.Hor} \end{pmatrix} = 3555.9\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 2675.9\,kN \cdot m$$

LC.5 - Resultant and Bearing Stresses

$$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.40\,m$$

$$E_0 := \frac{L_{incl}}{2} - x_0 = 1.57\,m$$

$L_{incl} = 7.95\,m$
$M_{net0} = 2675.9\,kN \cdot m$
$F_{perp0} = 1112.9\,kN$

Stress Calculations

$q_{max0} = 184.2\,kPa$ $\qquad$ $q_{min0} = 0.0\,kPa$

$L_{comp0} = 7.21\,m$

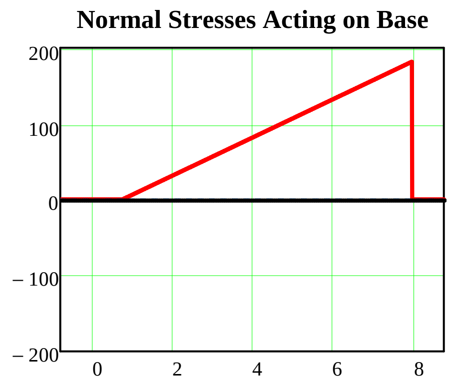
$L_{tens0} = 0.00\,m$

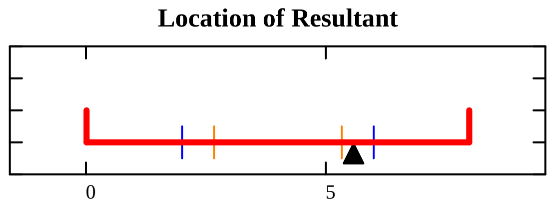
$L_{crack.eq} := L_{crack0} = 0.74\,m$

$$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \dfrac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1112862.9$$

$$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$$

$$\frac{L_{comp0}}{L_{incl}} = 90.7 \cdot \% \qquad \frac{L_{tens0}}{L_{incl}} = 0 \cdot \% \qquad \frac{L_{crack0}}{L_{incl}} = 9.3 \cdot \%$$





Red lines indicate extent of structure, blue lines indicate middle half of base, orange lines indicate middle third of base

LC.5 - Sliding

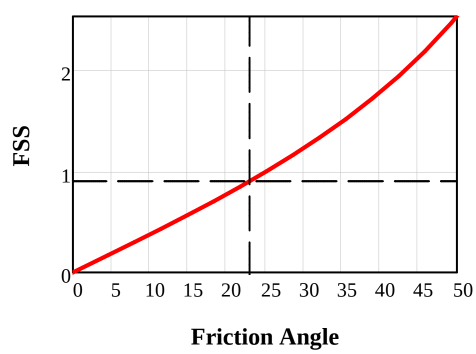
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$

$FSS_0(\phi_{cf}) = 0.90$

Factor of safety against sliding for specified friction angle



LC.5 - Cracked Base Analysis

Note: Iterative cracked base analysis does not occur during seismic conditions. Initial uplift pressures are assumed to be maintained even if cracking occurs, as per CDA guidelines.

Store results for summary

Store (uncracked) results for Combined Analysis

Load Case 6. Post-Earthquake (D+H+S+U_{PQ})

LC.6(U) - Uplift

Updated uplift calculations

$L_{crack0} := L_{crack.eq} = 0.74\,m$

Crack length is set to the resulting crack length from LC.4.

$p_{U.eq}(x) := p_{UL}(x, L_{crack0}, p_{USUL.Sum}, p_{DSUL.Sum})$

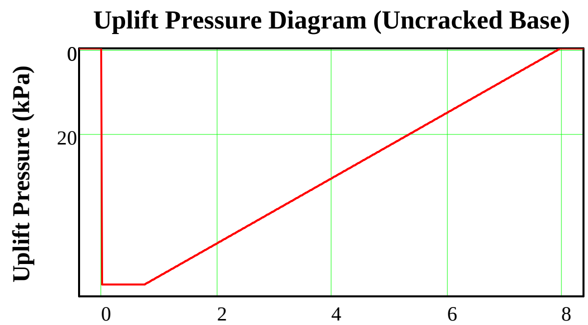
$$F_{U0.eq} := \int_0^{L_{incl}} p_{U.eq}(x) \cdot B\,dx = 401.8 \cdot kN$$

$$MA := L_{incl} - \frac{1}{F_{U0.eq}} \left(\int_0^{L_{incl}} p_{U.eq}(x) \cdot x \cdot B\,dx \right) = 5.28\,m$$

$M_{U0.eq} := F_{U0.eq} \cdot MA = 2120.9 \cdot kN \cdot m$

$F_{U0.eq.Hor} := -F_{U0.eq} \cdot \sin(\alpha) = 0 \cdot kN$

$F_{U0.eq.Ver} := -F_{U0.eq} \cdot \cos(\alpha) = -401.8 \cdot kN$



Updated uplift calculations

LC.6 - Summary of Forces

Deadloads (D):

$W_{conc} = 1567.8 \cdot kN$ $\quad M_{conc} = 6231.8 \cdot kN \cdot m$

$W_{log.Sum} = 0$ $\quad M_{log.Sum} = 0$

$W_{slab} = 0\,kN$ $\quad M_{slab} = 0\,kN \cdot m$

$W_{tower} = 0$ $\quad M_{tower} = 0$

Hydraulic (H):

$F_{US.Sum.Hor} = 260.4 \cdot kN$ $\quad M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$

$F_{US.Sum.Ver} = 0 \cdot kN$ $\quad M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$F_{DS.Sum.Hor} = 0\,kN$ $\quad M_{DS.Sum.Hor} = 0\,kN \cdot m$

$F_{DS.Sum.Ver} = 0\,kN$ $\quad M_{DS.Sum.Ver} = 0\,kN \cdot m$

$F_{gateH.Sum} = 103.4\,kN$ $\quad M_{gateH.Sum} = 316.1\,kN \cdot m$

$W_{Water.Above.Sum} = 0$ $\quad M_{Water.Above.Sum} = 0$

Soil (S):

$F_{US.silt.Hor} = 0\,kN$ $\quad M_{US.silt.Hor} = 0\,kN \cdot m$

$W_{US.silt} = 0\,kN$

$F_{DS.fill.Hor} = 0$

$W_{DS.fill} = 0$

$W_{Granular.Post.EQ} = 0\,kN$

$M_{US.silt.Ver} = 0\,kN \cdot m$

$M_{DS.fill.Hor} = 0$

$M_{DS.fill.Ver} = 0$

$M_{Granular.Post.EQ} = 0\,kN \cdot m$

Uplift (U):

$F_{U0.eq.Hor} = 0 \cdot kN$

$F_{U0.eq.Ver} = -401.8 \cdot kN$

$M_{U0.eq} = 2120.9 \cdot kN \cdot m$

Other Forces:

$F_{anchor.Hor} = 0$

$F_{anchor.Ver} = 0$

$F_{other.Hor.1} = 0$

$F_{other.Ver.1} = 0$

$M_{anchor.Hor} = 0$

$M_{anchor.Ver} = 0$

$M_{other.Hor.1} = 0$

$M_{other.Ver.1} = 0$

LC.6 - Combine Forces and Moments

$$F_{hor0} := \left(F_{US.Sum.Hor} - F_{DS.Sum.Hor} + F_{gateH.Sum}\right) + \left(F_{US.silt.Hor} - F_{DS.fill.Hor}\right) \dots + \left(F_{U0.eq.Hor}\right) + \left(F_{anchor.Hor} + F_{other.Hor.1}\right) = 363.8\,kN$$

$$F_{ver0} := \left(W_{conc} + W_{log.Sum} + W_{slab} + W_{tower}\right) + \left(F_{US.Sum.Ver} + F_{DS.Sum.Ver} + W_{Water.Above.Sum}\right) \dots + \left(W_{US.silt} + W_{DS.fill} + W_{Granular.Post.EQ}\right) + \left(F_{U0.eq.Ver}\right) + \left(F_{anchor.Ver} + F_{other.Ver.1}\right) = 1166\,kN$$

$$F_{parallel0} := F_{hor0} \cdot \cos(\alpha) - F_{ver0} \cdot \sin(\alpha) = 363.8 \cdot kN$$

$$F_{perp0} := F_{hor0} \cdot \sin(\alpha) + F_{ver0} \cdot \cos(\alpha) = 1166.0 \cdot kN$$

$$M_{stab0} := \left(M_{conc} + M_{log.Sum} + M_{slab} + M_{tower}\right) + \left(M_{US.Sum.Ver} + M_{DS.Sum.Hor} + M_{DS.Sum.Ver} + M_{Water.Above.Sum}\right) \dots + \left(M_{DS.fill.Hor} + M_{DS.fill.Ver} + M_{US.silt.Ver} + M_{Granular.Post.EQ}\right) + \left(M_{anchor.Ver} + M_{anchor.Hor} + M_{other.Hor.1} + M_{other.Ver.1}\right) = 6231.8\,kN \cdot m$$

$$M_{overturn0} := \left(M_{US.Sum.Hor} + M_{gateH.Sum}\right) + \left(M_{US.silt.Hor}\right) + \left(M_{U0.eq}\right) = 2925.8\,kN \cdot m$$

$$M_{net0} := M_{stab0} - M_{overturn0} = 3306.1\,kN \cdot m$$

LC.6 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net0}}{F_{perp0}} = 2.84\,m$

$E_0 := \frac{L_{incl}}{2} - x_0 = 1.14\,m$

$L_{incl} = 7.95\,m$
$M_{net0} = 3306.1\,kN \cdot m$
$F_{perp0} = 1166.0\,kN$

Stress Calculations

$q_{max0} = 162.9\,kPa$ $q_{min0} = 12.3\,kPa$

$L_{comp0} = 7.95\,m$

$L_{tens0} = 0.00\,m$

$L_{crack0} = 0.00\,m$

$L_{crack0} := \begin{cases} L_{crack.eq} & \text{if } L_{crack.eq} > L_{crack0} \\ L_{crack0} & \text{otherwise} \end{cases} = 0.74$

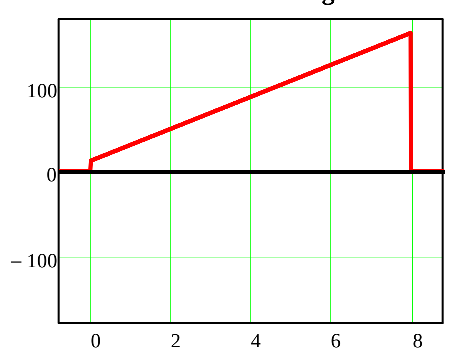
Adjust the crack length to be larger of eq, or post-eq load case.

$F_{comp0} := \begin{cases} F_{perp0} & \text{if } q_{min0} \geq 0 \\ \frac{B \cdot q_{max0} \cdot L_{comp0}}{2} & \text{otherwise} \end{cases} = 1165998.8$

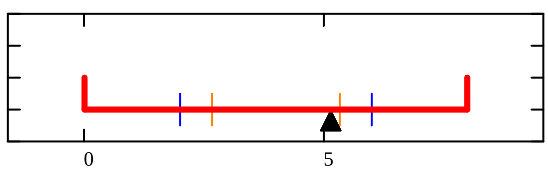
$F_{tens0} := \frac{B \cdot q_{min0} \cdot L_{tens0}}{2} = 0\,kN$

$\frac{L_{comp0}}{L_{incl}} = 100 \cdot \%$ $\frac{L_{tens0}}{L_{incl}} = 0 \cdot \%$ $\frac{L_{crack0}}{L_{incl}} = 9.3 \cdot \%$

Normal Stresses Acting on Base



Location of Resultant



Red lines indicate extent of structure,
blue lines indicate middle half of base,
orange lines indicate middle third of base

LC.6 - Sliding

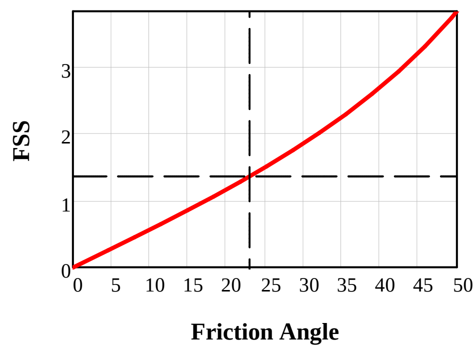
$$FSS_0(\theta) := \frac{F_{comp0} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp0} + \frac{L_{tens0}}{2}\right)}{F_{parallel0}}$$

Define function to evaluate sliding using a range of friction angles

$\phi_{cf} = 23 \cdot deg$
$c = 0$
$L_{incl} = 7.95\,m$
$\alpha = 0 \cdot deg$
$B = 1.67\,m$

$\boxed{FSS_0(\phi_{cf}) = 1.36}$

Factor of safety against sliding for specified friction angle



LC.6 - Cracked Base Analysis

Note: This program runs an interative analysis to determine the length of a crack along the concrete-foundation interface. The values for F.hor, F.ver, M.overturn, need to be modified for each load combination.

$$\text{crackactive} := \begin{vmatrix} 1 & \text{if } L_{crack0} > L_{crack.eq} \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Determines if the cracked analysis should run.

Cracked Base Analysis

Cracked Base Results

Store results for summary

Store (uncracked) results for Combined Analysis

Summary of Forces/Moments

Dead Loads (and related seismic)

$W_{conc} = 1567.8 \cdot kN$ $M_{conc} = 6231.8 \cdot kN \cdot m$
$F_{eq.conc.Hor} = 130.8 kN$ $M_{eq.conc.Hor} = 370.7 kN \cdot m$
$F_{eq.conc.Ver} = 87.2 kN$ $M_{eq.conc.Ver} = 346.5 kN \cdot m$

$W_{log.Sum} = 0$ $M_{log.Sum} = 0$
$W_{log.Win} = 0$ $M_{log.Win} = 0$
$W_{log.IDF} = 0$ $M_{log.Win} = 0$

$F_{eq.log.Hor} = 0$ $M_{eq.log.Hor} = 0$
$F_{eq.log.Ver} = 0$ $M_{eq.log.Ver} = 0$

$W_{slab} = 0 kN$ $M_{slab} = 0 kN \cdot m$
$F_{eq.slab.Hor} = 0 kN$ $M_{eq.slab.Hor} = 0 kN \cdot m$
$F_{eq.slab.Ver} = 0 kN$ $M_{eq.slab.Ver} = 0 kN \cdot m$

$W_{tower} = 0$ $M_{tower} = 0$
$F_{eq.tower.Hor} = 0$ $M_{eq.tower.Hor} = 0$
$F_{eq.tower.Ver} = 0$ $M_{eq.tower.Ver} = 0$

Soil Loads (and related seismic)

$F_{US.silt.Hor} = 0 kN$ $M_{US.silt.Hor} = 0 kN \cdot m$
$F_{eq.silt.Hor} = 0 kN$ $M_{eq.silt.Hor} = 0 kN \cdot m$
$W_{US.silt} = 0 kN$ $M_{US.silt.Ver} = 0 kN \cdot m$
$F_{eq.silt.Ver} = 0 kN$ $M_{eq.silt.Ver} = 0 kN \cdot m$

$F_{DS.fill.Hor} = 0$ $M_{DS.fill.Hor} = 0$
$F_{eq.fill.Hor} = 0$ $M_{eq.fill.Hor} = 0$
$F_{eq.fill.Ver} = 0$ $M_{eq.fill.Ver} = 0$
$W_{DS.fill} = 0$ $M_{DS.fill.Ver} = 0$
$W_{Granular.Sum} = 0 kN$ $M_{Granular.Sum} = 0 kN \cdot m$
$F_{eq.Granular.Ver} = 0 kN$ $M_{eq.Granular.Ver} = 0 kN \cdot m$
$F_{eq.Granular.Hor} = 0 kN$ $M_{eq.Granular.Hor} = 0 kN \cdot m$

Uplift Forces

$F_{U0.Sum} = 367.7 kN$ $M_{U0.Sum} = 1949 \cdot kN \cdot m$
$F_{U0.Sum.Hor} = 0 \cdot kN$
$F_{U0.Sum.Ver} = -367.7 \cdot kN$

$F_{U0.Win} = 260.6 kN$ $M_{U0.Win} = 1381.2 \cdot kN \cdot m$
$F_{U0.Win.Hor} = 0 \cdot kN$
$F_{U0.Win.Ver} = -260.6 \cdot kN$

$F_{U0.IDF} = 761.6 kN$ $M_{U0.IDF} = 3165.8 \cdot kN \cdot m$
$F_{U0.IDF.Hor} = 0 \cdot kN$
$F_{U0.IDF.Ver} = -761.6 \cdot kN$

$F_{U0.eq} = 401.8 kN$ $M_{U0.eq} = 2120.9 \cdot kN \cdot m$
$F_{U0.eq.Hor} = 0 \cdot kN$
$F_{U0.eq.Ver} = -401.8 \cdot kN$

Hydraulic Forces (and related seismic)

$F_{US.Sum.Hor} = 260.4 \cdot kN$ $M_{US.Sum.Hor} = 488.7 \cdot kN \cdot m$
$F_{eq.HD.US} = 23.3 kN$ $M_{eq.HD.US} = 52.8 kN \cdot m$
$F_{US.Sum.Ver} = 0 \cdot kN$ $M_{US.Sum.Ver} = 0 \cdot kN \cdot m$

$W_{Water.Above.Sum} = 0$ $M_{Water.Above.Sum} = 0$
$F_{eq.Water.Above.Ver} = 0$ $M_{eq.Water.Above.Ver} = 0$
$F_{eq.Water.Above.Hor} = 0$ $M_{eq.Water.Above.Hor} = 0$

$F_{US.Win.Hor} = 130.8 \cdot kN$ $M_{US.Win.Hor} = 174 \cdot kN \cdot m$
$F_{US.Win.Ver} = 0 \cdot kN$ $M_{US.Win.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.Win} = 0$ $M_{Water.Above.Win} = 0$

$F_{US.IDF.Hor} = 353.6 \cdot kN$ $M_{US.IDF.Hor} = 752.8 \cdot kN \cdot m$
$F_{US.IDF.Ver} = 0 \cdot kN$ $M_{US.IDF.Ver} = 0 \cdot kN \cdot m$
$W_{Water.Above.IDF} = 0$ $M_{Water.Above.IDF} = 0$

$F_{DS.Sum.Hor} = 0 kN$ $M_{DS.Sum.Hor} = 0 kN \cdot m$
$F_{DS.Sum.Ver} = 0 kN$ $M_{DS.Sum.Ver} = 0 kN \cdot m$

$F_{DS.Win.Hor} = 0 kN$ $M_{DS.Win.Hor} = 0 kN \cdot m$
$F_{DS.Win.Ver} = 0 kN$ $M_{DS.Win.Ver} = 0 kN \cdot m$

$F_{DS.IDF.Hor} = 207.9 kN$ $M_{DS.IDF.Hor} = 348.5 kN \cdot m$
$F_{DS.IDF.Ver} = 0 kN$ $M_{DS.IDF.Ver} = 0 kN \cdot m$

$F_{gateH.Sum} = 103.4 kN$ $M_{gateH.Sum} = 316.1 kN \cdot m$
$F_{eq.HD.gate} = 9 kN$ $M_{eq.HD.gate} = 32.1 kN \cdot m$
$F_{gateH.Win} = 33.9 kN$ $M_{gateH.Win} = 87.2 kN \cdot m$
$F_{gateH.IDF} = 150.5 kN$ $M_{gateH.IDF} = 477.9 kN \cdot m$
$F_{drag} = 0$ $M_{drag} = 0$

Ice Loads

$F_{ice.1} = 139.9 kN$ $M_{ice.1} = 516.1 kN \cdot m$
$F_{ice.gate} = 127.3 kN$ $M_{ice.gate} = 469.6 kN \cdot m$
$F_{ice} = 267.1 kN$ $M_{ice} = 985.7 kN \cdot m$

$F_{ice.1.usual} = 125.6 kN$ $M_{ice.1.usual} = 463.6 kN \cdot m$
$F_{ice.gate.usual} = 114.3 kN$ $M_{ice.gate.usual} = 421.8 kN \cdot m$
$F_{ice.usual} = 239.9 kN$ $M_{ice.usual} = 885.3 kN \cdot m$

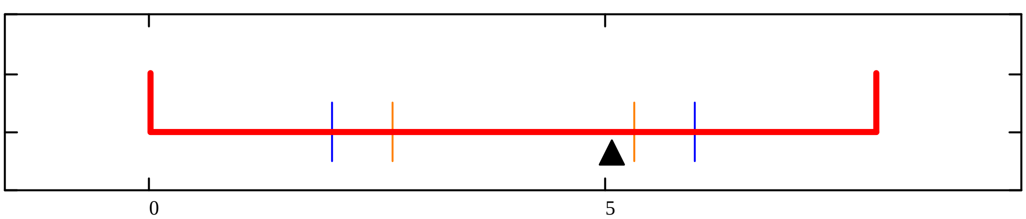
Other Forces:

$F_{anchor.Hor} = 0$ $M_{anchor.Hor} = 0$
$F_{anchor.Ver} = 0$ $M_{anchor.Ver} = 0$
$F_{other.Hor.1} = 0$ $M_{other.Hor.1} = 0$
$F_{other.Ver.1} = 0$ $M_{other.Ver.1} = 0$

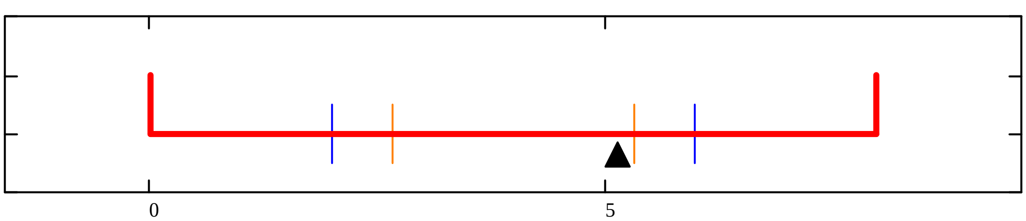
Results of Analysis

	FSS (Φ.cf)	E (m)	x.o (m)	L.comp (m)	% of Base in Compression	L.crack (m)	F.hor (kN)	F.ver (kN)	F.parallel (kN)	F.Perp (kN)	q.max (kPa)
LC.1 - Summer	1.40	1.08	2.90	7.95	100%	0.00	363.8	1,200.0	363.8	1,200.0	163.3
LC.2 - Winter (Usual)	1.37	1.14	2.83	7.95	100%	0.00	404.6	1,307.1	404.6	1,307.1	182.7
LC.3 - IDF	1.16	1.27	2.71	7.95	100%	0.00	296.2	806.2	296.2	806.2	118.4
LC.4 - Winter (Unusual)	1.28	1.22	2.76	7.95	100%	0.00	431.8	1,307.1	431.8	1,307.1	188.4
LC.5 - EQ	0.90	1.57	2.40	7.21	91%	0.74	526.8	1,112.9	526.8	1,112.9	184.2
LC.6 - Post - EQ	1.36	1.14	2.84	7.95	100%	0.74	363.8	1,166.0	363.8	1,166.0	162.9

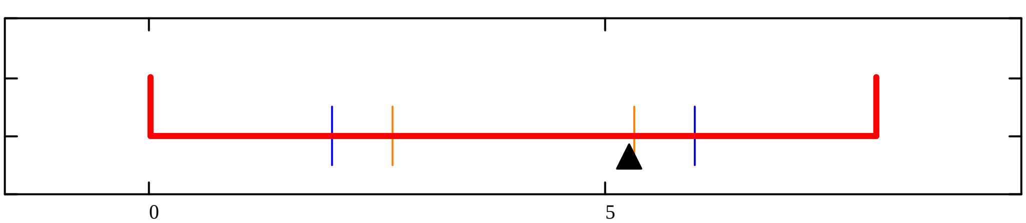
Location of Resultant



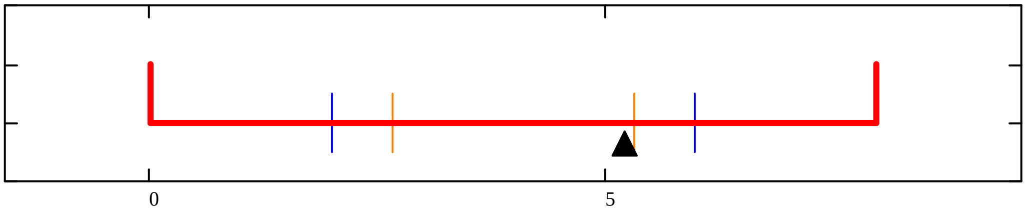
LC 1



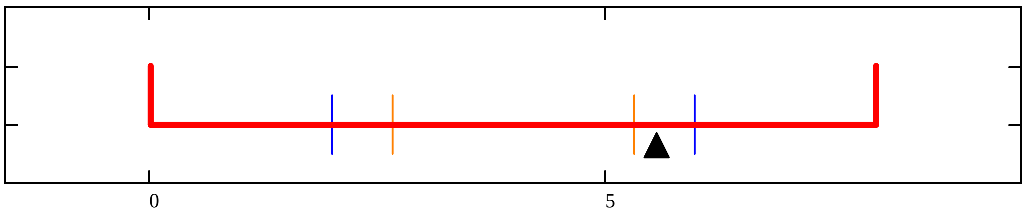
LC 2



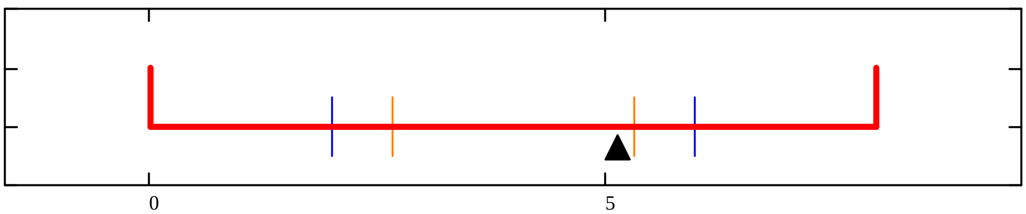
LC 3



LC 4



LC 5



LC 6

KGS GROUP	DESIGN CALCULATIONS COVER SHEET				
Project No. :	17-3212-001	**Project Name :**	Howson Dam (South Sluiceway)		
File No. :		**Discipline :**	Structural Engineering		
Calculation Title :	**Combined Rollway & Pier Stability Analysis – Bridge Deck Removed**				
Calculation No. :	CIV-005	**Prepared by :**	HS	**Date :**	Feb. 23, 2018
No. of Sheets :		**Checked by :**	YF	**Date :**	April 20, 2018
Supersedes Calc. No. :		**Approved by :**		**Date :**	

Calculation Description :

The dam has been reviewed against LRIA technical bulletins

Related Design Concept :

Stability analysis for the structures is carried out using the "Gravity Method".
Six loading cases are utilized in the analyses based on the LRIA Technical Bulletin "Structural Design and Factors of Safety (August 2011).

Reference Codes and Standards :
1. *Design of Small Dams,* Third Edition, U.S. Government Printing Office, Washington, D.C. 1987.
2. Structural Design and Factors of Safety – Technical Bulletin Ontario Ministry of Natural Resources (August 2011)

ENGINEER'S SEAL

Rev. #	**Rev. Description**	**Rev. Author**	**Date Revised**	**Checked by**	**Approved by**	**Approved Date**

References

Pier

Reference:U:\FMS\17-3212-001\CIV-004 Howson Dam S - Pier (no Deck) -HS YF.xmcd(R)

Rollway

Reference:P:\Projects\2017\17-3212-001\Design\Struct\HS\MathCad\S Structure\CIV-002 Howson Dam S - Sill Section HS YF.xmcd

Properties of Materials

$\phi_{cf} := 23 \cdot deg$ *Friction angle of concrete/foundation interface*

$f_t := 0MPa$ *Tensile strength at concrete/rock interface (generally set to 0). This is a negative number.*

$c := 0MPa$ *Cohesion at concrete/foundation interface (generally set to 0)*

Geometry of Structures

Unit width of structure used in calculation sheet

$B_{pier} = 1.67m$ $B_{roll} = 9.91m$

$L_{incl.pier} = 7.95m$ $L_{incl.roll} = 6.2m$

$\alpha_{pier} = 0 \cdot deg$ $\alpha_{roll} = 0 \cdot deg$

$B := B_{pier} + B_{roll} = 11.6m$

$$L_{incl} := \frac{L_{incl.pier} + L_{incl.roll}}{2} = 7.08m$$

$$\alpha_{avg} := \frac{\alpha_{pier} + \alpha_{roll}}{2} = 0 \cdot deg$$

Load Case 1. Usual Loading Summer Case (D+H+S+U)

$LC := 1$

LC. 1 - Forces from Structures

$F_{hor.pier_{LC}} = 363.8 \cdot kN$	$F_{hor.roll_{LC}} = 1007.4 kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 1200 \cdot kN$	$F_{ver.roll_{LC}} = 2010.2 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 1200 \cdot kN$	$F_{perp.roll_{LC}} = 2010.2 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 363.8 \cdot kN$	$F_{para.roll_{LC}} = 1007.4 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8 m$	$L_{comp.roll_{LC}} = 6.2 m$	*Length of base in compression*
$M_{net.pier_{LC}} = 3478 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 6099.8 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.1 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1371.2 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 3210.2 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1371.2 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 3210.2 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 9577.8 \cdot kN \cdot m$

LC.1 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 2.98 m$ *Distance of resultant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.55 m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 57.6 kPa$ $q_{min} = 20.8 kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08 m$ *Length of base in compression before iterative cracked base analysis*

$L_{tens} = 0.00 m$ *Length of base in tension before iterative cracked base analysis*

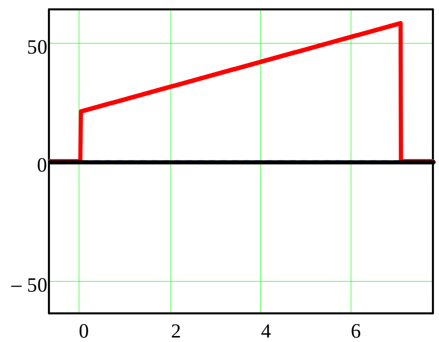
$L_{crack} = 0.00 m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 3210.2 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0 kN$$

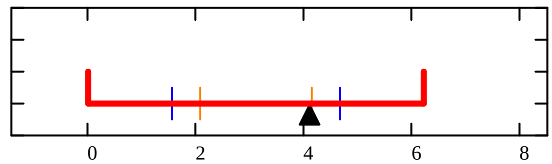
Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



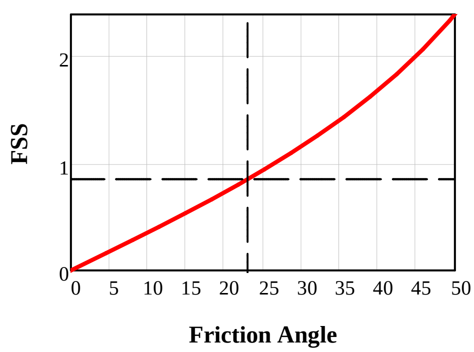
LC.1 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS(\phi_{cf}) = 0.99}$

Factor of safety against sliding for specified friction angle



Store results for summary

Load Case 2. Usual Loading Winter Case (D+H+S+U+I)

$LC := 2$

LC. 2 - Forces from Structures

$F_{hor.pier_{LC}} = 404.6 \cdot kN$	$F_{hor.roll_{LC}} = 1240.4\,kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 1307.1 \cdot kN$	$F_{ver.roll_{LC}} = 1668 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 1307.1 \cdot kN$	$F_{perp.roll_{LC}} = 1668 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 404.6 \cdot kN$	$F_{para.roll_{LC}} = 1240.4 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8\,m$	$L_{comp.roll_{LC}} = 6.2\,m$	*Length of base in compression*
$M_{net.pier_{LC}} = 3704.2 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 3854.6 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.2 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1645 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 2975.1 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1645.0 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 2975.1 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 7558.8 \cdot kN \cdot m$

LC.2 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 2.54\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 1\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 67\,kPa$ $q_{min} = 5.6\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \ge 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 2975.1 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$$

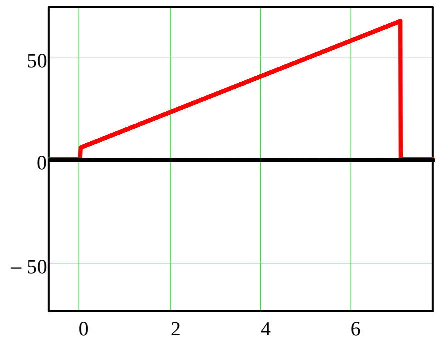
Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression*

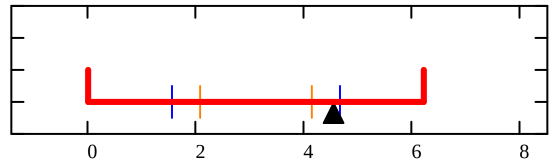
$\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension*

$\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant



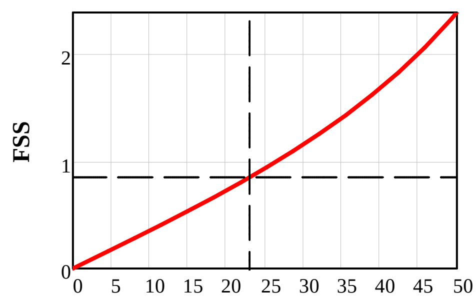
LC.2 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS(\phi_{cf}) = 0.77}$

Factor of safety against sliding for specified friction angle



▶ Store results for summary

Load Case 3. Unusual Loading IDF (D+H_{IDF}+S+U_{IDF})

$LC := 3$

LC. 3 - Forces from Structures

$F_{hor.pier_{LC}} = 296.2 \cdot kN$ | $F_{hor.roll_{LC}} = 497.5\,kN$ | *Force acting in horizontal direction on structure*

$F_{ver.pier_{LC}} = 806.2 \cdot kN$ | $F_{ver.roll_{LC}} = 1533.2 \cdot kN$ | *Forces acting in vertical direction on structure*

$F_{perp.pier_{LC}} = 806.2 \cdot kN$ | $F_{perp.roll_{LC}} = 1533.2 \cdot kN$ | *Force acting perpendicular to base from structure*

$F_{para.pier_{LC}} = 296.2 \cdot kN$ | $F_{para.roll_{LC}} = 497.5 \cdot kN$ | *Force acting parallel to base from structure*

$L_{comp.pier_{LC}} = 8\,m$ | $L_{comp.roll_{LC}} = 6.2\,m$ | *Length of base in compression*

$M_{net.pier_{LC}} = 2183.9 \cdot kN \cdot m$ | $M_{net.roll_{LC}} = 5334.6 \cdot kN \cdot m$ | *Net resisting moment from structure*

LC.3 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 793.7 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 2339.4 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 793.7 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 2339.4 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 7518.6 \cdot kN \cdot m$

LC.3 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 3.21\,m$ *Distance of resultant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.32\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 36.4\,kPa$ $q_{min} = 20.7\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

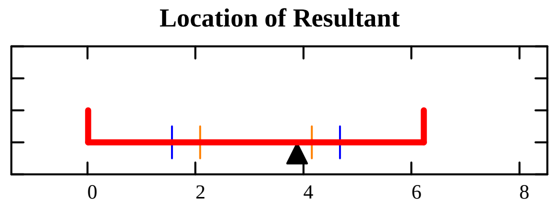
$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 2339.4 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$$

Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*



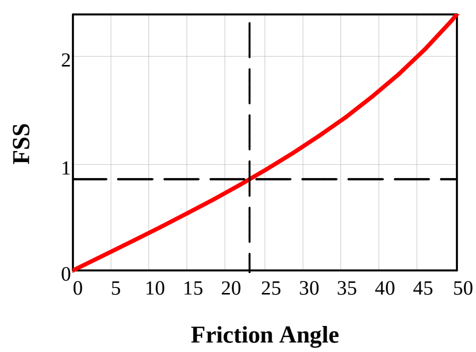
LC.3 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$\boxed{FSS(\phi_{cf}) = 1.25}$

Factor of safety against sliding for specified friction angle



Store results for summary

Load Case 4. Unusual Loading Winter Case (D+H+S+U+I)

$LC := 4$

LC. 4 - Forces from Structures

$F_{hor.pier_{LC}} = 431.8 \cdot kN$	$F_{hor.roll_{LC}} = 1324.6\,kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 1307.1 \cdot kN$	$F_{ver.roll_{LC}} = 1668 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 1307.1 \cdot kN$	$F_{perp.roll_{LC}} = 1668 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 431.8 \cdot kN$	$F_{para.roll_{LC}} = 1324.6 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8\,m$	$L_{comp.roll_{LC}} = 6.2\,m$	*Length of base in compression*
$M_{net.pier_{LC}} = 3603.8 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 3610.4 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.4 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1756.4 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 2975.1 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1756.4 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 2975.1 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 7214.3 \cdot kN \cdot m$

LC.4 - Resultant and Bearing Stresses

$x_0 := \dfrac{M_{net}}{F_{perp}} = 2.42\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \dfrac{L_{incl}}{2} - x_0 = 1.11\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 70.6\,kPa$ $q_{min} = 2\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

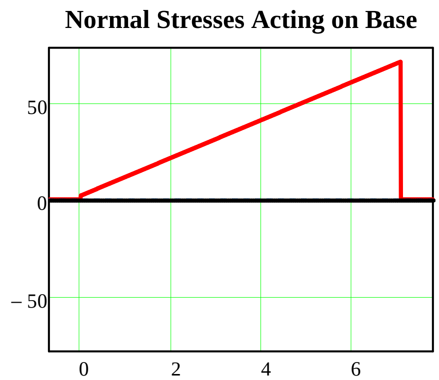
$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

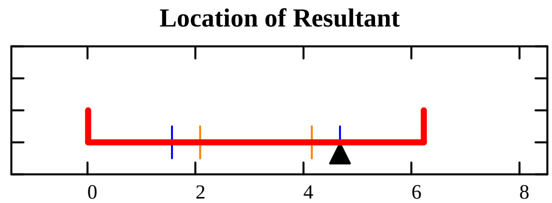
$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \ge 0 \\ \dfrac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 2975.1 \cdot kN$ $F_{tens} := \dfrac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$ *Compression and tension forces in foundation*

$\dfrac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\dfrac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\dfrac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*





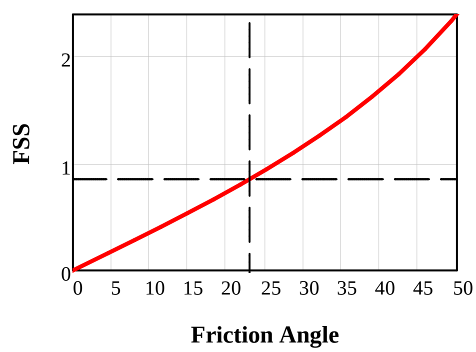
LC.4 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$

Define function to evaluate sliding using a range of friction angles

$FSS(\phi_{cf}) = 0.72$

Factor of safety against sliding for specified friction angle



Store results for summary

Load Case 5. Extreme Loading Earthquake (D+H+S+Q+U_Q)

$LC := 5$

LC. 5 - Forces from Structures

$F_{hor.pier_{LC}} = 526.8 \cdot kN$ | $F_{hor.roll_{LC}} = 1309.4 kN$ | *Force acting in horizontal direction on structure*

$F_{ver.pier_{LC}} = 1112.9 \cdot kN$ | $F_{ver.roll_{LC}} = 1817.3 \cdot kN$ | *Forces acting in vertical direction on structure*

$F_{perp.pier_{LC}} = 1112.9 \cdot kN$ | $F_{perp.roll_{LC}} = 1817.3 \cdot kN$ | *Force acting perpendicular to base from structure*

$F_{para.pier_{LC}} = 526.8 \cdot kN$ | $F_{para.roll_{LC}} = 1309.4 \cdot kN$ | *Force acting parallel to base from structure*

$L_{comp.pier_{LC}} = 7.2 m$ | $L_{comp.roll_{LC}} = 6.2 m$ | *Length of base in compression*

$M_{net.pier_{LC}} = 2675.9 \cdot kN \cdot m$ | $M_{net.roll_{LC}} = 4778.1 \cdot kN \cdot m$ | *Net resisting moment from structure*

LC.5 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1836.2 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 2930.2 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1836.2 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 2930.2 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 7454.1 \cdot kN \cdot m$

LC.5 - Resultant and Bearing Stresses

$x_0 := \frac{M_{net}}{F_{perp}} = 2.54 m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \frac{L_{incl}}{2} - x_0 = 0.99 m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 65.9 kPa$ $q_{min} = 5.6 kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08 m$ *Length of base in compression before iterative cracked base analysis*

$L_{tens} = 0.00 m$ *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00 m$ *Length of crack between concrete and base before iterative cracked base analysis*

$$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \frac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 2930.2 \cdot kN \qquad F_{tens} := \frac{B \cdot q_{min} \cdot L_{tens}}{2} = 0 kN$$

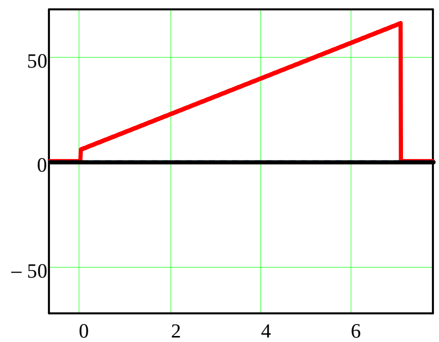
Compression and tension forces in foundation

$\frac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression*

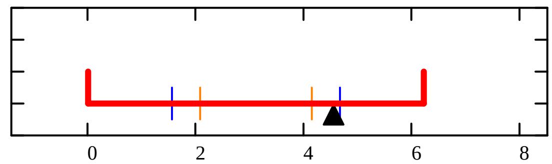
$\frac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension*

$\frac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



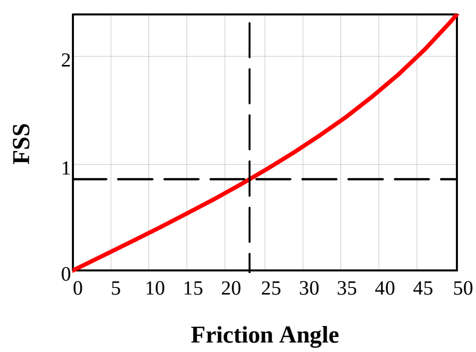
Location of Resultant



LC.5 - Sliding

$$FSS(\theta) := \frac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \frac{L_{tens}}{2}\right)}{F_{parallel}}$$ *Define function to evaluate sliding using a range of friction angles*

$FSS(\phi_{cf}) = 0.68$ *Factor of safety against sliding for specified friction angle*



Store results for summary

Load Case 6. Extreme Loading Earthquake (D+H+S+Q+U_Q)

$LC := 6$

LC. 6 - Forces from Structures

$F_{hor.pier_{LC}} = 363.8 \cdot kN$	$F_{hor.roll_{LC}} = 1007.4 kN$	*Force acting in horizontal direction on structure*
$F_{ver.pier_{LC}} = 1166 \cdot kN$	$F_{ver.roll_{LC}} = 2010.2 \cdot kN$	*Forces acting in vertical direction on structure*
$F_{perp.pier_{LC}} = 1166 \cdot kN$	$F_{perp.roll_{LC}} = 2010.2 \cdot kN$	*Force acting perpendicular to base from structure*
$F_{para.pier_{LC}} = 363.8 \cdot kN$	$F_{para.roll_{LC}} = 1007.4 \cdot kN$	*Force acting parallel to base from structure*
$L_{comp.pier_{LC}} = 8 m$	$L_{comp.roll_{LC}} = 6.2 m$	*Length of base in compression*
$M_{net.pier_{LC}} = 3306.1 \cdot kN \cdot m$	$M_{net.roll_{LC}} = 6099.8 \cdot kN \cdot m$	*Net resisting moment from structure*

LC.6 - Combine Forces and Moments

$F_{hor} := F_{hor.pier_{LC}} + F_{hor.roll_{LC}} = 1371.2 \cdot kN$

$F_{ver} := F_{ver.pier_{LC}} + F_{ver.roll_{LC}} = 3176.2 \cdot kN$

$F_{parallel} := F_{hor} \cdot \cos(\alpha_{avg}) + F_{ver} \cdot \sin(\alpha_{avg}) = 1371.2 \cdot kN$

$F_{perp} := -F_{hor} \cdot \sin(\alpha_{avg}) + F_{ver} \cdot \cos(\alpha_{avg}) = 3176.2 \cdot kN$

$M_{net} := M_{net.pier_{LC}} + M_{net.roll_{LC}} = 9405.8 \cdot kN \cdot m$

LC.6 - Resultant and Bearing Stresses

$x_0 := \dfrac{M_{net}}{F_{perp}} = 2.96\,m$ *Distance of resulant from right side of base (measured parallel to base)*

$E := \dfrac{L_{incl}}{2} - x_0 = 0.58\,m$ *Ecentricity of resultant (positive is to the right)*

Stress Calculations

$q_{max} = 57.7\,kPa$ $q_{min} = 19.8\,kPa$ *Maximum/minimum bearing stress before iterative cracked base analysis*

$L_{comp} = 7.08\,m$ *Length of base in compression before iterative cracked base analysis*

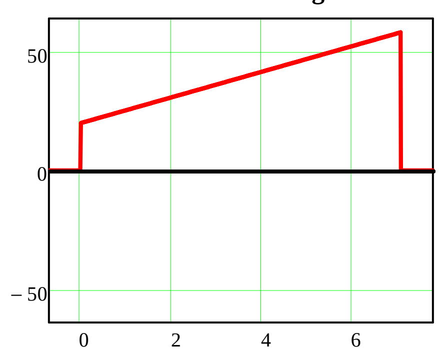
$L_{tens} = 0.00\,m$ *Length of base in tension before iterative cracked base analysis*

$L_{crack} = 0.00\,m$ *Length of crack between concrete and base before iterative cracked base analysis*

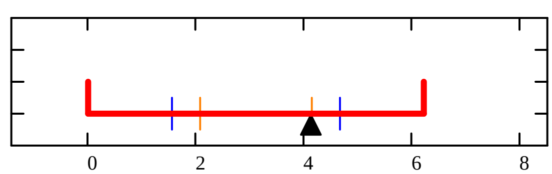
$F_{comp} := \begin{cases} F_{perp} & \text{if } q_{min} \geq 0 \\ \dfrac{B \cdot q_{max} \cdot L_{comp}}{2} & \text{otherwise} \end{cases} = 3176.2 \cdot kN$ $F_{tens} := \dfrac{B \cdot q_{min} \cdot L_{tens}}{2} = 0\,kN$ *Compression and tension forces in foundation*

$\dfrac{L_{comp}}{L_{incl}} = 100 \cdot \%$ *% of Base in Compression* $\dfrac{L_{tens}}{L_{incl}} = 0 \cdot \%$ *% of Base in Tension* $\dfrac{L_{crack}}{L_{incl}} = 0 \cdot \%$ *% of Base Cracked*

Normal Stresses Acting on Base



Location of Resultant

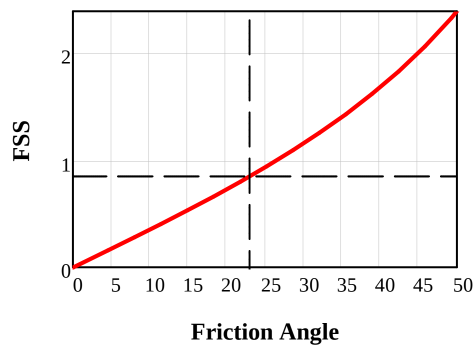


LC.6 - Sliding

$FSS(\theta) := \dfrac{F_{comp} \cdot \tan(\theta) + c \cdot B \cdot \left(L_{comp} + \dfrac{L_{tens}}{2}\right)}{F_{parallel}}$ *Define function to evaluate sliding using a range of friction angles*

$FSS(\phi_{cf}) = 0.98$

Factor of safety against sliding for specified friction angle

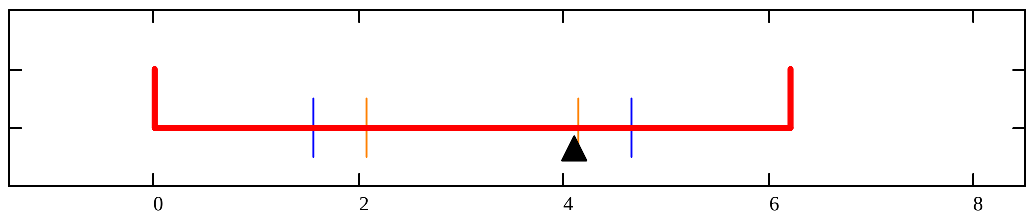


Store results for summary

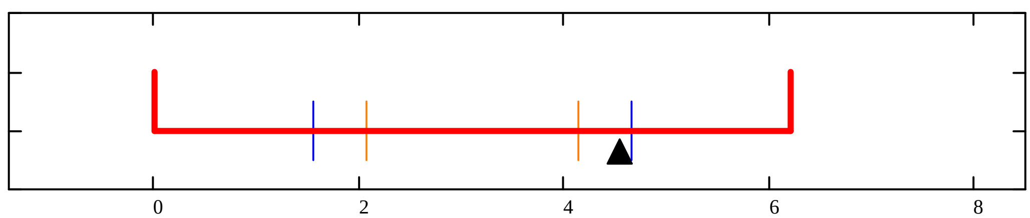
Results of Analysis

	FSS (Φ.cf)	E (m)	x.o (m)	L.comp (m)	% of Base in Compression	L.crack (m)	F.hor (kN)	F.ver (kN)	F.parallel (kN)	F.Perp (kN)	q.max (kPa)
LC.1 - Summer	0.99	0.55	2.98	7.08	100%	0.00	1,371.2	3,210.2	1,371.2	3,210.2	57.6
LC.2 - Winter (Usual)	0.77	1.00	2.54	7.08	100%	0.00	1,645.0	2,975.1	1,645.0	2,975.1	67.0
LC.3 - IDF	1.25	0.32	3.21	7.08	100%	0.00	793.7	2,339.4	793.7	2,339.4	36.4
LC.4 - Winter (Unusual)	0.72	1.11	2.42	7.08	100%	0.00	1,756.4	2,975.1	1,756.4	2,975.1	70.6
LC.5 - EQ	0.68	0.99	2.54	7.08	100%	0.00	1,836.2	2,930.2	1,836.2	2,930.2	65.9
LC.6 - Post - EQ	0.98	0.58	2.96	7.08	100%	0.00	1,371.2	3,176.2	1,371.2	3,176.2	57.7

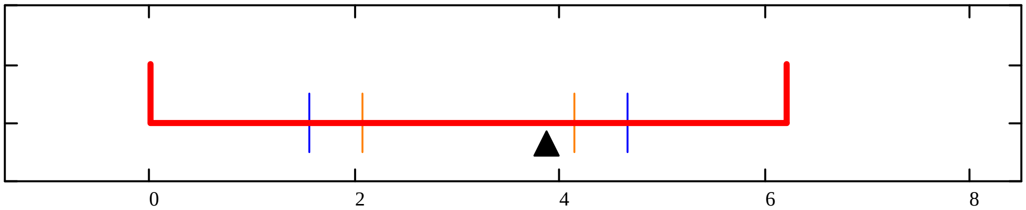
Location of Resultant



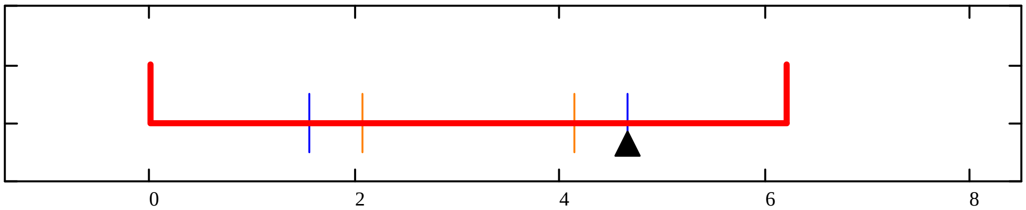
LC 1



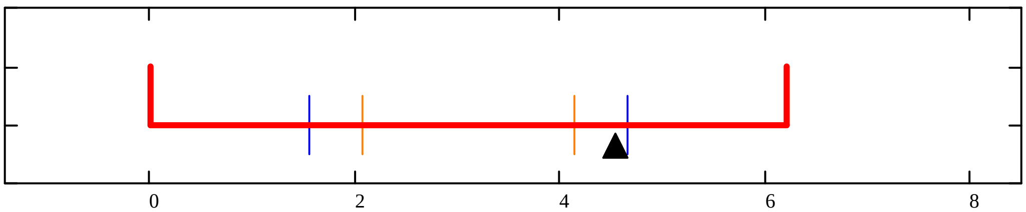
LC 2



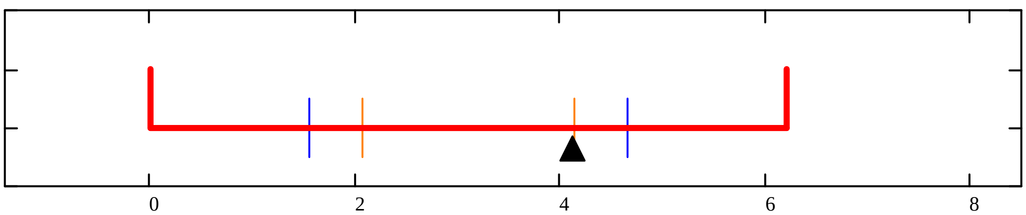
LC 3



LC 4



LC 5



LC 6

APPENDIX C

DAM SAFETY GENERAL INSPECTION (DSGI) SHEETS

DAM SAFETY GENERAL INSPECTION

Site Name: Howson Dam (South structure) **River System:** North Maitland River
Dam Component: Concrete Structures **HWL:** 311.9 m (IDF from DSA) **TWL:** 310.3 m (IDF from DSA)
Description: This section has four sluice bays and an ogee type weir at El. 309.25 m (BM Ross, 2015). The top elevation of the deck of the structure is at El. 312.48 m (geodetic elevation provided by the Township of North Huron). Four bays, from north to south are 10.6 m, 11.5 m, 10.8 m, and 10.7 m in length (BM Ross 2013a).
Purpose: Originally built to prevent flooding and to create a reservoir for recreational use
Length: 54 m **Height:** approx. 6.5 m **Width:** **6.2 m (deck)** ICC Rating: **High (from DSA)**

Summary of Inspection Observations and Identified Deficiencies:

Recommended Actions:

Item	Summary of Inspection Observations and Identified Deficiencies:	Recommended Actions:
	Concrete of girders and decks in some areas are severely spalled and exposed corroded rebar was evident. Collapse of the bridge could occur resulting in injury or death to the public. Rusted steel girders and decayed timber transverse beams	Required to check the strength of the bridge for pedestrian crossing based on the compressive strength of existing concrete. Replacement or repair is required. Clean the rust on the beams and paint it and replace the decayed timber transverse beams.
	Piers and abutments in some areas are severely spalled and map cracks were evident. The concrete of upstream of pier 1 is mostly destroyed. Collapse of the bridge could occur resulting in injury or death to the public. Some of the stop logs are weathered and decayed.	Required to check the strength of the bridge for pedestrian crossing based on the compressive strength of existing concrete. Replacement or repair is required. Replace the decayed stop logs.
	Upstream and downstream face of the weirs are spalled/severe spalled and undercutting was observed in weir of span 4.	Based on the compressive strength of the concrete the replacement or repair is required. Undercutting would be addressed.
	Severe spalling and map crack were evident in areas of retaining walls.	Based on the compressive strength of the concrete the replacement or repair is required.
Yr-#		

Date of Inspection: November 22, 2017 **Date of Last Inspection:** November 20, 2013

Weather: Cloudy

Persons Present During Inspection: Shan Gnanasunthar – Henry Safavian

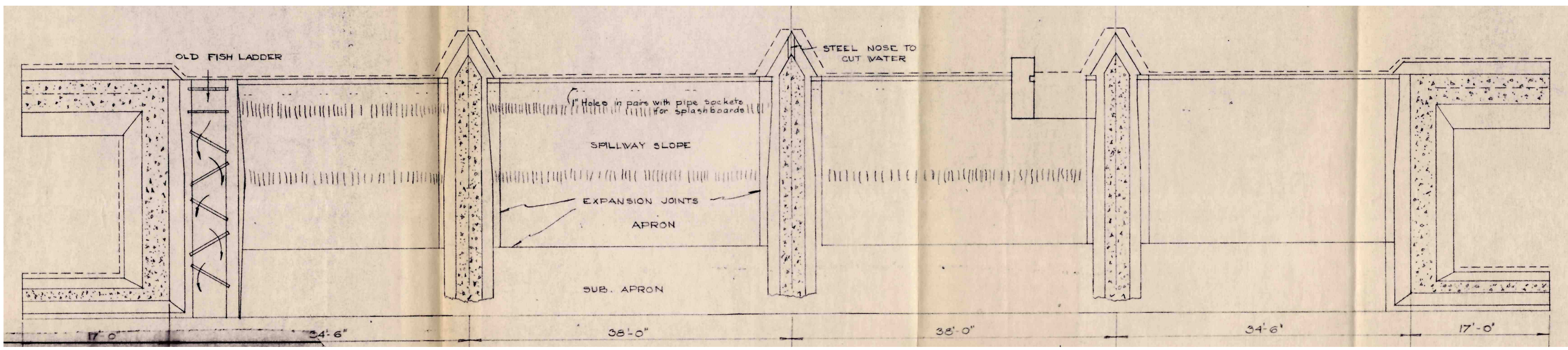
KGS GROUP

DAM SAFETY GENERAL INSPECTION

This is to certify that the above dam has been inspected and the following are the results of this inspection.

Name and Signature of Inspection Leader

SITE or STRUCTURE



Abut. North **Pier 1** **Pier 2** **Pier 3** **Abut. South**

N ←

KGS GROUP

DAM SAFETY GENERAL INSPECTION

DECK [Photo 1 to 10]

CONDITION	OBSERVATION: SKETCH, MEASURE, PHOTOGRAPH, LOCATE
Surface Condition	The in-situ concrete girders were spalled and disintegrated in many areas. The exposed corroded rebar was evident. Spalling was observed underside of the deck with exposed corroded rebar. Icicles hung from underside of the girders can be an evidence of surface water seepage through the deck. Downstream steel girders rusted in some areas and lost their sections. Decayed areas are observed in wood transverse beams supported by steel beams. Map cracks are observed on the asphalt. Parapet was spalled in some areas with the evidence of exposed rebar.
Condition of Joints	N/A
Movement	None evident
Hand Rails	N/A
Gate Superstructure	N/A
Chainage Markers	N/A

PIERS & ABUTMENTS [Photo 11 to 23]

CONDITION	OBSERVATION: SKETCH, MEASURE, PHOTOGRAPH, LOCATE
Surface Condition	North abutment: Spalling, honeycombing and downstream stressed cracks South abutment: Erosion along with water line as well as pattern cracks and cold joints Piers: Pattern cracks (could be due to Alkaline-Aggregate-Reaction) upstream of all piers, honeycombing, spalling and severe/very severe spalling and severe disintegration. Upstream of pier 1 (from North) is mostly destroyed.
Condition of Joints	N/A
Movement	None evident
Waterline Deterioration	Erosion in few areas.
Beam Seats	N/A
Stop Log/Gate Gains & Covers	Weathering and decay were observed in stop logs.

DAM SAFETY GENERAL INSPECTION

WEIR [Photo 24 to 30]

CONDITION	OBSERVATION: SKETCH, MEASURE, PHOTOGRAPH, LOCATE
Surface Condition	Spalling/severe spalling upstream and downstream of ogee type weir and spalling on the exposed apron
Condition of Joints	N/A
Movement	None evident
Undercutting	Evident in span 4 (numbering from North)

RETANING WALL

UPSTREAM FACE [Photo 31 to 33]

CONDITION	OBSERVATION: SKETCH, MEASURE, PHOTOGRAPH, LOCATE
Surface Condition	Almost entire upstream face of the South retaining wall severely spalled
Condition of Joints	N/A
Movement	None evident
Waterline Deterioration	N/A

DOWNSTREAM FACE [Photo 34 to 36]

CONDITION	OBSERVATION: SKETCH, MEASURE, PHOTOGRAPH, LOCATE
Surface Condition	Severely spalling and pattern cracks (could be due to Alkaline-Aggregate-Reaction) downstream of the South retaining wall
Condition of Joints	N/A
Movement	None evident
Waterline Deterioration	N/A

DAM SAFETY GENERAL INSPECTION

PHOTOS/SKETCHES/FIGURES

Photo 1 – Top of the Deck – Map Crack in Asphalt Looking North

Photo 2 – Spalled Concrete and Exposed Rebar in Parapet - Looking Upstream

Photo 3 – Diagonal Crack in Parapet

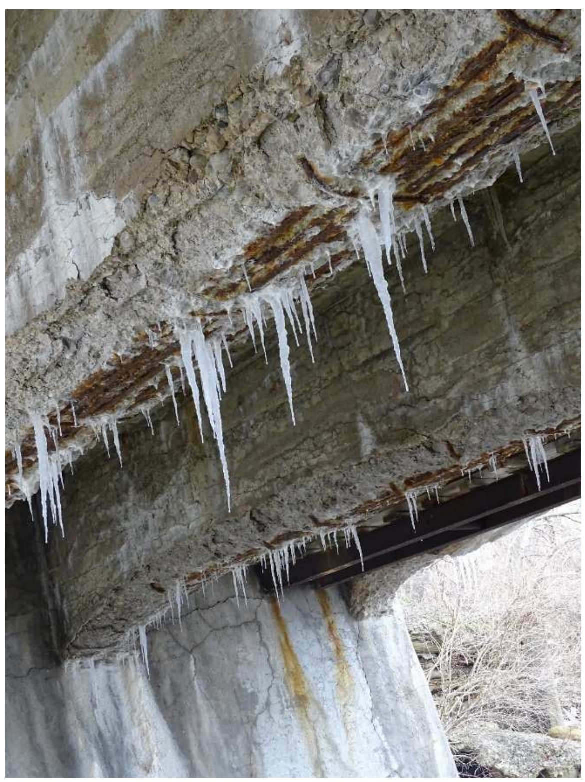


Photo 4 – Severe Spalled Concrete with Exposed Corroded Rebar underneath the Deck – Span 4

Photo 5 – Spalling and Exposed Corroded Rebar underside of the Girders and Deck – Span 4 Looking South

Photo 6 – Spalling and Exposed Corroded Rebar underside of the Girders and Deck – Span 2 Looking South

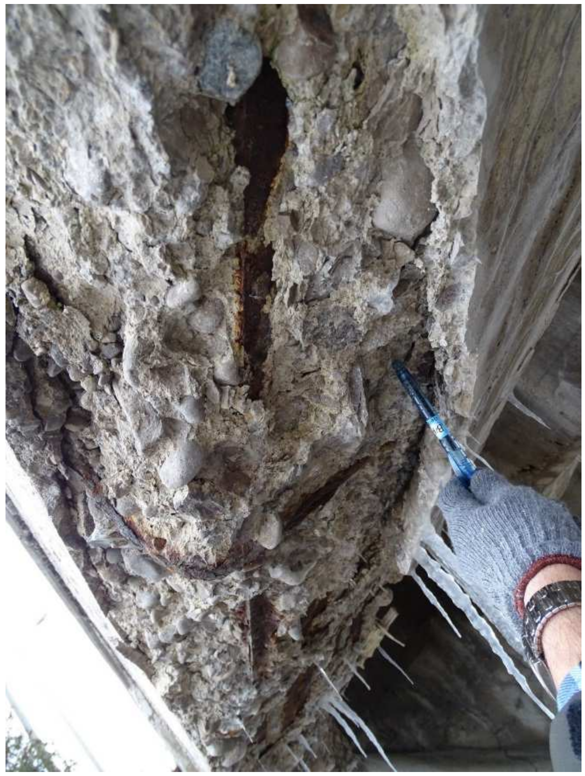


Photo 7 – Icicles underneath the Girders with Severe Spalling and Exposed Corroded Rebar – Span 3

Photo 8 – Severe Spalling and Exposed Corroded rebar underneath the Girder – Span 3 Looking North

Photo 9 – Severe Spalling underneath the Girder – Span 2 Upstream

Photo 10 – Rusted Steel I Beam and Decayed Timber Transverse Beam– Span 1 Looking South

Photo 11 – North Abutment – Looking North

Photo 12 – North Abutment Spalling and Honeycombing – Looking North

Photo 13 – North Abutment wide Crack - Looking Northeast

Photo 14 – South Abutment – Erosion, Joint Cold and Pattern Cracks

Photo 15 – Spalling and Pattern Cracks on Downstream of Piers - Looking South

Photo 16 – Severe Spalling and Honeycombing on Pier 1 (from North) – Looking Southwest

Photo 17 – Severe Spalling and Pattern Cracks on Pier 1 (from North) – Looking South

Photo 18 – Severe Spalling, Honeycombing and Hole in Pier 1 – Looking South

Photo 19 – Severe Spalling, Disintegration and Pattern Cracks on Pier 1 & 2 – Looking North

Photo 20 – Destroyed and Very Severe Spalled Concrete - Upstream of Pier 1 Looking South

Photo 21 – Spalling on Pier 2 (from North) – Looking North

Photo 22 – Severe Disintegration, Spalling and Pattern Cracks on Pier 3 – Looking South

Photo 23 – Weathered and Decayed Stop logs – Looking South

Photo 24 – Spalled Concrete – Upstream Weir of Span 1 (from North)

Photo 25 – Spalled Concrete – Downstream Weir of Span 1 Looking South

Photo 26 – Spalled Apron – Span 1 Looking Downstream

Photo 27 – Spalled Concrete – Upstream Weir of Spans 1 & 2 (from North) Looking North

Photo 28 – Spalled Concrete – Upstream Weir of Span 4 (from North)

Photo 29 – Undercutting and Spalled Concrete – Span 4 (from North)

Photo 30 – Spalled Concrete – Upstream Weir Looking North

Photo 31 – North Upstream Retaining Wall – Severe Spalling

Photo 32 – North Upstream Retaining Wall – Severe Spalling

Photo 33 –South Upstream Retaining Wall – Severe Spalling

Photo 34 – North Downstream Retaining Wall - Spalling and Pattern Cracks

Photo 35 – North Downstream Retaining Wall - Spalling and Pattern Cracks

Photo 36 – North Downstream Retaining Wall – Severe Spalling

APPENDIX D

COST ESTIMATE ALTERNATIVES

TABLE D1
COST ESTIMATES DAM DECOMMISSIONING

DESCRIPTION		COST
CONSTRUCTION COSTS (ROUNDED)		$ 296,000
DESIGN, ENGINEERING AND PERMITTING	12%	$36,000
CONSTRUCTION COST CONTINGENCY	25%	$74,000
OWNER'S ADMINISTRATIVE COST (including overhead and project management)	10%	$30,000
		$436,000

DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
MOBILIZATION	Lump Sum	1	$ 28,560	$ 28,560
DEMOBILIZATION	Lump Sum	1	$ 14,280	$ 14,280
ENVIRONMENTAL PROGRAM & ENVIRONMENTAL MONITORING	Month	6	$ 9,520	$ 57,120
SITE RESTORATION AND CLEANING	Lump Sum	1	$ 5,712	$ 5,712
DEMOLITION OF COFFERDAM AND WATER DIVERSION MEASURES	m^3	680	$280	$ 190,400
TOTAL COSTS SITE STUDIES AND CONSTRUCTION				$ 296,072

TABLE D2
COST ESTIMATES DAM REHABILITATION WITH POST-TENSION ANCHORS

DESCRIPTION		COST
CONSTRUCTION COSTS (ROUNDED)		$1,952,000
DESIGN, ENGINEERING AND PERMITTING	12%	$234,000
CONSTRUCTION COST CONTINGENCY	25%	$488,000
OWNER'S ADMINISTRATIVE COST (including overhead and project management)	10%	$195,000
		$2,869,000

DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
MOBILIZATION	Lump Sum	1	$ 153,798	$ 153,798
DEMOBILIZATION	Lump Sum	1	$ 76,899	$ 76,899
ENVIRONMENTAL PROGRAM & ENVIRONMENTAL MONITORING	Month	1	$ 76,899	$ 76,899
GEOTECHNICAL INVESTIGATION	Lump Sum	1	$ 50,000	$ 50,000
MATERIAL QUALITY CONTROL - INDEPENDENT LABORATORY	Lump Sum	1	$ 10,000	$ 10,000
SITE RESTORATION AND CLEANING	Lump Sum	1	$ 46,139	$ 46,139
DEMOLITION OF BRIDGE DECK AND PART OF PIERS	m3	400	$ 280	$ 112,000
MODULAR COFFERDAM	kg	4545	$ 15	$ 68,175
SEAL MEASURES FOR DIVERSION	Lump Sum	1	$ 9,800	$ 9,800
INSTALLATION OF ANCHORS	m	340	$ 2,000	$ 680,000
CONCRETE SURFACE REPAIR	m3	167	$ 4,000	$ 668,000
TOTAL COSTS SITE STUDIES AND CONSTRUCTION				$ 1,951,709

TABLE D3
COST ESTIMATES DAM REHABILITATION WITH ADDED MASS

DESCRIPTION		COST
CONSTRUCTION COSTS (ROUNDED)		$3,116,000
DESIGN, ENGINEERING AND PERMITTING	12%	$374,000
CONSTRUCTION COST CONTINGENCY	25%	$779,000
OWNER'S ADMINISTRATIVE COST (including overhead and project management)	10%	$312,000
		$4,581,000

DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
MOBILIZATION	Lump Sum	1	$ 248,415	$ 248,415
DEMOBILIZATION	Lump Sum	1	$ 124,208	$ 124,208
ENVIRONMENTAL PROGRAM & ENVIRONMENTAL MONITORING	Month	1	$ 124,208	$ 124,208
GEOTECHNICAL INVESTIGATION	Lump Sum	1	$ 50,000	$ 50,000
MATERIAL QUALITY CONTROL - INDEPENDENT LABORATORY	Lump Sum	1	$ 10,000	$ 10,000
SITE RESTORATION AND CLEANING	Lump Sum	1	$ 74,525	$ 74,525
DEMOLITION OF BRIDGE DECK AND PART OF PIERS	m3	400	$ 280	$ 112,000
MODULAR COFFERDAM	kg	9090	$ 15	$ 136,350
SEAL MEASURES FOR DIVERSION	Lump Sum	1	$ 9,800	$ 9,800
CONCRETE REMOVAL IN WEIRS	cu. m	224	$ 3,000	$ 672,000
INSTALLATION OF NEW CONCRETE	cu. m	777	$ 2,000	$ 1,554,000
TOTAL COSTS SITE STUDIES AND CONSTRUCTION				$ 3,115,505

TABLE D4
COST ESTIMATES DAM REPLACEMENT WITH CONCRETE WEIR

DESCRIPTION		COST
CONSTRUCTION COSTS (ROUNDED)		$4,224,000
DESIGN, ENGINEERING AND PERMITTING	12%	$507,000
CONSTRUCTION COST CONTINGENCY	25%	$1,056,000
OWNER'S ADMINISTRATIVE COST (including overhead and project management)	10%	$422,000
		$6,209,000

DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
MOBILIZATION	Lump Sum	1	$ 338,573	$ 338,573
DEMOBILIZATION	Lump Sum	1	$ 169,287	$ 169,287
ENVIRONMENTAL PROGRAM & ENVIRONMENTAL MONITORING	Month	1	$ 169,287	$ 169,287
GEOTECHNICAL INVESTIGATION	Lump Sum	1	$ 50,000	$ 50,000
MATERIAL QUALITY CONTROL - INDEPENDENT LABORATORY	Lump Sum	1	$ 10,000	$ 10,000
SITE RESTORATION AND CLEANING	Lump Sum	1	$ 101,572	$ 101,572
REMOVAL OF EXISTING DAM	m^3	680	$ 280	$ 190,400
MODULAR COFFERDAM	kg	12810	$ 15	$ 192,150
BACKFILL FOR DIVERSION	m^3	308	$ 50	$ 15,400
SEAL MEASURES FOR DIVERSION	Lump Sum	1	$ 8,580	$ 8,580
NEW CONCRETE STRUCTURE	m^3	1410	$ 2,000	$ 2,820,000
RIP RAP	m^3	72	$ 100	$ 7,200
SUPPLY AND INSTALLATION OF SHEET PILES	m^2	180	$ 800	$ 144,000
DRAIN SYSTEM	unit	4	$ 2,000	$ 8,000
TOTAL COSTS SITE STUDIES AND CONSTRUCTION				$ 4,224,448

TABLE D5

COST ESTIMATES DAM REPLACEMENT WITH NEW EMBANKMENT AND NEW SLUICEWAY

DESCRIPTION		COST
CONSTRUCTION COSTS (ROUNDED)		$2,694,000
DESIGN, ENGINEERING AND PERMITTING	12%	$323,000
CONSTRUCTION COST CONTINGENCY	25%	$674,000
OWNER'S ADMINISTRATIVE COST (including overhead and project management)	10%	$269,000
		$3,960,000

DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT
MOBILIZATION	Lump Sum	1	$ 214,108	$ 214,108
DEMOBILIZATION	Lump Sum	1	$ 107,054	$ 107,054
ENVIRONMENTAL PROGRAM & ENVIRONMENTAL MONITORING	Month	1	$ 107,054	$ 107,054
GEOTECHNICAL INVESTIGATION	Lump Sum	1	$ 50,000	$ 50,000
MATERIAL QUALITY CONTROL - INDEPENDENT LABORATORY	Lump Sum	1	$ 10,000	$ 10,000
SITE RESTORATION AND CLEANING	Lump Sum	1	$ 64,232	$ 64,232
DEMOLITION OF BRIDGE DECK AND PART OF PIERS	m^3	680	$ 280	$ 190,400
MODULAR COFFERDAM	kg	12810	$ 15	$ 192,150
BACKFILL FOR DIVERSION	m^3	308	$ 50	$ 15,400
SEAL MEASURES FOR DIVERSION	Lump Sum	1	$ 8,580	$ 8,580
EMBANKMENT DAM				
Clearing / Grubbing of vegetation	m^2	2000	$ 10	$ 20,000
Subgrade Preparation	m^2	2000	$ 15	$ 30,000
Supplying & placing Earth Embankment Backfill (Till Material)	m^3	6200	$ 30	$ 186,000
Supplying & Placing Riprap (Upstream Slope)-500 mm thick	m^3	400	$ 120	$ 48,000
Supplying & Placing Riprap (Downstream Slope)-500 mm thick	m^3	200	$ 120	$ 24,000
Steel Sheet Piling Cut-off	m^2	400	$ 450	$ 180,000
Supplying and placing Granular backfill (Crest, 300 mm thick)	m^3	150	$ 45	$ 6,750
Turf Mat and seeding	m^2	900	$ 15	$ 13,500
SLUICEWAY STRUCTURE				
New Concrete	m^3	540	$ 2,000	$ 1,080,000
Rip Rap	m^3	18	$ 100	$ 1,800
Supply and Installation of Sheet Piles	m^2	40	$ 800	$ 32,000
Winches and supports	unit	2	$ 9,000	$ 18,000
Stoplogs	unit	24	$ 2,000	$ 48,000
Metal Railings	m	55	$ 700	$ 38,500
Signage	unit	2	$ 4,000	$ 8,000
TOTAL COSTS SITE STUDIES AND CONSTRUCTION				$ 2,693,528

KGS GROUP
CONSULTING ENGINEERS