Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 73/1/73/2 (1995)

Artikel: Dynamic characteristics of Port Mann Bridge by modal testing

Autor: Ventura, Carlos E. / Felber, Andreas J. / Prion, Helmut G.L.

DOI: https://doi.org/10.5169/seals-55322

Dynamic Characteristics of Port Mann Bridge by Modal Testing

Caractéristiques dynamiques du pont Port Mann à partir d'essais modaux

Dynamische Charakteristik der Port-Mann-Brücke, ermittelt durch modale Schwingungsmessungen

Carlos E. VENTURA
Assistant Professor
Univ. of British Columbia
Vancouver, BC, Canada

Andreas J. FELBER
President
EDI Ltd
Vancouver, BC, Canada

Helmut G.L. PRION
Assistant Professor
Univ. of British Columbia
Vancouver, BC, Canada

Peter R. TAYLOR
Vice President
Buckland & Taylor Ltd
Vancouver, BC, Canada

Aegide VAN SELST
Specialist
Buckland & Taylor Ltd
Vancouver, BC, Canada

SUMMARY

This paper describes the vibration studies conducted at the Port Mann Bridge over the Fraser River, near Vancouver. Ambient vibration measurements were conducted on the 585 m long main span of the bridge and on one of the sections of its south approach. The information obtained from these tests was used to gain confidence in a computer model of the bridge used as part of a seismic assessment. The unusually light and flexible superstructure and the massive foundations presented an ideal opportunity to use ambient testing to increase understanding of prototype behaviour.

RÉSUMÉ

Cet article présente les essais de vibrations effectués sur le pont Port Mann traversant la rivière Fraser près de Vancouver. Des mesures de vibrations furent effectuées sur la portée principale de 585 mètres du pont, ainsi que sur un des accès. L'information obtenue à partir de ces essais fut utilisée pour le calibrage d'un modèle de la structure utilisé pour une étude portant sur la sécurité parasismique du pont. Le faible poids et la flexibilité de la structure métallique par rapport aux fondations ainsi que les conditions du sol en place présentaient une occasion intéressante pour l'utilisation de mesures ambiantes afin de mieux connaître le comportement des prototypes.

ZUSAMMENFASSUNG

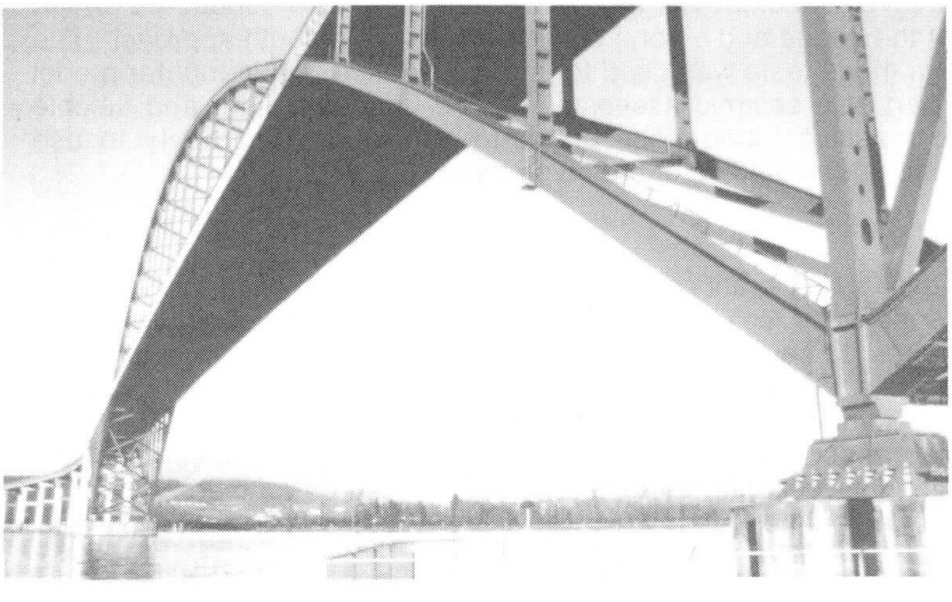
Schwingungsstudien wurden an der Port-Mann-Brücke über den Fraser River nahe Vancouver durchgeführt. Verkehrs- und winderregte Schwingungen wurden an der 585 m langen Bogenbrücke und an der südlichen Anfahrtsrampe vorgenommen. Die ermittelten Schwingungsformen und Eigenfrequenzen wurden zur Verifikation eines Computermodells verwendet, welches zur Bestimmung der Erdbebensicherheit der Brücke diente. Die ungewöhnlich leichte und flexible Brücke bot eine ideale Gelegenheit für Schwingungsmessungen am bestehenden Tragwerk, was zu einem besseren Verständnis des dynamischen Verhaltens führte.

1. INTRODUCTION

The Port Mann Bridge , built in the early 1960s, is today a key component of the Trans Canada Highway carrying traffic across the Fraser River, between the municipalities of Coquitlam and Surrey, east of Vancouver, British Columbia, Canada. Because of the importance of the bridge and the seismic hazard of the region, in March of 1994 the Ministry of Transportation and Highways of British Columbia contracted Buckland and Taylor (B&T) Ltd. of Vancouver to assess the seismic behaviour of the bridge and to develop a seismic retrofit strategy. As part of this study, EDI Experimental Dynamic Investigations Ltd. was contracted to conduct a series of ambient vibration measurements of selected portions of the bridge. The tests were performed using the eight channel vibration measurement system of the University of British Columbia. Results from this study provided the necessary information to calibrate the analytical model of the bridge and its foundations used to determine its resistance to earthquake motions and to plan possible means of retrofit. This paper describes the results of the ambient vibration study (AVS) of the Main Span and a portion of the South Approach of the bridge, and the process followed to calibrate the computer model used in a three-dimensional dynamic analysis.

2. DESCRIPTION OF BRIDGE

A general overview of the Port Mann Bridge is shown in Fig.1. The bridge crossing is located where the Fraser River is about 900 m wide and consists of three structures: the Main Span and the North and South Approaches as shown in Fig.2. The Main Span crossing the navigational channel is formed by two three-span steel stiffened tied arches that provide a 44 m vertical clearance above high water level and a 365 m clear centre span for shipping. The side spans are 110 m long. The arches, in combination with the stiffening girders, were designed to act as a funicular polygon with no bending moments under dead load. The arch supports were pinned at pier N1, on longitudinal rollers at S1 and on rockers at N2 and S2, permitting longitudinal movement.



Because of poor foundation conditions, the weight of the superstructure was kept to a minimum. As a consequence, an orthotropic steel deck was chosen for the Main Span [3,4], which was designed to simultaneously fulfil the function of supporting the wheel loads and act as the upper flange of the stiffening girders. It also doubles as a horizontal diaphragm to transfer lateral loads and support the stiffening girder and arches. Longitudinal steel ribs are welded to the 12 mm thick

Fig. 1 Underside View of the Port Mann Bridge

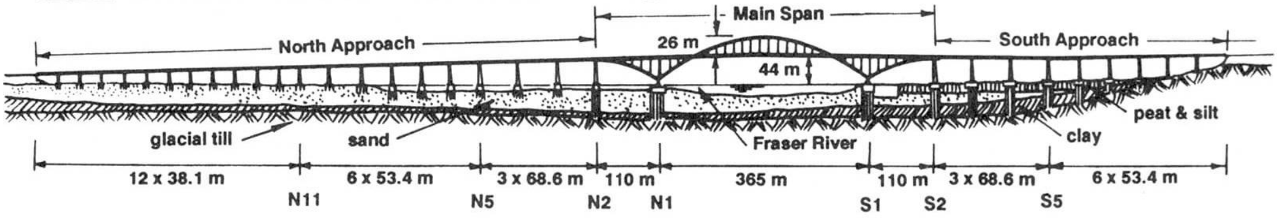


Fig. 2 Elevation View of Port Mann Bridge

steel deck, forming panels 7.6 m long and spanning between the stiffening girders. A 50 mm layer of asphalt paving covers the steel deck. The 1.2 m wide sidewalks, made of precast lightweight concrete, are connected to the deck with stud welded anchor bolts. Cross beams that are tapered to provide the transverse roadway slopes, support the deck at 1.9 m spacing.

The arches consist of riveted steel boxes, 1.35 m deep and 1.32 m wide, with plate thickness varying between 27 mm at the apex and 38 mm at the supports. The stiffening girders are box sections with 12 mm thick webs, 3.66 m deep. The bottom flange consists of a 1.32m x 25 mm plate with 25 mm cover plates for local reinforcement; the top flange consist of a 1.48 m x 12 mm plate with one or two 20 mm cover plates over part of its length. The orthotropic deck forms part of the top flange.

Both hangers and columns are riveted I-sections built from medium grade angles and plates. All hangers except the shortest one have the same cross-section and have a slender appearance (533 mm deep). The cross-section of the columns below deck vary with length and have batten plates between the flanges. Cross braces at the main piers S1 and N1, and diagonal braces between the arches provide lateral stability to the structure. At the intersections of arches and stiffening girders, braces had to be eliminated to provide clearance for the traffic and a service gantry below. Boxed cross beams provide stiff portals to transfer the lateral loads across the openings.

The bridge approaches consist of a 200 mm thick reinforced concrete deck supported by three main steel plate girders and four stringers which are supported by cross beams at 5.7 m spacing. The North Approach consists of seven sets of three-span continuous composite girders with span lengths ranging from 38.1 m to 53.4 m to 68.6 m. The South Approach consists of three sets of three-span continuous girders with span lengths of 53.4 m and 68.6 m. The main girder depth varies from 1.68 m to 2.44 m to 3.36 m for the respective span lengths. The approach superstructure is supported on reinforced concrete bents with tapered hollow columns which are founded on common pile caps.

In general, the soil profile consists of compact till-like founding material at a depth of about 60 m, overlain by a 30 m layer of very sensitive marine deposited clay, topped by sand layers of varying density to within about 13 m of the surface. Along the south bank a thick layer of peat and silt overlays the sand. The thickness of the clay decreases and the sand layer increases towards the north side of the river. The four piers supporting the Main Span (S2, S1, N1 and N2) and the South Approach bents S3, S4 and S5 have the most problematic foundations and rely on a total of 612 concrete-filled steel tubular piles, some in excess of 65 m deep. The main piers S1 (which is D-shaped and located on the south bank) and N1 (which has an elliptical shape) are aligned along the flow direction of the river, resulting in a skewness of 27 and 16 degrees with respect to the bearing lines respectively.

As a reference, the mass of the superstructure is about $16*10^6$ kg while the masses of the main piers are about $20*10^6$ kg (N1) and $23*10^6$ kg (S1). Details of the foundations and soil conditions determined at the time of construction of the bridge are given by Golder and Willeumier [2].

3. VIBRATION MEASUREMENTS

The AVS was conducted in two phases. The work during the first phase concentrated on pier N1 and on the northern part of the Main Span was completed in April 1994. The information obtained during this phase provided a general idea of the fundamental modes of vibration of the bridge. The work during the second phase, conducted in June 1994, concentrated on refining the mode shapes of the Main Span, on determining in which modes pier S1 had a significant participation, and on determining the fundamental modes of vibration of the South Approach structure between piers S2 and S5.

UBC's eight-channel accelerometer vibration measurement equipment and EDI's testing hardware and data analysis software were used to collect and analyze the ambient vibration data from more than 120 selected locations on the bridge and its foundations. Details of the AVS are described in Felber and Ventura [1]. The first nine experimentally determined natural frequencies and associated mode shapes of the Main Span are shown in Fig. 3. Plan views and elevation views of the inferred mode shapes are shown in the figure. The lowest frequencies are very close (0.46 Hz and 0.50 Hz) and the corresponding mode shapes are mainly a transverse mode and a longitudinal mode, respectively. All the modes determined experimentally include significant components in the vertical, transverse and longitudinal directions of the bridge. As a consequence, the calibration of the computer model of the bridge could be accomplished only through a three-dimensional dynamic analysis.

Mode No.	Frequency (Hz) Exp.	Frequency (Hz) Anal.
1	0.46	0.461
2	0.50	0.464
3	0.68	0.670
4	0.84	0.795
5	0.87	1.089
6	1.07	1.129
7	1.08	1.073
8	1.18	1.197
9	1.37	1.229

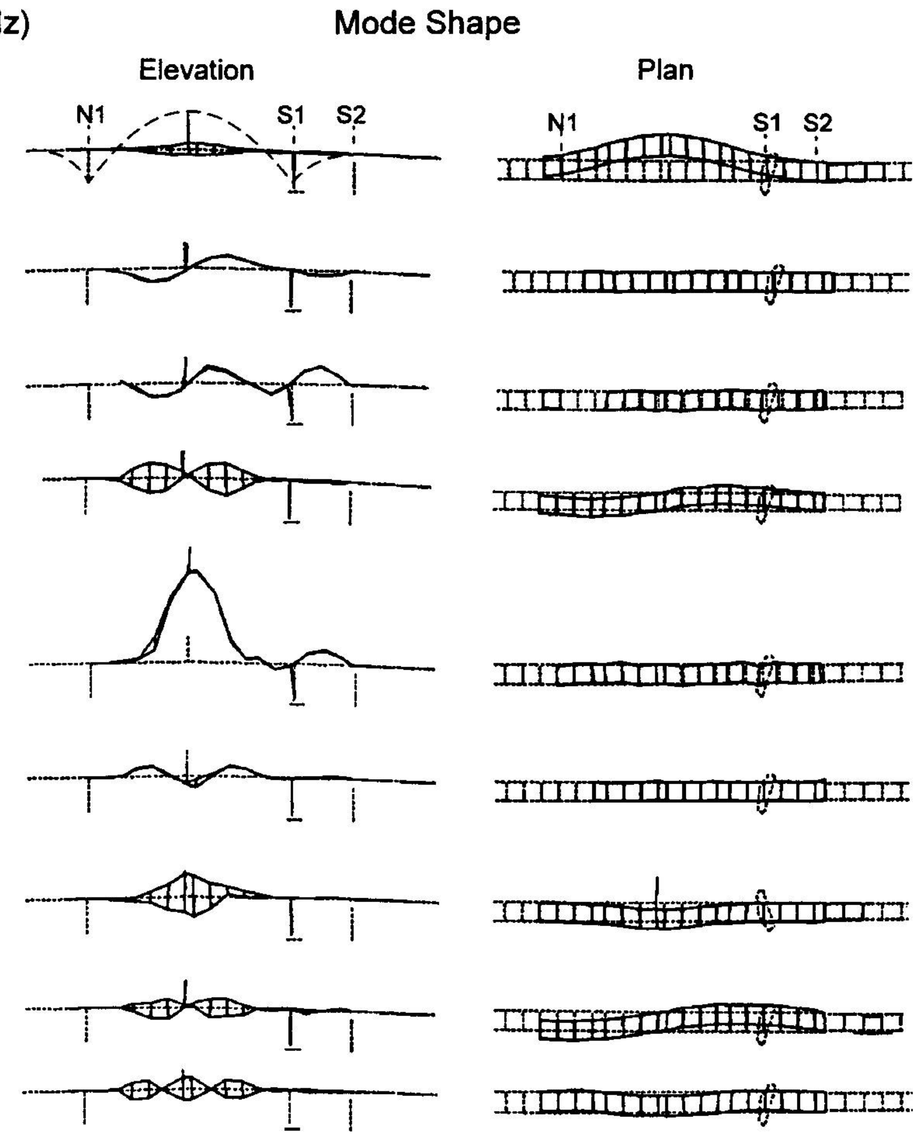


Fig. 3 First Nine Natural Modes of the Main Span of Port Mann Bridge

4. ANALYTICAL MODEL

Although the bridge might seem to be a relatively simple structure to model, critical assumptions regarding fixities and boundary conditions had to be made. A very important part of the modelling process was to establish realistic and accurate foundation stiffness parameters. Since the mass of the piers of the Main Span was far in excess of the structure itself, it was expected that modelling of the foundations would be a crucial part of the analysis. All the members of the Main Span were modelled as linear beam elements with the moments of inertia, torsional constants and masses derived from construction drawings. A spine member along the centre of the bridge was introduced to model the orthotropic deck.

For the approach spans, the concrete deck was modelled as equivalent cross braces while all the other members, including the reinforced concrete bents were represented as linear beam elements. Based on the AVS results, the interface (or bearings) between the superstructure and the piers were modelled as pins on pier N1 and S1, and as rollers permitting longitudinal translation for piers N2, S2. Bearings at S1 were designed as rollers, but appeared to be jammed according to the AVS results. For the approach spans, all the bearings were attached to the support bents and were allowed to move longitudinally, but were restrained to move in the transverse direction. The bridge foundations were modelled as linear springs with six components (three axial and three rotational). The spring stiffnesses were derived from soil data provided by the geotechnical consultant.

A layout of the bridge model and a closer view of the Main Span are shown in Fig. 4. The finite element linear elastic dynamic analysis was conducted first using B&T's finite element program CAMIL in order to calibrate the model and subsequent seismic assessment studies. CAMIL's calibrated model was subsequently analyzed with the commercially available program SAP90 [6] on a 486-PC computer. Details of the computer modelling and results are given by Ventura et al, [5].

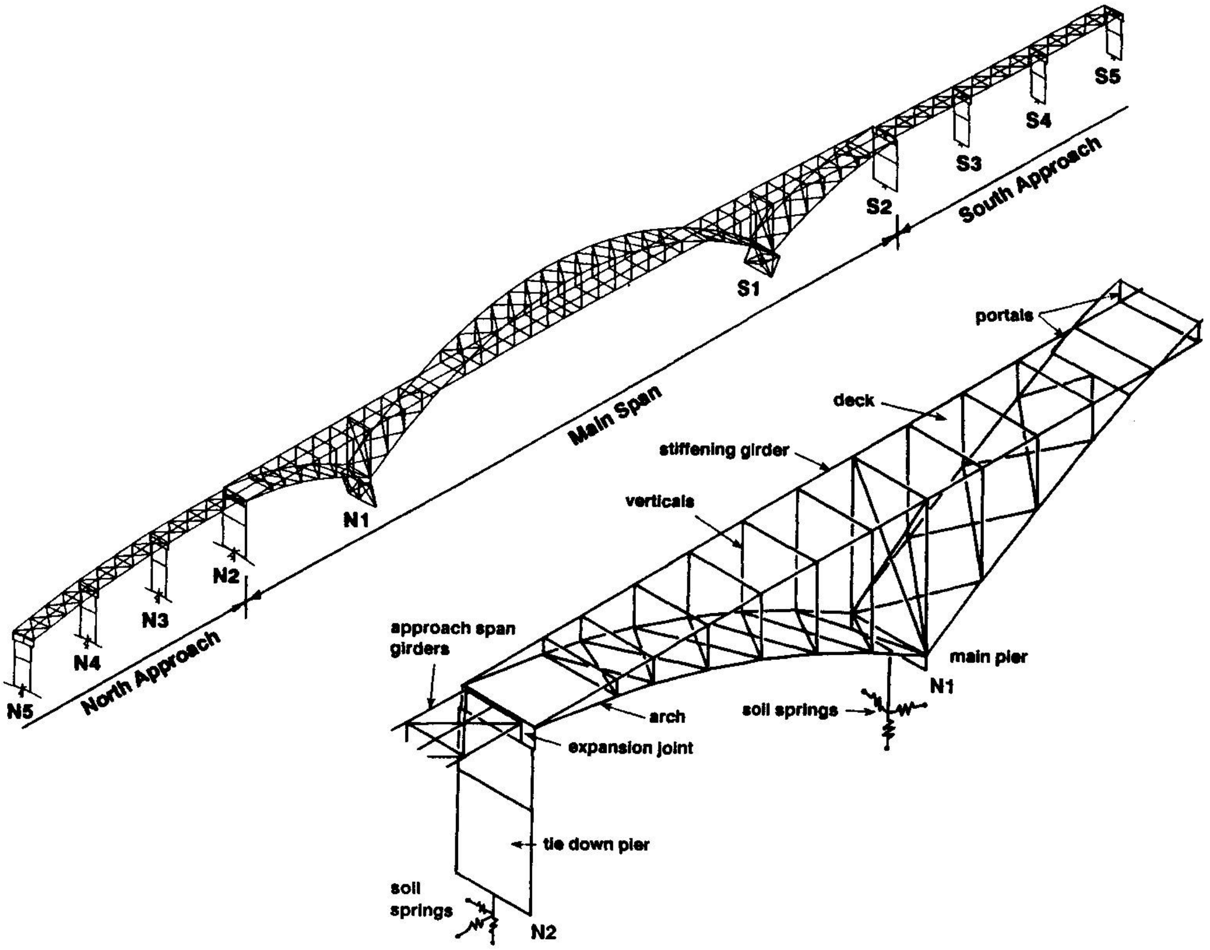


Fig. 4 Finite Element Model of Port Mann Bridge

The fundamental frequencies of the calibrated model correlated well with the experimental frequencies and are shown in Fig. 3. The associated mode shapes matched very well the experimental modes, but are not shown here due to space limitations.

The sensitivity of the model dynamic properties to the selection of the equivalent foundation springs was investigated by increasing and decreasing the spring constants determined by the geotechnical consultant. It was found that more than a tenfold variation of the spring constants would be needed to induce significant changes on the computed mode shapes and frequencies. It was concluded, therefore, that a very detailed refinement of the estimated spring constants was not warranted for the model calibration.

Additional studies included determination of the equivalent spring constants using the results from the AVS. The simple model shown in Fig. 5 was used to determine the values of the translational, K_t, and rotational, K_r, stiffnesses as a function of the measured motions along the height of the pier and at the foundation level. Using the recorded data, the relative values of the bending, d_b, rotational, d_r, and translational, d_t, components of the pier motion at its lowest natural frequency were determined. These values were used to compute the spring constants in terms of the flexural stiffness of the pier. The resulting spring constants were K_t=4.2x10^5 kN/m and K_r= 3.9x10^8 kN·m/rad. Considering the simplicity of this approach, these values compare reasonably well with those provided by the geotechnical consultant for low strain levels of the soil, K_t=10x10^5 kN/m and K_r= 1.6x10^8 kN·m/rad. No further refinements were attempted to improve this correlation.

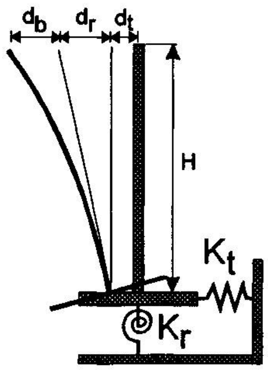


Fig. 5 Pier-Foundation Model

Because the experimental work was limited to measuring vibrations of the Main Span and part of the South Approach, not all the modes of vibration of the complete bridge could be properly identified and correlated with the finite element model. The correlation study presented here was limited to the first nine measured modes of the Main Span, which did not necessarily correspond to the first nine modes of the complete bridge model. Nevertheless, because of the large number of secondary modes, the correlation between the experimental and analytical study proved to be a crucial step in gaining insight and confidence about the dynamic characteristics of the bridge.

5. CONCLUSIONS

Correlation between the analysis and the model was not achieved initially because the boundary conditions indicated on the drawings did not agree with the actual behaviour of some bearings (S1). Also, some structural members of the bridge were found to be different from what was indicated on the drawings. Once these differences were accounted for, good agreement between measured modes and the computer model could be achieved. The information obtained from the ambient vibration testing helped the consulting engineers increase their confidence on the computer bridge model and significantly reduced the uncertainties on the analyses that came after, including the assessment of the soil-structure interaction effects for different levels of ground shaking.

ACKNOWLEDGEMENTS

The support and cooperation of the Ministry of Transportation and Highways of British Columbia for this project is gratefully acknowledged.

REFERENCES

1. FELBER, A.J. and VENTURA, C.E., Port Mann - Modal Testing and Model Correlation; Part I: Experimental Testing and Modal Analysis. Procs. of the 13th Int. Modal Analysis Conf., Nashville, Tennessee, February, 1995.
2. GOLDER, H.Q. and WILLEUMIER, G.C., Design of the Main Foundations of the Port Mann Bridge. The Engineering Journal, The Journal of the Engineering Institute of Canada, August, 1964.
3. HARDENBERG, G., Design of the Superstructure of the Port Mann Bridge. The Engineering Journal, The Journal of the Engineering Institute of Canada, July 1961.
4. LAKE, G.W.C., The Port Mann Bridge. Engineering Institute of Canada Annual Meeting Paper, 1964.
5. VENTURA, C.E., FELBER A.J. PRION, H.G.L., TAYLOR, P.R., and VAN SELST, A., Port Mann - Modal Testing and Model Correlation; Part II: Dynamic Modelling and Correlation. Procs. of the 13th Int. Modal Analysis Conf., Nashville, Tennessee, February 1995.
6. WILSON, E.L. and HABIBULLAH, A., SAP90 Structural Analysis Manual. Computer and Structures, Inc., Berkeley, California, 1992.