Yokohama-Bay Bridge Response Characteristics in the 2011 Great-East Japan Earthquake

Dionysius SIRINGORINGO
Research Assistant Professor
The University of Tokyo
Tokyo, JAPAN
dion@bridge.t.u-tokyo.ac.jp

Dionysius Siringoringo, born 1976, received his PhD in civil engineering from the Univ. of Tokyo in 2005.

Yozo FUJINO
Professor
The University of Tokyo
Tokyo, JAPAN
fujino@civil.t.u-tokyo.ac.jp

Yozo Fujino, received his PhD in civil engineering from the Univ.of Waterloo Canada in 1977. He is a professor of bridge and structure, and the vice president of IABSE.

Summary

Yokohama Bay Bridge with the total span length of 860m (200-460-200) is the second longest span cable-stayed bridge in East Japan and one of the most densely instrumented bridges in Japan. On March 11, 2011, northeastern Japan was shaken by the Great East Japan earthquake and at the bridge location seismic intensity with PGA 1.40–2.50 m/s² was recorded. This paper describes response analysis of the bridge by focusing on the following subjects: 1) temporal and spectral analysis of the bridge responses, 2) system identification and observation of the changes in modal parameters with respect to earthquake amplitude, 3) performance evaluation of link-bearing connection –a seismic isolation device, during the earthquake and 4) post-earthquake field observation.

Keywords: *long-span bridge vibration***,** *cable-stayed bridge, seismic response, monitoring, 2011 Great East-Japan earthquake*

1. Introduction

Yokohama-Bay Bridge is a part of the Tokyo-Yokohama Bay Shore expressway link that connects Tokyo and Yokohama harbor area. The bridge is a continuous three-span cable-stayed with the total span length of 860m consisting of 460m center span and 200m side spans. At 14:46 on March 11, 2011, Japan was shaken by the Great East Japan earthquake (Mw 9.0). The largest earthquake ever recorded in Japan. Epicentre of the earthquake was about 398km away from the bridge, with the focal depth of 24km. The fault rupture consists of about 440km long from north to south and 230km wide area of northeast Japan, which means that the closest distance from the bridge to the rupture fault area is about 180km. Seismic intensity 5+ according to Japan Meteorology Agency (JMA seismic intensity), which is equivalent to scale VII in MMI, was recorded on the bridge location.

Table 1: Recorded accelerations and displacements during the main shock (March 11, 2011 14:47)

Sensor Code and Location	Max Acceleration [direction] (cm/s^2)	Max Displacement (cm)
S5R (Girder, mid of center-span)	51.14 [L],299.17[T], 194.25 [V]	19.6 [L],61.8[T],19.5[V]
S4 (Girder, quarter of center-span)	250.78 [T], 163.58 [V]	47.15 [T], 11.32 [V]
S2 (Girder, sidespan midpoint)	335.77 [T], 165.80 [V]	20.50 [T], 6.94 [V]
T1 (Top of tower P2)	252.99 [O], 635.94 [I]	25.00 [O], 54.60 [I]
T2 Top of tower P3	418.67 [O], 656.87 [I]	24.28 [O], 48.36 [I]
T3 (Middle of tower P2)	124.37 [L], 344.41 [T]	23.40 [L], 43.40 [T]
T4 (Middle of tower P3)	138.80 [L], 411.73 [T]	22.50 [L], 42.70 [T]
T8L(Footing of tower P3)	71.38 [L], 67.27 [T]	17.50 [L] , 18.00 [T]

Note: V: Vertical, L: Lateral, T: Transverse, O: Out-of-plane, I: In-plane

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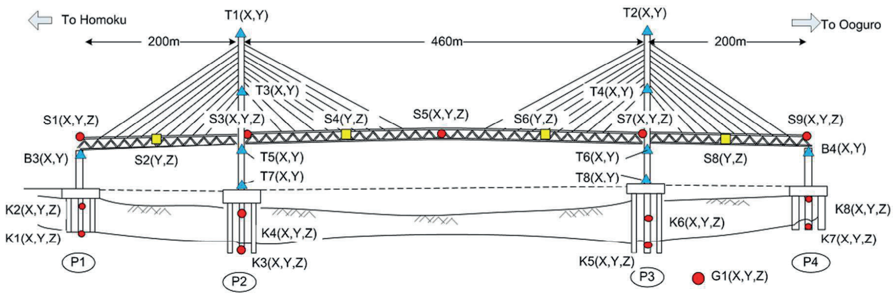

Fig. 1: Yokohama-Bay Bridge seismic monitoring system

2. Description of Seismic Responses Characteristics

The input excitations recorded on the bridge foundation are still below the design and seismic-retrofit ground motions. The bridge experienced intense shaking for about 10 minutes, but no structural damage was reported. A time-frequency analysis was conducted by wavelet transform of accelerations in transverse and vertical acceleration. In transverse direction, the scalogram of acceleration shows frequency peak at the initial response appears at 0.29Hz. The frequency increases and reaches up to 0.32Hz during the largest excitation before later decreases to 0.27Hz near the end of response. On contrary for the vertical acceleration, the frequency peak at the initial response appears at 0.34Hz. The frequency decreases slightly to 0.32Hz during the largest excitation, and increases to 0.34Hz near the end of the response. The similar result was also observed during aftershock 1 (March 11, 2011 15:16). Changes in transverse and vertical frequency indicate non-linearity of the response. Maximum acceleration larger than 600cm/s^2 was recorded on the top of both towers, which result in the maximum tower in-plane displacement of more than 50cm. The large tower transverse vibrations were mainly dominated by the modes that correspond to the tower local frequency at 0.42Hz.

In transverse direction, wind shoes limit girder movement over the pier and tower. Small gap exists between girder and pier at wind shoes to allow for small relative displacement. Tower transverse accelerations are characterized by many periodic spikes similar to a periodic impulse response. Post earthquake visual inspection reveals several marks of scraped paint on the link head of tower P2. Nuts of several bolts on the upper disc of the lower head of P2 tower link were crushed. The scraped paint and broken nuts could be caused by transverse pounding between tower and girder at tower link and by combination of transverse and excessive vertical motion of girder at tower-to-girder connection. These physical evidences show that girder and tower have experienced large transverse vibration and may explain the occurrence of periodic impulses on the accelerations recorded by sensors near the pier-to-girder and the tower-to-girder connections.

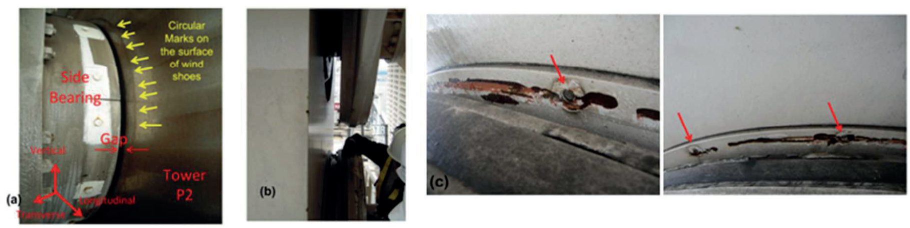

Fig. 2. Circular scratch marks on the surface of wind shoe as a result of side bearing movement indicates girder longitudinal movement of about 8cm. (b) Location of head of tower link (P2) bottom head is connected to girder, top head is connected to tower. (c) Scratch marks on the surface of the bottom link head caused by combination of vertical and transverse movement of the girder. The arrows point to locations of three broken bolts caused by the movement