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Principal Direction Analysis of Strong Motion Records for a Bridge with Skewed Wall-type Piers

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SUMMARY

In conventional aseismic design and analysis for bridges, examinations focus on the bridge axis direction and on the direction perpendicular to that axis in the horizontal plane as the major vibration directions. In a bridge with wall-type RC piers that are skewed and whose stiffness in the bridge axis direction differs from that in the direction perpendicular to the bridge axis in the horizontal plane, the vibration direction is unknown. This is because the bridge axis is oriented different from the plane of the vulnerable pier face. It may not be always possible to represent the bridge vibration direction in terms of bridge axis direction and direction perpendicular to the bridge axis. To gain a clear understanding of vibration directions of piers with oblique angle during earthquakes, we used three-element strong motion waveforms (bridge axis direction, direction perpendicular to that axis, and vertical direction) for a bridge with skewed piers to calculate characteristics of the elliptical sphere of particle locus of three-dimensional groundmotion, toward obtaining the azimuth directivity (major axis) of vibration.

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INTRODUCTION

The 2003 Tokachi-oki Earthquake occurred around 4:50 a.m. on September 26, 2003. The epicenter was at 41° 47' N. Lat. by 144° 05' E. Long., and the hypocenter was approximately 42 km below the epicenter. The magnitude was 8.0. The intensity on the Japanese scale was nearly 6 in Makubetsu, Shikaoi, and Toyokoro towns and in Churui village. It was over 4 in a large part of the Tokachi district. This earthquake caused damage in many parts of Hokkaido.

Some of the seismographs in the Hokkaido Development Bureau's Warning Information System of Earthquake (WISE) are installed on bridges. These seismographs obtained much waveform data during the 2003 Tokachi-oki Earthquake, based on which the principal vibration directions of bridges with skewed piers were analyzed.

Conventional seismic bridge design considers two principal directions of bridge vibration: that parallel to the bridge axis (hereinafter: parallel direction) and that perpendicular to the bridge axis (hereinafter perpendicular direction). In wall-type PC piers and rigid-frame piers, the parallel stiffness differs from the perpendicular stiffness. When the piers of these bridges are skewed, the direction most prone to vibration is not the parallel direction. Vibration directions of bridges with such piers remain unknown. When the natural period is calculated and the dynamic response is analyzed for such bridges, it is found that the parallel and perpendicular directions do not always represent the principal vibration directions.

Fig – 1 outlines the conventional design method, in which the angle of the pier is neglected for calculation even if the bridge has a skewed pier. Thus, the calculation takes the value that is on the safe side. Neglecting the skew angle results in a greater estimated stiffness in the bridge axis direction. Irrespective of the angle, the same model is therefore used for calculation of the natural period and dynamic response analysis.

In conventional design methods, dynamic response analysis does not always produce results indicating that the value is on the safe side, because the natural period of the bridge pier is calculated from the stiffness of the pier in the weak direction. If the effects of the angle are neglected, bridge pier stiffness cannot be properly evaluated. The estimated vibration period of the bridge pier could be longer than the actual one.

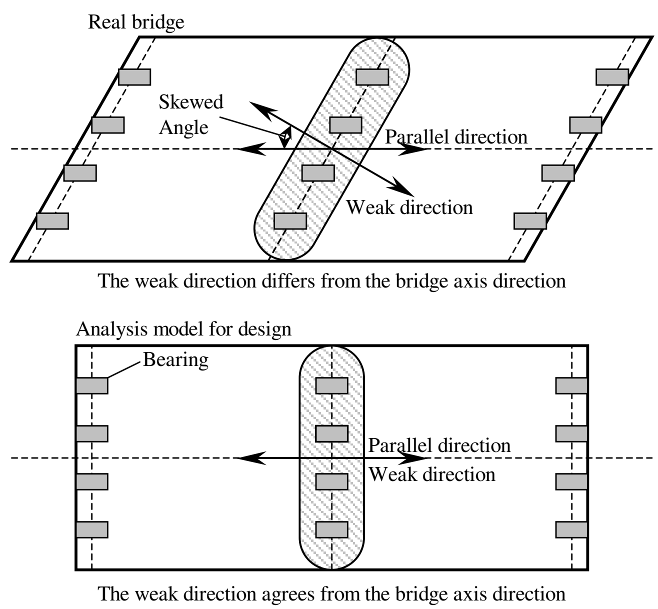


Fig – 1 Schematic of the design model of bridges with skewed piers

To acquire basic information for better design of bridges with skewed piers, this study examines the seismic behavior of such bridges. Specifically, waveforms of strong motion for bridges with skewed piers were analyzed to find the principal direction during earthquakes. This paper discusses the analysis of two bridges.

OUTLINE OF THE BRIDGES

The two bridges are in Hokkaido. Bridge A (Fig – 2) is a 3-span continuous steel box girder bridge. Its length is 137.00 m, and its superstructure has spans whose lengths are 52.90 m, 66.00 m, and 52.90 m. The substructure is composed of two wall-type piers and two inverted T-type abutments. The

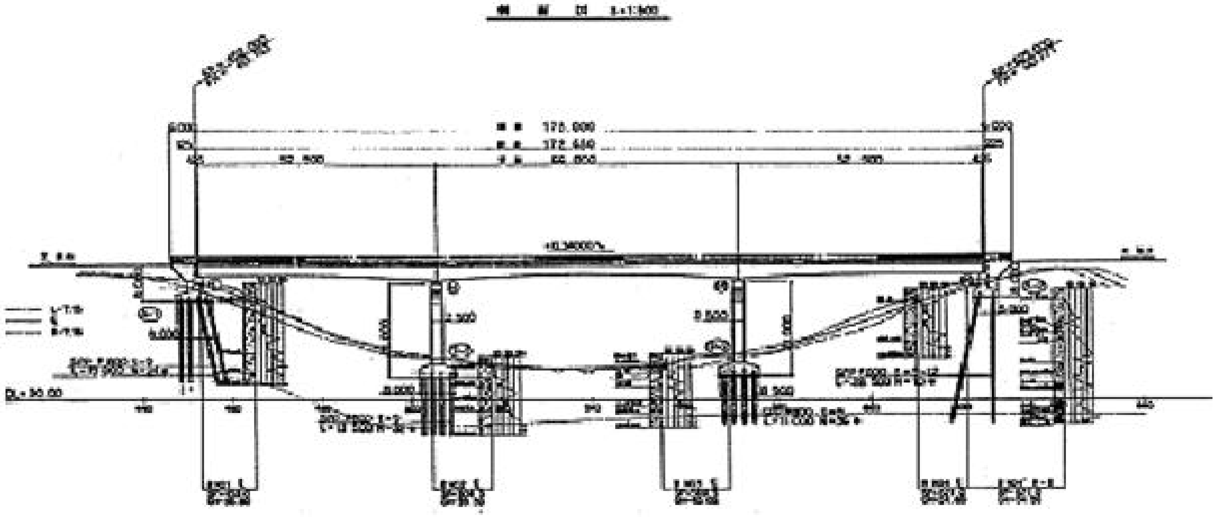


Fig – 2 Lateral view of Bridge A (Skewed angle: 90°)

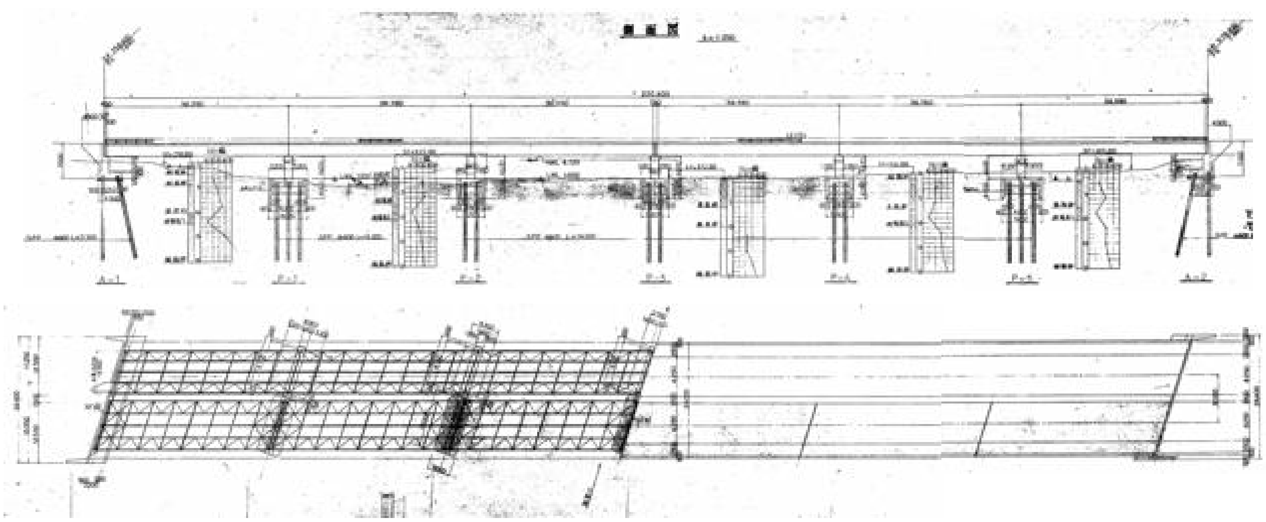


Fig – 3 Lateral view of Bridge B (Skewed angle: 72°30')

foundation is of steel pipe pile (φ600, L = 13.00 m). The A1 abutment is a fixed bearing, and the other bearings are movable. The bridge piers are not skewed, so the angle is 90°00' with respect to the bridge axis direction.

Bridge B (Fig – 3) is composed of two 3-span continuous steel plate girders. Its length is 220.80 m, and its superstructure has spans whose lengths are 36.39 m, 36.78 m, and 36.39 m. Its substructure consists of five rigid-frame bridge piers and two inverted T-type abutments. The foundation is of simple well and steel-pipe pile (φ600, L = 16.00 m). The P1 and P5 piers are fixed bearings, and the other piers are movable in the parallel direction. Each bridge pier is fixed by side blocks in the direction perpendicular to the bridge axis. The bridge piers are skewed, and the angle is 72° 30' with respect to the bridge axis.

Strong seismic motions were recorded by seismographs installed at the crown of the P1 bridge pier, the girder of the P2 bridge pier, and on the ground. The directions of vibrations were analyzed by using strong motion records obtained at the three locations. The waves were analyzed in three directions: parallel, perpendicular and vertical.

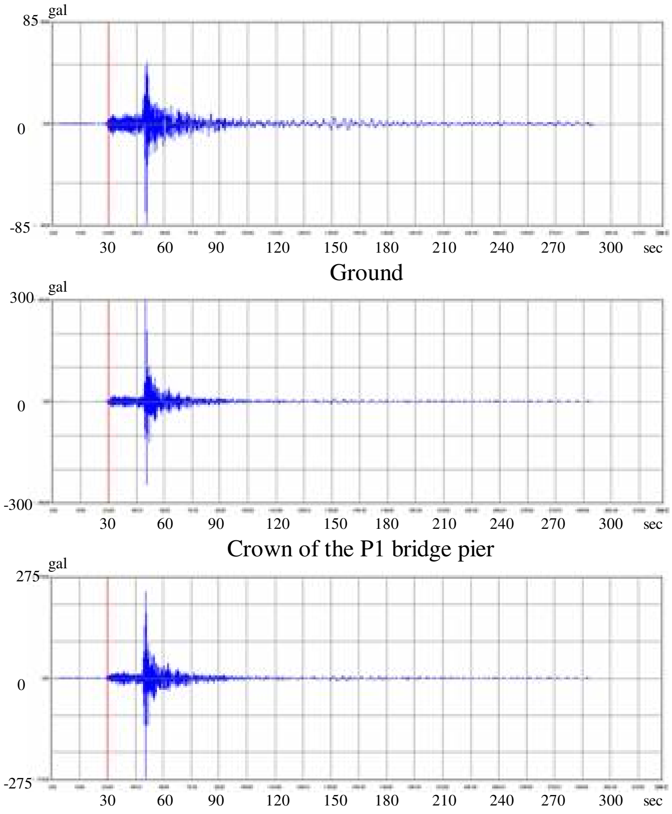


Fig – 4 Waveforms of acceleration for Bridge A recorded on January 28,2000

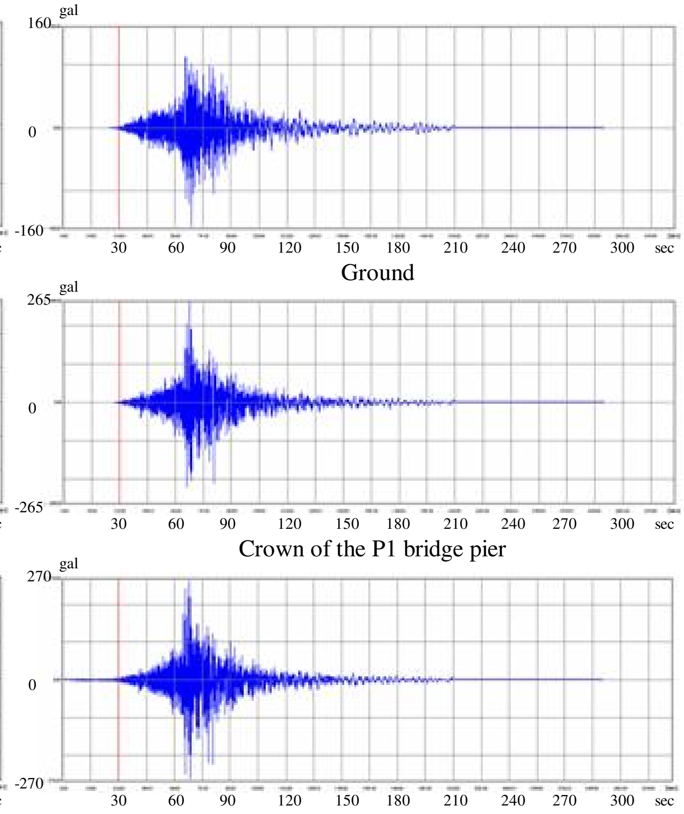


Fig – 5 Waveforms of acceleration for Bridge B recorded on October 4,1994

RECORDED WAVEFORMS

Fig – 4 shows waveforms of acceleration in the parallel direction recorded at Bridge A on January 28, 2000. The graphs at the top, in the middle, and at the bottom show the waveform on the ground, at the crown of the P1 bridge pier, and at the girder of the P2 bridge pier, respectively.

Fig – 5 shows waveforms of acceleration in the bridge axis direction recorded by the seismographs at Bridge B on October 4, 1994. The graphs at the top, in the middle, and at the bottom show the waveform on the ground, at the crown of the P1 bridge pier, and at the girder of the P2 bridge pier, respectively.

ANALYSIS METHOD

trong motion waveforms were used for principal axis analysis, in which the azimuth directivity of seismic motions was obtained. Unlike traditional Fourier analysis, three elements of waveforms (parallel, perpendicular, and vertical) were employed to find characteristics of the elliptical sphere of particle locus of three-dimensional seismic motion. Fig – 6 outlines the principal axis analysis.

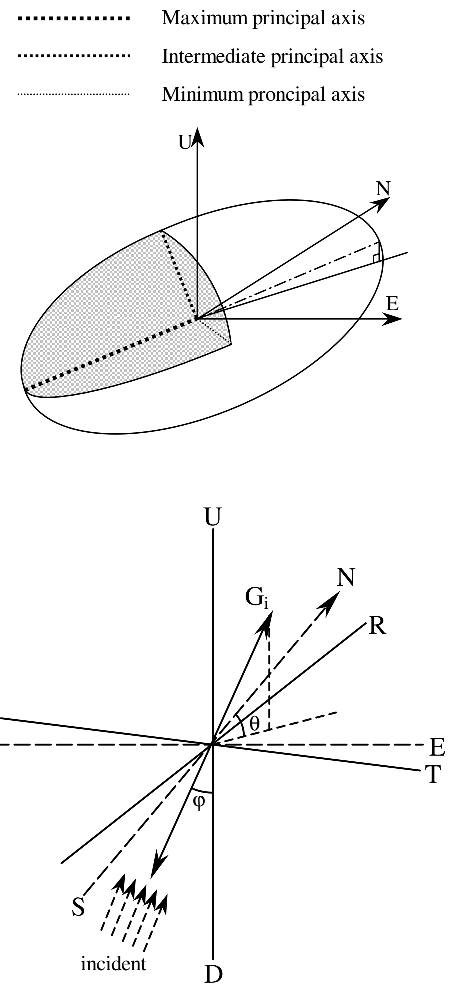
To find three-dimensional azimuth directivity during earthquake, the principal axis analysis used the waveforms of the strong motions obtained on the ground, at the crown of the P1 bridge pier, and at the girder of the P2 bridge pier. From the obtained azimuth directivity, the principal vibration direction of the structure was estimated. The vibration direction at the time when the wave components of the maximum principal axis of seismic motions demonstrated the maximum acceleration (i.e., the maximum principal axis in SIGMA takes its maximum value) was assumed to be the principal vibration direction.

ANALYSIS RESULTS

Fig – 7 graphs the principal axis analysis. The graphs at the top, in the middle, and at the bottom show the analysis results for the ground, the crown of the P1 bridge pier, and the girder of the P2 bridge pier, respectively. The upper graphs in each pair present temporal changes in angles of the maximum, intermediate, and minimum principal axes with respect to the bridge axis direction. The lower graphs in each pair show temporal changes in seismic waves. The black solid line, the green dashed line, and the blue dot-dashed line represent the maximum, intermediate, and minimum principal axes, respectively.

When the maximum principal axis of the ground at Bridge B takes a maximum value, the principal vibration axis is +17° from the bridge axis direction. However, at the crown of the P1 bridge pier, it is −16°, which is shifted slightly from the weak direction to the bridge axis direction. Also, at the girder of the P2 bridge pier, it is −8°, which is almost halfway between the bridge axis direction and the weak direction. Other waveforms of seismic motion demonstrate the same trend, so this is a characteristic of Bridge B.

These facts show that the vibration direction of bridge piers differs from the direction of ground vibration and that they tend to vibrate in a direction between the bridge axis and the weak directions. The major axis direction at the bridge pier differs from that at the bridge girder, and the difference depends on the type of bridge bearing and the measurement location.



Acceleration with
respect to the principal axis : λi（Sigma in the graph）
Incident Angle : φi　Angle with respect to the vertical direcsion on the NE plane
Azimuth Angle : θi（Theta in the graph）Angle With respect to the N axis on the NE plane

Fig – 6　Graph analysis of the principal axis

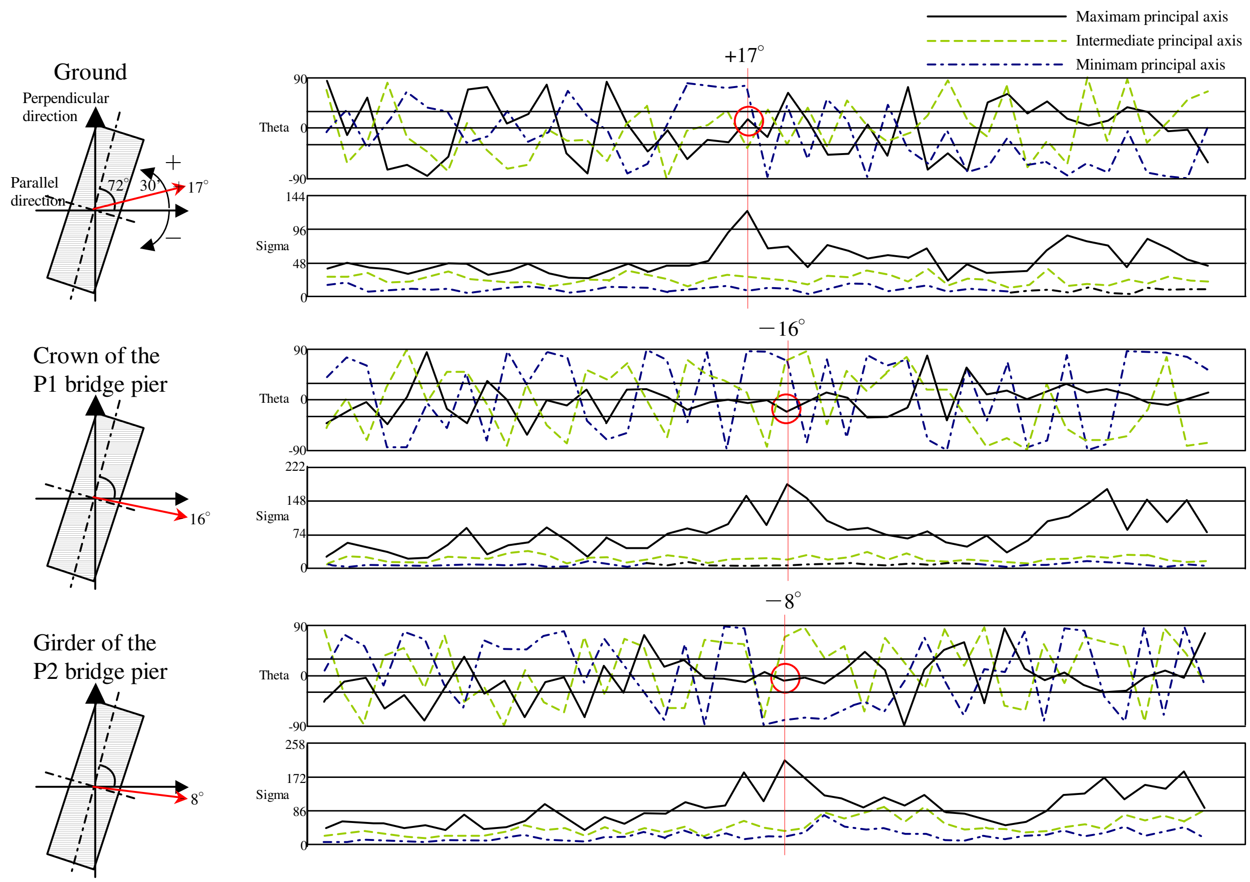


Fig – 7 Principal axis analysis on Bridge A

CONCLUSIONS

This research on the behavior of skewed bridge piers during earthquake has clarified the following:

1) Principal axis analysis for bridges with skewed piers shows that the piers tend to vibrate in a direction between the bridge axis and the weak directions.
2) The vibration direction of the P2 bridge pier is closer to the bridge axis direction than is that of the P1 bridge pier. The superstructure restrains the vibration of the bridge pier toward the weak direction and shifts it toward the bridge axis direction.

In the future, the number of survey bridges and seismic analyses will be increased. Comparative analysis of skewed piers with different angles and types of bearings is needed.