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Recorded seismic response of the Samoa Channel Bridge-foundation system and adjacent downhole array

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ABSTRACT

A large set of earthquake records from the highly instrumented Samoa Channel bridge-ground system has been compiled and made available by the California Geological Survey. During six seismic events, more than 30 data channels have been documenting the seismic response of the bridge, abutments, and adjacent ground surface. Of special interest is the response of one of the bridge piers with records at the deck level, pile cap and within the underlying pile foundation. Response of this pile foundation is compared to that of the ground as documented by the nearby Eureka geotechnical downhole array. In this paper, records from the strongest to date 2010 Ferndale earthquake (PGA of about 0.16 g), along with other available low-amplitude events (2007–2014) are employed to evaluate the ground, pile foundation, and overall bridge seismic response. Spatial variation of the recorded motions is examined. Linear and nonlinear response of the ground and the bridge are assessed using system identification techniques. During the strong shaking phase of the 2010 Ferndale Earthquake, a clear and significant stiffness reduction was observed in the column as well as in the foundation of the instrumented pier.

1. Introduction

For over two decades, strong motion sensors have been deployed on California bridges and nearby free-field/downhole sites [1] through the joint efforts of the California Department of Transportation (Caltrans) and the California Geological Survey (CGS). As of 2013, 65 highway bridges, 13 toll bridge structures and 38 downhole geotechnical arrays have been instrumented in California [2–4].

The recorded data sets along with system identification techniques are permitting the evolution of further insights into the involved response mechanisms [5–8]. For instance, the seismic characteristics of the heavily instrumented Meloland Road Overpass have been evaluated using a number of different assessment methodologies [7,9–11]. Response of the I-10/215 Northwest Connector during the Landers and Big Bear earthquakes was evaluated [12,13] based on an extensively deployed strong motion instrumentation network. With such invaluable recorded data sets, relative bridge displacements, modal frequencies, and mode shapes can be identified [14–17]; and our understanding of the involved soil-structure interaction (SSI) effects has been further advanced [18–26].

More recently, accelerometers within bridge pile foundations are being deployed. As of 2014, eight bridges include such instrumentation, along with a nearby geotechnical downhole array (the Benicia-Martinez East Bridge, the Benicia-Martinez West Bridge, the Carquinez Bridge West Span, the Oakland – SF Bay Bridge/East, the San Francisco - Bay Bridge/West, the San Rafael Bridge, the Samoa Channel Bridge and the Eureka Channel Bridge). Among those, only the Samoa Channel Bridge and the Eureka Channel Bridge have multiple earthquake records available, varying in peak ground acceleration, epicentral distance, shaking duration, and frequency content bandwidth. The recorded bridge, deep foundation, and adjacent downhole-array seismic motions provide a unique opportunity for documenting and analyzing the associated salient ground-foundation-structure response mechanisms.

In this paper, seismic response of the instrumented Samoa Channel Bridge and the closely neighboring Eureka geotechnical array is investigated. Time history response along the bridge deck and the underlying ground is presented. Performance of the bridge structure and the effects of local site geology during this earthquake are discussed. Response of the instrumented Pier (S-8) and its foundation is closely studied. Focus is placed on the bridge seismic response during the Ferndale Earthquake of January 9, 2010 which resulted in a moderate but substantial level of earthquake excitation (PGA of about 0.16 g). As a reference, comparisons are made with the other available

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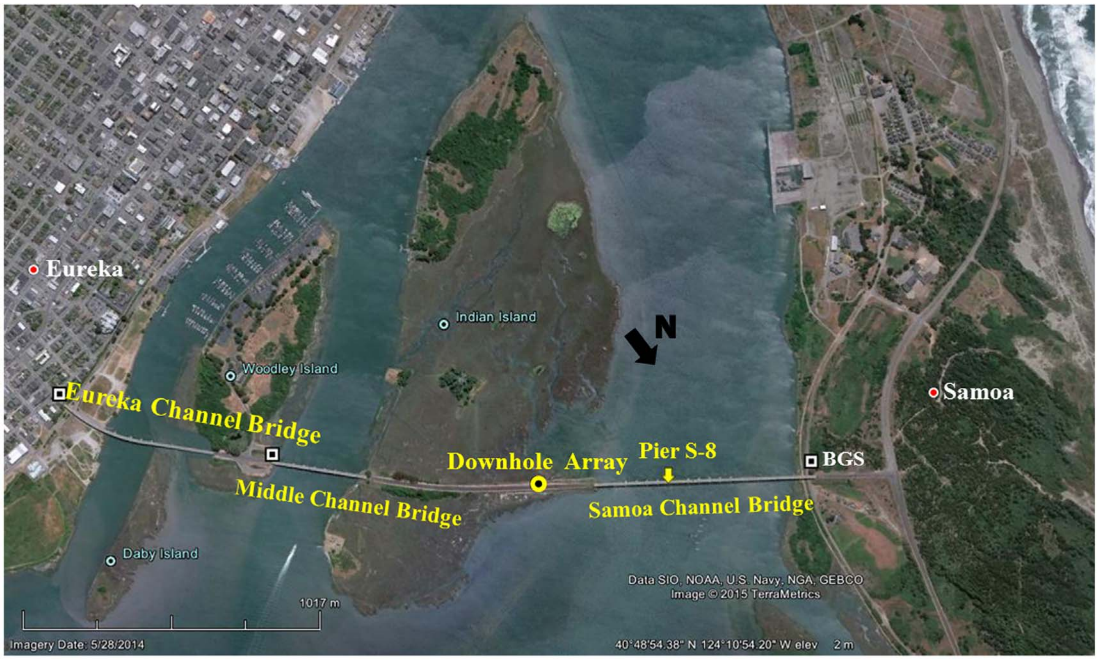

(a)

(b)

Fig. 1. Bridge configuration: (a) Samoa Channel Bridge, geotechnical downhole array, Middle Channel Bridge and Eureka Channel Bridge (Map Data @2015 Google) and (b) photo of the Samoa Channel Bridge (http://www.strongmotioncenter.org).

low amplitude seismic motions. Spatial variation of the recorded motions is examined. Resonance parameters are identified to describe the behavior of the downhole array site, the bridge super-structure, and the overall soil-foundation-structure system. The salient characteristics of linear and nonlinear response of the site, the bridge, and the foundation are highlighted and analyzed.

2. Instrumentation at the Samoa Channel Bridge and adjacent downhole array

2.1. Bridge configuration

The Samoa Channel Bridge connecting the Samoa Peninsula and Indian Island (Fig. 1) is one of three bridges crossing the Humboldt Bay in Eureka, California. It was designed in 1968, constructed in 1971, and since has undergone a seismic retrofit that was completed in 2006. Retrofit details along with soil boring data at the site are presented in Caltrans [27,28].

This 20-span bridge is 764 m long and 10.4 m wide (Fig. 2). The superstructure consists of a cast-in place reinforced concrete deck with four precast, prestressed concrete I-girders. As shown in Fig. 2, there are eight separation joints along the bridge superstructure. The bridge I-girders are supported on 19 concrete single column piers and seat-type abutments. The piers and abutments are numbered S-1 through S-21 from the Indian Island side to the Samoa Peninsula side (Fig. 2). Significant soil profile variability can be seen as depicted in Figs. 2 and 3.

The abutments and piers were supported originally on pile groups consisting of driven pre-cast prestressed concrete piles. Referenced to the mean sea level (MSL), elevation of the underlying ground surface (mudline) varies from −15.8 m below Pier S-8 to +0.9 m at Pier S-20 (Fig. 2). Eleven pile groups (from S-3 to S-13) have a pile cap located above the mudline with a maximum free span of 16.72 m (up to the pile cap base) at Pier S-8 (Fig. 2 and Fig. 4).

The seismic retrofit work completed in 2006 included (Fig. 4): i) strengthening of the foundations by installing additional cast-in-steel shell (CISS) piles (e.g. 6 additional 1.52 m diameter, 19 mm shell thickness piles at Pier S-8), ii) enlarging the pile caps to cover the new piles, and iii) encasing the original bridge columns in reinforced concrete (RC) jackets.

2.2. Samoa Channel Bridge instrumentation

The Bridge is heavily instrumented with over 30 accelerometers (deployed mostly in 1996). Side view and deck level plan view of the bridge instrumentation are shown in Fig. 2, where sensor locations are