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Gudangaay Tlaats'gaa Naay Tsunami Tower Design And Construction

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ABSTRACT

As part of the upgrade of the Gudangaay Tlaats'gaa Naay High School in Masset on Haida Gwaii Canada's first Tsunami evacuation tower was designed and constructed. The tower provides an escape route for the school students and staff in the event of a tsunami. The previous evacuation method involved a lengthy journey though the tsunami prone zone to higher ground and the time to evacuate to higher ground is often greater than the expected warning time for oncoming tsunamis. While Canada has had more deaths due to tsunami's than from structural failures in earthquakes this the first tsunami evacuation tower in Canada. The tower must be designed for two loads, it must be capable of resisting earthquakes and wind loads without significant damage and must then be capable of resisting the loads from tsunami water and debris flow. The design for these two separate loads is well established with good refences for both loads.

Haida Gwaii is a very active seismic area in the 1949 Magnitude 8.0 event occurred in Haida Gwaii that remains the largest recorded earthquake in Canada. While the 1949 earthquake created only a 600 mm high tsunami several models predict that the town of Masset will be completely inundated by a tsunami.

To mitigate the risk to life from the tsunami's a steel moment frame was designed for the tower lateral system providing minimal obstruction for water and debris flow. Haida Gwaii is a remote construction location and the design needed to reflect this by having a steel frame that could be erected with minimal site welding. Durability in this location, exposed to frequent high winds near ocean water, was also a consideration during the design and the steel frame is galvanized to prevent corrosion. The tower forms the dual purpose of acting as a tsunami evacuation platform and providing cover for a basketball court.

The construction of the tower started in 2022 with foundation construction and erection of steel members for the tower occurring in April and May 2023 with the tower opening for the start of school year in September 2023.

Keywords: Tsunami, Tsunami Evacuation Tower, Haida Gwaii, Seismic Design, Remote Construction.

INTRODUCTION AND EARTHQUAKE AND TSUNAMI HAZARD

The Gudangaay Tlaats'gaa Naay High School is in Masset on the northern coast of Haida Gwaii. The school is subject to two risks to life safety, one from earthquake shaking and one from tsunami inundation. The safe zone for Masset is at an elevation of 10m. All of Masset, including the school, is at an elevation of 6m or less. Masset is on a peninsula and the evacuation route to an area where the elevation is above 10m requires a drive of 12 kM from the school to the designated place of refuge which is a gravel pit. Figure 1 shows the Village of Masset Evacuation Map with the school site added. The expected zone of inundation is large and with a permanent population of Masset of approximately 800 people this makes evacuation in a timely manner challenging. Escape from the tsunami requires realizing there is a risk of tsunami, getting in vehicles and then driving to the safe location resulting in evacuation times often run to over 40 minutes. Several of the tsunami scenarios for Masset have the wave arriving in less than 10 minutes of the earthquake occurring.

The use of tsunami evacuation towers is well established particularly in Japan where lives were saved in the 2011 Tohoku earthquake generated tsunami using vertical evacuation facilities. Since the 2011 several new towers have been constructed in the Sundai area as well as other areas of Japan where rapid evacuation to high ground is not possible. Haida Gwaii is a seismically active region with a record of significant seismic events, the largest recorded Canadian earthquake is the 1949 magnitude 8.0 event that occurred off Haida Gwaii. Since 2012 there have been two earthquakes in the region that were magnitude 7.5 and greater. With the established risk of tsunami, Masset has a tsunami warning system and well-established protocols for evacuation.

The school is located about 0.5 kM from the Masset Inlet which has the potential to funnel a tsunami in the same way that the Alberni Inlet funneled the Port Alberni Tsunami in 1964. Alternatively, to the north of the school is 2.7 km of low-lying ground followed by an open ocean with Alaska and its seismically active zones to the north. In the Sundai tsunami of 2011, the wave reached 10 km inland and in the Sumatra earthquake of 2004 the wave reached 4 km inland.

The site of the school contains both the high school and elementary schools with over 70 students in grade 8 to 12 and a staff of 20. Seismic upgrading of the school was identified as a priority in the BC Schools assessment program and as part of that upgrading there was a need identified to provide a life safety evacuation from the tsunami zone with an escape time matching the expected warning time. A tsunami tower was felt to provide the best solution to the life safety as the solution did not rely on providing transportation out of the tsunami zone. To obtain budget estimates and funding a preliminary design of the tower was developed by Bush, Bohlman & Partners and priced in 2019. This design was then taken through working drawings and constructed with expected opening in September 2023. When complete the tower will the first tsunami evacuation tower in Canada.

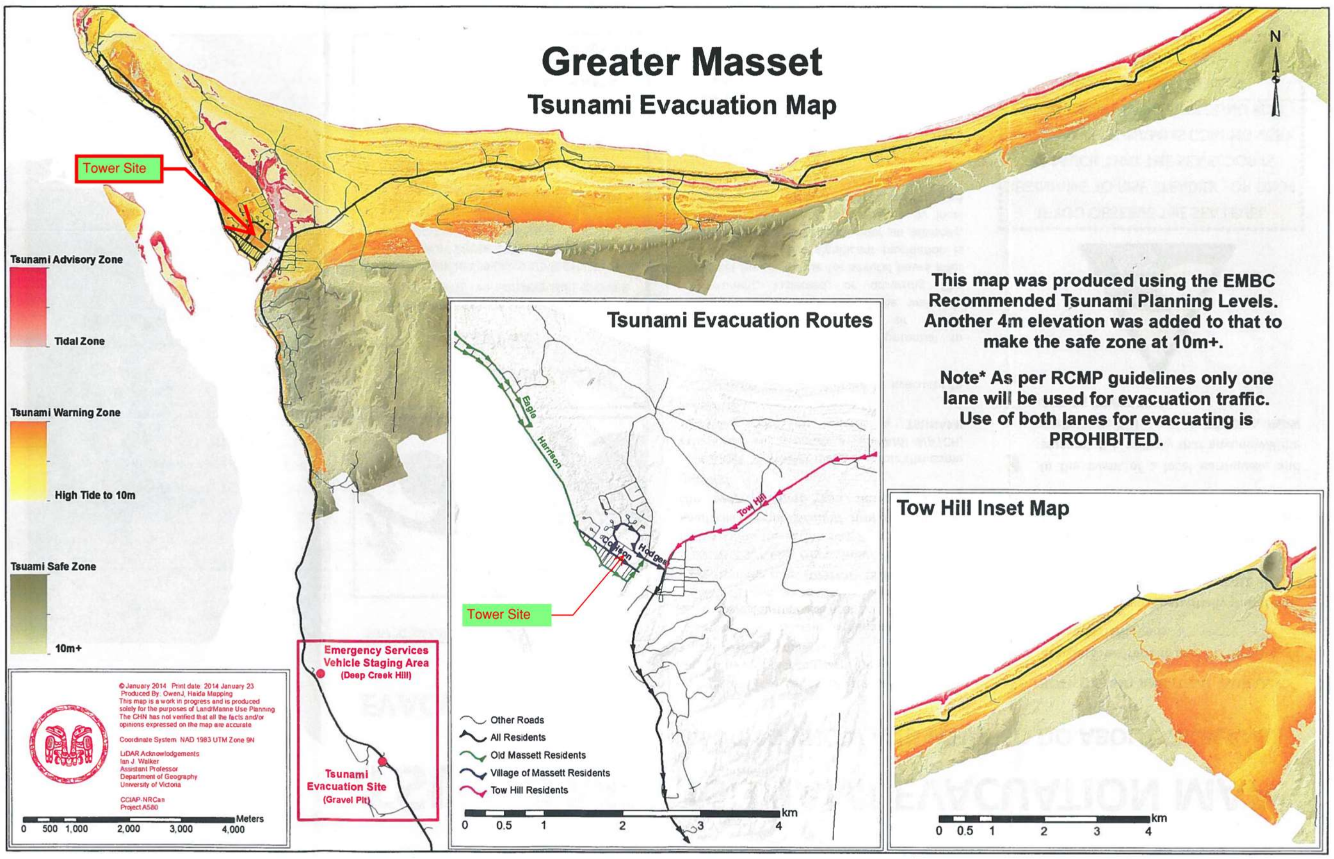

Figure 1. Tsunami Evacuation Map with site added from Village of Masset website. [1]

Past Tsunami's in Canada

Canada has been affected by several tsunami's including those that have caused loss of life:

- Following the magnitude 9 subduction event in January 1700 off the west coast of Vancouver Island there is well established oral history of several first nations villages being washed away by the tsunami generated by the event. The number of people killed in this is not established, however complete villages were destroyed by the waves.
- In November 1929 a seismic event of magnitude 7.3 in the grand banks of Newfoundland caused an underwater landslide which producing a tsunami that affected several communities in the Burin Peninsula with waves that destroyed buildings, in some cases washing them out to sea and killed 28 people.
- In 1964 following the Great Alaskan Good Friday earthquake of Magnitude 9.2 event several tsunami waves were generated from both the faulting action and underwater landslides generated by the earthquake. The tsunami caused

deaths in Oregon and California, in Port Alberni the tsunami travelled up the Alberni inlet and damage 375 houses, no deaths occurred in Port Alberni as the tsunami affected zone had been evacuated.

- In 1949 there was a magnitude 8.1 event near Haida Gwaii that resulted in a tsunami that was 600mm high in Masset.

Canada has been very lucky with structural damage and death due to past earthquakes and the recorded death toll from past earthquakes in Canada is zero. [2] Therefore the Canadian death toll from earthquake caused structural failures has been much lower than the number of people killed in Canada from Tsunami's.

Given the risk of tsunamis on both east and west coasts of Canada there is a need for more tsunami evacuation towers especially in vulnerable low-lying areas where there is little other opportunity for escape from a seismic event.

DESIGN STAGE

Preliminary Design

The first stage of the design of the Tsunami tower was to prepare a schematic design of the tower so that it could be priced and included in upgrading budgets. At the end of preliminary design, the tower size and configuration had been established as well as the height. The site sits at an elevation of 6.45 m with a required clearance of 10m for the tsunami, the underside of the platform could be 3.55 m above the basketball court that forms the site of the tower. However, as the tower provides a rain cover for the reinstated basketball the level is raised to 13.650 m giving a clearance to the basketball court from underside of beam of 6.5 m or greater. The 13.650m meets the design 10m tsunami height. The relationship between the heights is shown in Figure 2.

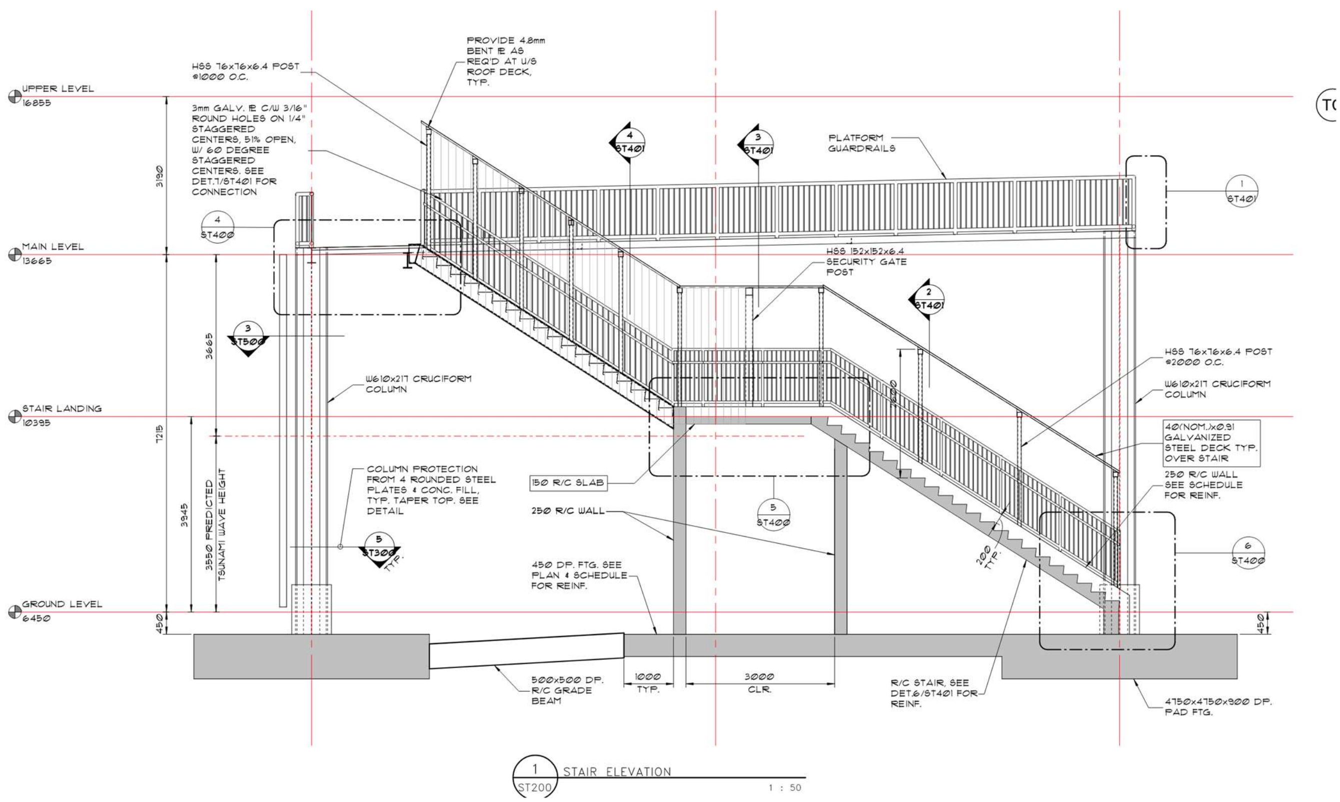

Figure 2. Cross section of the tower showing the maximum expected tsunami height.

Design Intent

The design intent of the tsunami tower was to provide a place of refuge for staff and students of the Gudangaay Tlaats'gaa Naay school in Masset. The school has approximately 100 students and staff. The intent is that following a tsunami warning or in the case of seismic shaking of long duration the staff and students would exit the school and go to the tsunami tower where the tsunami wave could pass below them without loss of life.

Tsunami Evacuation Structures

The design intent of any tsunami evacuation is to get people out of the zone where they could be drowned or killed from debris flow. There are three main groups of tsunami evacuation structures:

1) A purpose-built tower with open platforms at a level above the expected tsunami height. Sometimes these structures will also have a non-tsunami function such as stage, viewing platform for birdwatching or in the case of the Gudangaay Tlaats'gaanaay Tsunami Tower as a cover for a basketball court.
2) A building which has open decks or enclosed levels above the tsunami affected zone. Often then buildings have break away panels that would reduce the pressures on the building from the tsunami.
3) Creation of a hill where the top of the hill is above the tsunami flood level. These hills may contain structures that can be used as a shelter after the tsunami or may just have a road or path that gives access to the higher level. The hill will often have a hardened base to resist water flow without erosion. This type of facility may require ground preparation to prevent liquefaction and uses more of a footprint than either option 1 or 2.

Geotechnical considerations

The site soils report was prepared by Thurber Engineering Limited [3]. It showed that the site had fills of up to 3m thick over a mix of sands and gravel. The site is Site Class D and was determined not to be liquefiable under NBC 2015 shaking, under NBC 2020 levels of shaking one of the three test pits was identified to have a potential liquefaction at a depth of 13.3 with post liquefaction settlements estimated to be 25 mm. The V_{s30} was found to be 283 m/sec which places the site closer to the upper end of NBC 2020 Site Class D. Spread footing foundations were recommended with a ULS bearing of 260 kPa and an SLS bearing of 170 kPa. As the project is located on site class D and to mitigate against any spreading under seismic loads grade beams are required to connect the foundations in two directions.

Vertical Design Loading

There are no specific live load requirements for tsunami towers in the building Code. The tower could be classified as a viewing platform or balcony or as an exit, each of which would require a live load capacity of 4.8 kPa (100 psf). With a platform size of 16.3 m by 24.5 m giving a platform area of 400 m^2 this gives the tower the ability to resist over 1900 kN of live load. The roof is designed for a ground snow loading of 1.8 kPa with an associated rain load of 0.4 kPa which is almost identical to the snow loading in Vancouver. Snow loads were increased with the importance factor of 1.25 that is appropriate for a post-disaster building. The roof was designed for a factored net wind uplift of 2.1 kPa, the wind loading also has a post disaster importance factor applied.

Seismic Design Loading

The expected earthquake and tsunami scenario is that that earthquake would occur and then evacuation to the tower would be required. It is therefore vital that the tower withstands the earthquake without damage so that it can accommodate those who are exiting the school building and looking for refuge from the tsunami. Seismic design was performed using the requirements of the 2018 British Columbia Building Code (BCBC 2018) [4] which has similar seismic requirements as the 2015 edition of the National Building Code. The tsunami tower was treated as Post Disaster structure rather than High Importance which is the required importance designation for schools.

The period of the structure is less than 0.5 seconds, and the structure lies in the flat part of the design spectrum that exists at 0.5 seconds and below. The 2020 edition of the National Building Code of Canada [5] has an updated seismic hazard model and a more extensive database of earthquakes than the previous seismic hazard model. This new model resulted in an increase in the seismic force on the tower if the 2020 edition of NBC was used. Table 1 shows the expected base shear for NBC 2015 / BCBC 2018 and for NBC 2020/ BCBC 2023. The base shear under the new code has risen by over 40%.

Table 1: Expected base shear for Masset from BCBC 2018 and BCBC 2023:

Calculation parameter for base shear	Base shear for period less than 0.5 seconds.
BCBC 2018 (NBC 2015) Seismic base shear using R_d=2.0 R_o=1.3 I_E=1.5, Site Class D	0.499g
BCBC 2023 (NBC 2020) Seismic Base shear using R_d=2.0 R_o=1.3 I_E=1.5, V_{s30}=283 m/sec	0.721g

To account for the increase in base shear the tower design was checked against the new loads and sizes adjusted slightly to make the design work for structural capacity. However, the deformations of the tower under the 2020 seismic loading exceed the requirement of $0.01h_s$ for a Post Disaster building. The deflection being higher than permitted for a Post Disaster building is not of concern with the tower as it is likely that the tower would not be occupied during the initial tsunami causing earthquake and there are minimal finishes and services in the tower that would be damaged by the slightly higher deformations.

Tsunami Design Loading

There are no specific design loadings for tsunamis in the Canadian building code, however the provisions for tsunami wave loading on exposed objects is well established in the literature including ASCE7-16 and its commentary on Tsunami Loads and Effects [6] and in FEMA P656[7] and forces on exposed objects such as the platform columns is given in these references. The forces take account of the difference in height of the water from one side of the column to the other side, the flow of the water from the incoming wave and the effects of debris in the water along with current forces on the debris and impact from the debris. The loading from a tsunami is very similar to the forces on a bridge pier or on an ocean pier where there are forces from water flow, debris, and wave action. Canada has many structures that resist these forces on a regular basis.

To make the cruciform steel columns less likely to snag tsunami debris curved corners are added and the interior filled with concrete. This is shown in Figure 3. This makes the columns more streamlined and produces less drag during the tsunami flow.

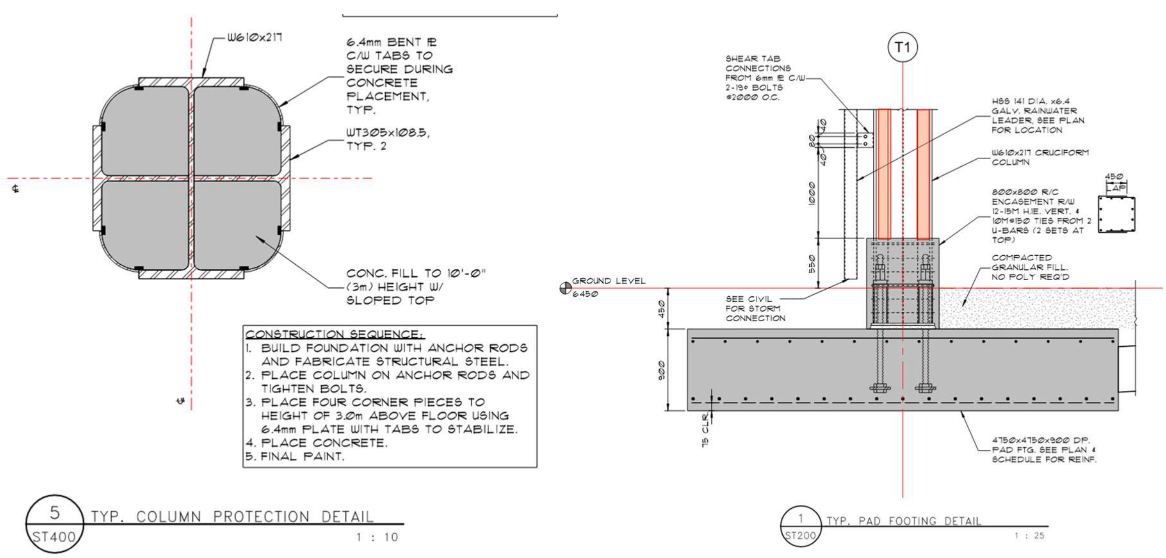

Figure 3. Rounding of cruciform columns to make flow easier and less likely to snag debris.

Remote Site Considerations

Masset is in Haida Gwaii which is 800 kM by air Northwest of Vancouver with limited airline access especially in the winter when the fishing season is closed, and the passenger demand is lower. During the summer and fall fishing season there are more flights, however this did not coincide with much of the on-site construction. Alternative means of transport by land is a four-hour ferry from Prince Rupert that travels only three times a week in the winter and gives priority to food and other non-construction supplies. The remoteness of the site has several design implications, construction implications and operational implications. The tower design was based on keeping the sitework as simple as possible, all the steel sections were designed to be bolted together with no significant site welding. To achieve this the moment connections in the steel frame are end bolted moment connections shown in Figure 5. From a construction standpoint the desire was to have concrete formwork easy to fabricate and use local labor and materials where possible. From an operational standpoint the desire was to have minimal maintenance, to achieve this steel was galvanized, there was no elevator and there was minimal mechanical and electrical in the tower. The tower deck was formed concrete with a flat soffit and no use of composite deck which could be subject to corrosion. Obtaining concrete on Haida Gwaii was one of the most difficult parts of this project as there is no permanent batch plant and concrete is obtained by purchase from temporary plants set up to service other projects. As aggregate, plant and cement must be brought in by barge or ferry the costs of concrete when it can be obtained are high. The cost of concrete on a per meter basis for the tower was approximately four times what a similar volume of concrete would be in Vancouver.

Architectural Considerations

The design of tsunami towers is not well covered in the building Code and there are several aspects that are difficult to rationalize with the building Code. For example, most building Code provisions assume that after an earthquake or fire the occupants of the building are trying to exit the building and therefore door swings go outward. In the tsunami tower the situation is reversed and in a tsunami warning event the students and staff would exit the school and exit into the tsunami tower and door swings are therefore designed to open into the tower. Another consideration was the number of stairs. For exiting from a platform of this size there would be a requirement for two stairs to exit. The tsunami tower conceptual design had a single stair as this would be sufficient for access, however as the design progressed the tower design proceeded to tender with two stairs, improving access during an emergency and allowing for some redundancy should one of the stairs be damaged or blocked by debris after the tsunami. The layout of stair runs and configuration as well as overall configuration were performed by the architect. The stairs were concrete at the base using a gravel filled concrete walls to make them more resistant to tsunami flow and were steel above the expected flow line. The tower and the basketball court have no combustible materials and the tower is treated as not being occupied and is not sprinklered. This eliminates several issues that would occur with sprinkling the exterior structure.

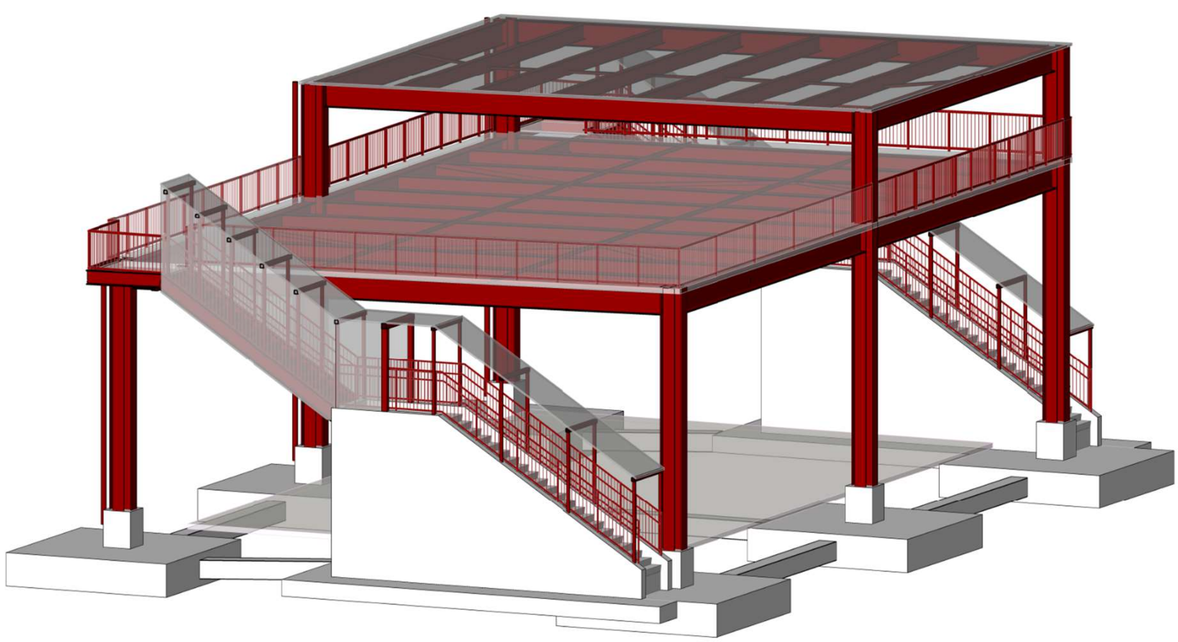

Figure 4. Three-dimensional model of the tsunami tower at time of tender

STEEL FABRICATION AND FOUNDATION CONSTRUCTION STAGE

Steel Fabrication

The steel for the tsunami tower was fabricated in Pemberton, British Columbia by Whistler Welding. The Quality control is an important component of a successful steel project, and the steel was fabricated using Canadian Welding Bureau (CWB) certified welders and inspected by an independent inspection agency. The design was intended to maximize bolting and where possible eliminate site welding that would be more difficult to maintain quality and inspect. Figure 5 shows portions of the shop drawing model, the figure on the right shows a portion of the frame and the figure at the right shows a beam column joint. All beam connections are bolted with the moment connections being done with end bolted moment connections that are detailed to requirements of the CISC manual on seismic moment connections [8].

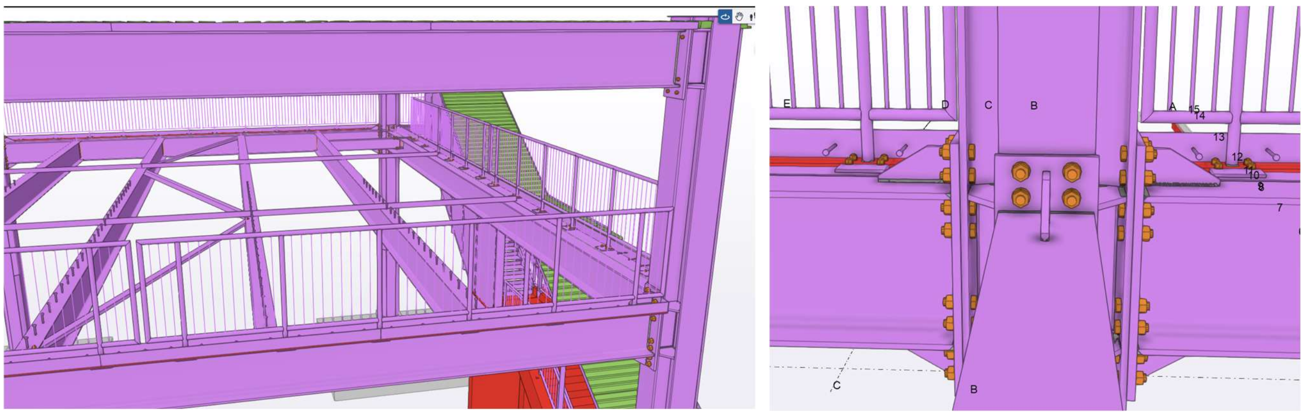

Figure 5. A three-dimensional model of the tsunami tower produced by the fabricator during shop drawing stage. Model view curtesy of Whistler Welding.

Following fabrication, the steel was sent to Ebco Industries for galvanization before shipping to Haida Gwaii. Galvanizing was chosen as a finish method for its durability and corrosion resistance. Shipping was via truck and ferry and ferry bookings for shipments of the steel were time-consuming and problematical.

Figure 6. Galvanized steel at Ebco Industries in Surrey. The steel now had a two-to-three-day journey from the galvanizing plant to the site.

Foundation Construction

During the fabrication of the steel the footing and concrete stair construction was proceeding which allowed for an overlap in the schedule between concrete work and steel fabrication. The footings are large rectangular footings capable of resisting overturning moments from the moment connected columns. The large footings will be buried below the basketball court making them resistant to tsunami flow scouring. Figure 7 shows the formwork under construction in August 2022 with reinforcing placed in September 2022. Local labor was used for the formwork construction. To save concrete the intent was to only remove those portions of the basketball court required for footing and grade beam installation.

Figure 7. Foundation construction large spread footings, the construction required temporary closure of the basketball court. The photo at right is courtesy of Unitec Construction Ltd.

Steel Erection and Deck Construction

The steel erection is to take place in the last week of April 2023 and first week of May 2023. Both galvanizing and shipping to the site took more time than anticipated, however the on-site erection of the steel using a truck mounted crane went very smoothly due to extensive quality control in the fabrication plant and the use of 3D shop drawings.

The deck concrete will be formed in May and June 2023 using formwork that is supported on the steel beams. The deck will be a formed soffit deck akin to a bridge deck and will not have metal deck formwork due to the corrosion risk from the metal deck.

Figure 8. Tower following steel erection. Drone photograph courtesy of Whistler Welding.

OPERATION STAGE

Once completed the operation of the tower would be on an as needed emergency only basis with expected earthquake and fire drills occurring each year. The tower would be occupied for only brief periods of time even in the case of a tsunami alert or an actual tsunami. School earthquake drills will include evacuation to the tsunami tower. One of the schools that was inundated by the Sundai tsunami in Japan had earthquake drills that stressed evacuation from the school after an earthquake but did not have protocols for getting students to a tsunami safe zone after the earthquake resulting in significant loss of student lives, documented in the book Ghosts of the Tsunami [6].

SCHEDULE

The overall design schedule for the tower took four years from conceptual design to implementation.

- Conceptual design for the purpose of establishing funding: July 2019 to August 2019.
- Obtaining funding and assignment of consultants for detail design and start-up: September 2019 to August 2021.
- Geotechnical site investigation and report June 2021-August 2021.
- Detail design of the tower: August 2021 to November 2021
- Tendering and procurement phase: November 2021 to February 2022
- Construction of footings, shop drawings, fabrication of steel, galvanizing steel. February 2022 to April 2023
- Shipping of steel to site: Mid-April 2023.
- Steel Erection: Last week of April and first week of May 2023.
- Construction of concrete deck: May – June 2023.
- In service: Fall 2023 (start of school year).

CONCLUSIONS

The Gudangaay Tlaats'gaa Naay High School Tsunami Tower in Masset on Haida Gwaii forms an important part of the seismic safety for the school.

The tower was designed using well established principles for this type of structure with the most significant load being the seismic loading rather than the loading from the tsunami water flow along with the expected debris flow. The remote location had a significant influence on the design and construction.

The tower fills a life safety need that is real and there is a need for more such structures on the BC Coast as well as other low-lying and tsunami affected coastal zones in the world.

ACKNOWLEDGMENTS

The tower is located on the unceded territory of the Haida Nation. This paper would not have been possible without the commitment of the Province of British Columbia and School District 50 to seismically upgrade schools and mitigate seismic risks for students and staff throughout the seismic prone areas of British Columbia. The architectural design for the tower was by Station One Architecture. Seismic Upgrading of the School Building was performed by David Nairne and Associates, fabrication of the structural steel was by Whistler Welding Ltd and project manager and in the role of general contractor was Unitec Construction Management Inc.

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