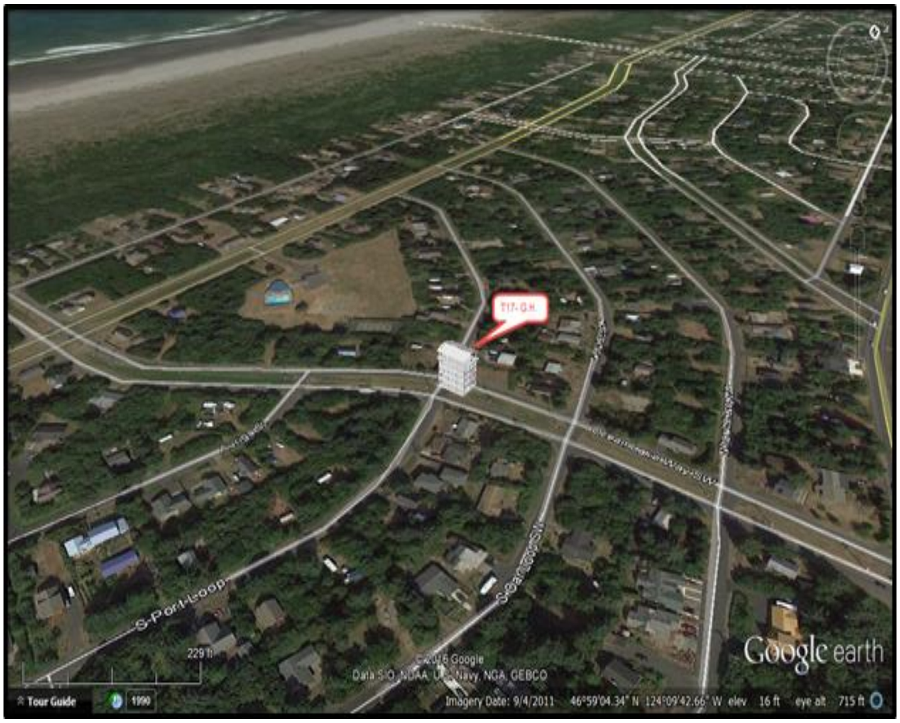

PROJECT SAFE HAVEN: TSUNAMI VERTICAL EVACUATION ON THE WASHINGTON COAST

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Project Safe Haven: Tsunami Vertical Evacuation on the Washington Coast

1. Introduction

The Cascadia Subduction Zone is a convergent plate boundary extending over an approximate distance of 1000 Km. It stretches from Northern California to Southwestern British Columbia on the west coast of North America (Mazzotti and Adams, 2004). Large subduction earthquakes can occur at the Cascadia Subduction Zone when the subducting floor of Juan de Fuca plate is pushed beneath the continental North America plates (Cascadia Region Earthquake Workgroup, 2005). These earthquakes can trigger tsunami waves, which are series of huge waves that can cause severe devastation and loss of life when they strike the coast.

In Washington State, the Pacific, Grays Harbor and Clallam Counties are subject to two types of tsunamis: (1) tsunamis as a result of distant seismic event, such as the 2011 Japan earthquake; and (2) tsunamis created due to local offshore earthquakes. A possible scenario of a local earthquake centered along the Cascadia Subduction Zone is expected at a magnitude of 9.1, where earthquakes of similar size occur along the Washington State coast every 300-500 years on average. The last similar earthquake is the orphan tsunami, which struck 1000 km of the pacific coast of Japan in January 1700 (Atwater et al., 2006). A local subduction earthquake can be defined by a group of characteristics, including (1) originating 80 miles off the Pacific Northwest Coast; (2) causing six feet of subsidence along the coast; (3) lasting from five to six minutes; (4) creating tsunami waves that will reach the Pacific County, WA 40 minutes after the shaking stops; and (5) causing large-scale injuries, fatalities, and property damage.

In a tsunami event, residents need to evacuate to high ground. However, some coastal communities in WA State lack natural high ground. In addition, these communities are within close proximity to Cascadia Subduction Zone, which makes these communities vulnerable to significant damage due to tsunami waves. The lack of time and high ground require the development of vertical evacuation structures that should be accessible on foot within fifteen minutes from the occurrence of earthquake. In 2011, Project Safe Haven was conducted by the University of Washington to study and propose vertical evacuation solution under a funding by the National Tsunami Hazard Mitigation Program. These solutions include proposing the locations and types of safe haven structures that should be designed to withstand forces of magnitude 9.1 Cascadia Subduction Zone earthquake and the resulting tsunami waves. Project Safe Haven explored the use of four different types of vertical evacuation structures, including towers, berms, tower-berm combinations, and buildings (such as fire stations and parking garages).

This project resulted in recommended vertical evacuation strategies to communities in each of Pacific, Grays Harbor and Clallam Counties based on a participatory approach that incorporated the needs of local residents. For instance, feedback from residents of the Grays Harbor County resulted in an evacuation strategy that includes developing 32 vertical evacuation structures for 18,450 residents through the construction of 3 berms, 20 towers, 8 tower-berms, and 1 building. This effort also included developing conceptual cost estimates for each of the proposed safe havens in order to assist decision makers in prioritizing which safe havens to construct given their budget availability.

The design heights for the proposed safe havens were identified based on modeling an earthquake and tsunami event with a 500-year return period. Recently, a new model was developed which accounts for an earthquake and tsunami event with a 2,500-year return period. Obviously, the model results showed larger flow depths; and accordingly, the design heights and their corresponding conceptual cost estimates need to be revised. To address this need, *the objective of this new study is to identify the flow depths at the proposed locations of each safe haven, calculate new design heights, and revise their conceptual cost estimates based on the new design and current construction costs*. The following section presents the proposed research methodology to achieve this objective.

2. Research Methodology

In order to develop new cost estimates to the tsunami safe havens, the adopted research methodology included ten main tasks. Figure 1 presents these tasks, which include (1) identifying the locations of safe haven structures; (2) identifying the topography elevations; (3) identifying the flow depths; (4) calculating the design heights; (5) developing BIM models for selected structures; (6) projecting the developed BIM models in Google Earth; (7) performing quantity surveying; (8) performing conceptual cost estimating; (9) prioritizing safe havens for redesign; and (10) designing and conceptual cost estimating for a proposed training tower for the Fire Department in Long Beach to be used as a tsunami safe haven.

2.1 Identifying the Locations of Safe Haven Structures

The first task is to identify the locations of the proposed vertical evacuation structures in Pacific County, Grays Harbor County and Clallam County. The addresses of these structures were identified using previous Safe Haven reports. In these reports, each proposed safe haven is identified using a unique map number.

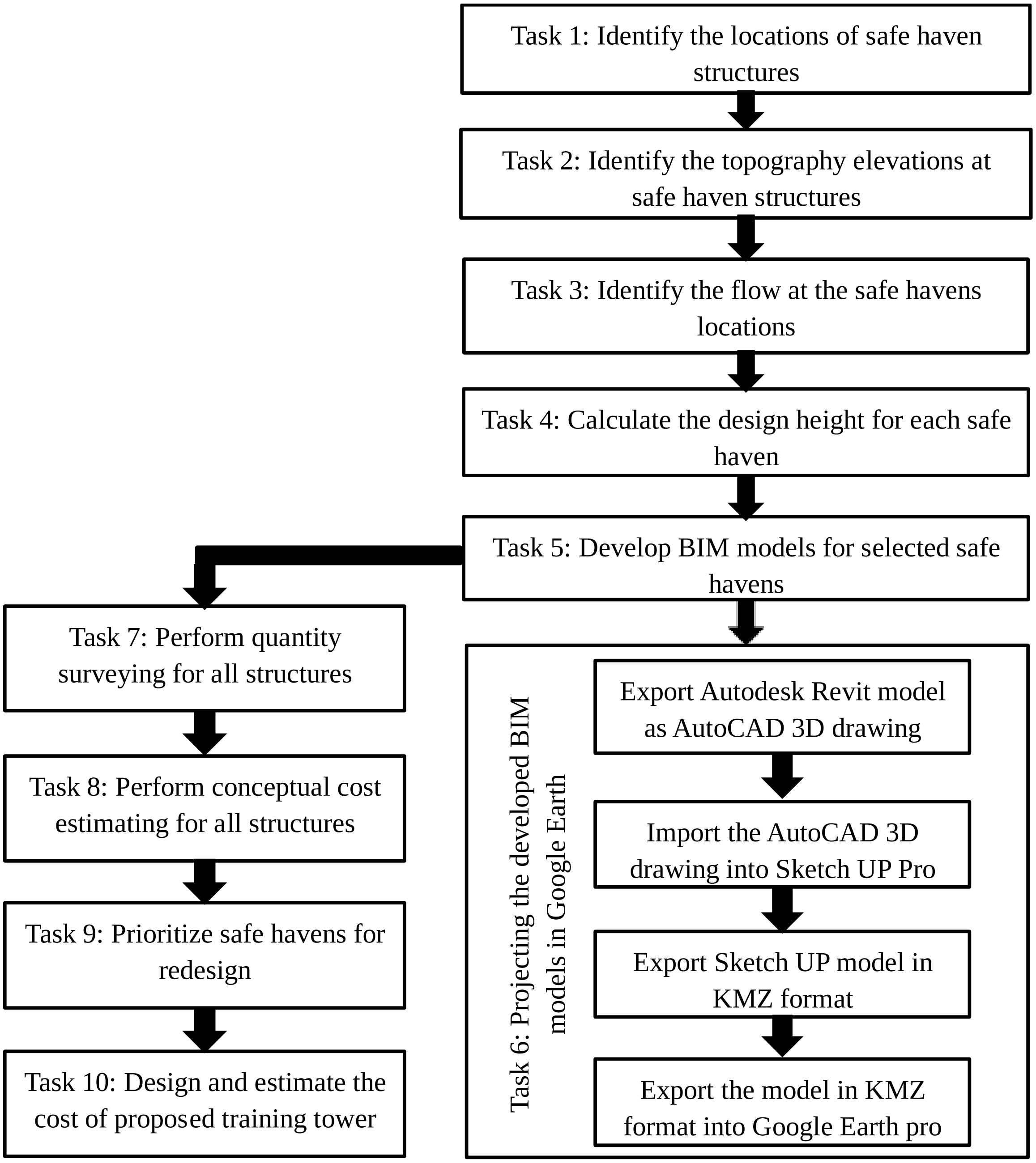

Figure 1: Adopted Research Tasks

Google Earth Pro is then used to identify the latitude (N, S) and longitude (E, W) of each safe haven. For instance, the location of Berm #1 in the city of Long Beach in Pacific County is depicted in Figure 2 and the location of Tower Berm #14 in Ocean Shores in Grays Harbor County is depicted in Figure 3. Table 1 presents the type of each vertical evacuation structure in Pacific County, as well as its map number (as shown in Table 1), address, latitude, and longitude. Tables 2 and 3 present this information for safe havens in Grays Harbor County and Clallam County, respectively.

Figure 2: Location of Berm 1 in Long Beach

Figure 3: Latitude, Longitude and Altitude of Tower Berm 14 in Ocean Shores

Table 1: Type of Each Vertical Structure, Map Number, Location, Latitude, Longitude, and Topography Elevation in Pacific County

Structure Type	*Map Number*	*Location (Address)*	*Longitude*	*Latitude*	*Topography Elevation (feet)*
Berm	B1	N Place & 41st Place, Long Beach, WA	124° 3.224’ W	46° 19.930’ N	22
Berm	B2	5th Street S & Washington, Long Beach, WA	124° 3.136’ W	46° 20.930’ N	18
Berm	B3	NE 2nd & Washington, Long Beach, WA	124° 3.129’ W	46° 21.924’ N	20
Berm	B4	NE 13th & Washington, Long Beach, WA	124° 3.288’ W	46° 20.645’ N	19
Berm	B5	NE 26th & Washington, Long Beach, WA	124° 3.042’ W	46° 22.248’ N	21
Berm	B6	227th and U Street, Ocean Park, WA	124°02'41.8" W	46°27'59.5" N	23
Berm	B7	210th & SR 103, Ocean Park, WA	124°03'10.1" W	46°27'14.8" N	27
Berm	B8	188th & SR 103, Ocean Park, WA	124°03'03.8" W	46°26'18.2" N	24
Berm	B9	162nd Ln & SR 103, Ocean Park, WA	124°03'07.2" W	46°25'08.0" N	24
Berm	B10	Cranberry & SR 103, Ocean Park, WA	124°03'10.5" W	46°23'43.4" N	20
Berm	B11	U Street & 260th Street, Ocean Park, WA	124°02'39.7" W	46°29'25.9" N	22
Berm	B12	Fire Dept. (N Street & 37th St), Illwaco, WA	124°02'33.4" W	46°18'34.4" N	12
Berm	B13	Vandalia (Ortelius Dr. &Scarboro Ln), Illwaco, WA	124° 0'13.89" W	46°19'8.36" N	8
Parking Garage	PK 1	Shoalwater Bay Casino, Tokeland, WA	124° 1'13.98" W	46°43'29.14" N	15
Parking Garage	PK 2	Shoalwater Bay Tribal Complex Tokeland, WA	124° 0.954’ W	46°43.294’ N	15
Tower	T1	3088 Kindred Ave, Tokeland, WA.	123°58'40.62" W	46°42'19.98" N	12
Tower	T2	Tokeland Rd & Evergreen St, Tokeland, WA	123°59'36.07" W	46°42'36.69" N	15
Tower	T3	Tokeland Rd & Pine Ln, Tokeland, WA	124° 0'30.98" W	46°43'7.75" N	13
Tower	T4	Wipple Ave & SR 105, Tokeland, WA	124° 4'46.64" W	46°44'30.54" N	19
Tower	T5	Warrenton Cannery Rd & SR 105, Tokeland, WA	124° 5'10.29" W	46°44'44.81" N	20

Table 2: Type of Each Vertical Structure, Map Number, Location, Latitude, Longitude, and Topography Elevation in Grays Harbor County

Structure Type	***Map Number***	***Location (Address)***	***Longitude***	***Latitude***	***Topography Elevation (feet)***
Tower	1	Ocean City, Ocean Shores, WA	124°9'22.63"W	46°58'25.3" N	15
Tower	2	Quinault Beach Resort, Ocean Shores, WA	124° 10.247’ W	47° 2.559’ N	24
Tower	3	Downtown Ocean Shores, Ocean Shores, WA	124°10'2.57" W	46°57'22.72" N	18
Berm	4	North Beach Junior/Senior High School Berm, Ocean Shores, WA	124° 9.639' W	47° 1.078' N	19
Tower Berm	5	Golf Course, Ocean Shores, WA	124° 9.475' W	46° 59.893' N	18
Tower	6	Ocean Shores Airport, Ocean Shores, WA	124° 9.803' W	47° 0.679' N	18
Tower Berm	7	Ocean Shores Elementary Civic Complex, Ocean Shores, WA	124° 9.298' W	46° 58.662' N	18
Tower	8	Ocean Shores BLVD & Taurus BLVD SW, Ocean Shores, WA	124° 9.951’ W	46° 58.329’ N	18
Tower Berm	9	Blue Wing Loop SE & Duck Lake Drive SW, Ocean Shores, WA	124° 8.365’ W	46° 58.141’ N	16
Tower	10	Cormorant Street, Ocean Shores, WA	124° 8.645’ W	46° 57.536’ N	14
Tower	11	Ocean Shores BLVD & Marine View Drive SW, Ocean Shores, WA	124° 10.078’ W	46° 57.128’ N	19
Tower	12	Emeritus Senior Living, Ocean Shores, WA	124° 7.866' W	46° 57.287’' N	19
Tower	13	Wowona Ave. SE &Tonquin Ave. SW, Ocean Shores, WA	124° 8.468' W	46° 56.999' N	15
Tower Berm	14	Spinnaker Park, Ocean Shores, WA	124° 9.98’ W	46° 56.076’ N	17
Tower Berm	15	Ocean City State Park Campground, Ocean Shores, WA	124° 9.983’ W	47° 1.972’ N	18
Tower	16	Duck Lake Drive, Ocean Shores, WA	124° 8.397‘ W	46° 58.237’ N	18
Tower	17	Ocean Lake Way & N Port Loop, Ocean Shores, WA	124° 9.722’ W	46° 59.074’ N	16
Tower Berm	18	North Razor Clam Drive & Butterclam St. SW, Ocean Shores, WA	124° 9.896’ W	46° 57.742’ N	15

Tower Berm	19	North Razor Clam Drive &Butterclam St. SW, Ocean Shores, WA	124° 9.896’ W	46° 57.742’ N	15
Tower	20	Mt. Olympus, Ocean Shores, WA	124° 8.677’ W	46° 57.879’ N	21
Tower	1	Marina, Westport, WA	124° 6.659’ W	46° 54.412’ N	14
Tower	2	Adams & Washington, Westport, WA	124°6.998' W	46°54.036' N	13
Tower	3	Forrest & Newell, Westport, WA	124° 6.731’ W	46° 52.58’ N	16
Tower	4	Surf & Ocean, Westport, WA	124° 7.056’ W	46° 53.2’ N	29
Berm	5	Ocosta School, Westport, WA	124° 6.012’ W	46° 51.721’ N	28
Tower	6	HWY 105 & W Bonge, Westport, WA	124° 6.376’ W	46° 50.968’ N	20
Tower	7	Wood lane, Grayland, WA	124° 5'53.99" W	46°49'52.79" N	17
Tower	8	HWY 105, Grayland, WA	124°5.831' W	46°49.138' N	19
Building/Fire Station	9	McDermontt Lane, Graysland, WA	124°5'31.33" W	46°48'7.65" N	21
Tower Berm	1	2nd Ave & Spruce St, Taholah, WA	124°17.59' W	47°20.654' N	17
Berm	2	5th Ave & Commux St, Taholah, WA	124°17.383' W	47°20.783' N	19
Tower	3	Park Place Neighborhood, Taholah, WA	124°17.055' W	47°20.724' N	19

Table 3: Type of Each Vertical Structure, Map Number, Location, Latitude, Longitude, and Topography Elevation in Clallam County

Structure Type	***Map Number***	***Location (Address)***	***Longitude***	***Latitude***	***Topography Elevation (feet)***
Tower	1	Neah Bay School RC, Neah Bay, WA	124°37.335' W	48°21.806' N	17
Berm	2	Quileute tribal school, La Push, WA	124°38.28' W	47°54.593' N	24

2.2 Identifying the Topography Elevations

The altitude (elevation) at the proposed location of any safe haven was determined using Google Earth Pro. For example, the altitude at Berm 1 in Long Beach is determined to be 21 feet, while the altitude at the Tower Berm 14 in Ocean Sores is 17 feet (as shown in Figure 3). Tables 1, 2, and 3 list the topography elevation at each proposed location for safe havens in Pacific Country, Grays Harbor County, and Clallam County, respectively.

2.3 Identifying the Flow Depths

The third task aims at identifying the expected flow depth at each safe haven based on the modeled heights of tsunami waves. The flow depth is necessary to determine the new design heights for the safe havens. The new model that considered a 2,500-year return period produced larger value of flow depths than the previous 500-year model. The flow depth at each safe haven was obtained using ArcGIS, as shown in Figures 4 and 5.

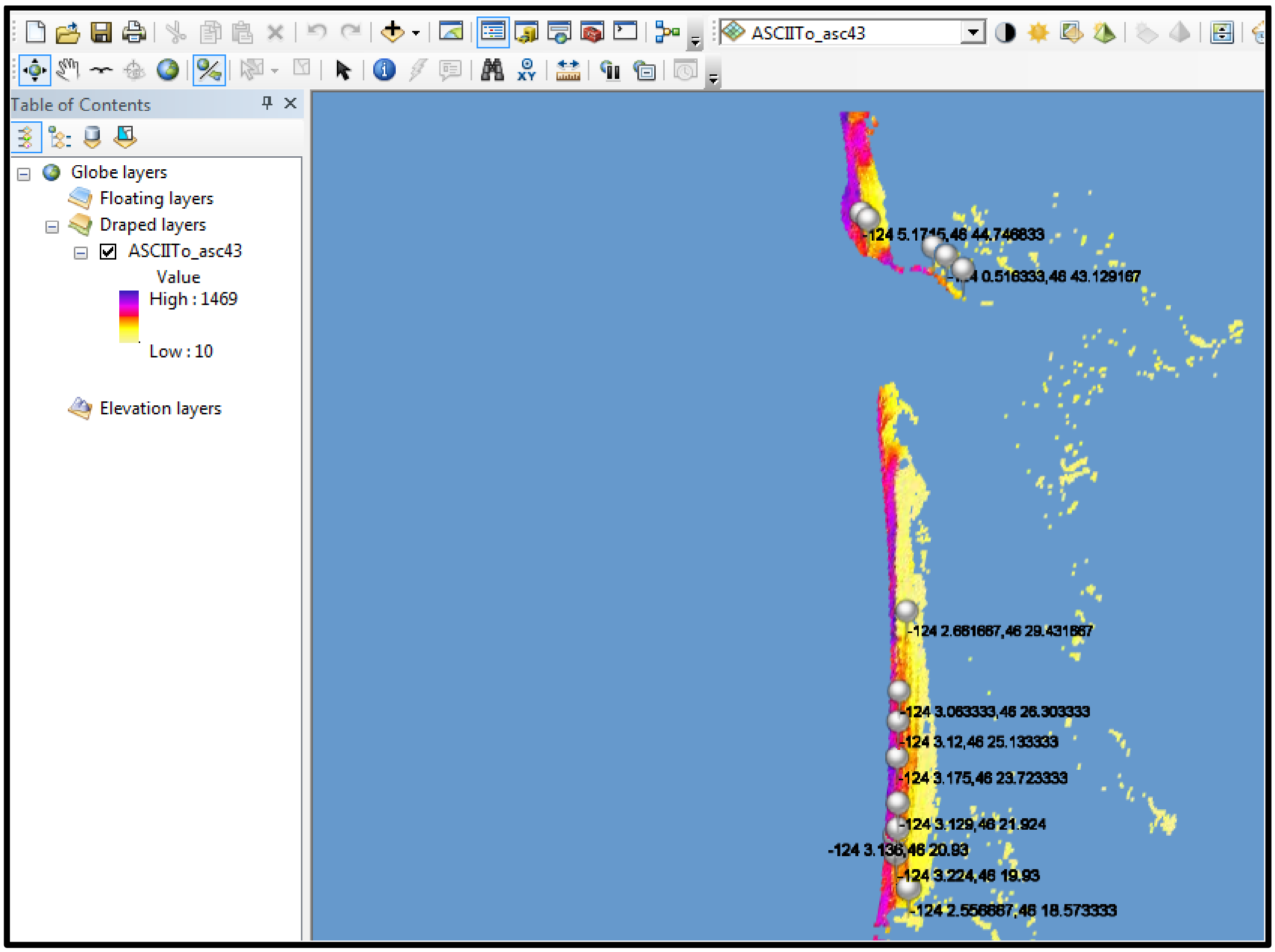

Figure 4: Flow Depths at Some Safe Haven Structures in Pacific County

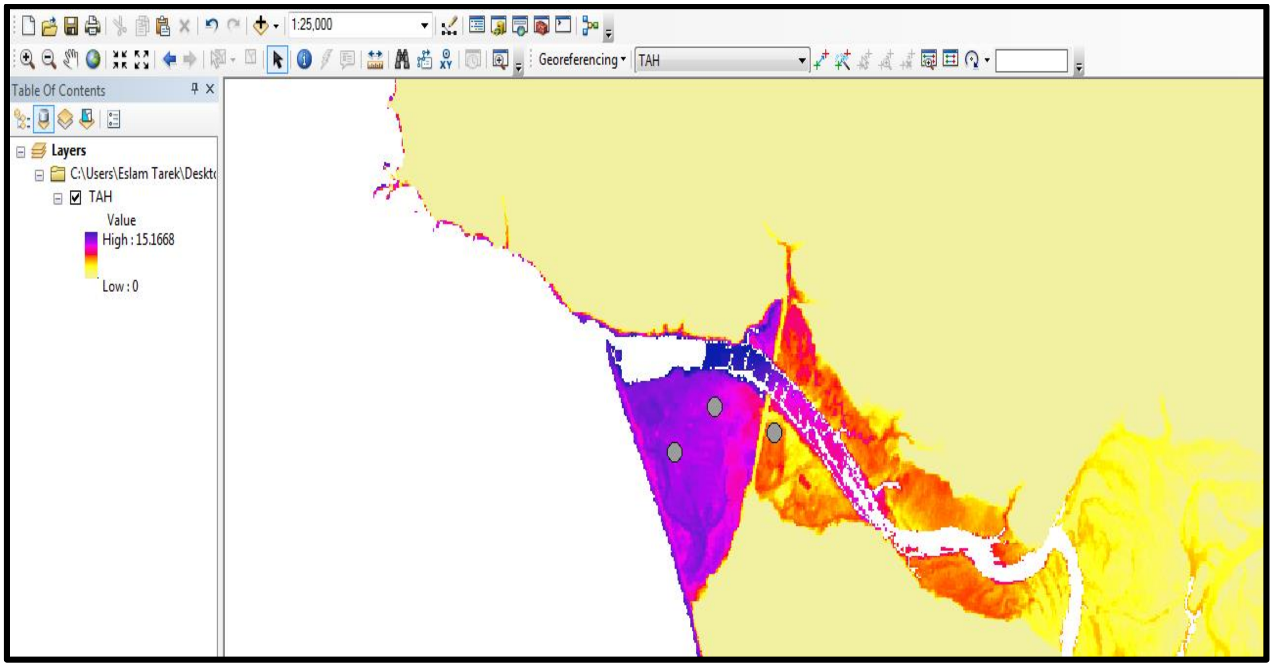

Figure 5: Flow Depths at Some Safe Haven Structures in Taholah, Grays Harbor County

It is noteworthy that there was no flow depth data for few safe haven structures, because the projections of these structures in the ARCGIS files were in non-modeled areas. This issue was resolved by identifying the nearest conservative flow depth value. For instance, there was no flow depth data at the location of Tower 3 in Long Beach (as shown in Figure 6), where the nearest conservative flow depth value is at an approximate distance of 50 meters. Structures that were located in non-modeled areas are highlighted in Table 4. Table 5 shows the identified flow depths at the location of each safe haven.

Table 4: List of Structures Located in Non-Modeled Areas

Structure	***Type***	***Location***	***Latitude***	***Longitude***
B13	Berm	Vandalia (Ortelius Dr. & Scarboro Ln), Illwaco, WA	46°19'8.36" N	124° 0'13.89" W
PK 1	Parking Garage	Shoalwater Bay Casino, Tokeland, WA	46°43'29.14" N	124° 1'13.98" W
T1	Tower	3088 Kindred Ave., Tokeland, WA	46°42'19.98" N	123°58'40.62" W
T2	Tower	Tokeland Rd & Evergreen St., Tokeland, WA	46°42'36.69" N	123°59'36.07" W
T3	Tower	Tokeland Rd & Pine Ln, Tokeland, WA	46°43'7.75" N	124° 0'30.98" W

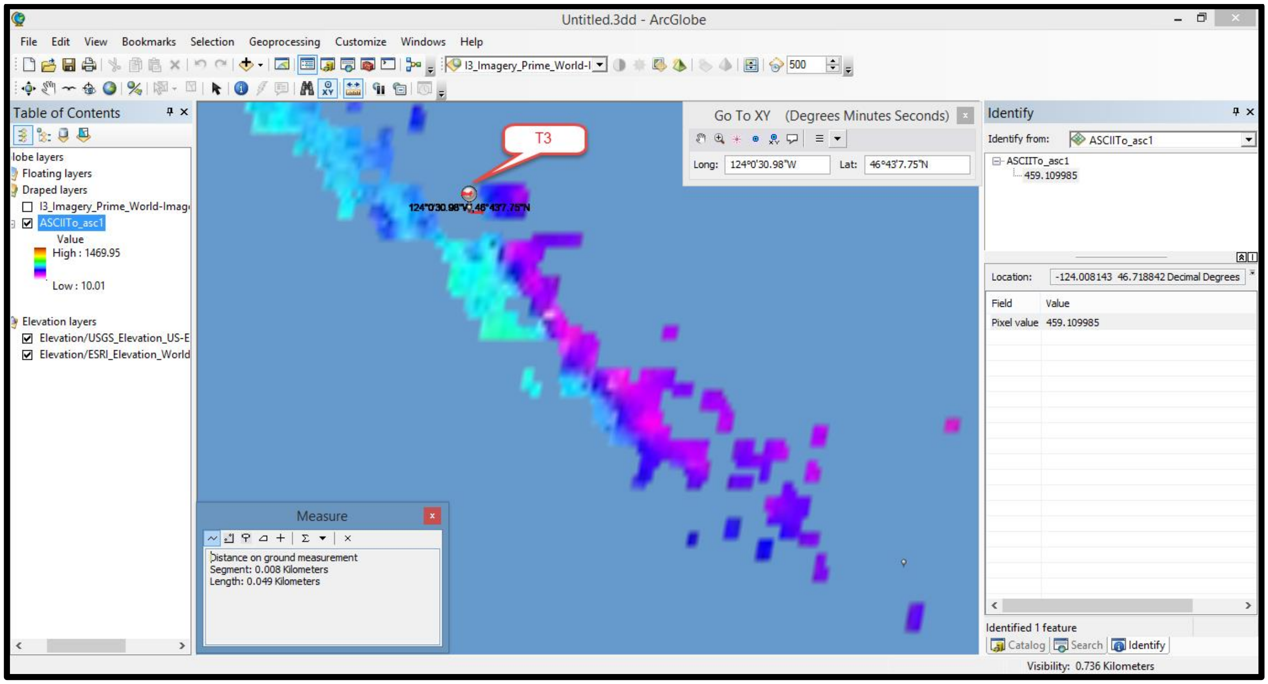

Figure 6: Tower 3 in Long Beach in Pacific County Located in a Non-Modeled Area

2.4 Calculating the Design Heights

The fourth step is to calculate the design height where the design height of vertical evacuation structures can be calculated using the following equation (FEMA p646; Heintz and Robertson 2008).

$$DH = 1.3 * FD + CL$$

Where;

DH refers to design height in feet, FD represents flow depth, and CL refers to clearance height. CL is assumed to be 10 feet.

The new design heights for all safe haven structures in Pacific County, Grays Harbor County, and Clallam County are listed in Tables 5, 6, and 7, respectively. These tables also show the original design heights based on the 500-year model to allow for comparison.

Table 5: Calculated Flow Depth and Design Heights of the Safe Haven Structures in Pacific County

Structure Type	*Map Number*	*Location (Address)*	*Old Design Heights (feet)*	*New Flow Depth (feet)*	*New Design Heights (feet)*
Berm	B1	N Place & 41st Place, Long Beach, WA	13	13.31	27.3
Berm	B2	5th Street S & Washington, Long Beach, WA	10	37.73	59.0
Berm	B3	NE 2nd & Washington, Long Beach, WA	13	15.66	30.4
Berm	B4	NE 13th & Washington, Long Beach, WA	10	17.87	33.2
Berm	B5	NE 26th & Washington, Long Beach, WA	10	18.42	33.9
Berm	B6	227th and U Street, Ocean Park, WA	10	14.09	28.3
Berm	B7	210th & SR 103, Ocean Park, WA	13	6.92	19.0
Berm	B8	188th & SR 103, Ocean Park, WA	17	14.25	28.5
Berm	B9	162nd Ln & SR 103, Ocean Park, WA	26	18.15	33.6
Berm	B10	Cranberry & SR 103, Ocean Park, WA	10	19.19	34.9
Berm	B11	U Street & 260th Street, Ocean Park, WA	17	13.22	27.2
Berm	B12	Fire Dept. (N Street & 37th St), Illwaco, WA	13	4.21	15.5
Berm	B13	Vandalia (Ortelius Dr. &Scarboro Ln), Illwaco, WA	17	5.91	17.68
Parking Garage	PK 1	Shoalwater Bay Casino, Tokeland, WA	26	19.78	35.72
Parking Garage	PK 2	Shoalwater Bay Tribal Complex Tokeland, WA	20	19.78	35.72
Tower	T1	3088 Kindred Ave, Tokeland, WA.	20	7.17	19.32
Tower	T2	Tokeland Rd & Evergreen St, Tokeland, WA	20	9.88	22.84
Tower	T3	Tokeland Rd & Pine Ln, Tokeland, WA	20	15.09	29.62

Tower	T4	Wipple Ave & SR 105, Tokeland, WA	22	10.40	23.52
Tower	T5	Warrenton Cannery Rd & SR 105, Tokeland, WA	24	18.12	33.56

Table 6: Calculated Flow Depth and Design Heights of the Safe Haven Structures in Grays Harbor County

Structure Type	***Map Number***	***Location (Address)***	***Old Design Heights (feet)***	***New Flow Depth (feet)***	***New Design Heights (feet)***
Tower	1	Ocean City, Ocean Shores, WA	14	20.18	36.2
Tower	2	Quinault Beach Resort, Ocean Shores, WA	14	42.02	64.6
Tower	3	Downtown Ocean Shores, Ocean Shores, WA	10	38.27	59.8
Berm	4	North Beach Junior/Senior High School Berm, Ocean Shores, WA	10	36.77	57.8
Tower Berm	5	Golf Course, Ocean Shores, WA	10	30.25	49.3
Tower	6	Ocean Shores Airport, Ocean Shores, WA	10	31.29	50.7
Tower Berm	7	Ocean Shores Elementary Civic Complex, Ocean Shores, WA	10	22.39	39.1
Tower	8	Ocean Shores BLVD & Taurus BLVD SW, Ocean Shores, WA	17	32.77	52.6
Tower Berm	9	Blue Wing Loop SE & Duck Lake Drive SW, Ocean Shores, WA	10	20.06	36.1
Tower	10	Cormorant Street, Ocean Shores, WA	10	22.31	39.0
Tower	11	Ocean Shores BLVD & Marine View Drive SW, Ocean Shores, WA	14	34.57	54.9
Tower	12	Emeritus Senior Living, Ocean Shores, WA	10	5.43	17.1
Tower	13	Wowona Ave. SE &Tonquin Ave. SW, Ocean Shores, WA	14	24.12	41.4

Tower Berm	14	Spinnaker Park, Ocean Shores, WA	17	25.87	43.6
Tower Berm	15	Ocean City State Park Campground, Ocean Shores, WA	14	34.39	54.7
Tower	16	Duck Lake Drive, Ocean Shores, WA	10	9.16	21.9
Tower	17	Ocean Lake Way & N Port Loop, Ocean Shores, WA	10	26.12	44.0
Tower Berm	18	North Razor Clam Drive & Butterclam St. SW, Ocean Shores, WA	17	19.83	35.8
Tower Berm	19	North Razor Clam Drive &Butterclam St. SW, Ocean Shores, WA	10	19.83	35.8
Tower	20	Mt. Olympus, Ocean Shores, WA	10	20.14	36.2
Tower	1	Marina, Westport, WA	17	10.84	24.1
Tower	2	Adams & Washington, Westport, WA	17	15.78	30.5
Tower	3	Forrest & Newell, Westport, WA	14	10.70	23.9
Tower	4	Surf & Ocean, Westport, WA	17	14.04	28.3
Berm	5	Ocosta School, Westport, WA	11	18.69	34.3
Tower	6	HWY 105 & W Bonge, Westport, WA	14	13.98	28.2
Tower	7	Wood lane, Grayland, WA	14	15.48	30.1
Tower	8	HWY 105, Grayland, WA	17	22.56	39.3
Building/Fire Station	9	McDermontt Lane, Graysland, WA	10	18.74	34.4
Tower	1	2nd Ave & Spruce St, Taholah, WA	16	10.03	23.0
Tower	2	5th Ave & Commux St, Taholah, WA	16	10.15	23.2
Tower	3	Park Place Neighborhood, Taholah, WA	16	5.40	17.0

Table 7: Calculated Flow Depth and Design Heights of the Safe Haven Structures in Clallam County

Structure Type	*Map Number*	*Location (Address)*	*Old Design Heights (feet)*	*New Flow Depth (feet)*	*New Design Heights (feet)*
Tower	1	Neah Bay School RC, Neah Bay, WA	30	6.35	18.3
Berm	2	Quileute tribal school, La Push, WA	30	14.65	29.0

2.5 Developing BIM Models

Building Information Modeling (BIM) is one of the fastest growing and promising concepts in the architecture, engineering, and construction industry. Building information model can be defined as "data rich, object oriented, intelligent and parametric digital representation of the facility where views and data required by different users can be extracted and analyzed to generate information that can be used to take decisions and improve the process of delivering the facility" (Azhar et al., 2008). Moreover, a building information model stores all data and information related to the building its physical and functional characteristics, as well as its project life cycle information (Azhar et al., 2008).

In this research, BIM is used with some safe havens to support (1) quantity surveying for the construction assemblies incorporated in the safe havens; and (2) visualizing the proposed structures. BIM models were developed using Autodesk Revit 2015. For example, a Revit model of Tower 6 in Ocean Shores in Grays Harbor County is illustrated in Figure 7. Moreover, Figure 8 presents a plan view obtained from the Revit model for Tower 6; and Figure 9 presents a 3D-section view for the tower, which shows the structural system of the foundation and its components. It should be noted that shown structural components are not fully designed and are included only to support conceptual cost estimating purposes. Annex A shows all the developed BIM models for the selected safe havens.

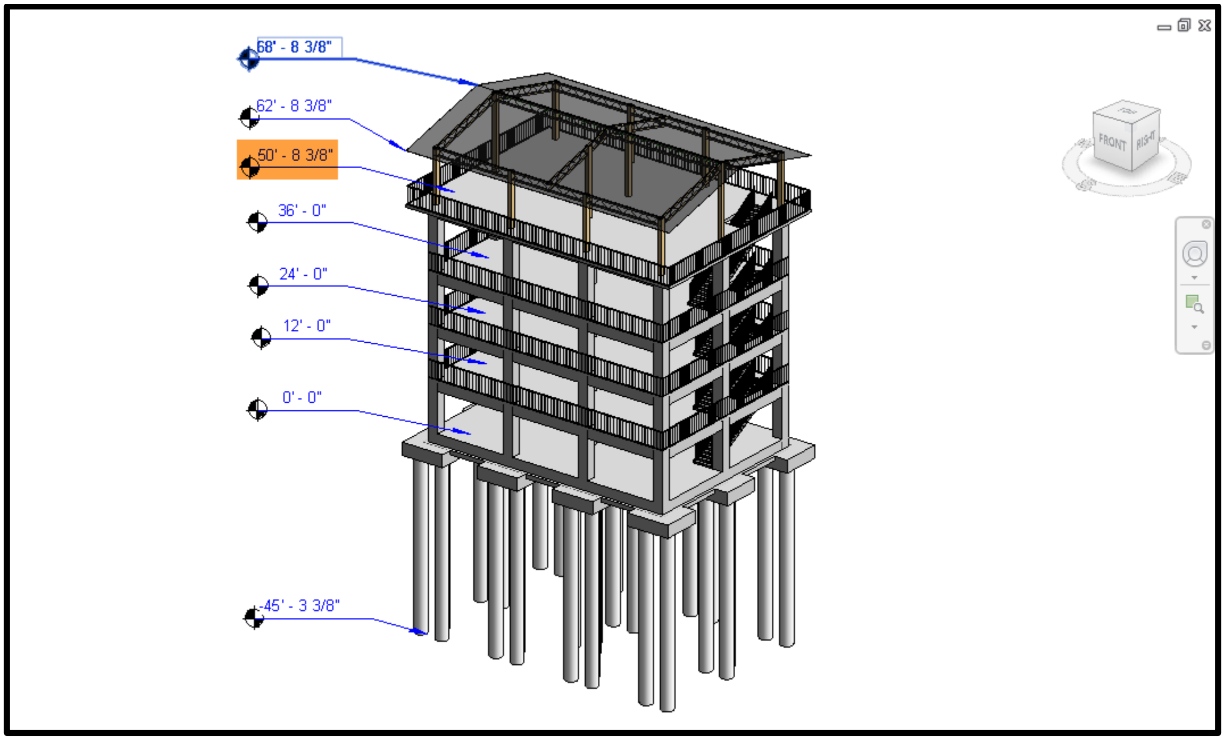

Figure 7: A BIM Model for Tower 6 in Ocean Shores

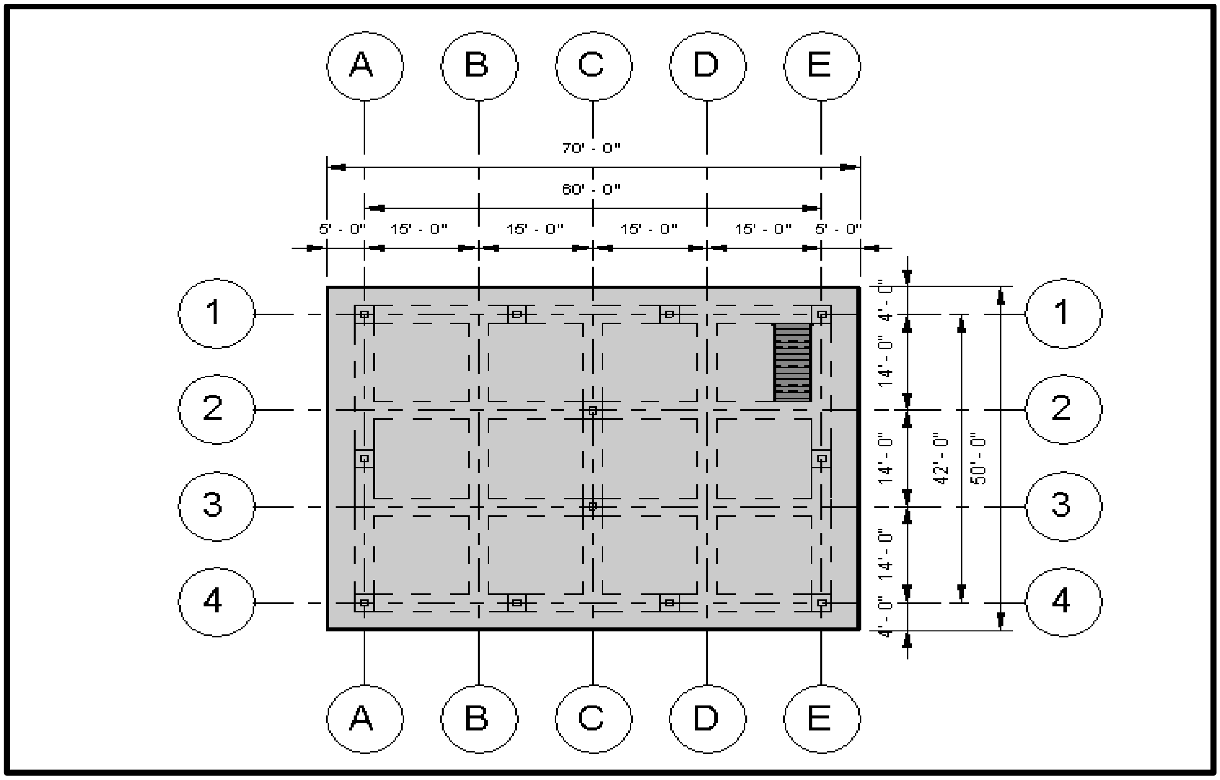

Figure 8: Plan View for Tower 6 in Ocean Shores Generated Using Revit

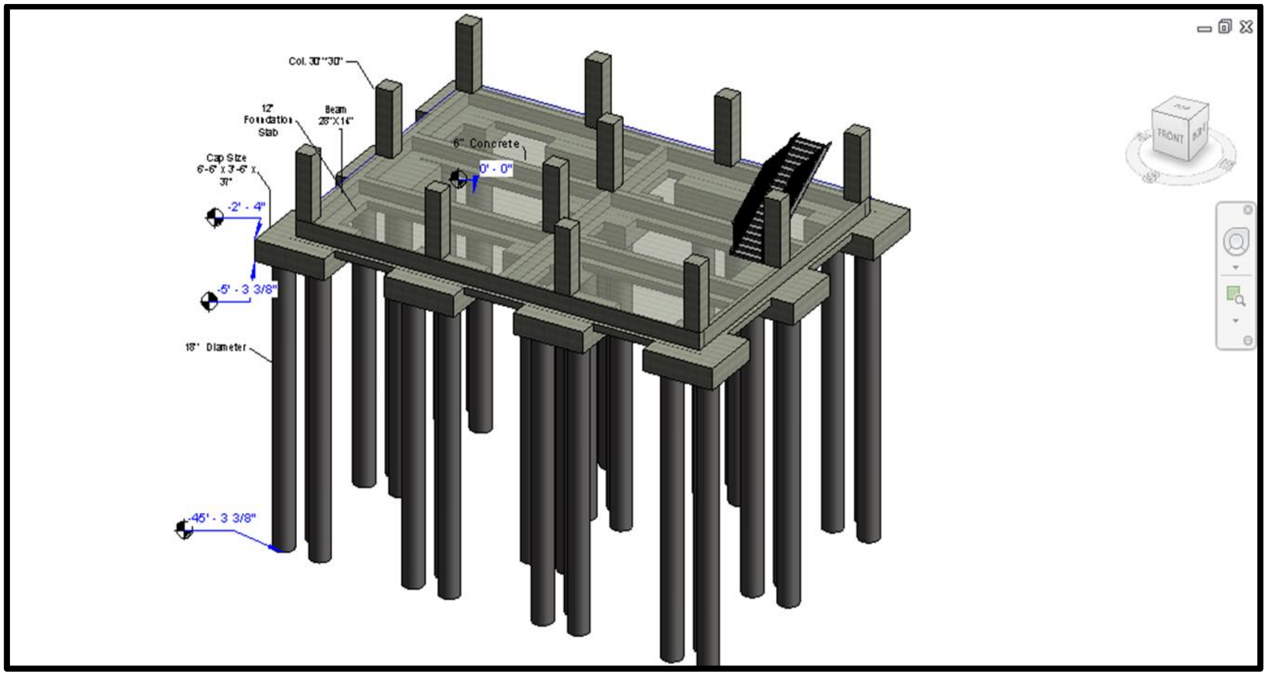

Figure 9: A 3D-Section View for Tower 6 in Ocean Shores Generated Using Revit

2.6 Projecting the Developed BIM Models

The objective of this task is to project the developed BIM models in Google Earth in order to visualize how the proposed structure fits within its environmental and built environment contexts. The projection is implemented in four main steps. The first step is to export the developed Revit model to an AutoCAD 3D drawing. For instance, the generated AutoCAD 3D model for Tower 6 in Ocean Shores in Gray Harbors County is shown in Figure 10.

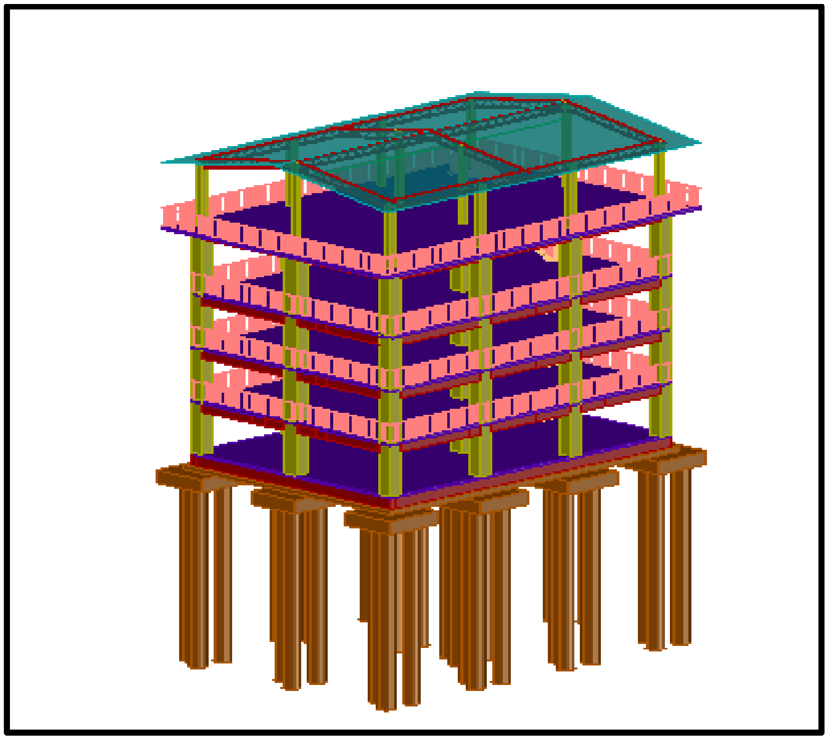

Figure 10: An AutoCAD 3D Model for Tower 6 in Ocean Shores

Second, the AutoCAD 3D model is imported into Sketch UP Pro. The Sketch UP model for Tower 6 in Ocean Shores in Gray Harbors County is shown in Figure 11. The third step is to define the geo-locations of the safe haven structures using Sketch UP Pro. The model is then exported in the KMZ format.

Fourth, the model in KMZ format is imported into Google Earth Pro. Google Earth Pro enables the user to present the model with the surrounding environment. The projected model in Google Earth for Tower 6 in Ocean Shores in Grays Harbor County is shown in Figure 12. Annex B presents all the projected BIM models in Google Earth.

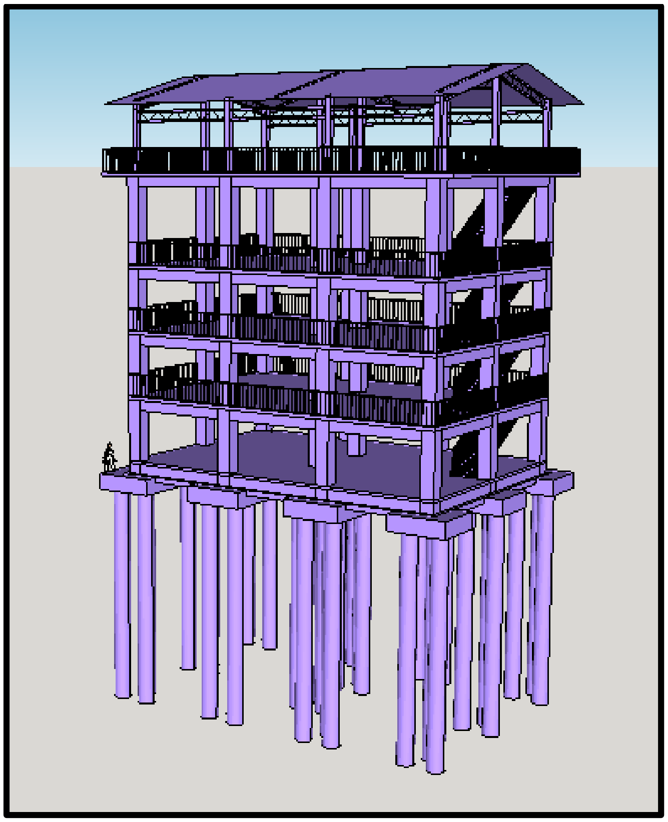

Figure 11: Sketch UP Model for Tower 6 in Ocean Shores

Figure 12: The BIM Model Projected in Google Earth for Tower 6 in Ocean Shores

2.7 Performing Quantity Surveying

This task aims at performing quantity surveying for all the proposed safe haven structures. To this end, each structure is broken down into a number of main items, where the level of breakdown depends on the selected type of conceptual cost estimating for that type of structures. For instance, a fire station type of building was conceptually cost estimated using a parametric method, which did not require breaking down the project. This is attributed to the availability of parametric cost estimates for this type of structures in cost-estimating reference books. Whereas, a berm was conceptually cost estimated by breaking it down into work packages, calculating the quantities of materials and work for each work package, and estimating the corresponding costs. This level of detail was necessary because of the lack of parametric cost estimates to berms. Most structure types need this level of details, including towers and berm-towers. However, in the case of towers, a higher level of work breakdown was sufficient in some components because of the availability of cost estimates at the assemblies' level.

Accordingly, for each structure quantity surveying was conducted by calculating the values of the parameters, or the quantities of the assemblies and work packages, as necessary. The developed BIM models facilitated the quantity surveying at the assemblies and work packages level for structures where a model was developed.

2.8 Performing Conceptual Cost Estimation

A conceptual cost estimate was developed for each proposed safe haven. As previously mentioned and depending on the structure type, different cost estimating methods were used such as parametric cost estimating and estimating the cost of assemblies and work packages. RSMeans Building Construction Cost Data (2016), RSMeans Assemblies Cost Data (2016), and RSMeans Square Foot Costs (2016) were used to include the most recent cost estimates.

Tables 8, 9, 10, and 11 present a comparison between the costs estimates of the proposed safe havens based on their old heights for the 500-year model and according to the calculated new heights for the 2,500-year model. These costs also account for some changes in the design to accommodate the new heights as well as the increase in unit costs to represent the 2016 estimates. These four tables present the conceptual cost estimates by structure types; namely, for berms, towers, tower-berms, and fire stations and parking garages. Annex 3 shows the calculations that resulted in the conceptual cost estimate for each safe haven.

Table 8: Conceptual Cost Estimates for All Berms

Map Number	*City*	*County*		*Capacity*	*Total Cost Estimate*	
					Old (2011)	*New*
B1	Long Beach	Pacific County	27.3	480	$659,297	**$1,855,857**
B2	Long Beach	Pacific County	59.0	800	$722,208	**$5,793,358**
B3	Long Beach	Pacific County	30.4	320	$529,345	**$1,579,677**
B4	Long Beach	Pacific County	33.2	560	$577,233	**$2,463,858**
B5	Long Beach	Pacific County	33.9	400	$476,366	**$2,018,885**
B6	Ocean Park	Pacific County	28.3	480	$527,344	**$1,916,623**
B7	Ocean Park	Pacific County	19.0	160	$388,286	**$919,863**
B8	Ocean Park	Pacific County	28.5	160	$507,381	**$1,493,201**
B9	Ocean Park	Pacific County	33.6	120	$769,830	**$1,700,521**
B10	Ocean Park	Pacific County	34.9	320	$423,765	**$1,805,649**
B11	Ocean Park	Pacific County	27.2	320	$822,725	**$1,927,296**
B12	Ilwaco	Pacific County	15.5	320	$529,345	**$922,445**
B13	Ilwaco	Pacific County	17.68	240	$599,130	**$1,043,173**
4	Ocean Shores	Grays Harbor County		800	$659,297	**$8,836,319**
5	Westport	Grays Harbor County		1500	$722,208	**$6,178,192**
2	Taholah	Grays Harbor County		400	$645,834	**$1,804,677**
2	La Push	Clallam County		845	$3,165,246	**$2,883,597**

Table 9: Conceptual Cost Estimates for All Towers

Map Number	*City*	*County*		*Capacity*	*Total Cost Estimate*	
					Old (2011)	*New*
1	Tokeland	Pacific County	19.32	80	$358,023	**$818,847**
2	Tokeland	Pacific County	22.84	120	$425,619	**$1,077,413**
3	Tokeland	Pacific County	29.62	60	$323,501	**$873,062**
4	Tokeland	Pacific County	23.52	80	$359,187	**$825,486**
5	Tokeland	Pacific County	33.56	80	$360,351	**$1,018,043**
1	Ocean Shores	Grays Harbor County		300	$782,212	**$2,827,682**
2	Ocean Shores	Grays Harbor County		500	1,246,299	**$6,232,864**
3	Ocean Shores	Grays Harbor County		1700	$3,339,039	**$19,822,330**
6	Ocean Shores	Grays Harbor County		350	$836,607	**$3,875,230**

8	Ocean Shores	Grays Harbor County		350	$856,037	**$3,881,455**
10	Ocean Shores	Grays Harbor County		350	$836,037	**$3,176,490**
11	Ocean Shores	Grays Harbor County		350	$847,710	**$3,889,042**
12	Ocean Shores	Grays Harbor County		500	$1,228,372	**$2,783,379**
13	Ocean Shores	Grays Harbor County		350	$847,710	**$3,184,142**
16	Ocean Shores	Grays Harbor County		350	$836,607	**$2,561,303**
17	Ocean Shores	Grays Harbor County		350	$836,607	**$3,853,411**
20	Ocean Shores	Grays Harbor County		350	$836,607	**$3,167,347**
1	Westport	Grays Harbor County		1500	$2,815,371	**$10,065,629**
3	Westport	Grays Harbor County		900	$1,762,672	**$6,151,377**
4	Westport	Grays Harbor County		900	$1,776,117	**$7,514,524**
6	Westport	Grays Harbor County		900	$1,762,672	**$7,514,036**
7	Grayland	Grays Harbor County		550	$1,311,608	**$4,795,827**
8	Grayland	Grays Harbor County		550	$1,325,054	**$4,840,989**
3	Taholah	Grays Harbor County		200	$654,942	**$1,321,012**
1	Neah Bay	Clallam County		660	$447,026	**$3,626,313**

Table 10: Conceptual Cost Estimates for All Tower-Berms

Map Number	***City***	***County***	***Capacity***	***Total Cost Estimate***	
				Old (2011)	***New***
5	Ocean Shores	Grays Harbor County	350	$1,163,273	$4,358,314.90
7	Ocean Shores	Grays Harbor County	350	$1,163,273	$3,593,678.61
9	Ocean Shores	Grays Harbor County	350	$1,163,273	$3,583,854.95
14	Ocean Shores	Grays Harbor County	500	$1,163,273	$5,164,471.40

15	Ocean Shores	Grays Harbor County	350	$1,163,273	$4,456,254.03
18	Ocean Shores	Grays Harbor County	350	$1,163,273	$3,867,491.98
19	Ocean Shores	Grays Harbor County	350	$1,163,273	$3,582,882.32
1	Taholah	Grays Harbor County	300	$1,163,273	$2,718,595.78

Cost estimates of buildings (such as parking garages and fire stations) are multiply by 1.2 as a factor of safety for the additional required buildings strength (FEMA P646).

Table 11: Conceptual Cost Estimates for the Fire station and Parking Garages

Map Number	***City***	***County***	***Capacity***	***Total Cost Estimate***	
				Old (2011)	***New***
9	Grayland	Grays Harbor County	550	$1,384,013	$4,926,431
PK1	Tokeland	Pacific County	800	$1,772,685	$5,021,756
PK2	Tokeland	Pacific County	400	$646,997	$2,546,243

2.9 Prioritizing Safe Havens for Redesign

The calculated cost estimates are based on the designed developed in 2011. These designs took into account design heights based on the 500-year model and the community needs at that time. Since the 2,500-year model resulted in higher (and in some cases, significantly higher) design heights and since the community needs might have changed, some structure might need to undergo a new conceptual design. Accordingly, a list of priority structures is created as a recommendation for a redesign effort. The structured are selected such that (1) they account for all main cities; and (2) they offer the highest capacity (based on the number of evacuees) and/or are located near a school. Tables 12, 13, and 14 list the selected structures for a possible redesign in Pacific County, Grays Harbor County, and Clallam County, respectively.

Table 12: Priority Structures for Redesign in Pacific County

City	***Structure Type***	***Map Number***	***Location***	***Reason for Choice***
Long Beach	Berm	B2	Long Beach, WA, 5th Street South & Washington	Highest Capacity (800)
Ocean Park	Berm	B6	Ocean Park, WA, 227th and U Street	Highest Capacity (480)

Illwaco	Berm	B12	Illwaco, WA, Fire Dept. (N Street & 37th St)	Highest Capacity (320)
Tokeland	Parking Garage	PK1	Tokeland, WA, Shoalwater Bay Casino	Highest Capacity (800)

Table 13: Priority Structures for Redesign in Grays Harbor County

City	***Structure Type***	***Map Number***	***Location***	***Reason for Choice***
Ocean Shores	Tower	3	Ocean Shores, WA, Downtown Ocean Shores	Highest Capacity (1700)
	Berm	4	Ocean Shores, WA, North Beach Junior/Senior High School	School and has high capacity (800)
Westport	Berm	5	Westport, WA, Ocosta School	School and has highest capacity (1500)
Grayland	Tower	8	Grayland, WA, HWY 105	Highest Capacity (550)
Taholah	Berm	2	Taholah, WA, Elementary School	School and has highest capacity (400)

Table 14: Priority Structures for Redesign in Clallam County

City	***Structure Type***	***Map Number***	***Location***	***Reason for Choice***
Neah Bay	Tower	1	Neah Bay, WA, Neah Bay School RC	School and has high capacity (550)
La Push	Berm	2	La Push, WA, Quileute Tribal School	School and has high capacity (845)

Furthermore, some berms might need a redesign using another safe haven type because as their new design height has increased, their footprint has also increased. Accordingly, the available land parcel might not accommodate the new footprint. To this end, the new footprints for all berms have been investigated along with land vacancies using Google Earth. This analysis needs further verification, but the preliminary results are presented in Tables 15, 16, and 17 for Pacific County, Grays Harbor County, and Clallam County, respectively. As shown, two berms in Pacific County are recommended to be changed to towers.

Table 15: The Length of Each Berm in Pacific County

Berm's Map number	***Berm Typology***	***Berm Length (feet)***	***Comments***
B1	A	197.03	***Change to tower***
B2	A	240.59	
B3	A	193.31	***Change to tower***

B4	A	227.67	
B5	A	215.78	
B6	A	201.03	
B7	B	92.65	
B8	B	116.4	
B9	B	123.1	
B10	A	211.31	
B11	B	131.8	
B12	A	133.71	
B13	B	99.49	

Table 16: The Length of Each Berm in Grays Harbor County

Berm's Map number	***Berm Typology***	***Berm Length (feet)***	***Comments***
Ocean shores "4"	B	245.45	
Westport "5"	B	223.98	
Taholah "2"	B	129.37	

Table 17: The Length of Each Berm in Clallam County

Berm's Map number	***Berm Typology***	***Berm Length (feet)***	***Comments***
2	B	149.19	

A revised conceptual cost estimate is developed for each of the two berms that are recommended to be changed to towers. Table 18 presents the revised cost estimates.

Table 18: Conceptual Cost Estimates for Berms Recommended to be Converted to Towers

Map Number	***City***	***County***	***Capacity***	***Total Cost Estimate***	
				Old (2011)	***New***
1	Long Beach	Pacific County	480	$659,297	**$4,235,933**
3	Long Beach	Pacific County	320	$529,345	**$2,944,806**

2.10 Design and Cost Estimation for Fire Department Training Tower in Long Beach

The fire department in Long Beach is considering developing a tsunami safe haven within a new building intended to be used for training activities. The proposed location is at the North-East corner of Pacific Way and 168th Ln, Long Beach, WA. Accordingly, a brief design charrette was conducted to identify the optimal design for the proposed building in terms of its day-to-day function as well as potential use as a safe haven.

First, the specific location of the building was used to identify an expected flow depth of about 20' in a tsunami event, as shown in Table 19 and Figures 13 and 14. Accordingly, the required design height is 36'. The building is proposed as a four-story training tower 36 feet high designed as an open steel frame 40 x 60 feet in floor area. The first floor height is 12' and remaining floors are 8' each. The structure includes lateral bracing and sheer wall on two of its sides. There are two access options:

1. A six feet wide steel staircase on inside of structure (at one corner), as shown in Figure 15.
2. A six feet wide steel staircase on inside of structure (at one corner) in addition to a ramp, which can have one of three options as follows:
    a) The ramp is along the 40 feet side with 1:8 rise, as shown in Figure 16.
    b) The ramp is wrapped around the corner in proximity to interior stair tower with 1:8 rise, as shown in Figures 17 and 18.
    c) The ramp is approximately 324 feet long, consisting of a steel structure, and begins at the front portion of the site extending to the structure in a linear configuration and culminating at the rear end where east corner of the structure is. This design is shown in Figures 19 and 20.

Table 19: Point Flow Depth and Calculated Design Height

Longitude (E,W)	Latitude (N,S)	Flow Depth (cm)	Flow Depth (feet)	Design Height (feet)
-124.051152	46.423532	600.42	19.97	36.0

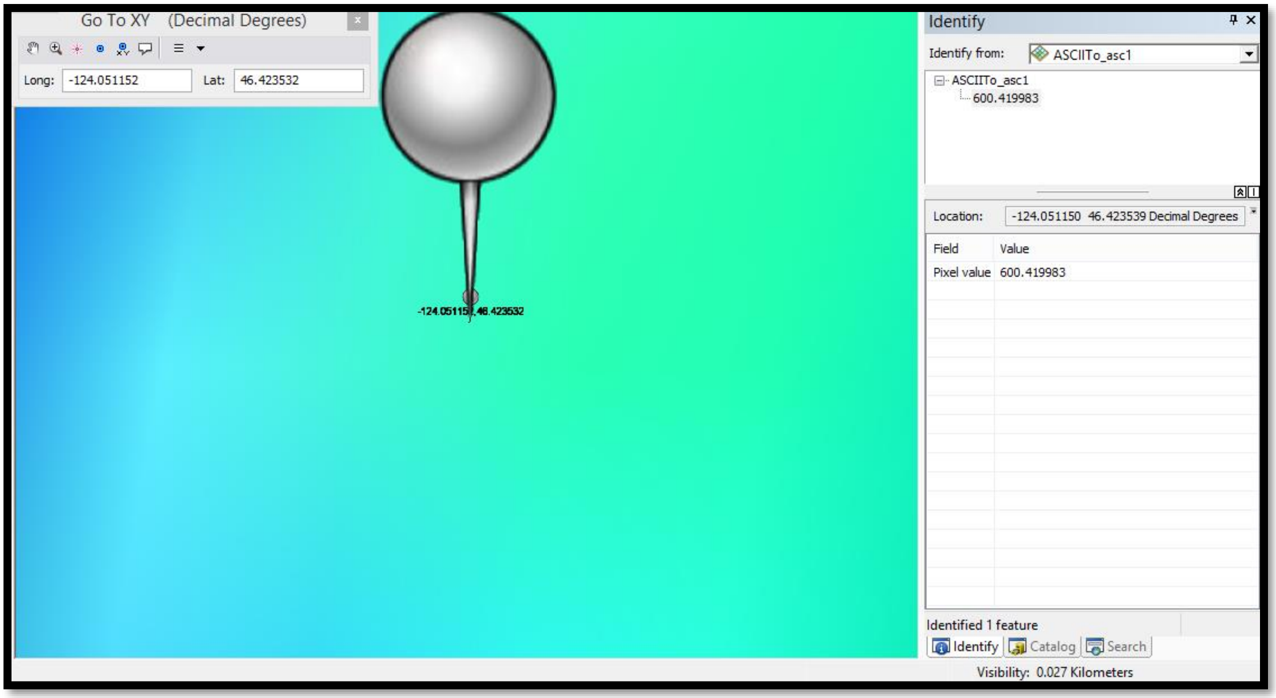

Figure 13: Location of the Proposed Site in the Inundation Model

Figure 14: Location of the Proposed Site in Google Earth

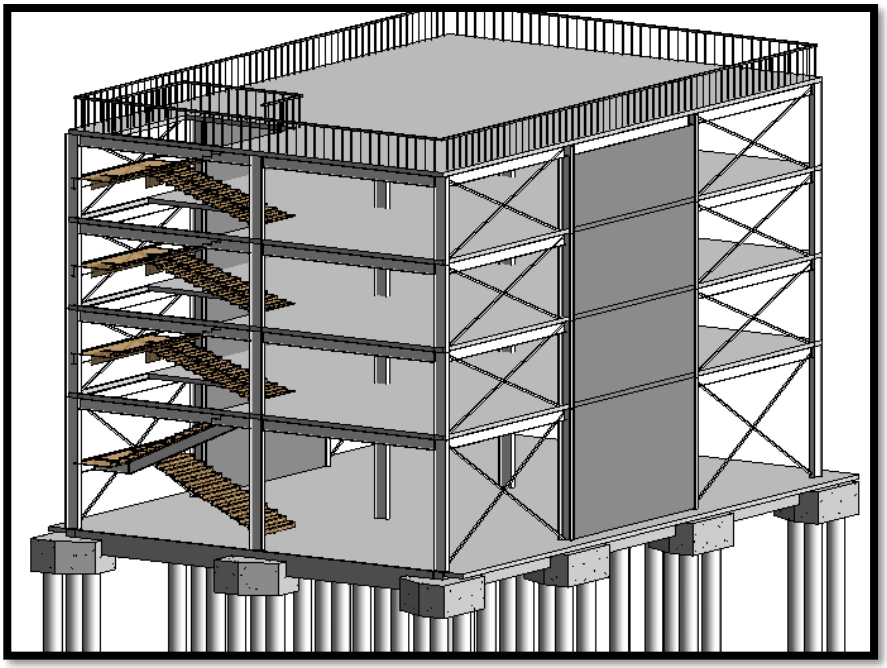

Figure 15: Option 1: A Six Feet Wide Steel Staircase on Inside of Structure (One Corner)

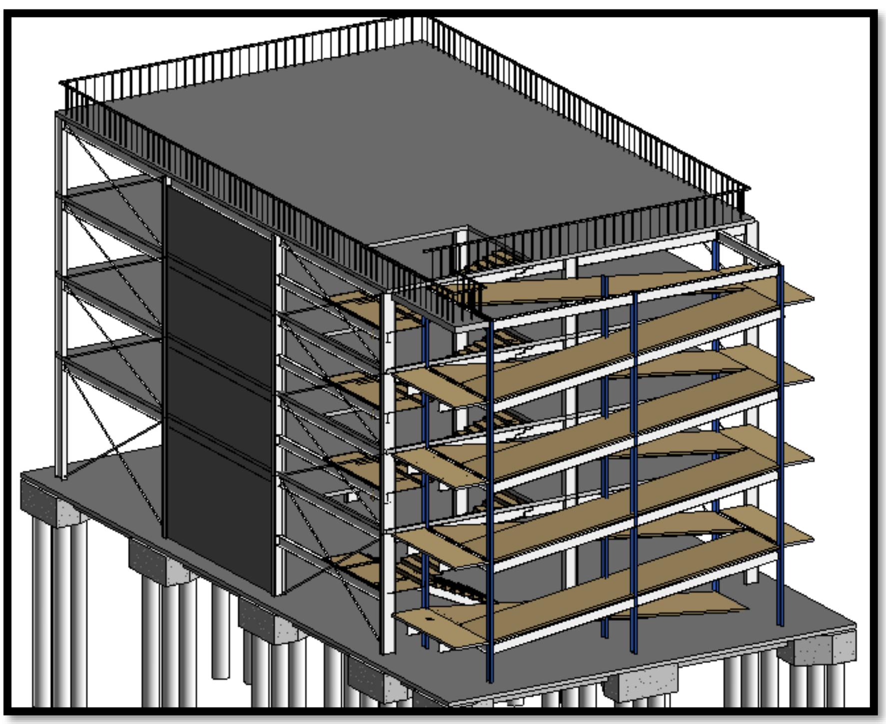

Figure 16: Option 2-a): 4’ Ramp Runs Along the 40 feet side in Proximity to Interior Staircase

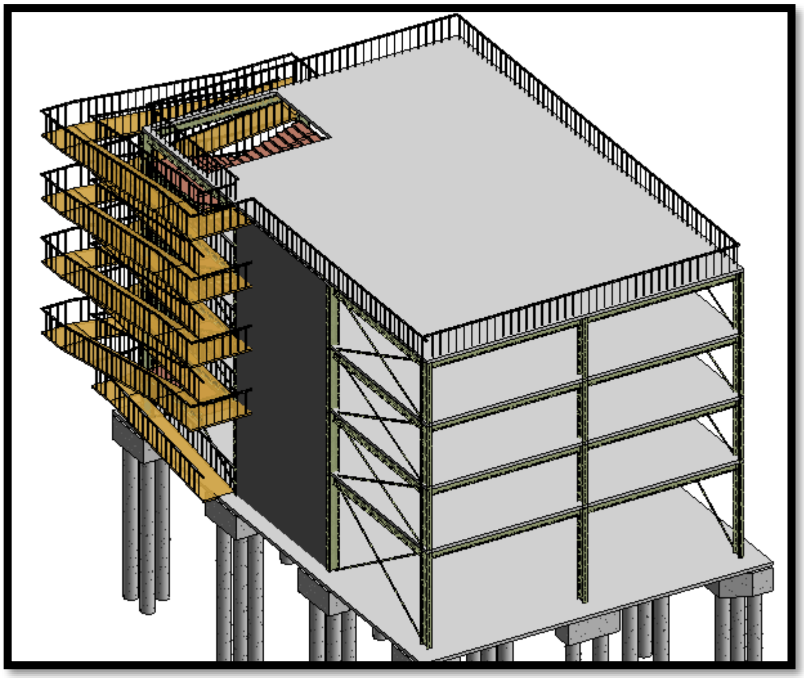

Figure 17: Option 2-b): 4' Ramp Wrapped Around Corner in Proximity to Interior Staircase

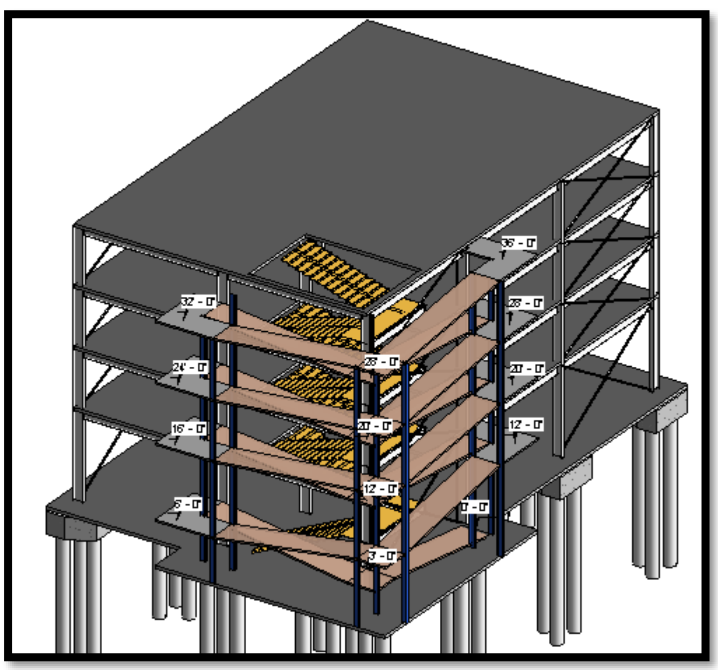

Figure 18: Option 2-b): 4' Ramp Wrapped Around Corner in Proximity to Interior Staircase (Showing Structural Support for the Ramp)

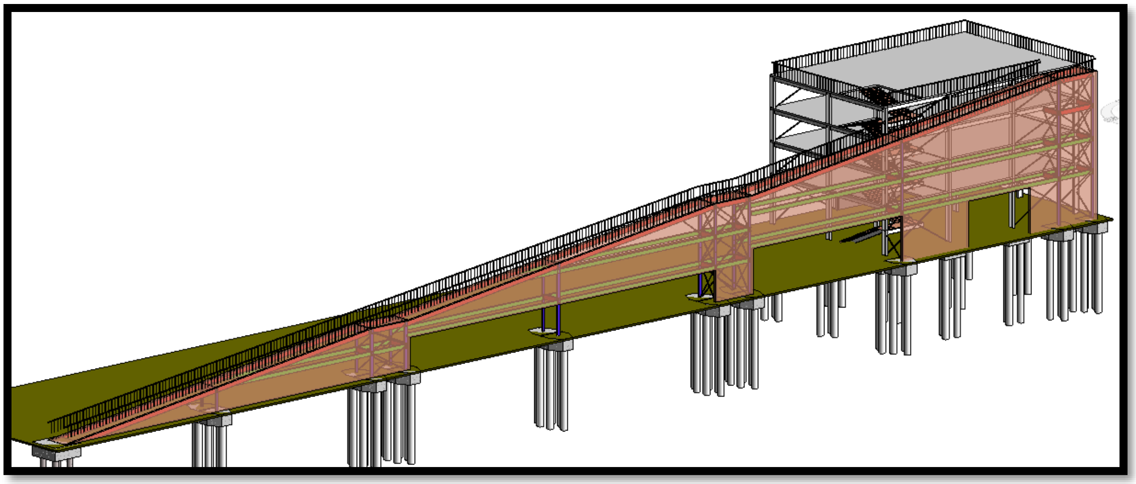

Figure 19: Option 2-c): 4’ Ramp Approximately 324 feet Long Showing Metal Cladding

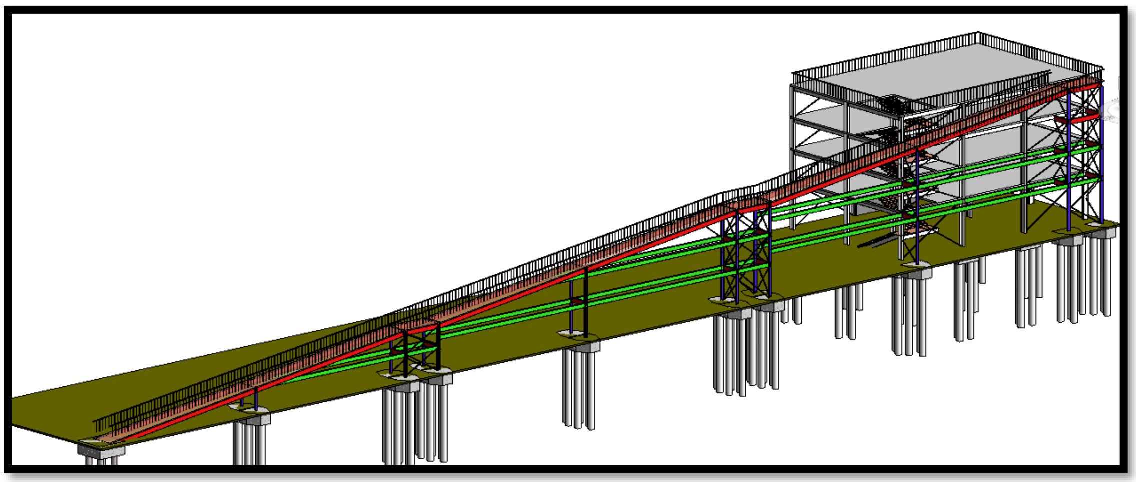

Figure 20: Option 2-c): 4’ Ramp Approximately 324 feet Long Hiding Metal Cladding

3D BIM Models (as shown in Figures 15 to 20) were created to support in visualizing the proposed designs and the corresponding cost estimates for each alternative. The conceptual cost estimate for all design options were calculated and summarized as shown in Table 20. It is noted that the roof is not shown in these figures, but is accounted for in the cost estimates.

Table 20: The Conceptual Cost Estimate for All Options

Design Option	Conceptual Cost Estimate (USD)
1 (Figure 15)	$2,436,848
2-a (Figure 16)	$3,218,965
2-b (Figures 17 and 18)	$3,394,616
2-c (Figures 19 and 20)	$4,360,857

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Annex A: Developed BIM Models for Selected Safe Haven Structures

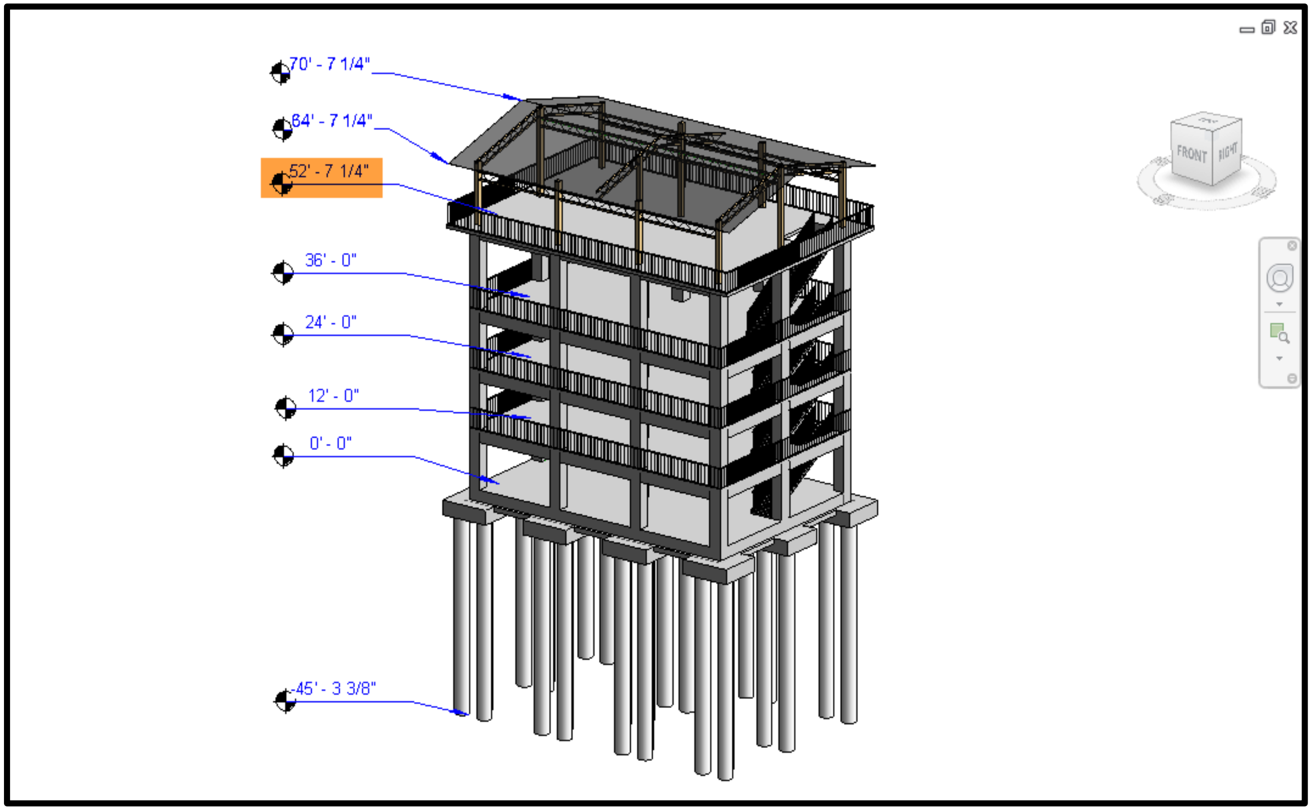

Figure 21: BIM Model for Tower 8 in Ocean Shores

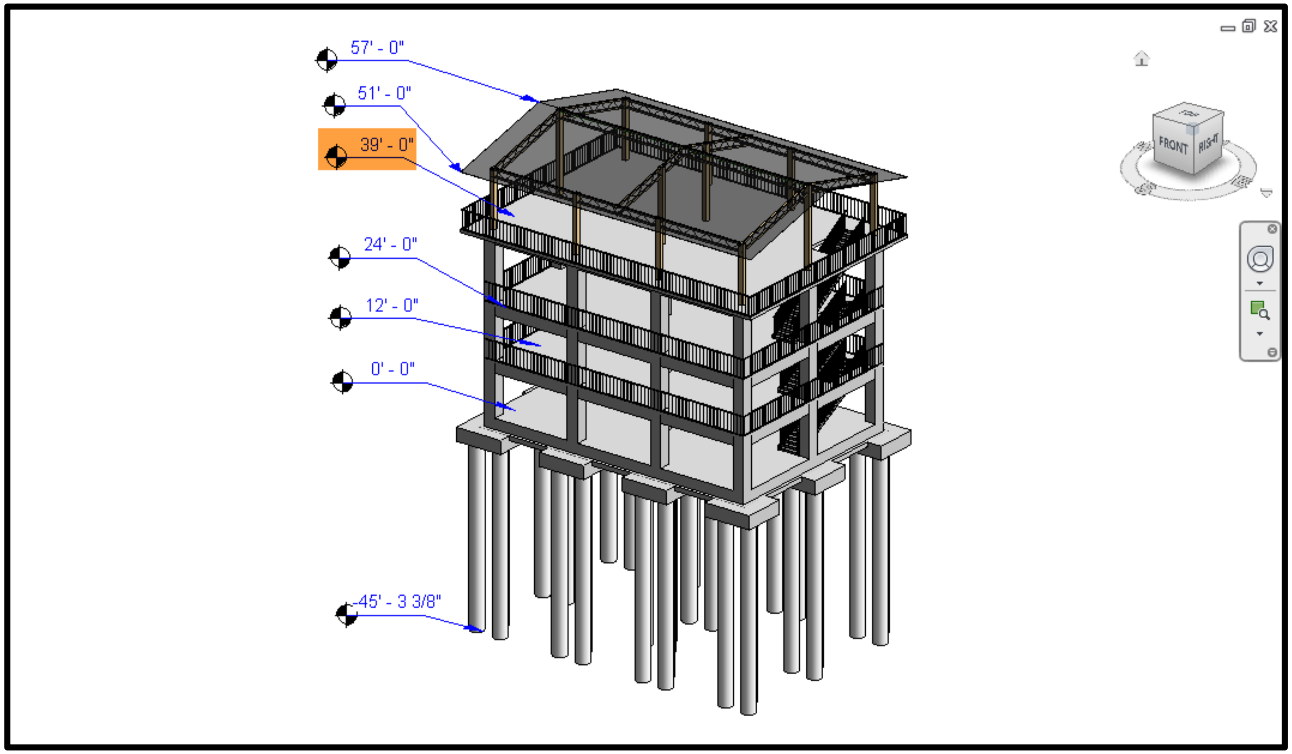

Figure 22: BIM Model for Tower 10 in Ocean Shores

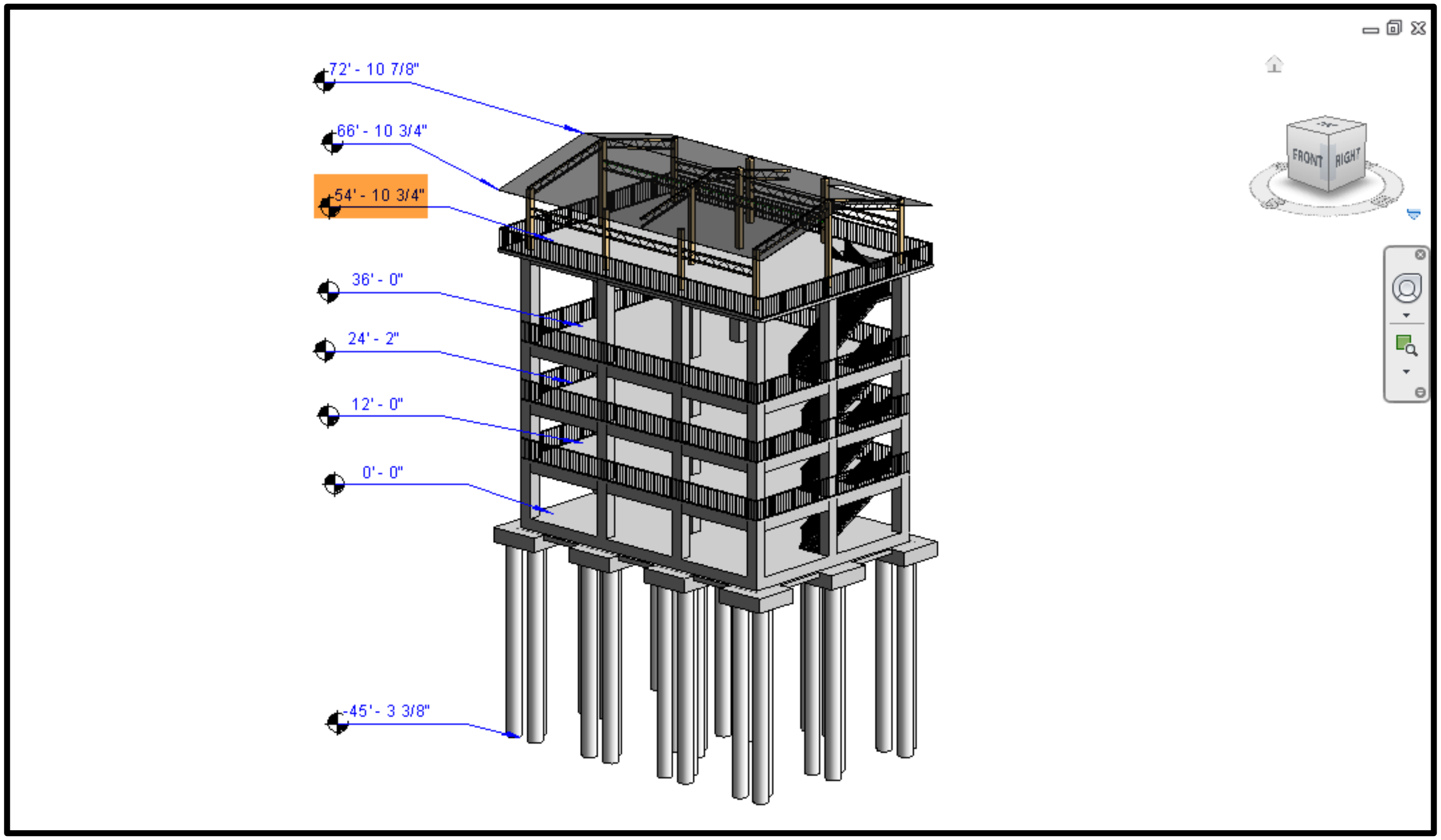

Figure 23: BIM Model for Tower 11 in Ocean Shores

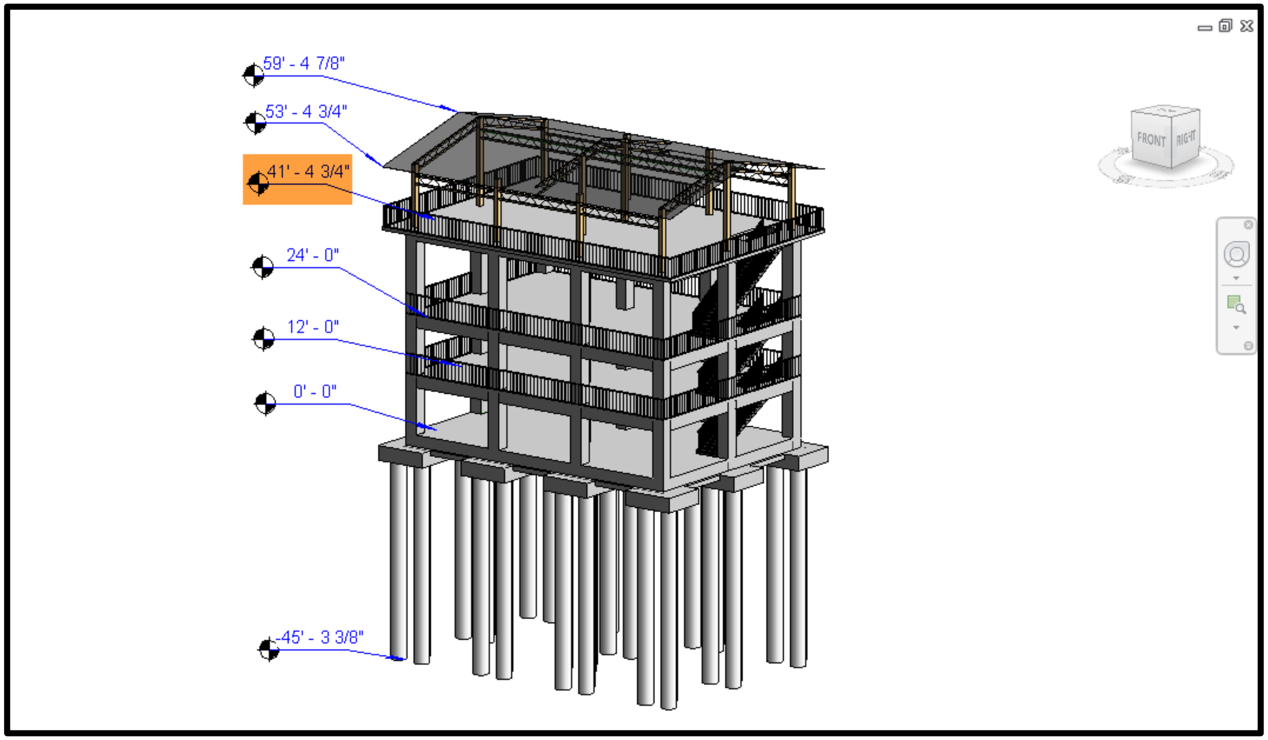

Figure 24: BIM Model for Tower 13 in Ocean Shores

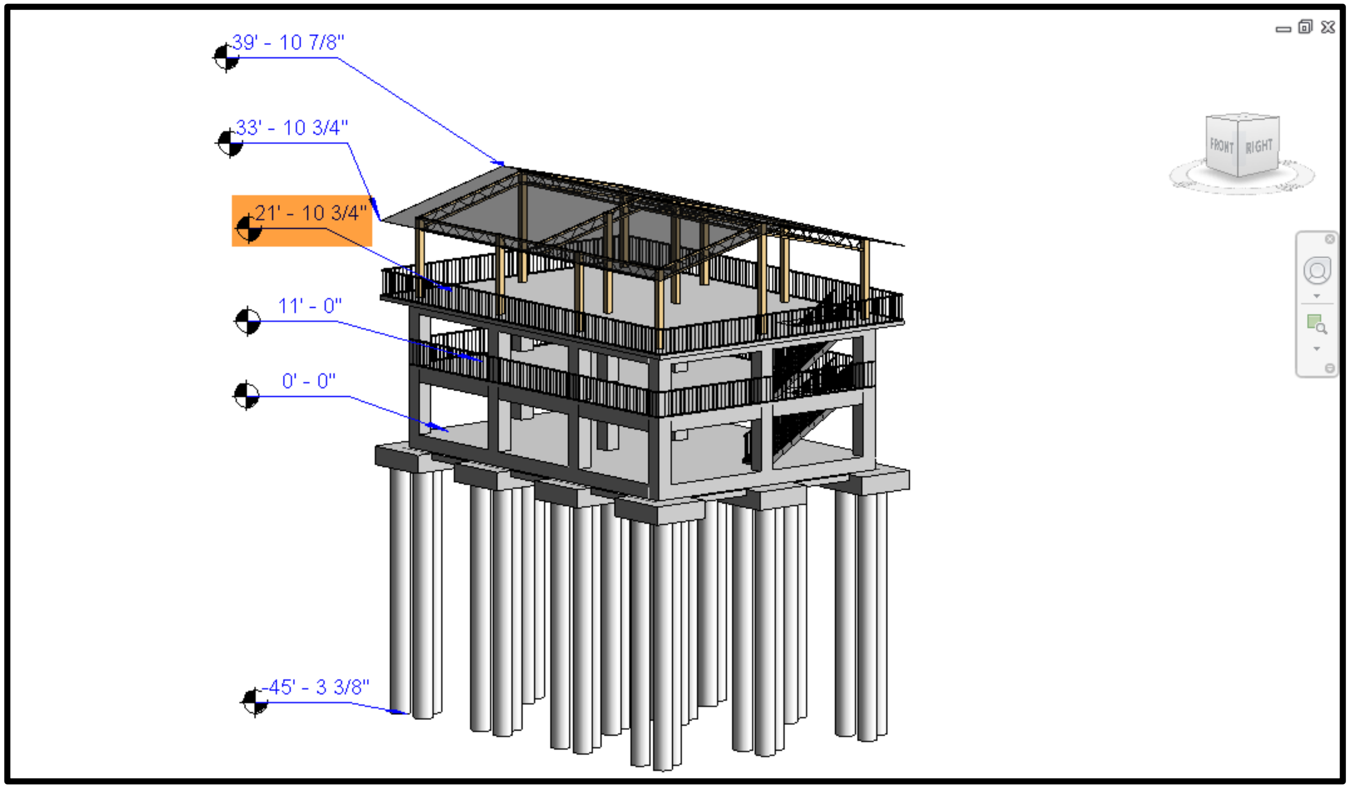

Figure 25: BIM Model for Tower 16 in Ocean Shores

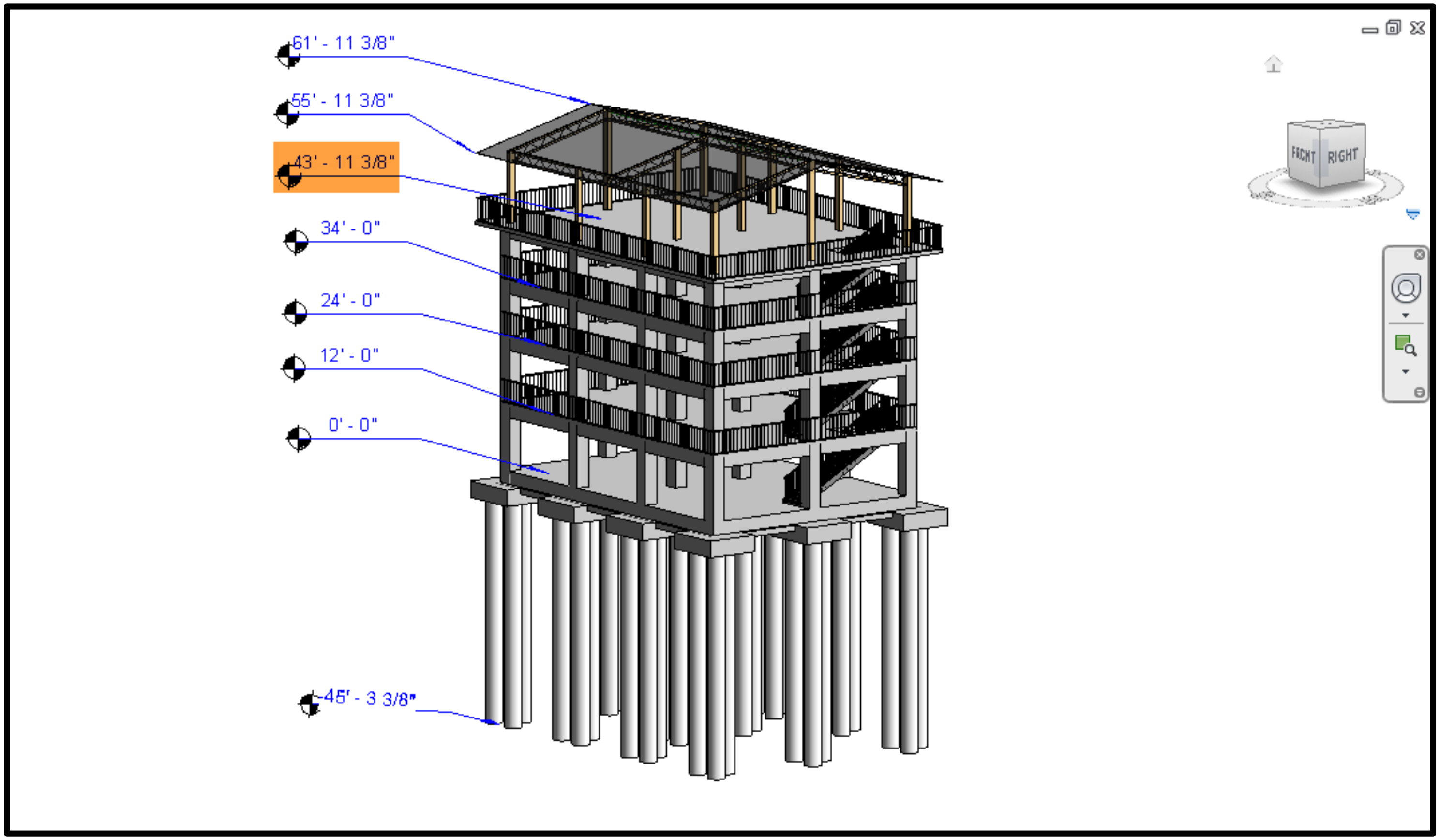

Figure 26: BIM Model for Tower 17 in Ocean Shores

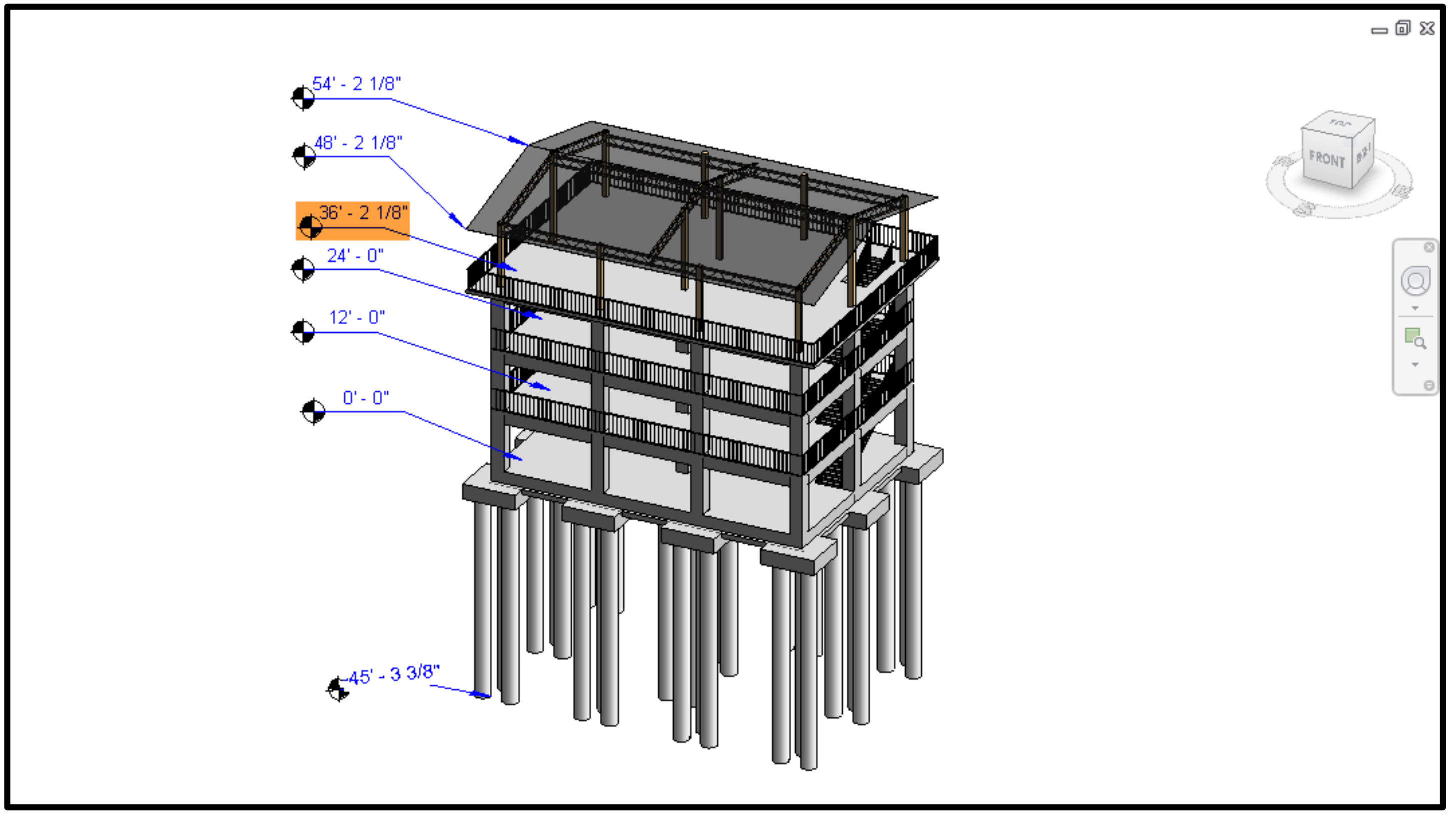

Figure 27: BIM Model for Tower 20 in Ocean Shores

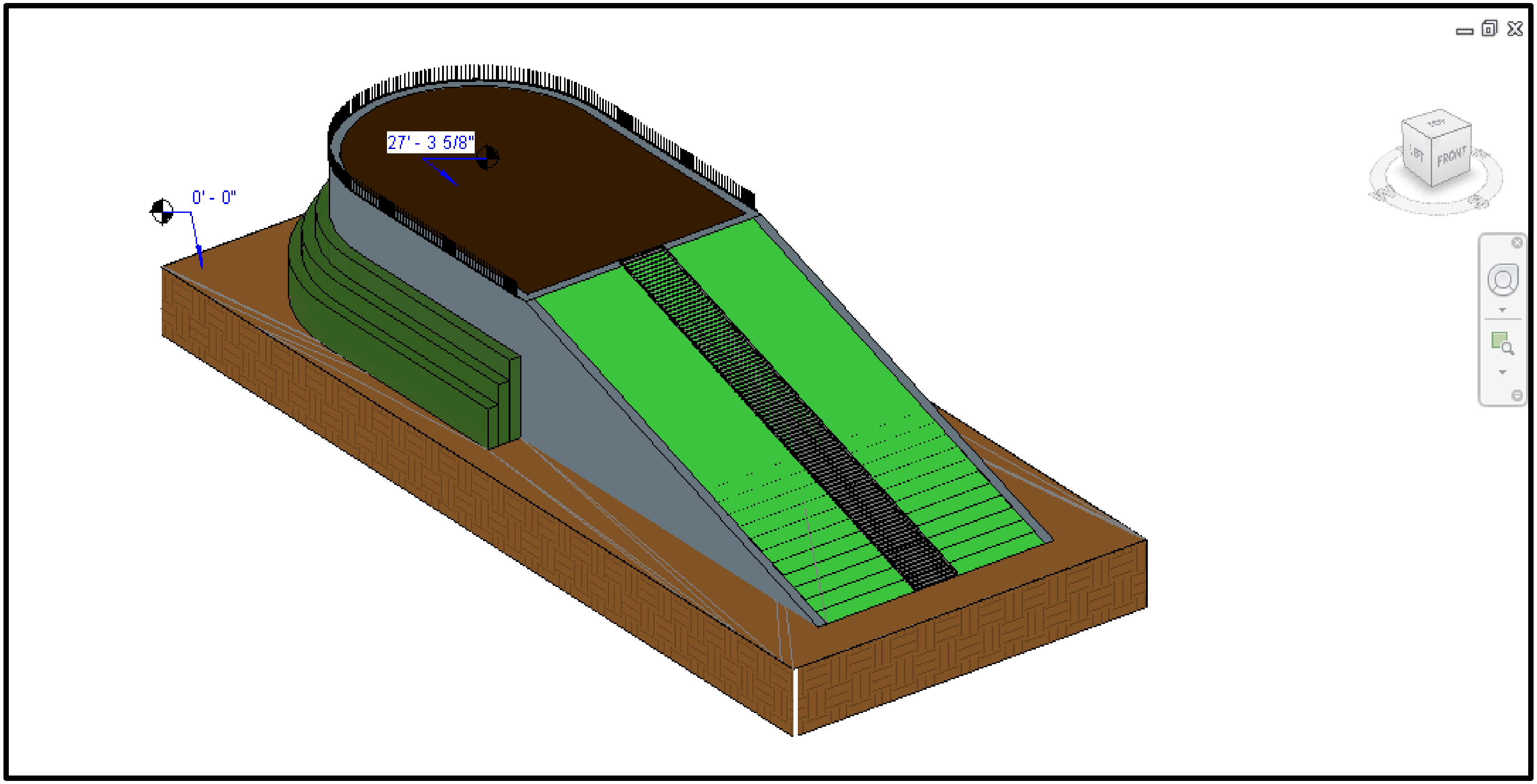

Figure 28: BIM Model for Berm 1. Long Beach, WA, N Place & 41st Place

Annex B: BIM Models Projected in Google Earth

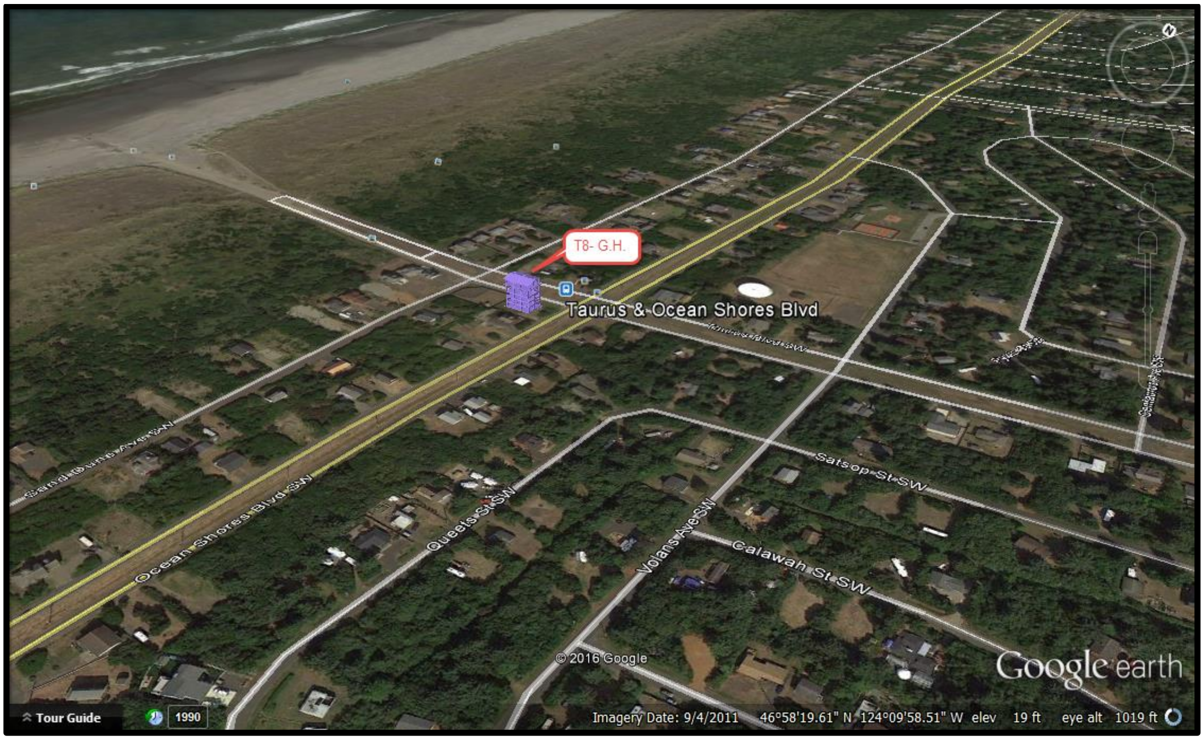

Figure 29: BIM Model Integrated with Google Earth for Tower 8 in Ocean Shores

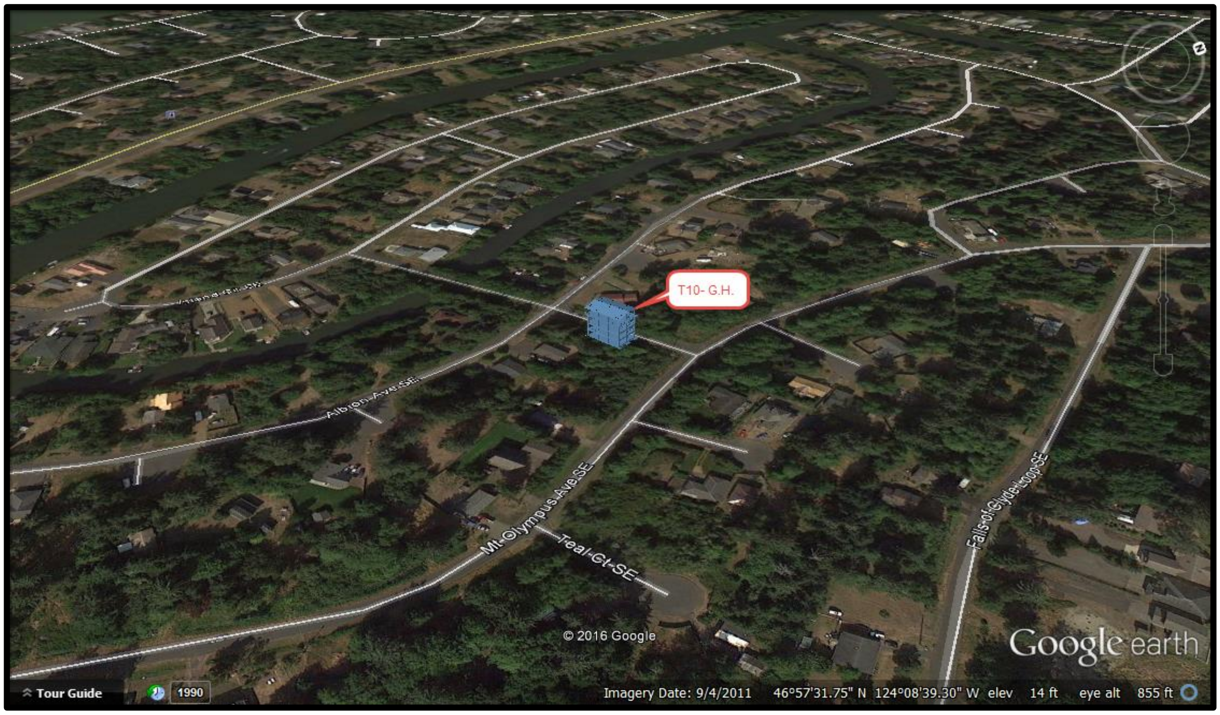

Figure 30: BIM Model Integrated with Google Earth for Tower 10 in Ocean Shores

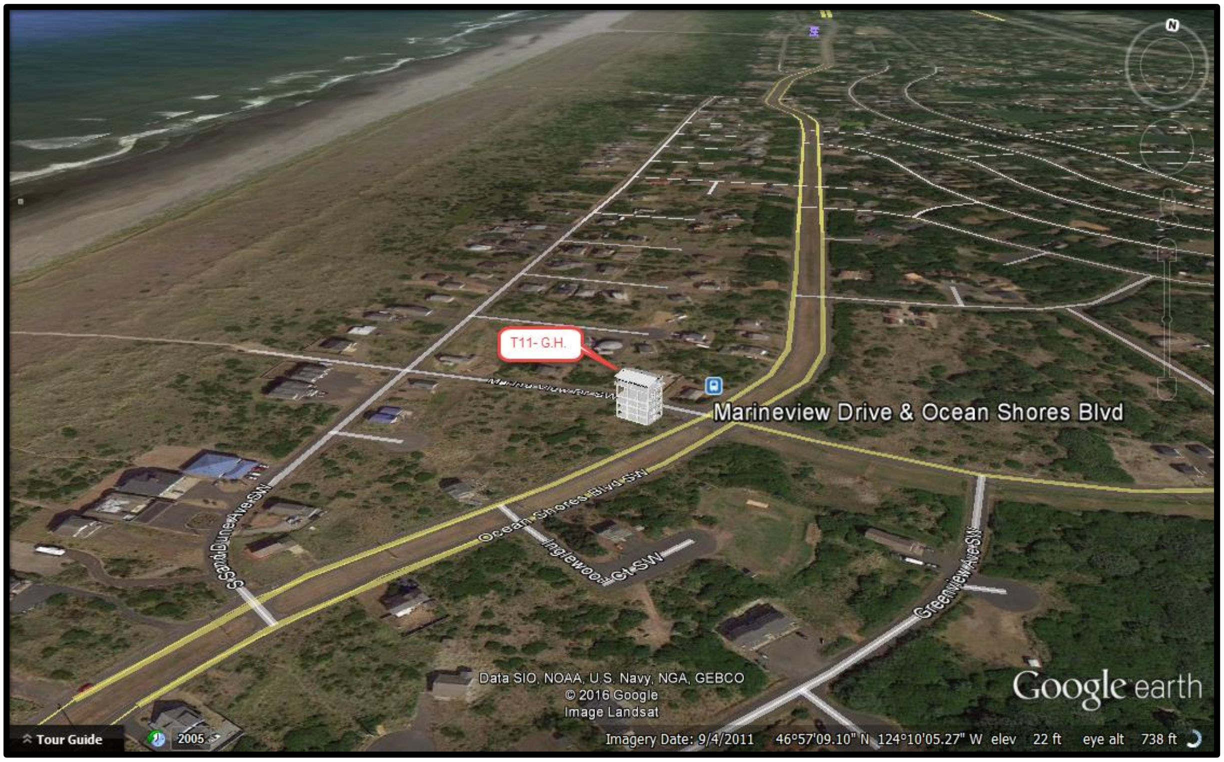

Figure 31: BIM Model Integrated with Google Earth for Tower 11 in Ocean Shores

Figure 32: BIM Model Integrated with Google Earth for Tower 16 in Ocean Shores

Figure 33: BIM Model Integrated with Google Earth for Tower 17 in Ocean Shores

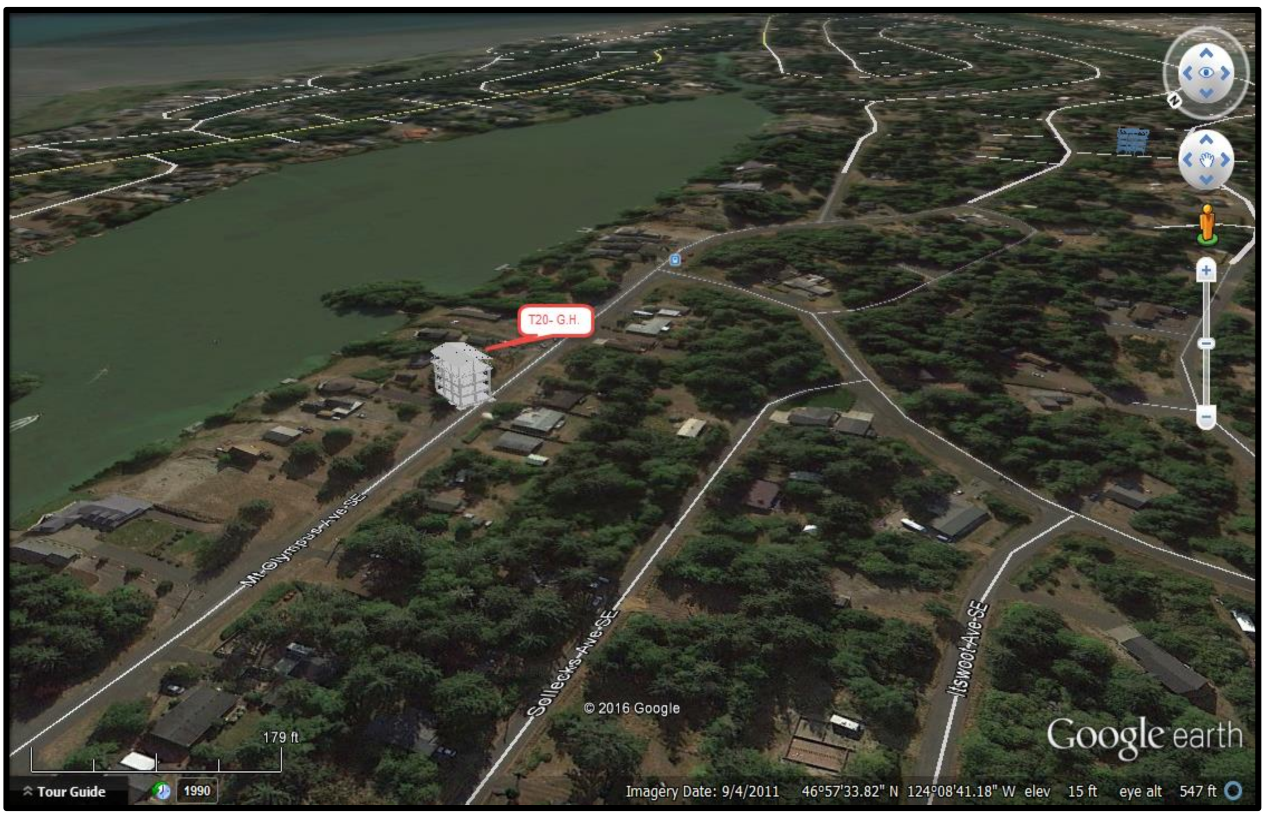

Figure 34: BIM Model Integrated with Google Earth for Tower 20 in Ocean Shores