LESSONS FROM KOBE ON THE SEISMIC RESILIENCE OF LONG-SPAN BRIDGES

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Introduction

Experience with the performance of new long-span steel bridges during the 1995 magnitude 6.9 Kobe earthquake demonstrated that even new bridges, designed to state-of-the-art seismic standards that were developed specifically for each project, can have hidden vulnerabilities that can result in loss of use of these essential structures for significant periods of time. Not only did these failures point out a surprising lack of resiliency of the bridges, but also the loss of use of these bridges substantially impacted the recovery of the broader Kobe area.

New Long-Span Bridges in Kobe

Three new long-span steel bridges along the Kobe waterfront sustained significant damage:

- Higashi-Kobe Bridge: 885m cable-stayed; opened in 1992
- Rokko Island Bridge: double-deck arch; opened in 1992
- Nishinomiya Port Bridge: opened in 1993
  main span: single-deck cable-arch
  approach span: composite box girder

More complete structural details of these bridges and the damage sustained by them are available in Bruneau et al., (1996) and Wilson (2003).

The damage to these bridges, each less than three years old at the time of the earthquake, had a major impact on Kobe's transportation systems in the months following the earthquake. Although many valuable lessons have been learned from field studies of the damage to these bridges there were also important lessons from the processes used to repair these bridges and the time required to return them to service. These lessons give an indication of the resiliency (or lack of) of these structures and also give an idea of where new lesson might be learned in enhancing the resiliency of this type of structure in other communities. These lessons are of particular importance because these bridges were on vital transportation links where there was an urgency to re-open the transportation routes as quickly as possible.

Of particular importance in this earthquake was the fact that the ground motions in Kobe City were much more intense than predicted by the scenario earthquakes used in developing seismic design criteria for these bridges. The earthquake had a fault rupture that propagated directly towards and under the centre of Kobe City. Peak horizontal ground accelerations in the most heavily damaged parts of Kobe were very large, ranging from 0.3 - 0.8g, much greater than the typical 0.1 - 0.3g design ground motions for Kobe.

Lack of Resiliency

Three of the key characteristics of a resilient system: reduce chances of a shock; absorb a shock if it occurs; recover quickly; were notably absent in the seismic behaviour of these three bridges. Lessons from Kobe on the lack of resiliency in new steel long-span bridges include:

- Severe damage was sustained by bridge bearings, girder-to-pier connections and seismic restrainers (which didn't work very well at all).
- It can take considerable time to fabricate new bridge components to replaced ones that have failed, such as bridge bearings.

- The time required to repair bridges may be controlled by external factors, such as availability of specialized equipment, including heavy lift equipment. In Kobe, heavy lift cranes were readily available but this was exceptional good fortune.
- The time required to return the Kobe bridges to service ranged from three to nine months.

Ensuring Resiliency

Lessons from the Kobe earthquake are of considerable value in learning how to enhance and ensure resiliency in major transportation structures.

Small details matter!

From a technical perspective the failures and hence loss of use of each of the three bridges resulted from failure of rather small but vitally important components. None of these bridges experienced catastrophic failures (ie., collapse) and in fact most of the failures on all three occurred to embarrassingly small but important components. For example, each bridge had problems with failure of the bridge bearings. These were typically brittle failure modes, ones that should be avoided at all costs because of their unpredictable and sudden nature. Careful attention to the small details of force transfer through bearings; the actual resiliency in these systems; and the consequences of failure of these components needs to be emphasized.

The design scenario may not happen; what happens might be worse!

The scenario earthquakes used for design of these bridges very substantially underestimated the intensity of the ground shaking in Kobe. This points out very clearly that the scenario event may in fact not be the one to occur. It further points out that multi-level assessments need to be done on critical structures. Resiliency in performance of these structures can only really be established when multiple scenarios are examined. For example, for earthquake ground motion, the system performance under various levels of ground motions corresponding to various probabilities of exceedance needs to be examined. In the current (2005) Canadian National Building Code the design ground motion is specified for a 2% probability of exceedance in 50 years (return period of ~2500 years). However, the ground motions associated with this event are specified as median levels. In other words, should the design level event occur then there is a 50% chance that the specified ground motions could be exceeded. The best estimate of the standard deviation associated with this ground motion give a ratio of $84^{th}/50^{th}$ percentile in the range of ~1.5~3.

Estimated times for recovery can vary widely!

With one exception, all major land-based transportation routes through Kobe were heavily damaged and were generally unusable immediately after the earthquake. Furthermore, response was hampered by disruptions to many other public services. While it is desirable to have such critical infrastructure links functioning almost immediately after even a major earthquake, in this case two bridges required three months of repair time to return them to service, and the third bridge was not re-opened until nine months after the earthquake. All of this however, was accomplished at a time when the earthquake imposed severe demands on all construction-related resources throughout Japan.

Bruneau, M., Wilson, J.C., and Tremblay, R., (1996), "Performance of steel bridges during the 1995 Hyogo-ken Nanbu (Kobe, Japan) earthquake", Canadian Journal of Civil Engineering, Vol. 23, No. 3, pp 678-713.

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