EFFECT OF THE SOUTHERN HYOGO EARTHQUAKE ON THE AKASHI-KAIKYO BRIDGE

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1. INTRODUCTION

On January 17, 1995, a huge earthquake hit Kobe city and its neighboring cities as well as Awaji island in Hyogo prefecture. This earthquake which was officially named “Southern Hyogo Earthquake” caused a devastating damage including over 5,000 death and collapse of infrastructure.

The epicenter was at the northern tip of Awaji island, close to the Akashi-Kaikyo Bridge. However, the bridge survived without any sever structural damage.

This report describe an effect of the quake on the Akashi-Kaikyo Bridge based on a field survey and a basic structural study.

2. SUMMARY OF TOPOGRAPHY AND GEOLOGY OF THE AKASHI STRAIT

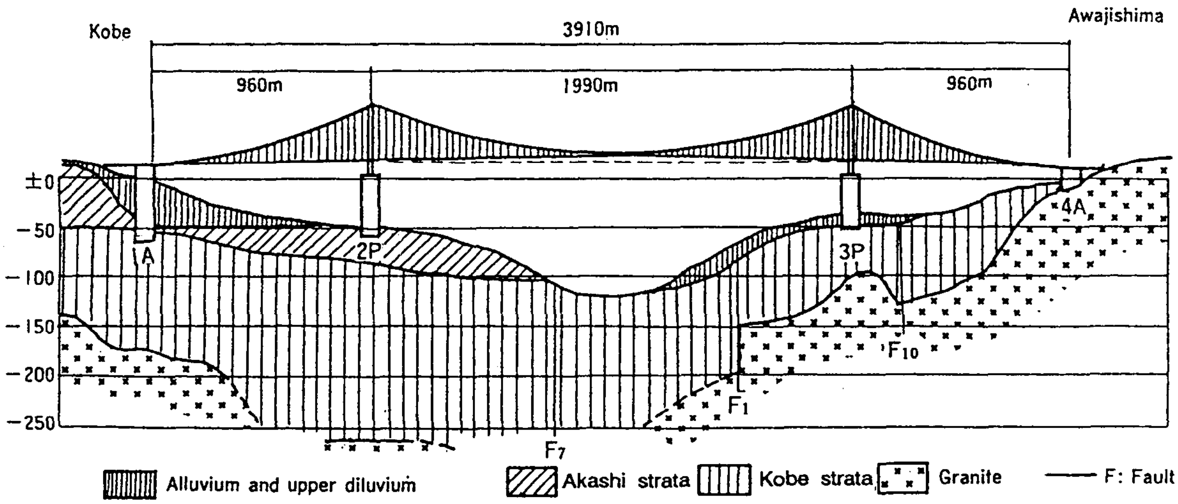
The Akashi Strait extends in a northwest-to-southeasterly direction and is about 4 km wide. At the center of the strait, the topography consists of a 400 m wide seapotshaped valley with a water depth of 100 m, the two sides of which slope steeply.

The geology comprises granite of the Mesozoic era as the bedrock. This is covered roughly with the Kobe stratum of the Mesozoic epoch of Neocene, the Akashi layer of the diluvial epoch of the Quaternary period, an upper diluvial formation, and an alluvial formation (Fig.1).

Results of past sonic prospecting and borehole surveys indicate that east-west system faults centering on F1, F6, and F7 are crossed perpendicularly by a north-south system fault in this part of the strait (Fig.2). Since these faults were only observable below the Kobe layer and do not reach into the Quaternary formation, it was assumed that they had not slipped for at least for 2 million years which is the definition of a nonactive fault.

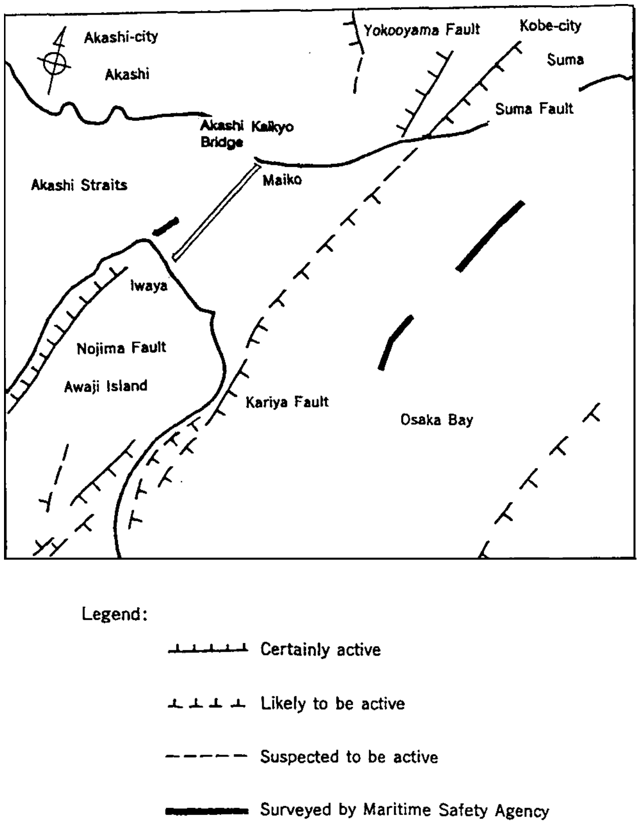
All three east-west faults, including F1, fall toward the north and do not cross the Quaternary period formation. At the center of the strait they are very clear in the results of sonic prospecting, but are somewhat vague at both extensions.

In choosing foundation locations for the Akashi Kaikyo Bridge, the relative position of the extension of the north-south fault F5 offshore of Awaji Island and the extension of faults F11 and 4A were investigated by various means. Result showed that the extensions did not approach the periphery of proposed foundations. Thus the foundations of the Akashi Kaikyo Bridge were chosen so as to avoid the vicinity of faults under the strait.

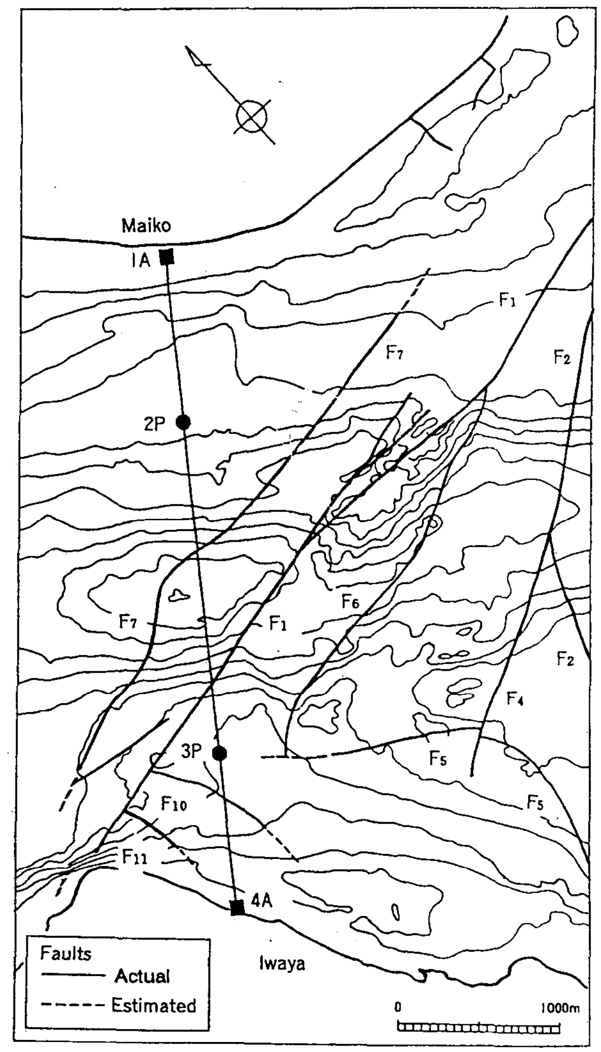


Geological time			Dates back to (X 1,000 Years)	Geological profile of Akashi Strait
Era	Period	Epoc		
Cenozoic	Quartern	Alluvium	6 ~ 1 0	Alluvium
		Diluvium	2,000	Upper Diluvium Akashi strata
	Neocene	Pliocene	7,000	
		Miocene	13,000 20,000 26,000	Kobe strata
	Paloepgene			
Mesozoic	Cretaceous		65,000	Rokko Granite
	Jurassic		135,000	
	Triassic		190,000	

Fig.1 Geological profile of Akashi Kaikyo Bridge site



(a) Source: Active Faults in Japan (1991), Seabed Investigation by Maritime Safety Agency (Intermediate Report) (Jan. 24, 1995)



(b) Source:Report for Recapitulation of Geological Survey of Akashi Strait (No. 1) * by the Honshu-Shikoku Bridge Authority, Dec.1984

* This report was a collection of geological surveys and reports of academic institutions and committees since 1959.

Fig.2 Seabed topography and active fault lines around the Akashi-Kaikyo Bridge

3. SEISMIC DESIGN PHILOSOPHY FOR AKASHI KAIKYO BRIDGE

3.1 Design Seismic Input

The common seismic input for each foundation was defined as the envelope of two acceleration response spectra on the ground surface, assuming that bedrock equivalent to Type I (defined in the Specifications for Highway Bridges) is exposed at the ground surface:

(1) Acceleration response spectrum at the point of bridge construction in the case of an earthquake of magnitude 8.5 at an epicentral distance of 150 km

(2) Since a nearby earthquake could cause greater seismic loading than in (1) above, response spectra for past earthquakes (of magnitude 6.0 or more within a radius of 300 km) evaluated from the theory of probability for a recurrence interval of 150 years

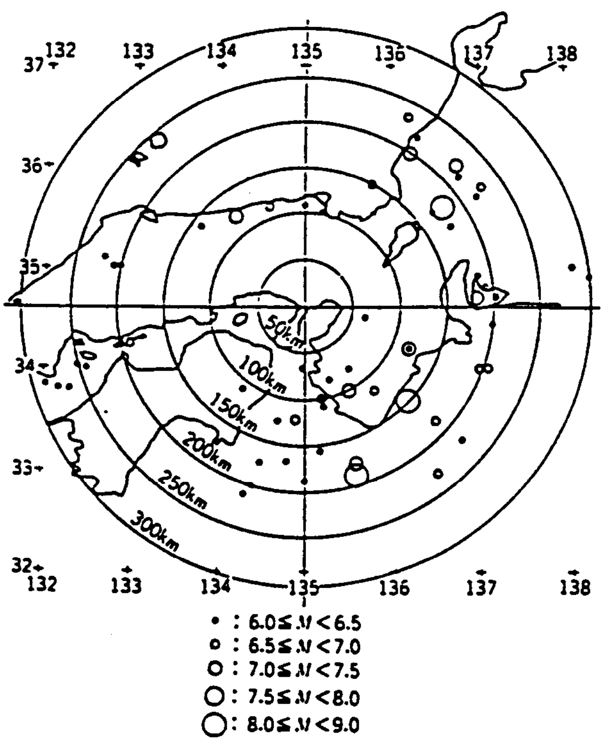


Fig.3 Earthquake records taken into consideration

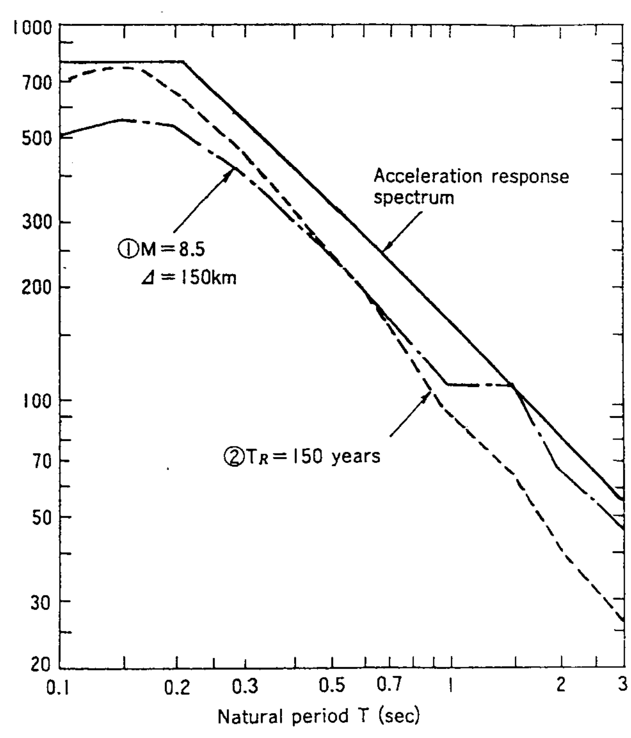


Fig.4 Standard acceleration spectrum of Akashi Kaikyo Bridge

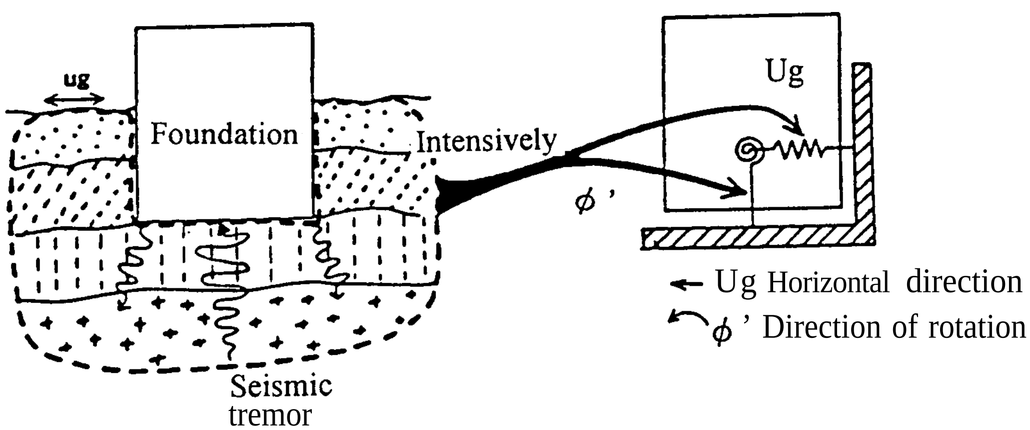
3.2 Seismic Design features of the Akashi Kaikyo Bridge

The Akashi Kaikyo Bridge has the following unique characteristics as compared with bridge constructed in the past:

(1) The substructure is particularly large.

(2) Since the granite rock stratum is extremely deep at the point construction, the thick soft rock layer (the Kobe layer) of the Miocene epoch of Neocene and the unconsolidated gravel stratum (the Akashi layer) of the Pliocene to diluvial epoches laid down on top of the granite have to be the bearing layers.

Due to these unique characteristics, the geological conditions at each foundation position were required to be modeled accurately. Further, a new seismic design procedure was established to take into account the non-linear nature of the ground during an earthquake, and the dynamic interactions between the foundations and ground. The foundation response was obtained by means of dynamic analysis using a rigid-body system model with two degrees of freedom as in the earlier standards as well as by carrying out stability checks by means of time-history response with an FEM model able to accurately take into account nearby ground conditions when checking the seismic stability of the foundations.



(a) Foundation-ground system model (b) Rigid-body two-degree-of-freedom system model

Fig.5 Designing model of foundation- ground system

4. EARTHQUAKE RECORDS IN THE VICINITY OF THE AKASHI STRAIT

Table 1 shows the list of the observation and their results obtained at the Akashi Kaikyo Bridge site and Fig.6 shows the points of the observation.

Fig.7 shows the distribution of maximum acceleration observed in each of these observations.

Table 1
Observation at the Akashi Kaikyo Bridge site

	(1)Observation of intensive quake motion	(2)Array observat-ions of long-period quake motion	(3)Observations of tower behavior (velocity)
Purpose	Field records of large earthquake	To obtain phase difference charact-eristics of seismic motion	To obtain wind response character-istics on superstru-cture
Specification of the observation	Instrument:acceler -ometer Measured depth: 5 m ,60 m ,250 m Maximum accelera -tion detected: 400 gal	Instrument:Servo-type velocity-meter Measured point: Ground surface Measured range: +/-3 kine	Instrument:Servo-type velocity-meter Measured point: Top of tower and middle of tower Measured range: +/- 100 kine
Results	Data exceeded the measurable range	Data exceeded the measurable range	Scheduled to be analyzed

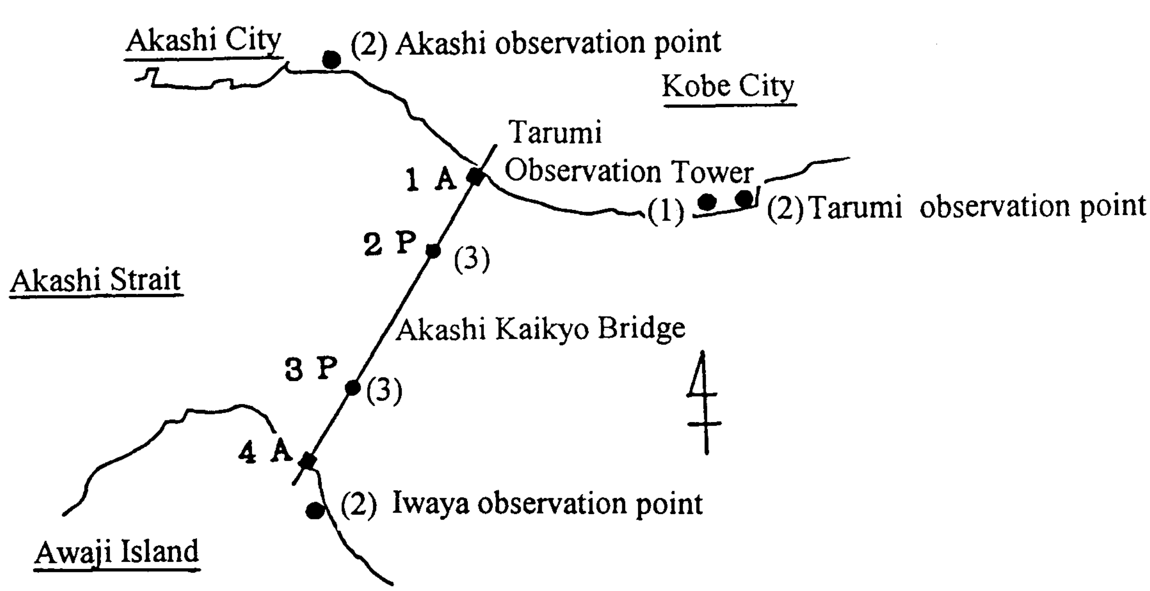


Fig.6 Earthquake-related observations points for the Akashi Kaikyo Bridge

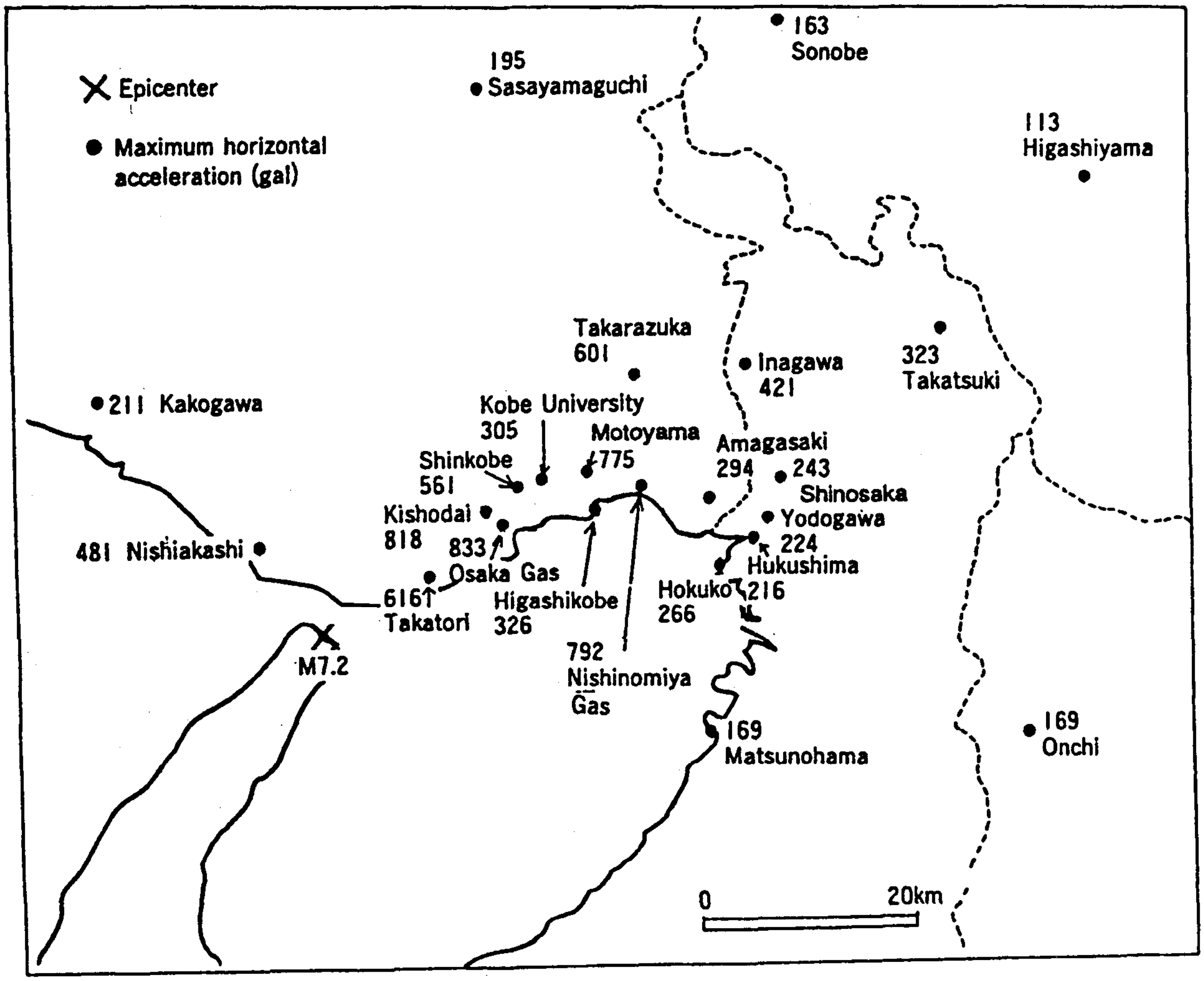


Fig.7 Distribution of maximum acceleration observed

5. EFFECT ON THE AKASHI-KAIKYO BRIDGE

At the time of the Southern Hyogo Earthquake on January 17, 1995, work on the AKashi-Kaikyo Bridge was at the stage of cable squeezing. As soon as possible after the earthquake, investigations of the situation were undertaken by means of structural inspections, surveys, underwater cameras, etc. to estimate the effects of the earthquake on the structure as well as on the bed rock. The results of these investigations are described below.

(1) No damage was incurred by the already-erected main structures, including the anchorages, tower foundations, towers, and cables, etc.

(2) Survey results indicated that the main tower foundation on the Awaji Island side (3P) had suffered a relative displacement of about 1.3 m in an approximately westerly direction, while the Awaji Island anchorage (4A) had also been displaced by about 1.4 m to the west.
As a consequence, the center span has increased from 1990 m to approximately 1990.8 m , with the side span on the Awaji Island side also increasing from 960 m to approximately 960.3 m .

(3) Since a submarine survey indicated no trace of foundation slippage relative to the ground, the measured displacement is assumed to have resulted from displacement of the bed rock itself bearing the foundation.

5.1 Visual Inspection of Structures

Table 2 shows the results of visual inspections urgently conducted immediately after the earthquake (from January 17 to 19). No visual damage were noted on the structures of the 1A and 4A anchorages. Nor were any visual damage noted on the main towers, cables, catwalks, etc.

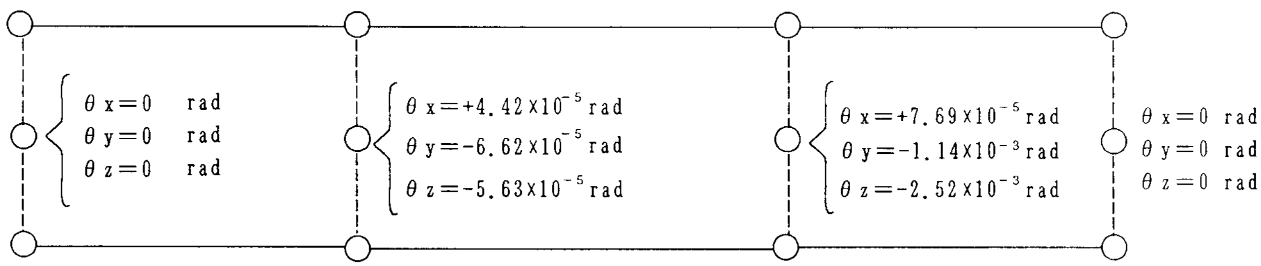
Table 2
Results of visual inspections and countermeasures implemented

Location	Results of visual inspection	Countermeasures
1A	(1) No visual damage found on the anchorage (2) Reclaimed revetment settled by about 50 cm at maximum and displaced by about 30 cm (3) Cracking in pavement of work yard parking lot (4) Subsidence of channel by 30 cm (extended channel)	(2) Restoration of the revet- ment completed (3) Urgent repairs to fill the gaps completed (4) Restoration completed
2P and 3P	(1) No damage in top deck of main tower foundation (2) No damage in main tower and cable saddle (3) Airplane warning light and neon sign properly illuminated (4) Temporary electric substation system at 3P tower damaged (5) Tower elevators halted (6) Catwalk handrail support and side wire net partially damaged (7) Part of cable squeezing machine damaged	(4)Repair completed (5) 2P restored 3P(east)restored (6) Restoration completed (7) Restoration completed
4A	(1) No damage found in anchorage (2) Reclaimed revetment settled about 1 m at maximum,displac -ed by about 20 cm (3) Electric substation system for construction collapsed (4) Work yard settled 1 m at maximum (5) Subsidence of channel by about 50 cm (Tanowaki channel)	(2) Restoration of revetment and channel completed (3) Repair completed (4) Restoration of ground completed (5) Restoration completed begun

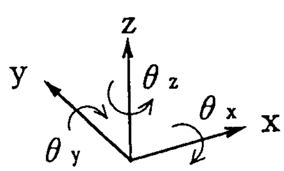
5.2 Observed displacement of the substructures

Δx	0	Δx	+ 4	Δx	unit mm	Δx	+ 872	Δx	+ 1,085
Δy	0	Δy	+ 58	Δy		Δy	− 1,191	Δy	− 1,101
Δz	+ 132	Δz	+ 91	Δz		Δz	− 198	Δz	+ 209

center line of eastern main cable



Δx	0	Δx	+ 4	Δx	+ 872	Δx	+ 1,096
Δy	0	Δy	+ 58	Δy	− 1,191	Δy	− 1,101
Δz	+ 132	Δz	+ 91	Δz	− 198	Δz	+ 205



direction of X−axsis:1A→ 2P

Fig.8 Measured displacement of foundations

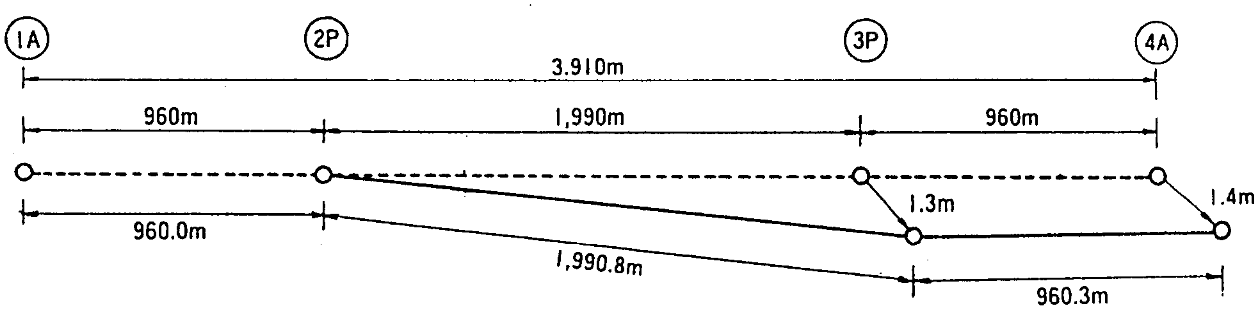


Fig.9 Relative displacement of foundations

5.3 Investigation of Ground Around Main Tower Foundations

1) It is found that no slippage of the main tower foundations occurred, judging from the result of visual ground survey with an underwater camera, sounding surveys, and measurement of the rock bed displacement.
2) With respect to the condition of the ground around the towers, no particularly notable uplift or settlement could be seen.

6. EFFECT OF DISPLACEMENT ON THE STRUCTURE

The effect of the displacement caused by the earthquake on the skeleton of the Akashi-Kaikyo Bridge is shown in Fig.10

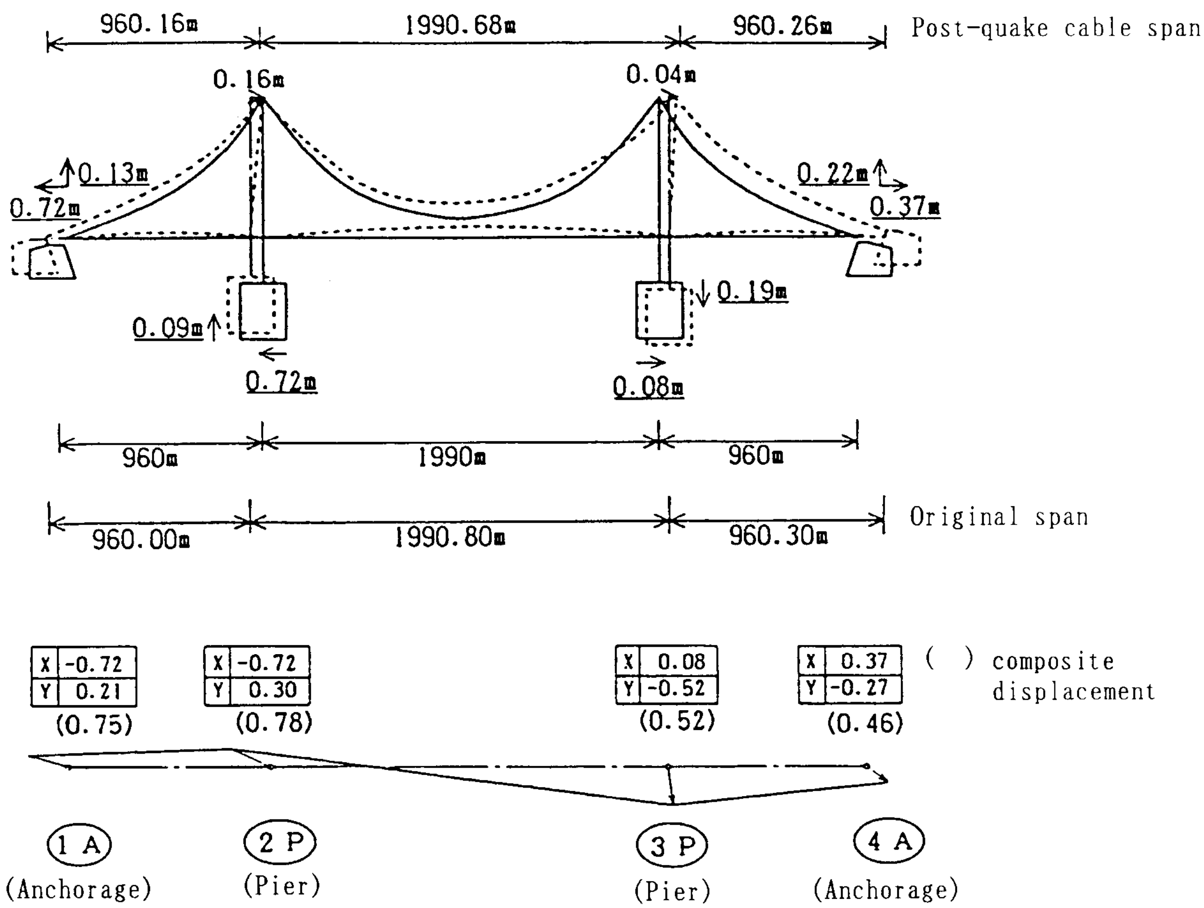


Fig.10 Effect on the structural skeleton of Akashi-Kaikyo Bridge

The effects of changes caused by the earthquake, and the measures being taken to cope with them, are summarized in the table below.

Table 3
Effects of changes and measures to cope with them

Issue	Effects of earthquake and measures to cope with them
Strength	According to the results of an analysis in which the earthquake-induced foundation displacement is added to the completed structure, there would appear to be no problems from a stress viewpoint as regards towers, cables, the stiffening girder, etc.
Alignment	Although the part of vertical alignment exceeds 3% due to the lessened cable sag in the center and the side spans, no problem will occur under the conditions of the highway structure ordinance. Also, the horizontal alignment is now off by about 0.03 degree at the tower, which is not expected to present problems as far as the passage of cars is concerned.
span	The increased 2P-3P and 3P-4A spans will be coped with by adjusting the length of the stiffening girder now being fabricated.