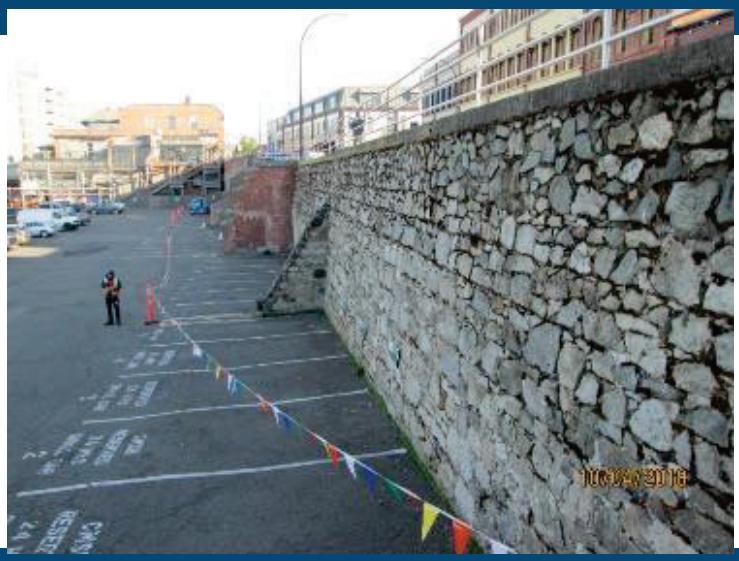
WHARF STREET RETAINING WALL CONDITION ASSESSMENT REPORT

Wharf Street, Victoria, BC.



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HEROLD ENGINEERING

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APPENDIX A: DRAWINGS

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S03 – Wharf Street Wall Proposed Structural Upgrade Sections

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1.0 Executive Summary

Herold Engineering Limited (HEL) was retained by the City of Victoria to perform a condition assessment of the retaining wall at 1112 Wharf Street, Victoria BC. The scope of the assessment included a review of existing relevant documents, a visual, non-destructive field investigation, and a global structural stability analysis.

The subject retaining wall extends for approximately 103.6 meters and ranges in height from 6.7 meters at the northerly end to 3.73 meters at the southerly end. The wall is comprised of four distinct segments that are reflected in the materials used and the original purpose for construction.

- Wall section 1 – Comprised of two separate walls; a granite and sandstone outer wall and a buried stone wall running parallel to the exposed outer wall, with a 1.8m tunnel separating the two. This section of the wall was originally the Wharf Street elevation of the Hudson's Bay Company (HBC) Warehouse constructed in 1858 and demolished in 1937.
- Wall Section 2 – Constructed of cast-in-place concrete.
- Wall Section 3 - Assumed to be comprised of two separate walls as per wall Section 1with the outer wall constructed of clay brick masonry with a granite field stone foundation course. This section of wall is the remnants of the 1864 Turner Beeton & Co warehouse building demolished in 1937.
- Wall Section 4 – Constructed of mortared igneous gneiss and split granites field stone with a stone buttress at mid-point.

The field investigation was conducted over two days and covered the exposed west face and top of the wall and the visible areas of wall and sidewalk slab accessed from inside the tunnel beneath the Wharf street sidewalk. Based on the field assessment, the following issues were identified:

- Wall Section 1: Poor to Fair condition - notable mortar loss, voids, spalling, and loose masonry, erosion and exfoliation of sand stone due to weathering.
- Wall Section 2: Fair condition – some spalling and organic growth, condition is poorest at the top of wall that forms the sidewalk curb.
- Wall Section 3: Poor condition – notable mortar loss, degradation of brick surfaces.
- Wall Section 4: Poor condition – notable cracks, failed mortar joints, loose and de-bonded stonework.

A structural stability analysis of the retaining wall under static and dynamic (earthquake) loading was conducted as part of this assessment. As the scope of work was limited to visual investigation and existing documents, the analysis is based on conservative assumptions where field measurements could not be taken due to inaccessible and buried conditions. Lateral earth pressures (static and dynamic) used in the analysis are based on common data from other Victoria sites, to be verified by a geotechnical review.

The following table shows the calculated Factors of Safety for wall sections.

Load Case	Static Condition		Dynamic Condition	
Wall Section	Overturning	Sliding	Overturning	Sliding
Sections 1 and 3	1.2	1.3	0.3	0.5
Sections 2 and 4	1.1	1.1	0.3	0.4

The wall has successfully carried its service loads to date, indicating a Factor of Safety of 1 as a minimum for the current condition under static loads. The calculated performance under seismic loads results in a factor of safety less than 1 which indicates the wall will fail in overturning and sliding under a code level seismic event.

It is recommended that the wall at 1112 Wharf Street be repaired to address safety risks due to falling hazards and to mitigate further deterioration of the wall. Removal and repair of loose and failed bricks is considered urgent work for the health and safety of the general public and protection of private property.

It is also recommended that detailed destructive investigations be undertaken to verify assumptions made in the structural stability analysis and that seismic upgrades be undertaken to prevent wall failure during an earthquake. Proposed investigative work includes extracting eight horizontal core holes (2 from each wall section) and one vertical core, and making good the wall surface at core locations.

The following remedial work items are recommended to help stabilize and conserve the existing wall while retaining its Heritage Characteristic, the service life of the repointing repairs is expected to be a minimum of 30 years:

- Cleaning and removal of organic debris, repointing of the mortar joints, replacing decayed clay brick, scaling and sealing of Sandstone.
- Shotcreting of cast in place concrete wall and addition of protective cast in place caps.
- Seismic stability upgrades, including: constructing concrete buttress walls within the tunnel area, installing soil anchors, and adding steel beams to the inside face of the tunnel.

Cost estimates for the above noted work items has been included in the report. The opinion of probable cost for all work items is estimated at $1,200,000.00

2.0 Terms of Reference and Limitations

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This report is based on visual observations and data acquired from the Client, and is limited to major items and major maintenance activities. Private property was not inspected. Unless otherwise agreed in writing by HEL, this report shall not be used to express or imply warranty to the property for any particular purpose.

The work reflects the Consultant's best judgment in light of the information reviewed by them at the time of preparation. HEL is not providing advice about mold, mildew, pollutants, contaminants or other hazardous materials. We recommend an Environmental Consultant be retained for these services.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Herold Engineering Limited and our consultants accept no responsibility for damage, if any, suffered by any third party because of decisions made or actions undertaken based on this report.

3.0 Introduction

Herold Engineering Limited (HEL) was retained by the City of Victoria to perform a condition assessment of the retaining wall that forms the boundary of 1112 Wharf Street, Victoria BC. The subject wall is comprised of segments of varying age, and construction types. The condition of the wall has deteriorated over time and an assessment of its current condition and recommendations for repairs is required.

The scope of the assessment included a review of existing relevant documents, a field investigation, and a global structural stability analysis. Field investigation work was limited to visual/tactile methods, no destructive testing was performed. The field review was conducted over two days and covered the exposed west face and top of the wall and the visible areas from inside the tunnel beneath the Wharf street sidewalk. Structural stability analysis included a review of the overturning and sliding capacities vs demand on the wall for static and dynamic (seismic) load cases. Results of the field assessment and stability analysis are outlined in the following report.

4.0 Historic Context and Description

The subject retaining wall extends for approximately 103.6 meters and ranges in height from 6.7 meters at the northerly end to 3.73 meters at the southerly end.

The wall is comprised of four distinct segments that are reflected in the materials used and the original purpose for construction. This report sequentially follows geographically from North to South the four segments as they also generally relate to the periods of construction. An undated survey drawing provided by The City of Victoria is reproduced below. The drawing includes both a plan view of the subject wall and five cross sections.

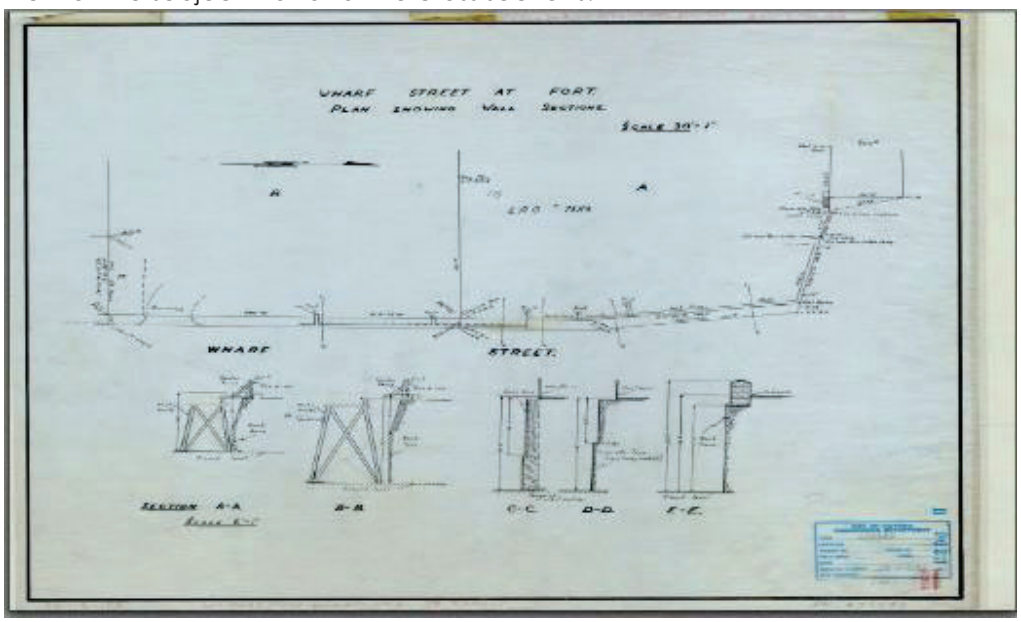

PHOTO 1: City of Victoria Engineering Department survey drawing circa 1949.

Photos 2 to 5 below show the current configuration of the wall:

PHOTO 2: **SECTION 1**, formerly part of the Hudson's Bay Company Warehouse.

PHOTO3**: SECTION 2** Cast in place concrete section formerly part of the wharf access ramp.

PHOTO 4: **SECTION 3**, Formerly part of the Turner Beeton & Co. warehouse

PHOTO 5**: SECTION 4**, Stone retaining wall.

WALL SECTION 1

Built in 1858 this section of the retaining wall was originally the Wharf Street elevation of the Hudson's Bay Company (HBC) Warehouse. A contemporary description of the building indicates that it was a three storey building with a basement and a sub-basement (crawlspace). The warehouse is described as substantially constructed of clay brick with field stone foundations. The warehouse is recorded as demolished in 1937.

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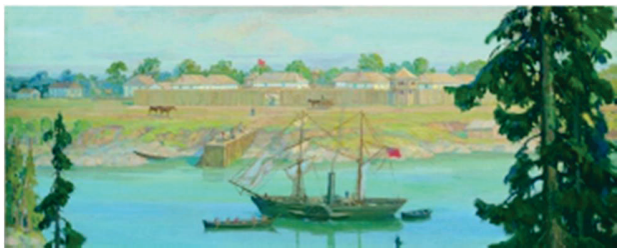

PHOTO 6: 1846 Fort Victoria viewed from the Songhees Lands. The original wooden wharf can be seen

PHOTO 7: 1863 map of Victoria. The HBC Warehouse is shown together with a development of the wharf structure.

PHOTO 8: An early photograph (circa 1857) taken from a similar view point as the painting above. The original warehouse is the white painted building on the shoreline to the right. The subject warehouse was built directly east of the original building. Refer to the Fire Insurance Map.

PHOTO 9: 1885 Fire Insurance Map. The HBC Warehouse building together with the original warehouse are identified. The Turner Beeton & Co. warehouse is shown together with a boardwalk ramp between the two buildings.

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PHOTO 10: 1928 Aerial photograph

PHOTO 11: 2015 Aerial Photograph

WALL SECTION 2

Section 2 is a 10.5 meter section of cast in place concrete retaining wall. It likely was originally constructed as a retaining wall extending south from the corner of the HBC Warehouse. It is likely that it was used as the head wall to a wooden wharf access ramp between the HBC Warehouse and the Turner Beeton warehouse. It appears that by the early 1930's the ramp was no longer used for vehicle access and a wooden stairway provided pedestrian access to the lower coaling yard and foreshore.

PHOTO 12: Wharf Street looking North. In the left foreground is an area of unfinished road way and fencing. Taken circa 1863, this photo shows

PHOTO 13: Wharf street looking west showing the gap between the two buildings

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the gable end of the HBC Warehouse.

PHOTO 14: Showing the timber platform between the two warehouses.

PHOTO 15: likely taken at the same time as Photo 13, the pedestrian access stair can clearly be seen to the left.

WALL SECTION 3

Built in 1864 this section of the retaining wall is the visible remains of the below grade section of a substantial warehouse built by Turner Beeton & Co. This Wharf Street warehouse was built for owner John Turner in the Second Empire Style. Used to transship imported fabrics and millinery to a retail store on Government Street known as London House. In 1896 Turner and company built a combined retail and warehouse on Wharf Street at the foot of Yates Street. Known as the Yates block, this building still exists.

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PHOTO 16: Wharf Street Elevation circa 1868

PHOTO 17: South elevation 1930's

PHOTO 18: Post demolition, the access to an additional basement located below the sidewalk can be clearly seen. As with the HBC Warehouse there was likely a sub basement area. Photo is circa 1971.

PHOTO 19: Current condition of the brick infill to the sub basement doorway.

WALL SECTION 4

Section 4 is a mortared field stone retaining wall approximately 46.5 meters long with a stone buttress at the midpoint. It has likely always functioned as a retaining wall, however there is little archival record of it.

An investigation and condition assessment was completed in 2008 and 2009 with some remedial and maintenance work being undertaken as a result of these assessments. The wall is primarily composed of locally sourced metamorphosed igneous gneiss and split granites. The wall lay-up is typically referred to as random rubble. It is likely that the wall may pre-date the construction of the Turner Beeton Warehouse. Careful scrutiny of the southerly brick buttress of the Turner Beeton warehouse wall indicates that there may have been a gap between the face of the stone wall and the exterior of the old warehouse wall. The infill brickwork is not tied by coursing into the warehouse wall and the stonework appears to extend beyond the wall. The mid-point buttress also appears to have been added as an afterthought, it is noted that with the exception of the two cap stones, there are no through stones locking the buttress to the wall.

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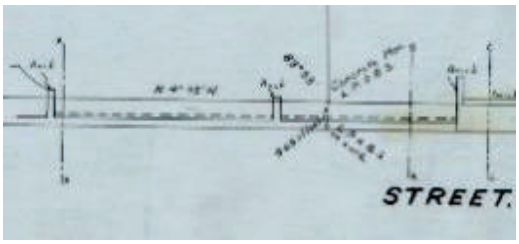

PHOTO 20: An extract from the survey drawing showing the stone retaining wall

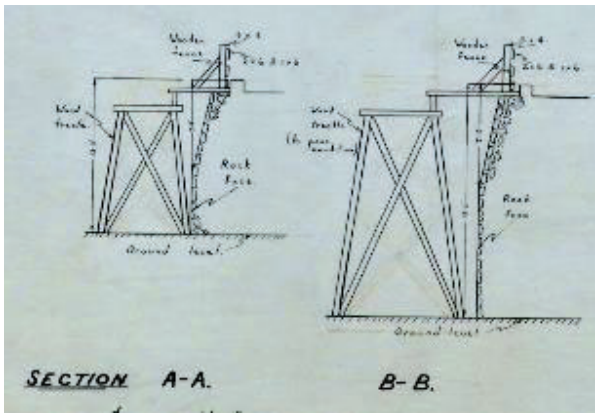

PHOTO 21: Survey sections A & B indicate that a trestle structure and platform existed as perhaps part of a sidewalk.

PHOTO 22: The infill brickwork between the Turner Beeton warehouse wall and the rock retaining wall.

PHOTO 23: The infill brick is coursed and cut to fit to the stone wall, indicating that the stone wall may extend beyond the infill brick.

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PHOTO 24: Enlarged view of the Turner Beeton Building. In the foreground the sidewalk appears to be suspended between the building and the line of the stone retaining wall.

PHOTO 25: An enlargement of a section of PHOTO 17 appears to indicate a trestle type structure to the west of the stone retaining wall.

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5.0 Condition Assessment

A condition assessment of the Wharf street retaining wall was completed by Goal Engineering in September 12, 2008. It is clear that only a portion of the repair and remedial work recommended in the report have been implemented to date.

WALL SECTION 1

As described in the preceding historic context, SECTION 1 is primarily the remnants of the HBC warehouse. The remaining portion of the wall that is exposed was the interior side of the wall. The wall has been exposed to continual weathering since demolition of the building in 1937.

The wall is built using two distinct types of stone and clay brick. The wall is 34.74 meters long with a height of 6.7 meters. It appears to have been originally constructed as a free standing structure with a consistent thickness of 600mm. A stone wall located approximately 2.1 meters to the east of the exposed wall runs parallel to the subject wall and may have been built to create a working space for the construction of the exterior wall of the HBC Warehouse. There is evidence that a doorway (now filled in) was created to gain access to the space created between the two walls. The void between the two parallel walls is accessed from a manhole in the sidewalk. The void has been partially back filled with construction debris, this may have occurred in 1937 during the demolition of the building.

Photographs taken in 2008 provide a useful reference point for assessing the current condition of the wall and allows a visual comparison to gauge the ongoing rate of erosion.

PHOTO 26: Current (2018) overview of northerly section of wall. Some poorly executed re-pointing of the upper section of brick work is evident.

PHOTO 27: Current (2018) overview of southerly section of wall. Poorly executed re-pointing and filling of the old beam pockets is evident.

PHOTO 28: Dated 13 November 2008, clearly shows the condition of the upper brick section prior to the repointing work and filling of the beam pockets at the northerly end of the wall.

PHOTO 29: Dated 13 November 2008, shows more clearly the beam pockets at the upper brick section. It is also a useful reference for the condition of the buttress, before repairs were completed in 2013.

PHOTO 30: A general view of SECTION 1 showing the different construction materials.

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Several types of building materials were used in the construction of SECTION 1.

At the base of the wall for a height of approximately 1.2 metres, the exposed portion of the wall appears to have been built using granite stone in a random rubble pattern. The individual stones range in size from approximately 100mm x 100mm face dimension to 400mm x 350mm face dimension. The majority of the stones have been laid to present a flat face. There is some evidence to indicate that the work was vertically coursed at approximately 400mm intervals with smaller pieces inserted to level off the work at the top of each course. The exposed mortar joints vary in width as is normal for this type of masonry work. The type of granite is commonly identified as Gneiss. This stone naturally splits into angular pieces with flat surfaces on the cleaving plains. It is likely that the material was quarried locally. The mortar is generally in fair condition with some evidence of erosion and aging.

PHOTO 31: Granite layed in a random rubble patternat the base of the wall

At the 1.2m level the wall material is predominantly sandstone. This band is approximately 800mm in width. The sand stone has been subjected to weathering and there is evidence of erosion and exfoliation to the exposed surfaces.

Some remedial mortar repointing work appears to have been completed within the last decade and what may have been the lower floor beam pockets have been filled with cementitious material.

PHOTO 32: 1.2m – 2.0m Predominantly Sandstone

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At the 2.0m level and extending to a height of 3.9m the wall composition is predominantly granite.

The mortar jointing is generally in poor condition with significant material loss. The wall surface presents many small ledges and openings which will retain rainwater at the mortar joints rather than freely shedding it.

The integrity of a masonry wall relies on its ability to control water penetration and accumulation. With natural aging of the mortar joints, erosion and minor damage to the assembly, the severity of the damage increases due to a lack of moisture control.

Until the mortar loss is addressed the condition of the wall will continue to deteriorate in an uncontrolled manner.

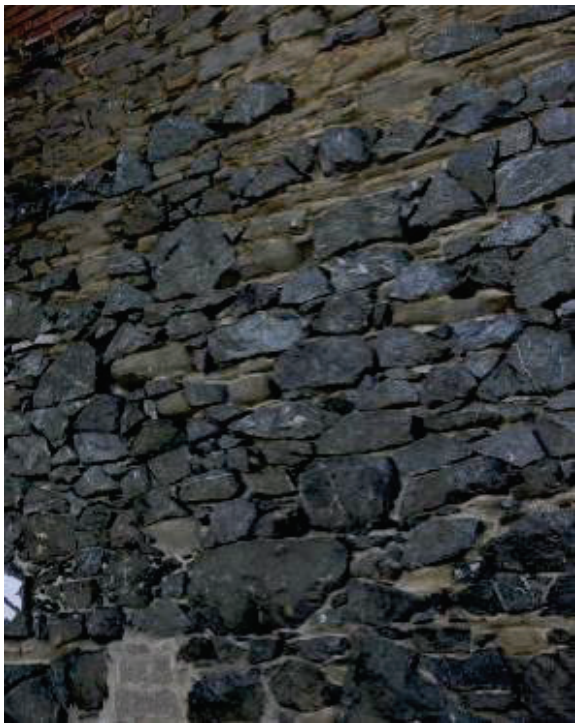

PHOTO 33: 2.0m – 3.9 m Granite band

PHOTO 34: Large void in mortar joint

PHOTO 35: Transition to upper band of Sandstone

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At the 3.9m level the material changes from granite to mostly Sandstone. This has been laid in a band approximately 1.4m wide and extends for the visible length of the wall.

This section of the masonry wall is in poor to fair condition. Biological growth and staining is evident throughout the length of the wall; the mortar has been eroded in most locations; and the sandstone is eroded and exfoliated. This is all likely due to water ingress and accumulation, along with damage due to exposure to salts and other environmental conditions.

PHOTO 36: Exfoliation of the Sandstone surface is clearly evident

At the 5.3m level the construction material changes to clay brick masonry.

The outer wythe of the clay masonry and mortar is generally in an advanced stage of deteriorated condition. Erosion and spalling has occurred due to the effects of moisture ingress and accumulation, and possibly the presence of salts. This damage has affected the ability of the masonry to effectively shed water and, as a result, the wall has extended periods of moisture saturation. Efflorescence, biological growth and staining are all by-products of moisture accumulation that also cause damage to the mortar.

It is evident that some repairs to the mortar joints have been attempted. The repairs while likely well intended have been poorly executed, with mortar material covering large areas of the clay brick. The mortar used in the repairs appears to be extremely hard unlike a mortar with a higher lime content typically used in the conservation of heritage clay brick walls.

PHOTOS 37 & 38: Poorly executed mortar re-pointing.

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In addition to the changes in masonry construction materials, Section 1 also contains a number of significant features

PHOTO 39: Photo taken in 2008 showing degraded condition of the lower portion of the remains of the HBC warehouse gable end wall.

PHOTO 40: Current condition of the wall. Repaired using a mixture of recycled and modern clay bricks.

PHOTO 41: Close up of the inside corner of the buttress.

PHOTO 42: Former floor joist pockets have been filled with cementitious material

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PHOTO 43: Infilled doorway. The red brick may be recycled from the original construction.

PHOTO 44: Relieving arch in detail. The tan bricks are clearly part of the original construction.

PHOTO 45: Door sill. The height of the door sill aligns with the tops of the filled in joist pockets seen at the remains of the two gable ends. This was likely a goods access to the basement from Wharf Street. Approximately 3.0m above.

PHOTO 46: Sandstone and clay brick interface. Barnacles were observed on the faces of the sand stone indicating that the material was collected from a shoreline rather than quarried.

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PHOTO 47: Transition from sandstone masonry to clay brick masonry. There is clear evidence of three cast in place concrete door sills.

PHOTO 48: Closeup of the cast in place concrete door sill complete with an outline and profile of the wooden door frame and mouldings.

PHOTO 49: The transition ledge now filled with wind deposited soils and organic growth.

PHOTO 50: A former mortar line at the first brick course indicates that the transition may have been parged to form a water shedding slope.

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PHOTO 51: The sidewalk section 1. In the foreground is the metal access lid to the chamber below.

PHOTO 52: Access was gained using confined space protocols.

PHOTO 53: The HBC warehouse wall. Mortar jointing has not been subjected to prolonged weathering and was found to be in good condition.

PHOTO 54: The northerly intersection between the stone retaining wall and the exterior wall of the old warehouse.

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PHOTO 55: Looking south, access to the full extent of the chamber is blocked by a precast concrete vault.

PHOTO 56: Construction debris, possibly from the deconstruction of the warehouse in 1937.

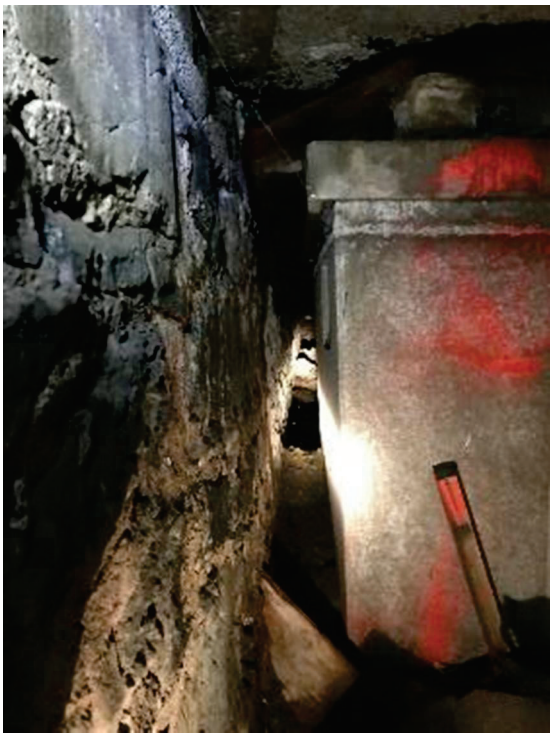

PHOTO 57: A stone masonry end wall appears to align with the end of the warehouse building.

PHOTO 58: The end wall appears to be perpendicular to the warehouse wall.

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PHOTO 59: A 1.0 x .75 m area of masonry has been removed from the HBC wall. In this location the remaining stone work appears to be 150mm thick.

PHOTO 60: Taken during repairs to the exterior buttress, this photo confirms that the chamber extends south of the concrete vault.

PHOTO 61: A close up of the easterly side stone retaining wall. The mortar joints appear to be in good unweathered condition.

PHOTO 62: Sections of the northerly gable end of the warehouse are preserved. The original mortar has been repointed using a "heritage mortar mix" and is a good example of what the exposed west wall would look like when restored.

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WALL SECTION 2

Section 2 is a 10.5 meter section of cast in place concrete retaining wall. It likely was originally constructed to function as a retaining head wall for a wooden wharf access ramp between the HCB warehouse and the Turner Beeton warehouse. As the gable ends of both warehouses clearly continue east beyond the face of the concrete it is likely that this section of the wall was formed after both buildings were built. With photographs from 1971 and 2008 as a reference, the wall has not deteriorated at the same rate as the brick and stone portions.

PHOTO 63: The cast in place concrete wall shows a stratification typical of concrete placement technique, common place in the early 20th century.

In our field investigation, we were unable to gauge the thickness of the wall. In several locations we were able to insert a tape measure into the voids created at the pour joints but this produces very unreliable data. It is very likely that form work was only used on the west side of the wall and concrete was poured in place to fill a natural gap between the form and the natural profile of the land behind.

At approximate 3.5 m above grade there is a 150mm step in the face of the concrete. Organic material has accumulated on this shelf which inhibits the free drainage of rainwater.

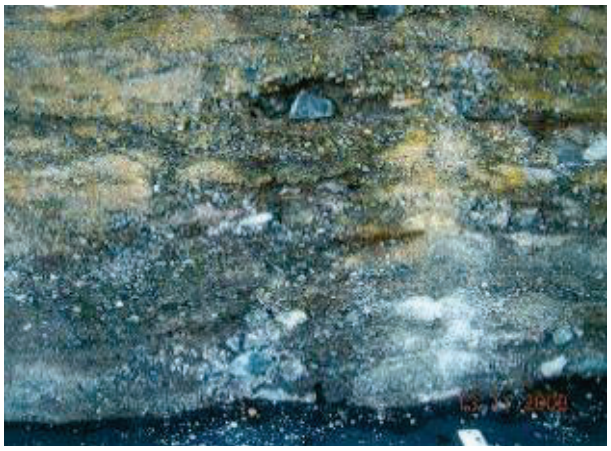

PHOTO 64: Taken in 2008, this photo forms a good base line for our assessment of the current condition of the wall.

PHOTO 65: A general overview of the section 2 wall and the northerly buttress, repaired in 2013. Highlighted is the small aperture where the void behind section 1 was observed.

PHOTO 66: The aperture through which PHOTO 60 was taken by personnel from Innovative Structural Preservation in 2013. The image was published in the Times Colonist Newspaper.

PHOTO 67: poorly executed patch repair. This repair predates the 2008 photos and appears as a lighter patch in PHOTO 18, taken in the early 1970's

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PHOTO 68: Poor condition of the upper and presumably later layers of concrete that form the current sidewalk curb.

PHOTO 69: Clay drain tile insert.

WALL SECTION 3

As noted in SECTION 1, this section of the retaining wall is the remnants of a substantial warehouse built by Turner Beeton & Co in 1864. The wall is primarily constructed of clay brick masonry with a granite field stone foundation course. The granite blocks serve as an impermeable layer preventing moisture from entering the clay brick from the surrounding and underlying soils. It in fact provides conclusive evidence that this was a free standing wall rather than a retaining wall. It appears that clay bricks were more readily available in1864 compared to 1858 when the HBC warehouse was built. The selection of materials may also speak to the nature of the business conducted by the owners. The clay bricks appear to be formed with a high Devonian period red clay indicating that the bricks were imported rather than made locally.

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PHOTO 70: General view of the clay brick wall.

PHOTO 71: Comparable photo taken in 2008.

PHOTO 72: Infilled borrowed light window. The opening was likely filled in using recycled bricks,

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PHOTO 73: An overhead view clearly reveals the mortar loss at the joints and degradation of the exposed brick surfaces.

PHOTO 74: Sample area showing different rates of degradation due to variations in the density of the clay brick. Typically, the bricklayers would select the lower fired and duller sounding bricks for the interior surfaces during construction.

PHOTO 75: The original mortar droppings are clearly visible on this set back ledge. Organic material deposits and growth further act to retain water in high wind and rain events.

PHOTO 76: The friable nature of the decayed mortar, simply demonstrated. The burnt lime that provides the material stability has been lost due fresh water leaching.

It is our understanding that the Turner Beeton Warehouse was demolished in 1937. The observed deterioration and weathering is fairly evenly distributed over the length of the wall and is the result of 80 years of continuous exposure to the elements. Whilst we have identified portions of the wall where the deterioration is at an advanced stage it is reasonable to consider a repair strategy that would be applied to the entire exposed surfaces of the wall.

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Using the 2008 Goal Engineering report and recommendations it is evident that only selected repairs to the buttresses have been completed. The recommended replacement of eroded brick and re-pointing work has not been implemented.

WALL SECTION 4

As stated earlier in the Historical Context, Section 4 is a mortared field stone retaining wall approximately 44.5 meters long with a stone buttress at the midpoint. It has likely always functioned as a retaining wall, however there is little archival record of it.

An investigation and condition assessment was completed in 2008 and 2009 with some remedial and maintenance work being undertaken as a result of these assessments. The wall is primarily composed of locally sourced metamorphosed igneous gneiss and split granites. The wall lay-up is typically referred to as random rubble. It is likely that the wall may pre-date the construction of the Turner Beeton Warehouse.

PHOTO 77: General view of the stone retaining wall, showing the upper sloped (battered) section.

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PHOTO 78: Organic growth at the exposed top of wall.

PHOTO 79: Organic growth at the mortar joints.

PHOTO 80: Failed mortar joints, cracks vary in width from 10mm to 25mm.

PHOTO 81: Loose stonework. Several of the smaller stone filler pieces where coursing and levelling occurred during construction are now loose or debonded from the wall.

PHOTO 82: Recent repairs to the buttress are evident. Stone has been added to provide a facing guide for the sloped mortar cap.

PHOTO 83: several granite blocks were originally shaped using the plug and feather technique.

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PHOTO 84: The upper sloped section of the wall typically is exposed to rainwater during high rain and wind events. The integrity of the mortar joints is critical to the overall drainage of the wall.

PHOTO 85: A distinct drainage and wetting pattern to the surface of the wall was observed during a recent high rain event.

6.0 Field Review Summary

The subject retaining wall extends for approximately 103.6 meters and ranges in height from 6.7 meters at the northerly end to 3.73 meters at the southerly end.

The wall is comprised of four distinct segments which is reflected in the materials used and the original purpose for construction.

The current condition of the wall varies from fair to poor depending on the ability of the materials to resist weathering and subsequent erosion.

GRANITES AND GRANITIOD GNEISSES

The density and natural water resistive properties of igneous rocks such as granites and gneisses make the use of these igneous materials a good choice for retaining walls or where ground water control is required.

The granite portions of the wall are proving to be the most durable, with the least amount of observable deterioration. It appears that the mortar joints to this wall have received some attention. However, the organic growth at the top of exposed top of the wall is impeding the free draining of rain water and presents a concern that water will be retained in the mortar joints where leaching of the free lime component affects the long term effectiveness of the bond.

The removal of loose debris together with removal of organic growth and contaminants and repointing of mortar joints would be an effective remediation.

SANDSTONE AND QUARTZ BASED STONE

Sedimentary stone such as Sandstone is primarily composed of quartz crystals (sand) cemented with silica. While the material has a natural high density and compressive strength the quartz crystals are

moderately soluble allowing the stone to absorb and retain water and when subjected to weathering has a propensity to exfoliate when subjected to prolonged wetting.

The sandstone originally selected for the construction of the wall appears to have been collected from a shoreline or beach rather than quarried and likely selected for their manageable size and smooth or rounded appearance. Several barnacles were observed on sheltered exterior faces of individual stones. In the same way that the stone weathers at a crystalline level, the mortar bonding is critical to the overall durability of the assembly.

In addition to the remediation recommended for the granite sections of the wall, the predominately sandstone wall areas will require careful scaling and removal of loose or exfoliated surfaces. Consideration may be given to treating the exposed stone with a consolidation material containing ethyl silicate to address the loss of the natural crystalline binder.

CAST IN PLACE CONCRETE

The cast in place concrete is generally of poor quality and limited compressive strength. However, the erosion of the finer surfaces and cement coating to aggregate is a concern. The presence of organic growth in the many water retaining cavities and surfaces are inhibiting the free draining of rainwater from the wall. This will increase the amount of water that can enter the wall which further accelerates the depletion of the cement binder by solution. Where larger amounts of water are present during the winter months the wall may now be subject to freezing and the loosening of aggregate as a result.

To address the water permeability of the cast in place concrete repair with shotcrete is recommended. Following the removal of all loose debris and organic materials a 150mm x 150mm mesh of 10/10 steel is mechanically attached and shotcrete applied with a course trowel float finish.

CLAY BRICK MASONRY

The exposed brick sections of the wall is made up of clay brick and mortar of varying densities. The density of a brick and its ultimate durability is in large measure determined by the initial firing temperature. The type of cement mortar available in the second half of the 19th century contained less hydraulic cement and a higher proportion of lime. The mortar was used as a contour conforming material to space the clay bricks apart rather than to act as an adhesive. Clay bricks absorb water, the capacity for water absorption is directly related to the fired density. Traditional mortar also absorbs water. The drying mechanism is typically through evaporation at the surface.

Repairs to the brick masonry would include raking all mortar joints, removal and replacement of deteriorated bricks and repointing using a weak type N (1:2:10) mortar, often referred to as a "Heritage Mix". The replacement bricks can be well fired recycled bricks or new bricks matching the size of the originals and can be purchased directly from several brick manufacturers who specialize in heritage or handmade bricks, most of which are located in the UK.

7.0 Structural

Herold Engineering Limited has conducted a structural stability analysis of the retaining wall under static and dynamic (earthquake) loading. As the scope of work was limited to visual investigation and review of historical information and previous studies, the assessment is based on conservative assumptions about the walls cross sectional dimensions and foundation configuration where field measurements could not be taken due to inaccessible and buried conditions. HEL recommends destructive investigation be undertaken in order to verify the assumptions made regarding the geometry of the wall and the validity of the structural stability analysis results undertaken for the purpose of this report.

As noted in previous sections, the wall is made up of four separate sections, each with different geometric and material properties. The attached drawings S01 and S02 show the cross-sections of each of the four wall types with estimated dimensions for hidden and undocumented elements. The estimated dimensions provided on the figures were used for the stability analysis.

Lateral earth pressures (static and dynamic) used in the analysis are based on common data from other Victoria sites and should be verified by a site specific geotechnical review. The following parameters were used in the stability calculations:

- Static backfill pressures are based on an equivalent fluid pressure = 6.3kN/m2
- Dynamic (seismic) backfill pressures are based on the following equation for a non-rigid wall
- P = 0.375(PGA)*gamma*H2, where
- PGA = peak ground accelerations from NBC 2015 (equivalent to BCBC 2017)
- Gamma = unit weight of soil, assumed to be 20kN/m3
- H = height of the wall
- The bearing capacity of the soil is assumed to be a non-governing factor based on 1988 Thurber Engineering drawings that show inferred depth to bedrock of 1m-2.7m adjacent to the subject wall.

These values were applied to the analysis for all wall section types.

SECTION 1 & SECTION 3

Wall Section 1 and Section 3 are assumed to be of similar construction owing to the fact that they were both originally part of buildings as noted in SECTION 1 of this report; therefore stability analysis results are common to both sections. It is noted that wall section 3 has buttress structures at each end allowing for a measure of horizontal spanning however the spacing of the buttress elements at 12m suggests the wall will behave as a vertically spanning element for most of its length similar to wall section 1.

As shown in the drawings, the primary structural element working to resist lateral earth pressures is the buried stone wall to the east of the tunnel. The outer stone and clay brick masonry wall visible from the parking lot is only subject to the backfill loads beneath the tunnel. The two walls that make up this section were analyzed based on the following assumptions:

- The exposed westerly wall is considered non-rigid (free to rotate) and resists lateral earth pressure loads from backfill beneath the tunnel only.
- The buried easterly wall is subject to full height active lateral earth pressures from retained soil east of the wall under Wharf Street, and a counteractive passive pressure from the backfill beneath the tunnel.
- The buried easterly wall is considered a cantilever free to rotate (laterally unsupported at the top by the sidewalk structure).
- Wall dimensions used for analysis are based on accessible field measurements and estimations from historical photos and anecdotal information.

Based on the assumptions listed, the following table shows the factor of safety against failure for both static and dynamic load cases:

Load Case	Static Condition		Dynamic Condition	
Wall Section	Overturning	Sliding	Overturning	Sliding
Sections 1 and 3	1.2	1.3	0.3	0.5

SECTION 2 & SECTION 4

Wall Sections 2 and 4 are treated the same for the purpose of stability analysis. There is assumed to be no secondary wall to the east of the exposed wall as shown in the attached drawings. Wall sections 2 and 4 were analyzed based on the following assumptions:

- The exposed westerly wall is considered non-rigid (free to rotate) and resists full height active lateral earth pressure loads.
- Wall dimensions used for analysis are based on accessible field measurements and estimations from historical photos and anecdotal information.

Based on the assumptions listed, the following table shows the factor of safety against failure for both static and dynamic load cases:

Load Case	Static Condition		Dynamic Condition	
Wall Section	Overturning	Sliding	Overturning	Sliding
Sections 2 and 4	1.1	1.1	0.3	0.4

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In general, the wall has successfully carried its service loads to date, indicating a Factor of Safety of 1 as a minimum for the current condition under static loads. The calculated performance under seismic loads results in a factor of safety less than 1 which indicates the wall will fail overturning and sliding under a code level seismic event.

SUSPENDED SIDEWALK

The sidewalk on Wharf Street above wall sections 1 and 3 is suspended concrete construction spanning across the tunnel. The concrete slab is approximately 300mm thick and spans North South between steel Wide Flange Beams that bear on the outer exposed wall and the inner buried wall. The concrete slab is in fair condition, the steel beams are showing signs of rust and deterioration. There appears to be no connection between the concrete slab and the retaining wall other than via the steel beams. Further destructive investigation is recommended to review the bearing conditions of the steel beams at the wall to determine if reinforcing of this connection is required.

8.0 Recommendations and Opinion of Probable Costs

It is recommended that the wall at 1112 Wharf Street be repaired to address safety risks due to falling hazards and to mitigate further deterioration of the wall. Removal and repair of loose and failed bricks is considered urgent work for the health and safety of the general public and protection of private property. The extent of urgent repair is summarized as follows:

- Wall Section 1 – 25 loose and failed bricks to be repaired
- Wall section 2 – all brick pavers lodged below concrete curb
- Wall Section 3 – 220 loose and failed bricks to be repaired
- Wall Section 4 – Upper portion of wall, significant risk of mortar and packer and filler pieces falling.

It is also recommended that detailed destructive investigations be undertaken to verify assumptions made in the structural stability analysis and that seismic upgrades be undertaken to prevent wall failure during an earthquake.

The following recommendations are for remedial work to be completed in order to help stabilize and conserve the existing wall while retaining its Heritage Characteristics. It is our understanding that the wall is listed on the Heritage Registry and therefore any conservation or restoration work will have to be in keeping with the requirements of conserving its heritage features within the constraints of also minimizing the falling hazards.

Remediation and repair work includes the following:

- Cleaning and removal of organic debris

- Repointing of the mortar joints.
- Replacing decayed clay brick.
- Consideration for scaling and sealing of Sandstone.
- Shotcreting of cast in place concrete wall.
- Addition of protective cast in place caps.

Repointing/Mortar repairs will be durable and have a minimum expected service life of 30 years.

Seismic stability upgrade work includes the following:

- constructing concrete buttress walls within the tunnel area at 4m intervals
- installing soil anchors at 4m intervals along the length of the wall
- adding steel beams to the inside face of the tunnel to strong-back the masonry facing walls

The attached drawing S03 shows sections of the seismic upgrade concepts for Sections 1 and 3, and for Sections 2 and 4. Some dismantling and rebuilding of the heritage fabric will be required for anchor installation, however the intent is to conceal the anchor heads and maintain the existing aesthetic.

The above seismic upgrade schemes were developed based on the limited information available from existing documents and a visual assessment. To refine and validate the proposed upgrade work it is recommended that a detailed destructive testing plan be undertaken. Recommended destructive investigation work is as follows:

- Full depth horizontal coring through each of the four wall sections with a minimum of two cores at each section to determine wall material and dimensional properties.
- Vertical coring through the inside tunnel wall to determine material properties and depths.
- Localized excavation at the toe of the wall sections to determine foundation conditions.
- Removal of brick work at sidewalk slab beam support to determine bearing conditions.
- Localized repair at core hole locations with heritage conservation methodology.

OPINION OF PROBABLE COSTS

The following table provides estimated costs for the investigation, repair and seismic upgrade work described above.

Work Item	Quantity	Unit	Unit Rate	Total Amount ($)
TASK 1 - DESTRUCTIVE INVESTIGATION				
Horizontal Core test holes	8	ea.	$2,700	$21,600
Vertical Core test holes	1	ea.	$5,000	$5,000
Foundation excavation	3	ea.	$1,000	$3,000
			Subtotal	$29,600
Contingencies and Design				
			Contingency (30%)	$8,880
Review and Analysis of test cores	1	ea.	$3,000	$3,000
Verify Seismic Design Scheme	1	ea.	$2,500	$2,500
Report	1	ea.	$2,500	$2,500
			Task 1 Total	**$46,480**
TASK 2 - WALL REPAIR AND REMEDIATION				
General Requirements				
Mobilization/Demobilization	1	ea.	$15,000	$15,000
General Conditions	1	ea.	$25,000	$25,000
Section 1				
Repairs to Granite and Granitoid wall areas	112	m2	$385	$43,120
Repairs to Sandstone wall areas	45	m2	$450	$20,250
Repairs to Brickwork wall areas	50	m2	$430	$21,500
Section 2				
Repairs to Cast-in-place concrete wall areas	50	m2	$390	$19,500
Section 3				
Repairs to Brickwork wall areas	50	m2	$430	$21,500
Section 4				
Repairs to Granite and Granitoid wall areas	215	m2	$385	$82,775
			Subtotal	$248,645
Contingencies and Design				
			Contingency (30%)	$74,594
			Engineering Fees	$35,000
			Task 2 Total	**$358,239**

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TASK 3 - STRUCTURAL SEISMIC UPGRADES				
General Requirements				
Mobilization/Demobilization	1	ea.	$20,000	$20,000
General Conditions	1	ea.	$30,000	$30,000
Sections 1 & 3				
Sidewalk demolition and reinstatement	36	m2	$1,200	$43,200
Formwork for new walls	110	m2	$150	$16,500
Concrete in new walls	18	m3	$650	$11,700
Reinforcing in new walls	2000	kg	$3.00	$6,000
Steel beams anchored to masonry facing walls	95	lin. m	$400	$38,000
Soil anchors (43mm dia.)	10	ea.	$12,000	$120,000
Sections 2 & 4				
Rock/Soil Anchors (36mm dia.)	24	ea.	$10,000	$240,000
			Subtotal	$525,400
Contingencies and Design				
			Contingency (30%)	$157,620
			Engineering Fees	$50,000
			Task 3 Total	**$733,020**
TOTALS				
			Total for Tasks 1-3	$1,137,739
GOODS & SERVICE TAX				
			GST (5%)	$56,887
TOTAL				
			TOTAL	$1,194,625

We trust the information contained within this report satisfies your current requirements. Should you have any comments, questions or concerns, please do not hesitate to contact the undersigned.

Yours truly,

HEROLD ENGINEERING LIMITED

Prepared By:

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Senior Building Envelope Specialist

Kate Ulmer, P.Eng.
Principal, Senior Structural Engineer

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Appendix A - Drawings

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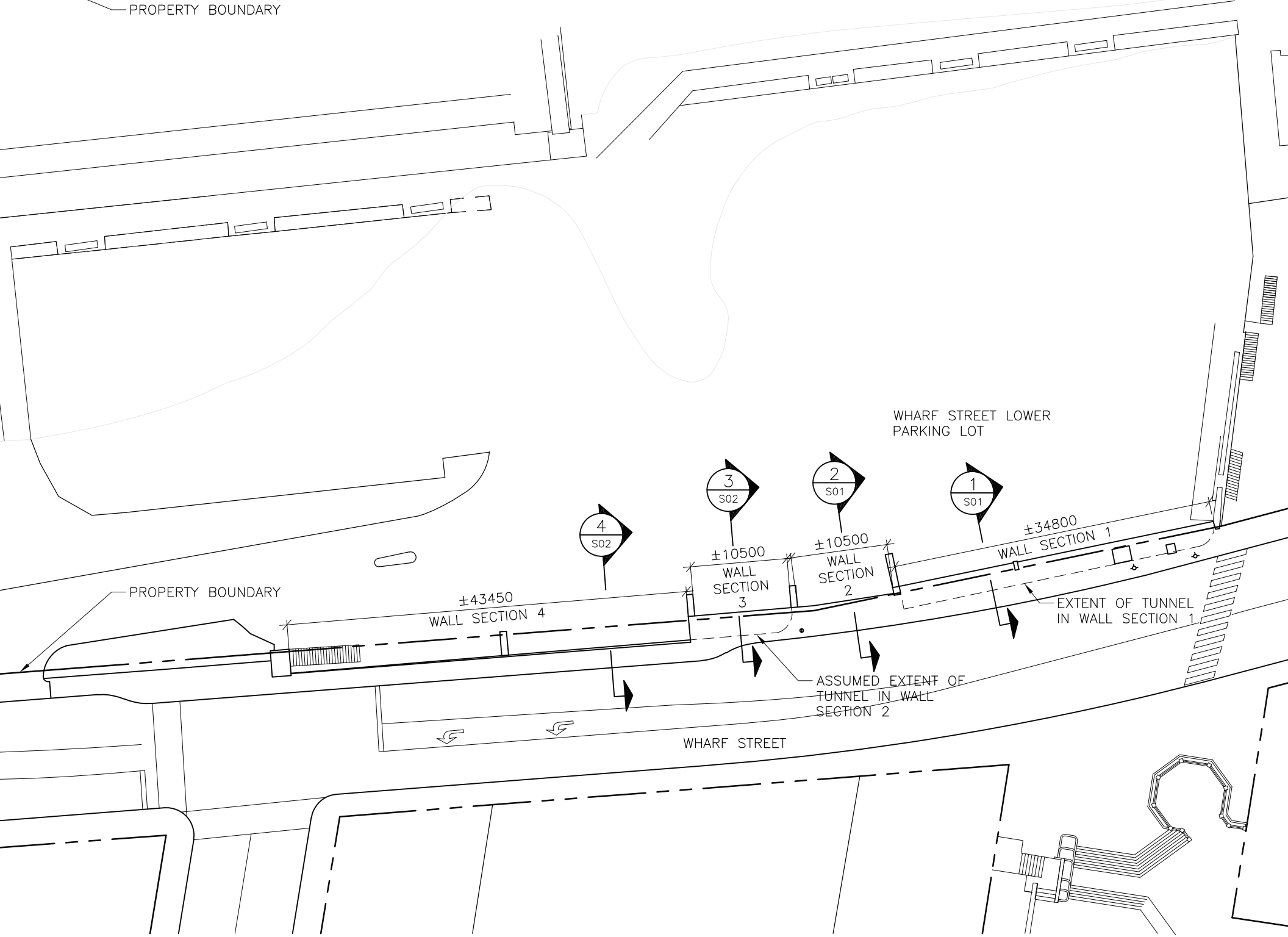
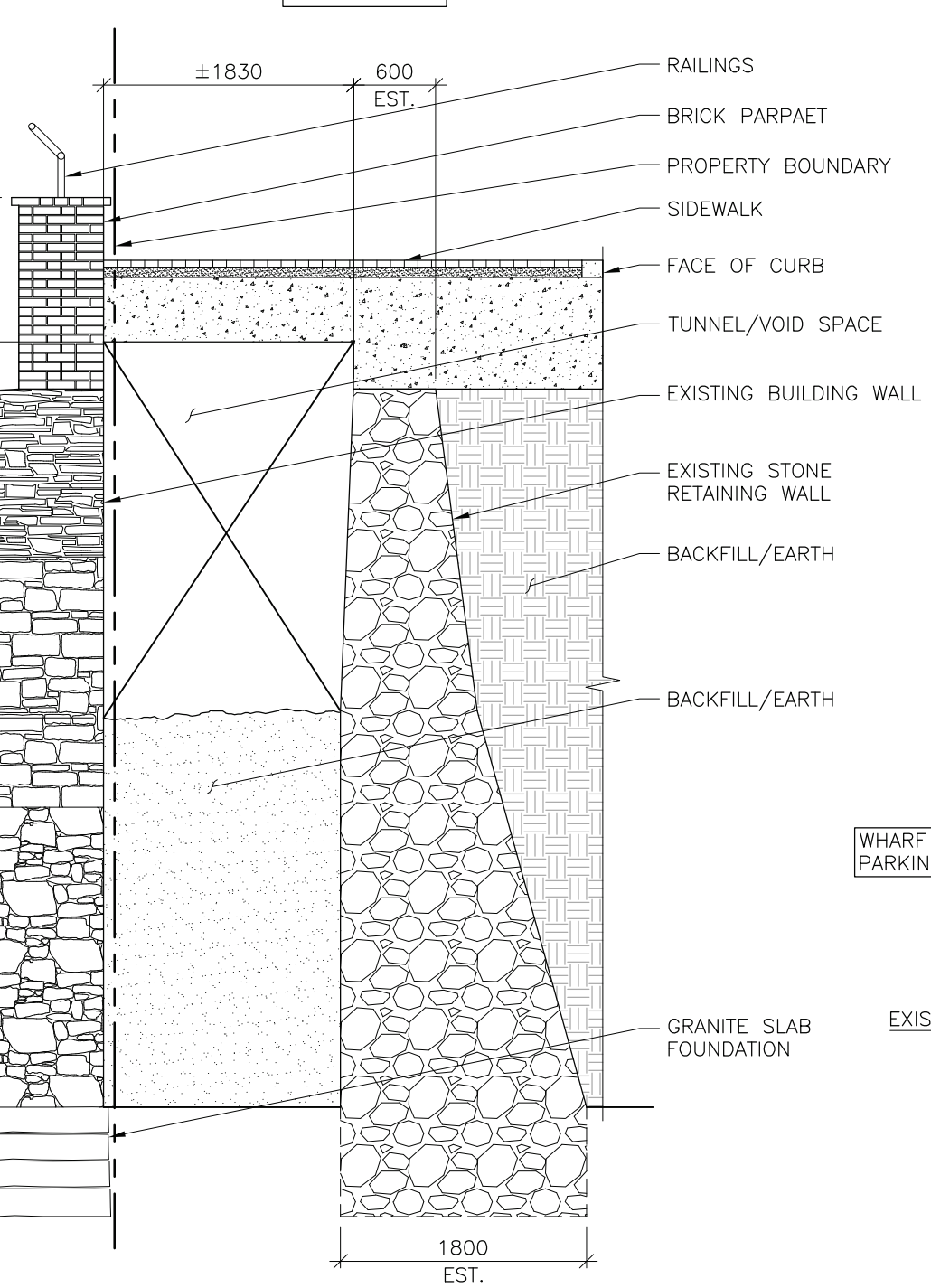
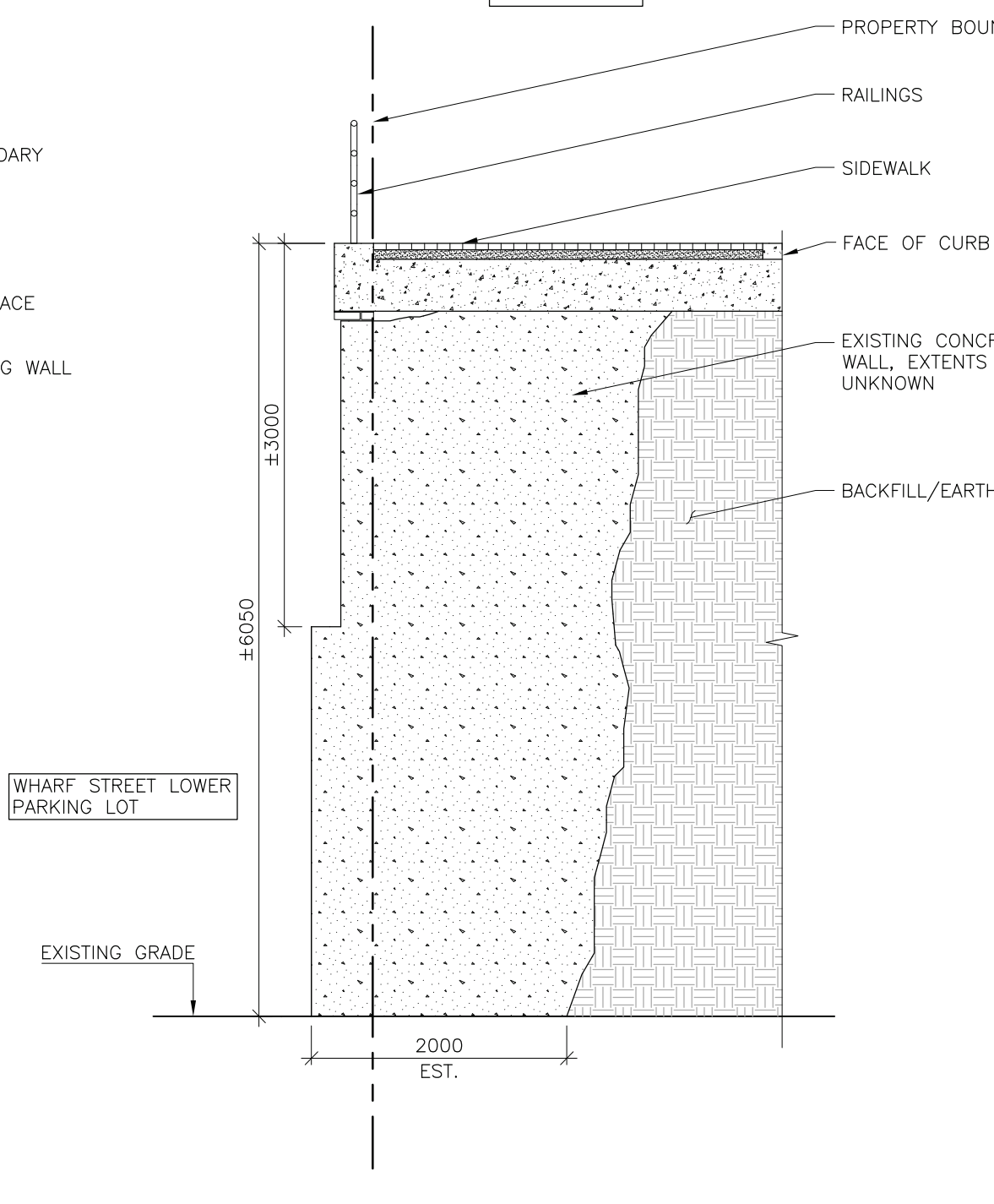

PROPERTY BOUNDARY
WHARF STREET LOWER
PARKING LOT
4
S02
3
S02
2
S01
1
S01
±43450
WALL SECTION 4
±10500
WALL
SECTION
3
±10500
WALL
SECTION
2
±34800
WALL SECTION 1
PROPERTY BOUNDARY
EXTENT OF TUNNEL
IN WALL SECTION 1
ASSUMED EXTENT OF
TUNNEL IN WALL
SECTION 2
WHARF STREET



1 S00 WALL SECTION 1

1:50

EXISTING CONDITION

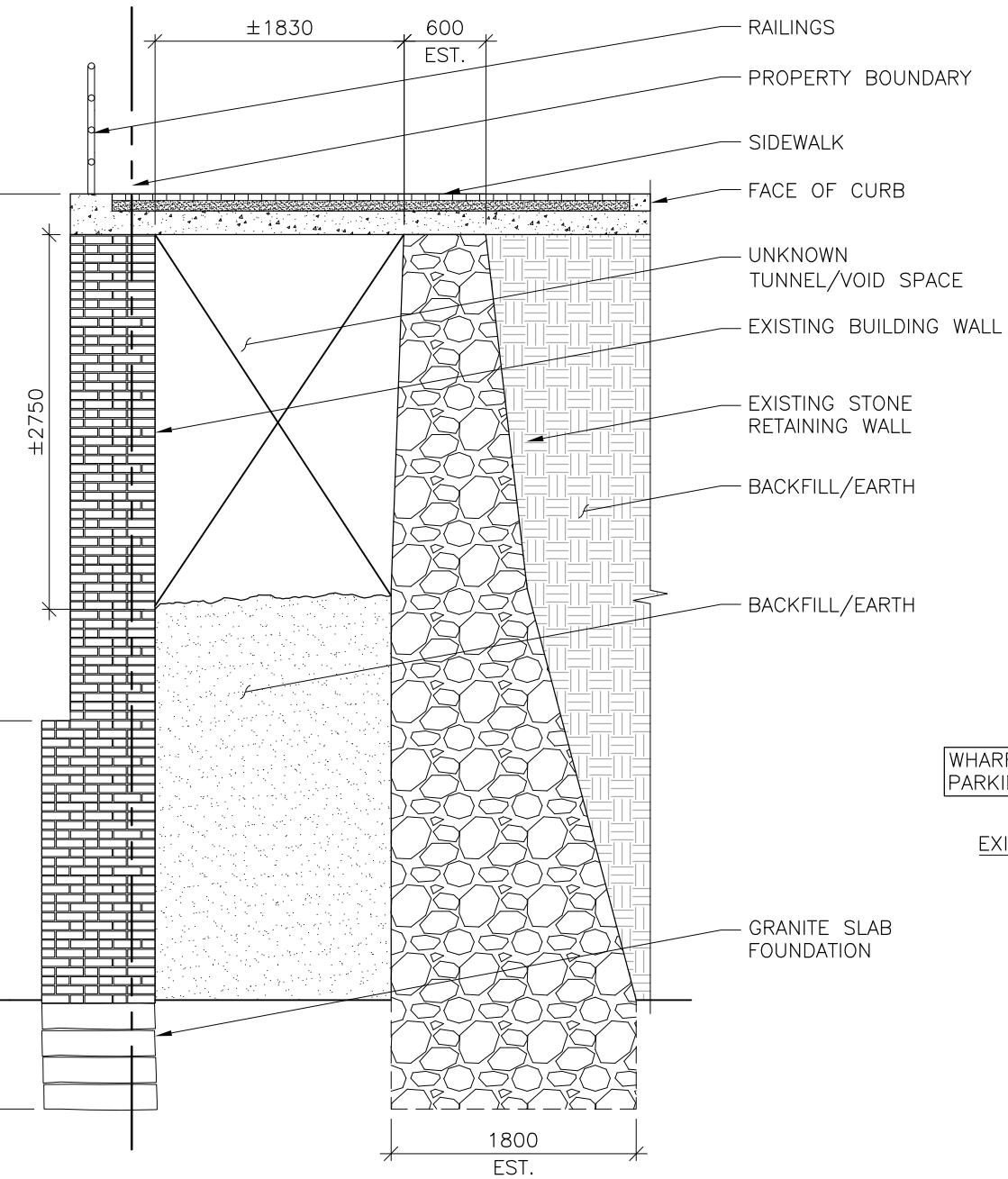


2 S00 WALL SECTION 2

1:50

EXISTING CONDITION

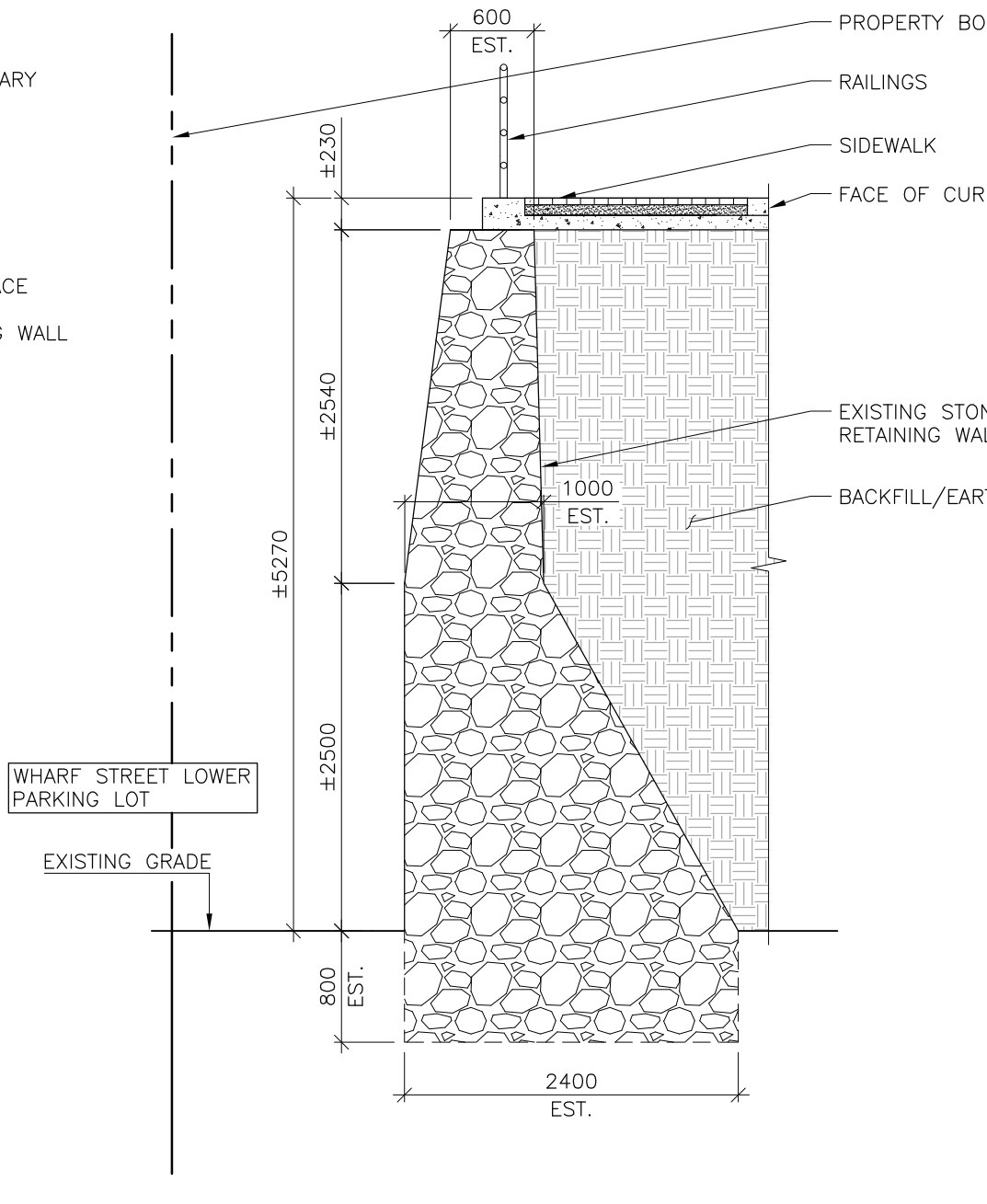
NOTE: DIMENSIONS ARE ESTIMA



3 S00 WALL SECTION 3

1:50

EXISTING CONDITION

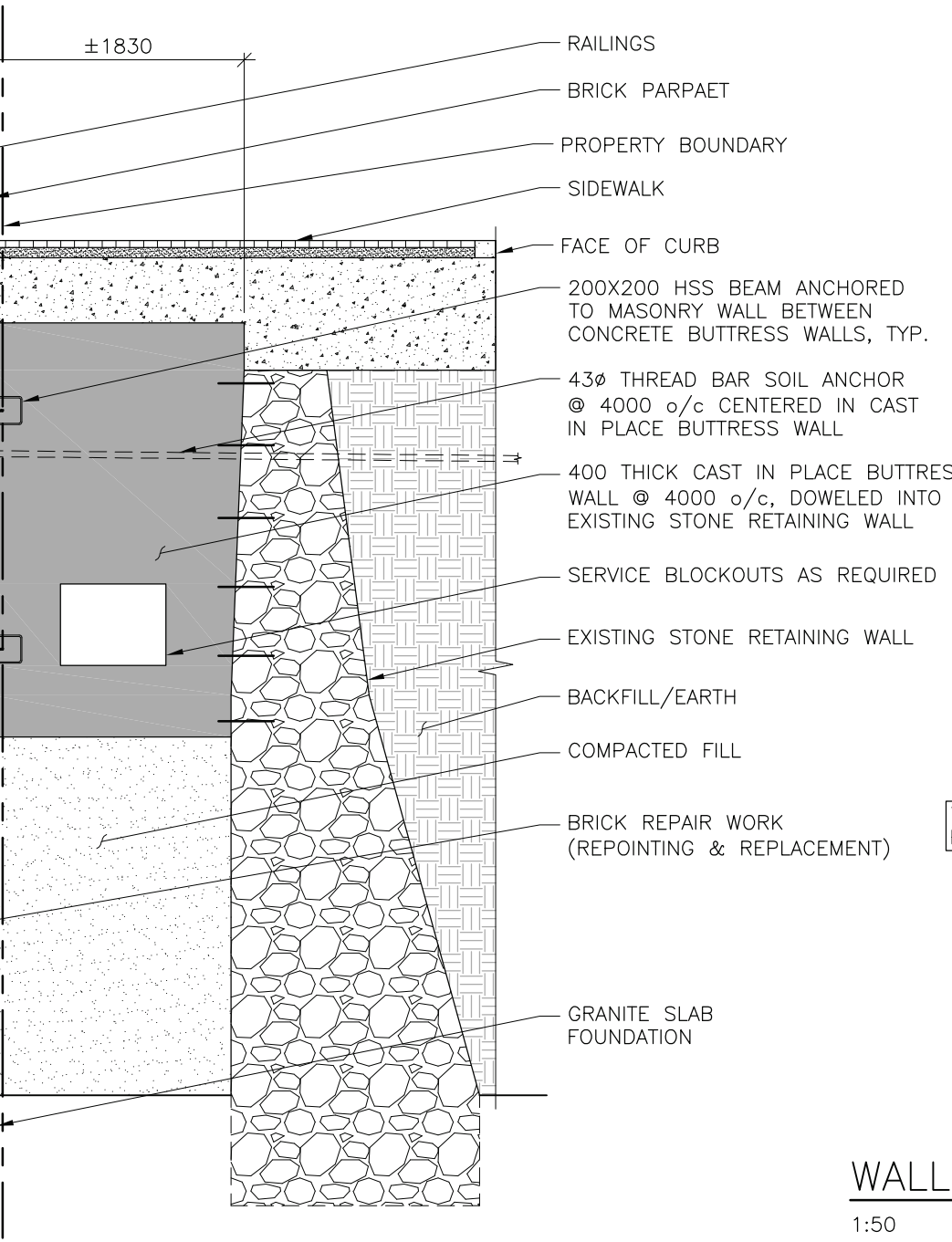


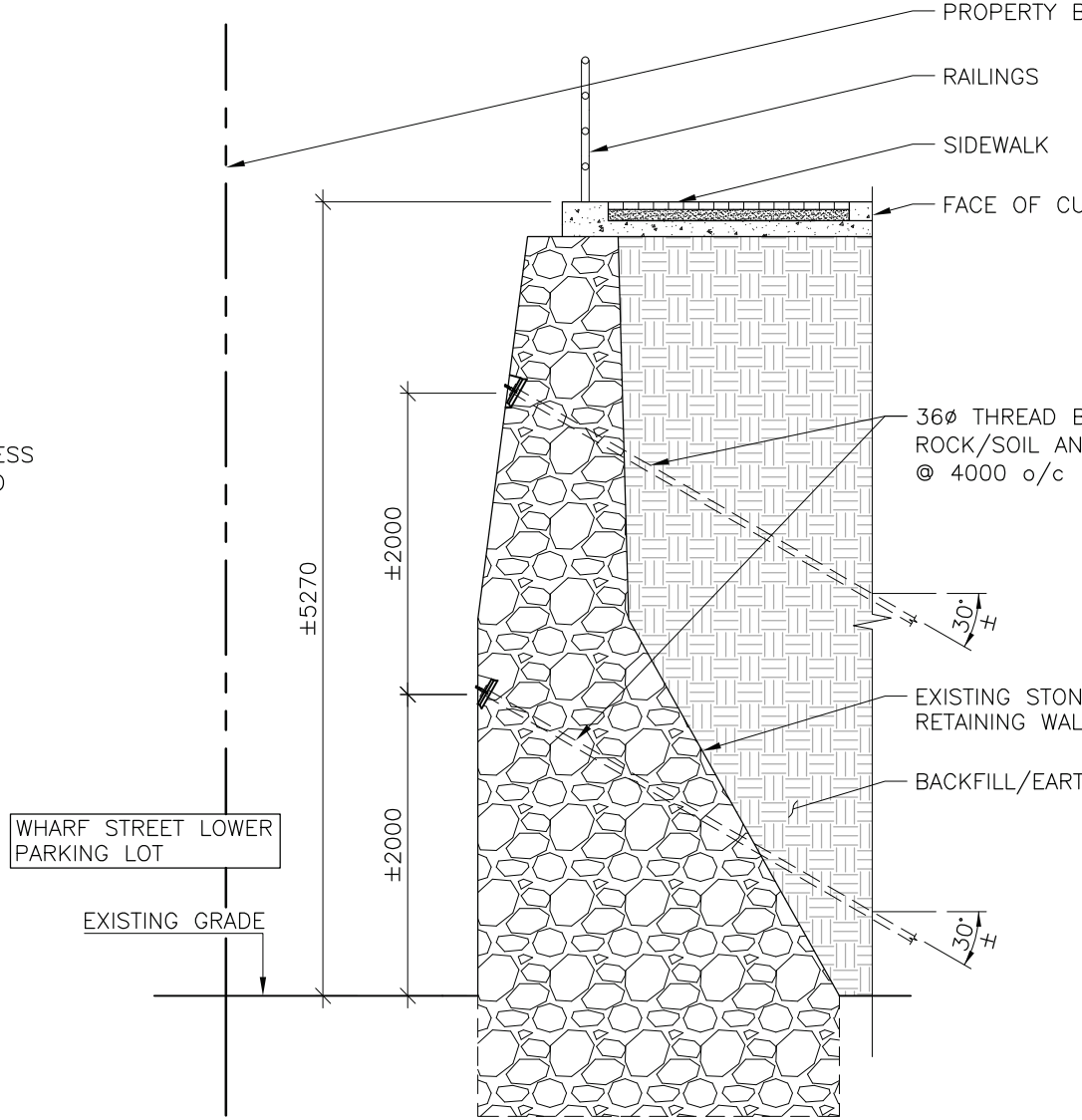
4 S00 WALL SECTION 4

1:50

EXISTING CONDITION

NOTE: DIMENSIONS ARE ESTIMA





WALL SECTION 4 – PROPOSED STRUCTURAL UPGR

1:50

1 & 3 – PROPOSED STRUCTURAL UPGRADE

NOTE: DIMENSIONS ARE ESTIMAT