SAFETY EVALUATION OF ASAHIBASHI BRIDGE BY USING A MODIFIED DESIGN METHOD TO VERIFY ITS SEISMIC PERFORMANCE

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Abstract

This study evaluated the safety of Asahibashi Bridge by assessing its seismic performance toward retrofitting with minimum change. The bridge has been in service since its construction 74 years ago in Asahikawa City, Hokkaido Prefecture. Seismic performance was assessed by using a modified design method to verify its seismic performance: 1) evaluating the regional seismic characteristics, 2) evaluating the structural soundness of the bridge through forced vibration tests and by analyzing the natural period, and 3) conducting seismic performance evaluation through 3-D finite-element analysis. The seismic performance of Asahibashi Bridge was found to be sufficient, and no major retrofit is required.

Introduction

Frequent large-scale earthquakes in recent years have been causing major disasters in many parts of the world. There have been such disasters in Japan as well, such as the Great Hanshin Awaji Earthquake (Kobe Earthquake) of 1995, and the Niigata Chuetsu Earthquake of 2004. Such cases have increased awareness of earthquakes throughout Japan.

In civil engineering, awareness of earthquakes has also heightened, and retrofitting of existing bridges is being actively performed. In light of this, it has become necessary to study methods for retrofitting old bridges. However, this is a problem because old bridges tend to have been built with construction technologies that differ from those of today, making it difficult to study the bridge with contemporary design methods. Furthermore, local residents often feel strongly about preserving historical structures that serve as landmarks. Therefore, retrofitting of such old bridges is difficult.

This paper reports on a study performed on Asahibashi Bridge, a historical landmark. To preserve the structural soundness of the bridge with the minimum change, and to secure safety against earthquakes, the study applied a modified design method to verify its seismic performance to assess the seismic performance of the bridge.

Asahibashi Bridge

Asahibashi Bridge is a 225.43-m-long road bridge that spans the Ishikari River in Asahikawa City. The bridge was constructed in 1932. Today, the bridge has symbolic and historical significance to the region.

Asahibashi Bridge is a beautiful bridge that ranks as one of the three finest in Hokkaido. The superstructure consists of a braced-rib cantilevered tied-arch center span, and a pony warren-truss side span. The substructure is a reinforced concrete (RC) bridge abutment and piers with distinctive granite panels. Photo 1 shows the center span.

Photo 1 Asahibashi Bridge

Evaluating the Seismic Characteristics of the Region

As a first step, a study was performed on the seismic characteristics of the Asahikawa region, where the bridge is located. Figure 1 shows the strong-motion records for that region. Earthquakes in Asahikawa have been monitored for 120 years by the Japan Meteorological Agency. In that period, about 130 earthquakes have been recorded, but intense earthquakes have rarely been recorded. The most intense recorded earthquake was 4 on the Japan Meteorological Agency seismic intensity scale (about VI to VII on the Modified Mercalli Intensity Scale), with a maximum acceleration in the range of 25 to 80 gal.

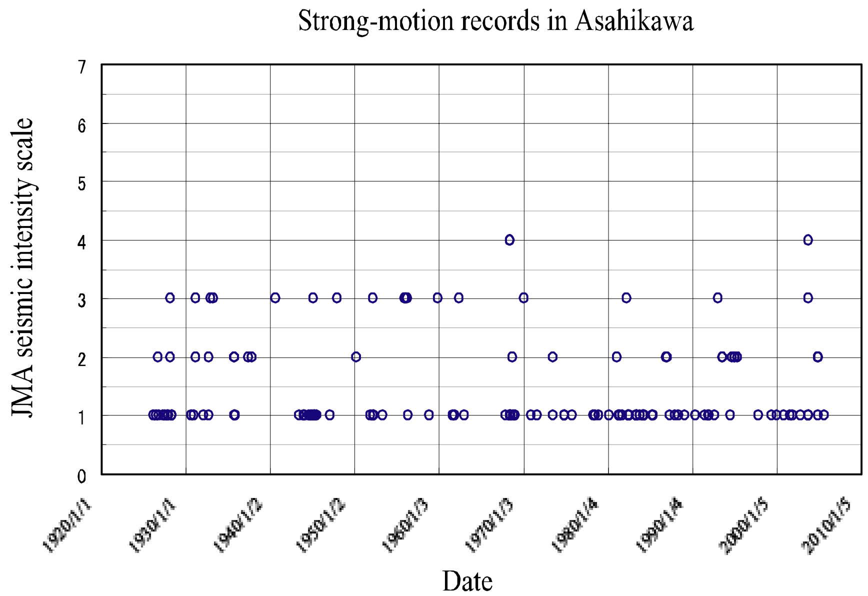

Figure 1　Strong-motion records for Asahikawa, with earthquake occurrences and intensity.

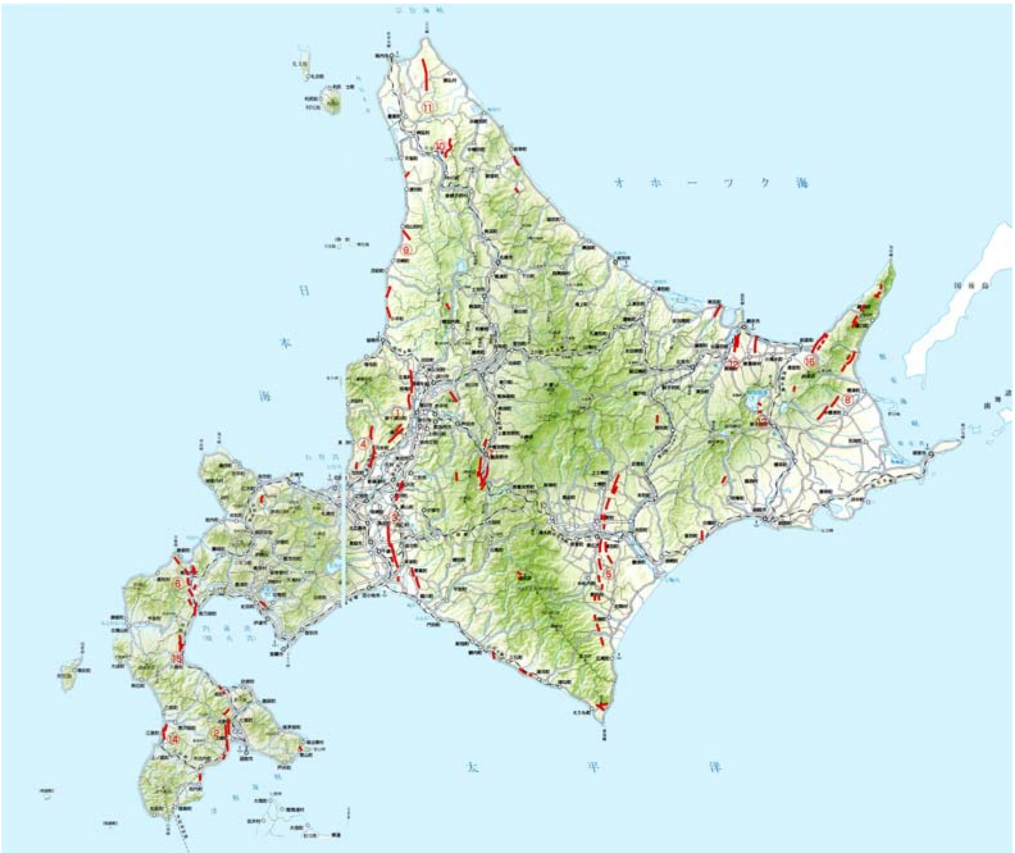

Figure 2　Distribution of active faults in Hokkaido

Based on past observations, the assumed maximum strong-motion has a maximum acceleration of about 60 gal. The strong-motion of this assumed earthquake is about the same as that of the largest earthquake the bridge has experienced.

The likelihood of an earthquake caused by an active fault was also considered. Figure 2 shows the distribution of active faults that have been discovered in Hokkaido. In the map there are no active faults around Asahikawa. This clarifies that Asahibashi Bridge is highly unlikely to be exposed to an intense earthquake caused by an active fault.

These studies lead us to believe that there is very little possibility that Asahibashi Bridge will be hit by an extremely intense earthquake, and from previous observation records, the maximum strong-motion that could be expected would have a maximum acceleration of about 60 gal.

<u>Evaluation through Forced Vibration Test and Analysis of the Natural Period</u>

The second step was to perform forced vibration tests at Asahibashi Bridge, using a truck-mounted crane and using a truck that applied force by stopping suddenly on the bridge. The results are compared with those of the analysis of natural period to evaluate the structural soundness of the bridge.

Photo 2 Forced vibration test on the bridge

The evaluation was performed by first obtaining the natural frequency and vibration characteristics through tests. Then, through detailed analysis of the natural period, the theoretical initial natural frequency and vibration characteristics of the bridge when it was constructed were obtained. By comparing the current values to the initial values when the bridge was constructed, the current performance relative to that of the initial design could be estimated.

Photo 2 shows the forced vibration test being performed. Two test methods

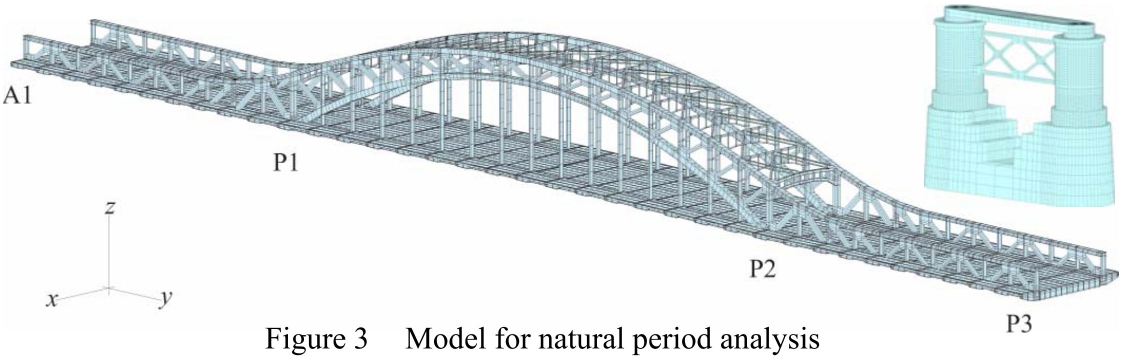

Figure 3 Model for natural period analysis

were used. One used a truck-mounted crane to apply reaction force and vibrate the bridge by raising and lowering a weight. The other used a truck that applied a force by stopping suddenly on the bridge. For measurement, many accelerometers were installed on the bridge, and the vibration characteristics were estimated by processing the acceleration waveforms.

Figure 3 shows the numerical analysis model used to analyze the natural frequency. The analysis was performed through a 3-D finite-element method, with precise modeling of the bridge according to initial design drawings. The natural period of the bridge was obtained theoretically through numerical analysis, and then the period and the vibration mode were compared with the test results.

The results from the forced vibration tests and the results from the natural period analysis are compared in Table 1 and Figure 4. In the figure, theoretical values from the numerical analysis and values from the test show similar vibration modes, and there are no significant differences in vibration characteristics from those of the initial design. Therefore, there is though to be no localized damage on the Asahibashi Bride that could affect the vibration mode of this bridge.

Also, Table X shows that the numerical analysis gives a slightly shorter period than do the test results. This suggests that minor deterioration has reduced the rigidity of the bridge from its original condition. However, the maximum difference is only about 5%; therefore, it is unlikely that this bridge has deteriorated significantly.

The results show that the performance of Asahibashi Bridge may be slightly reduced, but no major deterioration or localized damage has occurred, and therefore, the bridge is considered to be sound.

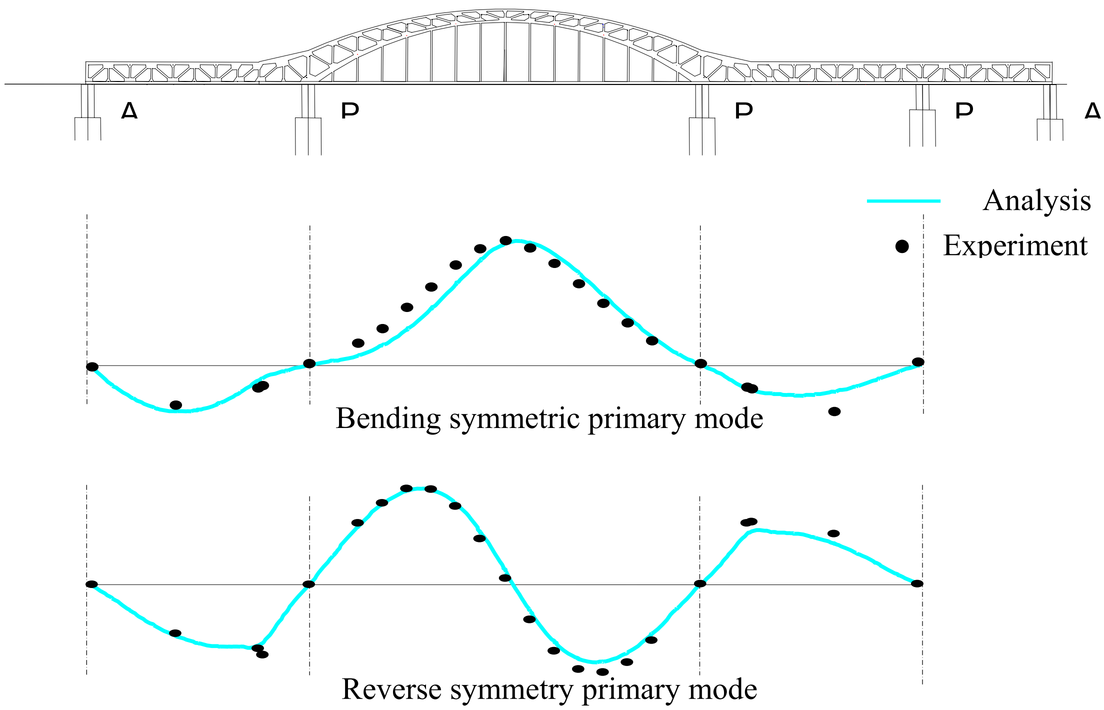

Figure 4 Comparison between vibration mode from tests and that from analysis

Table 1 Comparison between natural frequency from tests and that from analysis

vibration mode	Experiment Result (Exp/Ana ratio)		Analysis Result
	Forced vibration test	Stopping suddenly test	
Bending symmetric primary	2.63 (0.97)	2.58 (0.95)	2.72
Bending symmetric secondary	2.95 (0.95)	2.95 (0.95)	3.11
Bending symmetric third	4.80 (0.99)	4.83 (1.00)	4.84
Reverse symmetry Primary	-	2.09 (0.96)	2.17
Reverse symmetry secondary	-	-	3.31

Evaluation of Seismic Performance through 3-D Finite-Element Analysis

The last step is to evaluate the seismic performance of Asahibashi Bridge using the 3-D finite-element method.

Figure 5 shows the finite element model used in the analysis of the bridge piers. This figure shows a model of the P2 pier, which is a precise 3-D model of that bridge pier. At the top of this model bridge pier, a loading plate that simulates the weight of the superstructure was installed, and the dead load from the superstructure was simulated by changing the density of the plate in the computer program.

First, dead load analysis of the pier was performed. A condition was created in which dead load acted on the pier and the superstructure. Then, horizontal displacement was applied at the top of the bridge pier for pushover analysis.

Figure 6 shows an example of the results from the analysis. This figure shows the deformation after horizontal displacement had been applied to the crown of the bridge pier up to rebar yield. The deformation in this figure is amplified by a factor of 250 for ease of recognition. This clarifies that the granite panel joints opened and the bridge pier reached ultimate state with flexural failure.

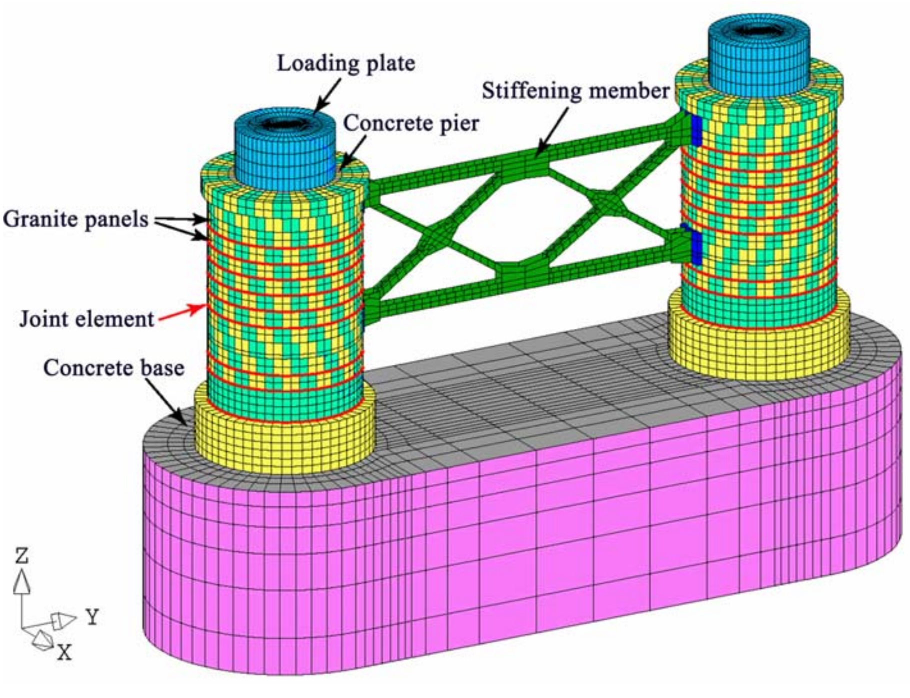

Figure 5 Example of finite-element model

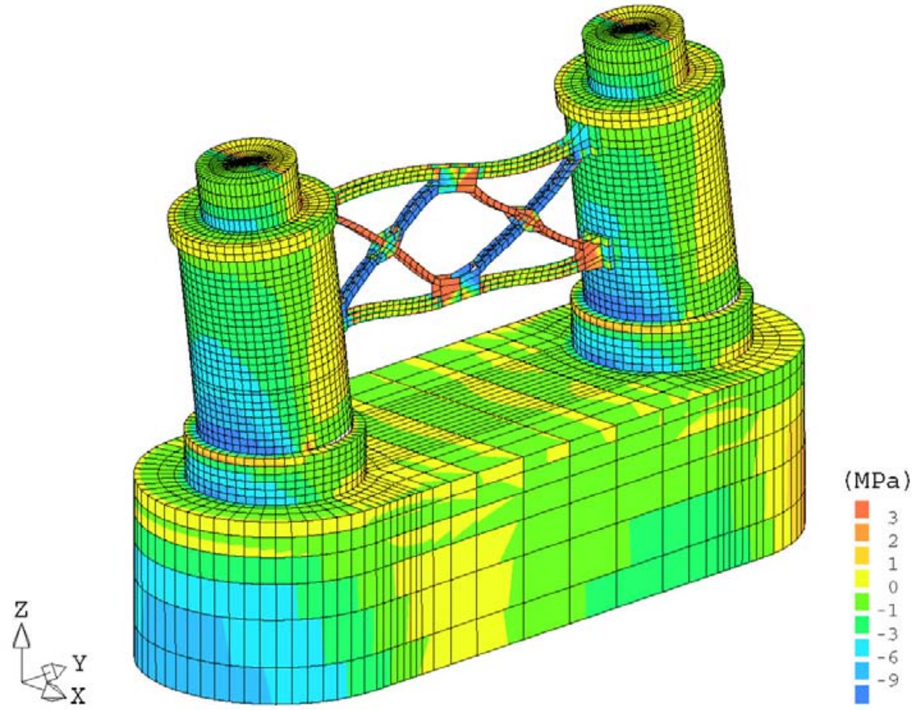

Figure 6 Example of analysis results (deformation amplified by a factor of 250)

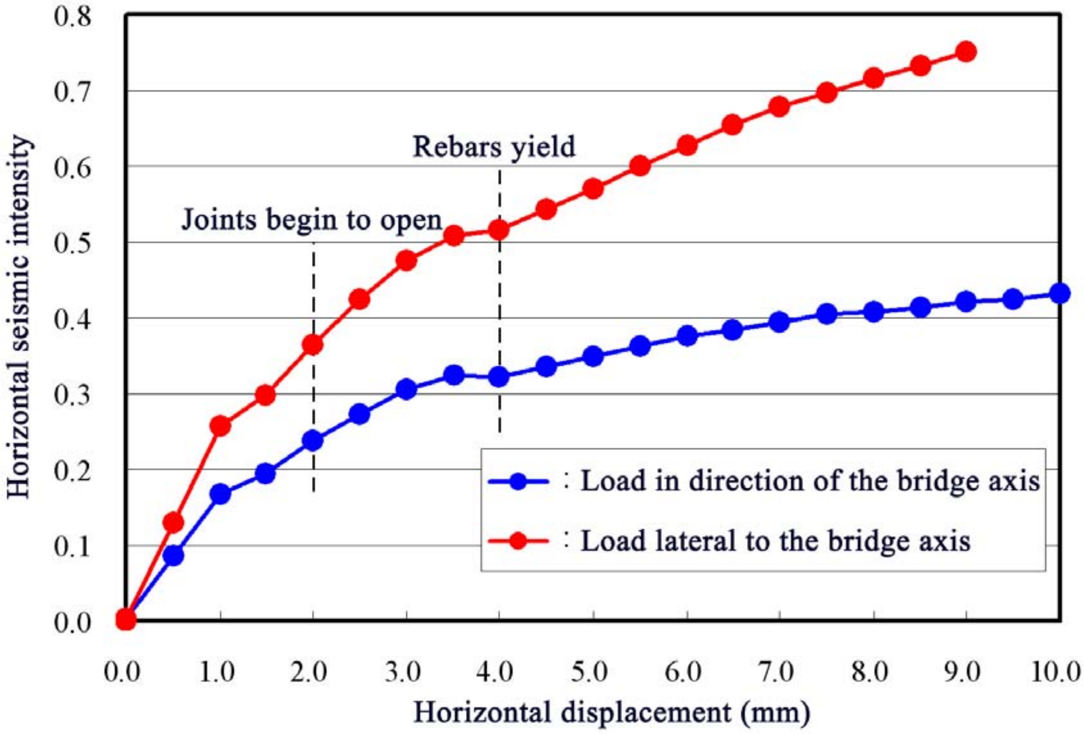

Figure 7 Horizontal seismic intensity - horizontal displacement curve

Figure 7 shows an example of the horizontal reaction - horizontal displacement relation in the analysis. The figure shows that this bridge maintains load capacity but lacks deformation capacity. It was determined that this bridge could withstand forces imposed by the aforementioned strong-motions.

Various other studies have been performed, such as on evaluation of stress at the superstructure when 1) horizontal acceleration was imposed on the model of the superstructure, and 2) displacement was imposed longitudinally or transversely to the bridge axis. However, the various analyses found no significant problems.

From the numerical analysis, it was determined that the Asahibashi Bridge has sufficient seismic performance to resist the assumed strong-motions.

Conclusion

In this study, the seismic performance of Asahibashi Bridge, a 74-year-old bridge in Asahikawa City, was assessed for retrofitting with minimum change to the bridge. The steps were these: 1) evaluate regional seismic characteristics, 2) evaluate the structural soundness of the bridge through forced vibration tests and analysis of the natural period, and 3) evaluate seismic performance through 3-D finite-element analysis. The results are summarized as follows:

1) In light of the seismic characteristics of the region, it is unlikely that Asahibashi Bridge will experience a major earthquake.
2) The forced vibration test and analysis of the natural period clarified that the deterioration of the present Asahibashi Bridge is insignificant.
3) The 3-D finite-element analysis showed that this bridge is structurally sound and has sufficient seismic performance to resist the strong-motions assumed.

From these findings, it was decided that the Asahibashi Bridge does not require major retrofitting but only be minor repairs of localized deterioration.