Beach Boulevard Infrastructure Resiliency Project

Feasibility Analysis of Project Alternatives

Draft Report

April 2021

City of Pacifica, CA

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1. Executive Summary

The Beach Boulevard Infrastructure Resiliency Project (BBIRP, or Project) aims to create a multi-benefit solution to protect public infrastructure, recreational activities, and the community at large, from further coastal hazard impacts along Beach Boulevard, including risks associated with future sea level rise (SLR). Protection and safety of people, homes and businesses from coastal hazards was the most expressed community concern received in an online public survey conducted for this Project (Kearns & West, 2020). The community also expressed concern over the costs of adaptation and the potential impacts on environmental resources, especially when factoring in anticipated sea level rise over the Project's duration.

The purpose of this report is to present a preliminary design of each alternative being considered for the BBIRP along with an assessment of the technical performance, financial implications, and environmental considerations associated with each alternative. These categories and their criteria were developed to reflect the Project objectives and public feedback gathered in the online survey and three public workshops. This report builds off of previous work, which includes the Existing Conditions Report and the Multi-Hazard Risk Assessment (MHRA)[1]. The MHRA provided a comprehensive analysis of natural hazards and the loss of infrastructure and resources along Beach Boulevard under a No Project alternative. The study found that risks of primary concern include damage from coastal flooding, erosion, and earthquake hazards. The understanding of these risks was used to inform the development and comparison of alternatives.

The selected alternatives are consistent with the Coastal Resilience policies described in the Local Coastal Land Use Plan (LCLUP) Certification Draft and include No Project, Beach Nourishment, Seawall, Rock Revetment and Sand Retention. The alternatives evaluated in this report have been developed to reduce the frequency of coastal flooding events and the volume of wave overtopping during these events. Beach Nourishment and Sand Retention alternatives rely on the sandy beach to provide a buffer against storm wave energy. Structural alternatives (i.e. Seawall and Rock Revetment) rely on the stability of the structure to withstand wave forces with a high enough crest elevation to satisfy the preliminary design criteria.

The preliminary design criteria used to develop the alternatives consists of 2 feet of SLR in combination with a 60-year storm event, with an anticipated design life of 50 years. Though it is unlikely that SLR will exceed 2 feet before 2070, there is a possibility it could occur sooner, based on the current projections (OPC, 2018). Once a preferred alternative is selected and advanced through permitting and detailed design, a phased adaptation plan will be developed to provide a roadmap for adapting to higher SLR scenarios than built into the initial Project. This plan is necessary to demonstrate consistency with the coastal resilience policies of the LCLUP and State SLR guidance documents (CCC and OPC, 2018) which recommend consideration of the full range of SLR projections over a project's design life.

[1] Public review draft available at: https://www.cityofpacifica.org/civicax/filebank/blobdload.aspx?t=40180.24&BlobID=18221

A multi-criteria analysis (MCA) was performed to analyze each alternative against a wide range of criteria that reflects the diversity of input received during the Project's public engagement activities. Each alternative was evaluated against 13 criteria, organized into three categories of Technical Performance, Financial, and Environmental. The maximum potential score for each alternative (up to 100%) is a function of how well the alternative satisfies the criteria within these categories. The results presented in this report are based on a category weighting of 40/30/30 (Technical/Financial/Environmental). In other words, the Technical Performance category has a maximum score of 40%, Financial and Environmental criteria each account for up to 30% of the total score.

The MCA weighting and scoring process occurred during multiple interactive workshops with Project team members from the City and consulting team with technical, financial and environmental expertise. The goal of these workshops was to incorporate thoughts and opinions from a diverse group of Project team members in an effort to reduce individual bias and subjectivity from influencing the results. The results of the MCA scored the Seawall alternative higher than the Revetment and Beach Nourishment alternatives, as shown in Table ES-1 below.

Table ES-1: Summary of Multi-Criteria Analysis

Category	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
	No Project	**Beach Nourishment**	**Seawall**	**Revetment**	**Sand Retention**
TECHNICAL PERFORMANCE (40%)	10%	23%	35%	33%	26%
FINANCIAL (30%)	12%	17%	23%	26%	13%
ENVIRONMENTAL (30%)	13%	26%	17%	12%	24%
Total Weighted Score out of 100%	**36%**	**66%**	**75%**	**71%**	**63%**
Ranking	**5**	**3**	**1**	**2**	**4**

The close rankings between Seawall, Revetment and Beach Nourishment warranted some sensitivity analysis of both scoring and weighting of the various criteria (e.g. flood protection, costs, recreation potential, etc). Findings from the sensitivity analysis determined that changing a single score within these criteria would only result in a marginal difference in the total score and would not affect the overall ranking of the alternative.

Sensitivity of Category Weightings was another area of interest to understand how the breakdown between Technical Performance, Financial and Environmental influences overall results. Five different combinations of category weightings were evaluated to gauge the sensitivity of the results. When these weightings are modestly adjusted a clear pattern emerges in which Seawall is consistently scored highest and No Project is consistently scored lowest. Variation of the rankings could change if significant changes were made in the weighting between each category. However, in the MCA workshop, the consensus of the Project team was that Technical performance warrants a slightly higher emphasis because its' criteria closely match the Project objectives and provides the best indicator for Project success.

The findings of the MCA suggest that an improved Seawall is a key element of the preferred alternative. The Seawall alternative was the highest scoring alternative in terms of Technical

Performance with the second highest score in Financial and a median score in Environmental. Revetment scored highest in the Financial category, but was lowest in the Environmental category, an indication this alternative would be very difficult to permit and costly to mitigate. The Beach Nourishment option received the highest Environmental category score, but a relatively low score in Technical Performance, largely due to reliability concerns.

In review of the opportunities and constraints of each option, there is the possibility that a hybrid alternative may prove to be the most technically, economically, and environmentally feasible option. A hybrid alternative that combines an improved seawall with a beach nourishment program could leverage the benefits of each of these alternatives to better align with the Project objectives and diverse interests and priorities within the community. If the Project team determines this is a viable alternative and worth consideration, the next step would be to develop and analyze the hybrid alternative in a similar manner as the other alternatives through the multi-criteria analysis. In addition, the Project team would begin preliminary consultation with regulatory agencies about all of the alternatives. Following further analysis and preliminary consultation with regulatory agencies, a preferred alternative will be identified by the Project team and presented to the City Council for advancement into the next Project phase (Environmental Studies, Permitting and Design).

2. Introduction

As part of the Beach Boulevard Infrastructure Resiliency Project (BBIRP, or the Project) the City of Pacifica (City) is in the process of completing a feasibility study to replace the existing Beach Boulevard Seawall. The current seawall infrastructure, built in the 1980s, has experienced failures in multiple locations and continues to be a public health and safety risk for the City. To protect the West Sharp Park neighborhood from future damaging coastal events, the City must be proactive and expedient in the approach to evaluating alternatives and implementing a solution.

The primary purpose of the Project is to:

- create a multi-benefit solution to protect public infrastructure, recreational activities, homes, businesses, and the community at large, from further coastal erosion impacts;
- ensure public health and safety in the general vicinity of Beach Boulevard including the West Sharp Park neighborhood;
- improve public access and use of the Beach Boulevard Promenade and the beach; and
- build climate resilience into one of the most vulnerable segments of the City's shoreline.

The Project is an example of how the City is taking proactive steps to adapt to current and projected future coastal hazards associated with sea level rise. These proactive steps will minimize impacts from coastal flooding and erosion on the infrastructure and resources along the Beach Boulevard corridor.

2.1 Project Location

The Project is located in northern Pacifica along a 0.5-mile stretch of coast along the western edge of the historic West Sharp Park neighborhood. This area runs parallel to Beach Boulevard just west of Highway 1 and the Palmetto Shopping District. The general Project vicinity, and Project boundary, is presented in Figure 2-1. The Project involves assessing the entire span of the current infrastructure and seawall which includes four different segments of shoreline, each with a different types of shoreline protection as described below:

1. **North wall:** Combination of armor stone revetment and concrete reinforced earth seawall.
2. **Pier abutment wall:** Steel sheet pile backed by a soil cement wall and repaired with an internal reinforced concrete wall.
3. **South wall:** Combination of armor stone revetment and concrete panel seawall.
4. **South gap:** A gap in structural shoreline protection centered at the western terminus of Clarendon Avenue between South Wall and Sharp Park Golf Course rock embankment/levee.

Figure 2-1 Project Location Map

2.2 Alternatives Analysis Approach

The MHRA (GHD, 2021) provided a comprehensive analysis of natural hazards and the loss of infrastructure and resources along Beach Boulevard under a No Project alternative. Risks of primary concern include damage from coastal flooding, erosion, and earthquake hazards. The understanding of these risks was used to inform the development and comparison of alternatives. The purpose of this report is to present a preliminary design of each alternative and an assessment of the technical performance, financial implications, and environmental considerations associated with each alternative. These categories and their criteria were developed to reflect the Project objectives and public feedback gathered in the online survey and three public workshops.

2.2.1 Selection of Alternatives

The alternatives were developed to be consistent with Coastal Resilience policies described in the Local Coastal Land Use Plan (LCLUP) Certification Draft – February 2020 (https://www.planpacifica.org/local-coastal-program). These policies describe several adaptation strategies that could be implemented to protect public infrastructure and important access and recreational resources like the Promenade and Pier for the likely range of sea level rise expected over the next 50 years (i.e. less than 2 feet of SLR). The objective of this report is to develop a preliminary design of each alternative to allow for a thorough assessment of the technical performance, financial implications, and environmental considerations associated with each alternative.

2.2.2 Design Criteria for Alternatives

Design life and acceptable levels of risk are important factors to determine at an early stage of the alternatives analysis. A design life of 50 years has long been a default value for civil infrastructure projects based largely on the durability of commonly used construction material and degradation in the marine environment. Sea level rise projections over the next 50 years could significantly increase the frequency and magnitude of wave forces impacting the structure and causing flooding along Beach Boulevard.

The amount of sea level rise to build into these alternatives depends on the risk tolerance of the community and when these risk thresholds could be exceeded. Risk tolerance can be related to combinations of storm events and sea level rise to estimate the likelihood of acceptable levels of risk being exceeded throughout the design life. For purposes of developing and evaluating alternatives, the following design criteria were applied in this analysis:

- Design life of 50 years, corresponding to an approximate time horizon of 2070[2].
- Provide resilient flood protection for an event comparable to the 1983 El Niño storm, estimated to have a 60-year return period. A 60-year return period storm event has a 1.67% (1/60) chance of exceedance in any given year.
- Include capacity for two feet of sea level rise (SLR) in combination with the design event. Ocean Protection Council (OPC) guidance (2018) indicates this amount of SLR is very unlikely (0.4% probability) before 2050 and estimates a 13% probability that SLR exceeds two feet before 2070.
- Based on these criteria there is an extremely low joint probability (~0.2%) the design criteria will be exceeded before 2070.

The risk tolerance may also increase throughout the design life as other assets and infrastructure are either relocated or improved to accommodate future hazards. For example, if the vulnerable utilities are upgraded or relocated and other development is better equipped to tolerate flooding, the overall risk tolerance may increase.

[2] The design team understands that the Project will likely take several years to be implemented and that the end of the 50-yr design life may be closer to 2075. However, for the purposes of estimating sea level rise, we are using probabilistic projections for the 2070-time horizon. The difference in sea level rise projections between 2070 and 2075 are small (i.e. 0.2 feet) and would not significantly change the outcome of the analysis. The specific design criteria may be refined in future Project phases (final engineering design and permitting).

The criteria listed above are preliminary and subject to change as the preferred Project is advanced through permitting, environmental documentation and detailed design. During this process the design criteria will be refined to balance the longevity, economics and benefits of the Project.

2.2.3 Methods of Analysis

The first step in the alternatives analysis is to develop a conceptual design of each alternative based on the criteria described in Section 2.2.2. Each alternative will be developed to a level of detail sufficient to evaluate technical performance and develop approximate cost estimates. The development of alternatives is discussed in more detail in Section 4.

The alternatives were analyzed based on a variety of considerations developed to reflect the community's feedback about the most important and consequential aspects of the Project. These considerations have been organized into three categories: Technical Performance, Economics and Environmental. A multi-criteria analysis (MCA) was performed for each alternative to provide comprehensive assessment and scoring system that accounts for a variety of considerations. The alternative analysis considerations and MCA scoring results are discussed in Sections 5 and 6, respectively.

3. Hazards Overview

3.1 Sea Level Rise

Sea level rise (SLR) is the primary issue of concern when considering how impacts from a changing climate could affect the Project. SLR projections for San Francisco, the nearest tide gauge to Pacifica, are provided in the *State of California Sea Level Rise Guidance* document (OPC, 2018). The range in probabilistic projections of SLR for the remainder of the century are illustrated in Figure 3-1.

The LCLUP Certification Draft (February 2020) includes policy CR-I-43 which states that technical reports for proposed development shall "consider the impacts from the medium-high projection (CalNRA & OPC 2018) of sea-level rise for the anticipated duration of the proposed development." The medium-high risk aversion SLR projections are indicated by the 0.5% probability curve in Figure 3-1. Based on these projections, it is extremely unlikely (0.5%) that SLR will exceed 3.5 feet by 2070, the end of the Project design life.

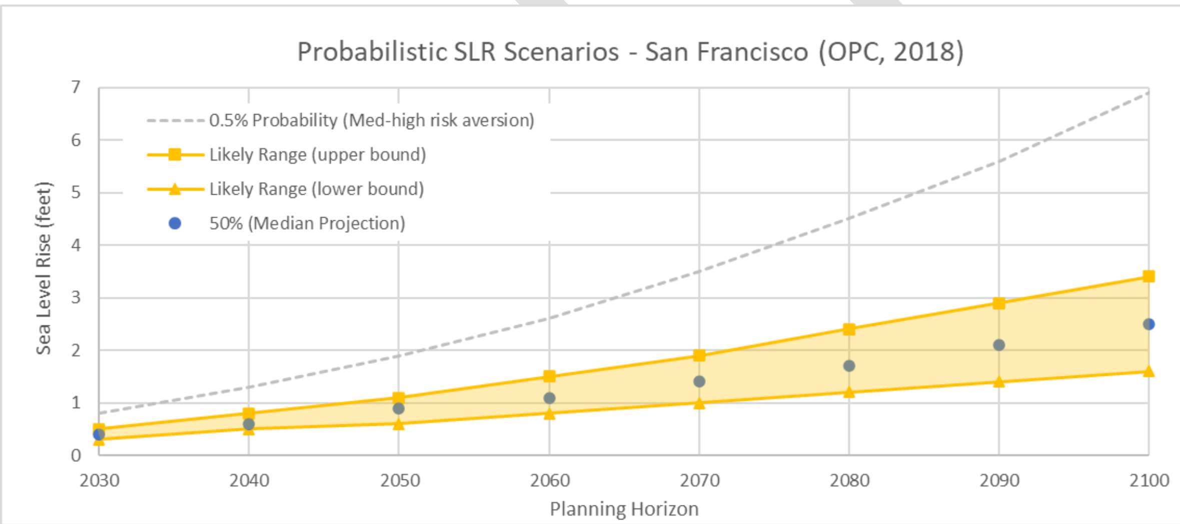

Figure 3-1 Sea Level Rise Projections, San Francisco (OPC, 2018)

The MHRA evaluated coastal hazards for a range of SLR scenarios up to 7 feet, which has a 0.5% probability of occurrence by in 2100. However, the specific SLR projection used in preliminary design of the Project alternatives must account for the trade-off between SLR capacity, economics, recreational and visual resources. Based on the hazards described in the MHRA, the Project team decided it would not be desirable (from a balancing of visual, recreational and financial resources perspective) to design the Project alternatives using an extremely low probability SLR scenario at the 2070 design horizon.

A SLR scenario of 2 feet, in combination with an extreme storm event, was selected as the preliminary design criteria for this alternatives analysis. Based on current "best available science" the Project would have sufficient capacity for the likely range of SLR through 2070. Although it is unlikely that SLR will exceed two feet before 2070, there is a possibility it could occur sooner based on the current projections. Specifically, the 2-foot SLR scenario has 0.4% probability of exceedance by 2050 and 13% probability of exceedance by 2070 (OPC, 2018).

As mentioned previously, the preliminary design criteria, including the design SLR scenario, are subject to change as the preferred Project is advanced through permitting, environmental documentation and detailed design phases. Throughout this process the design criteria will be refined to balance the longevity, economics, and benefits of the Project.

OPC's Strategic Plan includes an objective of ensuring the California coast is resilient to 3.5 feet of SLR by 2050 (OPC, 2020), which also aligns with the 2070 medium-high risk aversion projection. Once a preferred alternative is selected and advanced through permitting and detailed design, a phased adaptation plan will be developed to provide a roadmap for adapting to higher SLR scenarios than built into the initial Project (i.e. 3.5 feet of SLR). This plan will identify specific actions to be taken in response to triggers. Triggers may include significant changes in SLR projections or timing, acceleration of observed SLR trends, site-specific monitoring of coastal hazards, and the performance of the initial Project.

3.2 Coastal Flooding

Coastal flood hazards refer to wave runup and overtopping of the existing seawall along Beach Boulevard. Wave runup and overtopping are dynamic and sometimes violent processes that pose a danger to pedestrians, property, and infrastructure. The Project team performed a detailed assessment of wave runup and overtopping as part of the MHRA. The findings are listed below:

- Extreme wave runup elevations and overtopping rates vary along the Beach Boulevard seawall and are greater north of the pier than south of the pier.
- During a 10-year return period event, total water level (TWL) elevations are about fifteen feet above the North Wall crest and five feet above the South Wall crest. Lower TWL along the South Wall is due to the presence of a beach fronting the wall which dissipates more wave energy before impacting the wall.
- During a 60-year return period event (i.e. roughly equivalent to the 1983 El Niño storm), TWLs are significantly higher than the seawall crests and result in a wave/flood hazard zone that could extend up to 200 feet landward the North Wall and about 75 feet landward of the South Wall.
- Coastal hazards are anticipated to worsen with sea-level rise with wave runup and overtopping increasing at an amplified rate. A 2-foot sea-level rise scenario will increase TWL elevations by 8-10 feet during extreme events. The wave hazard zone would extend about 50 feet further landward along the North Wall and about 75 feet further landward along the South Wall under a 2-foot SLR scenario.

The alternatives evaluated in this report have been developed to reduce the frequency of coastal flooding events and the volume of wave overtopping during these events. Beach nourishment and sand retention alternatives rely on the sandy beach to provide a buffer against storm wave energy.

Structural alternatives (i.e. vertical seawall and rock revetment) rely on the stability of the structure to withstand wave forces with a high enough crest elevation to satisfy the preliminary design criteria.

The preliminary design criterion was to keep tolerable mean overtopping discharge during the design event (i.e. 60-year event and 2 feet of SLR) in the range of 0.5 – 2.0 cubic feet per second (cfs) per linear foot of wall. This design criterion is preliminary and was established to set a minimum benchmark for design of flood protection for each alternative. Like the other design criteria, the tolerable amount of overtopping is subject to refinement once a preferred Project is selected and advanced through permitting and design.

3.3 Coastal Erosion

The northern Pacifica shoreline and bluffs are highly erodible due to the narrow sandy beaches, high wave energy and the loosely consolidated nature of its bluffs. The long-term shoreline erosion rate was estimated to range from 0.7-2.2 ft/year, one of the highest in the San Francisco Littoral Cell (Griggs 2020). Sea level rise is expected to accelerate this long-term coastal erosion trend.

The MHRA considered a No Project alternative in which no shoreline protection was in place along Beach Boulevard and future erosion hazards were based on data from the Coastal Storm Modeling System (CoSMoS) Version 3.1. The results indicate that most of the Beach Boulevard corridor would be lost to erosion by 2030 without any protection in place. The coastal erosion hazard zone (Figure 3-2) progresses landward with time and sea-level rise resulting in significant property loss of approximately 50 buildings by 2050, and 165 buildings by 2100. The alternatives developed consist of both hard and soft shoreline protection measures to mitigate coastal erosion hazards.

Another consideration for alternative development is seasonal erosion of beach deposits (i.e., beach sand) that expose the beach platform (hardpan) and leads to scouring over time. Estimated potential future scour depths at the existing seawall alignment are -3 feet (NAVD88) for the south wall and -5.5 feet (NAVD88) along the north wall for the 2070 time horizon. Scouring (lowering) of the hard pan is primarily a consideration for hard shoreline protection structures because this process increases the depth and wave energy impacting the structure.

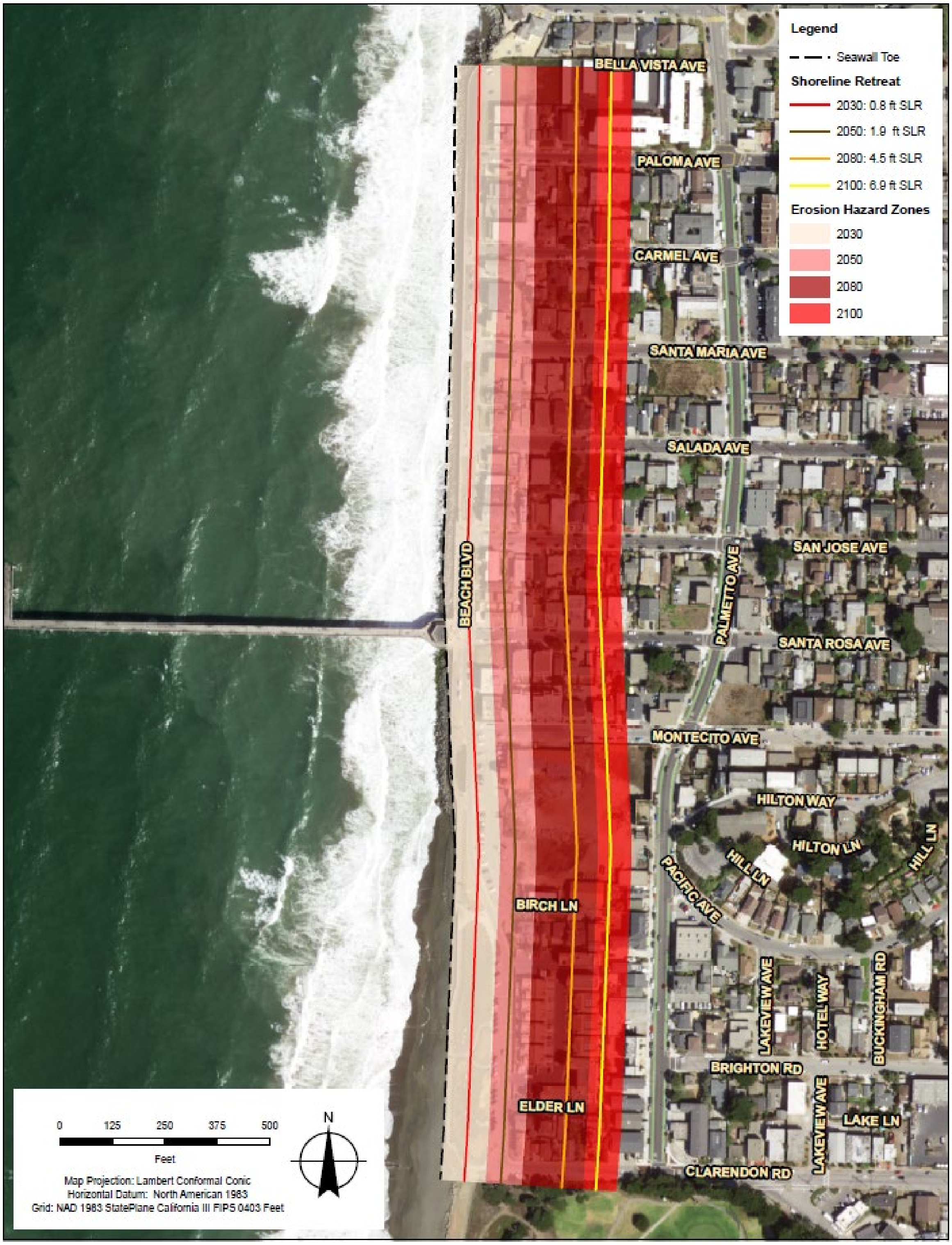

Figure 3-2 CoSMoS erosion hazards, No Project alternative

3.4 Earthquake Hazards

The presence of active faults nearby the Project (i.e. San Andreas, San Gregorio-Hosgri, and Hayward), shown in Figure 3-3, make the site susceptible to strong seismic shaking over the design life of the Project. An earthquake hazard risk assessment was completed by Haro, Kasunich and Associates (HKA, 2020b) with details presented in the MHRA.

Given the proximity to active faults and the young alluvial soils encountered below Beach Boulevard, severe shaking is likely to occur and will need to be accounted for in any new shoreline protection structure. The interbedded young alluvial soils and beach sand that exists in the Project area make the site vulnerable to liquefaction and potential ground settlement, particularly at the south end of the Project area.

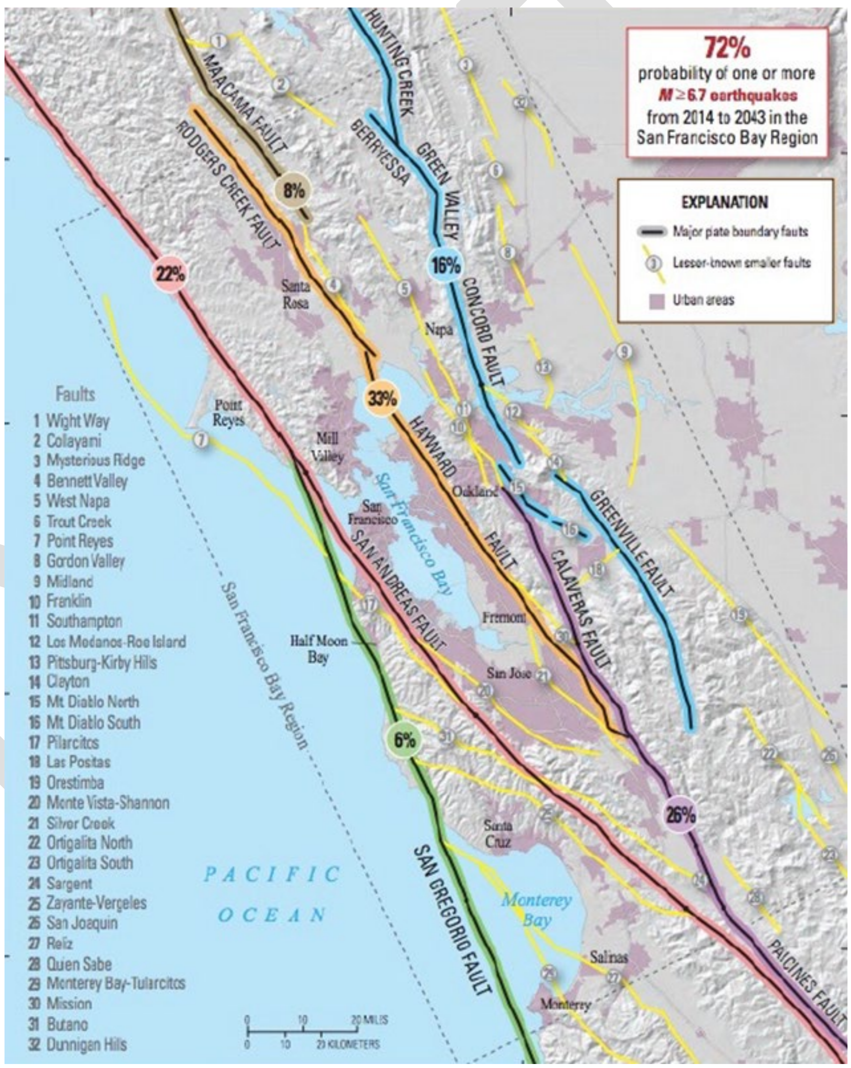

Figure 3-3 Earthquake Probabilities (San Francisco Bay Region 2014-2043)

Seismic hazards are a primary consideration for structures such as seawalls that will be subject to significant lateral forces during a large earthquake. These hazards are also relevant for coastal structures such as a rock revetment or offshore breakwater whose performance could be impacted if significant settlement occurs. Earthquake hazards are a lesser concern for non-structural shoreline protection such as beach nourishment.

Distant seismic events, such as a strong earthquake in the Alaska-Aleutian or Cascadia subduction zones, have the potential to generate tsunamis that can propagate across the Pacifica Ocean, posing a hazard to coastal cities such as Pacifica. Historically, despite the occurrence of several large earthquakes in these subduction zones, these seismic events have not produced a tsunami large enough to cause significant damage to coastal development in Pacifica. However, ASCE Technical Standard 7-16 (ASCE, 2017) indicates that an extreme tsunami event (2,475 year return period) could potentially result in runup elevations reaching 40 feet NAVD88 near the Project, which would result in significant flooding up to and beyond Highway 1.

Given the extremely low probability of this event (2% chance of occurring over a 50-year period), tsunami hazard mitigation is typically focused on public awareness, preparation, and evacuation to higher ground. Coastal protection structures are typically not designed for this type of tsunami event because the risk is not high enough the justify the cost necessary to build such a structure. ASCE 7-16 was developed to provide design guidelines for Risk Category III and IV buildings located in the tsunami hazard zones. These guidelines are typically used for vertical evacuation structures or essential facilities like hospitals or emergency operations centers located within these hazard zones. Although tsunamis do pose a risk to Pacifica, the risk is relatively low compared with other coastal hazards (erosion and flooding) evaluated in the MHRA. For this reason, tsunami hazards would not be a controlling factor in the development and analysis of Project alternatives and were not evaluated in detail as part of this analysis.

4. Alternatives Development

4.1 No Project

The No Project alternative was evaluated in the MHRA and is based on a hypothetical "No Action" or "Do Nothing" adaptation strategy. This represents a worst-case scenario in which the existing shoreline protection infrastructure is not maintained or upgraded and there are no other strategies implemented to mitigate current and future coastal hazards. Some of the key assumptions regarding the No Project scenario are described below:

- The existing seawall has limited remaining service life and requires frequent repair to maintain stability. In the hypothetical "No Project" scenario, without frequent repairs, it was assumed that the existing seawall and revetment would soon experience widespread failure, necessitating removal of the damaged structure.
- Under a No Project scenario the existing structures would not be replaced by any other adaptation strategy to mitigate coastal hazards along Beach Boulevard. Coastal erosion would likely become the primary hazard of concern given historic erosion trends and the dynamic coastal environment.

Coastal flooding poses a high risk to the safety of pedestrians and vehicles accessing the Promenade and Beach Boulevard during storm events. Overtopping observed during the January 2016 series of storms far exceeded the tolerable overtopping rate for safe pedestrian access. A 2-foot SLR scenario will nearly double the volume of water overtopping the seawall during a similar event.

Recreation resources such as the Promenade and Pier are at risk of damage, or complete loss due to coastal erosion under a No Project scenario. Loss of these resources would significantly reduce public access opportunities along the Project area. Under this scenario, a narrow and seasonal beach may be accessible to the public, though active erosion of the unprotected bluffs would also pose a safety concern. A key assumption of the No Project alternative, as evaluated in the MHRA, was that private homeowners would not install their own coastal protection structures in response to progressing erosion hazards. This assumption does not account for the possibility that property owners attempt to build seawalls or revetments at the parcel scale, which could potentially inhibit lateral beach access that would otherwise be available in a No Project scenario.

Erosion hazard projections in 2030 for a No Project alternative indicate the entire Beach Boulevard corridor would be lost to erosion along with the variety of infrastructure and uses supported by the corridor. The sanitary sewer, potable water, gas, and other utilities would require a major investment (~$42.5M) to be relocated and equipped to function outside the 2030 erosion hazard zones. The MHRA economic assessment estimated $95.6M of combined economic impacts would be expected before the 2030 time horizon and would exceed $243M by the end of the Project design life.

4.2 Beach Nourishment

Beach nourishment is characterized as a soft protection strategy that relies on a sandy beach of sufficient width to provide a buffer against seasonal and storm related erosion and flooding. Beach nourishment is a popular adaptation strategy because of the multiple secondary benefits including sandy beach habitat and enhanced recreation opportunities. Beach nourishment can result in temporary impacts to marine biological resources and changes to the beach profile which could have an indirect impact on recreational fishing from the Pier. These potential impacts will be evaluated in detail during the environmental review process if the preferred alternative includes beach nourishment.

Key design features of this alternative include the target beach width for coastal hazard protection, the volume of sand required to achieve this beach width and the frequency of re-nourishment events required to maintain a minimum beach width. A diffusion-type analysis was used to model the nourished beach width evolution over time for this option, which was used to identify the longevity of each nourishment event and estimate the number of re-nourishment events over the 50-year design life. This is an approximate and highly conceptual approach to estimate the persistence and longevity of beach nourishment but is a useful planning tool to assess different conceptual alternatives and parameter sensitivity.

Initial costs associated with a Beach Nourishment alternative are estimated to be about $60M with total lifecycle costs of about $165M.

Key features of the beach nourishment alternative include:

- Design beach width of 200 feet, which requires an initial fill volume of 1,000,000 cubic yards (cy).
- Minimum beach width of 100 feet required for storm protection, as illustrated in Figure 4-1.
- Renourishments required at an interval of 10-12 years with an estimated volume of 500,000 cy per event. Estimated timeline of re-nourishments over the 50-year duration is provided in Table 4-1.

Table 4-1 Beach Nourishment Frequency and Volumes

Year	Volume of Nourishment (cy)
Initial fill	1,000,000
2032	500,000
2043	500,000
2053	500,000
2063	500,000

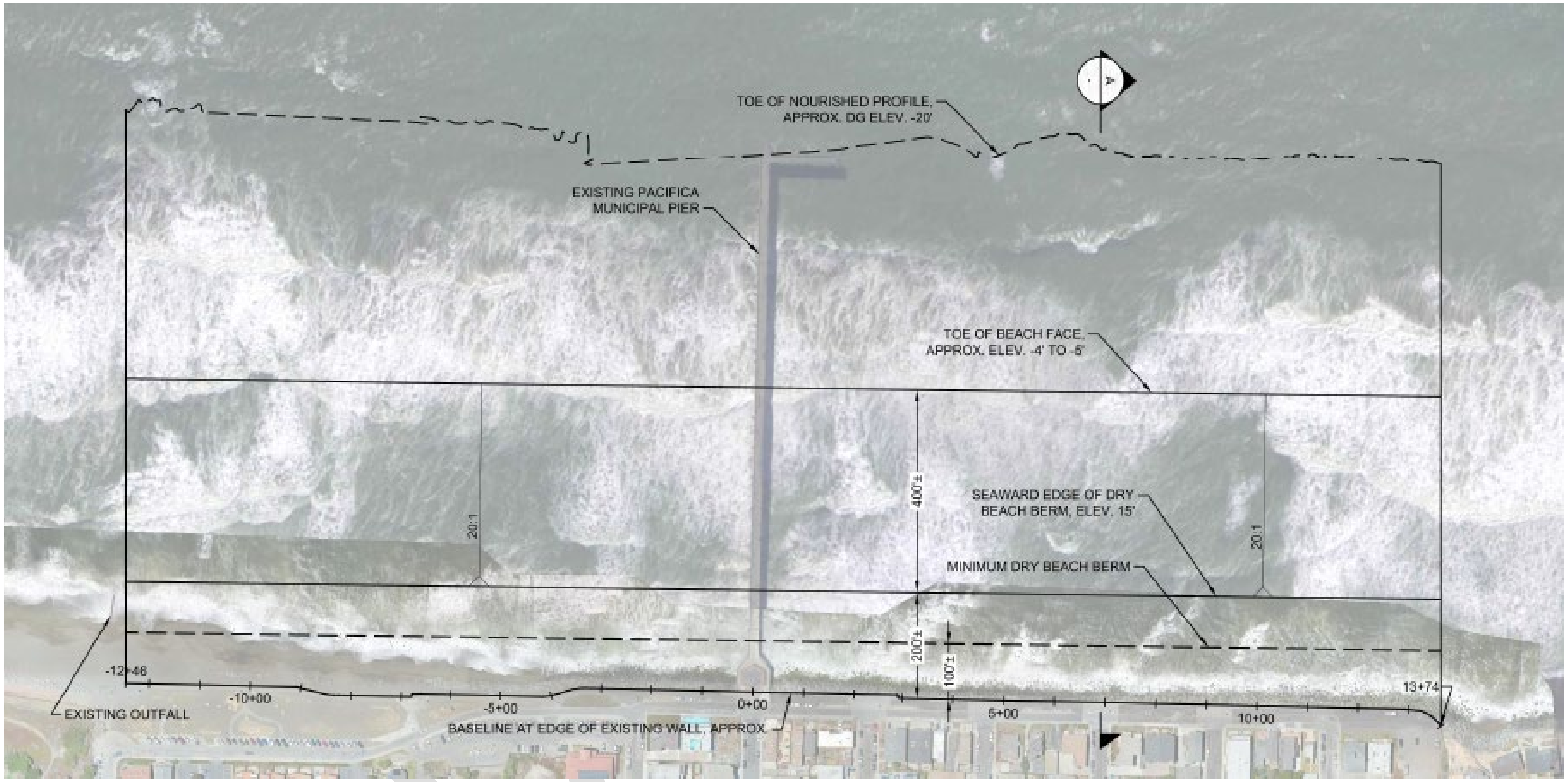

Figure 4-1 Beach Nourishment Alternative[3]

[3] Please refer to Appendix C for scaled drawings of the project alternatives that include the cross-sections indicated in plan view.

4.3 Seawall

This alternative involves replacement of the existing seawall and revetment with a new seawall along the entire Project length. This solution relies on the structural stability and crest elevation of the seawall to mitigate coastal erosion and flooding hazards. There are a variety of seawall types and configurations that could provide effective shoreline protection along Beach Boulevard. These include steel or concrete sheet pile walls, gravity walls, or secant pile walls. A key feature of each potential wall type is a deep foundation to prevent scour and undermining which is a persistent problem with the existing reinforced earth retaining wall that has a shallow foundation and relies on the rock revetment for foundation support and toe protection.

For purposes of this alternatives analysis a secant pile seawall was selected as the type of wall to be evaluated. Secant pile walls consist of intersecting primary and secondary reinforced concrete piles. Primary piles are installed first, followed by secondary piles drilled in between primary piles to form a continuous wall. This seawall type offers several advantages for application along Beach Boulevard such as increased wall stiffness (compared to sheet piles), a relatively narrow footprint (compared to a gravity wall) and easier installation (compared to other types considered).

Design considerations for the seawall include the total retained wall height, which depends on the crest elevation and potential scour elevation. Primary and secondary piles are then designed to account for a variety of loading scenarios that account for earth pressure (including hydrostatic), seismic forces, and wave loads. A plan view and section of the secant pile wall are illustrated in Figure 4-2. Initial costs associated with the Seawall alternative are estimated to be about $94M with total lifecycle costs of about $120M.

The crest elevation of the seawall was assumed to be at 30 feet, NAVD88 to reduce the frequency of wave overtopping events and limit the amount of flooding during the design event to less than 2 cubic feet per second (cfs) per linear foot of wall. The selected crest elevation was based on estimated wave overtopping rates using methods described in the Multi-hazard Risk Assessment (MHRA) which follow guidance provided in the EurOtop manual (2018). A scour elevation of -5.5 feet was selected based on the Feasibility Level Geotechnical Evaluation (HKA, 2020) which was summarized in the MHRA. Note, this scour level estimate assumes the existing rock revetment is removed to reduce the beach area occupied by the shoreline protection structure.

Key features of the vertical seawall alternative include:

- Seawall crest elevation of 30 feet, NAVD88
- 5-foot diameter reinforced concrete piles, following an alignment along the backside of the existing seawall, along the entire project length (2,650 feet).
- Cast-in-place reinforced concrete pile cap will extend to the design crest elevation of 30 feet, NAVD88.
- Overall pile length of 70 feet required to withstand preliminary design loads.

Seawall will be built within the existing seawall alignment (other alignments could be considered in future phases – final design and permitting).

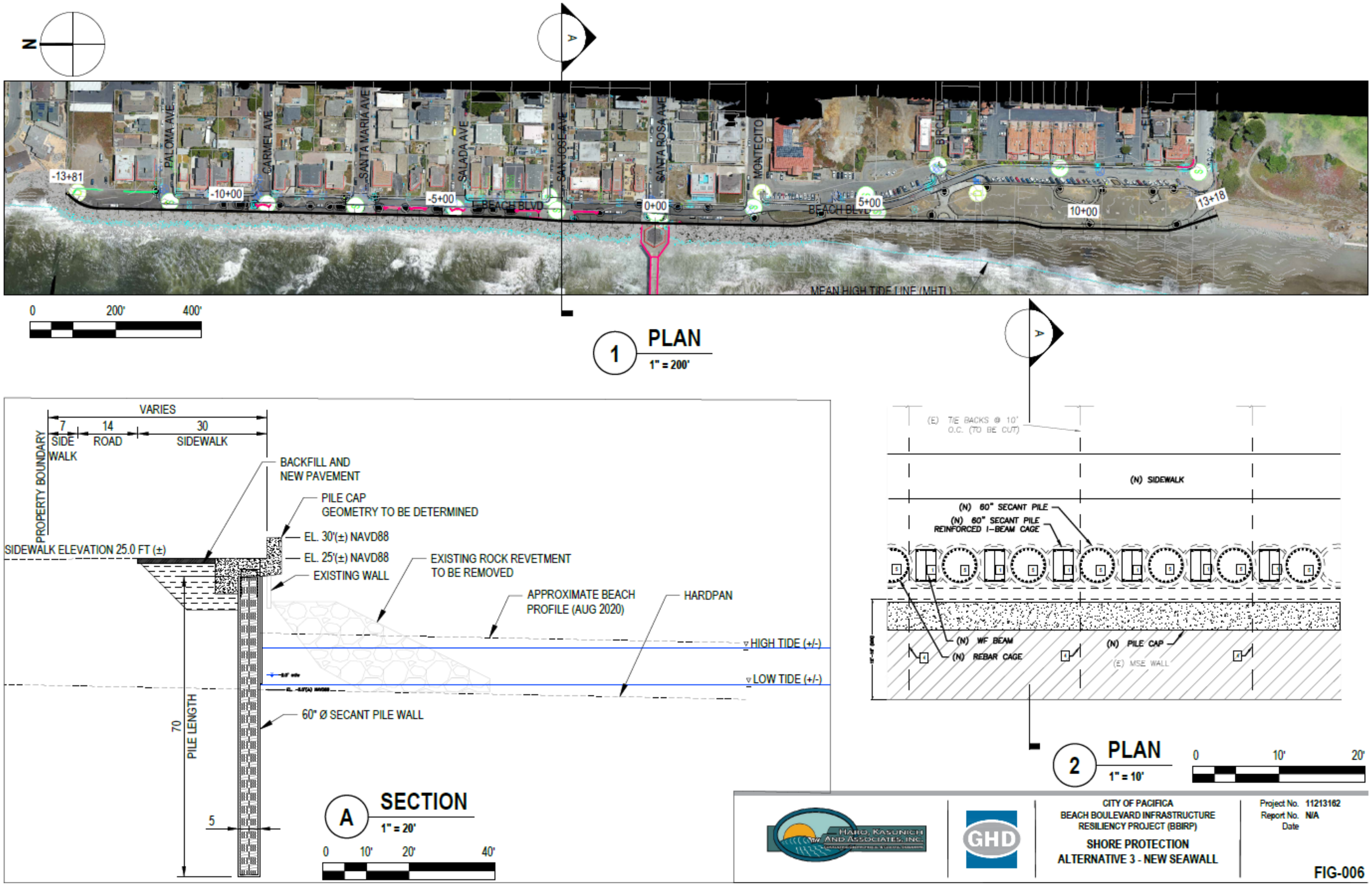

Figure 4-2 Seawall Alternative

4.4 Rock Revetment

Revetments are a common form of shoreline protection in response to coastal erosion hazards due to simplicity of design, low cost and effectiveness. Revetments involve the placement of erosion resistant materials on a prepared slope, typically located at the back of the beach. Though a variety of materials can be used to form a coastal revetment, this alternative is assumed to consist of large armor stone, similar to the rock that currently exists onsite.

The rock revetment consists of multiple layers of stone and a geotextile placed over a compacted slope, as shown in Figure 4-3. The outer layer consists of two layers of large armor stone designed to be stable under the expected wave conditions. The underlayer(s) consist of smaller stone and geotextile fabric designed to prevent loss of the subgrade which can result in settlement and failure of the revetment. The combined layers will form a rock mattress with a total thickness of 13-15 feet. A reinforced concrete retaining wall will be required along the back of the revetment to provide an impermeable barrier for the landside subgrade.

Key design considerations for a revetment include the stone size required for a stable armor layer, crest elevation required to limit wave overtopping and toe protection to limit scour and undermining of the revetment. The crest elevation of the revetment was assumed to be at 25.5 feet, NAVD88 to reduce the frequency of wave overtopping events and limit the amount of flooding during the design intent of limiting the overtopping rate to less than 2 cubic feet per second (cfs) per linear foot of wall during the 60-year event. The selected crest elevation was based on estimated wave overtopping rates using methods described in the EurOtop manual (2018) for depth limited wave conditions during the design event. The crest elevation of the rock revetment is four feet lower than the Seawall alternative because the large armor stone structure absorbs and dissipates more wave energy than a vertical structure.

Initial costs associated with the Rock Revetment alternative are estimated to be about $48M with total lifecycle costs of about $102M.

Key features of the rock revetment alternative include:

- Revetment crest elevation of 25.5 feet, NAVD88. Crest width assumed to be four stones wide (~20 feet). This structure would be significantly larger than the existing revetment, with a higher crest elevation and wider footprint as shown in Figure 4-3.
- 8-10 ton durable quarry stone will be required for the armor layers.
- ¼ ton durable quarry stone with a wider gradation will provide the primary underlayer.
- Non-woven geotextile fabric will provide a filter layer to retain the subgrade.
- Revetment toe will be keyed into hardpan layer and include a toe apron roughly three stones wide.
- A reinforced concrete retaining wall, similar to the existing south wall, to provide an impermeable barrier behind the revetment.

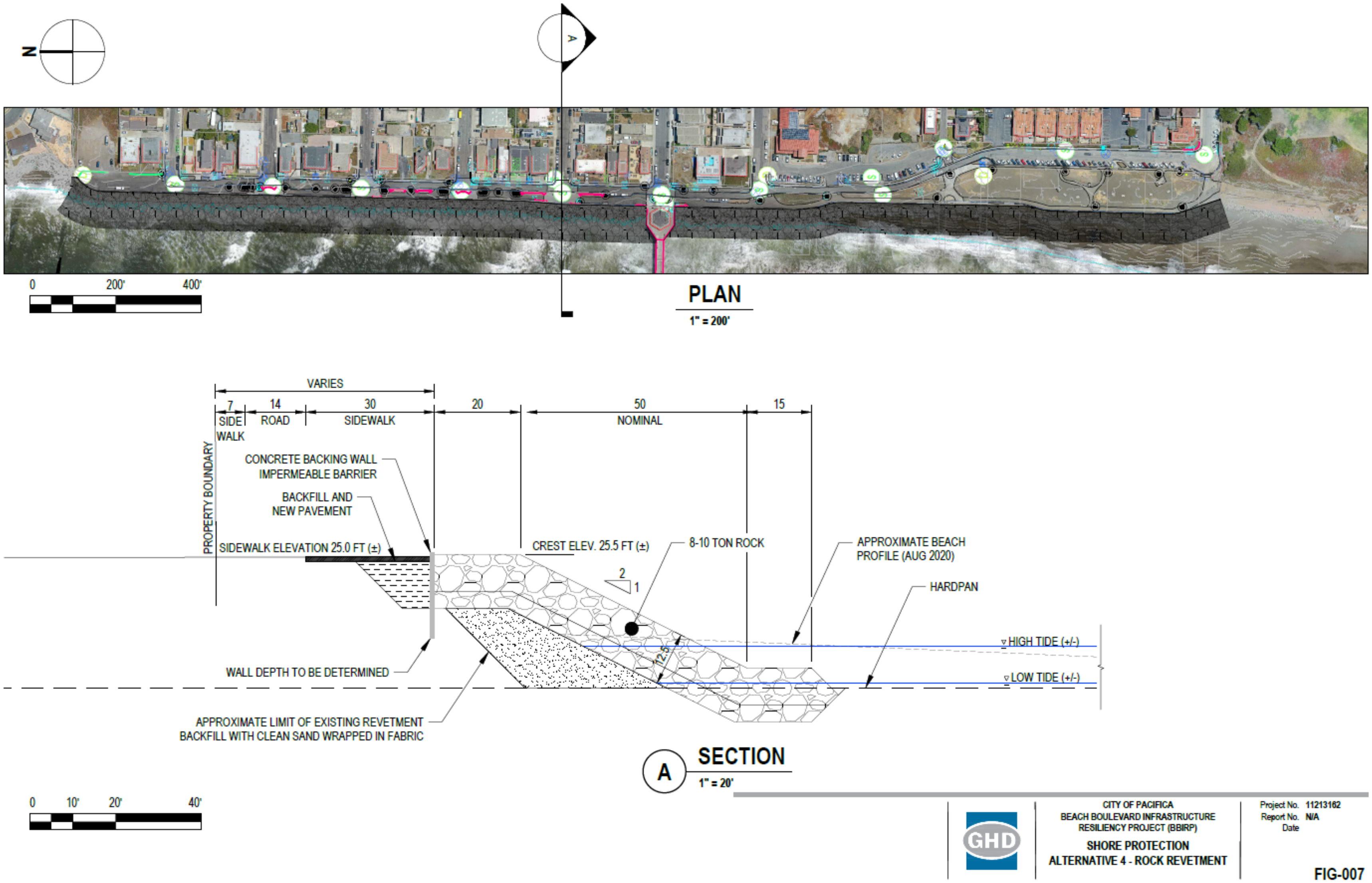

Figure 4-3 Revetment Alternative

4.5 Beach Nourishment with Sand Retention

This alternative combines beach nourishment with offshore breakwaters or reefs designed to stabilize the sandy beach behind these structures. The sand retention structures are intended to improve the longevity of each beach nourishment event by reducing the rate of sediment loss within the Project area. These structures include a shore parallel feature designed to dissipate wave energy and facilitate accretion or stabilization of sediment on the leeward side. An estimated timeline of beach nourishment events, with and without Sand Retention is shown in Figure 4-4.

Primary design considerations for this alternative involve the size, layout and spacing of the sediment retention structures. Two conceptual layouts were prepared to depict a conventional “T-head groin” (Figure 4-5) and a “multi-purpose reef” (Figure 4-6) which build on concepts considered in the Regional Sediment Management Plan for San Francisco Littoral Cell (ESA, 2016) and LCLUP (ESA, 2021b). For purposes of this analysis, it was assumed these structures consist of large armor stone. The actual dimensions of the structures are preliminary and subject to refinements pending additional analysis, such as hydrodynamic and morphodynamic modeling, that would occur during the design phase if these elements are part of the preferred alternative.

Initial costs associated with the Beach Nourishment with Sand Retention alternative are estimated to be about $111M with total lifecycle costs of about $235M.

Key features of the beach nourishment with sand retention alternative include:

- Similar beach nourishment program as described in Section 4.1. Initial design would consist of a large-scale nourishment (1 million cy) to achieve a dry beach width of 200 feet.
- Two sediment retention structures are proposed, one on either side of the Pier. These structures consist of two main elements:
    - Shore parallel low-crested breakwater or multipurpose reef.
    - Shore perpendicular “stems” that would connect these offshore structures to the shore.
- Sand retention structures are estimated to reduce the frequency of re-nourishment events by roughly 50% in comparison to the beach nourishment only alternative.

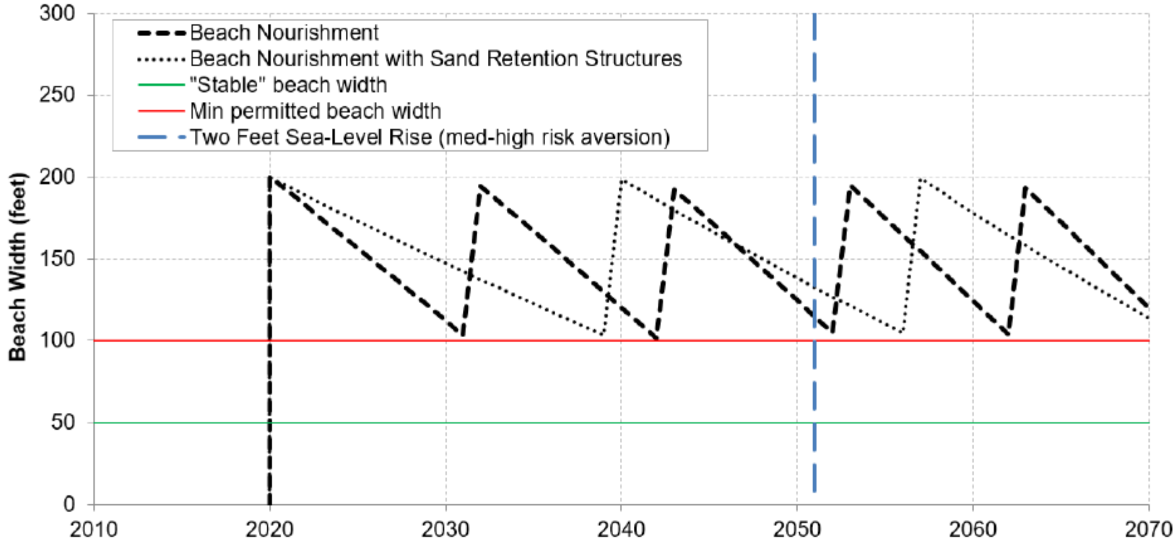

Figure 4-4 Beach Nourishment Timeline with and without Sand Retention

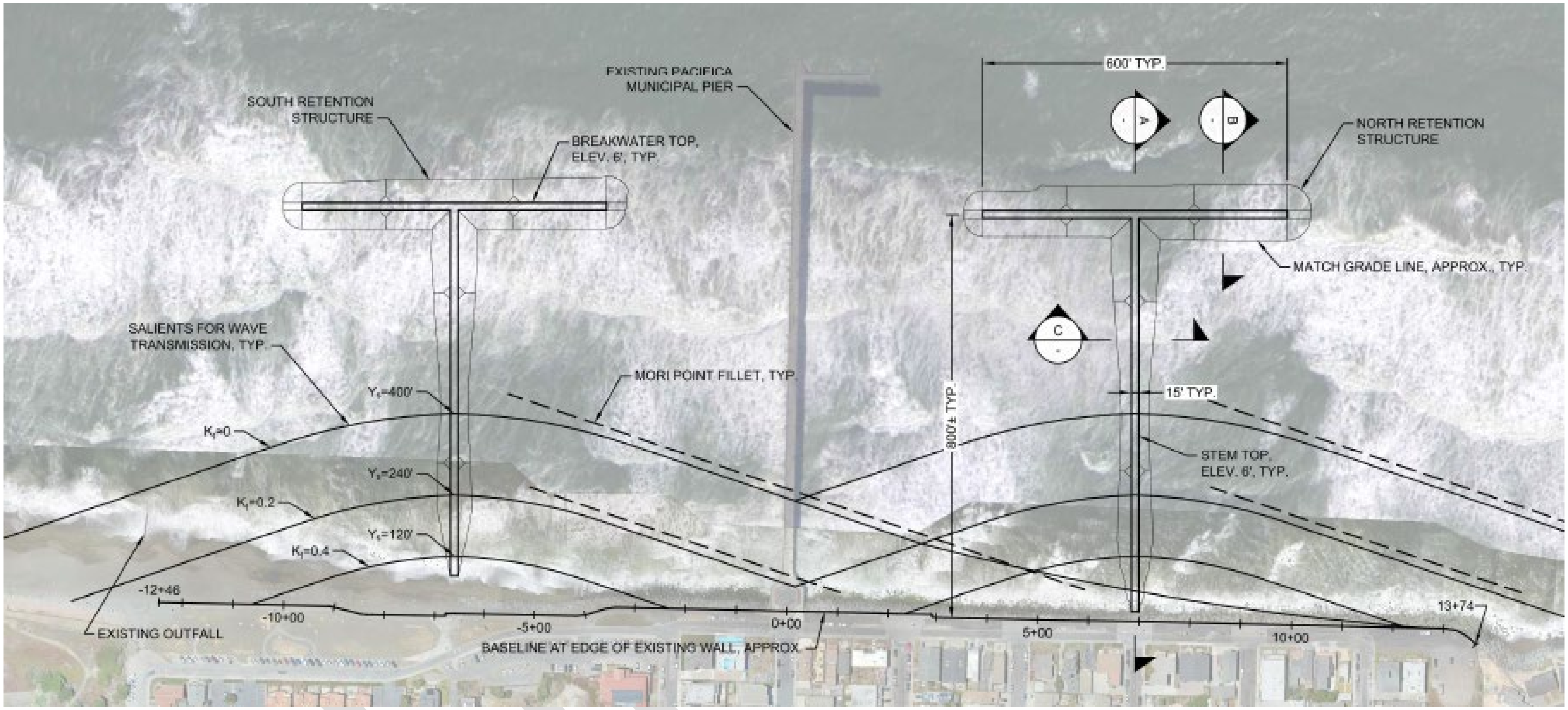

Figure 4-5 Low-crested Breakwaters, Sand Retention Alternative[4]

[4] Please refer to Appendix C for scaled drawings of the project alternatives that include the cross-sections indicated in plan view.

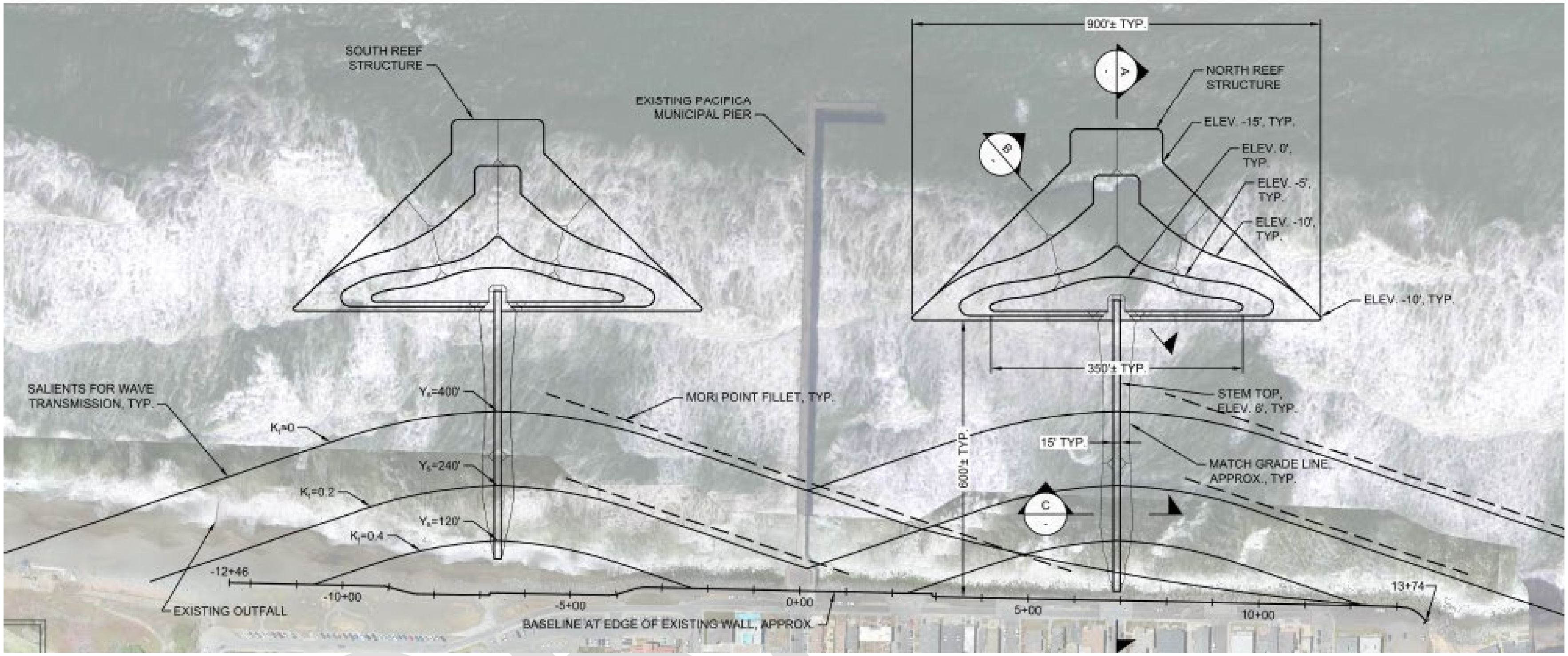

Figure 4-6 Multi-Purpose Reefs, Sand Retention Alternative[5]

[5] Please refer to Appendix C for scaled drawings of the project alternatives that include the cross-sections indicated in plan view.

4.6 Other Alternatives (considered but not evaluated)

4.6.1 Living Shorelines

Living shoreline is a broad term used to capture a wide variety of coastal protection strategies that use natural or living materials to provide erosion or flood protection in addition to ecosystem benefits. Living shoreline strategies such as oyster reefs, marsh restoration, and horizontal levees have been used with success in low wave energy environments (e.g. lagoons, estuaries or embayments). NOAA encourages the use of living shorelines as a shoreline stabilization technique along sheltered coasts (i.e., coasts not exposed to open ocean wave energy) to preserve and improve habitats and their ecosystem services at the land–water interface (NOAA, 2015). Unfortunately, these living shoreline techniques would not be applicable along the open coast of Pacifica due to the large and long period wave energy and dynamic littoral processes.

Living shoreline projects have been constructed along the open coast of California, but these rely on different techniques than listed above for sheltered coastlines. These projects typically aim to restore beach and dune systems to protect against erosion and flooding in addition to providing ecosystem and recreation benefits. The sand or cobble beach provides most of the erosion protection while the dune system offers increased protection from overtopping and flooding during extreme events. A key element of these projects is the presence of a relatively stable sand or cobble beach fronting the restored dunes. A stable sandy beach does not exist along most of Beach Boulevard, but two of the Project alternatives consider a beach nourishment program. If these alternatives are successful in creating a stable dry beach then living shoreline techniques such as dune restoration could be feasible, particularly at the south end of the Project reach.

4.6.2 Managed Retreat

Managed Retreat refers to an alternative in which the community takes pro-active steps to remove or relocate development away from existing and future hazard zones. A Managed Retreat strategy would involve removal of the existing shoreline protection structures to allow natural coastal erosion processes to occur. The “No Action” scenario, presented in the MHRA, evaluates a scenario in which the existing seawalls experience widespread failure posing a major risk to landward development and thus provides some indication of the impacts associated with a Managed Retreat scenario. Considering these impacts, it is not necessary to further evaluate a Managed Retreat strategy, as it is clear this alternative would not meet the project goals. Furthermore, the LCLUP Certification Draft approved by the City Council does not recommend Managed Retreat as a sea level rise adaptation policy for the Sharp Park area (LCLUP, page 6-11).

4.6.3 Infrastructure Relocation

Relocation of infrastructure is not a stand-alone alternative because it does not address other vulnerabilities along the Project reach (i.e. loss of public access along the Promenade, Pier and property landward of Beach Boulevard). Certain infrastructure like the Promenade and Beach Boulevard cannot be relocated and would experience damage and eventual loss without some type of coastal protection strategy.

The No Action scenario, evaluated in the MHRA, assessed the cost of relocating utility infrastructure in the event existing shoreline protection failed or was removed. Based on this analysis, there is some indication of the feasibility and approximate cost of utility infrastructure relocation. Relocation or replacement of city-owned utility infrastructure will be considered when a particular asset approaches the end of its useful life and will be informed by the effectiveness of coastal adaptation strategies implemented along the Beach Boulevard corridor and updated sea level rise projections.

5. Alternative Analysis Criteria

The Beach Boulevard Infrastructure Resiliency Project (BBIRP, or Project) aims to create a multi-benefit solution to protect public infrastructure, recreational activities, and the community at large, from further coastal hazard impacts. Protection and safety of people, homes and businesses from coastal hazards was the most expressed concern in the online public survey (Kearns & West, 2020). Sea-level rise also presents significant short-term and long-term challenges for the City in balancing the interests of the entire community.

An important aspect of the community feedback gathered to date is the lack of consensus on what specific adaptation strategies should be pursued to mitigate risks identified in the MHRA. The public response to a workshop #2 question (see inset) indicates that overtopping and flooding are a key concern but so are concerns about the costs of adaptation (economics) and potential impacts on environmental resources and coastal access opportunities. This has also been evident in the public comments and questions received during each workshop.

Public Workshop #2 Question: Which of the risks evaluated in the MHRA is most important to you?

- Overtopping & Flood Risk (38%)
- Economic Risk (23%)
- Environmental Risk (19%)
- Coastal Risks (10%)
- Utility Risks (6%)
- Earthquake Risk (4%)

The criteria that each alternative will be evaluated against have been organized into three categories of Technical Performance, Financial and Environmental. These categories reflect the general Project objectives listed and public feedback gathered in the online survey and three public workshops. The specific criteria within each category are discussed in the following sections and the basis of evaluating the alternatives have been informed by public input.

5.1 Technical Performance

Technical performance refers to the ability of each alternative to mitigate coastal hazards along the Project reach. Public safety is the over-arching performance objective that is common to each of the technical performance criteria. During winter months, high tides combined with even moderate wave heights result in waves overtopping the seawall. In severe events (Figure 5-1) the overtopping from individual waves can be violent with the potential to knock a pedestrian off their feet in addition to launching small rocks or other debris over the seawall. Vehicles travelling along Beach Boulevard are exposed to similar hazards as pedestrians along the Promenade and the road is often closed to vehicular traffic during winter storm events. Beach Boulevard provides storage and conveyance of flooding from wave overtopping and could pose a hazard to safe driving conditions during extreme events. The specific criteria within the Technical Performance category are listed in Table 5-1 along with a description about how alternatives will be evaluated for each criterion.

Figure 5-1 January 2016 Wave Overtopping[6]

Table 5-1 Technical Performance Criteria

Criteria	Basis of Evaluation
Flood Protection	Ability to achieve the design criteria listed in Section 2.2.2 (60-yr event + 2 ft SLR) while limiting mean overtopping rate to a range of 0.5 – 2 cfs/ft (50-200 l/s/m) during the design event. (Alternatives 2-5 were designed to meet this criteria)
Erosion Protection	Ability to prevent long-term, seasonal and storm related erosion hazards.
Reliability	Ability to accommodate a change in one or more variables (e.g. SLR, storm intensity, series of large storms, erosion trend) while maintaining desired levels of protection.
Operability	Will the alternative place a significant burden on operations to achieve the goals of protecting public safety, infrastructure and property?
Constructability	Does the alternative present unique constructability challenges that may affect ability to achieve design objectives?
Sea Level Rise Adaptability	Ability to adapt if SLR exceeds the design criteria (2 ft). How difficult would it be to augment or modify each alternative to accommodate a 3.5 ft SLR scenario[7]?

[6]Photo is a screen capture from an online video: https://www.youtube.com/watch?v=7lg-SliupQ4 accessed December 2020

[7] Based on the OPC Strategic Plan 2020-2025 objective to ensure the California coast is resilient to 3.5 feet of SLR by 2050. Also, 3.5 feet aligns with 2070 medium-high risk aversion projection (OPC, 2018).

5.2 Financial

The financial category includes several criteria that quantify the approximate lifecycle costs of each design alternative. These lifecycle costs are opinions of costs based on conceptual design drawings and are only intended to provide a rough order-of-magnitude estimate of potential Project costs for the sole purpose of comparing alternatives to one another. These opinions of cost do not reflect the actual cost of the Project and will be subject to refinement upon selection and optimization of a preferred alternative. Lifecycle costs include estimated costs associated with initial costs, operations & maintenance, decommissioning and mitigation.

Recognizing the Project cost will likely far exceed the availability of local funds, one of the criteria will evaluate how well each alternative would be a match for the requirements and objectives of various regional, state, or federal funding opportunities. Financial criteria and the basis of evaluation are listed in Table 5-2.

Table 5-2 Financial Criteria

Criteria	Basis of Evaluation
Lifecycle Costs:	
Initial Costs	Estimated capital cost of the initial Project including soft costs associated with permitting, design and construction management.
Operation & Maintenance	Estimated costs of operational and maintenance efforts over the 50-year design life (e.g. beach re-nourishment, or maintenance & repair of protective structures).
Decommissioning	Permits typically include a provision for removal of structures at the end of their service life. This criterion estimates the cost to demolish and remove non-native material placed as part of the Project.
Potential Mitigation	Estimated mitigation costs are based on fees from recent shoreline protection projects subject to CCC approval and CCC's study on Improved Valuation of Impacts to Recreation, Public Access, and Beach Ecology from Shoreline Armoring (Administrative Draft, 2015).
Project Funding:	
Grant Funding Potential	Would the alternative be eligible and competitive for grant funding from outside sources (e.g. regional, state or federal grant programs)?

5.3 Environmental

The natural beauty of Pacifica and its connection to the Pacific Ocean are highly valued by residents and visitors. Environmental resources in the Project vicinity were characterized in the MHRA and include marine, terrestrial, recreation, coastal access, and visual resources. The variety of coastal access and recreation opportunities available at the south end of the Project area during a nice summer day are illustrated in Figure 5-2. These criteria, listed in Table 5-3, provide the basis for evaluation of each alternative from an environmental perspective. The alternative which scores highest in this category would be likely viewed as the most favorable alternative from a regulatory agency perspective. However, this is just a concept level analysis and the preferred alternative will be subject to a rigorous environmental review process to secure the necessary permits.

Figure 5-2 Summer Coastal Access and Recreation[8]

Table 5-3 Environmental Criteria

Criteria	Basis of Evaluation
Marine Biological Resources	Ability to preserve and enhance marine biological resources which include subtidal, beach and foredune areas.
Terrestrial Biological Resources	Biological resources landward of the existing seawall. Although, outside of the Project area, potential impacts to Laguna Salada are also included due to its sensitivity. Within the Project limits, the Clarendon Gap presents a potential vulnerability to coastal flooding at Laguna Salada, particularly under future SLR scenarios.
Visual Resources	Ability to preserve view corridors along Beach Boulevard and side streets. Alternatives that increase the seawall crest elevation or involve placement of non-native material within the view corridors would have an adverse impact on visual resources.
General Recreation	Ability to preserve and enhance recreational opportunities along the Promenade, Pier and beach/ocean recreation.
Coastal Access	Ability to preserve and enhance lateral and vertical beach access along Beach Boulevard while maintaining parking.

[8] Photo is a screen capture from an online timelapse video:https://www.youtube.com/watch?v=XXC-pZOPZekv accessed March 2021

6. Multi-Criteria Analysis of Alternatives

The multi-criteria analysis (MCA) provides an opportunity to analyze each alternative against a wide range of criteria that reflects the diversity of input received from the multiple BBIRP public engagement activities. Rather than rely solely on economics, or a benefit-cost ratio (largely influenced by economics), the multi-criteria analysis allows for more flexibility in selecting a preferred alternative from criteria most important to the community.

6.1 MCA Weighting and Scoring System

The MCA scoring and weighting presented in this report reflects input from the multi-disciplinary Project team, collected during multiple interactive workshops on March 29th and 30th, 2021. The goal of these workshops was to incorporate thoughts and opinions from a diverse group of Project team members with technical, financial, and environmental expertise in effort to reduce individual bias and subjectivity from influencing the results. The workshop contributors included representatives from the City (Public Works and Planning), members of the consulting team (GHD, ESA and HKA), drawing on experience and knowledge from 13 senior professionals in the disciplines of planning, environmental science, coastal engineering, coastal science, civil & structural engineering, geotechnical & coastal geotechnical engineering, and construction management.

The maximum potential score for each alternative is a function of how well the alternative satisfies the criteria within three general categories of Technical Performance, Financial and Environmental. The results presented in this report are based on a weighting of 40/30/30 (Technical/Financial/Environmental) breakdown among these categories as shown in Table 6-1. In other words, the Technical Performance category has a maximum score of 40%, Financial and Environmental criteria each account for up to 30% of the total score. The Technical Performance category was weighted slightly higher because the criteria in this category closely align with the primary objectives of public safety and the protection of infrastructure and property along the Beach Boulevard corridor. The sensitivity of these weightings on the results were evaluated and discussed in Section 6.2.1.

Table 6-1 MCA Category Weighting

Category	Category Weight (Percentage of Total Score)
Technical Performance	40%
Financial	30%
Environmental	30%
Total Score	100%

The individual criterion within each category were also assigned a weighting to determine what percentage of the available score should be allocated to each. The criteria weightings are shown in the left column of Table 6-2 and make up 100% of the available score within each category. In most cases the criteria were equally weighted within the Technical Performance and Environmental categories, which reflected the feedback from the Project team that no single criterion was significantly more important than others. A few weightings were reduced for criteria deemed less essential to meeting the Project's objectives. The weightings of "Operability" and "Constructability" criteria were reduced relative to other criteria in the Technical Performance category because these were not seen as significant challenges or differentiators between the alternatives.

The Financial criteria was weighted 70% for Lifecycle Costs and 30% for Grant Funding Potential. Lifecycle cost is the estimated actual monetary cost of the project including costs for initial capital investment, operations & maintenance and decommissioning, which were calculated for each alternative (i.e. quantitative). The Financial criteria weightings were selected based on consensus of the Project Team. Whereas the Grant Funding Potential was scored qualitatively, based on how likely an alternative is to attract funding from various external sources (e.g. FEMA). The Lifecycle cost score was calculated by applying the highest possible score (5) to the alternative with the lowest Lifecycle cost, then the other alternatives were scored in proportion to the lowest cost alternative. For example, if an alternative had a Lifecycle cost twice as high as the lowest cost alternative it would receive a score of 2.5 (i.e. 5 x 1/2 = 2.5).

Scoring of individual criteria was based on a scale of 1 to 5 for each alternative. A high score indicates an alternative has a good chance of satisfying the objectives of each criterion. A low score indicates an alternative has a poor chance of satisfying the objectives of each criterion. Discussion among participants of the relative merits and demerits of each alternative was a key focus of the MCA workshops. For some criteria (e.g. Flood Protection, Capital and Operation & Maintenance costs) engineering analyses and calculations were available to support the scoring of each alternative. For other criteria, where metrics were unavailable to facilitate comparison, the scoring was based on the outcome of discussion and debate among participants.

Individual scores were multiplied by the criterion weighting and category weighting to arrive at a weighted score for each alternative and criterion. For example, if an alternative received a high score (e.g. 4 of 5), it would be multiplied by the criteria weighting (e.g. 20%) and the category weighing (e.g. 40%) for a weighted score of 6.4% (i.e. 4/5 x 0.20 x 0.40 = 0.064). The weighted scores were then summed for each alternative and category to form a total score. Note, the weighted and total scores have been rounded to the nearest whole percentage in the results table.

6.2 MCA Results

The results of the MCA indicate the highest ranked alternative is a Seawall, followed by Revetment and Beach Nourishment. The top three alternatives are separated by 4-5% from one another in total score which is significant when considering the sensitivity of the scoring and weighting system (discussed in Section 6.3). Sand Retention ranked fourth, about 12% lower than the Seawall. The No Project alternative ranked last with significantly lower scores in each category. A detailed summary of the analysis is provided in Table 6-2. A summary of the rationale used to assign scores and differentiate among alternatives is provided in the following sections. Please refer to Appendix B for the detailed scoring matrix which includes the numeric score, weighted score, and comments for each criterion.

Table 6-2 Multi-Criteria Analysis – Weighted Scoring Matrix

Weight	Aspect	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		No Project	Beach Nourishment	Seawall	Revetment	Sand Retention
		Weighted Score	Weighted Score	Weighted Score	Weighted Score	Weighted Score
40%	**TECHNICAL PERFORMANCE**					
20%	Flood Protection	2%	6%	6%	6%	6%
20%	Erosion Protection	2%	5%	8%	8%	6%
20%	Reliability	2%	3%	8%	8%	5%
10%	Operability	1%	2%	2%	2%	2%
10%	Constructability	3%	3%	2%	2%	2%
20%	Sea Level Rise Adaptability	2%	3%	8%	6%	5%
	SUBTOTAL out of 40%	*10%*	*23%*	*35%*	*33%*	*26%*
30%	**FINANCIAL**					
70%	Lifecycle Costs (see note 1)	9%	13%	18%	21%	9%
30%	Grant Funding Potential	4%	4%	5%	5%	4%
	SUBTOTAL out of 30%	*12%*	*17%*	*23%*	*26%*	*13%*
30%	**ENVIRONMENTAL**					
20%	Marine Biological Resources	4%	5%	2%	1%	5%
20%	Terrestrial Biological Resources	5%	5%	5%	5%	5%
20%	Visual Resources	2%	5%	2%	1%	4%
20%	Recreation General	1%	6%	4%	2%	6%
20%	Coastal Access	1%	6%	4%	2%	5%
	SUBTOTAL out of 30%	*13%*	*26%*	*17%*	*12%*	*24%*
	Total Weighted Score out of 100%	36%	66%	75%	71%	63%
	Ranking	**5**	**3**	**1**	**2**	**4**

1. Lifecycle costs include estimated costs associated with capital, operation & maintenance, decommissioning and mitigation costs.

6.2.1 Analysis of Technical Performance Criteria

While all Project alternatives are technically feasible, only the No Project alternative would fail to meet the flood and erosion protection objectives over the Project duration. Seawall and Revetment were the highest scoring alternatives in the Technical Performance category. The primary differentiators from the "softer" alternatives were related to reliability and adaptability. Structural alternatives maintain a more reliable level of protection when considering changes in water levels (i.e. El Niño or SLR increase), storm intensity, erosion trends, or series of storms. Performance of a nourished beach under these circumstances was considered less reliable because of uncertainties regarding the response of a nourished beach if exposed to prolonged water level increases, a particularly active winter season, or very large single storm event. Other reliability concerns include the lead time associated with re-nourishment events, the potential challenges with procuring a compatible source of sand with adequate volume, and the significant funding required for each re-nourishment.

Adaptability to sea level rise was another criterion in which the Seawall scored higher than other alternatives. This criterion evaluated how each alternative could be adapted to maintain protection from coastal flooding and erosion hazards in the event SLR of 3.5 feet becomes a likely scenario within the Project design life. This scenario would significantly increase the erosion and flood risk along Beach Boulevard and would be difficult to manage with beach nourishment alone. Although a beach will naturally shift upward and landward in response to sea level rise, the development along the backshore would remain vulnerable to flooding in an extreme event and it would be increasingly difficult to "hold-the-line" in front of existing development. It was assumed that each alternative would require additional structural improvements and elevation along Beach Boulevard. The Seawall and Revetment alternatives can be designed to accommodate an increased crest elevation under this scenario so were assigned higher scores. Beach Nourishment would likely require increased volumes or frequency of renourishment in addition to structural protection added along the back beach.

6.2.2 Analysis of Financial Criteria

Revetment ranked highest among the alternatives in the Financial category, largely due to having the lowest capital and operation and maintenance costs. However, the Revetment alternative would likely be subject to the highest mitigation fees due to the recreational impacts associated with the large footprint occupying potential beach area in addition to the sand mitigation fee. Seawall received the second highest score in the Financial category, only 3% behind Revetment. Beach Nourishment was scored significantly lower than Seawall because of the significant maintenance costs associated with renourishment events. In contrast, the Seawall has a relatively high capital cost and mitigation fees (though lower than Revetment due to smaller beach footprint), but relatively low operations and maintenance cost. Seawall and Revetment alternatives were considered slightly more competitive for federal coastal resilience grant programs (i.e. USACE or FEMA). Opportunities for State or local funding for nourishment are limited and inconsistent and are unlikely to cover the estimated Project costs. For example, the Shoreline Erosion Control & Public Beach Restoration grant program, administered by California State Parks Division of Boating and Waterways, does not have a dedicated revenue source and therefore the extent of funding authorized varies with each budget year.[9] This program has been used to cover local cost sharing of larger federally funded projects (e.g. USACE's San Clemente Coastal Storm Damage Reduction Project), but is also very competitive and subject to the State's annual budget-making process. Funding will be a major challenge regardless of the preferred alternative selected. Detailed breakdowns of the estimated costs for each alternative are provided in Appendix A. Estimated costs associated with the No Project alternative are based on the economic assessment presented in the MHRA.

6.2.3 Analysis of Environmental Criteria

Beach Nourishment and Sand Retention alternatives scored significantly higher than other alternatives in the Environmental category. Although some temporary marine biological resource impacts would be expected during each nourishment event, over longer durations these alternatives improve the sandy inter-tidal, beach and foredune habitat within the Project area. These alternatives also score higher in visual, recreation and coastal access due to the sandy beach areas created and use of native materials (sand) as the primary coastal protection feature. Seawall was ranked higher than a revetment in this category, largely due to the narrower footprint and ability to integrate vertical coastal access (access from the street to the beach, usually via stairway) into the structure.

[9] https://dbw.parks.ca.gov/?page_id=28766

6.3 Sensitivity

6.3.1 Criteria Scoring Sensitivity

The close rankings between Seawall, Revetment and Beach Nourishment generated questions from the Project team regarding sensitivity of the analysis. The key question being "How would these results change if one or two scores were revised up or down for each alternative?" There were only a few criteria in which the Project team had more difficulty arriving at a consensus score for a given alternative. One example is the scoring for SLR Adaptability, in which a strong case could be made that the Seawall should receive a 4 instead of 5, or that Beach Nourishment should be scored a 3 instead of a 2. In this case, changing a single score by one increment up or down for would result in only a 2% change in the total score. For each alternative there were only one or two criteria in which scoring was debatable and, in these cases, changing these scores by a single increment was found to not change the overall alternative rankings. There was less debate among Project team members regarding the Revetment criteria scores, indicating a robust consensus among the Project team that Revetment is the lowest scoring of the "hard protection" alternatives. Through this sensitivity analysis it was determined that changes to individual criteria scores could result in about a 2% change in the total alternative score, which would not change the overall alternative ranking.

6.3.2 Category Weighting Sensitivity

Sensitivity of Category Weightings was another area of interest to understand how the breakdown between Technical Performance, Financial and Environmental influences overall results. The results presented in Section 6.2 are based on a breakdown of 40% for Technical Performance (TP), 30% for Financial (FIN) and 30% for Environmental (ENV). The consensus of the Project team was that Technical performance warrants a slightly higher emphasis because it's criteria closely matches the Project objectives and provides the best indicator for Project success. Figure 6-1 illustrates the total scores for each alternative for several different Category Weightings. When these weightings are adjusted a clear pattern emerges in which Seawall is consistently scored highest and No Project is consistently scored lowest. If these Category Weightings are adjusted to place equal emphasis on each category (TP=33.3 / FIN=33.3 / ENV=33.3), the scores and rankings do not significantly change. If a major emphasis is placed on any single category (60% weighting), the top ranked alternative is either Beach Nourishment (ENV=60), Revetment (FIN=60), or Seawall (TP=60). If a much higher emphasis is placed on the Environmental category, as is often the case during environmental review and permitting process, then Beach Nourishment is the highest scoring alternative.

The findings of this sensitivity analysis give the Project team high confidence that the Seawall has the best chance to satisfy the Project objectives. Although the Revetment scores highest in the Financial category, the low Environmental score is an indication this alternative may be very challenging to permit.

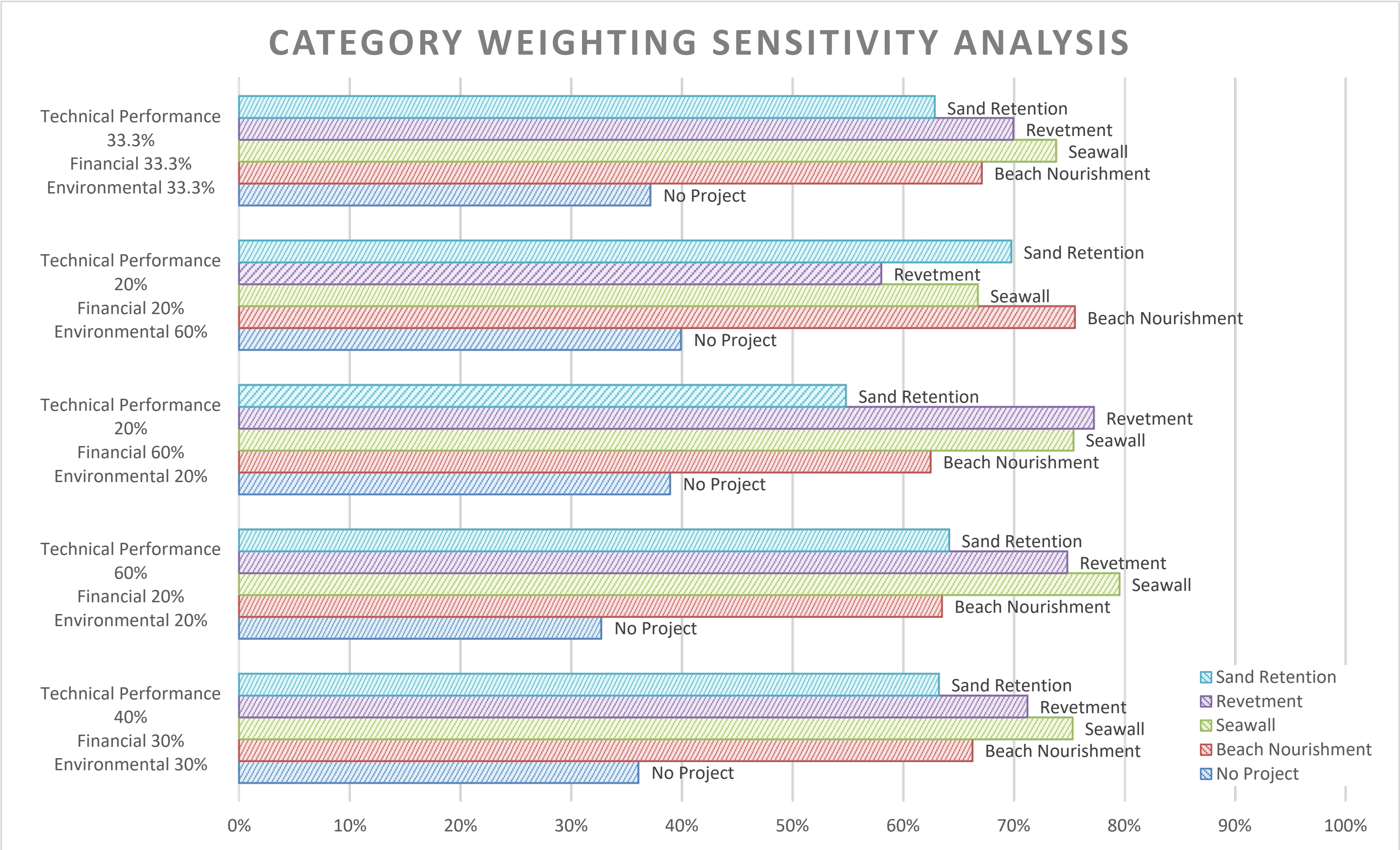

Figure 6-1 Sensitivity to Category Weighting

6.4 Opportunities for Alternative Refinement

In review of the opportunities and constraints of each option, there is the possibility that a hybrid alternative may prove to be the most technically, economically, and environmentally feasible option. A hybrid alternative that combines an improved seawall with a beach nourishment program could leverage the benefits of each alternative to better align with the Project objectives and diverse interests and priorities within the community.

This hybrid alternative would allow for some refinement of the design assumptions since a seawall with a sandy beach may not be subject to the same long-term scour of the hard pan anticipated for the Seawall only alternative. Similarly, if there were an improved seawall along the back beach, the nourishment program would not have to maintain a 100-foot beach width and the overall volumes required could be reduced. In other words, there is an opportunity to improve the overall Project benefits while also managing the financial implications of pursing both an improved seawall and a beach nourishment program.

The primary areas of improvement for the Seawall are in the Financial and Environmental categories. One opportunity for reducing the Seawall cost would be to limit potential scour in front of the wall to reduce pile size and embedment requirements. A successful Beach nourishment program would reduce long-term scour at the seawall but would depend on the longevity of each beach nourishment event. Relying solely on beach nourishment for scour protection would subject this alternative to similar reliability concerns described in Section 6.2.1. A rock scour apron could also be designed to provide some redundant scour protection. The design of this feature would be lower in elevation and narrower in footprint than the existing rock revetment. Ideally, the beach nourishment fronting the seawall would provide the bulk of erosion and scour protection with the rock apron and seawall only exposed during large storm events. Additional technical analyses and discussions with the Project team and regulatory agencies are necessary to further evaluate these opportunities.

7. Next Steps

7.1 Outreach and Feedback on Alternatives Analysis

The findings of this report will be presented at Public Workshop #4 to give the public an opportunity to ask questions and provide comment on the alternatives analysis and the selection of a preferred alternative to be advanced into the next Project phase (Environmental Studies, Permitting and Design).

7.2 Selection of Preferred Alternative

The four design alternatives and 'No Project' all have significant financial costs, based on the opinions of cost developed for the purpose of the MCA. The highest scoring alternative in the MCA was the Seawall; however, the benefits of Beach Nourishment and Rock Revetment were also evident in the results.

In an effort to reduce costs, and increase technical, financial and environmental benefits, a hybrid alternative will be investigated that consists of components of the seawall, rock revetment, and beach nourishment alternatives. An example of how a hybrid option could be formed is to reduce the size and depth of the seawall through incorporation of a small rock revetment in front of the wall for scour protection and utilizing a strategic volume of beach nourishment for redundant scour protection along with environmental benefits.

If the Project team determines this is a viable alternative and worth consideration, the next step would be to develop and analyze the hybrid alternative in a similar manner as the other alternatives through the multi-criteria analysis. In addition, the Project team would begin preliminary consultation with regulatory agencies about all of the alternatives. Following further analysis and preliminary consultation with regulatory agencies, a preferred alternative will be identified by the Project team and presented to the City Council for advancement into the next Project phase (Environmental Studies, Permitting and Design).

A benefit-cost analysis of the preferred alternative will be performed using the NOAA framework applied in the MHRA. The benefit-cost analysis is a typical requirement for grant funding applications and would be an indicator of how competitive the Project would be in pursuing grant funding. A written summary of the preferred alternative and the updated results will be incorporated into an updated version of this report.

8. References

American Society of Civil Engineers (ASCE), 2017. "Tsunami Loads and Effects" in Minimum Design Loads for Buildings and Other Structures. ASCE Technical Standard 7-16, Chapter 6, p.25-50.

Barnard, P.L., Erikson, L.H., Foxgrover, A.C., Limber, P.W., O'Neill, A.C., and Vitousek, S., 2018, Coastal Storm Modeling System (CoSMoS) for Southern California, v3.0, Phase 2 (ver. 1g, May 2018): U.S. Geological Survey data release, https://doi.org/10.5066/F7T151Q4.

California Coastal Commission. 2018. California Coastal Commission Sea Level Rise Policy Guidance. Retrieved from: documents.coastal.ca.gov/assets/slr/guidance/2018/0_Full_2018AdoptedSLRGuidanceUpdate.pdf

California Ocean Protection Council (OPC). 2018. State of California Sea Level Rise Guidance 2018 Update. Retrieved from: opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

California Ocean Protection Council (OPC). 2020. Strategic Plan to Protect California's Coast and Oceans 2020-2025 to "Build Resiliency to Sea-Level Rise, Coastal Storms, Erosion and Flooding". Retrieved from: http://www.opc.ca.gov/webmaster/ftp/pdf/2020-2025-strategic-plan/OPC-2020-2025-Strategic-Plan-FINAL-20200228.pdf

ESA (2016). San Francisco Regional Sediment Management Plan. Prepared for California Sediment Management Work Group. Draft – January 2016.

ESA (2021). City of Pacifica Beach Boulevard Infrastructure Resiliency Project, Wave Runup and Overtopping Risk Assessment. February 2021.

ESA (2021b). City of Pacifica Beach Boulevard Infrastructure Resiliency Project, Preliminary Design and Analysis of Beach Nourishment and Sand Retention Alternatives. Progress Draft Memorandum, March 2021.

EurOtop (2018). Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com.

GHD, 2021. Beach Boulevard Infrastructure Resiliency Project, Multi-Hazard Risk Assessment, City of Pacifica. Public Review Draft, March 2021.

Griggs, Gary (2020). Geological Evaluation for the Beach Boulevard Seawall Replacement Project, Pacifica, California.

Haro, Kasunich and Associates, Inc (HKA), (2020a). Feasibility Level Geotechnical Engineering Investigation, Beach Boulevard Infrastructure Resiliency Project (BBIRP), Pacifica, CA. Draft October 2020.

HKA (2020b). BBIRP Earthquake Risk Assessment Technical Report. Final Draft December 2020.

NOAA (2015). Guidance of Considering the Use of Living Shorelines. 2015.

Kearns & West (2020). Beach Boulevard Infrastructure Resiliency Project, Existing Conditions Survey Results. October 2020.

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	A. Holloway	B. Leslie		P. Henderson		04/02/2021
B	A. Holloway	P. Henderson		P. Henderson		04/14/2021
C	A. Holloway	B. Leslie		P. Henderson		04/21/2021

Appendix A

Opinion of Probable Cost Estimates for Alternatives Analysis

Summary of Alternatives Opinion of Project Costs

Date: 4/14/2021

Detailed Summary of Alternatives Opinion of Project Costs

Alternative	Item Description	Planning Horizon 1 (2020 - 2030)	Planning Horizon 2 (2030 - 2050)	Planning Horizon 3 (2050 - 2080)	Planning Horizon 4 (2080 - 2100)	Total
1 - No Project	Initial Costs	$ 95,600,000	$ -	$ -	$ -	$ 95,600,000
	O&M	$ -	$ 18,800,000	$ 55,100,000	$ -	$ 73,900,000
	Decommissioning	$ -	$ 18,800,000	$ 55,100,000	$ -	$ 73,900,000
	Mitigation Fees	$ -	$ -	$ -	$ -	$ -
	Total	**$ 95,600,000**	**$ 37,600,000**	**$ 110,200,000**	**$ -**	**$ 243,400,000**
2 - Beach Nourishment	Initial Costs	$ 59,900,000	$ -	$ -	$ -	$ 59,900,000
	O&M	$ 100,000	$ 52,000,000	$ 52,500,000	$ -	$ 104,600,000
	Decommissioning	$ -	$ -	$ 700,000	$ -	$ 700,000
	Mitigation Fees	$ -	$ -	$ -	$ -	$ -
	Total	**$ 60,000,000**	**$ 52,000,000**	**$ 53,200,000**	**$ -**	**$ 165,200,000**
3 - New Seawall	Initial Costs	$ 93,700,000	$ -	$ -	$ -	$ 93,700,000
	O&M	$ 100,000	$ 400,000	$ 1,500,000	$ -	$ 2,000,000
	Decommissioning	$ -	$ -	$ 2,600,000	$ -	$ 2,600,000
	Mitigation Fees	$ 22,100,000	$ -	$ -	$ -	$ 22,100,000
	Total	**$ 115,900,000**	**$ 400,000**	**$ 4,100,000**	**$ -**	**$ 120,400,000**
4 - Rock Revetment	Initial Costs	$ 48,100,000	$ -	$ -	$ -	$ 48,100,000
	O&M	$ 2,100,000	$ 3,900,000	$ 7,700,000	$ -	$ 13,700,000
	Decommissioning	$ -	$ -	$ 6,500,000	$ -	$ 6,500,000
	Mitigation Fees	$ 33,800,000	$ -	$ -	$ -	$ 33,800,000
	Total	**$ 84,000,000**	**$ 3,900,000**	**$ 14,200,000**	**$ -**	**$ 102,100,000**
5 - Sand Retention	Initial Costs	$ 111,200,000	$ -	$ -	$ -	$ 111,200,000
	O&M	$ 3,800,000	$ 35,800,000	$ 48,200,000	$ -	$ 87,800,000
	Decommissioning	$ -	$ -	$ 26,000,000	$ -	$ 26,000,000
	Mitigation Fees	$ 10,400,000	$ -	$ -	$ -	$ 10,400,000
	Total	**$ 125,400,000**	**$ 35,800,000**	**$ 74,200,000**	**$ -**	**$ 235,400,000**

Notes:

1. The values provided in this table are considered pre-planning level estimates, and should not be used for any purpose other than intended, which is the feasibility study for the BBIRP Project. Accuracy +50% - 30%
2. All values shown in this table are 2021 costs.
3. 'No Project' alternative project costs developed in Dec 2020. ENR construction cost index from Dec 2020 (13168.76) to April 2021 (13157.41) gives an escalation rate of -0.1%, therefore negligable change to the 2020 cost, which are presented in this table.
4. A 30% contingency amount is included in the above sums to cover unknown detail and costs considering the feasibility level of the design.

City of Pacifica
Beach Boulevard Infrastructure Resiliency Project (BBIRP)
Opinion of Probable Cost for Design Alternatives

Opinion of Costs for Alternative 2 - Beach Nourishment

Date: 4/14/2021

		Planning Horizon 1 (2020 - 2030)				Planning Horizon 2 (2030 - 2050)				Planning Horizon 3 (2050 - 2080)			
Item	**Item Description**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**
Project Construction Costs													
1	Mobilization (% other items see note 2)	5%	%	$ 7,303,159	$ 365,158	5%	%	$ 250,000	$ 12,500	5%	%	$ 450,000	$ 22,500
2	Traffic Control	1	LS	$ 150,000	$ 150,000				$ -				$ -
3	Remove existing rock revetment	0.5	LS	$ 4,478,819	$ 2,239,409				$ -				$ -
4	Demolish exisiting wall	1	LS	$ 550,000	$ 550,000				$ -				$ -
5	New wall	2,675	FT	$ 1,650	$ 4,413,750				$ -				$ -
6	Beach nourishment mobilization	1	LS	$ 2,500,000	$ 2,500,000				$ -				$ -
7	Beach nourishment	1,000,000	CY	$ 28	$ 27,500,000				$ -				$ -
8	Maint. beach nourishment mobilization	-	LS	$ 2,500,000	$ -	2	LS	$ 2,500,000	$ 5,000,000	2	LS	$ 2,500,000	$ 5,000,000
9	Maint. beach nourishment	-	CY	$ 28	$ -	1,000,000	CY	$ 28	$ 27,500,000	1000000	CY	$ 28	$ 27,500,000
10	Structure Maintenance	10	YR	$ 10,000	$ 100,000	20	YR	$ 12,500	$ 250,000	30	YR	$ 15,000	$ 450,000
11	Decommissioning									1	LS	$ 500,000	$ 500,000
	Project Construction Costs Total				**$ 37,818,317**				**$ 32,762,500**				**$ 33,472,500**
Project Professional Services Items													
1	Geotechnical Investigations	1	LS	$ 50,000	$ 50,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000
2	Survey	1	LS	$ 25,000	$ 25,000	1	LS	$ 20,000	$ 20,000	1	LS	$ 20,000	$ 20,000
3	Design	6%	%	$ 37,818,317	$ 2,269,099	6%	%	$ 32,762,500	$ 1,965,750	6%	%	$ 33,472,500	$ 2,008,350
4	Permits	8%	%	$ 37,818,317	$ 3,025,465	8%	%	$ 32,762,500	$ 2,621,000	8%	%	$ 33,472,500	$ 2,677,800
5	Construction Management	8%	%	$ 37,818,317	$ 3,025,465	8%	%	$ 32,762,500	$ 2,621,000	8%	%	$ 33,472,500	$ 2,677,800
	Professional Services Total				**$ 8,395,030**				**$ 7,252,750**				**$ 7,408,950**
Mitigation Fees													
1	Mitigation Fees	1	LS	$ -	$ -								
	Mitigation Fees Total				**$ -**				**$ -**				**$ -**
	Contingency	**30%**	**%**	**$ 46,213,347**	**$ 13,864,004**	**30%**	**%**	**$ 40,015,250**	**$ 12,004,575**	**30%**	**%**	**$ 40,881,450**	**$ 12,264,435**
	Project Total				**$ 60,077,351**				**$ 52,019,825**				**$ 53,145,885**
	Project Total Rounded				**$ 60,000,000**				**$ 52,000,000**				**$ 53,000,000**

Notes:

1 Half of existing rock revement volume is removed, remaining left to protect wall in case of sand being removed before re-nourishment

2 Mobilization is 5% of all items except Beach Nourishment. Beach Nourishment mobilization is separated from other mobilization due to the special requirements for marine equipment mobilization

3 Beach nourishment assumes 1,000,0000 cy in year 2020 plus 4 later individual 500,000 renourishment events

4 Structure maintenance costs increase over time as maintence needs increase with aging structure

City of Pacifica
Beach Boulevard Infrastructure Resiliency Project (BBIRP)
Opinion of Probable Cost for Design Alternatives

Opinion of Costs for Alternative 3 - Seawall

Date: 4/14/2021

		Planning Horizon 1 (2020 - 2030)				Planning Horizon 2 (2030 - 2050)				Planning Horizon 3 (2050 - 2080)			
Item	**Item Description**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**
Project Construction Costs													
1	Mobilization (% of all other items)	5%	%	$ 56,125,909	$ 2,806,295	5%	%	$ 200,000	$ 10,000	5%	%	$ 2,450,000	$ 122,500
2	Traffic Control	1	LS	$ 150,000	$ 150,000				$ -				$ -
3	Remove existing rock revetment	1	LS	$ 4,478,819	$ 4,478,819				$ -				$ -
4	Demolish exisiting wall	1	LS	$ 550,000	$ 550,000				$ -				$ -
5	New Secant Pile Wall	2,675	FT	$ 18,671	$ 49,944,772				$ -				$ -
6	Guard rail	2,675	FT	$ 169	$ 452,318				$ -				$ -
7	Beach access	3	EA	$ 150,000	$ 450,000				$ -				$ -
8	Beach Acces ADA	1	EA	$ 200,000	$ 200,000				$ -				$ -
9	Structure maintenance	10	YR	$ 5,000	$ 50,000	20	YR	$ 10,000	$ 200,000	30	YR	$ 15,000	$ 450,000
10	Decommissioning									1	LS	$ 2,000,000	$ 2,000,000
	Project Construction Costs Total				**$ 59,082,204**				**$ 210,000**				**$ 2,572,500**
Project Professional Services Items													
1	Geotechnical Investigations	1	LS	$ 50,000	$ 50,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000
2	Survey	1	LS	$ 25,000	$ 25,000	1	LS	$ 20,000	$ 20,000	1	LS	$ 20,000	$ 20,000
3	Design	6%	%	$ 59,082,204	$ 3,544,932	6%	%	$ 210,000	$ 12,600	6%	%	$ 2,572,500	$ 154,350
4	Permits	8%	%	$ 59,082,204	$ 4,726,576	8%	%	$ 210,000	$ 16,800	8%	%	$ 2,572,500	$ 205,800
5	Construction Management	8%	%	$ 59,082,204	$ 4,726,576	8%	%	$ 210,000	$ 16,800	8%	%	$ 2,572,500	$ 205,800
	Professional Services Total				**$ 13,073,085**				**$ 91,200**				**$ 610,950**
Mitigation Fees													
1	Mitigation Fees	1	LS	$ 17,000,000	$ 17,000,000								
	Mitigation Fees Total				**$ 17,000,000**				**$ -**				**$ -**
	Contingency	**30%**	**%**	**$ 89,155,289**	**$ 26,746,587**	**30%**	**%**	**$ 301,200**	**$ 90,360**	**30%**	**%**	**$ 3,183,450**	**$ 955,035**
	Project Total				**$ 115,901,876**				**$ 391,560**				**$ 4,138,485**
	Project Total Rounded				**$ 116,000,000**				**$ 400,000**				**$ 4,000,000**

Notes:

1 All of existing rock revement volume is removed

2 Mobilization is 5% of all items except Beach Nourishment. Beach Nourishment mobilization is separated form other mobilization due to the special requirements for marine equipment mobilization

3 New seacant pile wall rate includes piles, pile cap, backfill, guardrail, pavement reinstatement behind wall, rock sculpted wall facing

4 New seacant wall does not require tie-backs or rock protection

5 Decommissioning cost assumes cutting off piles below MLLW elevation and abandoning in place

City of Pacifica

Beach Boulevard Infrastructure Resiliency Project (BBIRP)

Opinion of Probable Cost for Design Alternatives

Opinion of Costs for Alternative 4 - Rock Revetment

Date: 4/14/2021

		Planning Horizon 1 (2020 - 2030)				Planning Horizon 2 (2030 - 2050)				Planning Horizon 3 (2050 - 2080)			
Item	**Item Description**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**
Project Construction Costs													
1	Mobilization (% of all other items)	5%	%	$ 30,116,595	$ 1,505,830	5%	%	$ 2,316,857	$ 115,843	5%	%	$ 8,475,286	$ 423,764
2	Traffic Control	1	LS	$ 150,000	$ 150,000				$ -				$ -
3	Remove existing rock revetment	0.25	LS	$ 4,478,819	$ 1,119,705				$ -				$ -
4	Demolish exisiting wall	1	LS	$ 550,000	$ 550,000				$ -				$ -
5	New wall	2,675	FT	$ 1,650	$ 4,413,750				$ -				$ -
6	Revetment embankment core	39,568	CY	$ 50	$ 1,978,380				$ -				$ -
7	New rock revetment	69,962	CY	$ 260	$ 18,168,573				$ -				$ -
8	Use existing rock	37,751	CY	$ 50	$ 1,887,569				$ -				$ -
9	Beach Acces ADA	1	EA	$ 200,000	$ 200,000				$ -				$ -
10	Maint. new rock revetment	5,386	CY	$ 260	$ 1,398,618	6,996	CY	$ 260	$ 1,816,857	10,494	CY	$ 260	$ 2,725,286
11	Maint. restacking	10	YR	$ 25,000	$ 250,000	20	YR	$ 25,000	$ 500,000	30	YR	$ 25,000	$ 750,000
12	Decommissioning									1	LS	$ 5,000,000	$ 5,000,000
	Project Construction Costs Total				**$ 31,622,424**				**$ 2,432,700**				**$ 8,899,050**
Project Professional Services Items													
1	Geotechnical Investigations	1	LS	$ 50,000	$ 50,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000
2	Survey	1	LS	$ 25,000	$ 25,000	1	LS	$ 20,000	$ 20,000	1	LS	$ 20,000	$ 20,000
3	Design	6%	%	$ 31,622,424	$ 1,897,345	6%	%	$ 2,432,700	$ 145,962	6%	%	$ 8,899,050	$ 533,943
4	Permits	8%	%	$ 31,622,424	$ 2,529,794	8%	%	$ 2,432,700	$ 194,616	8%	%	$ 8,899,050	$ 711,924
5	Construction Management	8%	%	$ 31,622,424	$ 2,529,794	8%	%	$ 2,432,700	$ 194,616	8%	%	$ 8,899,050	$ 711,924
	Professional Services Total				**$ 7,031,933**				**$ 580,194**				**$ 2,002,791**
Mitigation Fees													
1	Mitigation Fees	1	LS	$ 26,000,000	$ 26,000,000								
	Mitigation Fees Total				**$ 26,000,000**				**$ -**				**$ -**
	Contingency	**30%**	**%**	**$ 64,654,358**	**$ 19,396,307**	**30%**	**%**	**$ 3,012,894**	**$ 903,868**	**30%**	**%**	**$ 10,901,841**	**$ 3,270,552**
	Project Total				**$ 84,050,665**				**$ 3,916,762**				**$ 14,172,394**
	Project Total Rounded				**$ 84,000,000**				**$ 4,000,000**				**$ 14,000,000**

Notes:

1 Quarter of existing rock revement volume is assumed to be unsuitable and to be removed, remaining used in new rock revetment

2 Assume restacking of rock revetment will be required once every 20 years

3 Assume additional rock will be imported at a rate of 10% of original volume every 20 years (every 10 years there will be either restacking or new rock imported)

City of Pacifica
Beach Boulevard Infrastructure Resiliency Project (BBIRP)
Opinion of Probable Cost for Design Alternatives

Opinion of Costs for Alternative 5 - Sand Retention

Date: 4/14/2021

		Planning Horizon 1 (2020 - 2030)				Planning Horizon 2 (2030 - 2050)				Planning Horizon 3 (2050 - 2080)			
Item	**Item Description**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**	**Qty**	**Unit**	**Rate**	**Amount**
Project Construction Costs													
1	Mobilization (% other items see note 2)	5%	%	$ 40,309,587	$ 2,015,479	5%	%	$ 5,963,618	$ 298,181	5%	%	$ 29,020,428	$ 1,451,021
2	Traffic Control	1	LS	$ 150,000	$ 150,000				$ -				$ -
3	Remove existing rock revetment	0.5	LS	$ 4,478,819	$ 2,239,409				$ -				$ -
4	Demolish exisiting wall	1	LS	$ 550,000	$ 550,000				$ -				$ -
5	New wall	2,675	FT	$ 1,650	$ 4,413,750				$ -				$ -
6	Groin embankment core		CY	$ -	$ -				$ -				$ -
7	New rock groins	84,832	CY	$ 338	$ 28,639,563				$ -				$ -
8	Use existing rock	25,168	CY	$ 60	$ 1,510,056				$ -				$ -
9	Beach nourishment mobilization	1	LS	$ 2,500,000	$ 2,500,000				$ -				$ -
10	Beach nourishment	1,000,000	CY	$ 28	$ 27,500,000				$ -				$ -
11	Structure Maintenance	10	YR	$ 10,000	$ 100,000	20	YR	$ 12,500	$ 250,000	30	YR	$ 15,000	$ 450,000
12	Maint. beach nourishment mobilization	-	LS	$ 2,500,000	$ -	1	LS	$ 2,500,000	$ 2,500,000	1	LS	$ 2,500,000	$ 2,500,000
13	Maint. beach nourishment	-	CY	$ 28	$ -	500,000	CY	$ 28	$ 13,750,000	500,000	CY	$ 28	$ 13,750,000
14	Maint. new rock groin	5,500	CY	$ 338	$ 1,856,809	11,000	CY	$ 338	$ 3,713,618	16,500	CY	$ 338	$ 5,570,428
15	Maint. restacking	10	YR	$ 100,000	$ 1,000,000	20	YR	$ 100,000	$ 2,000,000	30	YR	$ 100,000	$ 3,000,000
16	Decommissioning									1	LS	$ 20,000,000	$ 20,000,000
	Project Construction Costs Total				**$ 72,475,066**				**$ 22,511,799**				**$ 46,721,449**
Project Professional Services Items													
1	Geotechnical Investigations	1	LS	$ 50,000	$ 50,000	1	LS	$ 25,000	$ 25,000	1	LS	$ 25,000	$ 25,000
2	Survey	1	LS	$ 25,000	$ 25,000	1	LS	$ 20,000	$ 20,000	1	LS	$ 20,000	$ 20,000
3	Design	6%	%	$ 72,475,066	$ 4,348,504	6%	%	$ 22,511,799	$ 1,350,708	6%	%	$ 46,721,449	$ 2,803,287
4	Permits	8%	%	$ 72,475,066	$ 5,798,005	8%	%	$ 22,511,799	$ 1,800,944	8%	%	$ 46,721,449	$ 3,737,716
5	Construction Management	8%	%	$ 72,475,066	$ 5,798,005	8%	%	$ 22,511,799	$ 1,800,944	8%	%	$ 46,721,449	$ 3,737,716
	Professional Services Total				**$ 16,019,515**				**$ 4,997,596**				**$ 10,323,719**
Mitigation Fees													
1	Mitigation Fees	1	LS	$ 8,000,000	$ 8,000,000								
	Mitigation Fees Total				**$ 8,000,000**				**$ -**				**$ -**
	Contingency	**30%**	**%**	**$ 96,494,581**	**$ 28,948,374**	**30%**	**%**	**$ 27,509,395**	**$ 8,252,819**	**30%**	**%**	**$ 57,045,168**	**$ 17,113,550**
	Project Total				**$ 125,442,955**				**$ 35,762,214**				**$ 74,158,718**
	Project Total Rounded				**$ 125,000,000**				**$ 36,000,000**				**$ 74,000,000**

Notes:

1. All of the existing rock revetment will be utilized in the sand retention structure(s)
2. Mobilization is 5% of all items except Beach Nourishment. Beach Nourishment mobilization is separated from other mobilization due to the special requirements for marine equipment mobilization
3. Beach nourishment assumes 1,000,0000 cy in year 2020 plus 2 later individual 500,000 renourishment events
4. Stucture maintenance costs increase over time as maintence needs increase with aging structure
5. Half of existing rock revetment remains in front of wall, half is utilized in construction of new groins
6. Assume restacking of rock will be required once every 20 years
7. Assume additional rock will be imported at a rate of 10% of original volume every 20 years (every 10 years there will be either restacking or new rock imported)

Appendix B

Detailed Multi-Criteria Analysis Scoring Matrix

Beach Boulevard Infrastructure Resiliency Project (BBIRP)
Summary of Multi Criteria Analysis Weighted Scoring Matrix

Weight	Aspect	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
		No Project	Beach Nourishment	Seawall	Revetment	Sand Retention
		Weighted Score	Weighted Score	Weighted Score	Weighted Score	Weighted Score
40%	**TECHNICAL PERFORMANCE**					
20%	Flood Protection	2%	6%	6%	6%	6%
20%	Erosion Protection	2%	5%	8%	8%	6%
20%	Reliability	2%	3%	8%	8%	5%
10%	Operability	1%	2%	2%	2%	2%
10%	Constructability	3%	3%	2%	2%	2%
20%	Sea Level Rise Adaptability	2%	3%	8%	6%	5%
	SUBTOTAL out of 40%	*10%*	*23%*	*35%*	*33%*	*26%*
30%	**FINANCIAL**					
70%	Lifecycle Costs (see note 1)	9%	13%	18%	21%	9%
30%	Grant Funding Potential	4%	4%	5%	5%	4%
	SUBTOTAL out of 30%	*12%*	*17%*	*23%*	*26%*	*13%*
30%	**ENVIRONMENTAL**					
20%	Marine Biological Resources	4%	5%	2%	1%	5%
20%	Terrestrial Biological Resources	5%	5%	5%	5%	5%
20%	Visual Resources	2%	5%	2%	1%	4%
20%	Recreation General	1%	6%	4%	2%	6%
20%	Coastal Access	1%	6%	4%	2%	5%
	SUBTOTAL out of 30%	*13%*	*26%*	*17%*	*12%*	*24%*
	Total Weighted Score out of 100%	36%	66%	75%	71%	63%
	Ranking	**5**	**3**	**1**	**2**	**4**

1. Lifecycle costs include estimated costs associated with capital, operation & maintenance, decommissioning and mitigation costs.

City Of Pacifica
Beach Boulevard Infrastructure Resiliency Project (BBIRP)
Multi Criteria Analysis Weighted Scoring Matrix

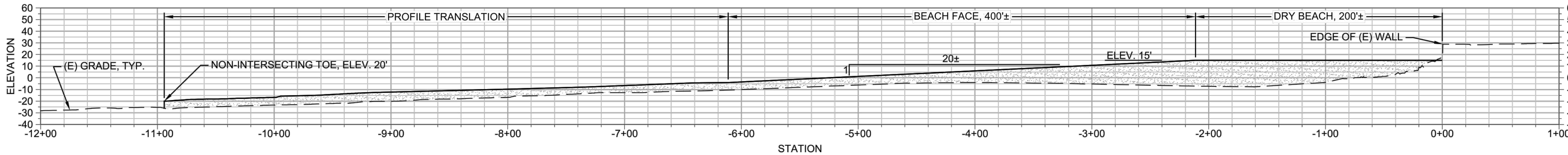
Scoring	1	2	3	4	5
	Low		Average		High

Importance	Aspect	Objectives	Alternative 1 No Project		Alternative 2 Beach Nourishment		Alternative 3 Seawall		Alternative 4 Revetment		Alternative 5 Sand Retention		Comments
			Score (out of 5)	Weighted Score	Score (out of 5)	Weighted Score	Score (out of 5)	Weighted Score	Score (out of 5)	Weighted Score	Score (out of 5)	Weighted Score	
40%	**TECHNICAL PERFORMANCE**												
20%	**Flood Protection**	Protect infrastructure and property from wave overtopping, flooding and other risks.	1	2%	4	6%	4	6%	4	6%	4	6%	Each alternative can achieve the design criteria for coastal flooding/overtopping
20%	**Erosion Protection**	Protect infrastructure and property from erosion hazards.	1	2%	3	5%	5	8%	5	8%	4	6%	Structural alternatives provide best protection against storm related erosion & scour, seasonal erosion & long-term erosion.
20%	**Reliability**	Maintain level of protection despite uncertainties around dynamic parameters such as beach condition, water level, wave height, period, sequence of storms etc..	1	2%	2	3%	5	8%	5	8%	3	5%	Structural alternatives maintain most reliable level of protection despite changes in water levels, storm intensity, erosion trends, or series of storms. Performance/longevity of sandy beach under these circumstances was considered less reliable.
10%	**Operability**	Minimize effort required to operate i.e. minimize requirements to make safe prior to/during storm events	1	1%	3	2%	3	2%	3	2%	3	2%	No major differentiators from an operational perspective.
10%	**Constructability**	Each alternative is feasible and constructable at the project location (dynamic ocean environment)	4	3%	4	3%	3	2%	2	2%	2	2%	Rock placement in dynamic ocean environment poses most significant constructability challenge.
20%	**Sea Level Rise Adaptability**	Ability to adapt to SLR scenarios greater than 2 feet. What other adaptations would be required in a 3.5 ft SLR scenario?	1	2%	2	3%	5	8%	4	6%	3	5%	Elevation of backshore feature (structure) will be logical adaptation to accommodate 3.5 ft SLR. This could be integrated into initial foundation design of seawall & revetment.
100%		**SUBTOTAL out of 40%**		**10%**		**23%**		**35%**		**33%**		**26%**	
30%	**FINANCIAL**												
70%	**Lifecycle Costs (see note 1)**	Ensure the capital investment, O&M costs and decommissioning costs provides the best value for the amount.	2.11	9%	3.10	13%	4.26	18%	5.00	21%	2.19	9%	Based on a score relative to the lowest cost i.e. lowest cost scores 5. Score is calculated hence 2 sig. fig.
30%	**Grant Funding Potential**	Ensure alternative can be funded i.e. grants vs City funds	2	4%	2	4%	3	5%	3	5%	2	4%	Structural alternatives considered slightly more competitive for federal coastal resilience programs (i.e. USACE or FEMA-BRIC). State or local funding for nourishment unlikely to cover estimated project costs.
100%		**SUBTOTAL out of 30%**		**12%**		**17%**		**23%**		**26%**		**13%**	
30%	**ENVIRONMENTAL**												
20%	**Marine Biological Resources**	Improved or no negative environmental impact to marine resources	3	4%	4	5%	2	2%	1	1%	4	5%	Beach & sand retention have temporary impacts but offer improved resources over time.
20%	**Terrestrial Biological Resources**	Improved or no negative environmental impact to terrestrial resources	4	5%	4	5%	4	5%	4	5%	4	5%	Each alternatives addresses potential flooding via Clarendon Gap. No project included cost of levees to protect adjacent property
20%	**Visual Resources**	Improved or no negative environmental impact to visual resources	2	2%	4	5%	2	2%	1	1%	3	4%	Bulk of rock revetment would obstruct views along BB and corridors. Seawall crest increase would also obstruct views in some locations.
20%	**Recreation General**	Improve recreation opportunities and encourage increased visits.	1	1%	5	6%	3	4%	2	2%	5	6%	Assumes beach & sand retention offer widest variety of recreational opportunities along Promenade, Pier and beach areas. NP would eliminate recreation along Promenade & Pier.
20%	**Coastal Access**	Improved or no negative impact to vertical and lateral beach access and available parking.	1	1%	5	6%	3	4%	2	2%	4	5%	Beach & sand retention offer most improvements to lateral & vertical beach access. NP could offer some seasonal beach although private shoreline protection structures are a possibility in this scenario.
100%		**SUBTOTAL out of 30%**		**13%**		**26%**		**17%**		**12%**		**24%**	
		TOTAL out of 100%		**36%**		**66%**		**75%**		**71%**		**63%**	

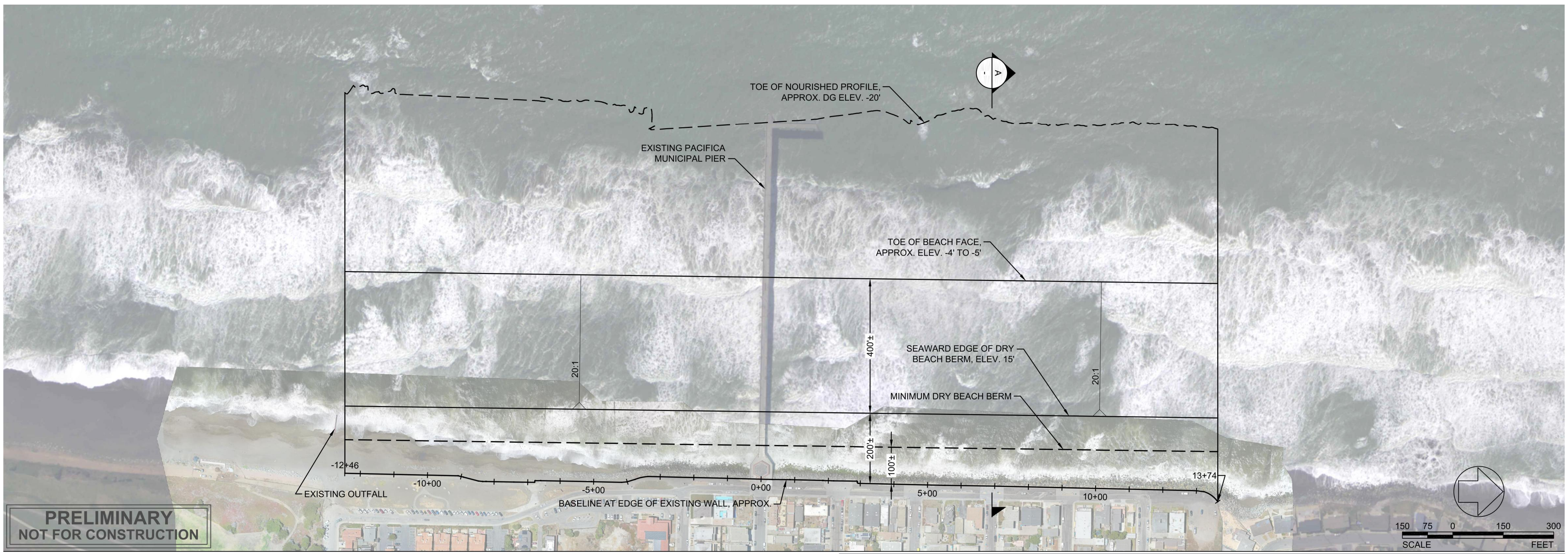
1. Lifecycle costs include estimated costs associated with capital, operation & maintenance, decommissioning and mitigation costs.

Appendix C

Drawings of Design Alternatives



A RETENTION STRUCTURE
TYPICAL PROFILE SCALE: 1"=100'



PRELIMINARY
NOT FOR CONSTRUCTION

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CITY OF PACIFICA
BEACH BOULEVARD INFRASTRUCTURE RESILIENCY PROJECT (BBIRP)

SHORE PROTECTION
ALTERNATIVE 2 - BEACH NOURISHMENT

Project No. 11213162
Report No. N/A
Date

FIG-005

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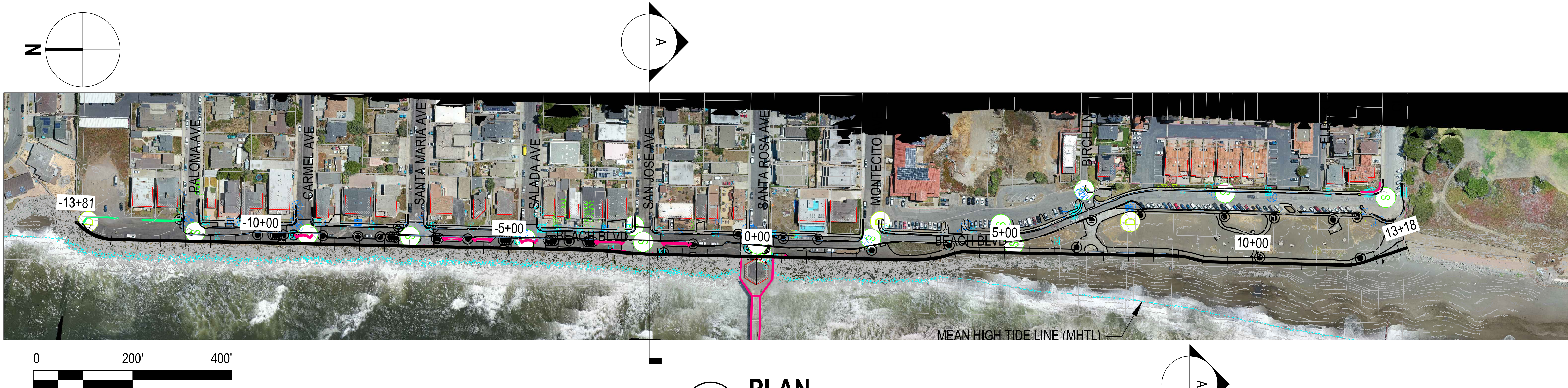
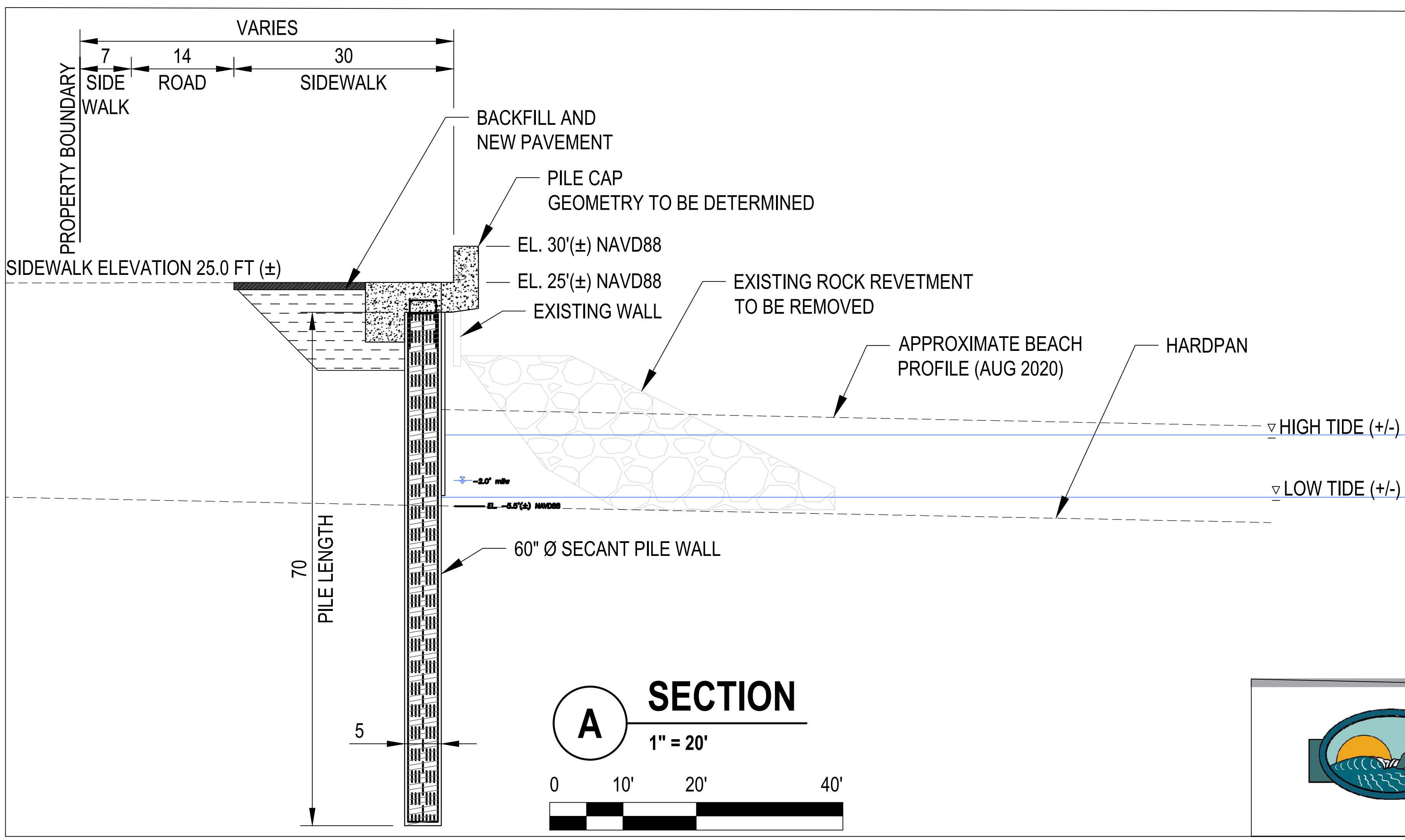
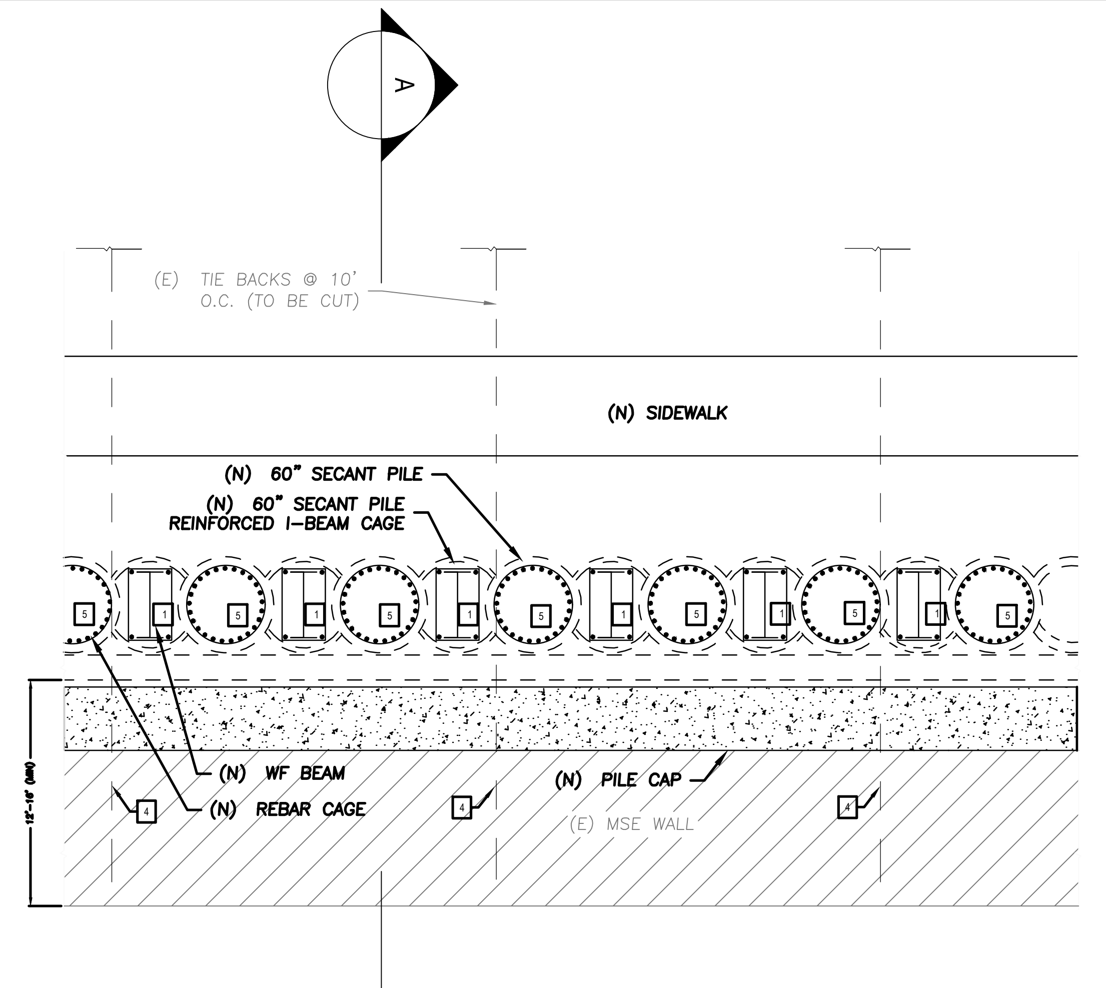


1 PLAN
1" = 200'



A SECTION
1" = 20'



2 PLAN
1" = 10'

0 10' 20'

HARO, KASUNICH AND ASSOCIATES, INC.
CONSULTING GEOTECHNICAL & COASTAL ENGINEERS

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CITY OF PACIFICA
BEACH BOULEVARD INFRASTRUCTURE
RESILIENCY PROJECT (BBIRP)

SHORE PROTECTION
ALTERNATIVE 3 - NEW SEAWALL

Project No. 11213162
Report No. N/A
Date

FIG-006

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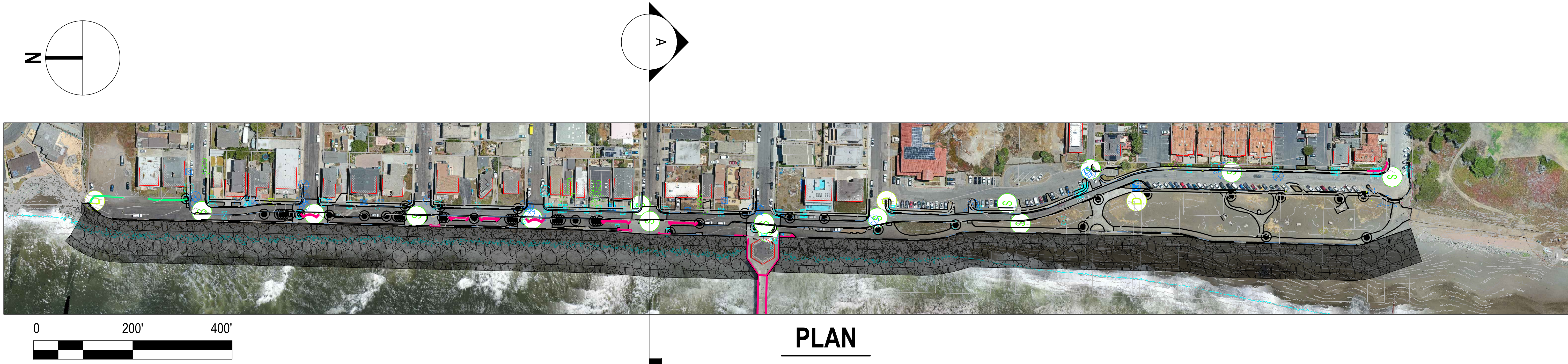
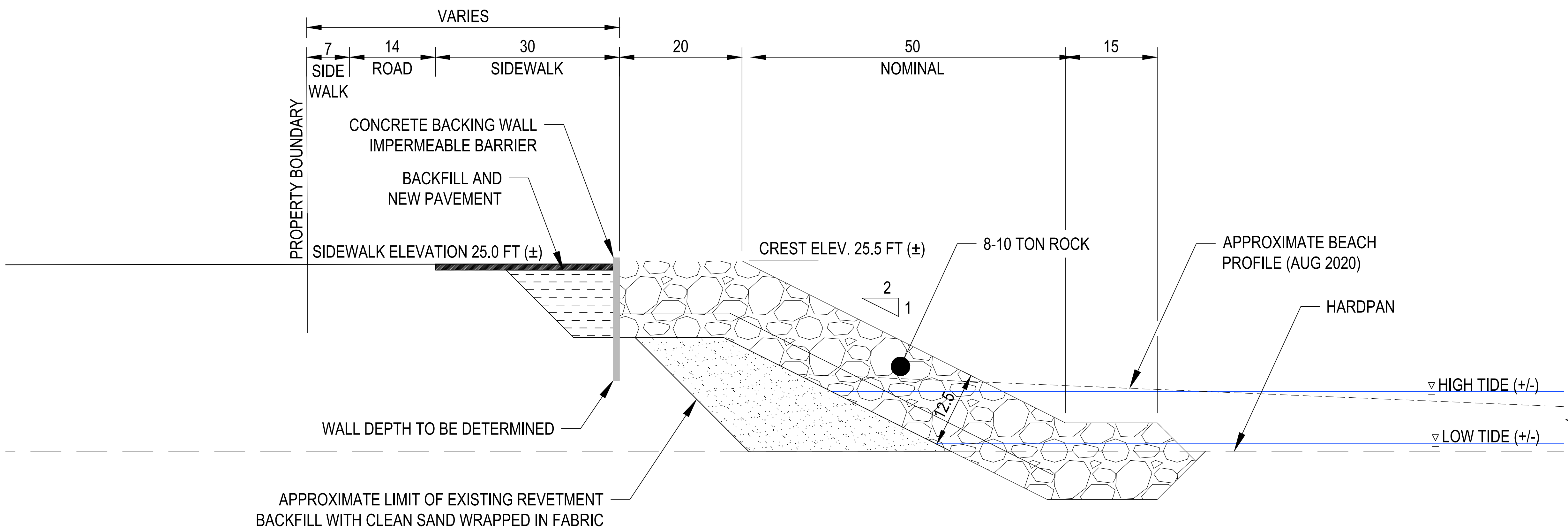


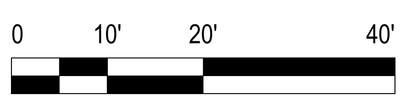
PLAN

1" = 200'



A SECTION

1" = 20'



CITY OF PACIFICA
BEACH BOULEVARD INFRASTRUCTURE
RESILIENCY PROJECT (BBIRP)

SHORE PROTECTION
ALTERNATIVE 4 - ROCK REVETMENT

Project No. 11213162
Report No. N/A
Date

FIG-007

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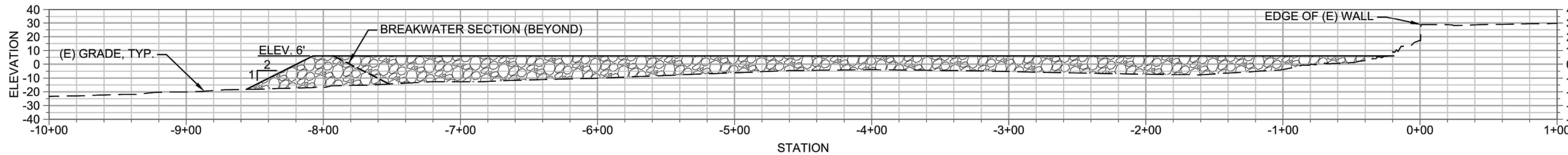
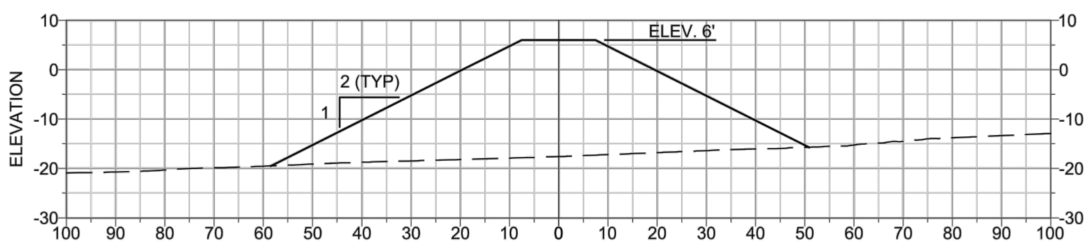
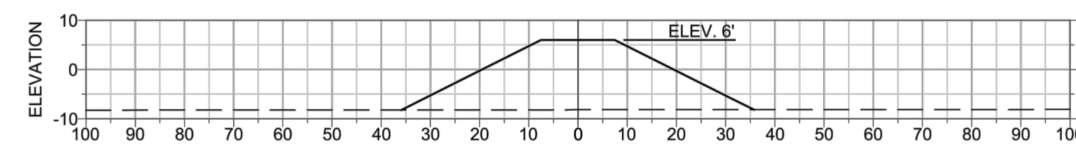


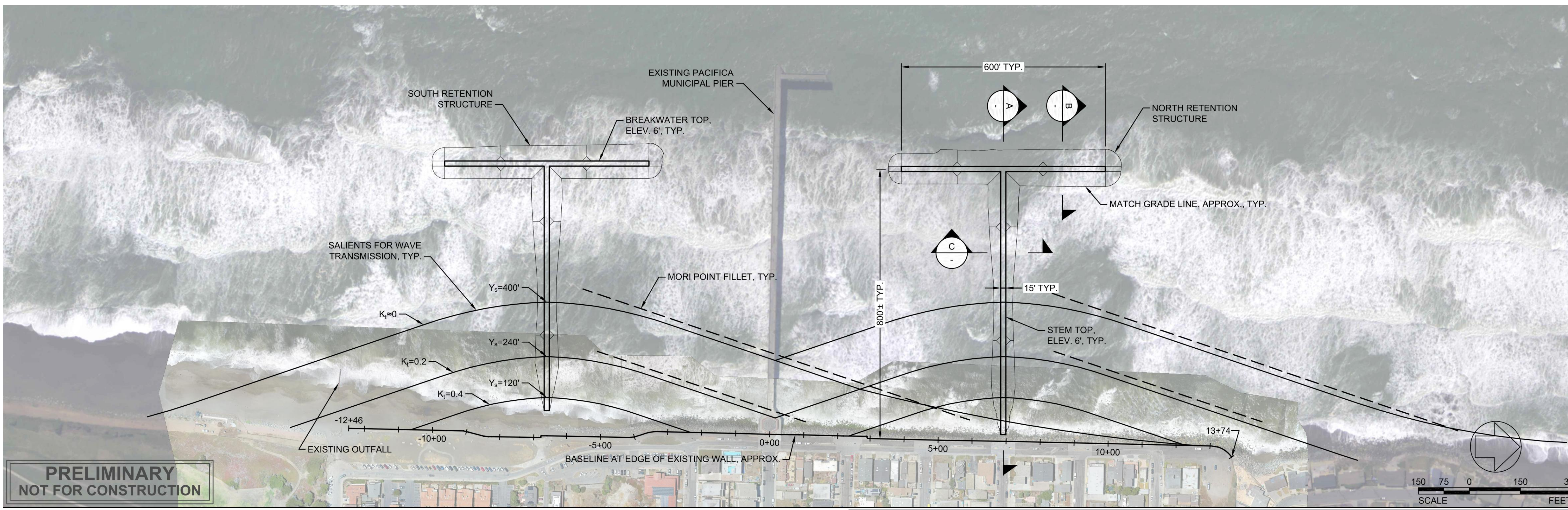
A - RETENTION STRUCTURE
TYPICAL PROFILE SCALE: 1"=100'



B - BREAKWATER
TYPICAL SECTION SCALE: 1"=40'



C - STEM
TYPICAL SECTION SCALE: 1"=40'



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CITY OF PACIFICA
BEACH BOULEVARD INFRASTRUCTURE RESILIENCY PROJECT (BBIRP)

SHORE PROTECTION
ALTERNATIVE 5a - BREAKWATER

Project No. 11213162
Report No. N/A
Date

FIG-008

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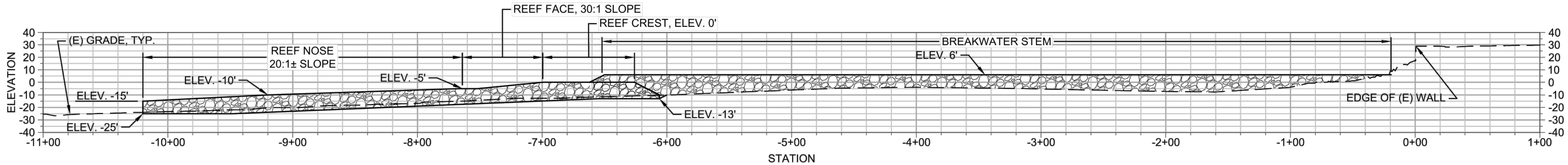
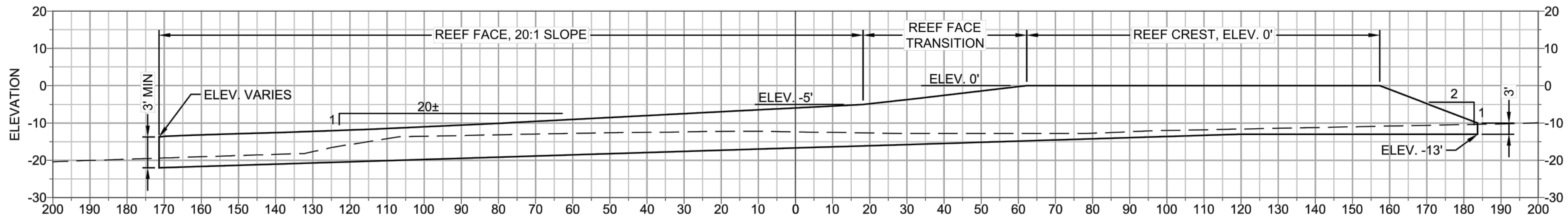
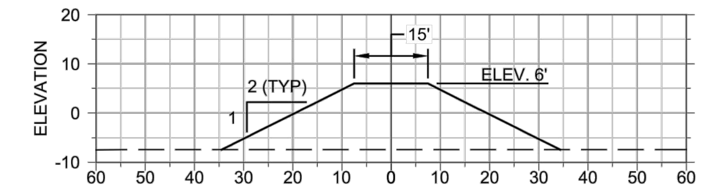


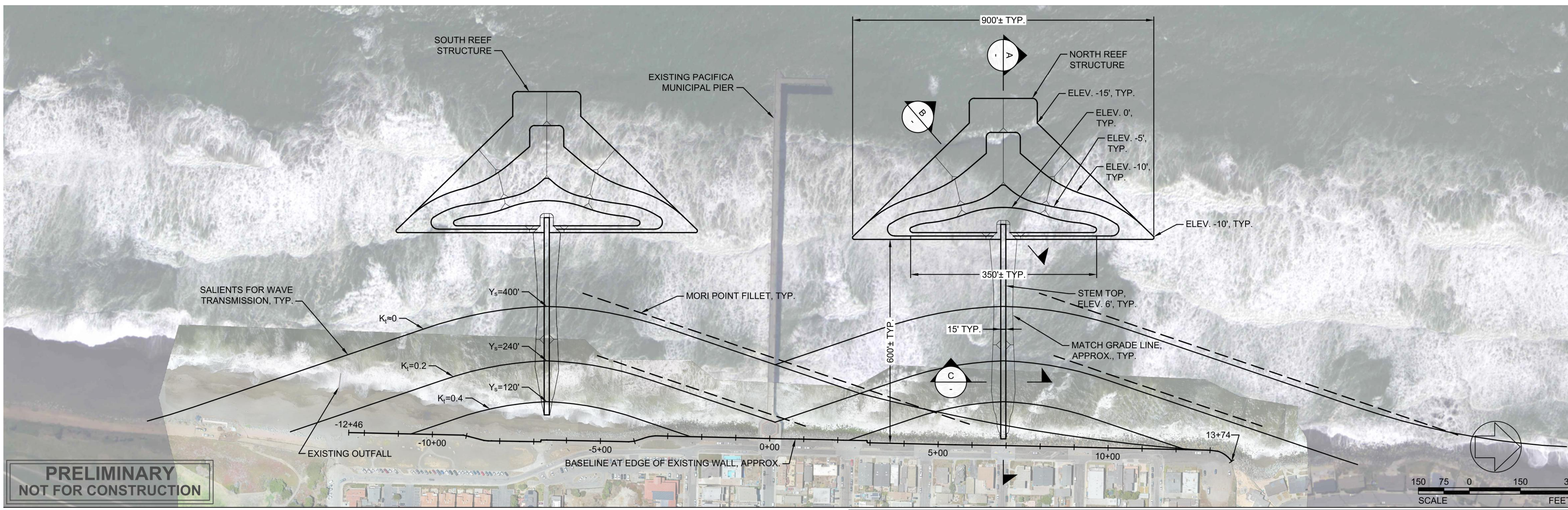
A REEF AND BREAKWATER STEM
TYPICAL PROFILE SCALE: 1"=100'



B OFFSHORE REEF
TYPICAL SECTION SCALE: 1"=40'



B BREAKWATER STEM
TYPICAL SECTION SCALE: 1"=40'



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CITY OF PACIFICA
BEACH BOULEVARD INFRASTRUCTURE RESILIENCY PROJECT (BBIRP)

SHORE PROTECTION
ALTERNATIVE 5b - OFFSHORE REEF

Project No. 11213162
Report No. N/A
Date

FIG-009

Filename: \\ghdnet\ghd\US\San Luis Obispo\Projects\561\11213162\Digital_Design\AutoCAD\Figures\11213162-FIG-009.dwg
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