Ground Failure During Loma Prieta EQ - Downtown Santa Cruz

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SYNOPSIS: Ground failure occurred in numerous locations in the downtown Santa Cruz area during the Loma Prieta Earthquake. These failures included liquefaction, lateral spreading and lurch cracking. Mapping of many of these features was made within three days of the earthquake, before heavy rains obscured much of the surface evidence. Data from a United States Geological Survey study of liquefaction potential in Santa Cruz has been examined. In addition, subsurface information has been collected from several downtown subsurface exploration studies. A comparison has been made between areas where ground failure was predicted and where it occurred during the Loma Prieta Earthquake. This comparison yielded a relatively good correlation between predictive tools and observed damage, although the highly complex geologic environment makes some aspects of interpretation difficult.

GROUND FAILURE MAPPING

The authors of this article, in conjunction with engineering geologist Michael Scullin (of RSA Associates, Van Nuys, California), were volunteer members of the ASCE disaster evaluation team. They arrived in Santa Cruz on October 18, 1989, and continued work through October 20. Although other geotechnical evaluation work was performed during this period, the primary focus of these investigators was the ground failure in the downtown area. A map summarizing the general observations recorded is presented as Figure 1.

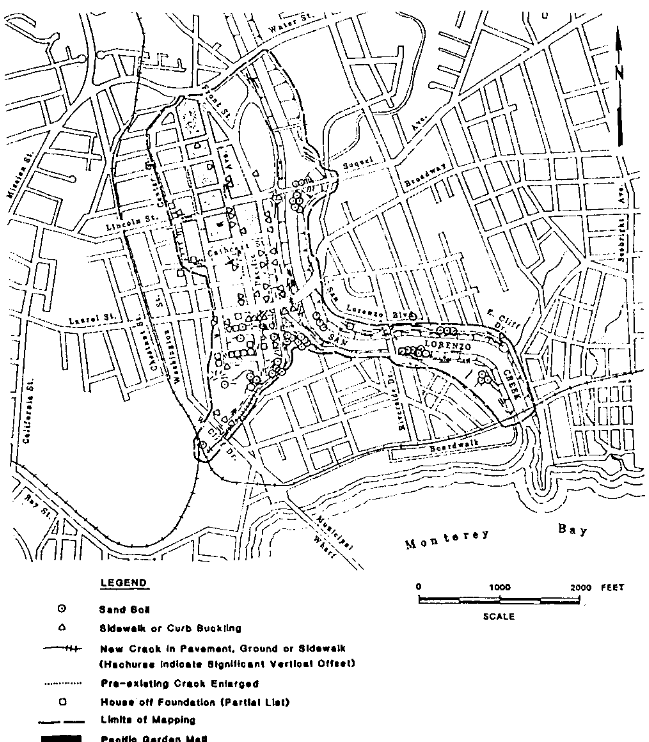

Figure 1 Ground Failure Features in Downtown Santa Cruz

Generally, relatively little ground failure was observed in the Pacific Garden Mall where serious structural damage occurred to many buildings. Varying amounts of damage were mapped in other downtown areas with the most severe ground damage located in the levee areas along San Lorenzo River. A detailed discussion of the ground failure features observed is presented in Kropp and Thomas (in press).

GEOLOGY AND LIQUEFACTION POTENTIAL MAPPING

In 1975, maps were prepared which showed the Quaternary geology of Santa Cruz County and assessed the liquefaction potential of these materials (Dupré, 1975). The location of the Quaternary deposits in the downtown area are shown on Figure 2. In addition, the non-Quaternary deposits have been labeled on Figure 2, using the data from the Preliminary Geologic Map of Santa Cruz County (Brabb, 1986).

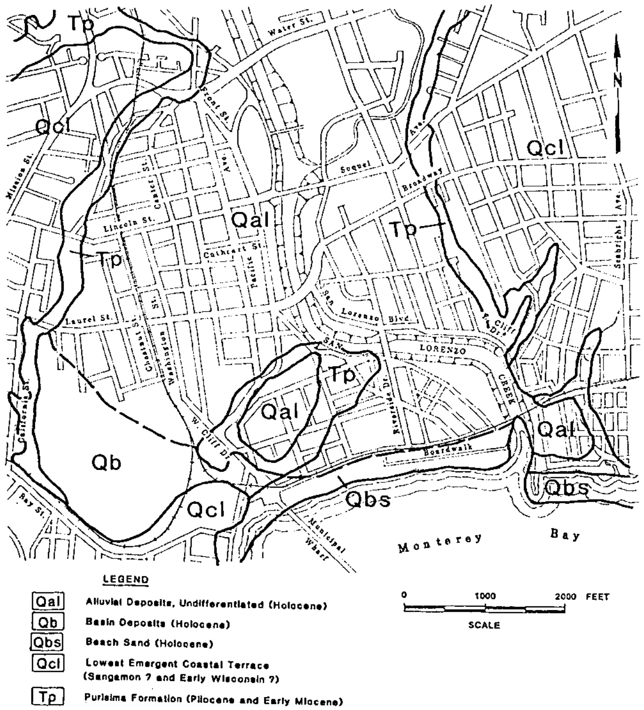

Figure 2 Geologic Map of Downtown Santa Cruz (After Dupré, 1975 and Brabb, 1986)

As seen on Figure 2, the majority of the downtown area is underlain by Quaternary Alluvium. These materials are described as undifferentiated, Holocene age materials. Dupré further describes them as "unconsolidated, heterogeneous, moderately sorted silt and sand with discontinuous lenses of clay and silty clay. Locally include large amounts of gravel." In the southwestern corner of the area there is also a section of basin deposits. These Holocene-age materials are described by Dupré as "unconsolidated, plastic, organic-rich clay and silty clay. Locally contain interbedded thin layers of silt and silty sand. Deposited in a variety of environments included estuaries, lagoons, marsh-filled sloughs, flood basins, and lakes." Along the beach area, Dupré indicates beach sands are present which are said to be "unconsolidated, well-sorted sand. Local layers of pebbles and cobbles." The final unit in the main downtown area is the Pliocene and upper Miocene-age Purisima Formation materials. These are described by Brabb as "very thick-bedded, yellowish-grey tuffaceous and diatomaceous siltstone with thick interbeds of bluish-grey semifriable, fine-grained and andesitic sandstone."

Dupré zoned the liquefaction potential of the Quaternary materials in four categories. Zone A was said to have a high liquefaction potential, Zone B a moderately high potential, Zone C a moderately low potential and Zone D a low potential. Most of the alluvial materials, as well as the basin materials in the downtown area, were placed in a high liquefaction potential zone (Zone A). A portion of the alluvial materials near the northwestern and the northeastern portions of the downtown area were placed in a Zone B, or moderately high potential area, because Dupré believed that groundwater was present at greater depths in this area. The City of Santa Cruz Seismic Safety Element duplicated the Zone A and Zone B areas on a special map for incorporation into the general plan. This general plan element was adopted in 1976, and Figure 3 indicates the limits of these zones in the downtown area. The Seismic Safety Element stated that during a great earthquake (such as the 1906 event), liquefaction could occur and "tremendous damage could result from liquefaction-induced failures, not only to buildings, but to utility and communication lines, roads, bridges and overpasses, and other vital facilities." A comparison of the observed damage features following the Loma Prieta Earthquake shown on Figure 1 with the Zone A area on Figure 3 indicates a good correlation between the anticipated and actually-occurring areas of liquefaction.

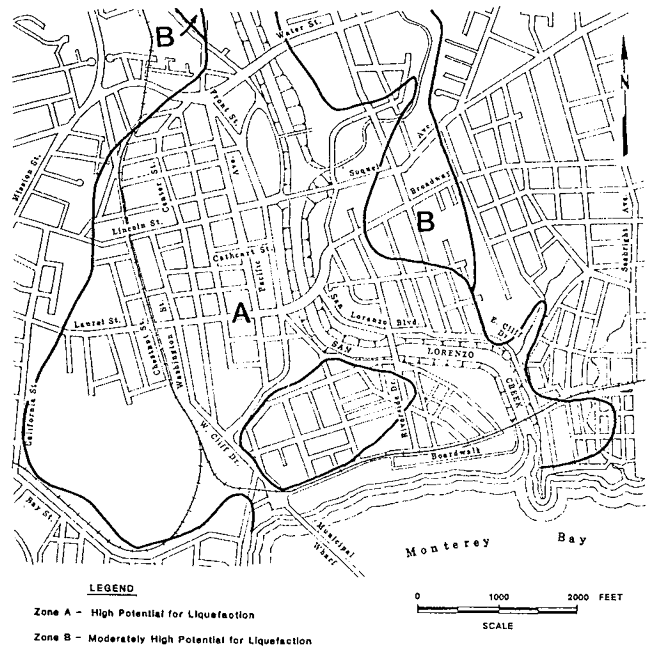

Figure 3 Liquefaction Potential Areas in Downtown Santa Cruz (City of Santa Cruz, 1976)

SITE SPECIFIC STUDIES

Data has been collected from various consultants who have performed subsurface explorations on sites in the downtown Santa Cruz area. In addition, information has been obtained from an Army Corps of Engineers regarding the construction of the levees along the San Lorenzo River during the 1950's.

Two downtown study sites were selected to illustrate the general conditions which were observed throughout the area. At these two sites, exploratory borings were drilled and Standard Penetration Tests performed during the drilling operations. In addition, samples were tested in the consultant's laboratory to determine the grain-size distribution of the materials encountered. Grain-size distribution curves from selected samples at each of the two sites are presented on Figures 4 and 5.

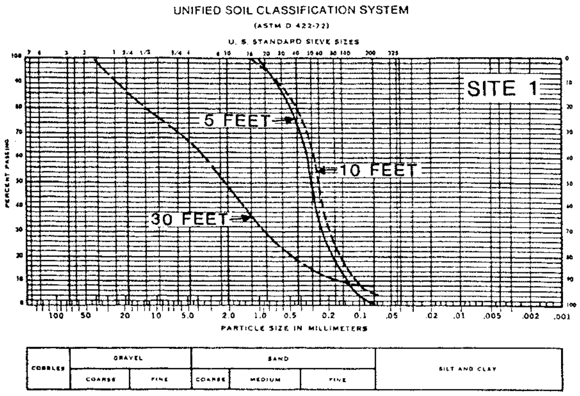

Figure 4 Gradation Curves for Site 1

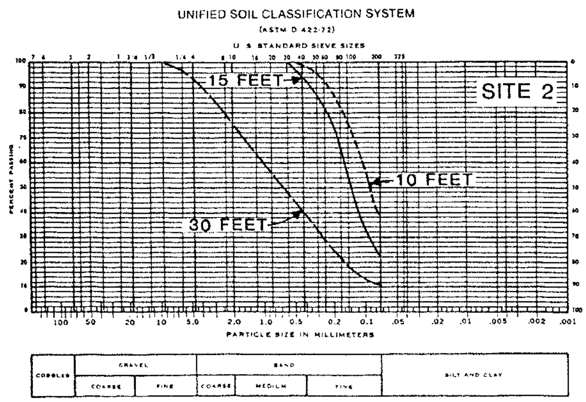

Figure 5 Gradation Curves for Site 2

Liquefaction potential was assessed for each of the samples presented on Figures 4 and 5 using the updated Seed-Idriss procedure (Seed and Harder, 1990). In the evaluation, it was determined that the sampling equipment for the Standard Penetration Tests were relatively similar to the standardized equipment and procedures and therefore no correction was applied. The blow counts were also corrected for overburden pressures to obtain the "equivalent" penetration resistance at an overburden pressure of 1 ton per square foot.

During the Loma Prieta Earthquake, a peak ground surface acceleration of 0.54g was recorded at a nearby station (Shakal, et al, 1989). Utilizing this peak ground surface acceleration as well as the data from the exploratory borings, liquefaction susceptibility was evaluated using the chart presented in Seed and Harder (1990) - see Figure 6. For various amounts of fine-grained material, points which plot to the left or above the indicated lines are believed to be susceptible to liquefaction while data points to the right or below the lines are not believed to be susceptible to liquefaction. As can be seen on the chart, five of the six data points indicate that the sand layers evaluated are susceptible to liquefaction. It should be noted that the cyclic stress ratio values should actually be increased by about 8 percent to adjust the standard chart based on a Magnitude 7½ earthquake to the Magnitude 7 level of the Loma Prieta Earthquake (See and Harder, 1990). This adjustment would not result in any significant changes of liquefaction susceptibility.

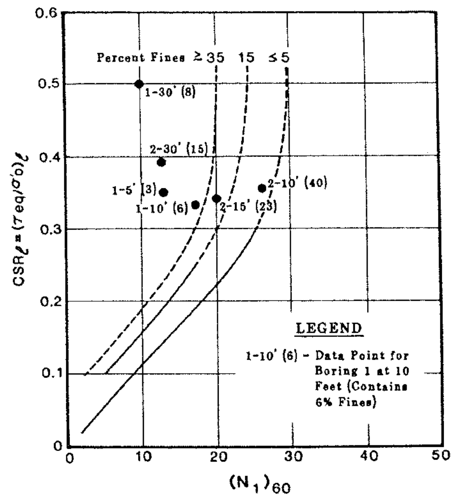

Figure 6 Relationship Between Cyclic Stress Ratio Causing Liquefaction and N_1-Values for M=7½ Earthquakes (From Seed and Harder, 1990) - With Data From 2 Downtown Santa Cruz Sites

INTERPRETATION AND CONCLUSIONS

Ground mapping indicated that liquefaction occurred in various areas within the downtown portion of Santa Cruz. Furthermore, the susceptibility to liquefaction could be reasonably predicted using generally accepted liquefaction evaluation procedures. However, many portions of the downtown area did not manifest surface evidence of liquefaction, including the two study sites discussed in the previous section. One reason which may explain the failure to see surface manifestations of underlying liquefaction could be that a non-liquefied layer was near the surface. Since the groundwater was present in these areas at a depth of 10 to 15 feet, there may have been a thick layer of non-liquefiable materials overlying the liquefiable layers. Ishihara (1985), provides a procedure to evaluate if a non-liquefied layer over a liquefied layer is thick enough to preclude manifestation of movement at the ground surface. In contrast, the very serious ground movements were observed in the levee area. As discussed by Seed and Harder, sloping ground may produce a higher potential for liquefaction than level ground where the liquefiable deposits have relative densities of less than 50 percent. Therefore, the sloping nature of the ground immediately adjacent to the San Lorenzo River may have produced an increased liquefaction susceptibility which led to the observed ground failures.

SUMMARY

The downtown Santa Cruz area is clearly susceptible to liquefaction failure. Significant areas of ground failure were observed during the Loma Prieta Earthquake. An evaluation of data obtained from borings at selected sites also indicates susceptibility to liquefaction using generally accepted, simplified procedures. However, because of a highly complex depositional environment of the alluvial materials, the liquefiable sand layers are probably not continuous and produce highly variable results during earthquake loading. Nonetheless, there is general agreement between the analytical tools used and the surface observations made.

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