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# EVALUATION OF INTEGRATED SEISMIC HAZARDS AND GROUND FAILURE IN PULL-APART BASINS DURING THE 1999 KOCAELI EARTHQUAKE, TURKEY: COLLABORATIVE RESEARCH BETWEEN THE UNIVERSITY OF TEXAS AND WILLIAM LETTIS & ASSOCIATES

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## TECHNICAL ABSTRACT

Earthquake-induced ground failure and subsidence can cause considerable damage to coastal infrastructure. During the 1999 Kocaeli earthquake ($M_w$=*7.4*) in Turkey, coastal failures, subsidence, and sea inundation were observed. These failures were particularly concentrated along the margins of Izmit Bay and Lake Sapanca, in pull-part basins created by stepovers in the fault rupture.

Geotechnical site characterization, geologic mapping, liquefaction evaluation, and slope stability analysis were carried out to identify the principal contributing factors of the coastal failures and sea inundation. Results from this study indicate that both liquefaction and tectonic subsidence contributed to the failures and sea inundation within the pull-apart basins. Most of the liquefaction sites were situated at the prograding nose of active delta fans, where the presence

of steep slopes coupled with the loose sediments found within young active delta fan deposits resulted in liquefaction-induced slope failures and sea inundation. Liquefaction in other coastal deposits outside the actively prograding delta fans caused limited lateral spreading and only minor sea inundation. Outside of the delta fans, where soils were not liquefiable, tectonic subsidence associated with normal faulting was the cause of the observed sea inundation. Generally, the tectonic subsidence caused the most severe sea inundation (greater than 100 m of shoreline retreat).

The results of this study show that there is a strong correlation between geologic setting and ground failure susceptibility. Pull-apart basins at stepovers in strike-slip faults can cause large areas of tectonic subsidence and inundation. This subsidence causes significant damage for facilities located close to the shore. Geologic mapping is necessary to identify areas susceptible to tectonic coastal subsidence so that facilities can be sited appropriately. Delta fans are highly concentrated within pull-apart basins because of the nature of the pull-apart mechanism. Downdropping caused by this fault-induced extension transforms the basin into a depocenter for sediments. The depositional process within delta fans results in loose sediments, which make them very susceptible to liquefaction. The steep slopes (about 20 degrees) that exist at the nose of a delta fan because of the soil deposition process are less stable than adjacent areas with flat slopes. As a result, more intense ground failure (ground cracking and slope failures) is observed in these steep areas. Thus, development on delta fans may result in dramatic losses within seismically active regions unless precautions are taken.

## NON-TECHNICAL SUMMARY

Earthquake-induced ground failure and subsidence can cause considerable damage to coastal infrastructure. During the 1999 Kocaeli earthquake in Turkey, significant ground failure and damage were observed in coastal areas, and were particularly concentrated in stepovers of the fault rupture. Investigations indicate that ground failure and subsidence occurred due to (1) liquefaction of loose, sandy soils and (2) faulting along the coastline. Liquefaction was concentrated along delta fans at the mouth of creeks, while subsidence occurred within stepovers of the fault rupture. In some places, liquefaction and tectonic subsidence were both present, causing even more intense damage. The results from this study can be applied to many sites in California, where critical facilities have been constructed in coastal areas near fault stepovers.