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Seismic Rehabilitation of Coastal Dikes by Sheet-pile Enclosures

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ABSTRACT

Past experience has shown that by far the most widespread source of earthquake-induced damage to coastal dikes and embankments has been liquefaction of the loose, saturated, sandy foundation soils that often prevail throughout the marine environment. In this paper, the potential of using sheet-pile walls for mitigating the adverse effects of foundation liquefaction on overlying coastal dikes-embankments is investigated through a series of heavily instrumented, dynamic centrifuge physical modeling tests. Mechanisms of earthquake-induced marine foundation liquefaction and associated hazards on a typical dike section are discussed based on the recorded dynamic response. The effectiveness of underground sheet-pile walls as retrofit is evaluated based on additional modeling tests.

INTRODUCTION

Recent major seismic events such as Loma Prieta 1989, Kobe 1995 and Izmit 1999 continue to demonstrate the damaging effects of liquefaction-induced loss of soil strength and associated damage to coastal structures. The most widespread source of earthquake-induced damage to coastal dikes and embankments has been liquefaction of the loose, saturated, sandy foundation soils that often prevail throughout the coastal environment. Seismically induced high pore pressure or liquefaction leads to a reduction in stiffness and a loss of shear strength in the foundation soil, resulting in ground failures and soil settlement as well as increased lateral pressures on retaining walls and a loss of passive resistance against walls and anchors. Soil liquefaction has caused damage to coastal facilities (e.g., port and harbor) during numerous past earthquakes in the form of (a) deformation and failure of dikes-embankments; (b) lateral sliding, rotation, settlement and deformation of retaining structures and quay walls, and associated lateral spreading and settlement of the wall backfill materials; (c) buckling, yielding and fracture of pile supports at piers and wharves; (d) disruption of crane operations due to displacement of crane rails resulting in buckling and yielding of crane legs and portal frames, and overturning of cranes; (e) excessive settlement and cracking of pavements in storage yards and access roadways; and (f) damage to buried pipelines (ASCE, 1998). The economic losses associated with damaged port structures and the suspension of port operations due to earthquake-induced damages have been substantial. Among numerous devastating earthquakes, Kobe 1995 has set the record for causing the most damage to coastal and port structures, with estimated repair costs around $5.5 billion (CKPHB, 1997) and costs due to port downtime during the first 9 months following the earthquake estimated at $6 billion (PHRI, 1996).

This paper concerns itself with the foundation liquefaction-induced deformation and failure of coastal earth dikes-embankments. Experience had demonstrated that even at modern ports, embankments have been susceptible to earthquake-induced damage. Liquefaction of the underlying foundation soils often appears as the predominant cause of earthquake-induced failures of existing embankments and associated damage to waterfront components (ASCE, 1998). The seismic performance of waterfront structures such as earth embankments is a key issue in the evaluation of the unimpeded operations of the port systems and affiliated facilities following earthquakes. The widespread economic consequences of earthquake-induced damage to waterfront structures and required serviceability of port components after earthquakes highlight the need for an improved understanding of failure mechanisms and ways of remediation.

This paper briefly presents and analyzes the experimental results from a series of highly instrumented, dynamic centrifuge model tests performed to investigate the seismic behavior of nonliquefiable earth embankments resting on liquefiable, loose, clean, sandy marine deposits. Documented are the characteristics of the dynamic response of both embankment and foundation soil under a series of moderate to strong base motions. Evaluated, through additional model tests, is the potential for using sheet-pile walls for foundation enclosure with and without toe area surcharge as liquefaction countermeasure retrofit techniques near existing embankments. The model response was monitored by numerous accelerometers, pore pressure transducers and displacement gages. Currently, such test results offer a valuable alternative to an actual full-scale dynamic response, for which data are virtually nonexistent.

We first briefly discuss some of the liquefaction countermeasure methods that may be applicable to existing coastal embankments, and present equipment and experimental methods used for the model testing. This is followed by the test results with corresponding comparisons and discussions.

LIQUEFACTION COUNTERMEASURES IN COASTAL ENVIRONMENT

Various ground-treatment strategies can be used to mitigate the liquefaction hazards in the coastal environment. Ground improvement against liquefaction hazards can be divided into 4 main categories: densification, drainage, solidification and inclusions. Presented below are brief overviews for each of these remediation

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