Proc. of the 6th Intl. Symposium on Reliability Engineering and Risk Management (6ISRERM)
31 May – 1 June 2018, Singapore
Editor(s) Xudong Qian, Sze Dai Pang, Ghim Ping Raymond Ong, Kok-Kwang Phoon

SEISMIC BEHAVIOR OF STEEL BRIDGE PIERS WITH CORRODED DAMAGES

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Many steel structures have been faced the problem of deterioration in Japan. Severe damages will be caused in such deteriorated structures subjected to huge earthquake. It is necessary to secure safety of such structures against earthquakes. However, 2 dimensional horizontal behavior of seismic response of structures with damages by corrosion has been hardly researched. In this previous study, experiments intended for rectangular steel bridge piers, with damages by corrosion in the corners were conducted in order to evaluate 2-dimensional behavior. Therefore, the seismic response analysis by dynamic analysis was carried out in order to clarify the seismic response behavior of the steel pier damaged by corrosion using numerical analysis. As a conclusion, it is found that the seismic performance of steel bridge piers corroded greatly deteriorates. Especially, the analysis results in inputting two directional waves were different from the results in inputting one directional wave. So it is important to accurately understand the seismic performance of corrosion-damaged steel piers.

Keywords: steel bridge pier, corrosion, dynamic analysis, seismic behavior.

1 Introduction

Earthquakes such as Hyogoken-Nanbu Earthquake in 1995 and Niigata Chuetsu Earthquake in 2004 occurred in Japan in recent years. Furthermore, the 9.0-magnitude earthquake inflicted unprecedented damage in Tohoku region in 2011. Many steel structures in Japan were built in the period of rapid economic growth. Most of them have reached the age of aging in recent years. As such steel structures are designed according to the earthquake resistance standards of those days, the seismic performance is low. Damage of such as pier with a low seismic performance is concerned. Figure 1 shows corrosion in the corner of the steel bridge pier. It is important to secure the earthquake resistant safety of the superannuated steel structures during earthquakes. However, judging from a current Japanese financial status, the rebuilding of the steel structures is difficult. Therefore, it is necessary in order to extend its life to maintain corroded steel structures (Abe et al., 2007）. Studies on seismic behavior of steel bridge pier considering the influence of two horizontal directions have been carried out since Hyogoken-Nanbu Earthquake (Watanabe et al., 2000, Nagata et al., 2004, 2006, Goto et al., 2005, 2007, 2009, Aoki et al., 2007). However, studies of corroded steel bridge piers have not been conducted. Therefore, the seismic response analysis by dynamic analysis was carried out in order to clarify the seismic response behavior of the steel pier damaged by corrosion using numerical analysis.

Figure 1. Corrosion of steel bridge pier

2 Steel Bridge Pier for This Study

As a steel bridge pier constructed in design criteria before Hyogoken-Nanbu Earthquake, the T-shaped single-column steel bridge pier with rectangular twin-walled hollow sections shown in Figure 2 was assessed. Buckling parameters of this steel bridge pier is shown in Table 1. Since this steel bridge pier has been designed previously Hyogoken-Nanbu Earthquake, it found that these piers are inferior seismic performance.

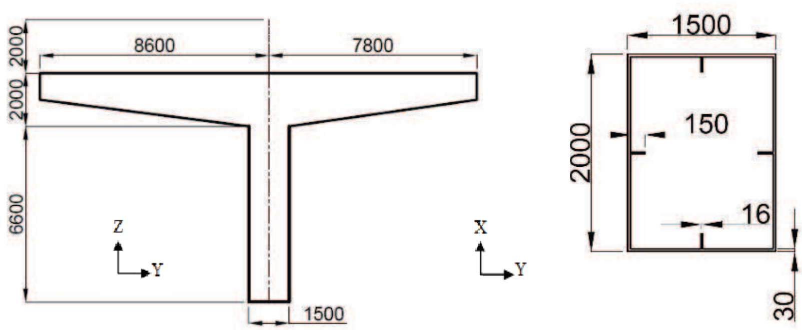

Figure 2. Steel bridge pier (unit:mm)

Table 1. Buckling parameters

	X direction	Y direction
Width-thickness ratio parameter *Rr*	0.511	0.685
Width-thickness ratio parameter *Rf*	0.584	0.688
Slenderness ratio parameter λ	0.346	0.433
Stiffness ratio of longitudinal stiffener γ/γ*	0.697	0.988

3 Analytical Model

In order to perform the parametric analysis, earthquake response analyses were carried out by using a general-purpose FEM code called ABAQUS. The discretization of steel bridge pier model is shown in Figure 3. Material properties, horizontal yield displacement δ_y and load H_y are shown in Table 2 and Table 3.

4 Case of Analysis

The list of analysis cases is shown in Table 4. For the model with corrosion damages, the corrosion rate in the thickness direction was set to 25% and 50%. Cross section view of a corrosion damaged model (for example, corrosion rate is 50%) is shown in Figure 4. The seismic waves used in the analysis are JRT seismic waveforms observed at the JR Takatori station in the Hyogoken-Nanbu Earthquake. In this study, Analyses were performed with the magnitude of seismic waveform and the input direction of seismic wave.

Table 2. Material properties

Young's Modulus E(N/mm^2)	Yield Stress σ_y(N/mm^2)	Poisson's Ratio ν
2.00×10^5	325	0.3

Table 3. Horizontal yield displacement δ_y and load H_y

	X direction	Y direction
δ_y(mm)	60.5	81.1
H_y(kN)	3.89×10^3	3.34×10^3

Table 4. List of Analysis cases

Analysis cases	Corrosion rate(%)	The magnitude of seismic wave form	Input direction
KENZEN-10-y	0	1.0 times	Only Y direction
KENZEN-15-y		1.5 times	
b30f25-10-y	25	1.0 times	
b30f25-15-y		1.5 times	
b30f50-10-y	50	1.0 times	
b30f50-15-y		1.5 times	
KENZEN-10-xy	0	1.0 times	X and Y direction
KENZEN-15-xy		1.5 times	
b30f25-10-xy	25	1.0 times	
b30f25-15-xy		1.5 times	
b30f50-10-xy	50	1.0 times	
b30f50-15-xy		1.5 times	

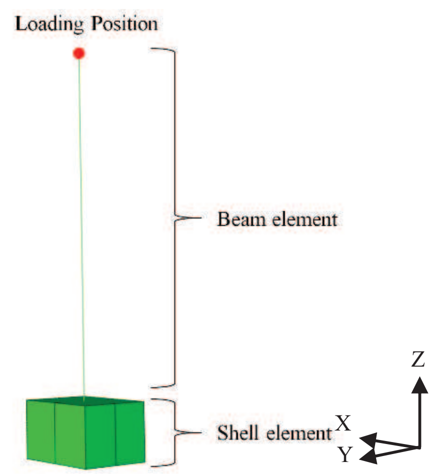

Figure 3. Analytical model

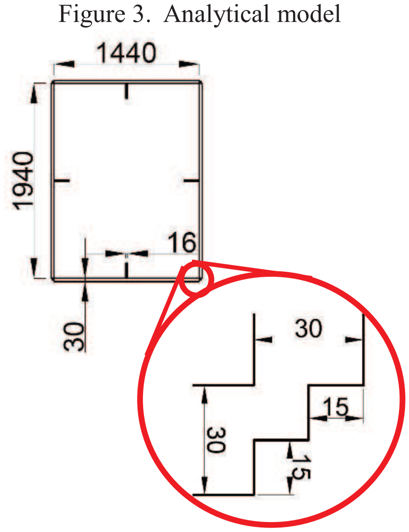

Figure 4. Cross section view of a model with corrosion damage (unit: mm)

5 Displacement-time Curves and Load-displacement Curves by This Analysis

Displacement-time curves obtained by the analysis are shown in Figure 5 (KENZEN-15-y, b30f50-15-y, b30f50-15-xy). In the analysis case with a corrosion rate of 50%, the maximum response displacement increased by about 7.4% compared with the sound analysis case. When large scale earthquakes occurred, it was revealed that corrosion damages advanced, the maximum response displacement was affected as compared with sound case. Load-displacement curves obtained by the analysis are shown in Figure 6 (KENZEN-15-y, b30f50-15-y, b30f50-15-xy). When comparing the results of maximum response displacement of KENZEN-15-y and b30f50- 15-y, the difference exceeds 50%. When changing from one direction to two directions and corrosion damage progressed, the result changes greatly. The magnification of maximum displacements are shown in Figure 7. As you can see, in the case of inputting 1.0 times waveforms, there is no big difference between these behaviors. However, in the case of inputting 1.5 times waveforms, a remarkable difference appeared in the results. The magnifications of maximum loads are shown in Figure 8. Large difference between these responses is observed only in the case of inputting in two directions with 1.5 times waveforms.

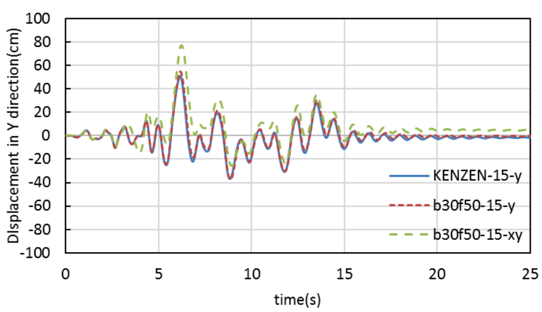

Figure5. Displacement-time curves
(KENZEN-15-y, b30f50-15-y, b30f50-15-xy)

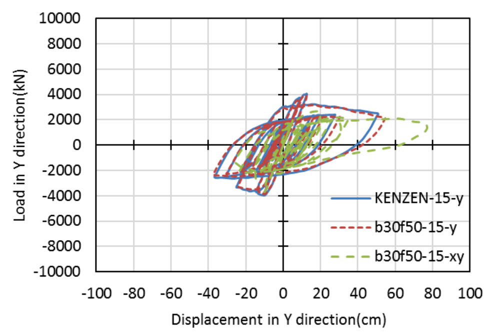

Figure6. Load-displacement curves
(KENZEN-15-y, b30f50-15-y, b30f50-15-xy)

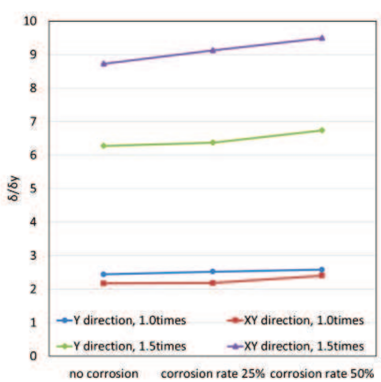

Figure 7. Plasticity rate of maximum displacement
(Y direction)

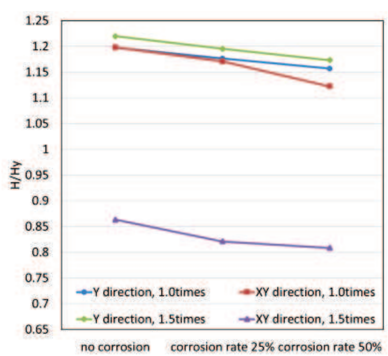

Figure 8. Magnification of maximum load
(Y direction)

(a) KENZEN-10-y (b) b30f50-15-xy

Figure 9. Buckling shape (KENZEN-10-y, b30f50-15-xy)

6 Evaluation of Buckling Shape

Buckling shape at maximum response displacement are shown in Figure 9(KENZEN-10-y, b30f50-15-xy). In the analysis cases where the earthquake waveform 1.0 times was input, there was no significant change in the shape of buckling. However, when the seismic waveform was input 1.5 times and in two directions, the shape of the local buckling changed significantly.

7 Conclusions

In this study, earthquake response analysis was performed to elucidate the seismic response behavior which is not clear to the steel pier with corrosion damaged. From the results of this study, it was found that two directions should be considered in order to know seismic performance and behavior during earthquake, especially for damaged pier. Therefore, earthquake resistance performance should be checked by inputting earthquake waveforms in two directions.

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