FULL-SCALE AMBIENT VIBRATION MEASUREMENTS OF THE GOLDEN GATE SUSPENSION BRIDGE

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SUMMARY

Extensive experimental investigations were conducted on the Golden Gate Bridge to determine, using ambient vibration data, the mode shapes, the associated frequencies, and the damping of the bridge vibration. The ambient vibration tests involved the simultaneous measurement of vertical, lateral, and longitudinal vibrations of the suspended span and the measurement of longitudinal and lateral vibration of the main tower. Measurements were made at selected points on different cross sections of the stiffening structure and the tower. A total of 91 modal frequencies and mode shapes of the suspended span and a total of 46 modal frequencies and modes of vibration of the tower are determined. Finally, comparison with previously computed mode shapes and frequencies shows good agreement with the experimental results.

DESCRIPTION OF THE BRIDGE

The Golden Gate Bridge (Figs. 2, 3, 4) which lies across the entrance to San Francisco Bay and joins the northern and southern peninsulas was completed in 1937. The main span is 4200 ft, and side spans are 1125 ft long each and are suspended from the main cables. The width of the roadway is 90 ft, and provides six traffic lanes and two sidewalks. The towers (Fig. 4) are made up of two shafts that are connected by horizontal struts in the panels that comprise the upper 500 ft of each tower. The towers are anchored to massive concrete piers which are founded on rock. The two cables are 36.5 inches in diameter. See Refs. 1, 2, 3 for the complete details of the bridge.

DESCRIPTION OF THE INSTRUMENTATION

Figure 1 summarizes the instrumentation used in the tests, the measuring procedures, the data processing, and the experimental set-up of the ambient vibration tests. More details of the description of the instrumentation can be found in Ref. 1. The following is a brief summary of the instrumentation:

1. Motion-Sensing Transducers: bridge response was measured at various locations using Kinemetrics' Model FBA-1 and FBA-11 Force-Balance Accelerometers.
2. Signal Conditioning: signals from the accelerometers were amplified and filtered using three Kinemetrics' Model SC-1 four-channel Signal Conditioners.

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3. Recording: the amplified and filtered data were recorded simultaneously on a Honeywell Model 5600E 14-channel FM tape recorder.
4. Spectrum Analyzer: A Hewlett-Packard 3582A dual channel Spectrum Analyzer was used in the field to observe the frequency content of the data.
5. Electronic Analog-Digital Converter: the recorded analog signals were digitized using the Kinemetrics DDS-1103 electronic analog-digital converter.

CENTER AND SIDE SPAN MEASUREMENTS

The vertical, longitudinal, and lateral motion of the center and side spans on half of the bridge were measured using 12 channels of accelerometers. During each testing session, six accelerometers were mounted at one of the stations (1-18) indicated in Fig. 2. The positions and orientations of these six accelerometers at a typical station are shown in Fig. 3. Six reference accelerometers were located at the cross section indicated by R (Station 8 in Fig. 2), where they remained throughout the tests on both spans. Summing the outputs of accelerometers C and E (Fig. 3) gives the purely vertical motion while subtracting their outputs gives the torsional motion. Similarly, summing the outputs of accelerometers A and B gives the purely lateral motion while subtracting their outputs provides information on the torsional motion.

TOWER-PIER MEASUREMENTS

The longitudinal and lateral motions of the south tower were measured using 9 channels of accelerometers. The reference station was chosen to be at the roadway level (Station 5 of Fig. 4). Purely longitudinal vibration was obtained by summing the outputs of accelerometers A and C (Fig. 4) while torsional motion was obtained by subtracting their outputs. Samples of the Fourier amplitude spectra of the recorded span-vertical motion as well as tower longitudinal motion are shown in Fig. 5.

NATURAL FREQUENCIES, MODES OF VIBRATIONS, AND DAMPING

The procedure for determining mode shapes was to divide the spectral amplitude of the response at a given station by the spectral amplitude of the simultaneously recorded response at the reference station. In this way, an amplitude proportional to the mode shape amplitude at that station is obtained for a given frequency of vibration. Repeating this procedure for every station, the mode shapes were determined. The phase of the response was compared to that of the reference instrument to determine the signs of the modal displacements. The measured mode shapes and natural periods are compared to those obtained by theoretical analyses (Refs. 1,3); Figs. 6, 7, 8, and 9 show some of these comparative results for the suspended spans and tower. Tables 1 and 2 summarize the comparative results for the first few modes of the span and tower vibrations. Certain similarities and differences between the measurements and the computations are apparent, but in general there is an excellent agreement between the measured and computed mode shapes and their associated natural periods. Finally, the estimated damping values in Tables 1 and 2 were obtained by the method of half-power bandwidth of the Fourier spectrum peaks.

ACKNOWLEDGMENTS

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2. Baron, F., Arikan, M., and Hamati, E., "The Effects of Seismic Disturbances on the Golden Gate Bridge," Report No. EERC 76-31, Earthquake Engineering Research Center, University of California, Berkeley, Nov. 1976.

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TABLE 1

COMPARISON BETWEEN MEASURED AND COMPUTED
NATURAL PERIODS OF THE STIFFENING-STRUCTURE VIBRATIONS
(THE GOLDEN GATE BRIDGE)

ORDER	VERTICAL VIBRATION				TORSIONAL VIBRATION				LATERAL VIBRATION			
	MODE	Measured Period in Seconds	Computed Period (sec) Refs. 1,3	Average Damping Ratio	MODE	Measured Period in Seconds	Computed Period (Sec) Refs. 1,3	Average Damping Ratio	MODE	Measured Period in Seconds	Computed Period (sec) Refs. 1,3	Average Damping Ratio
1	V-AS-1	10.917	10.558	.160	T-AS-1	4.429	5.376	.040	L-S-1	18.204	15.555	.163
2	V-S-1	8.190	8.145	.085	T-S-1	4.097	4.730	.038	L-AS-1	8.699	8.722	.083
3	V-S-2	5.650	6.461	.064	T-S-2	2.874	3.425	.030	L-S-2	5.112	4.786	.061
4	V-AS-2	5.120	5.511	.044	T-AS-2	2.410	2.867	.025	L-AS-2	4.312	3.910	.042
5	V-AS-3	4.429	4.924	.042	T-S-3	2.185	2.408	.022	L-S-3	3.901	3.773	.037
6	V-S-3	3.810	3.934	.038	T-AS-3	2.114	2.623	.021	L-AS-3	3.145	2.771	.039
7	V-S-4	3.413	3.498	.035	T-S-4	1.743	2.040	.021	L-S-4	2.482	2.307	.027
8	V-AS-4	2.731	2.976	.028	T-S-5	1.707	1.407	.016	L-AS-4	2.308	2.286	.024
9	V-S-5	2.601	2.407	.030	T-AS-4	1.550	1.683	.019	L-S-5	2.048	1.850	.022
10	V-S-6	2.446	2.400	.034	T-S-6	1.223	1.360	.012	L-AS-5	1.880	1.695	.019

V ≡ Vertical; S ≡ Symmetric; AS ≡ Antisymmetric; T ≡ Torsional; L ≡ Lateral.

TABLE 2

COMPARISON BETWEEN MEASURED AND COMPUTED
NATURAL PERIODS OF THE TOWER VIBRATION
(GOLDEN GATE BRIDGE)

MODE ORDER	LONGITUDINAL VIBRATION			TORSIONAL VIBRATION			LATERAL VIBRATION		
	Measured Period in Seconds	Computed Period (sec) Refs. 1,3	Average Damping Ratio	Measured Periods in Seconds	Computed Period (sec) Refs. 1,3	Average Damping Ratio	Measured Period in Seconds	Computed Period (sec) Refs. 1,3	Average Damping Ratio
1	1.332	1.441	.013	1.214	1.100	.013	2.185	2.307	.022
2	0.546	0.497	.006	0.495	0.440	.005	0.621	0.714	.008
3	0.266	0.278	.003	0.329	0.261	.004	0.375	0.398	.004
4	0.163	0.162	.002	0.220	0.187	.002	0.220	0.290	.002

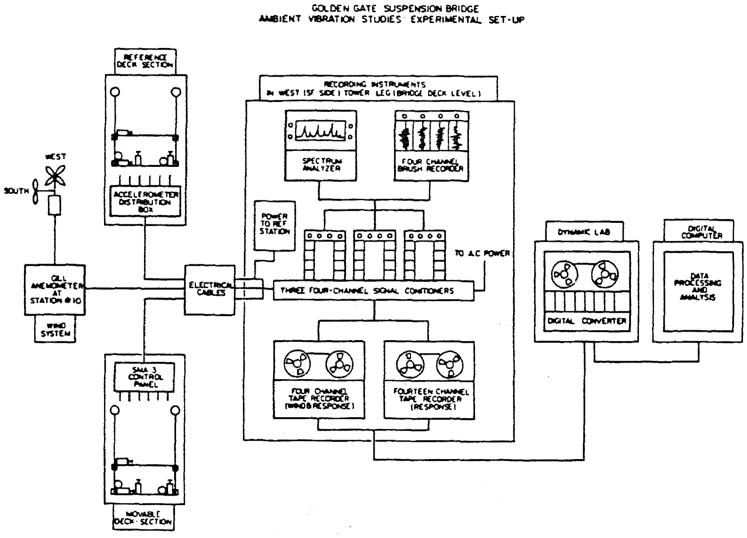


Fig. 1 Schematic diagram summarizes the instrumentation, the measuring procedures, the data processing, and the experimental set-up of the ambient vibration tests of the Golden Gate Bridge.

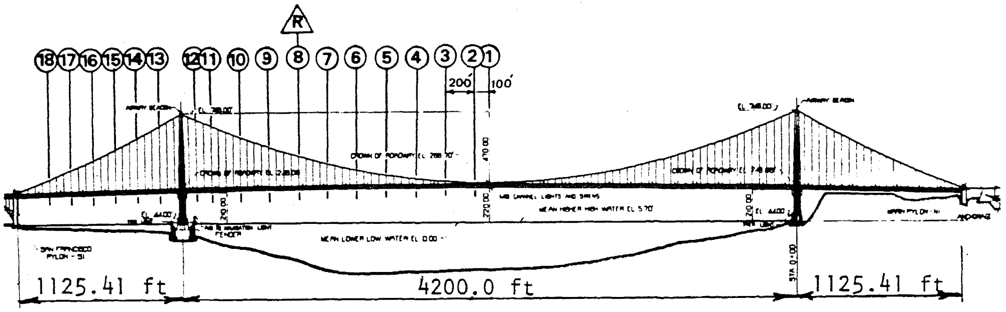
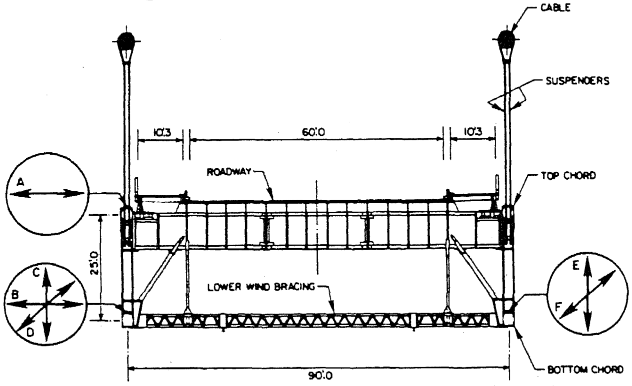


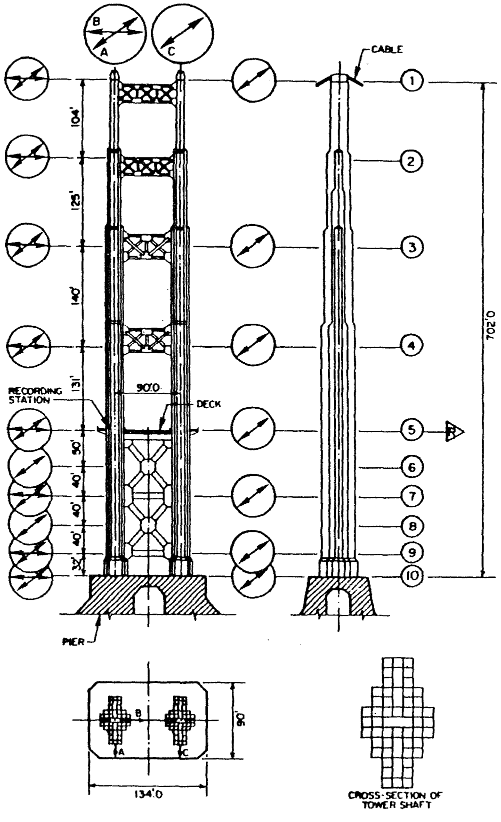
Fig. 2 **The Golden Gate Suspension Bridge : Measurement Stations**



CROSS-SECTION
THE GOLDEN GATE SUSPENTION BRIDGE

THE RECORDED MOTION AT DIFFERENT POINTS OF A TYPICAL CROSS-SECTION

Fig. 3 Deployment of accelerometers on typical cross section.



MEASUREMENT STATIONS OF THE GOLDEN GATE BRIDGE TOWER

Fig. 4

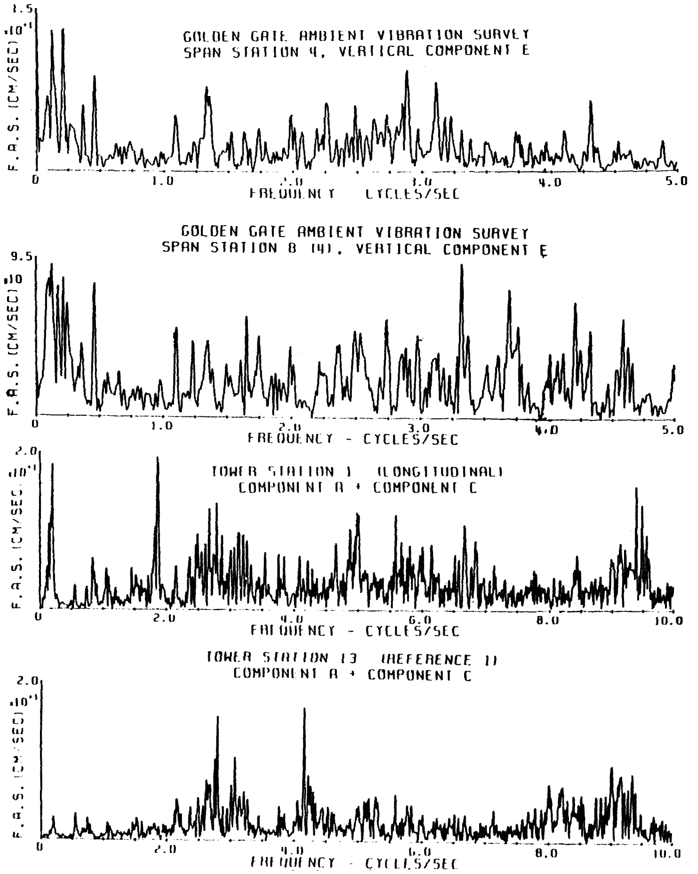


Fig. 5 Fourier amplitude spectra of the recorded acceleration on Station 4 of the span and Station 1 of the tower and their corresponding references.

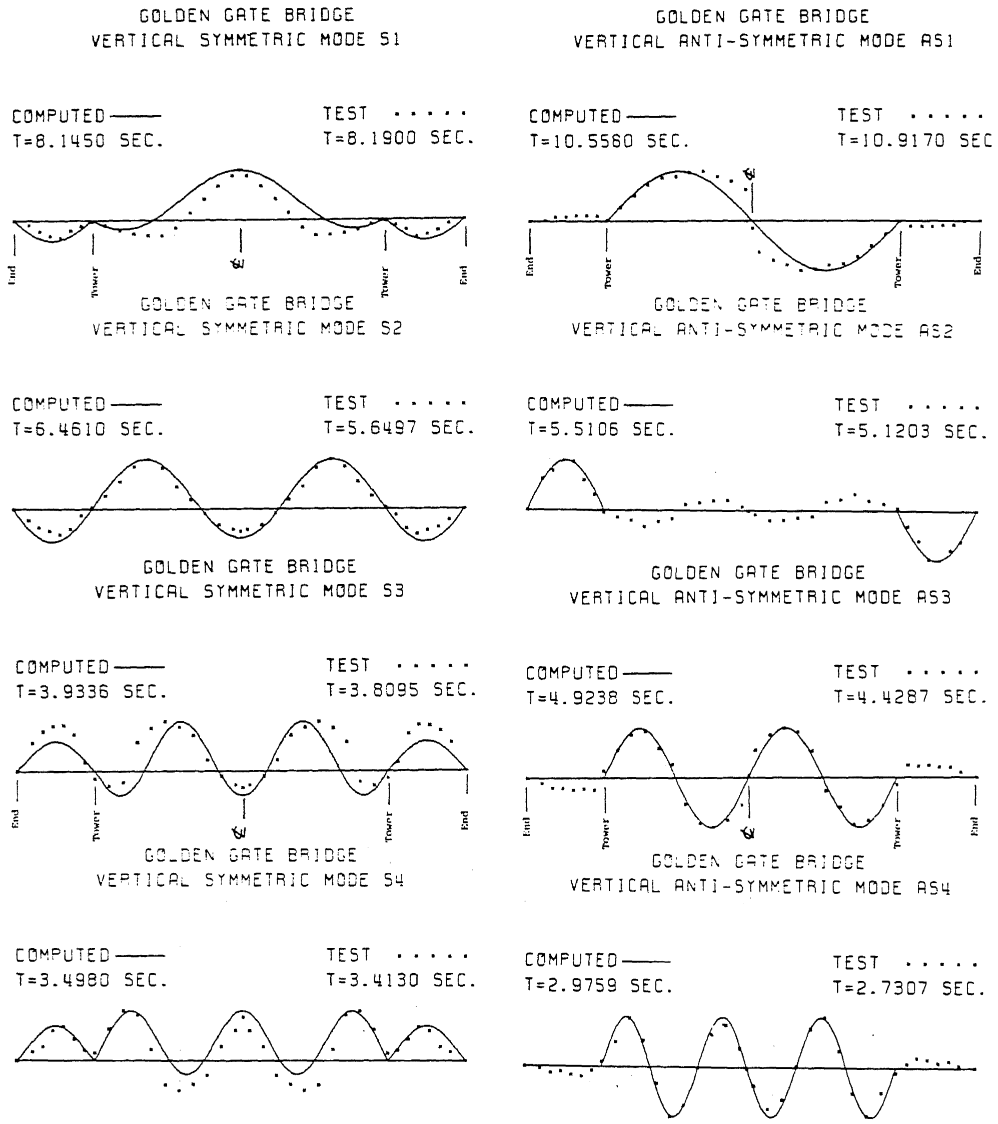


Fig. 6 Comparison between computed and measured first four natural periods and mode shapes of symmetric and antisymmetric vertical vibration of the stiffening structure of the Golden Gate Bridge.

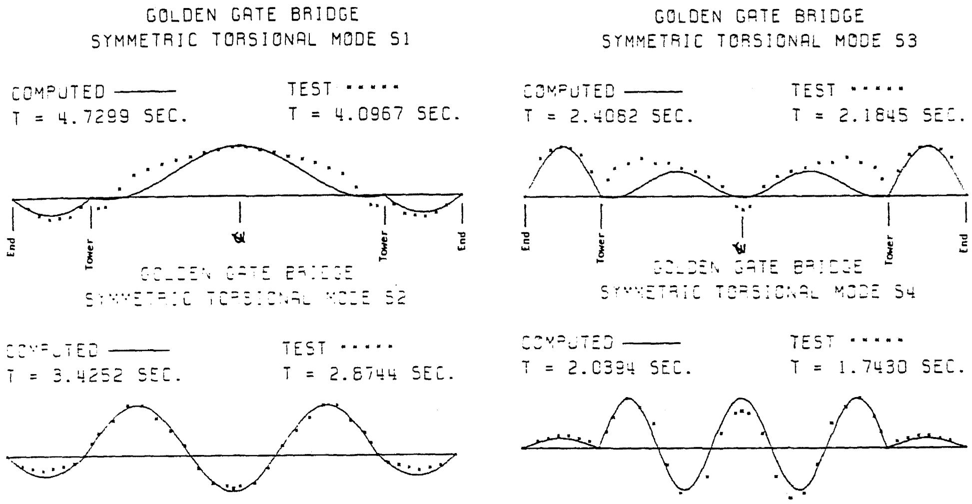


Fig. 7 Comparison between computed and measured first four natural periods and mode shapes of symmetric torsional vibration of the stiffening structure of the Golden Gate Bridge.

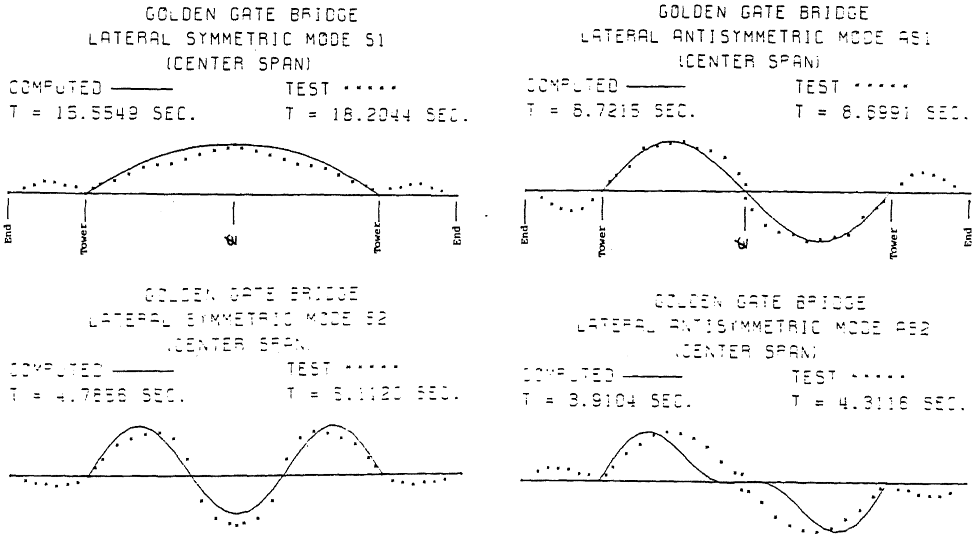


Fig. 8 Comparison between computed and measured first two natural periods and mode shapes of symmetric and antisymmetric lateral vibration of the stiffening structure of the Golden Gate Bridge.

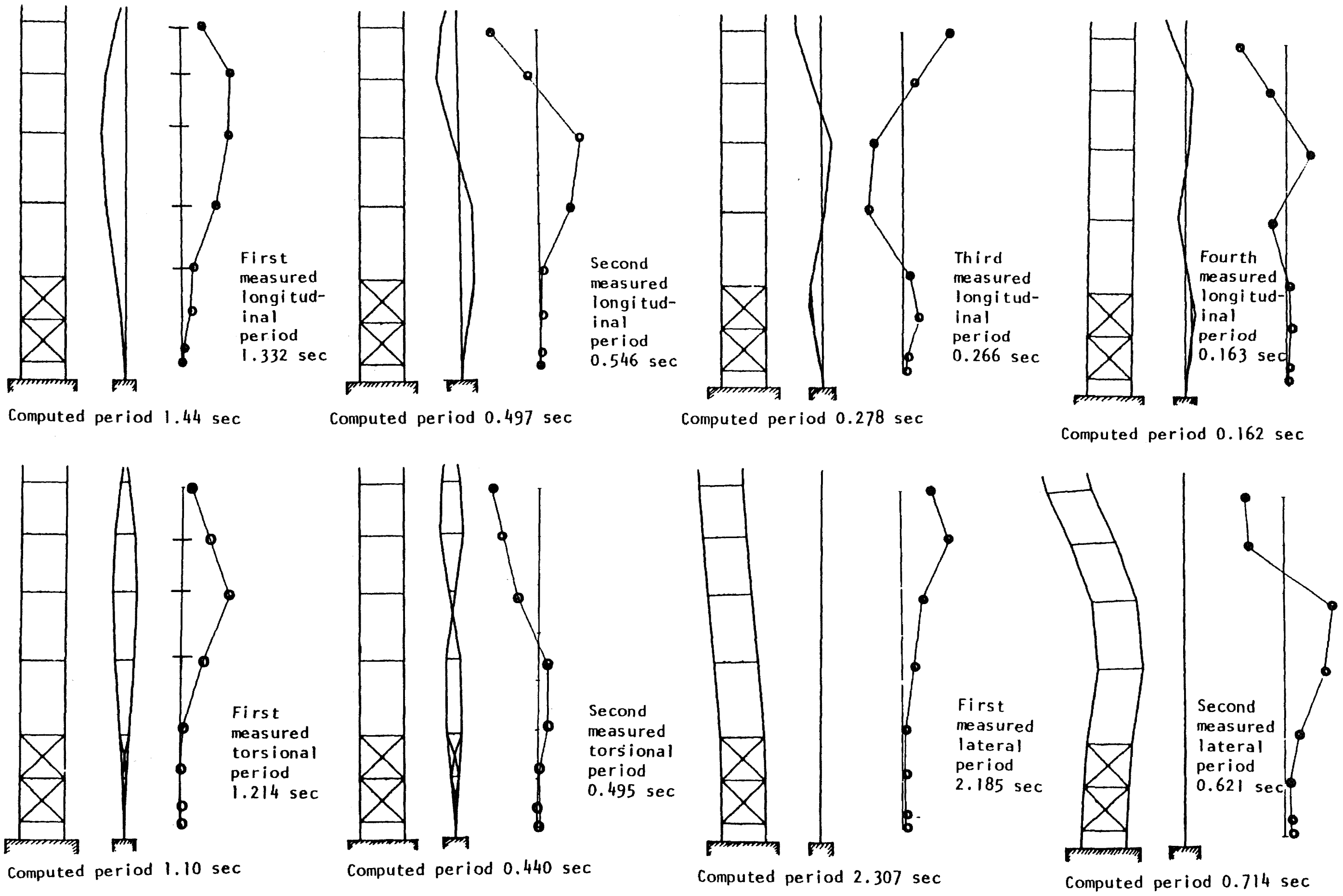


Fig. 9 Comparison between computed and measured natural periods and mode shapes of longitudinal, torsional and lateral vibrations of the tower of the Golden Gate Bridge.