Engineering Structures 98 (2015) 174–185

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

# Expected seismic performance of irregular medium-span simply supported bridges on soft and hard soils

J.M. Jara *, J.R. Reynoso, B.A. Olmos, M. Jara

*Civil Engineering School, University of Michoacan, Morelia, Mexico*

ARTICLE INFO

*Article history:*
Received 6 October 2014
Revised 17 January 2015
Accepted 18 April 2015

*Keywords:*
Pier irregularity
Seismic response of irregular bridges
Damage index
Bridges on hard and soft soil conditions

ABSTRACT

This paper presents the parametric study of irregular RC bridge structures subjected to strong seismic records. We determine the expected damages and the concentration demands on short piers of bridges with columns of unequal height located on soft and rigid soil sites. Medium length span bridges are analyzed using the most common structural configurations built in many countries with several height pier configurations. The structures were subjected to strong seismic ground motions recorded on soft and hard soils of earthquakes generated at subduction seismic sources. The parameters of interest in the study are the strength and stiffness characteristics of the substructure and the influence of the dynamic characteristics of the seismic records. The parameter combinations produced more than three hundred 3D non-linear time history analyses conducted with the Perform-3D software. Based on the evaluation of damages indexes, we determine the pier expected damages and the importance of the soil type, on the behavior of irregular pier bridge substructures. It is also quantified the impact of the pier configuration in the global behavior of the bridges and the influence of the shortest pier in the expected damages of the other piers. In most of the cases, the piers adjacent to the tallest piers of the bridge were the elements more affected by the irregularity.



## 1. Introduction

The height irregularity of bridges produces force demand concentrations in short piers and it is responsible of seismic damages observed in different countries. The substructures composed by piers with different heights conduct to strong lateral stiffness irregularities and several studies relate it with the observed seismic damages of bridges in China, Japan, New Zealand, Chile and other countries [2,8–10,13,16,17,27]. Despite that many countries have an important number of medium length span bridges with irregularity in the piers' height, there are limited number of studies quantifying the irregular configuration and the influence of the soil type.

Typical superstructures of medium length RC bridges are mostly composed of prestressed AASHTO concrete beams or I shape steel girders supported on neoprene bearings. The substructure in most of the cases consists of abutments and piers with one or more RC columns. These bridges usually cross rivers or topographical conditions that produce substructures with columns of unequal heights.

Several researchers have conducted studies of bridges with irregular substructures; some of them were focused in the required actions to make more regular the seismic response and to evaluate the currently design procedures [22]; other studies determine the applicability of simplified models to model bridges with irregularities in the frame of displacement-based design approaches [24]. The effects of the lateral stiffness irregularity in continuous bridges have been also studied, with a proposal of the column stiffness required to improve the seismic response [25]. The influence of soil–structure interaction in the displacement and force demands of irregular bridges have been analyzed by Kappos [14], and the importance of the strength of pier cross sections in irregular bridges is discussed in [26]. In addition of the pier stiffness to characterize irregular bridges, the use of fragility curves is proposed by Akbari [2]. Irregular bridges usually have out of phase deck movements which eventually cause unseating problems: this topic in an irregular bridge is discussed by Thakkar [23]. The use of isolation systems to retrofit irregular bridges and to produce a more regular behavior is also another topic of study [11,20]. Experimental tests of irregular bridges focused on rehabilitation techniques of heavily damage specimens have also been studied [3]. However, none of the previous studies discuss the influence of the type of accelerogram in the bridge response, nor the relation of the dynamic

* Corresponding author. Tel./fax: +52 4433 041002.
*E-mail address:* jmjara70@gmail.com (J.M. Jara).

http://dx.doi.org/10.1016/j.engstruct.2015.04.032
0141-0296/

characteristics of the records with the damage level and the limit states of behavior.

This study presents the effect of the substructure irregularity on the pier demands and expected damages of medium length RC bridges subjected to accelerograms recorded on hard and soft soils. We conduct a parametric study to investigate the contribution of the seismic record type on the seismic response of a regular bridge and three typologies of irregular bridges. The 3D non-linear models were subjected to a suite of scaled seismic signals of earthquakes occurred at the subduction zone in the Pacific Coast of Mexico.

## 2. Bridge models

To conduct the analyses we chose three possible bridge configurations selected after a study performed at the University of Michoacan. The study assessed the seismic vulnerability of medium-length reinforced concrete (RC) bridges in Mexico [12]. The first part of the study presents a general description of the superstructure and substructure characteristics of more than 200 bridges. Based on that information, we selected the most common longitudinal schemes that conduct to the three typologies used in this work. Additionally, other authors [7,14,24] have also worked with similar substructure irregularities in other countries.

### 2.1. Bridge description

The superstructure is composed by a 0.18 m thick RC slab supported by eight AASHTO Type IV prestressed beams, placed at every 1.3 m. Rectangular diaphragms of 0.38 $\times$ 0.77 m are located in each third and each end of the span. The piers consist of three circular columns with a diameter in the range of 1.2–1.7 m, as function of the pier height. The prestressed beams were modeled with a concrete compressive strength of $f'c$ = 34.3 MPa and the rest of the structural elements with $f'c$ = 24.5 MPa. Each beam is simple supported on 41 mm and 57 mm thick laminated elastomeric rubber bearings, which are typical supports of this type of bridges.

The substructure configuration produces a cantilever behavior of the piers in longitudinal direction and a frame type behavior in transverse direction, characterized by a lateral deformed shape with an inflexion point between the column ends.

### 2.2. Bridge irregularity type A

The selection of the bridge parameters characterizes typical schemes of variations in pier heights of a large number of medium length span bridges. The models consist in five and six-span simple supported bridges with three irregular pier height configurations. Fig. 1 shows the first model with two central piers of the same length and the other two shorter. The bridge is composed by five simple supported 30 m long spans, with four piers and two abutments. The superstructure in all models has the same geometrical and mechanical characteristics.

Four bridge models were created varying the $h_2$ and $h_3$ pier heights (Table 1). Model A1 is the 5 m high regular bridge model whereas model A4 is the model with more pronounced difference between the central and lateral pier heights. The last column of the Table 1 displays the ratio between the tallest and the shortest pier height in each model.

**Table 1**
Pier heights of the type A bridge models.

| Model | $h_1$ (m) | $h_2$ (m) | $h_3$ (m) | $h_4$ (m) | $h_2/h_1$ |
|---|---|---|---|---|---|
| A1 | 5 | 5 | 5 | 5 | 1.0 |
| A2 | 5 | 7.5 | 7.5 | 5 | 1.5 |
| A3 | 5 | 10 | 10 | 5 | 2.0 |
| A4 | 5 | 15 | 15 | 5 | 3.0 |

### 2.3. Bridge irregularity type B

Fig. 2 shows the longitudinal view of the bridge model with irregularity type B, which is the base of the following six models. Again, the bridge is composed by five simple supported 30 m long spans. The irregularity of this model consists in the height difference between pier 3 and the rest of the bridge piers.

The column height of pier 3 varies in the range of 7.5–15.0 m, while other column heights fluctuate between 5.0 m and 7.5 m. Table 2 displays the pier lengths of each model and the height ratio between the piers 3 and 1.

Models B5–B7, B9 and B10 are irregular models with three equal height piers and one pier (number 3) taller. The model B8 was included to analyze another regular model with higher columns (7.5 m), in addition to the model A1 presented in Table 1.

### 2.4. Bridge irregularity type C

The last group of models is composed by six simple supported 30 m long spans with a gradual height irregularity. Fig. 3 displays the bridge configuration that increases the pier height from the left abutment to the center of the bridge length (pier 3) and decreases to the right symmetrically. The length of pier 4 is in the range of 10–15 m and the rest of the piers are in the range of 5–10 m (Table 3). This model is a six-span bridge to locate the tallest pier in the middle of the bridge length.

## 3. Seismic demand

The seismic action for the nonlinear analyses consist of twelve seismic records from de Mexican Data Base of Strong Earthquakes [21]. The accelerograms correspond to four subduction earthquakes occurred along the Pacific Coast of Mexico (Fig. 4). Eight accelerograms were recorded on hard soils and four on soft soils. The former belongs to seismic stations relatively close to the Pacific Coast and the latter are accelerograms recorded in seismic stations far away from de epicenter in soft soils of Mexico City.

Table 4 presents the main characteristics of the ground motions, where Ms is the surface wave magnitude. The focal depth and geographical location situate the movements as part of the subduction process in this region.

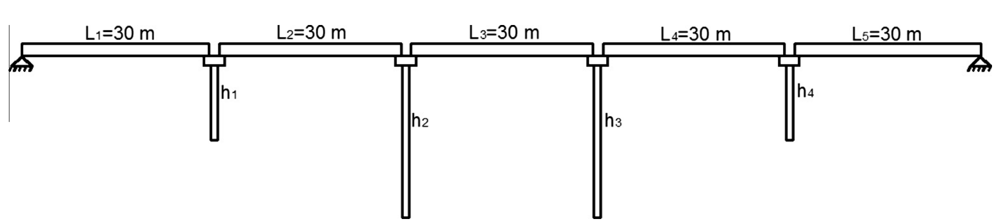


**Fig. 1.** Type A bridge model.