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FIGURES

1 LIQUEFACTION: INTRODUCTION

Liquefaction is a process in which water-saturated or gas-saturated sediment temporarily loses strength, cohesiveness, and volume as a result of a sudden increase in interstitial pore pressure brought on by strong shaking or excessive loading (Chaney & Fang, 1991; Committee on Earthquake Engineering, 1985; de Groot et al., 2006; Youd, 1973).

A review of the literature reveals an array of definitions for the term liquefaction which variously describe the mechanics of the process as well as the style of sediment deformation imposed by the process (Youd, 1973). For example, a 1985 report by the National Academy of Sciences (Committee on Earthquake Engineering, 1985, p. 12) noted that "[the] *word liquefaction, as used by engineers and nonexperts, does not refer to a single well-defined phenomenon, but rather to a complex set of interrelated phenomena that can contribute to the occurrence of unacceptable damage to a building or other facility during an earthquake*." Stated succinctly, "*Liquefaction is the transformation of a granular material from a solid state into a liquefied state as a consequence of increased porewater pressures*" (Youd, 1973, p. 10).

Liquefaction presents a potential hazard for above-ground facilities and underground pipelines, footings, and other infrastructure because of the loss of sediment cohesion and bearing capacity (Bardet & Kapuskar, 1991; Committee on Earthquake Engineering, 1985). The depth to which liquefaction can occur is dependent on the type of sedimentary deposit and depth of saturation (Chung & Rogers, 2013; Liao et al., 1988). As such deformation from liquefaction may occur from near the surface to potentially many tens of meters below the surface (Chung & Rogers, 2013; Holzer et al., 2011; Stewart & Knox, 1995). Large-magnitude earthquakes can trigger sites of liquefaction great distances (10s to 100s of kilometers) from the epicenter of the earthquake (Bardet & Kapuskar, 1991; Chaney & Fang, 1991; Earthquake Engineering Research Institute, 1989; Ishihara et al., 2014; H. B. Seed, 1968; Verdugo & González, 2015; Yasuda et al., 2012), and dependent on the setting, liquefaction from a single earthquake can extend over a wide geographic area (Committee on Earthquake Engineering, 1985; Davis et al., 2015; Potter et al., 2015). As the primary requirement for liquefaction is a geologically recent (non-indurated) saturated deposit, liquefaction occurs both in terrestrial settings (Ambraseys & Sarma, 1969; Audemard & de Santis, 1991; Chaney & Fang, 1991; Committee on Earthquake Engineering, 1985; Cubrinovski et al., 2011; Dengler, 2008; Duke & Leeds, 1963; Earthquake Engineering Research Institute, 1989; H. B. Seed, 1968) and the marine environment (Ambraseys & Sarma, 1969; Chaney, 1991; Chaney & Almagor, 2015; Chaney & Fang, 1986; Dalrymple, 1979; de Groot et al., 2006; Field, 1993; Puig et al., 2004; Sumer et al., 2007; T. C. Teh et al., 2006; T. E. Teh et al., 2004).

From the Committee on Earthquake Engineering (1985, p. 2), impacts from liquefaction may include:

- slope failure
- settling and tipping of buildings and bridge piers
- collapse of retaining walls
- lateral spreading of slightly inclined ground
- large deformations of the ground surface

- settlement and flooding of large areas

Additionally, sediment deformation from liquefaction often results in damaged or ruptured underground pipes and cables (Dengler, 2008; Earthquake Engineering Research Institute, 1989; Youd & Hoose, 1978).

2 Overview of Liquefaction Processes and Related Ground Failure

Liquefaction occurs because an anomalous force, such as shaking from an earthquake, suddenly disrupts the particle-to-particle structure of a saturated sedimentary deposit. When water-saturated deposits are in a stable state, the water present between the sediment particles exerts a steady pressure on the particles which keeps the deposit intact. However, when impacted by strong shaking from an earthquake or excessive loading from waves, the interstitial pressure suddenly rises, forcing out the interstitial water, which allows the sediment particles to collapse into one another and the mass to flow. In some cases the pore water is forced out as a sediment slurry that is channelized along fissures or cracks towards the surface (Audemard & de Santis, 1991; Committee on Earthquake Engineering, 1985). The displacement of the interstitial water causes large volumes of material to be dislodged towards the ground surface, while at the same time releasing the static pressure holding the sediment grains in place. The result is that the sediment changes nearly instantaneously from a solid state to a freely moving non-cohesive flow until the point at which equilibrium is restored (Berkeley Seismological Lab, 2008; Committee on Earthquake Engineering, 1985). As described by Field et al. (1982, p. 545) *"Once liquefaction has occurred, the sediment is free to flow, owing to the complete loss of shear strength."* The change in volume that occurs when the liquefied material at depth is ejected to the surface manifests as ground settlement (Bertalot et al., 2013; Committee on Earthquake Engineering, 1985; Earthquake Engineering Research Institute, 1989; Potter et al., 2015; H. B. Seed & Wilson, 1967), and the loss of cohesion between sediment particles leads to slumping, sliding, or lateral spreading (Bardet & Kapuskar, 1991; Chaney, 1991; Chaney & Fang, 1991; Committee on Earthquake Engineering, 1985; Dengler, 2008; Huang & Yu, 2013; Idriss & Boulanger, 2008; H. B. Seed & Wilson, 1967).

The 3 basic types of ground failures associated with liquefaction, from Youd (1973, p.6), are flow landslides, lateral-spreading landslides, and quick-condition failures. Flow landslides are those that are relatively unrestrained and therefore may displace over large areas. Lateral-spreading landslides are typically found on flatter surfaces and result in limited displacement. Quick condition failures refer to the loss of ground stability and weight-bearing capacity as a result of upward-percolating pore water. Youd (1973, p. 6) notes that in addition to these, "*the ejection of water and sediments in the form of sand boils has been a source of damage associated with liquefaction during earthquakes (Ambraseys and Sarma, 1969).*"

Deposits most likely to liquefy are geologically recent, saturated sediment, primarily sand but also some silts and gravels, lacking the presence of fines (clay, organic material) to add cohesiveness and reduce porosity (Committee on Earthquake Engineering, 1985). Lade and Yamamuro (2011, p. 247) noted that based on laboratory experiments as well as empirical case histories "*it is silty sands that liquefy under* *static and a majority of earthquake-induced conditions*.” Coastal sediment, including along the lower reaches of estuaries and on the continental shelf, is susceptible to liquefaction because of large areas of consistent grain size and saturated, non-indurated structures. For example, Chaney (1991) noted the correlation between grain size and the liquefaction-driven landslide off the Klamath River in 1980.

The most prevalent cause of liquefaction is strong shaking from earthquakes (H. B. Seed & Idriss, 1982; Committee on Earthquake Engineering, 1985; Idriss & Boulanger, 2008) but in the coastal environment liquefaction can also be triggered by excessive loading from large or sustained storm waves (Chaney & Fang, 1991; Dalrymple, 1979; Lee et al., 1993; Sassa & Sekiguchi, 1999), as well as tsunamis (Kastens & Cita, 1981; Young et al., 2009). Further, since the primary requirement for liquefaction is geologically recent, primarily sandy deposits, data show that deposits that liquefy during one earthquake may liquefy again in subsequent earthquakes (Committee on Earthquake Engineering, 1985; Towhata et al., 2014).

It was the shocking, large-scale damage from liquefaction associated with 2 different earthquakes in 1964—the M 7.5 earthquake in Niigata, Japan, and the M 9.2 Great Alaskan Earthquake—that served as catalysts for international cooperation in accelerated liquefaction studies in the laboratory (e.g., Chaney & Demars, 1985; Elgamal et al., 1989; Fiegel & Kutter, 1994; Holzer et al., 2011; K. Ishihara, 1993; Scott & Zuckerman, 1973; H. B. Seed & Lee, 1966; Sumer et al., 2007; Zhang et al., 2004, 2004; Zhu et al., 2017) as well as in the field (e.g., Seed and Idriss, 1967, 1971; Scott and Zuckerman, 1973; Dalrymple, 1979; Chaney and Demars, 1985; Lindenberg et al., 1989; Bardet and Kapuskar, 1991; Wotherspoon et al., 2015; Zhu et al., 2017). Since 1964, numerous other large earthquakes have provided additional sources of empirical measurements to evaluate the potential for liquefaction at industrial or populated sites. A few examples include the 1989 M6.9 Loma Prieta (California) earthquake (Bardet & Kapuskar, 1991; Earthquake Engineering Research Institute, 1989; Holzer, 1998; R. B. Seed et al., 1991); the 2010 M8.8 Maule (Chile) earthquake (Bertalot et al., 2013; Verdugo, 2012; Verdugo & González, 2015); the 2010 M 7.1 Darfield (New Zealand) earthquake (Potter et al., 2015; Wotherspoon et al., 2015); the 2011 M 9.1 Tohoku-aki (“Great East Japan”) earthquake (Ishihara et al., 2014; Towhata et al., 2014; Tsukamoto et al., 2012; Yasuda et al., 2012) and the 2016 M7.8 Kaiköura, New Zealand earthquake (Bray et al., 2018; Cubrinovski et al., 2017; Cubrinovski et al., 2017; Dizhur et al., 2019).

During the 1989 Loma Prieta earthquake, the damage sustained by the San Francisco Marina District showed the combined hazard of building on saturated deposits which, in addition to being susceptible to liquefaction, also amplify intensity from shaking (Holzer, 1992, 1998). For example, in their detailed analysis of liquefaction from the Loma Prieta earthquake, Seed et al. (1991, p. 1575) described damage in the Marina District as follows: "*Loose, fine sandy fill liquefied and this resulted in sand boils, lateral spreading, settlement, partial bearing failures, structural distress, pavement damage, and damage to pipes and other buried utilities. This region also suffered considerable damage to structures as a result of strong ground shaking. A number of buildings were destroyed or badly damaged; much of the area was evacuated and public access was restricted immediately following the earthquake.*" Although the Marina District was 97 km (60 mi) from the earthquake epicenter, peak ground acceleration (PGA) exceeded 0.05-0.1 g, the threshold for triggering liquefaction deformation in deposits in that area (Rosidi &

Wigginton, 1991). It is significant that the area of the Marina District that sustained the most severe damage is underlain by artificial or hydraulically placed fill, comparable to large areas fringing San Francisco Bay where liquefaction in artificial fill was "*significantly more pervasive and severe*" than in natural deposits (Seed et al., 1991, p. 1575). It should be noted that the majority of the artificial fill that failed in the San Francisco Bay area was emplaced prior to the 1960s and more recent advancements in soil liquefaction engineering (e.g., Seed et al., 2003).

2.1 Documented Liquefaction From North Coast Earthquakes

Liquefaction is a recognized hazard for areas of Humboldt County underlain by geologically young, saturated sedimentary deposits (Humboldt County, 2017; van Dohlen, 2015). The liquefaction hazard map of van Dohlen (2015) (Figure 1) identifies the potential hazard zones as all low-lying areas around Humboldt Bay, in addition to the Arcata Bottom to the north and Eel River valley to the south.

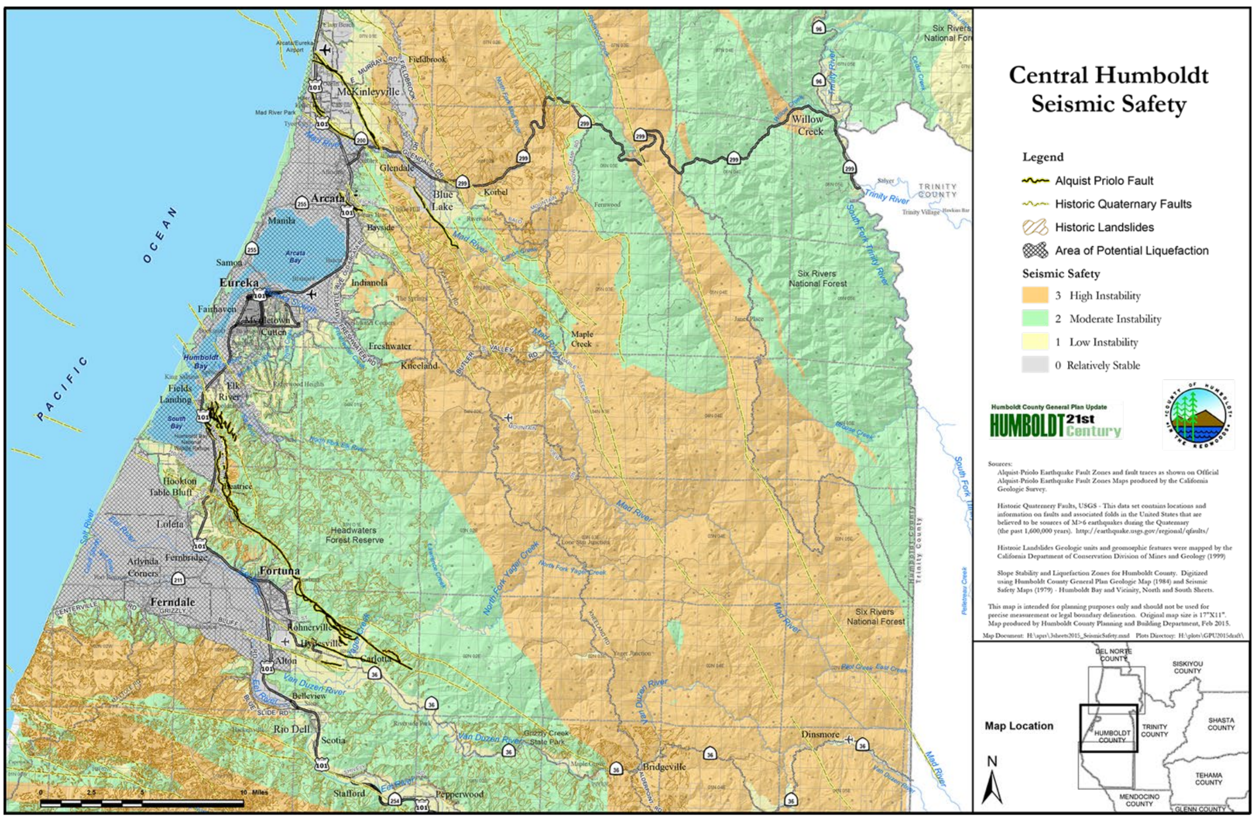


Figure 1. Map showing areas of varying levels of seismic instability, including liquefaction hazard zones (gray hatch pattern), for Humboldt County (from van Dohlen, 2015, https://earthworks.stanford.edu/catalog/stanford-nk595pg0743.)

In coastal Humboldt County, evidence for liquefaction from earthquakes was observed in the field following the events in 1980 (Chaney, 1991; Lajoie & Keefer, 1981), 1992 (O'Brien, 1992; Reagor & Brewer, 1992), and 2010 (Storesund et al., 2010). There were also reports of liquefaction from the 1906 San Andreas fault earthquake, with inventories based on field observations at the time (Lawson & Reid,

1908) as well as compilations from historical newspaper accounts and photographs (Dengler, 2008; Youd & Hoose, 1978). With the exception of the discovery by the USGS of a liquefaction-generated submarine landslide triggered by the 1980 earthquake (Field et al., 1981, 1982; Field and Hall, 1982; Field and Jennings, 1987; Field, 1993) (Section 6.1.2), there are no data available to determine if any offshore areas sustained liquefaction deformation during these events.

For coastal Humboldt County between the mouth of the Klamath River in the north to the lower Mattole River valley in the south, the effects of liquefaction from earthquakes in 1980, 1992, and 2010 were insignificant in terms of the built environment. Most evidence of liquefaction was observed on non-industrial areas of sand spits, river floodplains, or beaches. Further, in each of these cases, liquefaction features were confined to areas underlain by sandy or saturated deposits that were not only naturally highly susceptible to failure from liquefaction, but were also somewhat regionally controlled by proximity to the earthquake epicenters and areas of strongest shaking.

For example, the largest liquefaction features observed from the 1980 earthquake, which occurred on a fault in the Gorda plate northwest of Eureka (41.1°N/-124.2°)(Figure 15 in *Geologic Technical Memo 1: Strong Ground Motion*), were observed onshore at the Big Lagoon spit (Lajoie and Keefer, 1981) and offshore at the seaward edge of the marine delta of the Klamath River (Lajoie and Keefer, 1981; Field and Hall, 1982; Field and Jennings, 1987; Chaney, 1991; Field, 1993) (Figure 2). At the Big Lagoon spit, Lajoie and Keefer (1981, p. 20) observed that "*[l]iquefaction-induced lateral spreads, cracks, and sand boils were observed in numerous places along a kilometer-long traverse on foot at the southern end of this spit... Gary Carver and Tom Stephen*[1] *reported similar features along the entire 5-km length of the spit."* Other liquefaction features further to the south— small ground cracks at King Salmon, minor ground settlement at Fields Landing, and a few cracks and small sand boils on the southernmost South Spit (Figure 2)—were minor in comparison to the size and extent of the ground failure at Big Lagoon and the submarine slide off the Klamath River. No evidence for liquefaction in 1980 was observed in other areas underlain by saturated alluvial or estuarine deposits including Arcata Bottom, Arcata Bay, Jacoby Creek floodplain, Samoa Peninsula/North Spit, the northern half of South Spit, or the Eel River floodplain.

Liquefaction from the 1992 mainshock and aftershocks, with epicenters at Cape Mendocino (Figures SM16-18 in *Geologic Technical Memo 1: Strong Ground Motion*), triggered large liquefaction features in the Mattole and Eel River valleys (Reagor and Brewer, 1992, p. 2), but there were no reports of deformation north of the Eel River. The 2010 M6.5 earthquake west of the Eel River produced liquefaction features consisting of numerous sand boils at Centerville Beach and the lower Eel River valley, lateral spreading at King Salmon and along the banks of the lower Eel River, and minor ground cracking and displacements in areas of Eureka close to the bay (Storesund et al., 2010).

[1]

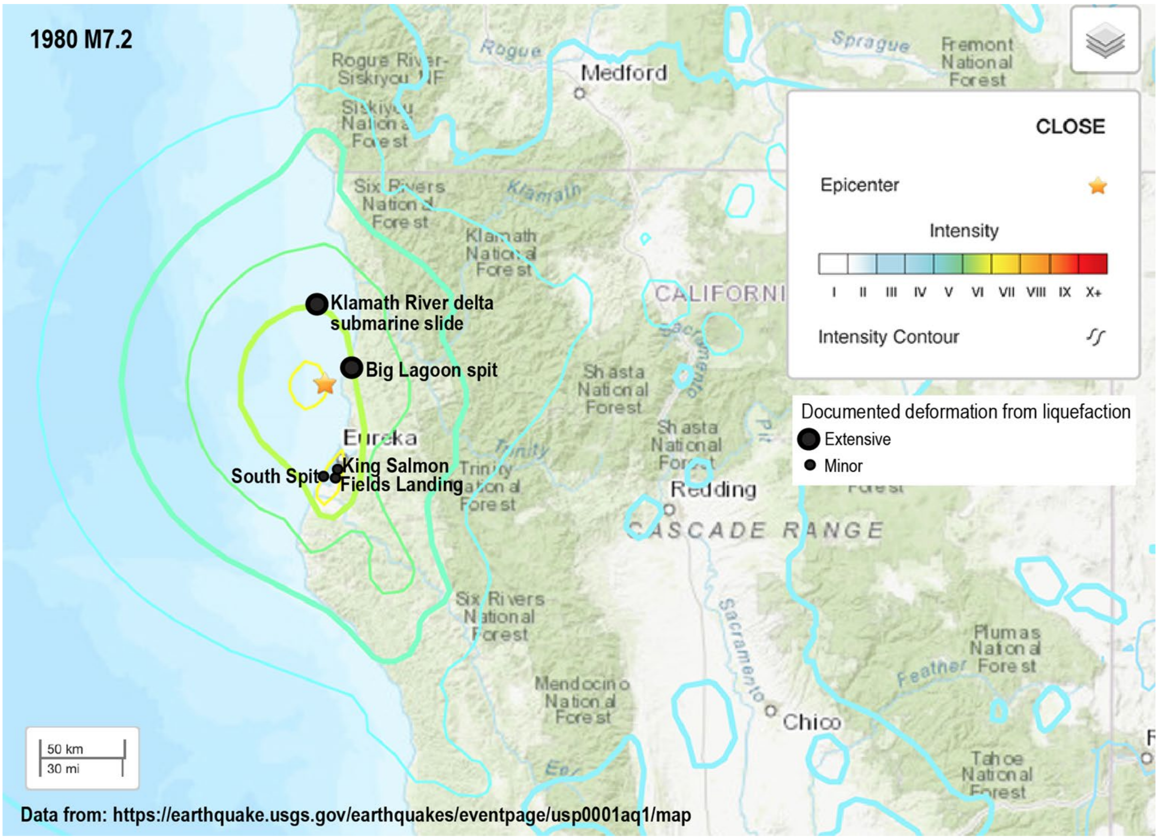
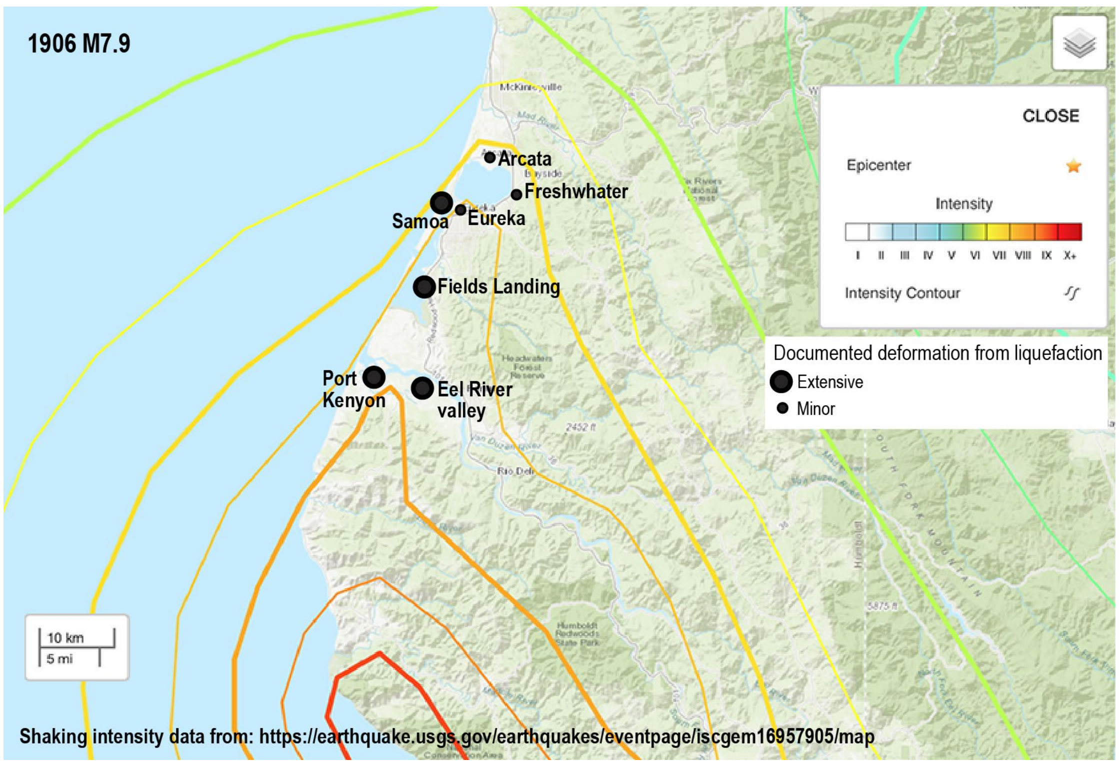


Figure SEQ Figure * ARABIC 2. Sites of documented liquefaction from the 1980 M7.2 earthquake superimposed on the USGS MMI

Liquefaction in the Eureka-Arcata area from the December 21, 1954, ~M6.5 earthquake, based on newspaper accounts (Coffman and Von Hake, 1973; Youd and Hoose, 1978; Stover and Coffman, 1993) was more substantial than in 1980, 1992, or 2010. As the earthquake preceded the seismic analysis capabilities of the NCSS network started in the 1960s (Section 3.3), the size and epicenter location of this earthquake is poorly understood, but is estimated as close to or directly beneath the Eureka-Arcata area (USGS, 2020b).

Although they don't mention the term "liquefaction" specifically and location information is mostly vague, Stover and Coffman (1993, p. 148) are clearly reporting liquefaction deformation in the Eureka and Arcata areas, including ground settling, from the 1954 event: "*Damage to structures and underground pipelines occurred in areas of unstable ground. Previous ground settling, as well as subsidence at the time of the shock, were observed in some of the damaged areas. Between Eureka and Arcata, U.S. Highway 101 was cracked and bulged in places*." Youd and Hoose (1978, p. 172-173) describe underground pipe damage and ground settling in the Eureka area, and underground water lines broken in Samoa: *In the poorly consolidated ground areas north and east of Eureka there were some pipeline failures, and Eureka's main water reservoir was cracked. A large section of the older, downtown filled area of Eureka settled from 2 to 6 inches*… [The] *Hammond Lumber Company brought its* *operations to a sudden halt when several breaks occurred in the underground main of the company's fire protection system. A. 0. LeFors, spokesman for Hammond, stated that the mill will not operate in Samoa or at its Eureka plants until repairs have been made."* This greater severity of liquefaction for sites around Humboldt Bay in 1954 as compared with 1980, 1992, and 2010 is likely the result of the close proximity of the earthquake epicenter to Humboldt Bay as interpreted by the USGS (2020b).

Compared to the minimal effects from liquefaction following the 1980, 1992, and 2010 earthquakes for coastal Humboldt County, and the larger but relatively isolated effects in 1954, surface deformation associated with liquefaction from the 1906 M7.9 San Andreas earthquake was significant in some locations, and reported from a broader geographic area (Lawson, 1908; Youd and Hoose, 1978; Dengler, 2008) (Figure 3).



Although communities around Humboldt Bay are distant (~360-390 km/~220-240 mi) from the 1906 earthquake epicenter off San Francisco, they are only about ~60-90 km (~40-55 mi) from the northernmost reach of the SAF, south of Cape Mendocino, where fault offsets were large and energy release was high (Thatcher et al., 1997; USGS, 2020a, 2020c) (Figure 5 in *Geologic Technical Memo 1: Strong Ground Motion*). The combination of high intensity and long duration (estimated 45-60 sec) shaking from the 1906 earthquake in coastal Humboldt County resulted in the widespread observed deformation from liquefaction, to include large areas of soft-sediment deformation, lateral spreading, and ground settling and subsidence (Youd and Hoose, 1978; Dengler, 2008). The shaking in Eureka was reported as lasting 47 sec by A. H. Bell, an observer at the Weather Bureau in Eureka (Lawson, 1908, p. 166) who kept notes on all earthquakes felt in the area between 1903 and 1911 (Dengler, 2008, p. 920).

Deformation from liquefaction in 1906 was extensive in the Eel River valley area, including the community of Port Kenyon (Figures 3 and 4), and included large areas of lateral spreading, ground settling, and sand boils. An eyewitness account by A.S. Eakle (Lawson, 1908, p. 165), a U.C. Berkeley geology professor who surveyed the region 3 weeks after the earthquake, describes the deformation in the Eel River valley as follows: "*At Dungan's Ferry, on the north bank of the Eel River, the ground was full of fissures. Every bar on the river had been opened by fissures, and the gravel toppled over leaving big ditches, some 6 feet deep and over 500 feet long. Coming up on the mainland the road had dropped about 2 feet in one place and was full of small fissures. A 40-acre field was entirely ruined. It was heavily fissured, having dropped down in strips from 2 to 6 feet wide, from 4 to 6 feet deep, and from 5 to 500 feet long, the fissures pointing between south and southwest. All the fields were full of quicksand volcanoes, some 1 to 3 cubic yards in size. They were perfect miniature volcanoes, everyone having a crater. It is said they extended 30 miles up the river*." The community of Ferndale sustained extensive damage from the 1906 earthquake, but although ground settling from liquefaction was indicated for the 1954 earthquake (Youd and Hoose, 1978), the extensive damage to buildings and homes in 1906 was attributed to the strong ground motion that wrenched buildings out of square (Lawson, 1908; Youd and Hoose, 1978; Beltz, 2006; Dengler, 2008). During the earthquake, local Ferndale citizens reported that the ground rose and fell "in great waves like those of the sea" (Lawson, 1908, p. 165).

Figure 4. Historical photograph of lateral spreading from liquefaction along the lower Eel River, at Port Kenyon, Humboldt County, triggered by the 1906 earthquake on the San Andreas fault. (Original photograph by E. Garrett; from Dengler, 2008, her Figure 11.)

Eakle's field observations (published in Lawson, 1908) plus compilations of historical records by Youd and Hoose (1978) and Dengler (2008) also document significant deformation at Fields Landing (Figure 5), south Eureka at the mouth of Elk River, and on the North Spit at Samoa. Ground settling and fissuring from liquefaction is mentioned for sites in Eureka, Arcata, and near Freshwater, but there are minimal details as most damage reports focused on structural damage to businesses and homes, particularly numbers of downed chimneys (Lawson, 1908; Youd and Hoose, 1978; Dengler, 2008). An account in one of the Humboldt area newspapers in 1906, the Weekly Humboldt Times, mentions problems encountered by the Northwestern Pacific Railroad because the "marsh land between [Eureka} and Arcata sand in places" (Youd and Hoose, 1978, p. 173), but no details are provided.

Figure SEQ Figure * ARABIC 5. Historical photograph of the Pacific Lumber Company dock at Fields Landing that collapsed from liquefaction triggered by the 1906 San Andreas fault earthquake. (Image reproduced from Dengler, 2008, her Figure 8.)

At Fields Landing, liquefaction caused significant lateral spreading and ground settling or subsidence (Lawson, 1908; Youd and Hoose, 1978). A full meter of subsidence was recorded for an island in the channel off Fields Landing, and the Pacific Lumber Company dock was destroyed when the ground settled beneath it (Dengler, 2008) (Figure LF5). Ground settlement at Samoa was problematic for at least one of the large timber mills: "At Samoa, where the Vance Company has its mill and warehouses… one warehouse, the ground sunk beneath it several feet. The floor of the planing mill sank several inches on the east side and some are of the opinion that the factors settled also at one wall" (Youd and Hoose, 1978, p. 173). There are no observations concerning possible liquefaction for other areas of the North or South spits, nor—as with most of the other strong earthquakes after 1906—any information as to possible effects in offshore areas.

However, liquefaction in seismically active areas, and particularly in coastal environments, has been an international area of focus for more than 60 years (Committee on Earthquake Engineering, 1985; ICRAGEESD, 2001, 2010, 2016; Seed et al., 2001, 2003; Holzer et al., 2011), with advances in liquefaction engineering gleaned from numerous case studies of past seismically induced engineering failures. For example, Seed et al. (Seed et al., 2003, p. 1) note that "*Soil liquefaction engineering has evolved into a sub-field in its own right, and engineering assessment and mitigation of seismic soil liquefaction hazard is increasingly well addressed in both research and practice. This rapid evolution in the treatment of liquefaction has been pushed largely by a confluence of lessons and data provided by a series of major earthquakes over the past dozen years, as well as by the research and professional/political will engendered by these major seismic events.*"

2.2 Liquefaction Potential along the HWY 101 Corridor

There has been substantial effort to assess the liquefaction potential along the Hwy 101 corridor between Eureka and Arcata, especially by Caltrans (Caltrans Engineering Services, 2001, 2006; Caltrans Geotechnical Services, 2006, 2019, 2022b, 2022a, 2023). Based on these assessments and geologic mapping (Kelley, 1984; McLaughlin et al., 2000) the majority of the Hwy 101 corridor between Arcata and Eureka is located near current mean sea level with high groundwater levels. Subsurface geology (Figure 6, Caltrans Geotechnical Services, 2022a, their Figure 2), along the highway route consists of largely Holocene bay marsh and bay margin sediments (Kelley, 1984; McLaughlin et al., 2000; Caltrans Geotechnical Services, 2022b, 2022a). The subsurface geology consists of Holocene alluvial deposits consisting of alluvial clay, silt, sand, gravel and boulders overlain largely by artificial fill (road construction-related) based on results from numerous geotechnical borings and CPT tests (Caltrans Geotechnical Services, 2022a, 2022b).

There have been detailed liquefaction potential investigations conducted along portions of the corridor conducted by Caltrans and consultants (for example: Caltrans Engineering Services, 2001, 2006; Caltrans Geotechnical Services, 2006, 2022b, 2022a; GHD, 2021). Significant portions of the corridor between Eureka and Arcata are liquefaction prone based on geological logging parameters and geotechnical lab analyses. Young bay muds at elevations ranging between -20 to -47 feet in the vicinity of the intersection of Indianola Road and Hwy 101 (Figure 2) (within the Qal unit of McLaughlin, 2000) are described in Caltrans Geotechnical Services (2022b, Appendix II, p. 4) as very low strength, low plasticity clays. These are, in turn, underlain by slightly less compressible, and slightly higher strength silty sand, sandy silt and silt with interbedded clays. Further underlying materials tend to be of higher strength clays which overly older Quaternary and Tertiary (Wildcat Group) deposits that are of greater strength and low compressibility Caltrans Geotechnical Services (2022b, Appendix II, p. 4-5).

Caltrans Geotechnical Services (2022a) reports that, at the Indianola intersection site, there is a strong potential for liquefaction, considering the likelihood for strong shaking and the conditions of subsurface materials (described above). They consider roadbed embankments at this location may experience up to 4 inches of settlement and up to 9 feet of lateral spread displacement.

At Eureka Slough (Figure 6), Caltrans Geotechnical Services (2023) reports the channel and adjacent tidal marsh are underlain by tidal marsh deposits up to 53 feet thick across the channel that pinch out to the north and south. This is underlain by a compacted to slightly compacted sand unit that is between 15- to 45-feet thick. Beneath this is likely older Quaternary sands and clays. They conclude that liquefiable sediments within the upper 70 feet of the Eureka Slough area exist. They also conclude that bearing capacity failure and lateral spreads may be anticipated at this site. The laboratory analysis to confirm this assessment had not been completed at the time of this report.

At Jacoby Creek, near the northern end of the project area (Figure 6), Caltrans Geotechnical Services (2019)conducted foundation recommendations for a replacement bridge along southbound Hwy 101 that included subsurface investigations to address liquefaction potential. They constructed two geotechnical borings and two CPT borings. The borings encountered artificial fill up to 6 feet thick overlying young bay margin soft clay up to 36 feet thick. These overly alluvial deposits encountered at a depth of about 60 feet that consist of a 35 to 60 foot-thick medium dense to dense silty sand unit with gravels in the lower 10 feet. These are underlain by older bay margin deposits that consist of stiff to medium stiff lean clay with minor fat clay.

The liquefaction analysis concludes that materials above 40 feet have a high risk of liquefaction given the regional seismic hazard and a large potential earthquake. They consider materials below 40 feet unlikely to liquify. They also conclude that, at that location, the potential for lateral spreading is minimal.

Based on the detailed analyses conducted at the three locations that span the length of the Hwy 101 project, it appears that the subsurface materials encountered along much of this portion of the highway are susceptible to liquefaction if strong motion conditions occur. The exception may be at Bracut where more compacted sediments of the Wildcat Group (QTw) extend to the highway and possibly beyond. (Figure 2).

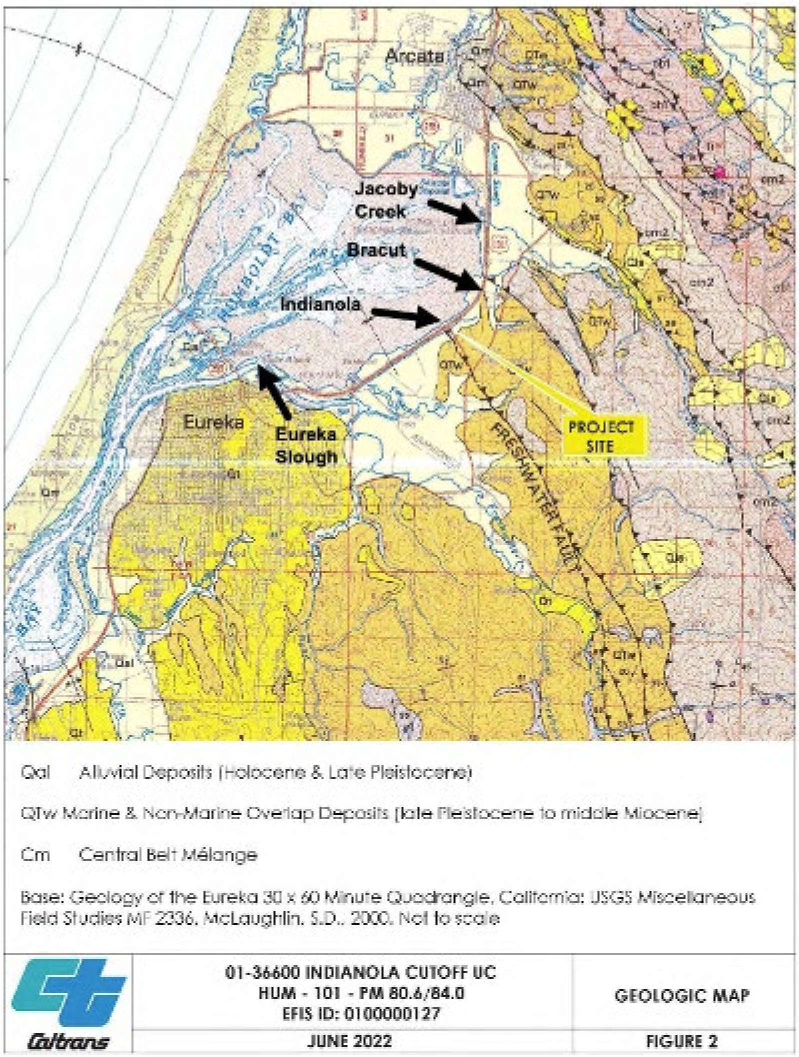


Figure 6. Geologic map of the Eureka-Arcata area including the Hwy 101 corridor, from McLaughlin et al. 2000, included in Caltrans Geotechnical Services 2022a, their Figure 2). Caltrans liquefaction investigations (Jacoby Creek, Indianola, and Eureka Slough) indicated.

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