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Assessment of the Samoa Channel Bridge-foundation seismic response

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ABSTRACT

Recorded earthquake motions from the extensively instrumented Samoa Channel Bridge provide valuable information on the mechanisms of structural response during seismic excitation. Using this data, system identification techniques are employed to derive salient response characteristics of the bridge system and its foundations. For that purpose, Finite Element (FE) modeling is employed along with the optimization software framework SNOPT, to study the transverse-direction bridge response. Records from the strongest to date 2010 Ferndale earthquake (PGA of about 0.16 g), along with five other low-amplitude shaking events (2007–2014) are employed to evaluate the bridge-ground-foundation-system behavior. As such, the FE model for this system is calibrated using the recorded data. On this basis, estimates of the column and foundation lateral stiffness during the low amplitude and the strong shaking phases of seismic response are derived. Reductions in the column and foundation stiffness as a function of response amplitude are clearly observed. Overall, the reported investigation highlights the significance of seismic instrumentation as a valuable tool to provide insight into the behavior of actual structure-ground-foundation systems.

1. Introduction

Dynamic response of the ground and the supporting foundations has a significant influence on the overall seismic behavior of the bridge structure. In order to gain insights into the involved mechanisms, dynamic field testing investigations were undertaken (e.g., [11,12,25,27,41]). In addition, effects of the soil, abutments, and pile foundations have been studied using available seismic records [15,23,45,47]. For instance, the seismic characteristics of the heavily instrumented Meloland Road Overpass have been evaluated using a number of different assessment methodologies [29,34,46]. Response of the I-10/215 Northwest Connector during the Landers and Big Bear earthquakes was evaluated based on an extensively deployed strong motion instrumentation network [19,20]. With such invaluable recorded data sets, relative bridge displacements, natural frequencies, and mode shapes can be identified [2,28]; and our understanding of the involved soil-structure interaction (SSI) effects has been further advanced [9,10,35-40].

In this vein of research, available seismic records at the Samoa Channel Bridge (Table 1) provide a unique opportunity for documenting and analyzing the salient ground-foundation-structure response mechanisms. In our study, insights into the characteristics of soil-structure interaction (SSI) are obtained based on these actual full-scale seismic performance data sets [43].

For that purpose, Finite Element (FE) modeling is employed to represent the bridge structural elements and configuration. The model stiffness properties are identified on the basis of matching the recorded seismic response. Data from one of the bridge piers, instrumented along its height from the mudline to the bridge deck, is addressed first so as to gain insights regarding flexural rigidity of the column and the underlying pile-group foundation. Thereafter, a FE model of the entire bridge is developed, with foundation springs at each column base (at the pile cap locations). An optimization technique is employed to estimate these foundation spring values.

Overall, the computed bridge seismic response shows reasonable agreement with the recorded earthquake data. Reduction in lateral stiffness due to nonlinear response was noted during the strong shaking phase of the recorded 0.16 g PGA event. In this event, estimated flexural rigidity of the instrumented pier was as low as about 60% for the column and 50% for the foundation, of that during the low-amplitude shaking time windows. Generally, the results of this research are of significance for validation and refinement of deep-foundation soil-structure interaction analyses [3,17,18,21].

2. Bridge description

The Samoa Channel Bridge [4,6] connecting Samoa Peninsula and Indian Island was designed in 1968, built in 1971, and underwent a

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Table 1
Recorded earthquakes at the Bridge site (arranged by order of peak acceleration).

Earthquake	Epicentral distance (km)	Transverse-direction peak acceleration (g)	
		Ground	Bridge
Ferndale 2010[a] (M_w = 6.5)	53.8	0.158	0.665[b] 0.216[c]
Trinidad 2007 (M_L = 5.1)	63.8	0.025	0.063
Ferndale 2014 (M_w = 6.8)	81.3	0.019	0.069
Trinidad 2008 (M_w = 4.6)	40.2	0.016	0.026
Willow Creek 2008 (M_w = 5.4)	56.6	0.014	0.032
Ferndale 2007 (M_w = 5.4)	62.4	0.011	0.022

[a] The January 2010 Ferndale Earthquake will be referred to as "0.16 g PGA event" in this study.
[b] large peak acceleration due to spikes emanating from interaction at the separation joints [26, 32]
[c] Estimated after elimination of spikes using a band-pass filter [43].

seismic retrofit between 2002 and 2006. This 20-span bridge is 764 m long and 10.4 m wide (Fig. 1) consisting of a cast-in place reinforced concrete deck (16.5 cm in thickness) resting on four precast, prestressed concrete I-girders. The bridge I-girders are supported on 19 hammer-head-cap single-column piers and concrete seat-type abutments. Free span length ranges from 36.58 m to 68.58 m. Between Pier S-8 and Pier S-9, there is a 50.29 m long prestressed precast concrete drop-in span.

Height of the single hexagonal concrete columns (Fig. 1) ranges from 6.19 m at Pier S-3 to 12.93 m at Pier S-14 (Table 2). Originally, the abutments and columns were supported on driven pre-cast prestressed concrete pile-group foundations (Fig. 1). Referenced to the mean sea level (MSL), elevation of the mudline varies from −15.8 m below Pier S-8 to +0.9 m at Pier S-20 (Fig. 1). Pile groups from S-3 to S-13 have a pile cap located above the mudline with a maximum elevation of 16.72 m at Pier S-8 (Fig. 1 and Fig. 2).

As designed in 1968 [6], pile groups under the main span (below Pier S-8 and Pier S-9) consisted of 8 (2 × 4) prestressed cylindrical concrete-shell piles (diameter D = 1.37 m), concrete filled along the entire length, with a 2D center to center spacing (Table 2). At the reinforced concrete seat-type abutments S-1 and S-21, there are 12 square-shaped concrete piles (D = 35.6 cm), with 7 batter piles (at a 1:3 orientation) in the front row and 5 vertical piles in the back. To aid in monitoring seismic response, the bridge has been heavily instrumented with a total of 33 sensors as shown in Fig. 1. For the purpose of this study, data sets from six different earthquakes (Magnitudes in a range of 4.6–6.8) are employed (Table 1).

3. Original construction and seismic retrofit

The Samoa Channel Bridge is located in an area of complex interaction among three tectonic plates (North American, Pacific, and Gorda) with high seismic activity. Minor damage was reported after earthquakes in 1992 and 1994. Some repairs and subsequently an initial seismic retrofit were completed prior to 1997 [6].

In order to further strengthen the bridge, an additional extensive seismic retrofit program was carried out [6,38]. This retrofit work included (Fig. 2): i) strengthening of the foundations by installing additional cast-in-steel shell (CISS) piles (e.g. 6 additional 1.52 m diameter and 19 mm shell thickness piles at Pier S-8, as shown in Table 2), ii) adding or enlarging the pile caps to cover the new piles, and iii) encasing the bridge columns in reinforced concrete column jackets to improve ductility. During this structural retrofit, accelerometers were installed (Fig. 2) inside one of the Pier S-8 retrofit CISS piles at two different elevations (−10.36 m and −16.46 m).

4. Site description

At this location, nineteen borings were drilled to a maximum depth of about 34 m below MSL [4]. Soil profile at the Samoa Channel Bridge based on the log of these borings (Fig. 1), reveals that the site is mantled

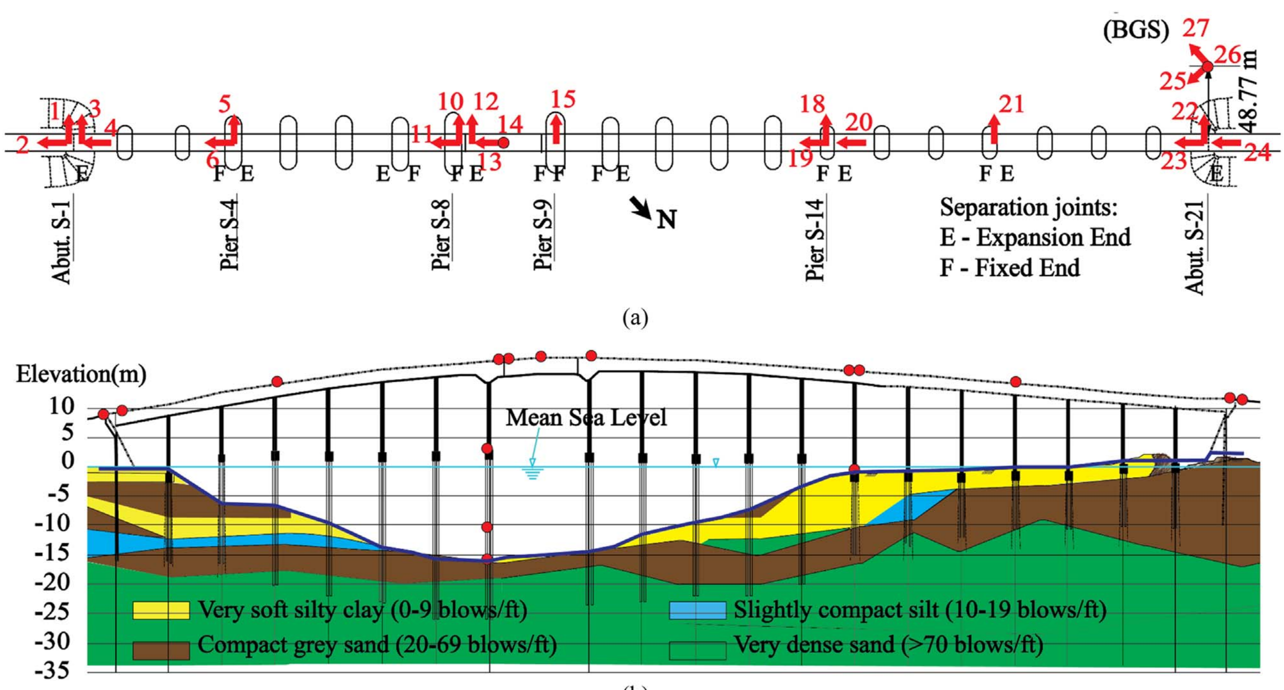

Fig. 1. Samoa Channel Bridge Instrumentation Layout: a) Plan view (http://www.strongmotioncenter.org), and b) bridge-ground side view.