Evaluating the seismic behavior of reinforced concrete piers of bridges by using fibre plastic hinge elements

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ABSTRACT
Concrete is widely used for bridge construction. Defining fibre elements in the finite element simulation process can give detailed properties of reinforced concrete elements and lead to improving the accuracy of the results. In this study, the behavior of concrete piers is discussed by using nonlinear static analysis under the effect of constant load pattern with definition of fibre plastic hinges. Defining nonlinear materials and plastic hinges results in more accuracy in stiffness distribution. Consequently, the shear capacity of the concrete piers is reduced by uneven stiffness distribution.

Keywords: Structural Design, Reinforcement, Modelling, Bridge, Fibre Hinge, Pushover Analysis

1. INTRODUCTION

Different factors such as versatility, aesthetic appearance and economic issues have led to more commonly use of concrete bridges compared to other types of materials. The possibility of building concrete bridges in long-spans or building in different forms such as single pier at each support make the bridges cost-effective and scenic [1,2].

Bridges are usually used as flyovers or natural cut crosses and they play a vital role in communication and everyday life. As one of the main elements of road transport, studying the seismic behavior of these structures under the effect of earthquake is essential. When an earthquake occurs, bridges play a unique role in linking roads and highways to send aid.

Concerning bridges with reinforced concrete piers, the shear capacity of the piers is one of the crusial factors in structural design, especially under seismic loads. Therefore, proper understanding of the behaviour of these elements is of great importance. In order to achieve appropriate accuracy, fibre plastic hinges can be defined in cross-sectional area. Using this definition, the relation between the biaxial moment and axial force, and distribution of non-linear behavior of the section is evaluated by particular stress-strain relationship in every fibre element. In this study the seismic behavior of reinforced concrete bridge piers are studied by defining fibre section features under nonlinear static analysis method [2,3].

2. INVESTIGATED BRIDGES

Nine reinforced concrete bridges are considered for the parametric study. This set includes both short and long bridges with 180 m and 280 m length, with pier height ratios of 1, 1.5, 2, 2.5 and 3, corresponding to a height of 7.5, 11.25, 15, 18.75 and 22.5 meters, respectively. The spans in short bridges are 40, 50, 50 and 40 meters and the spans in long bridges are 40, 50, 50, 50, 50 and 40 meters, respectively. These bridges are designed by Alvarez [4,5], at European School for Advanced Studies in Reduction of Seismic Risk by using displacement-based design method.

2.1 Bridge specifications

Material properties and some characteristics of the bridges are introduced in tables 1 and 2.

Table 1– Materials properties.

Steel rebar			
Yield stress	455	Mpa	f_y
Modulus of elasticity	200000	Mpa	E_s
Diameter of longitudinal rebar	43	mm	d_{bl}
Concrete			
Compressive strength	40	Mpa	f_c'
Modulus of elasticity	30000	Mpa	E_c
Unit Weight	25	KN/m^3	W_c

Table 2– Some characteristics of considered bridges.

Bridges group	All bridges
Type	Regula/ irregular
pier diameter (m)	2
Number of longitudinal rebar	74
The percent of longitudinal rebar	3.42%

2.2 Bridge deck

The design process of the deck is based on avoiding non-linear behavior, so the response will be elastic. The deck dimensions are based on positioning two crossing lanes. A cross-section of the bridge is shown in Figure 1. The moment of inertia of the deck is $I_m = 45m^4$ and the torsional moment of inertia has been neglected [5].

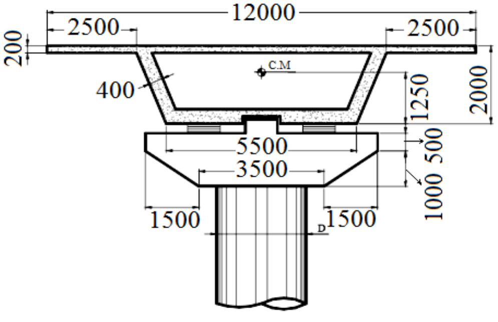

Figure 1– Cross section of the bridge [5].

2.3 Abutments

The equivalent linear springs are commonly used to show the deck constraints by abutment. In this study the spring stiffness is K_A = 75000 kN/m [5].

2.4 Fibre plastic hinges

By using finite fibre elements, it is possible to define reinforced concrete material properties more detailed and increase the accuracy of the results. By defining fibre hinge, it is possible to calculate the moment-curvature relationship in bending directions for different levels of axial loads during the nonlinear static analysis. The sriffness reduction due to concrete cracking, yielding in rebar and strain hardening can be applied to the fibre model.
Sufficient number of fibre elements should be considered to achieve adequate accuracy in the cross-sectional area. It is recommended that the section properties of the hinge such as area and moment of inertia would be within 5% of the gross section properties [6,7]. Some specifications of the fibre elements are presented in Fig. 2. Priestley-Park equation was used to calculate the length of plastic hinge, which is a popular model for reinforced concrete piers [8]:

$$L_p = 0.08L + 0.022 f_y d \quad (1)$$

Where L_p is effective length of the plastic hinge, L is the pier height, f_y is yield stress of the reinforcement and d is diameter of the reinforcement.

Table 3– Fibre section properties

	Fiber	Main Section
Pier diameter (m)	2	
number of fibre elements	300	
Area (square meter)	1.4895	1.4417
Moment of inertia 33 (m^4)	0.2441	0.2033
Moment of inertia 22 (m^4)	0.2441	0.2033
Difference in area (percent)	0.04	
Difference in moment of inertia 33(Percent)	0.02	
Difference in moment of inertia 22(Percent)	0.02	

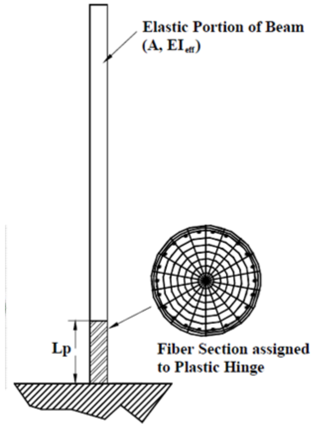

Figure 2 – Fibre hinge [9]

3. ANALYSIS METHOD

Nonlinear static analysis method under the effect of constant load pattern in transverse direction is used in this study. Pushover analysis obtains the response of the structure under lateral load pattern with monotonical increase.
The main product of this process is the diagram of base shear changes against the displacement of the control point, which is called structural capacity curve. Each point on the curve indicates a special type of structural damage. The entire process of cracking, plastic hinge formation and failure of structural components can be observed in the process [2].

4. RESULTS

The results are shown for two groups of short and long bridges in Fig. 3. The short bridge group with regular stiffness distribution have higher shear capacity compared to bridges with irrigularity. This indicates the higher strength of regular structures under applied loads. The capacity is reduced by increase in irregularity of stiffness distribution where the bridge 133 gives the highest irregularity and the lowest shear capacity. Furtheremore as illustrated in pushover analysis curves on the right side of Fig 3, the shear capacities of the reinforced concrete piers in long bridges are also reduced when the irregularity of stiffness distribution is increased. The bridge with caption 1،1.5،2،2.5،3 had the lowet shear capacity in this group.

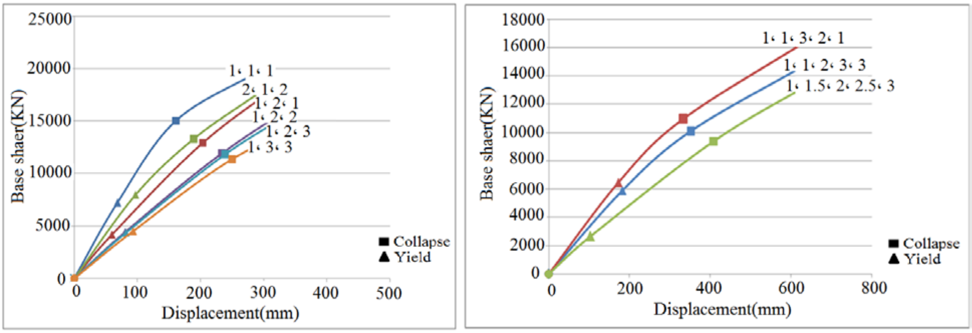

Figure 3 – Pushover analysis in transverse direction for short bridges (Left) and long bridges (Right), the curve numbers indicate the pier height ratios of the bridges as described in part 2.

Since there is a direct relationship between stiffness distribution and shear capacity, defining non-linear materials and fibre plastic hinges for the cross sections of reinforces concrete piers of bridges gives more accurate results.

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ISBN: 978-82-8208-056-9 ISSN: 0800-6377