01020

WIND TUNNEL TESTING OF MONOTUBE SIGN SUPPORT STRUCTURES

A Research Proposal Submitted to:

Mr. Frank R. McCullagh, P.E., Director
Arizona Transportation Research Center
Arizona Department of Transportation
College of Engineering
Arizona State University
Tempe, Arizona 85287

SUBMITTED BY: Arizona Transportation & Traffic Institute Jointly with the Engineering Experiment Station
College of Engineering
University of Arizona
Tucson, Arizona 85721

PRINCIPAL INVESTIGATORS:

Reidar Bjorhovde
Reidar Bjorhovde, Professor
Department of Civil Engineering and Engineering Mechanics
(602) 621-6568

M.R. Ehsani
Mohammad R. Ehsani, Assistant Professor
Department of Civil Engineering and Engineering Mechanics
(602) 621-6589

SUPPORT REQUESTED: $115,066

PERIOD OF SUPPORT: June 1, 1986, to November 30, 1987

APPROVED FOR THE UNIVERSITY: Laurel L. Wilkening/aer
Laurel L. Wilkening
Vice President for Research

86-CEE-199

TABLE OF CONTENTS

1.0 IDENTIFICATION

This research project entitled, "Wind Tunnel Testing of Monotube Sign Support Structures" is proposed by the Arizona Transportation and Traffic Institute, College of Engineering, University of Arizona, Tucson, Arizona.

Dr. Reidar Bjorhovde, Professor, and Dr. Mohammad R. Ehsani, Assistant Professor, Department of Civil Engineering and Engineering Mechanics, will serve as Project Directors and Principal Investigators and bear scientific responsibility for the project. The telephone numbers of Drs. Bjorhovde and Dr. Ehsani at the University of Arizona are (602) 621-6568 and (602) 621-6589, respectively.

Dr. R. A. Jimenez, Director of the Arizona Transportation and Traffic Institute, has been designated as the liasion with the Arizona Department of Transportation on research matters. In this capacity, he has knowledge of fiscal and contractual procedures. His telephone number is (602) 621-6564.

2.0 PROBLEM STATEMENT

The design of highway sign support structures currently is based on the criteria of AASHTO's 1975 "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals," revised in 1978 and 1979 (1), and one of its predecessors, the AASHTO 1968 "Specifications for the Design and Construction of Structural Supports for Highway Signs", (referred to hereafter as "The Specifications").

The Specifications were originally developed for truss-type sign support structures, and require that the static deflection of the structure be limited to a value of $d^2/400$, where d is the depth of the sign in feet. This is a semi-empirical formula that has proven to be excessively conservative in practical use. Due to the cost of fabrication of the truss-type structures and for aesthetic reasons, the use of tubular (monotube) sign support structures has gained considerable popularity in the last decade. The Specifications do not address the design of monotube structures adequately and, in the case of cantilever structures, the design is based entirely on "engineering judgment." In addition, there are no guidelines for the design of structures supporting luminaires and traffic signals.

The manufacturers of monotube structures, each having their own design procedures, fabricate such structures using sections which vary considerably, both in material as well as cross-sectional properties. As a result of this, the transportation authorities are faced with the problem of "accepting" or "rejecting" different designs without any reliable rational guidelines.

Research at the University of Arizona (2,3) has shown that the AASHTO deflection requirement cannot be satisfied for the range of spans (60 to 100 feet) that are common for the monotube structures, using normal sizes and placement of the traffic signs. (It should also be observed that some of the longer span truss-type sign structures cannot meet the deflection criteria either, although the degree of underdesign is less than for the monotube structures.) Analyzing the static as well as the dynamic behavior of a variety of typical structures, it was found that although the $d^2/400$-criterion was violated, the levels of stress in the members were entirely acceptable. In addition, it was recommended that for aesthetic purposes, it might be preferable to build these structures with a camber approximately equal to the dead load deflection.

Detailed evaluations of the rationale of the $d^2/400$ requirement have shown that it stems from a simplified dynamic analysis of a beam-type member, having a uniformly distributed mass and being subjected to a constant wind velocity of 80 mph (3,4). The vortex shedding effect of the wind on the beam and the assumed resonance condition prompted the development of the AASHTO deflection requirement. However, the theory that was used to establish the vortex shedding characteristics was based on wind speeds that correspond to Reynolds' Numbers less than 3×10^5. The latter implies a maximum wind speed of approximately 26-28 mph for the monotube structures, and the extrapolation of the theory to find the response at 80 mph is simply not correct. However, it is noted that the response of the structure at wind speeds exceeding 26-28 mph is non-deterministic (random); current fluid mechanics knowledge has no concise method of treatment of the random wind forces.

It is not proposed that a theory to handle non-deterministic forces and structural response be developed in this study; the scope of the project does not permit such extensive work. Rather, because of the lack of theoretical developments, as well as the absence of data on the response of actual, full-scale structures in the high wind velocity range (5), it is recognized that suitable wind tunnel tests of scale models will produce the missing information as it pertains to monotube structures. The field testing of full-scale monotube structures that was recently completed at the University of Arizona (5) has produced a wealth of data for responses up to approximately 25 mphs, including the finding that resonance does not occur. This has confirmed the results of the first study of monotube structures (2).

To make the response data complete, the wind tunnel tests are therefore the most suitable tool to establish the behavior of monotube structures under wind speeds up to approximately 100 mph.

The last few years, monotube frame-type structures have been used to an increasing extent, due to improved appearance and higher stiffness. Similar to the monotube span-type supports, data on the performance of the frames are limited. Thus, wind tunnel tests should also be conducted for these structures.

The details of the proposed study are given in the following sections of the proposal.

3.0 PROPOSED STUDY

Two typical monotube span-type structures and two frame-type structures will be modeled and studied in this investigation. The models will represent structures with medium and long spans. For each model, the specimen will be tested initially without any signs. In addition, two different sign placements will be used to investigate the effect of the location of signs on the behavior of the structure. This will result in a total of 12 specimens to be tested. The final specimen configurations will be determined following consultations with ADOT personnel.

It is imperative that these models be developed so that the dynamic characteristics of the actual structure can be duplicated in the scale model. Therefore, a mere scaling down would not result in a suitable test specimen (6). Furthermore, the overall dimensions of the specimens are limited by the dimensions of the wind tunnel that will be used. A large wind tunnel is available in the Department of Aerospace and Mechanical Engineering at the University of Arizona; it measures approximately 4 feet across by 3 feet high. In order to eliminate any boundary problems, the maximum span of the proposed specimens will be approximately 3 feet. Similarly, the column height will be proportionately reduced.

It has been shown that the wind-induced forces on a monotube sign support structure are a function of the mass and the diameter of the structural tube itself (2). Therefore, in order to replicate the dynamic characteristics of the prototype in the model, the dead load and the cross-sectional dimensions of the model cannot simply be "scaled off" the original structure (6,7). It is therefore anticipated that ample time is needed in the early stages of the project to design the models. This will involve proportioning the mass and the cross-sectional dimensions of the model so that the dynamic characteristcs of the model and the prototype are very similar, if not identical. Special attention will also be given in duplicating the connection of the beam element to the column for the case of span-type structures.

Previous studies have indicated that the magnitude of the stresses due to wind excitation in monotube span-type structures are not a major cause for concern (2,5). This was found to be true even for the cases near the theoretical resonance conditions. However, the beam displacements do seem to be large under many wind speeds, and are approaching resonance conditions for certain very narrow ranges of wind velocities. As a result, the primary data to be collected reflect the displacements of the structure, and in particular the vertical in-plane deflection at the middle of the span. It is noted that preliminary studies indicate that the use of other data collection devices, such as strain gages and accelerometers, are not feasible for this investigation. The size of the models will not allow easy placement of strain gages, and the drag produced by the strain gage cables is likely to influence the test results. Similarly, the mass of all reasonably priced accelerometers is too large to be supported at the middle of the span without affecting the vibration of the beam element significantly.

Analytical and experimental data on the behavior of monotube frame-type structures are virtually non-existent. It is anticipated that analytical evaluations of the performance of these structures will be carried out as a separate study.

Each model will be subjected to wind velocities ranging from 10 to 100 mph. The displacements of the model will be monitored and recorded by a high-speed movie camera. This will show whether resonance conditions can realistically occur. As indicated earlier, the current AASHTO criterion is based on extrapolation of the theoretical results for wind speeds up to approximately 30 mph into the non-deterministic region, which manifests itself at higher wind velocities.

The test results will provide data on the behavior of monotube structures for a range of wind speeds where currently no information is available. Added to the results of the previous (2,5) and concurrent studies at the University of Arizona, the complete information set will provide sufficient data to allow recommendations for new design criteria.

4.0 STUDY OBJECTIVES

The objectives of this investigation are summarized in the following categories:

1. <u>Survey and Review of Wind Tunnel Tests of Similar Structures</u>.

   a. Types of structures and materials
   b. Testing techniques and wind speed ranges
   c. Types of data collected
   d. Techniques and equipment used for data collections
   e. Interpretation of test results: Model vs. Prototype
   f. Problems and concerns of modeling techniques

2. <u>Development of Reduced-Scale Models</u>.

   a. Model Development. Develop the scale models for each of the structures, to produce the best approximation of the dynamic characteristics of the full-scale structures. This includes selecting the exact overall as well as cross-sectional dimensions of the models, in addition to the scaling and modeling of the beam-to-column connection element. The base of the columns will be detailed for full fixity to the floor of the wind tunnel.

   b. Fabricate the models designed in part (a) above.

3. <u>Wind Tunnel Testing of the Scale Models</u>.

   a. The models will initially be tested without signs to establish the behavior of the structure itself, separating out the effect of signs.

   b. The models will be subjected to wind speeds between 10 and 100 mph.

   c. The time-deflection history of the structures will be recorded, along with any other data required as concluded from part 1 above. In particular, the appearance of large in-plane and out-of-plane displacements will be carefully monitored.

   d. The structures will be rotated in the wind tunnel so that the direction of the wind is not perpendicular to the model. This is needed to determine whether the behavior of the model is influenced by the direction of the wind.

   e. Signs will be placed on the models in locations similar to the prototypes, and steps (b) through (d) above are repeated.

f. Step (e) above is repeated for an additional arrangement of signs along the span.

4. <u>Development of Design Recommendations</u>.

Based on the results of part 3, and combined with the previous (2,5) and concurrent studies at the University of Arizona, final design recommendations for monotube sign support structures will be developed. The recommendations will be of a form that is suitable for consideration by AASHTO for possible modification of the existing design criteria.

5.0 BACKGROUND AND SIGNIFICANCE OF WORK

The current methods of design of sign structures are reflected in the criteria of the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals (1). In brief, these are essentially limited to the requirement that the design be based on engineering judgment and rational principles.

The lack of detailed design criteria can partly be attributed to a sparsity of research and engineering data on the behavior and strength of such structures. This is due to the complexity of the topic, which involves a need for an understanding of the response of the structure to wind loads (i.e., aerodynamic behavior of a light-weight structure), the influence of material types and cross-sectional shapes of the monotubes, and the long-time service characteristics of the structure. The latter subject addresses the question of fatigue as well as the uses and re-uses of the structures. In particular, it is common practice to remove a sign from one location to another, thereby changing the service conditions of the structure. It is not known to what degree this form of usage changes the operating characteristics of the sign structure; conjecture can estimate that the cumulative effect of fatigue damage, for example, may be important.

The loads that should be considered in the analysis and design of overhead sign structures and related elements have been studied by some investigators (8,9,10,11,12). Some of these studies also addressed the fatigue behavior of the structure, using field and laboratory tests of steel and aluminum structures. Of particular interest to the proposed research work are the studies of Simiu (11) and Davenport (12); both of these examine the response of structures that are somewhat similar to the monotubes, and the methods and findings of these projects will be useful in the proposed study. Similarly, the state-of-the-art evaluation of Mirza and Smith (13) is important because of their focus on the utilization of tubular members in highway sign structures.

Wind tunnel testing of models of bridge structures and their components, as well as of buildings, has been significantly advanced over the past decade. Thus, the work of researchers such as Cermak (Colorado State University), Davenport and Isyumov (University of Western Ontario), and Scanlan (Princeton University) has led to testing refinements that have been used to define vibration characteristics of bridges and force distributions on buildings. References (14) and (15) give good overall descriptions of some of the results that have been obtained. In addition, the recently issued "Manual of Practice for Wind Tunnel Testing of Buildings and Structures" (6), is of particular importance for the proposed work. However, it is noted that there is a dearth of data regarding the response of structures akin to monotubes; in particular, their response under high wind velocities is not known. The importance of the proposed wind tunnel tests therefore cannot be overestimated, and their successful outcome may have applications in many other areas of structural analysis and design.

The most recent work on the behavior of monotube sign support structures are the research studies that have been conducted at the

University of Arizona (2,3,5). These have produced a large amount of information regarding the behavior of monotube structures, including the influence of parameters such as the stiffness of the column, the stiffness of the beam, the span of the structure, and the location of the signs along the span. Furthermore, the results of the field tests of full-scale monotube structures under actual wind loading conditions (5) indicate good correlation between theory and experiment, but no data have been obtained for high wind speed conditions.

In view of the above, the results obtained in the wind tunnel tests will complete the data base on the behavior of monotube sign support structures. As a result, it is anticipated that the final recommendations of the study will be used in presenting a proposal for revised design criteria to AASHTO.

6.0 BENEFITS

The study will result in a set of cohesive design criteria for an important class of structures; namely, the monotube span- and frame-type sign structures. As such, this will not only benefit the local and regional transportation authorities, but will have a national impact as well. It is anticipated that the recommendations will be presented to AASHTO for inclusion and revision of the design specifications for highway sign structures.

The presence of uniform criteria will allow the authorities to compare and evaluate the designs of different manufacturers. This is presently a difficult and controversial task that must be performed by the transportation authorities. The design that is selected from among a variety of widely different proposals must be justified on the basis of limited criteria. The end result of this study is intended to alleviate this problem.

The study will lead to more economical structures. Current designs appear to result in structures which have performed adequately and safely over the years. On the other hand, this may simply mean that they are overdesigned. Therefore, with improved design specifications, it is anticipated that both the material and fabrication costs of the structures can be reduced, in some cases substantially. Considering the number of sign support structures that are built every year, the overall savings that might be expected can be substantial.

7.0 IMPLEMENTATION

It is expected that the results of the study will lead to revisions in the AASHTO design criteria as they apply to monotube sign structures. This will include criteria for strength and stiffness of the structures, to ascertain satisfactory long- and short-term performance of the structures. The final report will contain the design guidelines, as well as recommendations for future work. In particular, static and dynamic (i.e., fatigue) testing of full- and reduced-scale components may be useful as it pertains to joint/connection details of the structures.

8.0 WORK PLAN

The following work plan will be followed to accomplish the tasks outlined in Section 4.0 of this proposal. The work plan is intended to complement the project schedule, presented in Section 11.0.

It is emphasized that the plan is based on fabrication of models and wind tunnel testing of four typical sign support structures. Each model will be tested with and without signs. If deemed necessary by ADOT authorities, modeling and testing of additional structures will be discussed and detailed plans prepared. However, such additional testing is not a part of this proposal.

A. Survey and Review of Literature (2 months)

This phase of the study involves a more thorough examination of the literature available on wind tunnel testing of structures, such as transmission towers or other related structures. It is important to pay special attention to the different modeling techniques and the range of wind speeds used in these studies. Additionally, the type of data collected and the equipment utilized will be of importance.

B. Development of Scale Models (4-1/2 months)

During this period, the four models to be tested will be designed. It is anticipated that this phase of the study will require a large number of trial designs until a model is obtained which will duplicate the dynamic characteristics of the full-scale structure. Such details as the construction material and the beam-to-column connection (for span-type structures) will also be worked out during this phase.

C. Fabrication of Models (2 months)

This period is devoted to the construction of the four models.

D. Preparation of Test Set-Up (3 months)

Concurrent with Part C above, the test set-up will be prepared for the experiments. During this period, final arrangements for the attachment of the specimens to the floor of the wind tunnel will be made. The location of video camera and lighting, as well as other data collection equipment, will be determined. Trial runs will be performed to insure that all equipment is functioning properly.

E. Wind Tunnel Testing (5 months)

This period is devoted to the wind tunnel testing of the specimens. The four models, each with two arrangements of signs, will be subjected to different wind speeds and directions. This will result in twelve individual specimens that are to be tested. The data collected from the tests will be concurrently analyzed as indicated in Part F.

F. Analysis of Test Results (6 months)

The test data will be analyzed and compared with the available analytical results for such structures. In particular, the performance of the structures at higher wind speeds (i.e., non-deterministic range) and the in-plane deflection of the beam will be examined closely. The results obtained in this phase of the study will be of importance in evaluating the AASHTO criterion which assumes that vortex shedding of the structure can take place at high wind velocities.

G. Development of Design Recommendations (2 months)

Combining the results of the previous (2,5) and concurrent research at the University of Arizona with this study, a new set of design recommendations for the monotube sign support structures will be developed. These will consider the behavior of the structures in the low wind speed (deterministic) range as well as the non-deterministic behavior associated with higher wind velocities. The recommendations will be of a format suitable for presentation to AASHTO for possible inclusion or modification of the existing code.

H. Preparation of Final Report (3 months)

The final three months of the project will be devoted to preparing a report which will document the results of the findings in Parts A through G.

9.0 MANPOWER AND ESTIMATED BUDGET

Drs. Reidar Bjorhovde and Mohammad R. Ehsani will serve as the Project Directors for the proposed study. In this capacity, they will have the scientific responsibility for the project.

Dr. Bjorhovde is Professor of Civil Engineering and Engineering Mechanics at the University of Arizona. He teaches undergraduate and graduate courses in the subjects of structural analysis and structural steel design, and has been actively involved in research dealing with a number of topics in these areas over many years. He is currently a member of the Specification Committee of the American Institute of Steel Construction and the Specification Advisory Group of the American Iron and Steel Institute. The attached vita gives additional details of his background and expertise.

Dr. Ehsani is Assistant Professor of Civil Engineering and Engineering Mechanics at the University of Arizona. He teaches undergraduate and graduate courses in the subjects of structural analysis and reinforced and prestressed concrete design, and has been actively involved in research in these areas, as well as earthquake resistant design of structures, for several years. The attached vita gives additional details of his background and expertise.

Dr. Lawrence B. Scott will serve as a Consultant to the project insofar as the wind tunnel testing work is concerned. This includes advising on model design and data acquisition, as well as the laboratory testing. Dr. Scott is Professor of Aerospace and Mechanical Engineering, and has had significant experience in the wind tunnel testing of aircraft and other structural components.

Other personnel that will be associated with the project are indicated in the budget tabulation. In particular, one Civil Engineering and one Aerospace and Mechanical Engineering graduate student will be employed as research assistants.

It is anticipated that, in addition to the University personnel that will be associated with the project, a small advisory group will be formed, using representatives from the Arizona Department of Transportation and the Arizona Transportation Research Center. The members of the group will be chosen on the basis of recommendations of the researchers and the staff of ADOT. The researchers feel that the input that can be provided by such a group can be very helpful in assuring that up-to-date information can be efficiently exchanged between government, industry, and research team members.

The estimated total budget for the 18-month study period is $115,066. Details of the budget are shown on the following pages. The Arizona Department of Transportation will be billed on a monthly basis in accordance with the present procedures of the University of Arizona. Also attached is a tabulation of the estimated hourly involvement of the research personnel.

WIND TUNNEL TESTING - ESTIMATED HOURS FOR INDIVIDUALS

	1st Yr.	1st Summ.	2nd Yr.	2nd Summ.	Total	% of Total
R. Bjorhovde	105	250	41	250	646	16.6
M. R. Ehsani	149	250	58	250	707	18.2
CE Assistant	747	375	291	375	1788	46.0
AME Assistant	374	-	145	-	519	13.3
Technician	60	-	20	-	80	2.1
Clerical	40	-	60	-	100	2.6
Consultant	50	-	-	-	50	1.3
TOTALS	1525	875	615	875	3890	100.0

NOTES:

One Man-Month = 166.67 hrs.
One Academic Yr. = 1494 hrs.
One Fiscal Yr. = 2088 hrs.

A Solicited Research Proposal
Research Project No. HPR-PL-1(29)Item 258

YEAR ONE

PROPOSED BUDGET - ARIZONA DEPARTMENT OF TRANSPORTATION

June 1, 1986 - May 31, 1987

<u>Direct Labor</u>	
R. Bjorhovde, Principal Investigator	
7% Academic Year	$ 3,469
1.5 Months Summer	8,468
M. R. Ehsani, Co-Principal Investigator	
10% Academic Year	3,625
1.5 Months Summer	6,194
Graduate Research Assistant	
50% Academic Year	7,271
2.25 Months Summer	3,727
Graduate Research Assistant (AME)	
25% Academic Year	3,735
Technician	
2.87% Fiscal Year	839
Secretarial/Clerical	
1.92% Fiscal Year	210
Total Direct Labor:	$ 37,538
<u>Payroll Taxes and Insurance</u>	
Faculty 17.4%	$ 3,786
Staff 23.4%	246
Student 1.5%	221
Total PTI:	$ 4,253

PROPOSED BUDGET - ADOT
YEAR ONE - June 1, 1986 - May 31, 1987
Page 1

Operations	
Expendable Supplies	$ 2,275
Computer	900
Total Operations:	$ 3,175
Consultant:	
L. B. Scott, Six (6) days @ $275/day	$ 1,650
Travel	
Domestic: Transportation	$ 150
Total Direct Costs:	$ 46,766
Indirect Costs	
44% MTDC	$ 20,577
TOTAL PROPOSED BUDGET:	$ 67,343

A Solicited Research Proposal
Research Project No. HPR-PL-1(29) Item 258

YEAR TWO

PROPOSED BUDGET - ARIZONA DEPARTMENT OF TRANSPORTATION

June 1, 1987 - November 30, 1987

<u>Direct Labor</u>

R. Bjorhovde, Principal Investigator	
7% Academic Year	$ 1,559
1.5Months Summer	8,976
M. R. Ehsani, Co-Principal Investigator	
10% Academic Year	1,629
1.5 Months Summer	6,566
Graduate Research Assistant	
50% Academic Year	3,268
2.25 Months Summer	3,511
Graduate Research Assistant (AME)	
25% Academic Year	1,679
Technician	
1% Fiscal Year	163
Secretarial/Clerical	
2.87% Fiscal Year	175
Total Direct Labor:	$ 27,526

<u>Payroll Taxes and Insurance</u>

Faculty 17.4%	$ 3,259
Staff 23.4%	79
Student 1.5%	127
Total PTI:	$ 3,465

PROPOSED BUDGET - ADOT
YEAR TWO - June 1, 1987 - November 30, 1987
Page 2

Operations	
Expendable Supplies	$ 500
Computer	1,200
Publications	350
Total Operations:	$ 2,050
Travel	
Domestic: Transportation	$ 100
Total Direct Costs:	$ 33,141
Indirect Costs	
44% MTDC	$ 14,582
TOTAL PROPOSED BUDGET:	$ 47,723
TOTAL REQUESTED FUNDS:	$ 115,066

10.0 EQUIPMENT AND FACILITIES

The research will be conducted in the Departments of Civil Engineering and Engineering Mechanics and Aerospace and Mechanical Engineering at the University of Arizona. The computational facilities include the Hewlett-Packard 9836S microcomputer of the Structural Engineering Laboratory, along with two Digital Equipment Corporation DEC-10's, linked to a Control Data Corporation Cyber 175, a VAX 11/780, and other equipment for the numerical analysis. In addition, portable data acquisition equipment with 20 data channels is available in the form of an HP 3421 unit with mass storage devices.

The experimental facilities include the 22-foot x 42-foot structural strong floor of the Structural Engineering Laboratory, two 110-kip dual-acting MTS actuators, controllers, and a 23 gpm hydraulic pump, a 200 kip capacity Tinius Olsen and smaller universal testing machines, as well as numerous smaller actuators and load cells. The laboratory also is equipped with various loading frames and data acquisition apparatus. A well-equipped shop is also available for assistance in construction of the models.

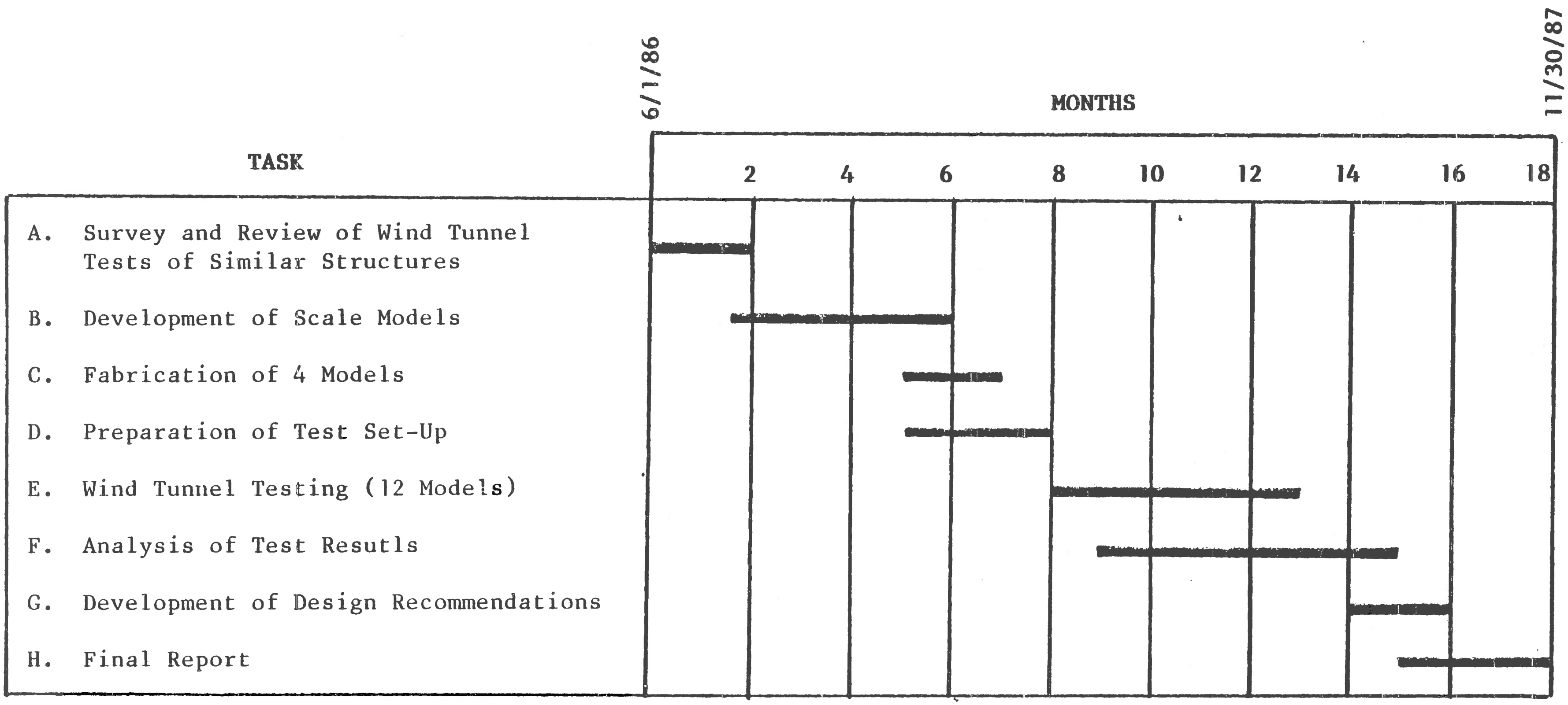
The wind tunnel to be used for this project is an open-circuit tunnel with a 4' wide by 2.8' high by 10' long test section. It can produce wind speeds ranging from 5 mph to 100 mph. The free stream turbulence of the tunnel is a mere 0.02%, which can be assumed as practically zero turbulence. The data acquisition system in the Aerospace and Mechanical Engineering Department utilizes a Hewlett-Packard 9835A microcomputer, which is compatible with the equipment available in the Civil Engineering Department. Using transducers, the system is capable of measuring and recording pressures and forces on the structures.

The University of Arizona Microcampus Office has available high-speed cameras and related equipment for recording the displacement history of the models during the testing. Suitable pieces of equipment will be available on a rental basis.

11.0 PROJECT SCHEDULE

The project is based on an 18-month research period. This includes time for the preparation of the final report, but not for a review period for the same. The detailed schedule for the project is shown in the attached Project Schedule Chart. It is emphasized that this is based on a starting date of June 1, 1986.

PROJECT SCHEDULE



12.0 REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), "Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals," AASHTO, Washington, D.C., 1975 (revised 1978 and 1979).

2. Ehsani, M. R., Chakrabarti, S. K., and Bjorhovde, R., "Static and Dynamic Behavior of Monotube Span-Type Sign Structures," Report No. FHWA/AZ85/194-I and II, Arizona Department of Transportation, Phoenix, Arizona, June, 1985.

3. Ehsani, M. R. and Bjorhovde, R., "Deflection Criteria for Sign Support Structures," paper submitted for publication in the Journal of Structural Engineering, ASCE, February, 1985.

4. Pelkey, R. E., "New Design Approach to Long-Span Overhead Sign Structures," **Highway Research Record**, HRB No. 34b, 1971.

5. Martin, K., Ehsani, M. R., and Bjorhovde, R., "Field Testing of Monotube Sign Support Structures," Report No. ATTI-85-5, Arizona Transportation and Traffic Institute, University of Arizona, September, 1985 (141 pp.).

6. ASCE Aerodynamics Committee, "Manual of Practice for Wind Tunnel Testing of Buildings and Structures," January, 1986 (29 pp.) (Draft available through ASCE.)

7. Charlton, T. M., "Model Analysis of Plane Structures," Pergamon Press, 1966.

8. American Society of Civil Engineers (ASCE), "Wind Forces on Structures," **ASCE Transactions**, Part II, Vol. 126.

9. Hayus, F., "Drag Measurements on One Square Section and Two Rectangular Sections with Different Corner Radii," CIDECT Report No. 1-NK-I-68-41, Brussels, Belgium, September, 1968.

10. Hay, J. S., "Forces on a Sign Gantry in Normally Directed Winds," **Transport and Road Research Laboratory Monograph**, England, 1978.

11. Simiu, E., "Wind Spectra and Dynamic Alongwind Response," **Journal of the Structural Division**, ASCE, Vol. 100, No. ST9, September, 1974 (pp. 1897-1910).

12. Davenport, A. G., "The Response of Slender, Line-Like Structures to a Gusty Wind," **Proceedings**, Institute of Civil Engineers, London, 1962 (Paper No. 6610, pp. 389-407).

13. Mirza, J. F. and Smith, J. C., "State-of-the-Art Study of Tubular Members in Highway Structures," School of Engineering, North Carolina State University, January, 1970.

14. Simiu, E. and Scanlan, R. H., "Wind Effects on Structures," John Wiley and Sons, New York, NY 1978.

15. Dowell, E. H., Editor, "A Modern Course in Aeroelasticity," Sijthoff & Noordhoff International Publishers, Holland, 1978.

13.0 SUPPORTING DATA

Biographical information for Dr. R. Bjorhovde and Dr. M. R. Ehsani is attached to this proposal.

RESUME

REIDAR BJORHOVDE

PERSONAL

Residence: 1700 East Chula Vista Road, Tucson, Arizona 85718

Office Address: Department of Civil Engineering
UNIVERSITY OF ARIZONA
Tucson, Arizona 85721

Telephone: 602-742-2247 (home)
602-621-6568/2266 (office)

Date and Place of Birth: November 6, 1941, Harstad, Norway

Citizenship: United States of America

EDUCATION

1960-1964 Technical University of Norway, Trondheim, Norway;
Sivilingenior (= M.S.) in Civil Engineering

1966-1968 Technical University of Norway, Trondheim, Norway;
Dr.-Ing. (Ph.D.) in Civil Engineering

1968-1972 Lehigh University, Bethlehem, Pennsylvania
Ph.D. in Civil Engineering

AWARDS AND HONORS

University Student Council Fellowship, Trondheim, Norway, 1964
Norwegian Government Postgraduate Fellowship, 1966-67 and 1967-68
Research Fellowship, Royal Norwegian Council for Scientific and Industrial Research, 1968-69
NATO Science Fellowship, Royal Norwegian Council for Scientific and Industrial Research, 1969-70
Member of the Society of Sigma Xi, 1972
Duggan Medal, Engineering Institute of Canada, 1980
Award of Excellence, Halliburton Education Foundation, 1983
Distinguished Lecturer, University of Houston, Houston, Texas, 1984

REIDAR BJORHOVDE

PROFESSIONAL EXPERIENCE

1. Department of Civil Engineering, University of Arizona, Tucson, Arizona; Professor of Civil Engineering and Engineering Mechanics (8/81 to present).
   Assignments: Teaching, research and consulting in structural engineering, particularly in all areas related to structural steel design, fabrication and construction.

2. Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada; Professor of Civil Engineering (7/79 to 7/81), Associate Professor of Civil Engineering (12/76 to 7/79).
   Assignments: Teaching, research and consulting in structural engineering, particularly in all areas related to structural steel design, fabrication, and construction. Director of the I.F. Morrison Structural Engineering Laboratory. Chairman of the Structural Engineering Group. Coordinator for the Graduate Degree Program in Welding Engineering of the Faculty of Engineering of the University of Alberta. Editor of the "Engineering Newsletter" of the University of Alberta.

3. American Institute of Steel Construction, New York, New York; Research Engineer (2/74 to 11/76).
   Assignments: Development and preparation of steel industry research needs and proposals; in charge of AISC-funded research projects at all American universities and laboratories; member of AISC and AISI research project committees; interpretation and development of AISC Specification provisions; special consulting services on steel construction to fabricators, architects and design engineers; service on engineering society committees; liaison with foreign organizations; educational programs for university students and practicing engineers; development and administration of budgets.

4. American Institute of Steel Construction, Inc., Boston, Massachusetts; Regional Engineer for Boston Region (6/72 to 1/74).
   Assignments: In charge of consulting services to architects, engineers, building officials, and educators for all aspects of the design, fabrication and construction of steel structures; interpretation of AISC Specification; lectures at universities, colleges and other schools and technical society meetings; conference arrangements; administration of office; budgets.

   Lecturer at Northeastern University, Center for Continuing Education, Boston, Massachusetts, during Fall Semester 1973, for the course "Modern Structural Steel Design".

PROFESSIONAL EXPERIENCE (Continued)

5. Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania; Research Assistant (9/68 to 5/72).
   Assignments: Research on residual stresses in steel members; stability and strength of columns; probabilistic concepts applied to the column strength problem; preparation of sections of the 3rd edition of the Structural Stability Research Council "Guide".

   Secretary of Structural Stability Research Council (previously named Column Research Council) from 2/69 to 12/70; administration of technical committees of the council, meetings, correspondence, finances.

6. Division of Steel Structures, Technical University of Norway, Trondheim, Norway; Assistant Professor and Norwegian Government Fellowship Postgraduate Scholar (7/66 to 8/68).
   Assignments: Research on fire protection/stability of steel structures; testing and theoretical evaluation of lag screw/timber connector joints for timber structures; field testing of suspension bridge tower; supervision of suspension bridge fabrication; teaching of courses on Norwegian structural design specifications; University's representative on Norwegian National Committee for Fire Protection of Steel Structures.

7. Division of Steel Structures, Technical University of Norway, Trondheim, Norway; Assistant Professor (3/65 to 6/66).
   Assignments: Teaching of courses on design of steel and timber structures; teaching and administration of courses on Norwegian design specifications.

8. Concrete Research Laboratory, Technical University of Norway, Trondheim, Norway; Research Engineer (10/64 to 2/65).
   Assignments: Research on corrosion of concrete reinforcement in sea water; eccentrically loaded columns; creep of concrete; teaching of concrete laboratory techniques.

REIDAR BJORHOVDE

RESEARCH PROJECTS

(D) signifies work as project director/principal investigator;
(I) signifies work as investigator.

1.	Creep of Concrete Sponsor: Concrete Research Laboratory, Technical University of Norway	1964-65	I
2.	Eccentrically Loaded Concrete Columns Sponsor: Royal Norwegian Council for Scientific and Industrial Research	1964-65	I
3.	Corrosion of Reinforcement in Concrete in Sea Water Sponsor: Royal Norwegian Council for Scientific and Industrial Research	1964-65	I
4.	Fatigue Resistance of High-Strength Bolted Joints Sponsor: Norwegian Department of Transportation	1965-66	I
5.	Material Properties of Lamellated Plates Sponsor: Technical University of Norway	1965-66	D
6.	Dynamic Characteristics of Suspension Bridge Tower Sponsor: Norwegian Department of Transportation	1966-67	Co-D
7.	Fire Protection of Steel Structures Sponsor: Technical University of Norway	1966-68	D
8.	Lag Screw and Timber Connector Joints Sponsor: Royal Norwegian Council for Scientific and Industrial Research	1966-68	D
9.	Evaluation of Column Strength Theories Sponsor: Column Research Council	1968-69	I
10.	Survey on the Use of Heavy Columns Sponsor: Column Research Council	1968-70	I
11.	Residual Stresses in Thick Welded Plates Sponsor: National Science Foundation	1968-71	I
12.	Probabilistic Analysis of Column Strength Sponsor: National Science Foundation	1970-72	I

RESEARCH PROJECTS (Continued)

(D) signifies work as project director/principal investigator.
(I) signifies work as investigator.

13.	Cold-Formed Hollow Structural Shapes Sponsors: Dominion Foundries and Steel, Ltd. Prudential Steel, Ltd.	1977-79	D
14.	Hydraulic Load Testing Reaction Frames (Equipment Grant) Sponsor: University of Alberta	1977	D
15.	Fatigue Testing Facility (Equipment Grant) Sponsor: Natural Sciences and Engineering Research Council of Canada	1979	Co-D
16.	Steel-Concrete Composite Trusses Sponsors: C. W. Carry, Ltd. Westeel-Rosco, Ltd.	1979	D
17.	Double-Angle Beam-Column Connections Sponsor: Canadian Steel Construction Council	1977-79	D
18.	Stub-Girder Floor Systems Sponsors: Canadian Steel Construction Council Dominion Bridge Company, Ltd.	1978-80	D
19.	Equipment for Welding Engineering Research Sponsor: Nova Corporation	1979	Co-D
20.	Computer Control System for Laser Welding (Equipment Grant) Sponsor: Natural Sciences and Engineering Research Council of Canada	1979	Co-D
21.	Connections for Structural Bracing Members Sponsor: Natural Sciences and Engineering Research Council of Canada	1977-80	D
22.	Panel-Braced Steel Frames Sponsor: Natural Sciences and Engineering Research Council of Canada	1980-83	D

RESEARCH PROJECTS (Continued)

(D) signifies work as project director/principal investigator.
(I) signifies work as investigator.

23.	Eddy-Current Non-Destructive Testing Equipment Sponsor: Natural Sciences and Engineering Research Council of Canada	1980	Co-D
24.	Distribution of Forces in Steel Connections Sponsor: American Institute of Steel Construction	1982-83	Co-D
25.	Strength and Stiffness of Connection Components Sponsor: American Institute of Steel Construction	1982-83	D
26.	Analysis of Bracing Connections Sponsor: American Institute of Steel Construction	1983-84	Co-D
27.	Development of Design Guide for Stub-Girders Sponsor: American Institute of Steel Construction	1983-84	D
28.	Monotube Span-Type Sign Structures Sponsor: Arizona Department of Transportation	1983-84	Co-D
29.	Equipment for Full- and Reduced Scale Testing of Structures Sponsor: National Science Foundation	1983-84	Co-D
30.	Field Testing of Monotube Span-Type Sign Structures Sponsor: Arizona Department of Transportation	1984-85	Co-D

PENDING RESEARCH PROPOSALS (Fall, 1985)

1.	Wind Tunnel Testing of Monotube Sign Support Structures Sponsor: Arizona Department of Transportation	1986-87	co-D
2.	Evaluation of Monotube Frame Sign Support Structures Sponsor: Arizona Department of Transportation	1986	D

REIDAR BJORHOVDE

UNIVERSITY TEACHING

University of Arizona

CE 217	Mechanics of Materials	Sophomore level
CE 336	Structural Design in Steel	Junior-Senior level
CE 432a	Advanced Structural Design in Steel	Senior-Graduate level
CE 532	Advanced Strength of Materials	Graduate level
CE 533x	Plastic Analysis and Design	Graduate level
CE 636x	Limit States Design of Steel Structures	Graduate level

University of Alberta

Eng.G. 231	Engineering Statics II	Freshman level
Civ.E. 360	Mechanics of Deformable Bodies	Sophomore level
Civ.E. 570	Design of Steel Structures	Senior level
Civ.E. 642	Risk and Decision in Civil Engineering	Graduate level
Civ.E. 666	Structural Concepts	Graduate level
Civ.E. 670	Behavior and Design of Steel Members	Graduate level
Civ.E. 671	Behavior and Design of Steel Structures	Graduate level

Northeastern University

	Modern Structural Steel Design	Continuing Education

Technical University of Norway

	Design of Timber Structures	Junior level
	Design of Steel Structures	Senior level
	Fire Protection of Steel Structures	Graduate level
	Norwegian Structural Design Specifications	Graduate level
	Concrete Laboratory Techniques	Junior level

GRADUATE STUDENT RESEARCH SUPERVISION

Since 1978, has supervised the studies and research work of 22 graduate students (Ph.D. and M.S.), in addition to supervising separate independent studies of 10 graduate students (Ph.D. and M.S.).

Currently (Fall 1985) supervises the studies and research work of 3 Ph.D. students and 6 M.S. students.

REIDAR BJORHOVDE

UNIVERSITY ADMINISTRATIVE DUTIES

1. College Advisory Committee, College of Engineering, University of Arizona (1983 - 1985).

2. Committee on Graduate Policy, Department of Civil Engineering, University of Arizona (1983 - 1985).

3. Promotion and Tenure Committee, Department of Civil Engineering, University of Arizona (1985 - 1989).

4. Director of the I. F. Morrison Structural Engineering Laboratory at the University of Alberta (1978-1981).

5. Chairman of the Structural Engineering Group, University of Alberta (10 faculty members) (1978-1981).

6. Coordinator of Graduate Program in Welding Engineering, University of Alberta (1978-1981).

7. Editor of "Engineering Newsletter", publication of the Faculty of Engineering, University of Alberta (1980-1981).

8. Selection Committee for Chairman of the Department of Geography, University of Alberta (1979-1980).

9. Academic Welfare Committee of the Academic Staff Association of the University of Alberta (1979-1981).

10. Salary Committee of the Academic Staff Association of the University of Alberta (1980-1981).

11. Committees of the Faculty of Engineering, University of Alberta:

    (a) Curriculum Committee (1977-1978)
    (b) Admission, Promotions and Timetables Committee (1978-1981)
    (c) Salaries and Promotions Committee (1979-1980)
    (d) Industrial Liaison Committee in Welding Engineering (1978-81)

12. Committees of the Department of Civil Engineering, University of Alberta:

    (a) Academic Planning Committee (1977-1980)
    (b) Timetabling Committee (1977-1979 and 1980-1981)
    (c) Selection Committee for New Academic Staff (1977-1978)
    (d) Non-Academic Staff Committee (1978-1980); (Chairman 79-80)
    (e) Nominating Committee (1980-1981)

REIDAR BJORHOVDE

SPECIAL CONTRIBUTIONS

1. Liaison faculty member between the Colleges of Engineering and Architecture, University of Arizona (1983 -).

2. Developed the Graduate Degree Program in Welding Engineering at the University of Alberta, including course and thesis requirements, accredition, funding, etc.

3. Developed proposal for the establishment of an endowed Chair of Welding Engineering at the University of Alberta. The proposal was accepted as a continuing funding commitment of the NOVA Corporation, Calgary, Alberta, Canada.

4. Developed a CORE Grant proposal for support of a computer systems analyst for the Structural Engineering Laboratory of the University of Alberta. This was funded by the Natural Sciences and Engineering Research Council of Canada for the period 1978-1981.

REIDAR BJORHOVDE

TECHNICAL/SCIENTIFIC COMMITTEE SERVICE
(items identified by * indicate currently active assignments)

1.* Member, Committee on Specifications, American Institute of Steel Construction (AISC) (1981 -).

2.* Member, Advisory Group for the Specification on Cold-Formed Steel Structures, American Iron and Steel Institute (AISI) (1982 -).

3. Member, Research Initiation Grant Panel, National Science Foundation (1984).

4. Chairman, Technical Administrative Committee on Metals, ASCE Structural Division (1978-1982).

5.* Member, ASCE Structural Division Committee on Research (1985 -).

6.* Chairman, ASCE Committee on Design of Steel Building Structures (1982-1986) (Member and Founder of Committee, 1981-1982).

7.* Member, ASCE Task Committee on Drift Control of Steel Building Structures (1984-1986).

8. Member, ASCE Committee on Structural Connections (1978-1981).

9. Member, ASCE Task Committee on Beam-to-Column Connections (1982-1985).

10.* Member, ASCE Committee on Compression Members (1982-1986).

11. Member, ASCE Committee on Safety of Buildings (1975-1978).

12. Member, ASCE Committee on Load and Resistance Factor Design (1977-1983).

13.* Chairman, Structural Stability Research Council (SSRC) Task Group 1 (1976 -) (Member, 1973-1976).

14.* Member, SSRC Task Group 6 (1979 -).

15. Member, SSRC Task Group 23 (1979-1984).

16.* Member, SSRC Task Group 25 (1984 -).

17. Member, SSRC Committee on Design Philosphy (1978-1980)

TECHNICAL/SCIENTIFIC COMMITTEE SERVICE (Continued)

18. Member, SSRC Committee on Research Priorities (1975-1981).

19. Member, SSRC Ad Hoc Committee on Column Curves (1982 -85).

20. Member, Welding Research Council (WRC) Committee on Beam-to-Column Connections (1976-1981).

21. Member, Subcommittee 1 of International Standards Organization (ISO) TC 167 (1977-1981).

22. Member (Alternate), Canadian Standards Organization (CSA) Committee W59 on Welded Steel Structures (1977-1981).

23. Member, CSA Committee S16 Task Group on Column Curves (1977-1980).

24. Member of the following Research Project Advisory Committees of the American Iron and Steel Institute (AISI):
    - (a) Effect of Beam Yielding on Column Stability (1974-77)
    - (b) Column Design in Unbraced Frames (1975-78)
    - (c) Steel Frames with Flexible Connections (1975-83)
    - (d) Single Plate Framing Connections (1976-83)
    - (e) Non-Principal Axis Bracing of Columns (1978-84)
    - * (f) Ultimate Capacity of Flexibly Connected Frames (1980 -)
    - (g) Beam-to-Column Web Connections (1979-81)
    - * (h) Load and Resistance Factor Design of Cold-Formed Steel Structures (1975 -)
    - (i) Fracture of Moment Connections (1980-82)

25.* Member of the following Subcommittees of the Advisory Group on the AISI Cold-Formed Steel Structures Specification:
    - (a) Bolted Connections (Subcommittee 3)
    - (b) Welding (Subcommittee 11)
    - (c) Research Needs (Subcommittee 21)
    - (d) Compression Members (Subcommittee 22)
    - (e) Load and Resistance Factor Design (Subcommittee 23)
    - (f) Flexural Members (Subcommittee 24)

26.* Member, Highway Development Advisory Committee, Arizona Department of Transportation (ADOT) (1985 -)

27.* Advisor, Special Committee for National Engineering Conference, American Institute of Steel Construction (AISC) (1985 -).

REIDAR BJORHOVDE

OTHER PROFESSIONAL COMMITTEE SERVICE

1. Publications Chairman, ASCE Structural Division committee on Metals (1975-1978).

2.* News Correspondent, ASCE Structural Division (1984-1987).

3.* Member, ASCE Structural Division Committee on Publications (1975-1978 and 1984-1987).

4.* Member, Editorial Board, Journal of Construction Steel Research (England) (Patrick J. Dowling, Imperial college, Editor) (1983 -).

5. Member, Editorial Board, Journal of Civil Engineering Design (USA) (C.P. Heins, University of Maryland, Editor) (1978-82).

6. Member, Canadian Society for Civil Engineering (CSCE) Committee on Publications (1980-1984).

7. Chairman, Structures Congress III (San Francisco, October, 1984) of the American Society of Civil Engineers (ASCE).

8. Member, Steering Committee for ASCE Structures Congress I (New Orleans, October, 1982).

9.* Member, Steering Committee for ASCE Structures Congress V (New Orleans, September, 1986).

10.* Member, Steering Committee for ASCE Speciality Conference on "The Mexico City Earthquake - One Year After," to be held in Mexico City, D.F., September, 1986.

11. International Coordinator, First International Symposium on Steel Structures, Mexican Institute of Steel Construction, Ciudad Obregon, Sonora, September, 1984.

12. Chairman, Fritz Engineering Laboratory 50th Anniversary Conference (Bethlehem, Pennsylvania, July 31 to August 2, 1985) (1983-1985).

REIDAR BJORHOVDE

RESEARCH PROPOSAL AND PAPER REVIEW ACTIVITIES

1. Reviewer of research proposals for the following organizations:
   - (a) National Science Foundation
   - (b) American Institute of Steel Construction
   - (c) American Iron and Steel Institute
   - (d) Structural Stability Research Council

2. Reviewer of technical/scientific papers for the following journals:
   - (a) ASCE Journal of Structural Engineering
   - (b) AISC Engineering Journal
   - (c) Canadian Journal of Civil Engineering
   - (d) Journal of Constructional Steel Research (England)
   - (e) Construction Metallique (France)
   - (f) Numerical Methods in Engineering (USA)

PROFESSIONAL REGISTRATION

Registered as Professional Engineer (P.E.) in the State of Montana (No. ENG5919E).

Registered as Professional Engineer (P.E.) in the Province of Alberta, Canada (No. 23915) (currently inactive).

ORGANIZATIONAL MEMBERSHIPS

Fellow, American Society of Civil Engineers (ASCE)
Professional Member, American Institute of Steel Construction (AISC)
Member, American Welding Society (AWS)
Member, International Association for Bridge and Structural Engineering (IABSE)
Member, the Society of Sigma Xi
Associate Member, Structural Engineers Association of Arizona (SEAoA)
Member-at-Large, Structural Stability Research Council (SSRC)

FOREIGN LANGUAGES

Fluent command of English, Norwegian, Swedish and Danish; very good command of French and German; working knowledge of Dutch, Italian and Spanish.

PUBLICATIONS, BOOKS AND REPORTS

See attached list

REIDAR BJORHOVDE

PUBLICATIONS, BOOKS AND REPORTS

1. Fire Stability and Fire Protection of Steel Structures
   Division of Steel Structures, Technical University of Norway, Trondheim, Norway, April, 1966 (Textbook, in Norwegian).

2. Material Properties for Lamellated, Orthotropic Plates; with Special Reference to Plywood
   Division of Steel Structures, Technical University of Norway, Trondheim, Norway, November, 1966 (Textbook, in Norwegian).

3.* Steel Structures and Fire: Assessment of a Complex Problem
   Published in the following three Norwegian Journals:
   (a) BYGG (Construction), Oslo, Norway, Nov. 1968
   (b) Jernindustri (Steel Industry), Oslo, Norway, Sept. 1968.
   (c) Ingenior-Nytt (Engrg. News), Oslo, Norway, Oct. 1968.

4. Investigations on the Lateral Bearing Capacity of Lag Screws Used in Timber Connector Joints
   Dissertation, Dr. Ing. Degree, Technical University of Norway, Trondheim, Norway, August, 1968.

5. Damping Capacity of a Concrete Tower: Field Tests on Tjeldsund Suspension Bridge
   Co-author with E. Hjorth-Hansen. Division of Structural Mechanics, Technical University of Norway, Trondheim, Norway, August, 1968.

6. The Philosophy of Column Design
   Fritz Engineering Laboratory Report No. 337.19, Lehigh University, Bethlehem, Pennsylvania, December, 1968.

7. Survey of Utilization and Manufacture of Heavy Columns
   Co-author with Lambert Tall. Fritz Engineering Laboratory Report No. 337.7, Lehigh University, Bethlehem, Pennsylvania, October, 1970.

8.* Structural Steel Research at Lehigh University
   BYGG (Construction), Civil Engineering Magazine of the Norwegian Society of Professional Engineers, No. 1, January, 1971 (pp. 33-38). (In Norwegian).

---

*Papers identified by * signify publication in peer-reviewed journals or conference proceedings (full papers).

PUBLICATIONS, BOOKS AND REPORTS (Continued)

9.* Modern Methods of Steel Construction in the United States
BYGG (Construction), Civil Engineering Magazine of the Norwegian Society of Professional Engineers, No. 2, February, 1971 (pp. 19-26). (In Norwegian).

10. Maximum Column Material Properties
Strength and the Multiple Column Curve Concept
Co-author with Lambert Tall. Fritz Engineering Laboratory Report No. 337.29, Lehigh University, Bethlehem, Pennsylvania, October, 1971.

11.* The Largest Testing Machine in the World
BYGG (Construction), Civil Engineering Magazine of the Norwegian Society of Professional Engineers, No. 2, February, 1972 (pp. 15-16 and 24) (In Norwegian).

12. Deterministic and Probabilistic Approaches to the Strength of Steel Columns
Ph.D. Dissertation, Lehigh University, Bethlehem, Pennsylvania, May, 1972.

13.* Residual Stresses in Thick Welded Plates
Co-author with J. Brozzetti, G. A. Alpsten and L. Tall. Welding Journal, American Welding Society, Vol. 51, No. 8, August, 1972 (pp. 392s-405s).

14.* A Probabilistic Approach to Column Strength
Proceedings, ASCE Specialty Conference on Safety and Reliability of Metal Structures, Pittsburgh, Pennsylvania, November, 1972.

15.* The Probabilistic Characteristics of Maximum Column Strength
Co-author with Lambert Tall. IABSE Colloquium on Column Strength, Paris, France, November, 1972.

16.* Development of Multiple Column Curves
Co-author with Lambert Tall. IABSE Colloquium on Column Strength, Paris, France, November, 1972.

17.* Discussion of "Illustrations of Reliability-Based Design", by M. K. Ravindra, N. C. Lind, and W. Siu.
Journal of the Structural Division, ASCE, Vol. 101, No. ST8, August, 1975 (pp. 1714-1716).

PUBLICATIONS, BOOKS AND REPORTS (Continued)

18. Centrally Loaded Columns
Co-author with J. W. Clark and L. Tall. Chapter 3 of the 3rd Edition of the "Structural Stability Research Council Guide to Stability Design Criteria for Metal Structures". Wiley-Interscience, New York, New York, 1976.

19. Elements of Steel Structures: History, State-of-the-Art, and Potential Developments, Part 2: Design of Columns
1976 ASCE Annual Convention, Philadelphia, Pennsylvania, September 27 - October 1, 1976.

20.* North American Column Research and Design Practice
Invited Theme Paper. IABSE Second International Coloquium on Stability of Steel Structures, Liege, Belgium, April, 1977.

21. Behavior and Strength of Cold-Formed HSS Columns
Structural Engineering Report No. 65, University of Alberta, Edmonton, Alberta, Canada, December, 1977.

22.* The Safety of Steel Columns
Journal of the Structural Division, ASCE, Vol. 104, No. ST3, March, 1978 (pp. 463-477).

23.* LRFD Criteria for Steel Beam-Columns
Co-author with T. V. Galambos and M. K. Ravindra. Journal of the Structural Division, ASCE, Vol. 104, No. ST9, September, 1978 (pp. 1371-1387).

24.* Limit States Design of HSS Columns
Co-author with P. C. Birkemoe. Canadian Journal of Civil Engineering, Vol. 6, No. 2, June, 1979 (pp. 276-291).

25.* Some Aspects of Stub-Girder Design
Co-author with T. J. Zimmerman. Engineering Journal, American Institute of Steel Construction, Vol. 17, No. 3, 3rd Quarter, 1980 (pp. 54-69).

26. Inelastic Behavior of Multistory Steel Frames
Co-author with M. H. El-Zanaty and D. W. Murray. Structural Engineering Report No. 83, University of Alberta, Edmonton, Alberta, Canada, March, 1980.

PUBLICATIONS, BOOKS AND REPORTS (Continued)

27.* Research Needs in Stability of Metal Structures
Journal of the Structural Division, ASCE, Vol. 106, No. ST12, December, 1980 (pp. 2425-2442).

28.* General Principles for the Stability Design of Metal Structures
Co-author with W. F. Chen, E. H. Gaylord, T. V. Galambos, J. S. B. Iffland, J. Springfield, and J. A. Yura. Civil Engineering Magazine, American Society of Civil Engineers, No. 2, February, 1981 (pp. 53-54).

29. Analysis and Design of Stub-Girders
Co-author with T. J. Zimmerman. Structural Engineering Report No. 90, University of Alberta, Edmonton, Alberta, Canada, March, 1981.

30.* Effects of Semi-Rigid Connections on Steel Column Strength
Co-author with M. H. Ackroyd. Technical Discussion, Journal of Constructional Steel Research, London, England, Vol. 1, No. 3, September, 1981 (pp. 48-51).

31.* Determination of Residual Stresses in Structural Shapes
Co-author with T. Pekoz, S. J. Errera, B. G. Johnston, D. R. Sherman, and L. Tall. Journal of Experimental Techniques, Society for Experimental Stress Analysis, Vol. 5, No. 3, September, 1981 (pp. 4-7).

32. Full-Scale Test of a Composite Truss
Structural Engineering Report No. 97, University of Alberta, Edmonton, Alberta, Canada, June, 1981.

33. Design Methods for Steel Box-Girder Support Diaphragms
Co-author with R. J. Ramsay. Structural Engineering Report No. 98, University of Alberta, Edmonton, Alberta, Canada, July, 1981.

34.* Discussion of "End Restraint and Column Stability" by W. F. Chen.
Journal of the Structural Division, ASCE, Vol. 107, No. ST8, August, 1981 (pp. 1696-1700).

35. Engineering Study in the United States and Europe
Reader Comment, Engineering Education, Journal of the American Society for Engineering Education, September, 1981.

36. Weld Defects: Causes and Methods of Avoidance
Test for Short-Course on "Welding in Civil Engineering", University of Arizona, Tucson, Arizona, September, 1981.

PUBLICATIONS, BOOKS AND REPORTS (Continued)

37. Welded Connections: Steel Grade Selection and Design Considerations
Test for Short-Course on "Welding in Civil Engineering", University of Arizona, Tucson, Arizona, September, 1981.

38. Graduate Programs to Meet Industrial Needs
Co-author with B. M. Patchett. Proceedings, 1982 Annual Meeting, American Society for Engineering Education, College Station, Texas, June, 1982.

39.* Design of Steel Structures by LRFD
Invited Paper. Proceedings, 3rd Mexican National Symposium on Steel Structures, Guadalajara, Mexico, October, 1982.

40.* Discussion of "Headed Shear Stud Connectors in a Stub-Girder Floor System" by T. Rezansoff and M. U. Hosain
Canadian Journal of Civil Engineering, Vol. 10, No. 1, March, 1983 (pp. 165-167).

41.* Behavior of Steel Columns: A Comprehensive Treatment
Co-author with W. F. Chen. Proceedings, W. H. Munse Symposium on Metal Structures: Research to Practice. American Society of Civil Engineers, Philadelphia, Pennsylvania, May, 1983.

42. Strength and Behavior of Connection Elements
Co-author with D. J. Irish. Research Report, Department of Civil Engineering, University of Arizona, Tucson, Arizona, May, 1983.

43. Tests of Gusset Plate Connections
Co-author with S. K. Chakrabarti. Research Report, Department of Civil Engineering, University of Arizona, Tucson, Arizona, May, 1983.

44.* Design Criteria for End-Restrained Columns
Co-author with W. F. Chen. Proceedings, Third International Colloquium on Stability of Steel Structures, IABSE, Paris, France, November, 1983.

45.* Effect of End Restraint on Column Strength: Practical Applications
Engineering Journal, American Institute of Steel Construction, Vol. 21, No. 1, First Quarter, 1984 (pp. 1-14).

PUBLICATIONS, BOOKS AND REPORTS (Continued)

46. Advances in Column Stability Considerations
Invited Contribution for "Verba Volant, Scripta Manent", 70th Anniversary Volume in Honor of Charles Massonnet, Universite de Liege, Liege, Belgium, March, 1984.

47.* Behavior and Strength of Stub-Girder Floor Systems
Invited Paper. Proceedings, U.S.-Japan Cooperative Conference on Composite Construction, University of Washington, Seattle, Washington, July, 1984 (ASCE Special Publication, 1985; C. W. Roeder, Editor [pp. 13-27]).

48. Gusset Plate Design Utilizing Block Shear Concepts
Co-author with S. G. Hardash. Research Report, Department of Civil Engineering, University of Arizona, Tucson, Arizona, August 1984.

49. Recent Advances in Column Design
Invited Paper. First International Symposium on Steel Structures, Mexican Institute of Steel Construction, Ciudad Obregon, Sonora, Mexico, September 24-25, 1984.

50.* Approches d'Analyse de Resistance au Flambement
(Developments in Column Stability Studies) (In French) Construction Metallique, Paris, France, Vol. 22, No. 1, March, 1985 (pp. 31-42).

51.* Tests of Full-Size Gusset Plate Connections
Co-author with S. K. Chakrabarti. Journal of Structural Engineering, ASCE, Vol. 111, No. ST3, March, 1985 (pp. 667-684).

52. Static and Dynamic Behavior of Monotube Sign Support Structures
Co-author with M. R. Ehsani and S. K. Chakrabarti. Reports No. FHWA/AZ 85/194-I and 194-II (two volumes), Arizona Department of Transportation, Phoenix, Arizona, June, 1985.

53.* New Design Criteria for Gusset Plates in Tension
Co-author with S. G. Hardash. Engineering Journal, American Institute of Steel Construction, Vol. 22, No. 2, Second Quarter, 1985 (pp. 77-94).

54.* Poutres Mixtes Composees sur Troncons Courts: Un Systeme de Plancher Efficace
(Stub-Girders: An Efficient Composite Floor System) (In French)
Construction Metallique, Paris, France, Vol. 22, No. 2, June, 1985 (pp. 43-54).

55.* Effective Width Criteria for Composite Beams
Co-author with C. R. Vallenilla. Paper approved for publication in the AISC Engineering Journal, 1985.

56.* Discussion of "Shear Capacity of Stub-Girders: Full-Scale Tests," by Rick B. Kullman and M V. Hosain. Approved for publication in the ASCE Journal of Structural Engineering, 1985.

57.* Deflection Criteria for Sign Support Structures
Co-author with M. R. Ehsani. Paper submitted for publication in the ASCE Journal of Structural Engineering, 1985.

58. Field Testing of Monotube Sign Support Structures
Co-author with K. A. Martin and M. R. Ehsani. Report no. ATTI-85-5, Arizona Transportation and Traffic Institute, University of Arizona, Tucson, Arizona, September, 1985.

59.* Centrally Loaded Columns
Co-author with T. V. Galambos. Chapter 3 of the 4th Edition of the "Structural Stability Research Council Guide to Stability Design Criteria for metal Structures." To be published by Wiley-Interscience, New York, in 1987.

CURRICULUM VITAE

Mohammad R. Ehsani, Assistant Professor
Department of Civil Engineering
and Engineering Mechanics
THE UNIVERSITY OF ARIZONA
Tucson, Arizona 85721
Telephone: (602) 621-6589/621-2266

PERSONAL DATA

Date of Birth:	June 28, 1954
Marital Status:	Single
Health:	Excellent

EDUCATION

BSCE — University of Michigan, December 1976
The academic program included general Civil Engineering coursework with emphasis on Structural Engineering.

MSCE — University of Michigan, August 1978
The academic program emphasized Structural Engineering.

Ph.D. — University of Michigan, July 1982
The doctoral dissertation, "Behavior of External Reinforced Concrete Beam to Column Connections Subjected to Earthquake-Type Loading," was supervised by J. K. Wight. Research objectives were to evaluate the effect of parameters influencing the inelastic behavior of beam-column connections.

EXPERIENCE

8/82 - Present — Assistant Professor of Civil Engineering and Engineering Mechanics, University of Arizona.
Responsible for research and instruction in structural engineering analysis and design.

5/84 - Present — Consultant to Cannon and Associates, Inc., Tucson, Arizona.
Involved in several bridge design projects, including the nine million dollar Kino Boulevard Overpass.

9/78 - 8/82 Graduate Research Assistant, Department of Civil Engineering, University of Michigan
Constructed and tested full-scale reinforced concrete subassemblies subjected to cyclic loading.

1/78 - 5/78 Graduate Teaching Assistant, Department of Civil Engineering, University of Michigan.

AREAS OF RESEARCH INTEREST

Analysis of Structures Subjected to Static or Dynamic Loading. Elastic and Inelastic Behavior of Reinforced Concrete and Composite Structures and Laboratory Testing of Structural Componenets.

TEACHING

1. New Courses Introduced at University of Arizona

   Prestressed Concrete Structures (CE 537), taught every Spring Semester since 1983, average enrollment of 12 graduate students.

   Behavior of Reinforced Concrete Members (CE 633), taught every Fall Semester since 1983, average enrollment of 12 graduate students.

2. Existing Courses

   CE 214 - Statics (Course Director)

   CE 300 - Senior Project

   CE 331 - Structural Engineering II

   CE 337 - Structural Design in Concrete

   CE 499 - Independent Study

3. Graduate Student Theses Supervised:

   Adel S. Benjar, (M.S.), "Analysis of Reinforced Concrete Columns Subjected to Axial Load and Biaxial Bending," April 1983.

   Kipp A. Martin, (M.S.), "Field Testing of Monotube Sign Support Structures," (Co-chaired with R. Bjorhovde), September 1985.

Tariq A. Al-Faris, (M.S.), "Experimental Study of Behavior of Unbonded Post-Tensioned Beams," October 1985.

Ali Karimnassaee, (M.S.), "Flexural Behavior of Lightly Reinforced Unbonded Post-Tensioned Beams," January 1986.

Mohamad Yacoub, (M.S.), "Performance Criteria for Reinforced Concrete Beam-Column Connections," March 1986.

Tamim A. Samman, (Ph.D.), "Behavior of Indeterminate Beam-Column Subassemblies Subjected to Earthquake-Type Loading," Expected Summer 1987.

Fadel F. Alameddine, (M.S.), "Cracked Stiffness of Circular Columns," Expected May 1986.

Wissam A. Kaddoura, (M.S.), "Computer-Aided Design of Prestressed Concrete Beams," Expected August 1986.

Robert D. Turton, (M.S.), "Effect of Diaphragm Skew on Torsional Stiffness of Bridges," Expected August 1986.

RESEARCH GRANTS

1. "Data Acquisition and Testing Equipment for Full- and Reduced-Scale Structures," National Science Foundation, $70,000, June 1983-May 1984, (Co-PI with R. Bjorhovde).

2. "Monotube Span-Type Sign Structures," Arizona Department of Transportation, $39,930, June 1983-May 1984, (Co-PI with R. Bjorhovde).

3. "Field Testing of Monotube Span-Type Structures," Arizona Department of Transportation, $68,802, July 1984-September 1985 (Co-PI with R. Bjorhovde).

4. "Minimum Reinforcement Requirements for Prestressed Concrete Beams," Saudi Arabian Educational Mission, $1,900, September 1984-August 1985.

5. Earthquake Resistant Behavior of High Strength Reinforced Concrete Beam to Column Connections," College of Engineering, University of Arizona, $6,000, August 1984-June 1985.

6. "Structural Testing Reaction Frame," Arizona Department of Transportation, $4,000 in steel sections, October 1984.

7. "Fiber Reinforced Concrete Beam to Column Connections Subjected to Simulated Earthquake Loading," University of Arizona Foundation, $2,100, November 1984.

8. "Cyclic Behavior of Indeterminante Reinforced Concrete Beam-Column Subassemblies," Saudi Arabian Educational Mission, $9,155, August 1985.

PUBLICATIONS

1. Ehsani, M. R., "Reinforced Concrete Beam to Column Connections Subjected to Earthquake-Type Loading," presented at the American Concrete Institute Convention, Atlanta, Georgia, January 1982.

2. Ehsani, M. R., "Behavior of External Reinforced Concrete Beam to Column Connections Subjected to Earthquake-Type Loading," Ph.D. Dissertation, University of Michigan, July 1982, 243 pp.

3. Ehsani, M. R., "Cyclic Behavior of Reinforced Concrete Beam to Column Connections," presented at the ASCE Annual Convention, New Orleans, Louisiana, October 1982.

4. Ehsani, M. R., S. K. Chakrabarti, and R. Bjorhovde, "Static and Dynamic Behavior of Monotube Span-Type Sign Structures," Report No. FHWA/AZ/194, Vols. I and II, Arizona Department of Transportation, Phoenix, Arizona, June 1985, 153 pp.

5. Ehsani, M. R., and J. K. Wight, "Reinforced Concrete Beam to Column Connections Subjected to Earthquake-Type Loading," Proceedings, Eighth World Conference on Earthquake Engineering, San Francisco, California, Vol. VI, July 1984, pp. 421-428.

6. Ehsani, M. R. and D. Rosenbaum, "Biaxial Bending of Reinforced Concrete Columns," ACI Publication COM-2(85), American Concrete Institute, Detroit, Michigan, March 1985.

7. Ehsani, M. R. and J. K. Wight, "Effect of Transverse Beams and Slab on Behavior of Reinforced Concrete Beam to Column Connections," Journal of the American Concrete Institute, No. 2, Vol. 82, March-April 1985, pp. 188-195.

8. Ehsani, M. R. and J. K. Wight, "Exterior Reinforced Concrete Beam to Column Connections Subjected to Earthquake Type Loading," Journal of the American Concrete Institute, No. 4, Vol. 82, July-August 1985, pp. 492-499.

9. Ehsani, M. R. and R. Bjorhovde, "Deflection Criteria for Sign Support Structures," ASCE Journal of Structural Division, under review, February 1985.

10. Ehsani, M. R., "Computer Aided Design of R/C Columns Subjected to Biaxial Bending," Concrete International: Design and Construction, under review, July 1985.

11. Blewitt, J. R. and M. R. Ehsani, "Charts for Tendon Profile in Prestressed Concrete Beams," PCI Journal, in press.

12. Martin, K. A., M. R. Ehsani, and R. Bjorhovde, "Field Testing of Monotube Sign Support Structures," Report No. ATTI-85-5, Arizona Transportation and Traffic Institute, College of Engineering, University of Arizona, September 1985, 155 pp.

13. Ehsani, M. R., T. A. Al-Faris, and A. Karimnassaee, "Behavior of Lightly Reinforced Unbonded Post-Tensioned Beams," PCI Journal, under review.

14. Moussa, A., C. Vallenilla, and M. R. Ehsani, "High Strength Concrete Beam-Column Subassemblies Subjected to Simulated Earthquake-Type Loading," accepted for presentation at the ACI Annual Convention, San Francisco, California, March 1986.

15. Ehsani, M. R., A. Moussa, and C. Vallenilla, "High Strength Concrete Frames Subjected to Inelastic Cyclic Loading," Proceedings, the Third U. S. National Conference on Earthquake Engineering, Charleston, South Carolina, August 1986, in press.

16. Martin, K. A., M. R. Ehsani, and R. Bjorhovde, "Field Tests of Highway Sign Structures," ASCE Journal of Structural Division, under review, January 1986.

SERVICE

1. University of Arizona

Course Director for CE 214 - Statics, January 1983-May 1984

College of Engineering Honors Program Committee, Member, 1983-present

Faculty Advisor for Student Chapter of ASCE, January 1983-1986
Hosted the Three-Day Pacific Southwest Conference with 295 students and faculty in attendance, March 28-30, 1985, and received national ASCE award for outstanding service.

College of Engineering Advisory Committee, Secretary, September 1984-1986

2. Scientific and Professional Committees

ASCE-ACI Committee 352, Joints and Connections in Monolithic Concrete Structures, Member, 1982-present

Structural Engineers Association of Arizona, Secretary, 1984-85, 1985-86

Arizona Chapter of American Concrete Institute, Director, 1985-87

ACI Fall Convention (Chicago, September 1985), Open Paper Session, Co-Chariman

ASCE - ACI Committee 445, Shear and Torsion, Associate Member (1985-present)

ASCE - ACI Committee 441, Reinforced Concrete Columns, Associate Member (1985-present)

ASCE - ACI Committee 442, Response of Concrete Buildings to Lateral Forces, Associate Member (1985-present)

ACI Annual Convention (San Francisco, March 1986), Open Paper Session, Chairman

OTHER

1. Honors and Awards

Chi Epsilon, Fall 1976
College of Engineering Scholarship, University of Michigan, Winter 1976
Clarence E. Groesbeck Scholarship, University of Michigan, Spring 1976
Award of Excellence in Teaching, Halliburton Education Foundation, University of Arizona, Fall 1983
The Society of the Sigma Xi, Spring 1984
Award for Outstanding Service, ASCE, 1985

2. Professional Memberships

American Society of Civil Engineers
American Concrete Institute
Earthquake Engineering Research Institute
Structural Engineers Association of Arizona

APPENDIX

ADOT REQUEST FOR PROPOSAL

REQUEST FOR PROPOSALS

RESEARCH PROJECT NO. HPR-PL-1(29)ITEM 258

"WIND TUNNEL TESTING OF MONOTUBE SIGN SUPPORT STRUCTURES"

PROJECT STATEMENT AND PROPOSAL GUIDELINES

JANUARY, 1986

ARIZONA DEPARTMENT OF TRANSPORTATION
ARIZONA TRANSPORTATION RESEARCH CENTER

ARIZONA TRANSPORTATION RESEARCH CENTER

HIGHWAY OPERATIONS RESEARCH

Request for Proposals

Project Number: HPR-PL-1(29)ITEM 258

Research Project Title: "WIND TUNNEL TESTING OF MONOTUBE SIGN SUPPORT STRUCTURES"

Research Problem Statement:

The current design criteria for monotube sign support structures utilizes a deflection limitation criteria that is a function of sign depth and is based on an empirical formula developed for use with truss-type structures. Previous research has shown that the current deflection criteria has no rational basis and tends to lead to very conservative designs. Limited field tests have been conducted under previous research; however, additional studies of the monotube structure should be conducted under high wind conditions. The intent of the study is to determine force and dynamic response characteristics for a range of typical scaled monotube sign support structures which will be subjected to high wind velocities under wind tunnel testing. The findings of this study will provide the foundation for the development of improved design criteria.

Objective

The objective of this study is to conduct wind tunnel testing of scale models of typical monotube sign support structures, using span lengths from 40 to 140 feet, and wind speeds up to 100 mph. The tests aim at determining the force distributions and the dynamic characteristics of the structures under the action of a wide range of wind velocities and orientation.

It is anticipated that the research will include the following tasks:

1) Survey and review of wind tunnel tests of similar structures.

2) Design of the reduced-scale models. The models shall conform to the details of typical ADOT structures. It is anticipated that four or five models will be required.

3) Provide an interim report detailing the proposed models to be tested, including number, size, and location of signs, wind speeds and orientation, as well as the proposed analysis methodology.

4) Wind tunnel testing of the scale models.

a) Models shall be fabricated in accordance with the proposed and approved designs.

b) Conduct wind tunnel testing for wind speeds varying from 10 to 100 mph.

c) Record displacements and any other effects for various wind directions.

5) Based on the results of this study and the previous analyticial and field evaluations, develop design recommendations for the monotube sign support structures. Such recommendations should be in a form suitable for consideration by AASHTO for possible modification of the existing design criterion.

6) Prepare final report.

Estimated Budget: $100,000

Contract Time: 12 months

Proposed Project Start Date: FY 1985-86

Proposal Delivery:

A. Sealed proposals will be received until 4:00 P.M. Mountain Standard Time on __________________ at the following location:

Arizona Department of Transportation
Design Section - Room 202E
205 South 17th Avenue
Phoenix, Arizona 85007

No proposals will be accepted after the time indicated. Proposals received after the deadline will be stamped for time and date, and returned unopened. All material submitted in accordance with this solicitation becomes the property of the State of Arizona and shall not be returned.

B. Twelve copies of the proposal are required. They should be packed in such a manner that the outer wrapping clearly indicates the following information:

Proposal
Research Project No. HPR-PL-1(29)ITEM 258
"WIND TUNNEL TESTING OF MONOTUBE SIGN SUPPORT STRUCTURES"

C. Any questions relating to this Request for Proposals should be directed to the attention of: Larry Scofield, Research Section, at the address stated above, or telephone (602)965-2368.

D. Proposals will be publicly opened at the time and place of submittal deadline, as designated above.

Proposal Content

The proposal shall be a well thought-out document which establishes the necessity for a research undertaking, clearly defines the objective, provides a detailed work plan for achieving the objective, and indicates how the research findings are expected to be used and includes a proposed budget. In accordance with A.C.R.R. R2-7-104, an offerer may designate as proprietary portions of a proposal.

Proposals should contain but are not limited to the following essentials:

A. Identification: A title sheet or equivalent which includes a concise (not to exceed 140 characters) title for the proposed study; name and business address of the organization that will conduct the work; name, title, and mailing address of the principal investigator(s); and the name, title, and organization unit of the person in the appropriate operating office who is monitoring the study.

B. Table of Contents: Self-explanatory.

C. Problem Statement: A clear and concise statement of the problem to reflect the proposers' understanding of the research issues to be investigated must be included.

D. Objectives of the Study: These are the technical objectives upon which the research staff is to focus attention and upon which research efforts are to converge. The objectives should clearly and concisely identify the products of research being sought.

E. Background and Significance of Work: Should provide a statement which:

   1. Describes the findings of the Transportation Research Information System (TRIS) and/or other literature searches.

   2. Evaluates alternative feasible solution strategies to the problem.

3. Supports the researcher's approach and states why he/she believes it is best.

F. Benefits: Tangible and intangible benefits of the selected research approach and anticipated research findings should be enumerated.

G. Research Work Plan: This is one of the most important elements of the proposal. The work plan must fully describe research tasks, including the submission of an acceptable report. It should define the proposed approach to the solution of the problem described in the research problem statement. The research methodology must be described in sufficient detail to permit evaluation of the probability of success in achieving the goals and objectives.

The research work plan must be subdivided into the following sections:

1. Introduction: Setting the stage for the presentation of research work plan.

2. Research Approach: Describes how the goals and objectives will be achieved through a logical and innovative plan. The plan should describe each task of the research to be undertaken. The task must delineate all products or deliverables specific to that phase of activity, e.g., working paper, presentation, journal article, survey tool, tabulation of data, computer software, draft final report, etc.

H. Work Time Schedule: A bar chart, or other type of progress chart, must be provided in the research proposal to illustrate the interrelationship and scheduling of the major operation phases (tasks) of the study. Milestones such as working paper submittals, meetings, and seminars are to be depicted.

I. Implementation: The research team should clearly describe how the research results can be used and by whom to improve practices in Arizona. The project team should present the strongest case possible to convince reviewers that the results of the research will be practical and implementable. Research projects under this program are sponsored with the intention that their results lead to decision-making and implementation. The proposal should, therefore, specify how the technology "know-how" may be transferred from the research team to practitioners. Results should be presented in the language of the practicing transportation professional so as to be immediately applicable to practice.

For studies which are expected to provide immediately implementable results, the proposal should specify implementable products such as a proposed specification, a procedural manual or guide, a training manual, hardware for demonstration, or software and instructions ready for computer application. If the findings of a study will not be suitable for immediate application, the research proposal should set forth additional steps which are expected to be required before application, e.g., additional research, field testing, etc.

It is required that research teams present a minimum of three briefings or seminars to practitioners during the project schedule.

Level of Effort by Tasks: Contribution of each team member (including sub-professionals or students) to each task should be identified in terms of person-hours. The level of involvement of each team member in the project must also be summarized as shown in Figure 1.

Manpower and Budget Estimate: The proposed budget should include salaries for professional and support personnel; overhead and indirect costs; travel; computer time; equipment (purchase and/or rental); expendable materials and suppliers; report printing and special services (where applicable).

Facilities Available: Each proposal should describe the general facilities at the researcher's disposal which are important to the conduct of his work.

Qualifications and Accomplishment of the Research Team: The proposal must describe how the research team members' academic, industrial and/or research experiences relate to the project. Proposals WILL NOT BE ACCEPTED if they do not contain a summary of the past accomplishments ("track record") of each team member.

Reports: The proposal should indicate the format and frequency of the reporting procedures to which the research team will adhere:

1. ATRC requires that a Monthly Progress Report be submitted by the 10th of each month during the project life. At minimum, this report must specify project title, period covered, tasks completed, tasks underway, percent of project completed, problems and strategies selected to solve them, tasks of the next period and expenditure to date. The table shown in Figure 1 will be completed for the effort to date and submitted with the Monthly Progress Report. All progress reports must be signed by the principal investigator. Figure 2 is a facsimile of such a report.

2. A draft Final Report must be submitted for review and comment by ADOT and the Federal Highway Administration. Sufficient project time should be

FIGURE 1

LEVEL OF EFFORT BY TASKS (MAN-HOURS AND COSTS)

Names of Principal Staff Members (include Sub-contractors and Consultants)	Role in Study	Time (%) Over Contract Period	Man-Hours Task 1	Task 2	Task 3	Task 4	Total	Hourly Rate ($)	Cost (%)
	Principal Investigator over-all project management								
	Co-principal Investigator								
Totals		100%							100%

Base: One man-month = 174 man-hours

FIGURE 2

MONTHLY PROGRESS REPORT

TO

ARIZONA DEPARTMENT OF TRANSPORTATION

Project Title:

Period Covered:

Expenditures To Date:

Research Agency:

% of Project Completed:

Progress:

Problems:

Work for Next Month:

Principal Investigator:

1/86