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Seismic Performance of Long-Span Suspension Bridges in the USA
Comportement sismique des ponts suspendus de grande portée , USA
Seismische Leistung von weitgespannten Hängebrücken, USA

Subcommittee on Seismic Performance of Bridges
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The subcommittee, started in 1993, reports on the performance of bridges in earthquakes. In addition to reporting on long-span bridges, reports are planned on the performance of bridges in the Northridge Earthquake of January 17, 1994, and the Kobe Earthquake of January 17, 1995.

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SUMMARY
Of the 117 long-span suspension bridges built in the USA between 1801 and 1994, 57 bridges are in service and 60 are not. The bridges have performed well in earthquakes. The 57 bridges in service, from 6 to 140 years in age, have main span lengths between 126 and 1299 meters. Seismic evaluation studies have started on some of the 57 bridges with the objective of predicting performance, assessing vulnerabilities, and recommending retrofit of deficient bridges.

RÉSUMÉ
Des 117 ponts suspendus à grande portée construits aux États-Unis depuis 1801, 57 sont actuellement en service et 60 ne le sont plus. Ces ponts suspendus se sont bien comportés sous l'action sismique. Les 57 ponts en service aujourd'hui ont de 6 à 140 ans, des portées entre 126 et 1299 mètres. Des études pour l'évaluation sismique ont déjà commencé pour quelques ponts afin de prévoir leur comportement sismique et déterminer leur vulnérabilité et pour en recommander la consolidation si nécessaire.

ZUSAMMENFASSUNG
Von 117 weitgespannten Hängebrücken, die in den U.S.A. zwischen 1801 und 1994 gebaut wurden, sind 57 noch in Betrieb und 60 nicht mehr. Die Brücken haben sich bei Erdbeben gut bewährt. Die 57 Brücken, die zwischen 6 und 140 Jahren alt sind, haben eine Spannweite des Hauptteils zwischen 126 und 1299 Metern. Seismische Beurteilungsstudien an einigen der 57 Brücken wurden begonnen mit dem Ziel, Leistungen zu prognostizieren, Anfälligkeiten zu beurteilen und Empfehlungen in Bezug auf eine Wiederherstellung von defekten Brücken anzubieten.

1. INTRODUCTION

This paper summarizes a work-in-progress report on the seismic performance of 117 long-span highway, railroad, and pedestrian suspension bridges built in the United States between 1801 and 1994. The report, based on available information, is under review by the subcommittee. A long-span suspension bridge is defined as one where the length of the main span is ≥ 122 meters. Fig. 1 shows the components of a suspension bridge. Of the 117 bridges, 57 bridges are in service and 60 are not. Of those not in service, 22 bridges were closed, replaced, or destroyed for reasons other than damage in earthquakes such as -- corrosion of the suspension cables, snow/ice overloads, wind storms and floods; inadequate load carrying capacity or general deterioration. At present, no information is available as to why the remaining 38 bridges are no longer in operation. However, a survey of available literature indicates no mention of poor performance in earthquakes. Table 1 lists data on the 57 bridges, in service, and Fig. 2 shows the number of such bridges in each state.

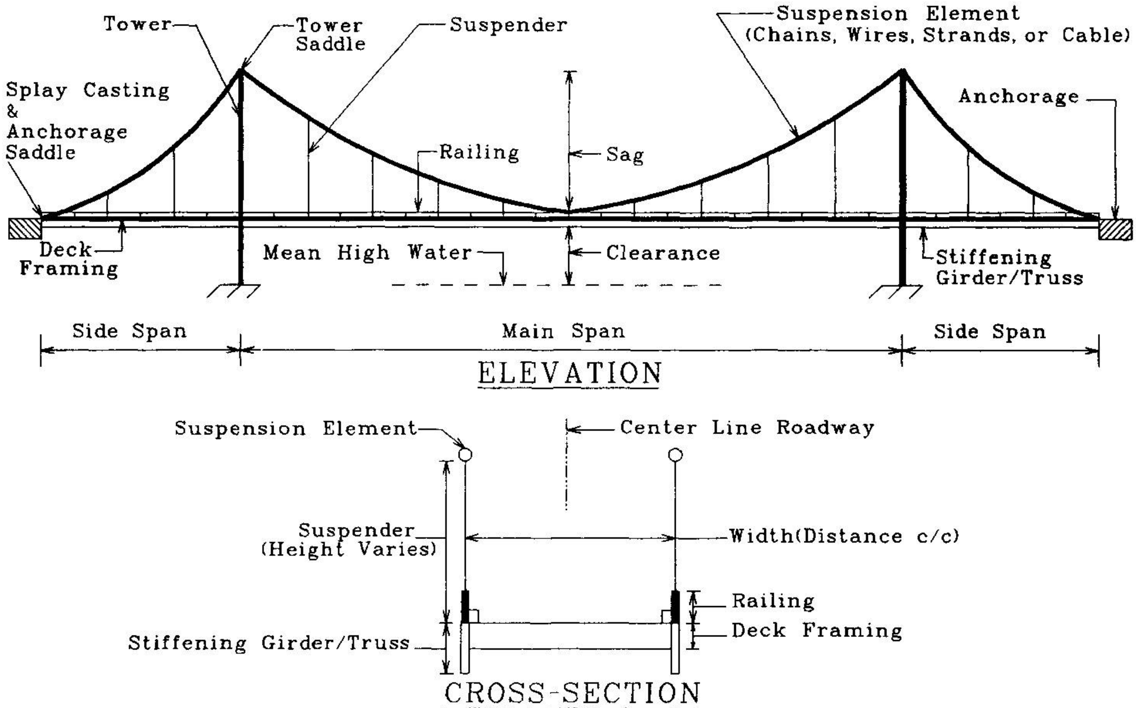


Fig. 1 Components of a Suspension Bridge

2. PERFORMANCE

The 57 bridges, in service, have performed well in earthquakes -- there are no reported failures. The majority of these bridges were neither designed to resist seismic forces nor subjected to strong (magnitude 6.0-6.9) or major (magnitude 7.0-7.9) earthquakes. Unless a bridge is shown to be safe, based on a seismic evaluation study, past performance should not be assumed to insure similar performance in the future. The subcommittee report documents: recorded performance of instrumented bridges, observed performance of non-instrumented bridges, predicted performance based on computer models, and simulated performance of laboratory models. The 31-year-old Vincent Thomas Bridge, located in Los Angeles, California, and instrumented with 26 strong-motion sensors, has performed well in earthquakes. Tiltmeters installed on the piers of the Golden Gate Bridge, in San Francisco, California, show that this 57-year-old bridge has not displaced as a result of settlement, scour, or earthquakes. The bridge performed well in the 1989 Loma Prieta earthquake, moment magnitude $M_w=7.0$, since the bridge site experienced a peak ground acceleration of only 8% of gravity. However, computer models have predicted that a major earthquake on a nearby segment of the San Andreas or Hayward faults, with a peak ground acceleration of 65% of gravity, would cause severe damage to the Golden Gate Bridge.

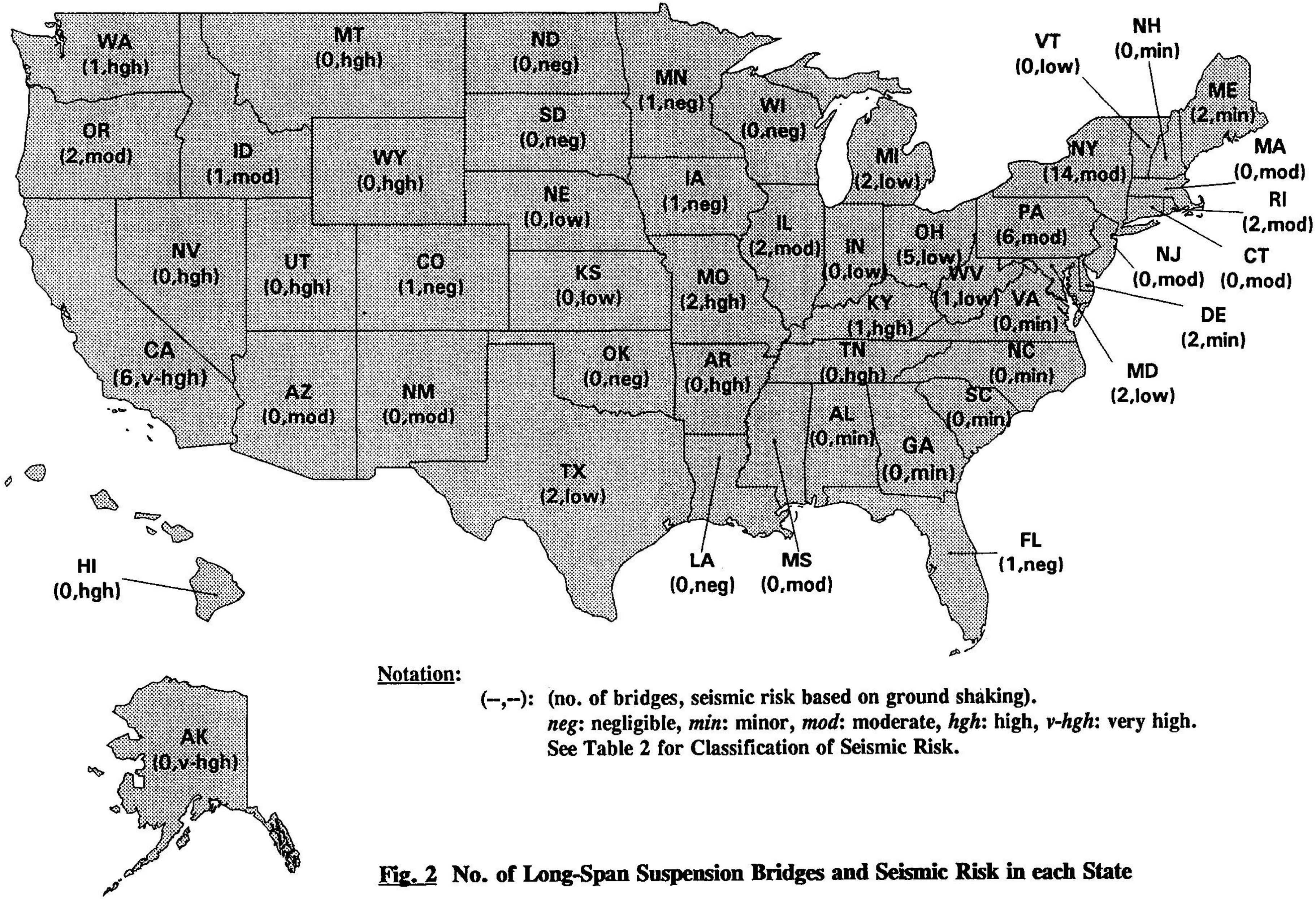
Name of Bridge	Location (state)	Opened to Traffic in	Main Span (meters)	Age as of 1994 (years)	Seismic Risk
San Francisco-Oakland Bay	California *(6)*	1936	704	58	Very High *(6)*
Golden Gate		1937	1280	57	
Vincent Thomas		1963	457	31	
Bidwell Bar		1965	338	29	
Klamath River II		1967	131	27	
Guy A. West		1968	183	26	
Maysville	Kentucky	1931	323	63	High *(4)*
Grand Auglauze	Missouri *(2)*	1920	126	74	
Missouri River		1954	188	40	
Tacoma Narrows II	Washington	1950	854	44	
Dent	Idaho	1972	320	22	Moderate *(27)*
Davenport	Illinois *(2)*	1935	226	59	
Missouri River		1956	196	38	
Brooklyn	New York *(14)*	1883	486	111	
Williamsburg		1903	488	91	
Manhattan		1909	448	85	
Kingston-Poughkeepsie		1922	215	72	
Bear Mountain		1924	498	70	
Mid-Hudson		1930	457	64	
George Washington		1931	1067	63	
Triborough		1936	421	58	
Thousand Islands-USA		1938	244	56	
Bronx-Whitestone		1939	701	55	
South Channel		1958	273	36	
Ogdensburg-Prescott		1960	351	34	
Throgs Neck		1961	549	33	
Verrazano Narrows		1964	1299	30	
St. Johns	Oregon *(2)*	1932	368	62	

Note: ( ) – refers to no. of bridges. Seismic risk is based on ground shaking – see Table 2.

Table 1 Data on 57 Long-Span Suspension Bridges

Name of Bridge	Location (state)	Opened to Traffic in	Main Span (meters)	Age as of 1994 (years)	Seismic Risk
Crooked River	Oregon*(cont)*	1963	179	31	Moderate *(cont.)*
Benjamin Franklin	Pennsyl-vania *(6)*	1926	534	68	
Seventh Street		1926	135	68	
Ninth Street		1927	131	67	
Sixth Street		1928	213	66	
South Tenth Street		1933	221	61	
Walt Whitman		1957	610	37	
Mount Hope	Rhode Island *(2)*	1929	366	65	
Newport		1969	488	25	
Delaware Memorial I	Delaware *(2)*	1951	655	43	Minor *(4)*
Delaware Memorial II		1968	655	26	
Waldo-Hancock	Maine *(2)*	1931	244	63	
Deer Isle		1939	329	55	
Chesapeake Bay I	Maryland *(2)*	1952	488	42	Low *(12)*
Chesapeake Bay II		1972	488	22	
Ambassador	Michigan (2)	1929	564	65	
Mackinac		1956	1159	38	
John A. Roebling	Ohio *(5)*	1867	322	127	
Steubenville		1904	213	90	
U.S. Grant		1927	229	67	
Fort Steuben		1928	210	66	
Anthony Wayne		1930	239	64	
Waco	Texas *(2)*	1870	145	124	
Red River		1927	213	67	
Wheeling II	West Virginia	1854	308	140	
Royal Gorge	Colorado	1929	268	65	Negligible *(4)*
Mayo	Florida	1947	129	47	
Missouri River	Iowa	1960	226	34	
Father Louis Hennepin	Minnesota	1988	191	6	

Table 1 **Data on 57 Long-Span Suspension Bridges** *(cont.)*



Notation:

(--,--): (no. of bridges, seismic risk based on ground shaking).
neg: negligible, *min*: minor, *mod*: moderate, *hgh*: high, *v-hgh*: very high.
See Table 2 for Classification of Seismic Risk.

Fig. 2 No. of Long-Span Suspension Bridges and Seismic Risk in each State

3. SEISMIC RISK

Since the seismicity and geology in the United States varies, bridges are subject to different seismic risks. Table 2 shows classification of seismic risk based on ground shaking using the maximum value of the AASHTO (American Association of State Highway and Transportation Officials Standard Specifications for Highway Bridges, 1992) acceleration coefficients specified for each state. This is only a preliminary guide. As more information becomes available, the subcommittee will document seismic risk based on site-specific conditions, probability of future earthquakes, and other factors. Fig. 2 also shows the seismic risk for each state -- varying from negligible to very high.

Seismic Risk	Value of AASHTO Acceleration* Coefficients	No. of States Subject to Seismic Risk	No. of Long-Span Suspension Bridges (Total = 57)
Very High	≥ 0.50	2	6
High	≥ 0.29 and < 0.50	10	4
Moderate	≥ 0.15 and < 0.29	12	27
Minor	≥ 0.10 and < 0.15	8	4
Low	≥ 0.05 and < 0.10	9	12
Negligible	< 0.05	9	4

* *Bedrock acceleration with a 90% probability of not being exceeded in 50 years*

Table 2 Classification of Seismic Risk based on Ground Shaking

4. SEISMIC EVALUATION STUDIES

The objective of an evaluation study is to predict how an existing bridge will perform in a design earthquake, assess vulnerabilities, and recommend retrofit of deficient bridges. In general, an evaluation study includes the following stages: (i) assessing seismic risk and developing input ground motions, (ii) establishing seismic performance criteria, (iii) developing and validating computer models based on soil-structure interaction, (iv) conducting linear and non-linear seismic analysis, (v) laboratory testing, and (vi) developing conceptual retrofit schemes and estimating their costs for deficient bridges. The most extensive study so far has been on the Golden Gate Bridge. Seismic retrofit on the bridge is scheduled to start in the spring of 1995. The retrofit is estimated to cost $155 million, including studies, design and construction, and is scheduled for completion in 1998. Studies have also been completed on the 140-year-old Wheeling II Bridge (West Virginia), the 58-year-old San Francisco-Oakland Bay Bridge (California), and the 44-year-old Tacoma Narrows II Bridge (Washington). Studies are in progress on the the 62-year-old St. John's Bridge (Oregon) and the 55-year-old Bronx-Whitestone Bridge (New York). The subcommittee will survey the owners of the remaining bridges regarding the status of evaluation studies and proposed retrofits, if any.

5. DISCLAIMER

Views expressed are those of the members and not those of the ASCE or their employers.

6. REFERENCES

Are too numerous to list and are included in the report which is under review by the subcommittee.