Geotechnical Challenges in Development of New Iona Island Wastewater Treatment Plant

Aran Thurairajah, Sadana Gamage, Lalinda Weerasekara, Viji Fernando, and Trevor Fitzell

WSP Canada Inc, Vancouver, BC.

Daniel LeBlond and Carol Yan.

Metro Vancouver, BC.

ABSTRACT Iona Island Wastewater Treatment Plant (IIWWTP), located north of Sea Island (YVR Airport) just south of North Arm of the Fraser River near the northern margin of the Fraser River delta. The existing IIWWTP is currently serving about 750,000 residents in the Vancouver Sewerage Area and expected to serve 950,000 residents by the year 2051. The existing facility is vulnerable to strong seismic shaking and sea level rise. it is one of the last wastewater treatment plants in west coast of North America that provides only primary wastewater treatment. However, the legislation requires the wastewater treatment plants to be upgraded to minimum secondary level of treatment no later than end of year 2030. Metro Vancouver is planning to build a new plant to provide tertiary level of treatment. The new IIWWTP would be a post-disaster facility and needs to be functional following the 2,475-year design ground motions consistent with the 2020 National Building Code of Canada. This paper presents the geotechnical challenges associated with the new plant development and the challenges associated with potential remedial measures that are being contemplated.

Background

The Iona Island Wastewater Treatment Plant (IIWWTP), located north of Sea Island (YVR Airport) just south of the North Arm of the Fraser River near the northern margin of the Fraser River delta. The IIWWTP is currently serving about 750,000 residents in the Vancouver Sewerage Area and expected to serve 950,000 residents by the year 2051. The existing wastewater treatment facility is vulnerable to strong seismic shaking and flooding due to sea level rise. The original facility was built in 1963, and it is one of the last wastewater treatment plants in west coast of North America that provides only primary wastewater treatment. This primary level treated water is currently being discharged to Salish Sea. However, the legislation requires the wastewater treatment plants to be upgraded to minimum secondary level of treatment no later than end of year 2030. Metro Vancouver is planning to build a new plant to provide tertiary level of treatment to protect water quality and marine environment, and to meet the post-disaster objectives under both the 2,475-year ground motions consistent with the 2020 National Building Code of Canada (2020 NBCC) and potential flooding due to future sea level rise. The following Figure 1 shows the location of the proposed new plant area east of existing wastewater treatment facilities.

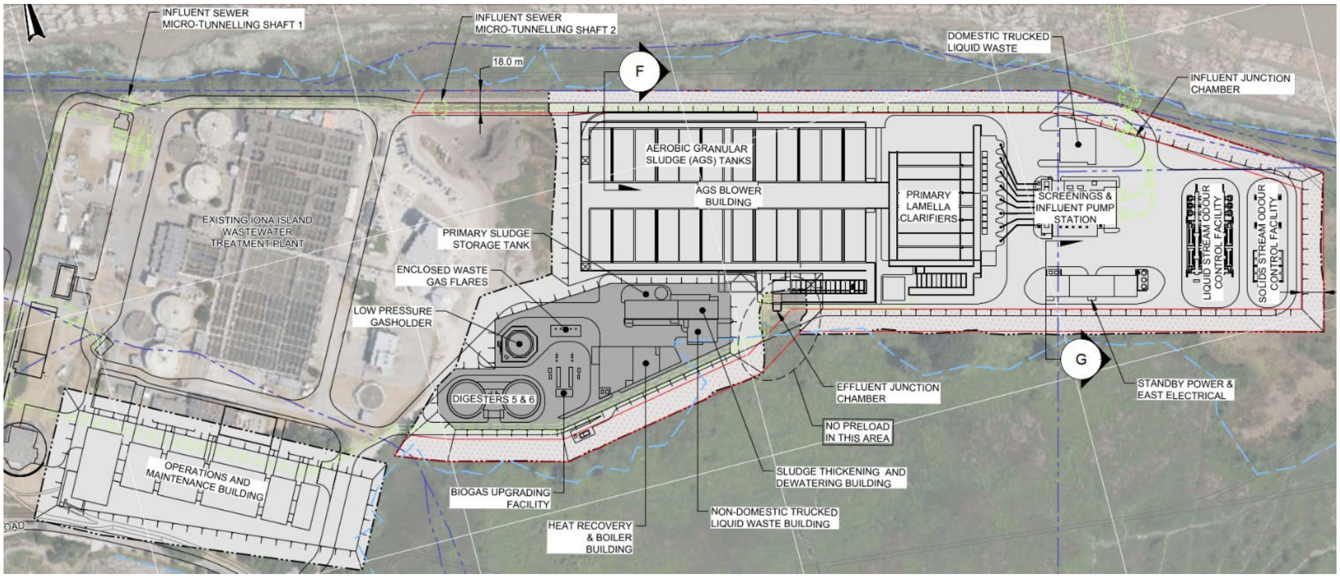
Fig 1. Proposed IIWWT Plant Location (Picture Courtesy – Google Earth

This paper summarizes the geotechnical challenges associated with the new plant development from both design and construction perspectives.

Proposed Development

The proposed development layout, at a conceptual level, is presented in Figure 2. The foundation elevations vary from El. +6.4 m to El. -9.6 m geodetic. The final site grade will be raised to El. +6.4 m for flood proofing and against the future sea level rise.

Fig 2. Proposed IIWWT Plant Development Design at Conceptual Level



The existing site grade is about El. +3.0 m and before construction, the site would be preloaded up to El. +20 m for a period to reduce post-construction settlements. It is estimated that the imported preload material volume could be up to 2.1 million cubic meters.

As part of the ground improvement work, the liquefiable ground conditions would be improved using vibro-replacement stone column technique over about 100,000 square meter area and about an average 12 m deep. A 10 m wide and 30 m deep Cutter Soil Mix (CSM) wall is also being considered to install along the perimeter of the site to limit the lateral spreading under the design ground motions due to cyclic softening of the marine clay underlying the site.

The geotechnical requirements for this project become significant leading to the foundation costs alone to be in the order of one billion dollars. This project is ranked as number 8th most expensive project in Canada based on the total project value of 10 billion dollars with expected substantial completion date in 2035. Given the overall costs and the geotechnical complexity of the project, the project is delivered through a Stage Gate Framework (SGF) with early works packages to reduce the overall project schedule.

The ground improvements (i.e., stone columns, CSM, and preloading) for the new plant are part of the early works and field trials for the stone columns and CSM are planned to be carried out to optimize the design of ground improvement program.

Site Stratigraphy and Geological Challenges

The Fraser Delta is a young geomorphic feature, having formed in the past 10,000 to 11,000 years as the Fraser River advanced its delta and floodplain from a gap in the Pleistocene uplands near the present-day New Westminster across a glacially sculpted, undulating Pleistocene surface. The river first flowed South into Boundary Bay and then west into the Strait of Georgia (northern Salish Sea). Sediments that comprise the delta are clay, silt, and sand and range in thickness from about 10 m to greater than 200 m (Clague et al. 1988).

North of the wastewater treatment plant, the deltaic sediments are thin and lap onto the southward-sloping Pleistocene Point Grey upland. Figure 3 is a north-south geological section that accompanies the Armstrong/Hicock map 1486A (1979), featuring a south-dipping sequence of outwash sands and gravels (Quadra Sand) deposited by a lobe of the Cordilleran Ice. The Iona Island is located south of this geological cross section as such relatively shallower depth to Pleistocene deposits was anticipated.

Fig 3. Geological Section across Point Grey from 16th Avenue to Marine Drive (North Vancouver)

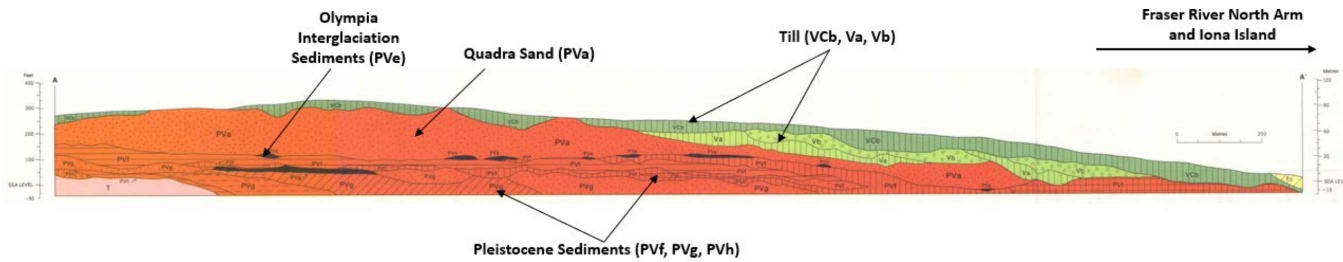


Fig 4. A Typical Soil Stratigraphic Profile – North South Direction

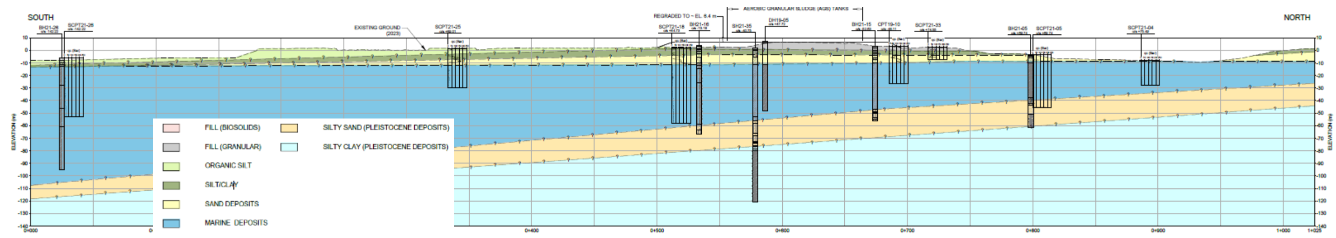
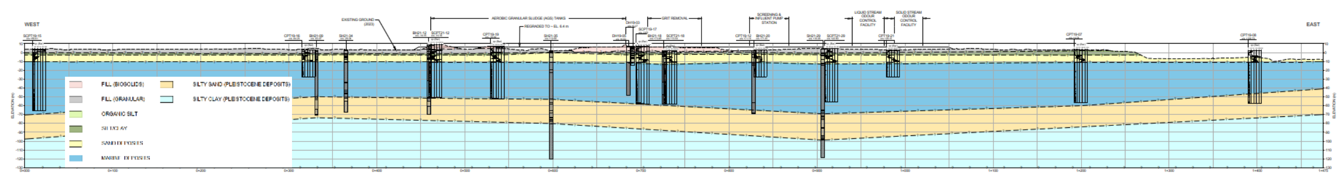


Fig 5. A Typical Soil Stratigraphic Profile – East West Direction



A geotechnical field investigation consisting of 21 mud-rotary holes with depths varying from 40 m to 80 m, four sonic holes with depths varying from 70 m to 170 m, and 28 seismic cone penetration tests with depths varying from 45 m to 120 m was carried out at the proposed plant area, Fraser River North Arm, and McDonald Slough. Multiple nested vibrating wire piezometers were installed in two of the sonic holes. Downhole shear wave velocity measurements up to 120 m depth were also collected at three locations.

In addition to intrusive geotechnical field investigation described above, Geophysics survey was conducted to collect shear wave velocity measurements using Micrometer Array Measurement technique across the site.

Regular index tests and advanced testing such as consolidation tests, cyclic simple shear tests, and monotonic simple shear tests were conducted on select samples. Advanced testing were generally focused on the marine clay underlying the site to characterize its settlement, strength, and cyclic behaviour.

The subsurface conditions at the proposed plant location generally consist of overbank sediments underlying by potentially liquefiable Fraser River sand deposits with varying fines content followed by compressible marine deposits which in turn underlain by Pleistocene deposits. A Typical soil stratigraphy in the north south direction and east west directions are presented in Figure 4 and Figure 5 respectively.

There are artesian conditions present within the marine deposits resulting in upward flow and potential leaching of the marine deposits.

The consistency of Fraser River Sand deposit could be subdivided into two units based on the fines content measurements and interpretations. The Upper Fraser River sand (i.e., from El. -3.0 m to El. -7.5 m) consist average fines content of 15% in general and 35% at a localized location. The lower Fraser River sand (i.e., below El. -7.5 m) consist average fines content of about 5%.

The following are some of the key findings identified during the geotechnical field investigation and followed up laboratory testing and analyses.

- Depth to Pleistocene deposits is shallower (in the range of 40 m to 65 m) within the proposed plant area compared to the existing plant area, where it is in excess of 130 m.
- Fraser River sand and granular fill deposits underlying the ground water are potentially liquefiable under the design ground motions.

- Artesian conditions are recorded within the Marine Clay underlying the Fraser River Sand.
- Top part of the Marine Clay would experience cyclic softening during seismic shaking representing design earthquake level.
- The Marine Clay is also compressible and subject to long term consolidation settlements following placement of site grading fill and structural loads.

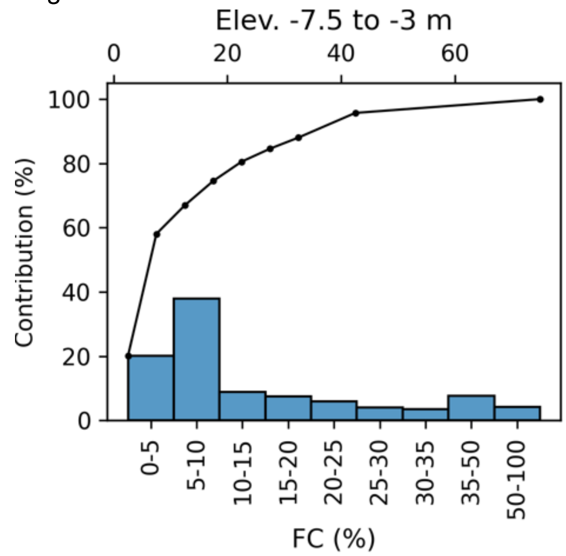
In addition to the above-mentioned key findings, it was recorded that the existing plant has settled about 900 mm from the time of construction and still settling at a rate of about 10 mm/year although the existing plant site was preloaded for about 2 years prior to construction. The proximity of the proposed IIWWTP to the waterfront on both sides along with the compressible and liquefiable soils has increased the geotechnical challenges in terms of designing the new plant to meet the post-disaster performance objectives.

Proposed Geotechnical Remediations and Challenges

Project definition phase of the new plant has been completed and the indicative design indicates that vibro-replacement stone columns to improve the sand deposits within the plant footprint and a seismic barrier comprising CSM along the perimeter of the site to limit the lateral spreading due to cyclic softening of the marine deposit are required to upgrade the site to meet the post-disaster performance objectives. In addition, the treatment plant facilities may need to be supported on piles to meet the post-disaster performance objectives.

Based on the laboratory measurements and interpretation of apparent fines content at the site, generally the upper Fraser River Sand up to depth El. -7.5 m consist of an average 15% fines. The coefficient of uniformity is in the range of 2.1. The target specification for the 15% fines content to meet the seismic demand under the design ground motions is predicted to be higher than the level of densification that may be achieved in these soils with the stone column technique. It is estimated that the stone columns would likely increase the densification by a factor of two (2) with respect to the pre-improved CPT tip resistance and therefore, additional effort may be required to meet the target specifications and the facilities need to be designed with potential liquefaction of the soils with the ground improvement. It was also identified that the fines content averaged to 35% in one part of the plant area and similar challenges are expected in achieving target specifications within that area as well. The following Figure 6 shows the fines content variations of the soils with average 15% fines content, where more than 80% of samples contributed to less than 15% fines.

Fig 6. Variation of Fines Content for soil layer with average 15% fines



The upper part of the marine clay is also subject to cyclic softening under the design ground motions resulting in lateral spreading of the site and the CSM wall is being considered to limit the lateral spreading. To prevent rotation, the CSM panels is required to be keyed into deeper marine clay that not subject to cyclic softening. However, installing the CSM panels to such deeper depths is also challenging due to equipment limitations.

Compared to the existing plant area, the proposed plant area is narrow in footprint, and the buildings are almost approaching the property boundaries. Designing of preloading near the property boundary is challenging and requires near vertical facing.

Field trials are being planned as part of the preliminary design to develop the ground improvement plan considering the seismic demand vs. the practical limits of the ground improvement techniques to meet the seismic performance objectives. In this regard, spacing and installation sequence of the stone columns including primary and secondary columns would be evaluated. With respect to the CSM, strength and cement content requirements would be evaluated to optimize the mix design.

Key Challenges and Remarks

The following are some of the key challenges identified in development of new Iona Island Wastewater Treatment Plant

- Amount of preloading material required to reduce the post-construction settlement is excessive to access. This may require sourcing of multiple suppliers who can supply such an excessive amount.
- It is impossible to preload the entire site at a same time due to physical limitations and existing site conflicts. Therefore, it is important to properly plan the construction staging to recycle the preloading material within the site.
- Due to proximity of future buildings at the project boundary, it is required to maintain near vertical facing for the preloading. Additional analysis is underway in determining suitable facing including Mechanically Stabilized Earth retaining facing.
- Due to higher seismic demand compared to the level of ground improvement that could be achieved in the field within the upper part of the Fraser River Sand (up to El. -7.5 m depth), it is expected that additional ground improvement measures such as secondary columns, wick drains, etc. are required to meet the target specifications.
- Due to cyclic softening of the upper Marine Clays, the CSM panels may require key in into the deeper Marine Clays that are not subject susceptible to cyclic softening. This may lead to equipment limitations for the ground improvement program.
- Field trails are planned to be carried out as part of the early works to reduce uncertainties associated with ground improvement during production phase. However, use of different contractors for the field trials and production phase could increase the uncertainties.

References

Armstrong, J.E. and Hicock, S.R. 1979. Surficial Geology, Vancouver British Columbia, Geological Survey of Canada ‘A’ Series Map 1486A, 1Sheet.

Clague, J.J., Luternauer, J.L., Monahan, P.A., Edwardson, K.A., Dallimore, S.R., and Hunter, J.A. 1998. Quaternary Stratigraphy and Evolution of the Fraser Delta. In Geology and Natural Hazards of the Fraser Delta, British Columbia. Edited by Clague, J.J., Luternauer, J.L., and Mosher, D.C. Geological Survey of Canada Bulletin 525, pp. 57-90.