EFFECTS ON THE AKASHI KAIKYO BRIDGE

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ABSTRACT

The epicenter of the main shock of the 1995 Hyogoken-Nambu earthquake was very close to the construction site of the Akashi Kaikyo Bridge, which will be a three-span, two-hinge stiffening truss suspension bridge with a total length of 3,910 m upon completion. The bridge consists of tower foundations, anchorages, towers, cables and girder.

At the time of the earthquake, the main cable installation had been completed and the working had reached the stage of cable squeezing. Immediately after the earthquake, a structural inspection, a survey of pier locations using an optical distance measuring instruments and a global positioning system and a geotechnical investigation were conducted. The basic information and technical data related to the earthquake and its impact including the displacements of the foundations on the Akashi Kaikyo Bridge are described in this paper.

Key words: bridge, earthquake, earthquake damage, fault, foundation, settlement, site investigation (IGC: B3/E2)

INTRODUCTION

A devastating earthquake measuring \(M=7.2\) hit Southern Hyogo Prefecture in Japan around 5:46 a.m. on the 17th of January 1995 and affected the Akashi Kaikyo Bridge now under construction. The construction site of the Akashi Kaikyo Bridge is very close to the epicenter (Fig. 1).

Discussion in this paper concentrates on the basic information and technical data related to this earthquake and its impact on the Akashi Kaikyo Bridge.

BRIEF DESCRIPTION OF AKASHI KAIKYO BRIDGE

The Akashi Kaikyo Bridge will be a three-span, two-hinge suspension bridge with stiffening truss, with a total length of 3,910 m upon completion. The bridge consists of tower foundations (2P and 3P), anchorages (1A and 4A), towers, cables and girder as shown in Fig. 2. The tower foundations were constructed by the laying-down caisson method. The pier foundation 2P was constructed on the Akashi Formation with a foundation level of T.P.-60 m below sea level, while 3P was founded on the Kobe Group with a foundation level of T.P.-57 m. Both of the foundations 2P and 3P consists of a cylindrical caisson of 80 m in diameter and 70 m high, 78 m and 67 m, respectively.

At the time of the earthquake, the main cable installa-

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Fig. 1. Location of Akashi Kaikyo Bridge

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Fig. 2. Geologic Profile along Akashi Kaikyo Bridge alignment and foundation cross sections.
tion had been completed and the project had reached the stage of cable squeezing.

The Akashi Strait forms a caldron-shaped valley with a maximum water depth of T.P.-110 m at the center of the strait and shallower extensions on both sides. The geological structure at the Akashi Strait is shown in Fig. 2. As shown in this figure, the basement consists of granite, overlain by the Kobe Group, Akashi Formation, upper diluvium and alluvium. The granite is related to the late Mesozoic period and its weathering has not progressed very much. The Kobe Group is a sedimentary soft rock of Miocene period, which consists of alternative layers of sandstone and claystone. The Akashi Formation is composed of a weakly cemented gravel and sand layer ranging from Pliocene to Pleistocene.

Figures 3 and 4 show a geological profile at the locations of foundation 2P and 3P, respectively. Figure 5 shows a schematic map of the faults which have been determined from sonic prospecting and borings previously completed in this area (i.e., prior to the earthquake). Most of these faults resulted from Rokko Movements, although slightly different from the Rokko system. The faults in the EW, ENE-WSW and NE-SW directions are predominant in this strait. The locations of the foundations were selected to avoid the faults existing in the Strait.

Fig. 3. Geotechnical profile perpendicular to the bridge axis (2P)
SEISMOLOGICAL ASPECTS

Main Shock and Aftershocks

According to the Japan Meteorological Agency, the magnitude of earthquake was 7.2 and its epicenter was 34°36'N and 135°03'E at the northern tip of Awaji Island with a focal depth of 14 km.

As shown in Fig. 6, the epicenters of the main shock and aftershocks were concentrated along a 50 kilometer line in a NE-SW direction with a discontinuity at the Akashi Strait, and their distribution, generally, corresponds to the Rokko Fault System and the Nojima Fault at Awaji Island.

Recorded Ground Motion

Figure 7 shows the maximum acceleration values which were observed at different places during the earthquake. Large earthquake motions were observed in Kobe City and the surrounding areas, with maximum horizontal acceleration amounting to either 600 gals or exceeding 800 gals. Figure 8 shows the records at the Kobe Marine Observatory (Kishodai in Fig. 7). Here the maximum acceleration was 818 gals in the NS component, 617 gals in the EW component, and 332 gals in the UD component. It was noted that the principal shock of large amplitude lasted only 10 seconds, and therefore large energy was released in Kobe from directly underneath the city for only a very short period of time.

Faults which caused Earthquake

Based on the movement of active faults and the distribution of aftershocks, it is considered that the fault
Fig. 6. Distribution of main shock and aftershock (After Yuro Ishikawa)
Fig. 7. Distribution of maximum acceleration observed by Hyogo Prefecture

Fig. 8(1). Acceleration waveforms (from Kobe Marine Observatory) (Note 2)
which caused the earthquake was of strike-slip type with right-lateral ground movement. The direction of the ground movement was from the south-west to the north-east. The maximum horizontal and vertical displacements which were observed at the ground surface are about 1.8 m and 1.3 m, respectively, according to the field investigation team of Kobe University.

Figure 9 shows the displacement vectors at several measurement points obtained by the global positioning system using a static survey method. The fixed station is the Shinomineyama Triangulation Station which is located at the boundary of Osaka and Nara Prefectures. It seems that the Kobe ground side moved in a northerly direction whereas Awaji Island shifted in various directions. Based on this fact, it is considered feasible that the ground movement with a pull-apart and/or right-lateral movement occurred at Akashi Strait. Considering that the Rokko fault system has right lateral movement and Nojima fault is also a thrust fault with right lateral movement, it might be possible that the occurrence was a pull-apart movement.
EFFECTS ON THE AKASHI-KAIKYO BRIDGE

Immediately after the earthquake, a structural inspection, a survey of the pier locations using both an optical distance measuring instrument and the global positioning system were made, and a geotechnical investigation was also conducted.

Visual Inspection of the Structures

The inspection confirmed no structural damage to the foundations, towers and cables, and only minimal displacement of the anchorages and piers. The shore-line of the construction yard, however, moved horizontally and the granular fill behind the shore protection settled.

Displacement of the Substructure

Figure 10 indicates the displacement observed by using both an optical distance measuring instrument and the global positioning system after the shock.

From the measurements which are shown in Fig. 10, it...
can be seen that foundations 1A and 2P moved in the NE direction; with their lateral movements being 0.75 m and 0.78 m, respectively. Foundation 3P shifted in the WNW direction by 0.53 m and 4A moved in the WSW direction by 0.46 m. As a result, the center span and the side span were lengthened by 80 cm and 30 cm, respectively, due to the crustal movement of the ground on which the piers and anchorages had been constructed. It was also found that the vertical movements of the foundation were 0.13 m heave at 1A, 0.09 m at 2P, 0.19 m downward movement at 3P and 0.21 m up at 4A.

Investigation of the Ground Surface adjacent to the Tower Foundations

Investigation of the ground surface around the tower foundations was made using an underwater video camera, Remote Operated Vehicle (ROV), sonic prospecting and an echo sounder to determine ground movement and fractures.

At the 2P site, there was no noticeable evidence which indicated that ground movement such as subsidence or heave took place near the foundation. Newly developed fractures were also not found around the foundation. A sliding micrometer which had been installed for measurements of the settlement of the foundation and the ground at different depths worked normally during and after the earthquake, indicating that the subsidence of the foundation was about 20 mm due to the shock. No damage to the measurement system indicated that the horizontal displacement of the foundation was due entirely to the movement of the ground itself, but not due to the sliding of the foundation relative to the bearing ground.

At the 3P site, the fractures in both the NNE and EW directions were observed by ROV on the seabed on the W-NW side of the foundation. Most of the cracks have a length in the range of from several cm to about 30 cm, including one crack over 10 m in length. According to the sonic prospecting there was no distinct fault around the foundation. The measurements by echosounder revealed that subsidence of the bedrock of about 20 cm on average took place in the foundation area due to the shock. The settlement of the bearing ground had been measured at several depths with a sliding micrometer. The measurement hole was choked due to the shock at a depth of 4 m below the footing base, making further measurements impossible. The state of the choked section was checked with a bore hole camera. It was found that a bend of about 35 mm was observed as shown in Fig. 11. This appears to have been caused by slight sliding of a mud layer which is contained in the bearing Kobe Group strata. There was no bend in other deeper sections in the measurement bore hole.

CONCLUSIONS

There is probably no precedent in world bridge history of a case where a large suspension bridge under construction had large earthquake forces imposed on it from directly underneath, causing its foundations to be displaced and the spans increased due to crustal deformation. This influence was investigated very carefully. It was confirmed that the effects were within the design tolerance which had been assumed, with respect to increase in the span, so that it is possible to partially adjust the length of the stiffening girder.

At present, an analysis of the behavior of the foundations is being executed on the basis of the data obtained. The results will be presented in the future together with data from additional investigation.

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