APPENDIX F

GEOTECHNICAL INVESTIGATION OF REVETMENT

CLEVENGER GEOCONSULTING, INCORPORATED
AMERICAN DISABLED VETERAN - OWNED CONSULTING COMPANY

and

CATO GEOSCIENCE, Inc.

ENGINEERING GEOLOGY INVESTIGATION

ROCK REVETMENT AT BROAD BEACH, MALIBU, CALIFORNIA

PREPARED FOR
AMEC ENVIRONMENT & INFRASTRUCTURE

JULY 31, 2012
PROJECT NO. 0018.0011.0008.01 (Cato PN 1047)

CLEVENGER GEOCONSULTING, INC.
American Disabled Veteran-owned Consulting Company

CATO GEOSCIENCE, Inc.

Project No. 0018.0011.0008.01

Project No. 1047

July 31, 2012

AMEC Environment & Infrastructure
104 West Anapamu St., Suite 204A
Santa Barbara, CA 93101

Attention: Michael Henry

Subject: Transmittal of Final Report
- ***Engineering Geologic Investigation of Rock Revetment at Broad Beach, Malibu, California***

The final report titled, "***Engineering Geology Investigation, Rock Revetment at Broad Beach, Malibu, California***," is enclosed.

We have appreciated the opportunity to work on this project. If you have any questions about this report, please call or email. An invoice for this work is also attached.

Sincerely,

CLEVENGER GEOCONSULTING, INC.

William R. Clevenger
President

CATO GEOSCIENCE, INC.

Kerry Cato,
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Enclosures: - Technical report
- Invoice

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Purpose and Scope

The Broad Beach Geologic Hazard Abatement District (GHAD) seeks permanent approval of the emergency rock revetment constructed in 2010, as permitted by the City of Malibu and the California Coastal Commission (CCC) among others. In order for this to occur, approval must be obtained through the California Environmental Quality Act (CEQA) process; the State Lands Commission is the designated lead agency for the CEQA process and all technical documents are being prepared for them. This is part of the long-term strategy for protection of homes and septic systems from coastal erosion provided the applicant conducts nourishment and backpassing for at least 20 years,. If approved, the revetment would remain in place and would be buried beneath a new system of sand dunes located at the landward edge of the widened, nourished beach. Additional nourishment is proposed to keep this shore protection structure buried over approximately 20 years unless severe beach erosion or other conditions preclude maintaining sufficient beach width for protection. The revetment would serve as a last line of defense against future severe erosion during extreme storm events. The revetment is constructed primarily on private land, but overlaps public land in some areas.

The purpose of this engineering geologic investigation is to evaluate the geologic conditions, data, information, and reports attendant to the site including site seismicity, faulting, liquefaction, lateral spreading, subsidence, flooding, and other geologic hazards or constraints. This report is being prepared for the State Lands Commission CEQA report. This report is not intended to act as a design document and does not collect subsurface or new quantitative data. It synthesizes existing work and attempts to evaluate the present and future performance of the rock revetment in context of these discussed geologic processes.

Our scope of services included a geologic reconnaissance of the site and vicinity conducted by a geologist with our firm in order to compare the current geologic conditions on the site with the researched information. The Malibu General Plan (2007) and Los Angeles County General Plan (1990, 2008) were reviewed for potential geologic hazards to the site. Our investigation, together with our conclusions and recommendations, is discussed in detail in the following report.

Project Description

The project site consists of the existing revetment at Broad Beach in the western portion of Malibu, California. The existing revetment is 4,100 feet long, extending from 30760 Broad Beach Road, approximately 600 feet west of Trancas Creek, to 31346 Broad Beach Road, just west of the western public access point for Broad Beach. A total of approximately 36,000 tons of bouldery rock was used to create the revetment in 2010. According to project documents, the constructed revetment was 27 to 41 feet wide at its base and 13 to 17 feet in height, with the overall height averaging around 15 feet; our field observations indicate that the wall is slightly lower than this height and that the wall is higher at the west end than at the east end. Individual boulders for the majority of the revetment are between ½ and 2 tons in weight. The portion of the revetment between 31302 and 31346 Broad Beach Road was designed to be more robust and incorporated larger boulders, up to 4 tons per rock. The majority of the existing revetment rests on private lands. However, portions of the seaward side of the revetment totaling approximately 0.85 acre rest on Public Trust Lands [Broad Beach Restoration Project, Draft Analysis of Impacts to Public Trust Resources and Values (BBRP Draft APTR, April, 2012)].

Geologic Setting

Broad Beach (previously known as Trancas Beach) is located in the western portion of the City of Malibu, west of Zuma State Beach and Point Dume (Enclosure 1- Location Map). Point Lechuza marks the western limit of Broad Beach. Broad Beach lies atop a buried wave-cut terrace etched upon rocks of the Trancas Formation [F$^{\underline{M}}$] (Dibblee and Ehrenspeck, 1993). See Enclosure 2 – Geologic Map. Broad Beach and the rest of Malibu is a part of the Santa Monica Mountains block. The Santa Monica Mountains block is located in the western portion of the Transverse Ranges geomorphic province. The Transverse Ranges province also includes the Santa Ynez Mountains, Santa Susana Mountains, San Gabriel Mountains, San Bernardino Mountains, Little San Bernardino Mountains, San Fernando and San Gabriel Valleys, Santa Barbara Channel, and the Channel Islands. The Transverse Ranges are considered to have formerly been located adjacent to the current southern California coast between Los Angeles and San Diego, but have subsequently rotated clockwise about 90 degrees during the Miocene epoch into their current east-west position and transported northward (Crouch, 1979; Kamerling and Luyendyk, 1985; Crouch and Suppe, 1993; Fritsche, 1998).

Broad Beach is comprised of medium-grained beach sand and finer-grained dune sand, both of Holocene-age (Dibblee and Ehrenspeck, 1993). The modified surface of the beach and dune sands exists at elevations ranging from mean sea level [MSL] to approximately 15 feet above [MSL]. The beach is nestled against a wave-cut cliff that exposes fine- to coarse-grained alluvial deposits of Pleistocene age (Dibblee and Ehrenspeck, 1993). The modified toe of this cliff is at an average elevation of 35 feet MSL. The top of the cliff represents a man-made surface cut into the older alluvium for placement of Pacific Coast Highway. Dibblee and Ehrenspeck (1993) mapped outcrops of the Sandstone Member of the Trancas Fm north of the highway. These outcrops may represent exposures of a marine terrace representing oxygen-isotope Stage 5e (Milankovitch, 1941). The stage 5e terrace was etched into the coastline of Malibu about 125,000 years ago. Remnants of this Pleistocene age terrace were identified in the Pacific Palisades area (Shaller and Heron, 2004).

Both the Holocene-age and Pleistocene-age sediments are deposited upon the wave-cut terrace cut into the Trancas Fm (Yerkes and Campbell, 1979, 1980; Campbell *et* al., 1970; Dibblee and Ehrenspeck, 1993). The Trancas Fm is comprised of metamorphic blueschist conglomerate-breccia (Dibblee and Ehrenspeck, 1993). The Trancas Fm is considered equivalent to the San Onofre Breccia (described by Woodford, 1925; Truex and Hall, 1969; Stuart, 1979) and the Upper Topanga Fm (described by Dibblee and Ehrenspeck, 1990). The Trancas Fm forms the top of the dense, highly cemented bedrock that underlies Broad Beach and Pt. Lechuza. Bedding in the Trancas Fm is mapped as overturned and dipping steeply to the north at Pt. Lechuza and the west portion of Broad Beach (Dibblee and Ehrenspeck, 1993). Outcrops of the Trancas Fm are exposed at the west end of Broad Beach and locally in the surf zone off the western portion of the beach. The thickness of the younger beach and dune sands at Broad Beach is not known, but is expected to underlie the beach at relatively shallow depths.

The southeast end of Broad Beach is separated from Zuma Beach by fluvial deposits derived from Trancas Creek. Holocene age alluvium is deposited at the mouth of Trancas Creek, forming a low mound at the interface with the beach sand. This mound is formed by wave action pushing sand back up into the mouth of Trancas Creek, combined with overlying dune sand. Low levels of surface flow from Trancas Creek generally pond landward of this mound most of the year in Trancas Lagoon. Surface freshwater flows change to subsurface groundwater flows beneath the alluvium/beach sand mound to discharge into the sea. During the rainy season, higher surface flows in Trancas Creek tend to breach the mound and discharge directly into the ocean.

Tectonic Setting

The Broad Beach area, including the portion occupied by the existing revetment, are not shown as affected by faulting (Jennings, 1975, 1977, 1992, 1994; Jennings and Bryant, 2010; Jennings *et al*., 2010; Dibblee and Ehrenspeck, 1993; Jennings and Strand, 1969; Bryant, 2005; Frankel *et* al., 2002; U.S. Geological Survey, 2002, 2006, 2007, 2008; Los Angeles County, 1990, 2008; Malibu, 1995). The area does not lie within an Alquist-Priolo Earthquake Fault Zone as defined by the State of California (Bryant and Hart, 2007). The area also does not lie within a County or City Fault Hazard Zone (Los Angeles, 1990, 2008; Malibu, 1995). The maximum magnitude earthquake (also referred to as M_{MAX}) of faults in the vicinity of the Broad Beach area are determined from measurements made by the U.S. Geological Survey (2008), Southern California Earthquake Center (2010), and Cao *et al*. (2003).

The Malibu Coast reverse fault is located as close as 1,300 feet north of Broad Beach (Jennings and Strand, 1969; Dibblee and Ehrenspeck, 1993). The east – west trending Malibu Coast fault generally marks the break in slope along the toe of the Santa Monica Mountains, with the mountains experiencing uplift along the fault. The Santa Monica reverse fault is shown as the eastern extension of the Malibu Coast reverse fault by Jennings and Strand, (1969). The east - west trending Santa Monica reverse fault is part of the Santa Monica-Hollywood fault zone. The Malibu Coast fault zone is expected to produce an M_{MAX} earthquake of M_W 7.0 and is shown to accommodate 0.3 mm/yr of slip (U.S. Geological Survey, 2008). The Santa Monica fault has an M_{MAX} earthquake of M_W 6.8 and the Hollywood fault has an M_{MAX} earthquake of M_W 6.7 (U.S. Geological Survey, 2008). Both the Santa Monica and Hollywood faults are shown to have slip rates of about 1 mm/yr each.

The City of Malibu (1995) showed the Escondido thrust fault located approximately 2,000 feet northeast of Broad Beach. Dibblee and Ehrenspeck (1993) mapped the portion of the east – west trending Escondido fault closest to the site as part of the Malibu Coast fault. The eastern portion of the Escondido fault, as shown by Malibu (1995), was mapped by Dibblee and Ehrenspeck as the Ramirez thrust fault. Dibblee and Ehrenspeck showed the western end of the Ramirez fault located approximately one-half mile southeast of Broad Beach. Dibblee and Ehrenspeck (1993) showed the east – west trending Ramirez fault offsetting rocks of Miocene age, but as buried beneath sediments of Pleistocene age. The Ramirez fault does not appear to represent an active fault as defined by the Alquist-Priolo Act. The City (1995) showed the Escondido thrust fault as offsetting rocks of Miocene age. Malibu (1995) did not show the Escondido fault on the general plan fault map. The state of activity of the fault is not known.

The Anacapa-Dume reverse fault lies off the coast approximately 6 miles south of Broad Beach (Veddar *et al*., 1986, Bryant, 2005). Pinter (2010) considered the east – west trending Anacapa-Dume fault and the Santa Cruz Island fault as primarily left-lateral faults with minor reverse components. The Anacapa-Dume fault marks the break in slope between the submarine slope of the Santa Monica Mountains and the floor of the San Pedro Basin. The Anacapa-Dume fault continues to the west as the Santa Cruz Island fault (Veddar *et al*., 1986). The Anacapa-Dume fault zone displays a slip rate of about 3 mm/yr and is considered to be capable of generating an M_{MAX} earthquake of M_W 7.2 (U.S. Geological Survey, 2008). The Santa Cruz Island fault is listed as capable of an M_{MAX} earthquake of M_W 7.2, with a slip rate of around 1 mm/yr (U.S. Geological Survey, 2008).

Dolan *et al*. (1995), Davis and Namson (1994), and Johnson et al. (1996) have postulated that the Santa Monica Mountains are underlain by a blind reverse fault responsible for additional uplift of the mountains. This fault is referred to as the Santa Monica Mountains blind thrust fault (Dolan *et al*., 1995) and its subsurface trend would be an east – west orientation. Dolan *et al*. (1995) considered the Santa Monica Mountains fault to be capable of an M_{MAX} earthquake of M_W 7.5, if the fault extends the full length of the Santa Monica Mountains and were to move along its entire length simultaneously. The slip rate of the Santa Monica Mountains blind reverse fault is not known.

Veddar *et al*. (1986) showed the northwest end of the Palos Verdes fault located about 10 miles southeast of Broad Beach. The northwest – southeast trending Palos Verdes fault displays evidence for both right-lateral strike slip and reverse slip movement (Fischer *et* al., 1987; Dibblee, 1999). The Palos Verdes Hills are considered to have been uplifted by movement along the Palos Verdes fault. However, recognition of the Palos Verdes Anticlinorium reverse fault along the submarine base of the Palos Verdes Hills by Sorlien *et al*. (2003) appears to provide a better source fault for uplift of the entire Palos Verdes Anticlinorium, as well as the Palos Verdes Hills. The northern end of the Palos Verdes Anticlinorium fault is expected to mimic the length and trend of the higher angle Palos Verdes fault, and, therefore, lies about 10 miles southeast of Broad Beach. The Palos Verdes Anticlinorium fault may also merge with the eastern portion of the Anacapa-Dume fault. The M_{MAX} earthquake of the Palos Verdes fault is provided as M_W 7.3, with an oblique slip rate of around 3 mm/yr (U.S. Geological Survey, 2008). The M_{MAX}

earthquake for the Palos Verdes Anticlinorium fault may be M_W 7.5, but the slip rate is not yet calculated (Sorlien *et al*., 2003).

Review of digital aerial photography available from Google Earth Pro (Google, 2012), World Wind (National Aeronautic and Space Administration (2011), and Bing 3D (Microsoft, 2011) suggests that several high angle right-lateral strike-slip faults traverse the Broad Beach area. These suspected faults, the strike slip faults generally trend in a northwest – southeast orientation and the reverse faults generally trend in an east-west orientation, can be traced through alluvial materials of Pleistocene age and older rocks on the photographs. Evidence for these features to represent faulting include offset ridge lines, offset canyons and drainages, aligned canyons, offset landslides, structural control of parallel ridgelines, vertically offset terraces and alluvial fan surfaces, aligned escarpments, and tonal lineaments associated with aligned vegetation. A review of geologic and geotechnical investigations on file with the City and County was beyond the scope of this study. The state of activity of these suspected faults is not known. However, the observed offset of alluvial materials mapped as Pleistocene in age and offsets observed across landslides considered to be Pleistocene in age would indicate that these features, if they do represent faults, would be considered potentially active faults utilizing criteria developed by the State (Bryant and Hart, 2007). The potential for surface fault rupture to affect the Broad Beach area is considered to be a Potentially Significant Impact (Class 1).

A large earthquake along any of the faults listed above would result in very strong ground motion at Broad Beach. In particular, earthquakes along the nearby Malibu Coast, Anacapa-Dume, or Santa Monica Mountains reverse faults would be expected to generate high levels of both horizontal and vertical shaking at Broad Beach. Based on peak ground accelerations measured from the 1971 San Fernando and 1994 Northridge reverse-motion earthquakes, peak accelerations over 1 g (greater than the acceleration due to gravity) should be expected to affect the Broad Beach area at some point in the future. The potential for strong ground shaking to affect the Broad Beach area is considered to be a Potentially Significant Impact (Class 1).

Numerous additional large faults are located within 50 miles of Broad Beach. These faults include: Newport-Inglewood, San Pedro Basin, Santa Susana, Oakridge, Northridge Hills, Chatsworth-Simi, San Cayetano, Holser, San Gabriel, Whittier, Compton-Wilmington, Puente Hills, Elysian Park, Raymond, San Fernando, Sierra Madre, Santa Cruz-Santa Catalina, Santa Catalina Escarpment, San Clemente, Channel Islands, Arroyo Parida, Mission Ridge, Santa Ynez, Pine Mountain, Red Mountain, Frazier Mountain, Verdugo, Redondo Canyon, and San Andreas faults. Earthquakes along any of these faults would be expected to generate moderate to strong ground shaking at Broad Beach.

Geology of Revetment Rocks

Dr. Kerry Cato of Cato Geoscience, Inc. conducted a geologic reconnaissance of the revetment on June 13, 2012. The boulders comprising the revetment were observed to range between 1 and 7 feet, as measured along the long axis. The boulders are generally larger in the western portion of the revetment. The Broad Beach Restoration Project Draft Analysis of Impacts to Public Trust Resources and Values (April, 2012) indicated that no boulders were placed over a 100-foot portion of Broad Beach at 30822 Broad Beach Road by design. In addition, gaps in the revetment were observed at 31022 Broad Beach Road, and in the northern portion of the area north of 31460 Broad Beach Road. A non-contiguous group of boulders was observed at 31346 Broad Beach Road. See Enclosures 3, 4 and 5 for photos. Residences at the northwestern end of Broad Beach use various means of engineered protection from wave action and do not rely on revetment protection. The constructed revetment ranged from 13 to 17 feet in height and was 27 to 41 feet in width at the base (BBRP, Draft APTR, April, 2012). Our field observations indicate that the wall is slightly lower than this height and that the wall is higher at the west end than at the east end. The Draft APTR indicated that a portion (approximately 0.85 acre) of the seaward face of the revetment rests upon Public Trust Lands. Removal and redistribution of the offending boulders is anticipated as part of several project alternatives.

Larger boulders within the revetment are listed as 4 tons per rock. The bulk of the rock is reported to range from ½ to 2 tons per rock (BBRP, Draft APTR, April, 2012). However, a considerable portion of the revetment consists of rock as small as 1 foot in maximum dimension. These smaller rocks act as filler between and among the larger boulders. The resistance of these smaller rocks to coastal erosion is entirely dependent on the stability of the larger boulders resting along the seaward edge of the revetment. The petrology of the revetment boulders consists primarily of a dark, fine-grained gabbro. Additional petrologies observed included diorite, granodiorite, gneiss, and marble. All of the boulders exhibited fresh, hard faces with little or no chemical weathering. Some of the smaller rocks may represent fragments of larger boulders broken off by mechanical weathering from wave action, abrasion from settlement and adjustment, or perhaps abrasion from the initial placement of the boulders. All of the boulders exhibited angular shapes conducive to interlocking reinforcement. The Draft APTR (April, 2012) noted that the boulders were placed on top of a filter fabric to support the boulders and helps resist vertical settlement of the rock into the beach sand. Stability of the existing revetment is, therefore, dependent on the stability of the sand layer underlying the boulders of the revetment. The source quarry (or quarries) for the boulders is/are not known. We understand that, due to the emergency nature of the original placement permits, a geotechnical/geological investigation for the original placement was not conducted. Further, it is understood that the filter fabric and overlying revetment stone were founded on beach sand; the thickness of the beach sand that separates the revetment from the underlying Trancas F$^{\underline{M}}$ bedrock is unknown, but could be several feet to several tens of feet in thickness.

The armor stone stability calculations are provided in the Broad Beach Restoration Project, Coastal Engineering Appendix (Moffat and Nichols, 2012). The hydraulic stability of the existing revetments armor stone was evaluated using the Hudson formula outlined in the CEM. This formula is widely used and has many years of successful application on the California coast. We briefly summarize pertinent aspects of the design assumptions and criteria in the following paragraph. Most of the existing revetment was constructed with two layers of armor stone between 0.5 and 3 tons. Based on specified gradation, the median armor stone is between 1 and 2 tons of rough quarry stone with random placement. To meet the 0 to 5 percent damage criteria, the acceptable design wave for the existing revetment is 6 feet for 1-ton stone to 8 feet for 2-ton stone. Depth limited wave heights greater than 6 to 8 feet breaking in front of the existing revetment will likely result in a higher percentage of damage, or displacement, of armor stone. The design wave heights calculated for the critical design condition of extreme tide, scour and SLR range from 8.9 feet to 9.6 feet. For comparison, the armor stone required to meet the 0 to 5 percent damage criteria for these wave heights is 3 to 4 tons in weight. These results indicate the western portion of the existing revetment can withstand these design wave heights with minimal damage. Armor stone for the remainder of the existing revetment is under-sized and greater than 5 percent damage can be expected under critical design conditions.

During our field visit, we substantiated many of the above-mentioned design assumptions and in place rock revetment conditions. As reported, we noted that the western end of the rock revetment consisted of larger rock stone than that at the eastern end. The BBRP Draft APTR, April, 2012 states that the change occurs near the property located at 31302 Broad Beach Rd. We noted that the change is gradational and occurs “generally” in this area. Based on our field observations, we estimate that the larger stone exists along the western 1,025 feet (25% of the length) and smaller stone exists along the eastern 3,075 feet (75% of the length) of the revetment. The use of smaller stone, which was reportedly placed on the interior, was unable to be observed as only the exterior of the wall could be observed.

Overall, the exterior stone appeared to be stable with little evidence of movement having occurred during the two-year performance period (2010 – 2012). In the eastern end where the smaller rock exists, we noted a few examples where individual rock pieces had been separated from the wall and now exist on the beach in front (seaward side) of the wall. In these local cases the wall appeared stable with no obvious perturbations in the overall linear shape of the wall. In these areas we did not note any deflections in the top of the wall that could indicate settlement of the overall wall. At the western end of the wall where the larger rock exists, we did not note any rock pieces that had been detached from the rock mass. It appears that the rock sizing indicates relative stability of the rock mass, but the observed examples of detached stones suggest that use of a larger size stone would be warranted.

The rock revetment was designed as a trapezoid that is 13-17 feet high and about 27-41 feet high at the base. Without an "As Built" survey to confirm placed conditions, our reconnaissance relied on multiple visual sitings along the top of the wall, which indicated that the wall is approximately level and without significant variations in elevation.

In our traverse along the beach at the upstream toe of the rock revetment, the height of the wall was observed to apparently increase from east to west; this would be the vertical distance between the top of the wall and exposed toe of the rock. Overall the height is lowest at the eastern end, on the order of 6 – 10 feet high, and greatest at the western end where the height is on the order of 10 to 13 feet high. We were working under the assumption that, as constructed, the top of the wall did not vary in elevation, but that the bottom of the wall rises toward the eastern end, but this needs to be verified if possible from any design drawings or construction reports. The other explanation is that beach sand deposition has been greater at the eastern end and thus more of the wall has been buried since the revetment placement. This observation is consistent with the known southerly longshore transport direction of sand that occurs along this beach. It is important to note that wave heights of 6 to 8 feet could conceivably overtop the wall at the eastern end and adversely impact structures in this area.

Another issue regarding wall stability is the foundation condition all along the rock wall. The rock revetment was placed as an emergency measure on the existing beach surface. This sand material is highly erodible and if the rock is left exposed the rock revetment could be undermined and destabilized.

The thickness of this sand foundation, or the depth to the underlying Trancas F^{M} is unknown. If the thickness of the sand foundation layer is small, say on the order of 5 feet, then the 15-foot high revetment wall would still provide protection if undermining and settlement occurred. However, if the thickness of the sand foundation is greater, say on the order of 10 – 15 feet thick then the rock revetment could settle a greater amount with the amount of remaining protection left in doubt.

Damage to the revetment from an extreme event of this type does not suggest a complete failure of the revetment. The flexible nature of a stone revetment is one reason it's the most commonly used shore protection device. This flexibility can accommodate minor settling and even displacement of some stones without complete loss of protection. Damage from waves exceeding the design wave is usually progressive and can be repaired provided there is sufficient time between consecutive storm events. Although the existing revetment lacks the safety factor of a typical coastal revetment, the structure has performed well under direct exposure over the past several years and will continue to provide a reliable last line of defense over the design life of the project.

Liquefaction

The Broad Beach area is included within a potential liquefaction area on the Los Angeles County General Plan (1990) and the State's Seismic Hazard Zones map (California Division of Mines and Geology, 2002). See Enclosure 6 – Liquefaction Zones. The Malibu General Plan (1995) did not show a map of liquefiable areas. The geologic materials underlying the revetment are mapped as beach and dune sands of Holocene age. These materials are loose and uncemented, as observed at the ground surface during the geologic reconnaissance. Although the thickness of these deposits is not known, these sands are expected to be relatively thin and unconformably resting upon dense rock of the Trancas F$^{\underline{M}}$. The depth to groundwater at Broad Beach was not available at the time of this study. Subsurface flow derived from the sea is expected to perennially infiltrate the beach sands underlying the revetment. Additional subsurface flow is anticipated to originate from each of the septic systems located immediately landward of the revetment. Sediments underlying the revetment are considered to be highly susceptible to liquefaction and vertical differential settlement in the event that a large earthquake occurs in the vicinity of Broad Beach. The potential for liquefaction and differential seismic settlement to affect the Broad Beach area is considered to be a Potentially Significant Impact (Class 1).

Lateral spread, the horizontal movement of near-surface sediment during liquefaction, is also considered to have a high potential in the vicinity of the revetment. The unsupported face of the beach sediments along the shore and the seaward-inclined surface of the wave-cut terrace underlying the sands would be expected to enhance the potential for lateral spread to affect the area of the revetment. The potential for lateral spread to affect the Broad Beach area in association with liquefaction is also considered to be a Potentially Significant Impact (Class 1).

Tsunami

The Los Angeles County General Plan (1990) showed all of Broad Beach located within a Tsunami Inundation Zone. The county's inundation zone is based on a locally generated 100-year earthquake. The State Tsunami Inundation Map for the Point Dume 7.5 minute quadrangle also showed the entire Broad Beach area situated within a Tsunami Inundation Zone (California Geological Survey, 2009). See Enclosure 7 – Tsunami Inundation Map. The State's Tsunami Inundation Zone is based on an earthquake generated from a local or distant fault source or landslide source. The Malibu General Plan (1995) indicated that the Broad Beach area could expect tsunami run-up of approximately 5.1 feet during any 100-year period of time and up to 8.7 feet over a period of 500 years. This amount of run-up would be on top of the tidal height at the time of tsunami generation.

The revised Draft EIR for the PRC 421 Recommissioning Project (October, 2011) indicated that movement along an offshore fault, or even more distant faults, could generate a tsunami with an anticipated wave height of 40 feet. The height of a tsunami wave is dependent not only on the magnitude of an offshore earthquake, but also on the style of fault rupture, especially reverse fault motion such as would be expected from an earthquake along the Anacapa-Dume, Santa Cruz Island, Palos Verdes Anticlinorium, or the offshore portion of the Malibu Coast reverse faults. The topography can also affect the maximum height of a tsunami wave. Rapidly rising ground near the coast can cause multiple tsunami waves to build upon one another, whereas flatter topography slows the energy of multiple tsunami waves to dissipate over a wider area and farther inland. The shape of the coastline is also critical with regards to the maximum build-up of a tsunami wave. Crescent-shaped (concave shorelines) coves and bays focus wave energy, causing higher wave heights. Points and peninsulas (convex shorelines) tend to refract wave energy, resulting in generally lower wave heights. The overall concave shape of the shoreline fronting the western portion of Broad Beach and the relatively narrow space between the existing shore and the cliff at the back of the beach would, therefore, tend to increase tsunami wave height as compared with the eastern portion of the Broad Beach and the western portion of Zuma Beach, especially near the mouth of Trancas Creek.

Tsunamis can also be generated from the movement of submarine landslides. The relatively steep slopes descending from the coastline down to the floor of the San Pedro Basin are considered highly susceptible to underwater landsliding. Although submarine slides can occur at any time, due to the perennially saturated condition of the slope face, the potential for the slope face to fail in association with a large, nearby earthquake is considered the more likely scenario. Locally situated underwater landslides can result in locally compounded wave generation. The 2004 Banda Aceh Earthquake in Indonesia also produced anomalously large wave heights in localized portions of the Sumatran coast due to triggered rupture of additional reverse faults closer to shore. The potential for tsunami inundation to affect the Broad Beach area is considered to be a Potentially Significant Impact (Class 1).

Slope Stability/Landslides

The State Seismic Hazard Zones map (California Division of Mines and Geology, 2002) did not include Broad Beach within a zone considered subject to earthquake-induced landsliding. These landslide zones are shown on Enclosure – 6 Liquefaction Zones. The closest Earthquake-induced Landslide Zones are shown coincident with the cliff face about 200 feet northwest of the revetment. The City of Malibu (1995) and the County of Los Angeles (1990) did not include Broad Beach within an area affected by mapped landslides. Based on the relatively flat topography in the immediate vicinity of the revetment, landsliding and slope stability issues are considered to represent a Less-Than-Significant (Class III) level of impact to the site of the existing revetment.

Climate Change/Sea Level Rise

Observational data suggest that the rate of sea-level rise was generally stable up until the late 19th century. Empirical observations from around the world have shown that sea level rose approximately 6.7 inches

(17 centimeters) during the 20th century [Intergovernmental Panel on Climate Change (IPCC), 2007]. The rise in the global mean sea level is due primarily to increases in mean global temperatures. The rise in temperature causes glacial ice to melt and ocean water to expand. However, sea levels at any one particular location may differ from the average worldwide sea level, based on tectonics, oceanic circulation patterns, atmospheric circulation patterns, gravitational effects, and isostatic effects from glacial melt.

The IPCC (2007) documented an increase in mean sea level of between 4 and 10 inches over the preceding 100 years. Between 1961 and 2003, sea level rose at an average annual rate of 0.07 inch (1.7 mm/yr.), although the average annual rate of sea level rise over the period between 1993 and 2003 accelerated to 0.12 inch per year (3.1 mm/yr.) (IPCC, 2007). The reason for this most recently measured increase in the rate of sea level rise was not known at that time. The IPCC (2007) predicted that sea level could rise between 7 and 23 inches over the next 100 years. The State of California has accepted these rates of sea level rise for purposes of calculating the potential impact of sea level rise on proposed coastal development.

A recently released study by the National Research Council’s Committee on Sea Level Rise in California, Oregon, and Washington (2012) provided updated rates of sea-level rise for the California coast south of Cape Mendocino. The committee projected a sea level rise of 16.5 to 65.7 inches (42 to 167 centimeters) for the 100-year period between 2000 and 2100 for the central and southern California coastline. By comparison, the Committee on Sea Level Rise (2012) projections are substantially higher than the IPCC (2007) projections. This is the result of differences in the calculations for thermal expansion of seawater and the contribution of glacial melt water used by the two studies.

The Committee on Sea Level Rise (2012) concluded that sea-level in the area of Broad Beach will rise between 1.5 and 11.8 inches (4 to 30 centimeters) by the year 2030, as compared with the year 2000 (a 30-year time period). These values, therefore, cover 18 years of the anticipated 20-year life of the Broad Beach project. Accounting for the 12 years of that expected sea-level rise has already occurred yields a sea level rise of 0.9 to 7.1 inches over the next 18 years. Over the 20 year life of the project, it is anticipated that sea level at Broad Beach would rise between approximately 1 and 8 inches.

The average inclination of the proposed beach in the eastern portion of Broad Beach would be 10 horizontal to 1 vertical (10:1 H to V), while the average inclination of the western portion of the beach would be 3 horizontal to 1 vertical. A minimum increase in sea level of 1 inch vertically over the next 20 years would result in the average encroachment of the sea landward by 3 inches in the western portion of the nourished beach and by 10 inches in the eastern portion of a nourished beach. A maximum increase in sea level of 8 inches vertically over the next 20 years would result in the average encroachment of the sea landward by 24 inches (2 feet) in the western portion of the nourished beach and by 80 inches (6.7 feet) in the eastern portion of a nourished beach.

California Executive Order S-13-08 directed affected state agencies to anticipate that sea level will rise and to plan for the potential impacts to coastal communities and infrastructure. Since the State of California has accepted that these amounts of sea level rise are expected to occur along the California coast, the effects of sea level rise on other potential geologic hazards should be considered cumulative. Therefore, the overall effects of the other potential geologic hazards along Broad Beach will be compounded by the anticipated rise in sea level. The potential for the anticipated rise in sea level, in conjunction with the potential for liquefaction, seismic settlement, lateral spread, storm surge, and/or tsunami waves, to affect the Broad Beach area, is considered to represent a Potentially Significant Impact (Class 1) to the project.

Aerial Photography Review

Digital aerial photography available from Google Earth Pro (2012) was reviewed in association with this study. The date of the oldest imagery that included the site was dated September 6, 1990. The sequence of additional imagery dates reviewed included May 31, 1994, June 11, 2002, December 31, 2002, December 4, 2004, December 31, 2004, January 11, 2005, January 26, 2006, March 15, 2006, October 22, 2007, January 8, 2008, and May 24, 2009 (Google, 2012). The Broad Beach area demonstrated varying amounts of sand accumulation along the shoreline on these images. The beach was narrowest at the time of the 2009 imagery. The placement of the emergency revetment occurred in 2010 (BBRP Draft APTR, April, 2012; CSLC NOP, April 15, 2011; CSLC SOI, April 15, 2011). Access to aerial photography flown subsequent to placement of the revetment was not available at the time of this study.

Conclusions

Many of the design assumptions and in place rock revetment conditions were verified based on site observations. The western end of the rock revetment consisted of larger rock stone than that at the eastern end. The use of smaller stone, which was reportedly placed on the interior, was unable to be observed as only the exterior of the wall could be observed.

We address wall adequacy in two ways. First, the rock revetment wall was under-designed and poorly constructed. The wall was not designed to U.S. Army Corps of Engineers standards. For example, it is founded on erodible sand and the depth to hard bedrock of sufficient strength to adequately support the revetment is unknown. The facing rock is undersized for an estimated 75% length of the wall. Field observations suggest that the rock was placed at a height equal to the existing geomorphic surface, which is also the elevation of the residence's foundations. The wall is at a higher elevation on the west end than the east end providing greater protection on the west. Protection for the residences and septic systems on the east end is less adequate. In addition, we point out four Potentially Significant Impacts to the wall as it exists (lateral spreading, liquefaction, tsunami, and sea level rise). If this wall were to be left as the ONLY protection, we believe it would ultimately fail. This would not occur rapidly, but over a period of time and with successive storms. This conclusion should not be overtly surprising because the wall was placed as an emergency measure.

Now, however, the wall is being considered as part of a long-term (20-year) mitigation for shore erosion. Our second point is that the wall is not being analyzed singularly. Instead, it will operate in conjunction with a more robust system of beach nourishment that provides significant distance from the wave attack to the buried rock revetment. The wall acts as the last defense against wave attack. It would provide protection and it buys time.

The shore protection with the wall is better, in our opinion, than without it. Most certainly the rock revetment provides significant protection to the residences and septic systems from wave attack. If the rock wall did not exist and beach nourishment were the only mitigation, the risk of damage to residences and septic systems would be much greater.

The existing rock revetment is not adequate, in our opinion, as a permanent solution to shoreline protection. It does not meet current Corps of Engineers standards as a permanent structure. However, as a supplemental means to reduce the rate of distress to the shoreline, it may achieve the results desired by the State Lands Commission (SLAC). This is a policy position for them to decide. The existing rock wall has been stable and on its own, without beach nourishment protection, and has provided adequate protection for two years. It is conceivable that, with the addition of beach nourishment and our recommendations, the wall could perform adequately for the 20-year life of the project.

Recommendations

Our recommendations are based on leaving the rock revetment wall in place. The following improvements, listed in the subsequent paragraphs, should be made in the wall prior to the addition of the beach nourishment. These recommendation's do not address the issue of foundation stability; that is a weakness that the SLAC and residences must accept if the wall is to remain. The following recommendations are presented to make the wall more robust and to mitigate the effect of the weaknesses.

The wall should provide an equal measure of protection from the west to the east end. Namely the entire top of the wall should be constructed to the same elevation. This may obstruct the views of some east end residents. The height of the wall should be surveyed and the amount of sand separating the foundation from the underlying Trancas F^M should be known. The depth to hard bedrock, in conjunction with the surveyed height of the wall, would provide information critical to estimating future settlement.

All gaps in the wall should be filled. These are the gaps that occur at 30822 Broad Beach, which is by design, at 31022 Broad Beach Rd, and at the western end for about 200-feet west of 31460 Broad Beach Rd. Refraction would bend in-coming waves around the ends of the existing revetment and focus wave attacks onto the unprotected properties.

Many technical studies and published reports were referenced during the preparation of this report,. These were not provided for review, but should ultimately be reviewed before moving forward with design and construction of additions or replacements. A list of these documents is contained in Appendix 1.

Limitations and Uniformity of Conditions

The analysis and recommendations submitted in this report are based in part upon the data obtained from published and project reports and site observations. The nature and extent of variations between and beyond this information may not become evident until construction. If variations then appear evident, it will be necessary to reevaluate the conclusions and recommendations of this report.

Findings of this report are valid as of this date; however, changes in conditions of a property can occur with passage of time whether they are due to natural processes or works of man on this or adjacent properties. In addition, changes in applicable or appropriate standards may occur whether they result from legislation or broadening of knowledge. Accordingly, findings in this report may be invalidated wholly or partially by changes outside our control. Therefore, this report should be considered valid for a period of 1 year from the date of issue, but should be updated if implementation is delayed beyond this period of time.

In the event that any changes in the nature, design, or location of the structure and other improvements are planned, the conclusions and recommendations contained in this report shall not be considered valid unless the changes are reviewed and this report modified or verified in writing.

This report is issued with the understanding that it is the responsibility of the user of this report to transmit the information and recommendations of this report to regulators, owners, developers, contractors, buyers, architects, engineers and designers for the project so that the necessary steps can be taken by the contractors and subcontractors to carry out such recommendations in the field and incorporate these into the design.

The conclusions and recommendations contained in this report are solely professional opinions. The professional staff of Cato Geoscience, Incorporated and Clevenger Geoconsulting, Inc. strives to perform its services in a proper and professional manner with reasonable care and competence. There are risks of earth movement and property damages inherent in land development. We are unable to eliminate all risks or provide insurance; therefore, no warranty or guarantee is expressed or implied.

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It is recommended that Cato Geoscience and Clevenger Geoconsulting be provided the opportunity for a general review of final design and specifications in order that earthwork and foundation recommendations may be properly interpreted in implementing the design and specifications. Along with this, the time to review the missing or yet-to-be-supplied documents listed in Appendix 1, should be provided. If Cato Geoscience and Clevenger Geoconsulting are not accorded the privilege of making this recommended review, we can assume no responsibility for misinterpretation of our conclusions and recommendations.

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Appendix 1

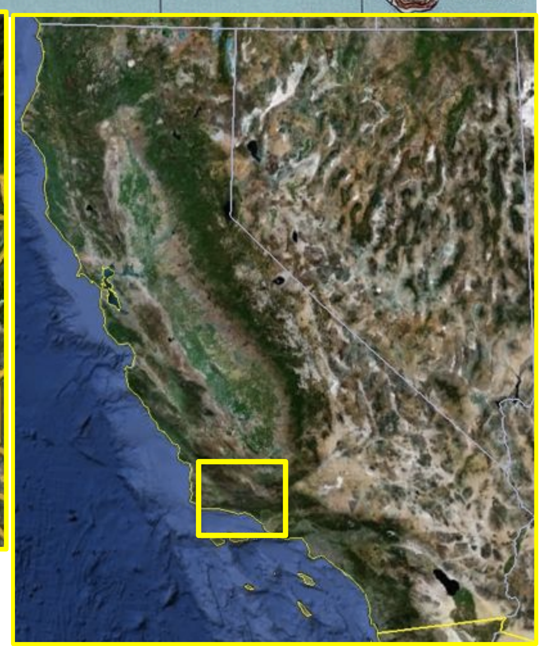
During the preparation of this report, many technical studies and published reports were referenced. These were not provided for review, but should ultimately be reviewed. Therefore we request they be provided, reviewed, and that information should be included in future versions of this report. These documents include:

- Chambers study
- Recent air photos (dated after 2010)
- Preliminary (Phase 1) Engineering Investigation (dated April, 2010)
- Sand Source Investigation Report (dated June, 2010)
- Offshore Sand Investigation Study, Phase 1 (dated June, 2011)
- Offshore Sand Investigation Study, Phase 2 (dated August, 2011)
- Sampling and Analysis Plan Results and Report (dated July, 2011)
- Sampling and Analysis Plan Results and Report, Appendix B (dated July, 2011)

Sampling and Analysis Plan Results and Report Addendum (dated July, 2011)
Shoreline Morphology Study (dated July, 2011)
Beach Profile Report (dated January, 2011)
Previous Geotechnical Investigations for existing coastal protection structures, including seawalls and piers
Previous Geotechnical Investigations for existing and proposed residences/additions along Broad Beach
As-built revetment grading plan
Locations of all septic systems
Drainage/storm drain plans
Beach grading plans
County Assessor's Parcel maps showing locations of public/private property boundaries
Map with locations of revetment encroachment upon Public Trust Lands
Map of propose dune restoration
Map of proposed public and private access management plans, including proposed routes across restored dunes Dune habitat restoration plans
Construction Management Plan
Environmental reports and documents
Regional Water Quality Control Board studies or actions
City of Malibu reports, studies, environmental documents
County of Los Angeles reports, studies, environmental documents
County of Los Angeles Department of Public Works stereoscopic aerial photographs
California Coastal Record project oblique aerial photographs
Geo-Tech International imagery
Pre-revetment coastal protection structures, including temporary sand bag revetments
MHTL Surveys

Location Map

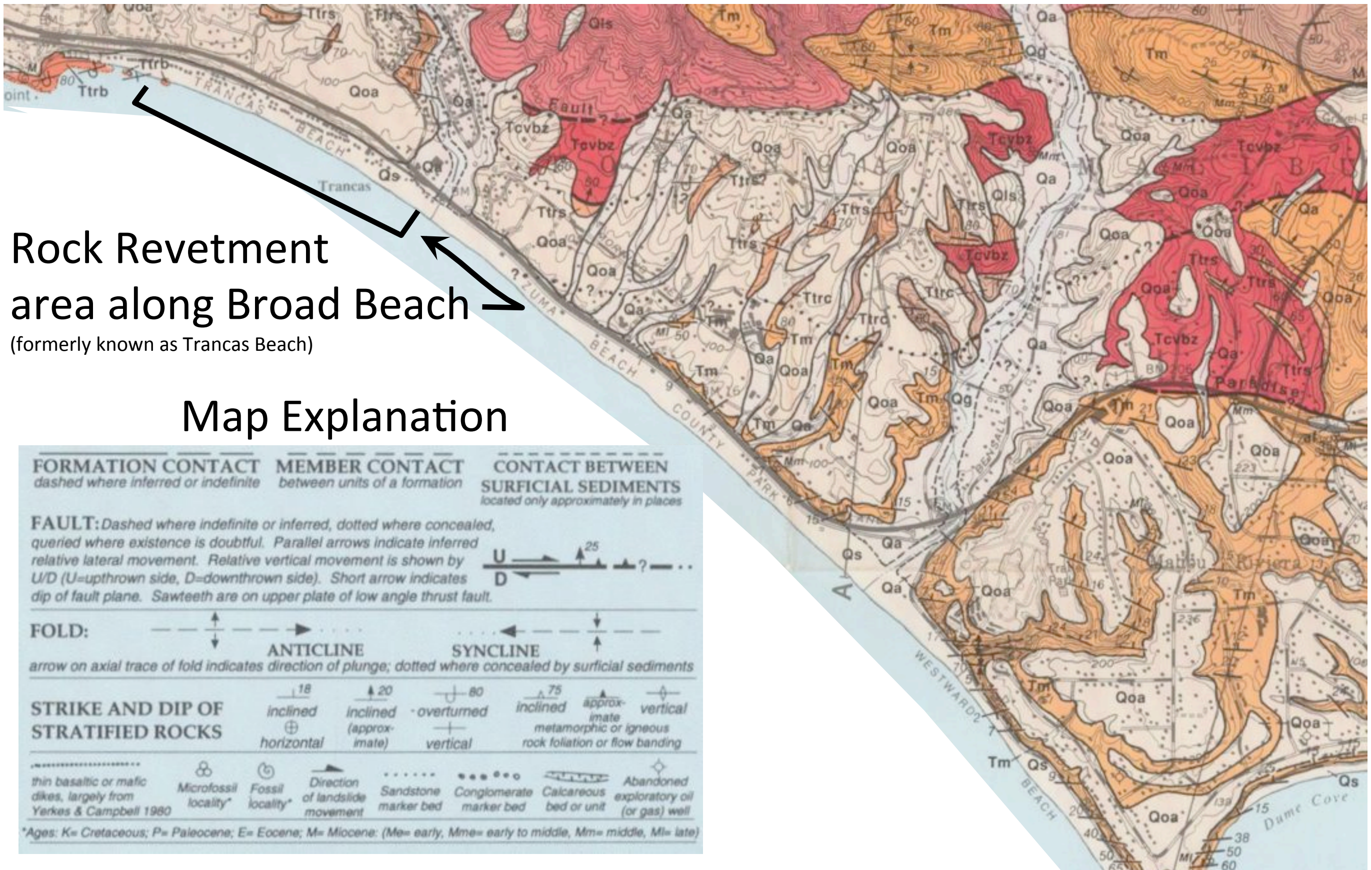
Enclosure 1

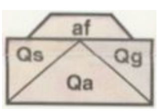


Source: Lower images – Google Earth Pro
Upper image-US Geological Survey, 7 ½ minute Point Dume Quadrangle, 1995

Geologic Map

Enclosure 2

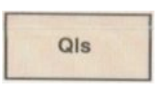




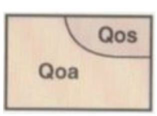
Surficial sediments

Qs-beach sand

Qa-alluvial gravel, sand and clay of floodplains

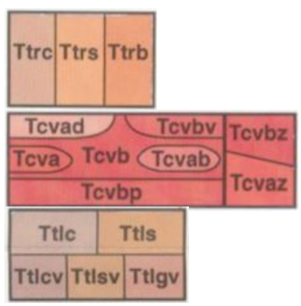


Qls-landslide debris, some of Pleistocene age



Older surficial sediments

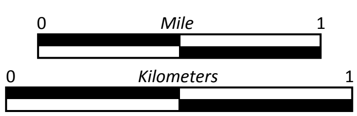
Qoa-older dissected alluvial gravel, sand and clay; deposited in part on a wave-cut platform; forms several terraces



Trancas Formation

Extrusive Conejo Volcanics

Lower Topanga Formation



Approximate Scale

Source: 1993, Dibblee and Ehrenspeck, Geologic Map of the Point Dume Quadrangle

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Malibu, California

Enclosure 3

Photos of Rock Revetment

Photo 3A. Size of exterior rock revetment at west end of wall, near 31346 Broad Beach Rd, ranges from 4-ft to 6-ft diameter. Measuring tape extends about 5-ft left of the person's hand. Rock is plutonic igneous and gneiss rock type.

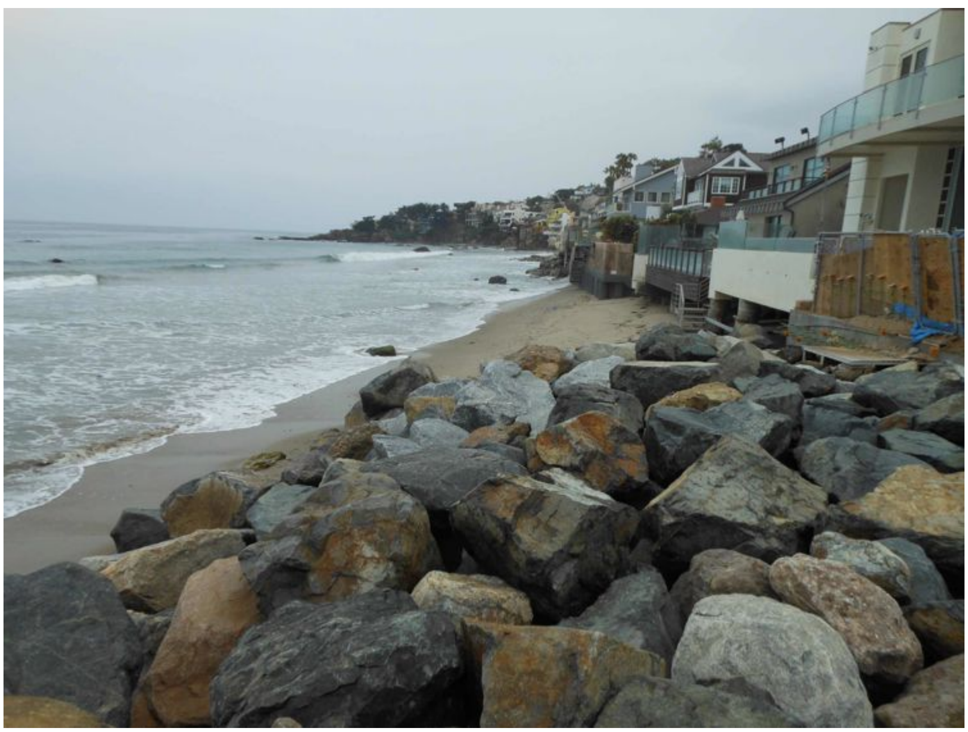


Photo 3B. An approximate 200-ft long gap in the revetment wall was created at the west end, west of 31346 Broad Beach Rd; photo taken from western beach access. Wall height in this area is approximately 10-ft to 12-ft. Note that erosion has exposed the substructure support of these residences.

Photos of Rock Revetment

Photo 4A. In the middle section, the height of the wall ranges from 6-ft to 8-ft high. For the most part the rock sizes appear to be adequately stable for the wave attacks during the last 2 years as few rock pieces were displaced.

Photo 4B. In the middle wall section, this view near 31038 Broad Beach, shows the rock diameter to range from 1-ft to 3.5-ft in diameter. Wall height is approximately 6-ft high.

Photos of Rock Revetment

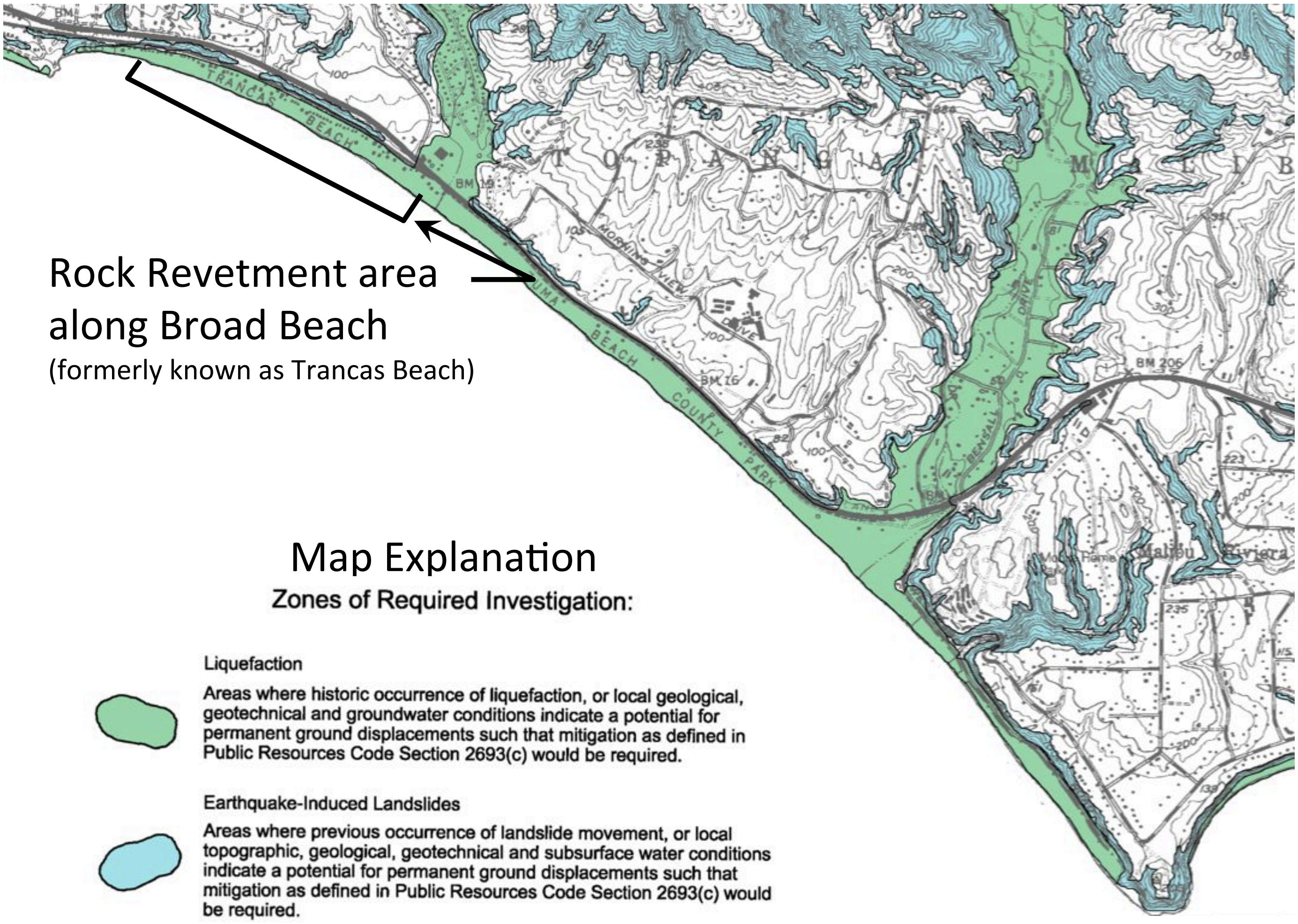
Enclosure 5

Photo 5A. Height of rock revetment wall at east end of wall, near 31078 Broad Beach Rd, is approximately 6-ft high. Measuring tape is 6-ft long. Rock size in this area ranges from 1-ft to 3.5-ft in diameter.

Photo 5B. An approximate 200-ft long gap in the revetment wall, located near 30822 Broad Beach Rd., was created at the time of placement. Wall in this area is approximately 6-ft high

Liquefaction Zones

Enclosure 6



Rock Revetment area along Broad Beach
(formerly known as Trancas Beach)

Map Explanation

Zones of Required Investigation:

Liquefaction

Areas where historic occurrence of liquefaction, or local geological, geotechnical and groundwater conditions indicate a potential for permanent ground displacements such that mitigation as defined in Public Resources Code Section 2693(c) would be required.

Earthquake-Induced Landslides

Areas where previous occurrence of landslide movement, or local topographic, geological, geotechnical and subsurface water conditions indicate a potential for permanent ground displacements such that mitigation as defined in Public Resources Code Section 2693(c) would be required.

NOTE: Seismic Hazard Zones identified on this map may include developed land where delineated hazards have already been mitigated to city or county standards. Check with your local building/planning department for information regarding the location of such mitigated areas.

0 *Mile* 1

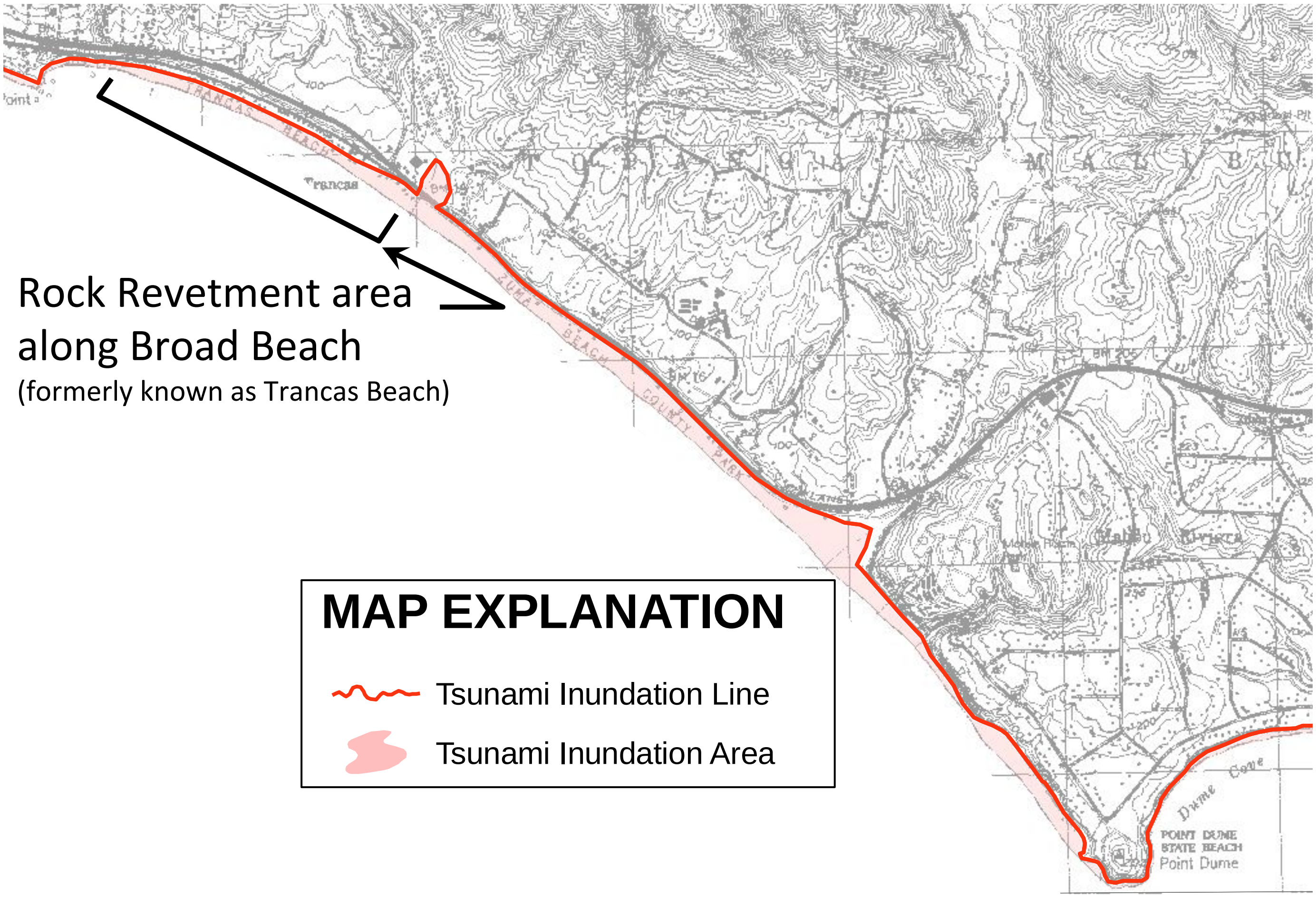
0 *Kilometers* 1

Approximate Scale

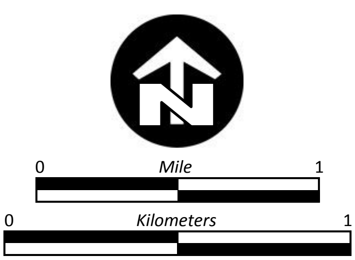
Source: 2002, Point Dume Quadrangle, State of California Seismic Hazard Zones

Tsunami Inundation Map

Enclosure 7



Sources (M = moment magnitude used in modeled event)		Areas of Inundation Map Coverage and Sources Used		
		Malibu	Santa Monica	Los Angeles Harbor
Local Sources	Anacapa-Dume Fault	X	X	
	Catalina Fault	X	X	X
	Channel Island Thrust Fault		X	
	Newport-Inglewood Fault			X
	Santa Monica Fault	X	X	
	Palos Verdes Landslide #1		X	X
	Palos Verdes Landslide #2			X
Distant Sources	Cascadia Subduction Zone #2 (M9.2)		X	X
	Central Aleutians Subduction Zone#1 (M8.9)		X	X
	Central Aleutians Subduction Zone#2 (M8.9)		X	X
	Central Aleutians Subduction Zone#3 (M9.2)	X	X	X
	Chile North Subduction Zone (M9.4)	X	X	X
	1960 Chile Earthquake (M9.3)		X	X
	1964 Alaska Earthquake (M9.2)	X	X	X
	Japan Subduction Zone #2 (M8.8)		X	X
	Kuril Islands Subduction Zone #2 (M8.8)		X	X
	Kuril Islands Subduction Zone #3 (M8.8)		X	X
	Kuril Islands Subduction Zone #4 (M8.8)		X	X



Approximate Scale

Source: Tsunami Inundation Map For Emergency Planning, Point Dume Quadrangle, State of California,County of Los Angeles, March 1, 2009

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