3-1-1988

1988 Research Program Summary

John E. Bower

ADVANCED TECHNOLOGY FOR LARGE STRUCTURAL SYSTEMS
Lehigh University

1988 RESEARCH PROGRAM SUMMARY

Edited by

John E. Bower

ATLSS Report No. 88-02

March 1988

An NSF Sponsored Engineering Research Center

1988 Research Program Summary

ATLSS Engineering Research Center

Cluster on: **Advances in Connection Technology**
(Cluster Leader: B. Vincent Viscomi)

. More Efficient Utilization of Steel Connections
George C. Driscoll, Principal Investigator

. Unified Design Methodology and Rational Models for Precast Concrete Connections
Peter Mueller, Principal Investigator

. Abrasive Waterjet Cutting of Concrete
G. Sathyanarayanan, Principal Investigator

. New Joining Technology
David A. Thomas, Principal Investigator

. Welding of High-Strength High-Value Steels
Alan W. Pense, Principal Investigator

. Construction Automation
N. Duke Perreira, Principal Investigator

Cluster on: **Knowledge-Based Systems in Construction**
(Cluster Leader: John L. Wilson)

. Knowledge-Based System for Bridge Fatigue Investigation
John L. Wilson, Principal Investigator

. Technical Information Center for Steel Structures
Frank A. Harvey and
Lynn S. Beedle, Co-Principal Investigators

ATLSS

Cluster on: **Knowledge-Based Systems in Construction**, continued

. Knowledge-Based System for Design Fabricator Interface
Donald J. Hillman, Principal Investigator

. Financial Packaging for Construction
Carl R. Beidleman, Principal Investigator

. Optimal Construction Management Systems
Carl R. Beidleman and
John H. Egbers, Co-Principal Investigators

Cluster on: **Sensor Technology for Performance Assessment**
(Cluster Leader: Henry Leidheiser)

. A Corrosion Monitor for Use on Structures
Malcolm L. White, Principal Investigator

. Crevice Corrosion of Structural Steel
Henry Leidheiser and
Richard D. Granata, Co-Principal Investigators

. Use of Acoustic Emission and Ultrasonic Sensors for Structural Monitoring
John D. Wood, Principal Investigator

ADVANCES IN CONNECTION TECHNOLOGY

PROJECT SUMMARIES

Summary of Project A3.1

More Efficient Utilization of Steel Connections

ABSTRACT

This project is addressing a widely acknowledged need for more knowledge about a wide range of connection types. The initial effort has been focused on some types of semi-rigid connections. Such connections appear in almost every type of steel structure. More information about them will help in improving their design. More important, the methodology developed can be applied to create and evaluate new connection types in the future.

One major test has been completed on a seat-and-top angle connection involving a 27 inch deep beam size, and a second is underway. Preliminary findings are: (1) Use of heavier sizes of angle and high strength steel permitted the semi-rigid connection to develop about 30 percent of the beam plastic moment. (2) The behavior was similar in nature to that predicted by a new simplified analysis procedure but the load achieved was significantly underestimated by the procedure. A better model for this detail is being developed with more attention to the flexibility of the bolts in the connection.

Additional connection types will be nominated for theoretical and experimental study.

OPPORTUNITY AND OBJECTIVE

Large structural systems are largely dependent on the style and quality of their connections for performance and economy. Many connections known to be among the most economical for fabrication cannot be utilized to their full effectiveness because practical methods for analysis and design are not available to the typical designer. The best design methods would include rule-of-thumb guides to permit initial design synthesis. These guides should be based on relatively simple analysis procedures backed up by a known correlation to both experiments and more exact analysis procedures.

Objectives: To assemble, based on the findings of theoretical and experimental programs, design guides and information about the behavior of numerous types of connections for moment-resisting frames, braced frames, frames with tubular members, and hybrid structures. To increase the knowledge base on the behavior and strength of partly restrained connections.

APPROACH

The work is being executed in phases, some of which are concurrent. The completed phases are:

(1) Development of a data base on connections with nonlinear moment-rotation characteristics.
(2) Review of survey findings and assignment of problem priorities.

The phases in process are:

(3) Selection of connection types for experimental and theoretical studies.
(4) Experiments on selected connection types.
(5) Theoretical studies of selected connection types.
(6) Recommendations for design and specifications.

IMPORTANCE

Results should fulfill needs expressed by both designers and fabricators for better information on connections which provide some end bending restraint but are not required to develop full member strength. Methodology developed will be useful in the synthesis of solutions for future connection types.

Relation to Strategic Plan and Other Clusters: The experimental effort can serve as a pilot project toward the evaluation of newly acquired data acquisition equipment. Software being developed for the project can be used to assist the experimental data processing needs of future projects. There is an opportunity to test certain types of sensors as add-ons to the instrumentation of these tests and provide a proving ground for efforts of the Sensor cluster. If efforts on the use of high-strength high-value steels in construction are to succeed, there will need to be a joint missionary or salesmanship job as well as proving technical feasibility.

DELIVERABLES:

Since the issuance of the Load and Resistance Factor Design specifications by AISC, designers have the opportunity to take advantage of the strength of partially restrained connections. Thus, this research project is aimed at gaining data base information that will aid in the development of guidelines for the effective use in design and construction of flexible structural connections with nonlinear moment-rotation characteristics.

BARRIERS TO PROGRESS:

Vendor software which accompanies modern data acquisition systems does not necessarily fit all the needs of our kind of testing.

A suitable model is needed for the interfaces between angles and other detail material, bolts, and main members.

PUBLICATIONS:

Driscoll, George C., 1987
ELASTIC-PLASTIC ANALYSIS OF TOP-AND-SEAT-ANGLE CONNECTIONS, Journal of Constructional Steel Research, Barking, Essex, England, Vol. 8, p119-135.

Chasten, Cameron P., Fleischman, Robert B., Lu, Le-Wu, and Driscoll, George C.
SEMI-RIGID STEEL CONNECTIONS AND THEIR EFFECTS ON STRUCTURAL STEEL FRAMES, Experimental and Theoretical Proposal, ATLSS Report No. 87-02, Lehigh University, May 1987.

Driscoll, George C., Heaton, Kenneth A., and Fleischman, Robert B.,
FORCES IN BEAM-TO-COLUMN CONNECTIONS, ATLSS Report No. 87-03, Lehigh University, July 1987.

STAFF

Principal Investigator: Dr. George C. Driscoll
Faculty Associates: Dr. Le-Wu Lu
Dr. Alan Pense
ATLSS Graduate Students: Mr. Cameron Chasten
Mr. Robert Fleischman
Student Assistant: Mr. Kenneth A. Heaton

Summary of ATLSS Project A3.2

Unified Design Methodology and Rational Models for Precast Concrete Connections

1. ABSTRACT

The objective of this project is to develop a unified design methodology for precast concrete connections as a basis for codification. The current focus is on truss models as the unifying rational model in the hope that code provisions for precast concrete connections can be tied into the truss model provisions that will be introduced with the 1992 ACI 318 Building Code. Truss models for commonly used connections are being developed and will be subjected to experimental confirmation. Results to date are encouraging, but point to a need for more detailed knowledge on anchorage and development of reinforcement in connection regions. As the project progresses, the application of advanced materials and new joining concepts are to be examined.

2. PROBLEM and OPPORTUNITY

Connections are highly labor- and cost-intensive elements and a major source of performance problems. Advances in connection technology are crucial to our quest for a more competitive and more automated construction industry. To improve the reliability of precast concrete connections code provisions are needed which are currently lacking.

The key problem of precast concrete construction is its connections. The lack of code provisions for precast concrete connections and the ensuing lack of confidence are a major impediment to their use, even though precast concrete offers more opportunities for construction automation than cast-in-place concrete.

3. APPROACH

The key element of a unified connection design methodology is to have rational models that are general enough to apply to whole classes of connections. Without such general models codification is virtually impossible. With the current empirical/semirational approach to connection design, virtually each of the hundreds of connection details would need to be tested and codified separately. Truss models have proven to be the unifying model for shear design of beams, walls, deep beams, brackets, corbels, etc. and will be introduced into the 1992 ACI Building Code. This project is therefore currently focusing on the development of truss models for commonly used connections and their comparison with test results. Results to date encourage us to believe that truss models also represent the unifying model for precast concrete connections and that their design and proper detailing can be tied into the truss model provisions of the 1992 ACI Code. We are interacting with industry through Englekirk Inc., the firm hired by the Prestressed Concrete Institute (PCI) to collaborate with this project and ATLSS.

While this project is focusing on the aforementioned immediate needs, its cross-disciplinary interaction with researchers in construction automation and advanced materials is expected to spark new joining concepts that are better suited for a higher degree of automation in fabrication and construction.

4. IMPORTANCE

A major objective of ATLSS is to contribute to a higher degree of automation in construction. This requires more modular structural systems, the components of which can be prefabricated in a factory environment and easily and reliably connected on site. Therefore, ATLSS has identified connection technology as a major emphasis in its program and, in concrete construction, is focusing on precast concrete.

The precast concrete industry perceives an urgent need to codify connection design and this is reflected in the collaboration established with Englekirk Inc. The understanding of connection behavior gained through the truss-model-based analysis of test specimens and the familiarity with the needs and constraints of industry gained through the collaboration with Englekirk Inc. will help identify the most promising opportunities for the application of advanced materials and new joining concepts that are being explored by other ATLSS researchers.

5. EVALUATION

Since Fall 1987 the following has been accomplished: A review of recent tests on simple and moment-resisting connections was conducted and revealed two major sources of unsatisfactory performance: (1) weld related failures and (2) neglect of eccentricities in the load path (Load path analysis using truss models can reveal and avoid the latter problem!) Truss models have been developed for seat angle connection regions found in precast concrete cladding panels. Truss models have been developed for beams with dapped ends and compared with test results from a recent PCI project in support of design guidelines to be developed by Englekirk Inc.

We are finding strong evidence that the reinforcement details not performing well are those which do not permit the development of truss action due to insufficient anchorage of rebars or compression struts. Guidelines on anchorage and development of reinforcement in connection regions will therefore represent a crucial element of a connection design methodology.

The research plan for the next year includes the following tasks:

(a) Develop truss models for more connection types and alternate reinforcement details
(b) Interpret existing connection test data using these truss models
(c) Reinterpret data on anchorage and development of reinforcement in a form useful for the truss model approach. Identify needed experimental data.
(d) Prepare report on draft guidelines for connection design. This report, to be finished by the end of 1988, represents a milestone and will serve as a vehicle to solicit industry comments.

6. PROJECT PERSONNEL

Dr. Peter Mueller, CE (PI)
John Pensiero , CE (RA)
Englekirk Inc. (Industry Contact)

EXPLORATORY STUDY OF ABRASIVE WATERJET CUTTING OF CONCRETE

ABSTRACT

Present study will look into the possibility of using Abrasive Waterjet for machining concrete slabs with hollow cores. An experimental work will be carried out by utilizing fractional factorial design for the process parameters. The effect of these parameters on the kerf quality will be used to yield the best results. Automating this process for cutting and slotting of the slabs will be explored.

POTENTIAL APPLICATION

The state - of - the - art literature review reveals that the current research on Concrete Slotting was carried out with continuous waterjets. Waterjets were not capable of cutting steel reinforcing bars and kerfing (slot width) was generally associated with spalling edges. Also waterjets require very high pressure and power for cutting concrete with rebars. By adding abrasives to the stream of water, it is possible to obtain a clean kerf on the steel reinforced concrete bars. In addition, abrasive waterjets can also be used for:

A. Removal of the top concrete layer for repairing roads.
B. Cutting and demolishing in the concrete industry.
C. Slotting for laying cables.
D. Cutting highway concrete for expansion joints.
E. Trenching for the prevention of crack propagation.

Although, numerous potential application exists for this process, current effort will look into the possibility of applying abrasive waterjet for cutting concrete slabs, which are usually cast with hollow cores. At present, **High ConcreteStructures, Inc.** of N. J. utilizes diamond tipped saws to cut these slabs to sizes. These cuts are either straight or angled cuts. Excessive tool wear and high cost for these diamond tools provide an impetus to replace diamond cutting with abrasive waterjet. In addition, the pocketing operations on these slabs are carried out with chisel and this can also be replaced by abrasive waterjet cutting. **High ConcreteStructures** is also very keen to automate this process of cutting, which can be done very easily with Abrasive Waterjets.

APPROACH

Several factors have been identified to have great impact on the effectiveness of abrasive waterjet cutting. An experimental work is necessary to determine the optimum values of these parameters for cutting concrete. Specifically, we are interested in identifying the effect of these parameters on the resulting effect and the values of the parameters that yield the best results. Since the number of factors is large, a fractional factorial design is utilized to include the following parameters:

Pressure
Nozzle Diameter
Traverse Rate

Abrasive Flow Rate
Number of Passes
Stand-off Distance
Nozzle Angle
Abrasive Size

Depth of cut, kerf quality (tolerance) and material removal rate are the responses that will be used for the present study. Kerf quality is perhaps a more important evaluation criterion for adapting Abrasive Waterjet system at **High ConcreteStructures.**

CONTRIBUTION TO ATLSS GOALS

Present effort will help **High ConcreteStructures** in identifying the potential of Abrasive Waterjet for cutting and slotting concrete, and in the automation of these processes. Current effort would also help in exploring the possibility of using this technology for demolision, trenching and deep kerfing.

MAJOR MILESTONES

This project was started in September, 1987. By the end of August, 1988 the experimental work related to cutting of concrete slabs will be accomplished. Automation of this process for cutting concrete at **High ConcreteStructures** will be completed in August, 1989. The application of this technology to other aspects of concrete industry will be carried out in the time frame of September 1989 to August 1991.

PROJECT PERSONNEL

This exploratory study is carried out by **Marc Q. Douglas**, a graduate student in the Department of Industrial Engineering, under the guidance of **Dr. G. Sathyanarayanan** (Assistant Professor of Industrial Engineering).

M. S. THESIS

The experimental work will be carried out at Ingersoll Rand's facility in Baxter Springs, KS. The concrete slabs of required thicknesses and with different core geometries will be provided by High ConcreteStructures. Results of the current study will be documented in Marc Douglas's M. S. thesis and will be also submitted for publication to a transaction quality journal.

February 1988

ATLSS A3.3 Project Summary
New Joining Technology

1. Abstract

This project is applying polymer and composite materials knowledge to the improvement of concrete beams by "external reinforcement." Fiber-reinforced plastic (FRP) plates are being bonded to the tension faces of reinforced concrete beams, which could be structurally inadequate because of underdesign, substandard materials, or degradation in service. Selection of different reinforcing fibers and fiber orientations for the FRP plates gives many possibilities in seeking cost-effective external-reinforcement performance. By Fall 1988, our testing will be able to determine the feasibility of strengthening concrete beams, and to decide if the method is worthy of further development and testing. Equally important, however, is the experience gained with fiber and adhesive technologies, which may be adapted in the future to innovative load-bearing connections for precast concrete and other types of structural members.

2. Problem Opportunity/Objective

Broadly, apply polymer and composite materials technologies to develop new and improved joining methods. Currently, the specific objective is to increase the stiffness and strength of concrete beams by bonding fiber-reinforced plastic (FRP) plates to the tension faces of beams. Thus the structural strength of substandard or degraded concrete can be upgraded by field repair and rehabilitation.

3. Approach

Previous investigators (notably Van Gemert of the Katholieke Universiteit in Belgium, and Cook and coworkers at the University of Cincinnati) have tested external reinforcement of concrete with steel plates and one type of FRP. However, the special properties of FRP--high strength, control of modulus and strength by fiber selection and orientation, light weight, and resistance to corrosion--have not been exploited.

Plates of several FRP materials are currently being acquired. These include materials with random glass fibers, oriented glass fibers, mixed glass and graphite (hybrid composites), graphite, and Kevlar. Tensile testing is underway to document the moduli, strengths, and failure mechanisms of this variety of materials.

Concrete beams 6 in. wide by 12 in. deep and 9 ft. long will be cast, and FRP plates 6 in. wide by approximately 1/8 in. thick and 8 ft. long will be bonded on the tension faces with an industrial epoxy adhesive. Flexural testing will determine the increased load capacity of the beams, as well as changes in failure modes. Tests will also be monitored by acoustic emission, with equipment expected to be available from another ATLSS project on sensors and performance assessment.

4. Importance

Structural systems advance in part by exploitation of the properties and fabrication possibilities provided by new materials and processes. This project brings together civil and materials engineers in an initial effort to combine fiber-reinforced composite materials with traditional materials (particularly reinforced or prestressed concrete). Future applications are expected as we become experienced with composite materials in the cross-disciplinary setting of the ATLSS center. In the next year, fiber-reinforced materials will be considered as a way of joining the ATLSS Connection Node to concrete structural members.

5. Evaluation

Effectiveness of the external reinforcements will be determined from test results, as well as application of the mathematical model already developed and used for designing the beams and selecting the FRP reinforcements. Within 6 months we will be able to determine the effectiveness of strengthening concrete beams. If the results are promising, further research support will be sought to apply external reinforcement to particular field problems.

6. Project Personnel

Philip A. Ritchie, Civil Engineering
Guy M. Connelly, Materials Research Center
Dr. Le-Wu-Lu, Civil Engineering
Dr. John A. Manson (deceased, February 1988)
Dr. David A. Thomas, Materials Science and Engineering

7. Project Reports, Papers

"External Reinforcement of Concrete Beams,"
Philip A. Ritchie, internal report for project advisory meeting, October 1987.

PROJECT A3.4 WELDING OF HIGH-STRENGTH HIGH-VALUE STEELS

Abstract

The research effort is intended to develop the mechanical properties that are characteristic of welded joints of high strength, high value steels, and to identify how welding variables can be controlled to optimize their properties.

The research on these materials has centered on two promising types of steels. These include microalloyed steels with Nb or V and advanced steel alloys precipitation strengthened with Cu. An additional more theoretical program aimed at establishing acceptable maximum levels of Nb and V, a present industrial problem for current weldments of older steels, has been initiated. The background for this work has been a series of studies on the base metal and weldment properties of more conventional high strength steels now used in construction, reports on which were published this year.

The experimental work on high-strength, precipitation-strengthened steel weldments has identified the coarse-grained heat-affected-zone as the critical zone in a weldment with respect to toughness. Limiting weld heat input to less than 3 KJ/mm, will produce a high strength weldment with adequate toughness for most structural connections. Studies have also demonstrated that these steels can be welded without pre- or post-weld heat treatment providing a substantial fabrication saving over conventional steels. The most economic application for these materials will be in composite construction where their excellent weldability allows them to be introduced into critical locations and their high static toughness increases the capacity of connections in structure. Their further application to structures is a subject of continuing study the connections group.

Problem Opportunity and Objective

The use of high strength high value steels for construction offers some opportunities for significant savings for two aspects of the construction system. The first is unique properties, for example higher strength and toughness resulting in lighter weight and higher capacity structures. The second is in greater ease of fabrication, for example, greater weldability, which can result in lower fabrication cost. The ATLSS Research project on high strength steels is intended to identify new steels that can provide both of these benefits.

Approach

Research plans include detailed studies of the effects of weld heat on toughness. While some high and low heat input welds will be made (2 and 5 KJ/mm) most work will be done using a weld thermal cycle simulator to allow a wider than normal range of variables to be explored and permit testing of broad heat affected zones. The tests planned include tension, Charpy impact, hardness, and light, SEM and TEM metallography and CTOD and J_{IC} fracture toughness. One aspect of material behavior of considerable importance to the application of this steel is response to post weld heat treatment (stress relief). Cracking on stress relief has been reported for this steel but tests done in the fall of 1987 showed this is not as severe as first supposed and should not limit its use. This work was done using a new variable restraint weldability specimen developed in an ATLSS joint test program in the summer of 1987. The continuation of this work is cosponsored by the Pressure Vessel Research Committee and an ATLSS industrial partner, Lukens Steel Corp.

The research team on this work has been primarily confined to the welding group in the Materials Science and Engineering Dept, however, it is planned in the 1988-89 year to add a Civil Engineering student to this project [such a student was involved in 1985-86] and to direct some of this work to application of this steel to the "ATLSS Connection" concept (project B2), for which it is especially suited in strength, toughness, and weldability. This will combine the activities of the welding group with those involved in automation of connections including the Mechanical and Civil Engineering faculty and students.

Importance

This welding work is of interest to both commercial fabricators and the Navy because the base steel is one being considered for structural and ship hull applications. Naval welding engineers have estimated a very substantial economic savings will result from its application in ships because of its good weldability. The cost reduction in fabrication can only be gained after initial investment in material because the base steel has a higher first cost. Thus it is the systems saving that is important, and requires a systems approach to the constructed product. This not only fulfills ATLSS goals to provide cost reduction but also promotes the ATLSS principal of life cycle costing in construction.

The greater weldability of these kinds of steel serves to increase potential for automation, thus providing greater potential for application in the ATLSS Connection and other automated construction techniques.

Evaluation

The first phase of this program was completed in 1987 with the finishing of the joint PVRC-ATLSS work on a single heat on this steel. The second phase will commence this year under joint PVRC-ATLSS-Lukens Steel sponsorship. This phase has these goals, and a two-year time frame

1. Develop a theoretical base for calculation and control of welding parameters for the A710 steel based on the thermodynamics and kinetics of the precipitation process.
2. Provide test data on reheat cracking potential in A710 steel in practical applications.
3. Identify and demonstrate the properties of a weld metal which can produce weldments that utilize the full properties of the base metal.
4. Demonstrate that weldments of A710 steel can meet requirements for current offshore platform applications, which requires CTOD testing.

Project Personnel

The project personnel are Dr. Alan W. Pense, Dr. Robert D. Stout, Dr. Eric Kaufmann, Mr. Rajan Varughese, Mr. Charles Robino and Ms. Wei-Fang Qin.

Project Reports

1. Mechanical Property Characterization of A588 Steel Plates and Weldments, by Alan W. Pense, ATLSS Report 87-07, November 1987.
2. The Effect of Fabrication Operations on the Strength and Toughness of A808 Steel, by R. Varughese, W. Bolliger, A. W. Pense, ATLSS Report 87-09, November 1987.
3. The Fracture Behavior of A588 Grade A and A572 Grade 50 Weldments, by C. V. Robino, R. C. Dias, R. Varughese, A. W. Pense. (in preparation).
4. A Study of the Weldability of MIL-A-12560 Armor Steel, by G. Reynolds, A. D. Wilson, B. R. Somers, B. J. French, E. J. Kaufmann, R. D. Stout, A. W. Pense, ATLSS Report 87-11, November 1987.

ATLSS B2 Project Summary

CONSTRUCTION AUTOMATION

Construction Robotics
Construction Automation in Connections
Smart Tools for Construction Automation
Tools for Vertical Integration and Automation

ABSTRACT

The Construction Automation project deals with the development of software and mechanical tools which will increase safety, productivity, and quality of the construction process at the job site. The primary emphasis is on automating the framing process for steel and reinforced concrete structures. The project lays at the intersection of the Innovations in Fabrication and Construction Thrust and the Advances in Connection Technology Cluster Group and also interfaces with a number of other projects.

The project is divided into four major sequential project phases: *construction robotics, construction automation in connections, smart tools for construction automation, and tools for vertical integration and automation.* The research from these four project phases will lead to: a general methodology for automating construction activities; a family of structural connections designed for ease of erection and fabrication; powered tools with sensory perception capable of transporting, positioning and/or connecting construction materials at the job site; and sensory and computational tools which gather and/or process designer, fabricator and construction data for use by other construction activities.

PROBLEM OPPORTUNITY/OBJECTIVE

The primary objective of this four phase project is to design, build and test automated construction systems. We are currently focusing on automated construction system for framing of reinforced concrete and structural steel systems. The major components of the automated construction systems include the raw materials, the construction element designs, the fabrication equipment, the construction equipment, and the sensors and control hierarchy required to ensure proper fabrication and construction. Each of these components must be properly understood in order to develop cost effect construction automation tools.

The construction automation project offers a rather unique opportunity to intermingle the expertise from Lehigh faculty and students from a wide range of specialties including: the computer and material sciences; and the mechanical, civil, electrical, industrial, and manufacturing engineering sectors. Each of these disciplines brings but a part of the solution to the table where problems, ideas and solutions originally voiced by researchers trained in one discipline are by a second discipline and then implimented by a third.

APPROACH

Nature of Research Effort:

Each of the four phases of the project has a well defined goal and deliverable. The four major goals are:

1) determining the current state of construction robotics and potential opportunities;

2) redesigning the geometrical form of construction materials so that they are more amicable to robotic and automated processes;

3) defining and prototyping sensory systems, mechanical forms and control methodologies for tools which will directly assist field construction workers;

4) developing sensory and computational tools for vertical integration between construction activities.

Major Technology Areas Project Focuses On:

The focus of the construction automation project is best described in light of the four primary goals of the connection cluster.

1) The first goal of the connection cluster is to design connections that are: inexpensive to fabricate, easy to assemble and use in the erection process; have appropriate strength, ductility, stiffness and durability; and allow for in situ and in laboratory monitoring. In the "construction automation in connections" phase of the construction automation project we concentrate on the first of these and interface with other cluster team members to insure that the other cluster goals are met. We are currently generating and refining a number of conceptual connection designs by using design for automation principles and generalization of node concepts first presented by Dr. Lu. We continue to survey novel connections generated by other groups, identify why they failed and learn from their mistakes.

2) A second goal of the connection cluster is to design, build and test connections, their fabrication and their construction systems. One of the primary emphasis of the construction automation project is to determine connection designs that can be easily fabricated and used in the construction site. During the "smart tools for construction automation" phase of the construction automation project information from other project teams will be integrated with our results in the development of fabrication systems and smart tools. The smart tools will be designed to assist workers by incorporating sensory information in the execution of construction tasks such as transporting, positioning and/or connecting construction materials.

3) A third goal of the connection cluster is the development of system design methodologies for structural frames and connections. These methodologies will insure that structural systems will have the appropriate strength, ductility, stiffness and durability. The role of the construction automation project toward this goal is minimal with the exception of insuring that connections suitable for automation are included within the design systems data bases.

4) The fourth goal of the connection cluster is to determine and incorporate design rules and knowledge within knowledge base systems for vertical integration. These results, may for example, lead to the the extension of the designer/fabricator interface into a designer/fabricator/erector interface with production scheduling and control capabilities. In the "tools for vertical integration and automation" phase of the construction automation project an on-site metrology

system will be developed and generation of an as-is data base of node and element locations will be made possible. The smart tools developed in the construction automation project could then be commanded by the designer/fabricator/erector interface in the placement of frame elements.

Evidence of Cross-Disciplinary Approach:

The approach taken to this research is inherently interdisciplinary. Although each of the systems being developed are to be used at the construction site they have major implications in other phases of the construction activity, in particular the designing, fabrication and in-service monitoring of structural elements within the framed system. Collaboration with other ATLSS projects on connections, welding of high value/high strength steels, reinforced concrete, sensors and knowledge base systems is required and ongoing.

IMPORTANCE

Contribution to ATLSS Goals:

The construction automation project will result in three major contributions; ATLSS Connections, Smart Tools for Construction Automation, and Tools for Vertical Integration. These are significant to three of the four thrusts of ATLSS: Advances in Design and Fabrication Concepts, Innovations in Fabrication and Construction, and Advances in In-Service Monitoring and Protection.

Relation to Strategic Plan and other Clusters/Projects:

The work done within the construction automation project can greatly effect and be effected by the activities within other projects and project clusters. For example, the ATLSS connection is a type of semi-rigid connection who's structural properties are not well known. It's use will require both theoretical analysis and experimental evaluation to be performed.

The use of high strength/high value materials within this connection may make it possible to use small, strong and ductile connections in architecturally innovative manners. This will require the welding and fabrication techniques for such materials to be further developed.

It's potential use within reinforced concrete structures is just beginning to be examined and may possibly be a means of eliminating a number of failure mechanisms found in reinforced concrete systems. It's use in conjunction with that of composite materials within reinforced concrete is also being examined.

The design of automated equipment for fabrication and construction of framing elements will most likely require the design of new metrology systems. These sensing systems could not only be used to locate the framing elements , they could also be used in plumbing buildings and possibly be used to determine the deformation of structures with time giving building designers information they have long sought.

The automated erection equipment will also require commands during the construction process. These commands could possibly be obtained through including an erection module within the designer fabricator interface currently being designed within the knowledge base systems cluster.

EVALUATION

Major Milestones Achieved in the last year:

- Completed survey of current utilization of robotics in construction related activities.

- Generated a document describing the current state of construction robotics, and the mobility and control requirements for future generations of construction robotics.

- Conceptual designs of three beam to column connections methods where developed. The connections use nodes which are fabricated off-site. We believe that the nodes have been designed to simplify the erection process while increasing the quality of the connection. The nodes are referred to as ATLSS Connections.

This year's research effort is geared toward:

- Determining the insertion compliance of one of the three ATLSS Connection families as a function of parameters that define the details of the connection node.

- Determining the effect of manufacturing and erection tolerances on the erection system process and in particular the effect on the plumbing activities.

- Determining the form of the sensory and mechanical equipment required to automatically erect structural systems using the ATLSS connections.

- Initiating the development of nodes for more complex multi-member connections.

- Determining how to use the ATLSS Connection concept within reinforced concrete structures.

PERSONNEL

Mr. Ceymal Doydem	I. E., Ph.D. Candidate
Mr. Viet Nguyen	M. E., Masters Degree Candidate
Mr. Uday Parshianikar	M. E., Masters Degree Candidate
Dr. Mikell Groover	I. E.
Dr. Vincent Viscomi	C. E., Lafayette College
Dr. N. Duke Perreira	M. E. and M. S. E.

PROJECT REPORTS, PAPERS, PRESENTATIONS

Reports:

- M. Groover, N. Perreira and others, "A Survey of Robotics Technology in Construction," ATLSS Report No. 87-04, August 1987.

Papers:

- Submitted to an appropriate Civil Engineering Journal, "A Survey of Robotics Technology in Construction," December 1987.

Presentations:

-

Proposals:

- C. Doydum, Ph.D. research proposal, "A Sensor Fusion System for Automated Framing," February 1988.

- G. Blank and N.D. Perreira, a proposal to NSF, "Automated Framing," July 1987.

KNOWLEDGE - BASED SYSTEMS
IN CONSTRUCTION

PROJECT SUMMARIES

ATLSS C2 Project Summary
Knowledge-Based Systems for Fatigue Evaluation

1. Abstract

The Bridge Fatigue Investigator (BFI) is a knowledge-based expert system under development to address a major infrastructure problem: the maintenance of America's immense inventory of existing bridges. The specific purpose of BFI is to assist a bridge engineer in the process of:

- inspecting for fatigue damage in steel girder bridges, and
- evaluating such structures for their susceptibility to fatigue and fracture problems.

BFI can be used in two different situations:

- Pre-inspection: Prior to a bridge inspection, BFI provides advice to focus the inspection task by answering the inspector's question,

  "Where should I inspect for fatigue damage?"

- Post-inspection: After an inspection is performed and some cracking found, BFI provides diagnostic advice regarding the bridge engineer's concerns,

  "How severe is the situation?", and

  "What alternatives should be considered next?"

BFI draws on the interdisciplinary knowledge of experts in fatigue and fracture at Lehigh University as it guides the user through inspecting and evaluating this class of structure for fatigue damage. By increasing the reliability of such evaluations and providing a medium through which relevant information may be easily accessed, the BFI research hopes to significantly reduce the risks of catastrophic bridge failure as well as increase the productivity of professional personnel.

2. Opportunity and Objective

The opportunity afforded by the BFI research effort is a convergence of cross-disciplinary technologies in producing a major deliverable of direct use to the profession. By leveraging expertise about fatigue evaluation, it provides a new medium for technology transfer as well as a basis for future exploratory KBS development.

3. Approach

The approach taken to this research is inherently and necessarily interdisciplinary. It draws on knowledge about structural connections and behavior as well as fatigue and fracture. The formalization of that knowledge, though, requires concepts and tools foreign to conventional structural engineering research and practice: Artificial Intelligence technologies arising out of Computer Science and related disciplines.

These tools are applied to the representation/modeling of knowledge about structural components and their connections AND processes of reasoning about their fatigue and fracture susceptibility. Modeling this knowledge renders the knowledge computational, developing rational models using both descriptive and mathematical approaches. As such, the resulting models are closer to the level of terminology and reasoning used by experts who perform fatigue evaluations of steel bridges. This is in contrast to more conventional modelling approaches such as:

- the nodes and elements of finite element analysis
- the oversimplified 2D mathematical models implicitly assumed by the bridge design codes which greatly affect the thinking of bridge engineers.

4. Importance

The BFI expert system constitutes a major deliverable in the ATLSS strategic plan.

It introduces innovations in modeling fatigue knowledge, benefitting structures industries by providing a vehicle for utilizing scarce expertise for the benefit of the profession.

Relation to Other Clusters:

- BFI is a necessary precedent to KBS integration with sensor technology for performance assessment. Based as it is on visual inspection for nondestructive evaluation, it avoids technical challenges that will have to be faced in knowledge-based processing of instrument signals, while focusing on symbolic models of the structures being evaluated and the knowledge involved in performing the evaluation.
- In its knowledge-based representation of connections, the BFI research:

a) is prerequisite to the proposed KBS for connection design.

b) addresses issues that must be addressed also by the DFI research team.

5. Evaluation

Major Milestones Achieved in the last year:

- Knowledge from the domain of fatigue evaluation in steel bridges was formalized and incorporated into the knowledge base of the pilot prototype (pre-prototype) version of BFI.

- For initial implementation, a pre-inspection portion of the system was developed separately from a post-inspection portion.

- A pilot prototype version of the pre-inspection portion was implemented, incorporating extensive computer graphics displays to help point out where to inspect for fatigue damage. This system was transported to the Annual Convention of the American Society for Engineering Education (ASEE) in Reno, Nevada for demonstration in June 1987.

- A demonstration version of the post-inspection portion of BFI was also implemented and demonstrated at the ASEE Convention. This featured uses of computer graphics in describing cracking as well as suggesting repair alternatives.

- A pilot prototype version of the post-inspection portion of BFI was implemented, to advise about diagnosis and assessment of observed fatigue cracking and suggest follow-up alternatives.

- The pilot prototype versions of both the pre-inspection and post-inspection portions of BFI were demonstrated at the ATLSS industry meetings in November, 1987, illustrating qualitative aspects of engineering problem-solving that can be computationalized using the knowledge-based systems approach.

Planned improvements were specified by the project investigators with input from industrial partners. Current work involves the consolidation of the pre-inspection and post-inspection portions and the incorporation of specified improvements, expanding the knowledge base to demonstrate full prototype capabilities.

Current research is geared to demonstrating that computerized consultative assistance on fatigue evaluation is both possible and of genuine usefulness to the profession, and beginning the transfer of BFI to the profession.

Toward these ends, the following milestones are planned in 1988.

Validation of prototype system

Extension of user interface to prototype system

Industrial field test of prototype system

Prototype system documentation

Work in 1989 will be devoted to making available a fieldable production version.

6. Personnel

Mr. Stuart S. Chen, CE; Mr. Stephen T. C. Wong, CSEE; Dr. John L. Wilson, CE; Dr. John W. Fisher, CE, and Dr. Alan W. Pense, Mat.

7. Project Reports, Papers, Presentations

Reports:

- ATLSS Report 87-01: Knowledge-Based Expert Systems in Civil Engineering at Lehigh University, March 1987.

Papers:

- "Knowledge-Based Expert Systems in Civil Engineering at Lehigh University", Proceedings of the National Conference on University Programs in Computer- Aided Engineering, Design, and Manufacturing (UPCAEDM-87), July 1987.

- "A Knowledge-Based Expert System for Fatigue Evaluation of Steel Bridges", invited article for PCTRANSmission, the newsletter of the FHWA- sponsored Transportation Center at the University of Kansas, March 1988.

Presentations:

- "The Bridge Fatigue Investigator Knowledge-Based System", Carnegie-Mellon University, Feb 1987

- "Knowledge-Based Systems for Fatigue Evaluation", ASEE Annual Convention, Reno, NV, June 1987

- "Knowledge-Based Systems for Fatigue Evaluation", ATLSS/FERS Seminar, Lehigh University, November 1987 (joint with K. Roddis of MIT)

- "BFI (Bridge Fatigue Investigator)", University of Jordan, Amman, Jordan, November 1987.

- "An Expert System for Visual Inspection of Steel Bridges", invited presentation at the ASNT Annual Conference, Orlando, FL, April 1988.

March 1, 1988

Technical Information Center for Steel Structures
ATLSS Project A4

Project Summary
11 March, 1988

1. Abstract

The major project objective is to identify the knowledge pertinent to all aspects of steel structures (including bibliographical material, technical data, case studies, and project reports, and other material) and to make it available for use through a Technical Information Center for Steel Structures (TICSS). The project will develop subsystems which can be used both independently and as support subsystems for other ATLSS projects such as the Bridge Fatigue Investigator and the Designer Fabricator Interpreter.

During the first year of the project, a preprototype bibliographic data base was developed in Turbo Prolog and pilot tested. Preprototype performance indicated the need for a complete redesign of the program concept and the development of special algorithms for searching and combining indexing lists referenced to an archival ASCII file. The redesigned preprototype is now being prepared for beta testing.

Specifications for a data base of steel structures software and a data base of current research in strucures have been completed, and preprototype versions of these subsystems are now under development. Major objectives for the third year of the project include identification of suitable development environments and delivery systems, development and testing of prototypes for those subsystems now in preprototype development, and the initiation of a plan for integrating TICSS into knowledge-based systems. Other long-term objectives are to develop and implement a plan for conversion to optical disc storage technology, complete development of the system for steady-state operation, and implement a marketing plan.

2. Opportunity and Objective

Objectives of the project are to develop a computer-manipulable information base of bibliographic and other reference information on steel structures, emphasizing those materials not readily available from existing sources. Materials were obtained from existing hard copy and machine-readable information bases in the Fritz Laboratory library, from other sources at Lehigh University, particularly the Structural Stability Research Council (SSRC) and the Council on Tall Buildings and the Urban Habitat (CTBUH), and from the American Institute for Steel Construction. Initial bibliographies developed were designed in such a way that they could be part of comprehensive knowledge-based systems developed by other ATLSS projects. Input on planning and development has been obtained from American Institute for Steel Construction (AISC), Council on Tall Buildings and the Urban Habitat (CTBUH), Structural Stability Research Council (SSRC), and Telemechanics, Inc. (College Park, Maryland).

3. Approach

A variety of approaches have been explored in order to identify that approach which is most effective. A bibliographic data base was designed and developed in Turbo Prolog in order to take advantage of Prolog's built-in relational data base capabilities and to develop data entry programs which would operate in the MS-DOS environment. Performance of the preprototype demonstrated the need for a more efficient approach. The version now under development will use an archival ASCII file for record storage and index files consisting of compound lists of pointers referenced to the archive file. Additional subsystems are being developed using commercial relational data base programs in order to explore the integration and adaptation of data developed with those products.

4. Importance

Engineering professionals are faced with an explosion of information. The TICSS system will help them identify, select, and utilize the information which is most appropriate to their current needs.

The Technical Information Center for Steel Structures will provide engineering researchers and practitioners with a single source of information on all aspects of steel structures. Emphasis will be placed on providing information about and access to information which is not readily available from other sources such as NTIS.

TICSS subsystems can be used independently, as stand-alone products, by engineering professionals. In addition, the TICSS subsystems will be integrated into other ATLSS systems. For example, at the point in the process of investigating a bridge where access to technical reports would be required, the Bridge Fatigue Investigator program would interface with the TICSS system to identify the appropriate reports and to provide the information in those reports. The TICSS system will also be designed as an intelligent system which will help users formulate a query for information.

5. Evaluation

Research and Development Program

Major milestones achieved in the last year include:

1. Preprototype software for the bibliographic data base, written in Turbo Prolog for MS-DOS XT-compatible microcomputers,was developed and distributed to ATLSS personnel and selected others for beta testing in Fall, 1987.
2. A specification for a standard ASCII archival file of document records was developed in order to aid the conversion of existing machine-readable document records to the TICSS system. Computerized procedures for automatically converting existing SCRIBE bibliographic files to the standard ASCII archival file format were developed during Summer, 1987, and SCRIBE records on several thousand documents have been converted to the standard ASCII archival file format.
3. Based on the results of the beta test of the data entry software and pilot testing of the preprototype search and retrieval software, a totally redesigned and rewritten version of the bibliographic data entry program is now nearing completion. The new version uses one large ASCII archival file instead of multiple relational files for data storage, and makes extensive use of index files and search algorithms developed by project programmers to provide fast and efficient Boolean searching of the archival file. Turbo Toolbox procedures for screen management are being extended to provide a friendlier user interface.
4. Specifications for a data base of steel structures software, and a data base on current research in steel structures have been developed, and software development is now beginning. These subsystems will be developed in DBASE III+, and will be beta-tested and revised during the Spring, 1988 semester.
5. Investigation of the potential use of optical disc storage technologies and initial planning for expanding the TICSS bibliographic data base to include knowledge-based system capabilities has continued. Discussions have been held with major developers of several new formats for digital optical disc storage technology, including DVI (Digital Video Interactive, and CD-I (Compact Disc-Interactive), concerning utilizing elements of the TICSS information system as beta test materials for development of the new technologies.

Goals for the next year are to:

1. Identify appropriate development environment and potential delivery systems for TICSS bibliographic data base and other subsystems, Spring/Summer 1988.
2. Develop and test prototype bibliographic data base, Summer/Fall 1988.
3. Complete development and testing of preprototypes of the data base of steel structures software and the data base on current research in steel structures, Spring, 1988. Develop and test prototype versions, Fall 1988/ Spring 1989.
4. Develop plan for the integration of TICSS with knowledge-based systems such as the Designer-Fabricator Interpreter and the Bridge-Fatigue Investigator. A major part of this activity will focus on the ways in which the capabilities traditionally found in data bases can be

combined with the capabilities of expert systems. Alternative designs will be considered and prototype systems will be developed to test the effectiveness of various designs. Fall 1988/ Spring 1989.

5. Begin development of a plan for converting existing and future TICSS subsystems to optical format. In preparing this plan, a general review and analysis of existing engineering data bases available on CD-ROM and a thorough analysis of data entry and techniques for converting existing material in print of computer-readable form will be conducted. Fall 1988/Spring 1989.

Additional activities for the third year of the project include identification of those TICSS subsystems which should be developed next. The particular subsystems to be developed will be identified through consultation with other ATLSS projects and with the TICSS Industry Advisory Panel.

Educational Program

An advanced graduate course, "Applications of Optical Disc Storage Technology (CD/ROM, CD-I, and others) in Education and Training" was developed and taught during Summer, 1987 at Lehigh by one of the principal investigators (Harvey).

6. Personnel

Dr. Lynn S. Beedle, Civil Engineering
Dr. Francis A. Harvey, Leadership, Instruction, and Technology
Ms. Eleanor Nothelfer, Fritz Laboratory Library
Mr. John E. Parnell, Leadership, Instruction, and Technology
Mr. Graham S. Stewart, Civil Engineering
(In addition, Ms. Lynn K. Milet, Director, Lehigh University Media Center, and Ms. Tina M. Liberty and Mr. William B. Story, are working with the project through graduate independent study courses in educational technology.)

7. Project Reports, Papers, Pre-Reports (1987-88)

Reports (1987-88):

ATLSS Project A4. Technical information center for steel structures (TICSS): Project management document. ATLSS Report No. 87.05, Lehigh University, Bethlehem, Pennsylvania, October, 1987.

ATLSS Project A4. Technical information center for steel structures (TICSS): Bibliographic Data Entry Software Operator's Guide. ATLSS Report No. 87.06, Lehigh University, Bethlehem, Pennsylvania, October, 1987.

ATLSS Project A4. Technical information center for steel structures (TICSS): Systems specifications for TICSS. ATLSS Report No. A4.2, Lehigh University, Bethlehem, Pennsylvania, 16 April, 1987.

Papers:

Applications of Artificial Intelligence to Information Search and Retrieval: The Development and Testing of an Intelligent Technical Information System. In Proceedings of selected research paper presentations at the annual conference of the Association for Educational Communications and Technology, New Orleans, Louisiana, January 15--19, 1988, ed. M. R. Simonson. Ames, Iowa: Instructional Resources Center, College of Education, Iowa State University. (In press)

Emerging digital optical disc technologies: An opportunity and a challenge for educational researchers. Newsletter of the Research andTheory Division of the Association for Educational Communications and Technology, **12:1** (Fall, 1987), 1-6.

CD/ROM, CD-I, and the "information revolution." In Proceedings of the eighth national educational computing conference (NECC '87), Philadelphia, Pennsylvania, June 24-26, 1987, ed. W. C. Ryan, 259-267. Eugene, Oregon: International Council on Computers in Education, University of Oregon.

Designer Fabricator Interface
Project Summary

ATLSS Project B1
March 1988

Keith J. Werkman
Dr. Donald Hillman

1. Abstract

The Designer Fabricator Interpreter (DFI) is a knowledge-based software system that attempts to provide design engineers and fabricators of structural steel systems with a computer tool that will help them better understand each others job constraints. Initially, the prototype DFI system will focus on rating beam to column connections based on ease of fabrication and field erection and present this information to the design engineer. The hope is that this pre-detailing of connections which is currently done by the fabricator will be considered by the design engineer at the time of design. Thus, when the design document goes out for bid, it will contain more comprehensive design information and thus be less ambiguous. This will allow fabricators to generate better competitive bids on the design since they will all be starting with a design which includes the engineers suggested detailed connection designs.

2. Problem

The particular problem of the designer fabricator interface has been identified by the National Science Foundation and by the industry itself as an important construction bottleneck that should be studied. Construction problems which are often not recognized at the design stage of the construction process usually reappear at the fabrication and erection stages. Usually at this point in the construction project a large amount of time and money has already be expended. Further changes to the design, when necessary, tend to cause delays and cost overruns.

The goal of the DFI system is to provide the structural design engineer with a better picture of what the fabricator and the field erector have to contend with while they perform their construction tasks. Thus, a better (more economical) design of a steel structure should be able to be produced simply by providing the design engineer with additional information about how the design is to be fabricated in the shop and erected in the field. The DFI project will attempt to pull together various bodies of knowledge in structural steel design, fabrication, and field erection in order to help guide the design process of steel structures.

3. Approach

Currently, the DFI research team is developing a knowledge representation which will allow the DFI system to reason about connections. This involves determining what parameters each component of a connection requires and then representing them in relation to the other components of a connection. In the pre-prototype of the DFI system, only simple shear (type 2) beam to column connections will be examined. The current representation includes a hierarchy of component parts represented in a frame structure (taken from AI in computer science). For example, a beam to column shear connection contains a beam, column, and connection material. Both the beam and column include standard member information. The connection material can be further broken down into framed beam connections and seated beam connection. Each of these can be further broken down into component parts. Each of these component parts will then have their own reasoning module (set of rules, component relations, etc.). Each component part will reason about itself and pass its information up the hierarchy where a finally rating for the connection will be determined.

In order to accomplish this task, the DFI team will initially be working with its fabrication domain experts to obtain connection detailing information as well as additional fabrication considerations necessary for reasoning about the alternate connection design rating process.

4. Importance

Since the prototype DFI system will be dealing exclusively with connections (classification, defining attributes, comparing and contrasting), it is indeed fortunate that local connection expertise is available at Lehigh through interactions with the Civil engineering department and other ATLSS research projects. For example, ATLSS research project A3.1, *Efficient Utilization of Steel Connections*, deals specifically with developing new connection techniques. Headed by Dr. Driscoll and Dr. Lu, project A3.1 has agreed to be the main clearing house for DFI's connection questions. As a result of this inter-project interaction, an ATLSS graduate student group dealing with connection technology has been formed in order to help pool resources and distribute research ideas.

Several other ATLSS research projects also deal with connections. In ATLSS project C2, *Bridge Fatigue Investigator (BFI)*, Stuart Chen models connections in his knowledge-based system which reasons about where to look for and how to evaluate fatigue cracking in bridges. Here, the DFI project hopes to contribute a knowledge representation of steel connections which might be applicable to both project DFI and BFI. Another group with connection expertise is ATLSS project A3.3, *New Joining Technology*. This group is looking at developing new joining techniques for connections, such as adhesives. Still another connections related group is ATLSS project B2, *Construction Robot Technology*. Here new types of connections are being developed so that robots can automate the assembly of connections in the field. Finally, ATLSS project A4, *Technical Information Center for Steel Structures (TICSS)*, has provided pointers to the reference literature on connections. In addition to the engineering expertise on connection, additional useful information on the economics of connections could be obtained from ATLSS project A3.1-Bus, *Economic Benefits of Semi-Rigid Connections*.

Thus, the DFI system has a good potential for drawing on and drawing together various forms of connection expertise at Lehigh. It should be noted that one possible side benefit of the DFI system could be to disseminate new connection information to users of the system once it is distributed to the industry. Thus, the production version of the DFI system could assist in the needed technology transfer between various ATLSS research projects developing new connection designs to the practicing engineers in the industry.

5. Evaluation

The DFI system will need to be evaluated before it will be considered available for general use. The system should be evaluated by both design engineers as well as fabrication and erection firms. The design engineer, being the initial end user of the system, will need to report on the ultimate usefulness of the DFI system when it comes to providing alternate design considerations based on fabrication and erection constraints. Initially, the engineer will review the systems various connection alternatives. The design engineer should comment on all the alternatives provided and specify if additional connection designs should be included.

Similarly, fabricators and erectors should evaluate the system to insure that the system is correctly reasoning about its rating methods for alternate connection designs. As additional fabricators and erectors review the system, newer or different rating methods will be identified and added to the system to increase the system's competency.

6. Project Personnel

The following sections outline the current list of steel design and fabrication experts that have expressed interest in connections and the designer fabricator interpreter research project.

6.1. Lehigh University ATLSS Personnel

```
Dr. Donald J. Hillman, PI for Designer Fabricator Interface (B1)
Keith Werkman-84605,       ATLSS Scholar, DFI (B1)

Dr. George Driscoll-83518, PI for Innovative Connections (A3.1)
Cameron Chasten-85146,     ATLSS Scholar, Innovative Connections (A3.1)
Robert Fleischman-83553    ATLSS Scholar, Innovative Connections (A3.1)

Dr. John Wilson-84828,     PI for Bridge Fatigue Invest. (C2)
Stuart Chen-83552          ATLSS Scholar, Bridge Fatigue Invest. (C2)

Dr. Lynn Beedle-83515,     PI for Tech Info Ctr Steel Str (TICSS) (A4)
Dr. Frank Harvey-83521,    PI for Tech Info Ctr Steel Str (TICSS) (A4)
Dr. Tuncer Akiner-84849,   PI for Tech Info Ctr Steel Str (TICSS) (A4)
(Architectural Design)

Dr. Duke Perreira-83969,   PI for Construction Robot Technology (B2)
(Working on Models of Connections in ME Dept.)
```

6.2. ATLSS/Industrial Participants

```
E.P. Stupp, III, Stupp Bros. Bridge & Iron Co. (Fabrication Consultant)

Mr. Ira Hooper, P.E.,  STV, NYC (Design Consultant)

Mr. Ed Becker, P.E., (Fabrication Consultant)

Mr. Tim Killen,  Bechtel National, Inc. (Design and Fabrication Consultant)

Mr. Jack Lessig, (Fabrication Consultant)
```

7. Project Related Reports

Currently, the DFI project has produced a preliminary description of the project entitled "Designer Fabricator Interface, Project Description and Specifications Document". This document provides an overall introduction of the problems associated with the Designer Fabricator Interface, background on connections, resources required for the development of the DFI project, the current research approach, and an index of domain experts (both industrial and academic) involved with the DFI project.

Additional documents include this document, entitled "Designer Fabricator Interface - Project Summary", is just a smaller version of thus larger document described above. ATLSS report 86-03 (Rev 1.2, Feb 1987), ***A Hardware and Software Review of AI Engineering Workstations*** provides a review of various AI engineering workstations considered for use by ATLSS.

7.1. Presentations

A variety of DFI project presentations have be given over the last year. These included overviews of the project as well as in depth discussions of the issues of the day involved in the designer fabricator interface. Talks included presentations in St. Louis, New York, and at local ATLSS Seminars.

FINANCIAL PACKAGING FOR CONSTRUCTION

Abstract

In recent years, the ability to implement financing of large construction projects has become increasingly important in international competitiveness. Financial considerations have increased in complexity as well as significance, and some international design-build contractors are now capable of assisting with the arrangement of financing for large turn-key projects.

This project will critically examine the roles in project finance of standardized contractual arrangements, transfer of liability, securitization of financial claims, hedging of foreign exchange and interest rate risk, and other means of preserving the residual value of construction collateral. Financial engineering will be employed to identify financial innovations and government subsidies that can be better utilized to improve the competitive position of the U.S. construction industry.

Problem Opportunity/Objective

While project financing represents an increasingly important factor in international competition for large construction projects, it has thus far been the subject of relatively little research. Segmentation in the U.S. of the construction industry and process has hindered the standardization of financial packaging of large projects, yet such standardization can help to reduce project costs by increasing the liquidity of financing instruments, simplifying transactions and contractual arrangements, and improving the securitization of financial claims. As international competition for large projects increases, standardized financial packaging can also help to hedge foreign exchange risks.

Involvement in ATLSS of the College of Business and Economics provides an opportunity to investigate project finance. The objective of this project is to improve the competitiveness of the U.S. construction industry by reducing financing costs through the development of standardized financial packages for large construction projects.

Approach

Being a new project, research efforts in this area are just beginning. The intent is to standardize the financing of large construction projects. Financial engineering will be employed to determine an optimal mix of financial instruments, including the role of derivative securities and related option strategies to minimize the riskiness of the cash flows associated with large construction projects.

Initial efforts will focus on identifying and evaluating commonly used financing mechanisms. A literature search will be conducted and meetings will be held with financial officers from U.S. design-build contractors and representatives of financial service firms in order to assess the competitive advantages of alternative financial packages and identify and analyze potential innovations. Attempts will be made to identify how off-shore contractors have utilized financial innovations and government subsidies to improve their competitive positions.

Importance

In addition to enhancing the competitiveness of the U.S. construction industry, this project reflects ATLSS goals of encouraging interdisciplinary approaches to solving industry problems and involving industry in research efforts.

Evaluation

Progress on this project during the coming year is likely to be reflected in increased understanding by ATLSS faculty and staff of project financing issues. A report representing progress regarding standardized componenets of a financial package for large construction projects is expected during 1989, with interim progress presented in reports and papers describing research on specific topics within the overall study effort, as appropriate.

Project Personnel

Principal Investigator: Carl R. Beidleman
Graduate Student: David Veshosky

Project Reports, Papers, etc.

A report developing components of a standardized package for financing large construction projects will present the results of this research effort. As appropriate, interim reports and papers will present the results of research on specific topics within the overall study effort. In addition, results of the research will be incorporated in industry seminars and a course on Project Management offered by the Civil Engineering department.

Carl R. Beidleman, 2.29.88

OPTIMAL CONSTRUCTION MANAGEMENT SYSTEMS

Abstract

Project management is a critical factor in the competitiveness of the U.S. construction industry. Effective management of large engineering and construction projects is often hindered by industry fragmentation and the unique nature of many projects. Improved project management will increase productivity and enhance integration of activities in the construction process, reducing costs and improving quality.

This project will evaluate the competitive advantages of alternative management systems that could be applicable for implementing large construction projects. Project management systems used by successful foreign and domestic competitors will be evaluated in terms of productivity, organizational behavior, and cost and schedule effectiveness, and the competitive advantages of alternative systems will be analyzed.

Problem Opportunity/Objective

Segmentation in the construction process and industry hinders effective integration activities of project activities. Lack of consideration in design of fabrication, construction, and operational factors can result in higher life-cycle costs and lower quality. Allocation of accountability, responsibility, and liability within a project organization is often complicated by ineffective management and coordination of the project team, which may include owners, designers, fabricators, contractors, and sub-contractors with little previous experience working together.

More effective management systems can enhance coordination and productivity. Improvements could involve organizational structures, management techniques, or project management systems. Involvement in ATLSS of project management disciplines provides an opportunity to investigate alternative combinations of project management structures and systems, and identify cost-effective innovations.

ATLSS expertise in knowledge-based systems provides an additional potential capability to focus research efforts on uses of expert systems to improve project management. The objective of this research effort is to improve the competitiveness of the U.S. construction industry by enhancing project productivity through more effective management.

Approach

Being a new project, research efforts in this area are just beginning. The intent is to proceed in two directions: alternative organizational structures for implementing large construction projects, and use of project management systems to improve management and integration. Initial efforts will focus on literature reviews and investigation of current use of matrix management and project management systems in the construction industry.

Importance

Research done by such groups as The Business Roundtable and The Construction Industry Institute has identified improvement of project management systems as a critical element in enhancing the competitiveness of the U.S. construction industry. More efficient utilization of project resources can be very cost-effective, resulting in significant benefits at minimal cost.

In addition to enhancing the competitiveness of the U.S. construction industry, this project will contribute significantly to several ATLSS goals, including increased integration of design, construction, and operations; an interdisciplinary approach to solving the problems of the construction industry; and improved technology for the construction industry.

Evaluation

Progress on this research project during the coming year ~~is~~ likely to be reflected in increased understanding by ATLSS faculty and graduate students of project management issues. A report on the results of research into matrix management in engineering and construction is expected by early 1989, with the results of research into project management systems and organizational alternatives expected later that year.

Project Personnel

Principal Investigator: John Egbers
Graduate Student: David Veshosky

Project Reports, Papers, etc.

Reports and papers are expected on matrix management, alternative organizational structures, and project management systems. In addition, research results will be incorporated in a course on project management offered by the Civil Engineering department.

Carl R. Beidleman, 2.29.88

SENSOR TECHNOLOGY FOR PERFORMANCE ASSESSMENT

PROJECT SUMMARIES

Project C-1A

A Corrosion Monitor for Use on Structures

ABSTRACT

A corrosion monitor, approximately 2" in diameter and 2" tall, has been developed for measuring the corrosion rate at specific locations on a structure such as a bridge or utility tower. The monitor integrates the effect of corrosion product, debris that collects in a specific place, and the time of wetness. A copper cup becomes electrically coupled to a steel screen when the system is wetted. The current that flows between the copper and steel is integrated by means of a very small coulometer. The iron screen rests on a porous mass that collects debris that might affect the time of wetness and the chemical nature of the environment in contact with the metals. Cells representative of the first stage of development are being exposed along with steel panels in order to relate coulometer readings with corrosion rates. Second stage devices will be installed on bridges in Bethlehem.

PROBLEM OPPORTUNITY

Time of wetness meters now exist but there is very poor correlation between the time wetness and the rate of corrosion of steel. These devices are not suitable for appraising corrosion because they do not take into account the effect of debris that alters the local environment in contact with the steel and the time of wetness.

COMMUNICATION OF RESULTS

A publication describing the device will be prepared after results are available from the outdoor exposure. It is expected that two years will be required to obtain results that enable comparison between corrosion rate and the coulometer readings of the device.

PROJECT PERSONNEL

Principal Investigator: Malcolm White, Research Scientist

Project C-1B

Crevice Corrosion of Structural Steel

ABSTRACT

Synthetic crevices were prepared and studied in the laboratory. They were wetted either by pure water or a sodium chloride solution. Parameters studied to date include: crevice gap, effect of alternate wetting and drying and ratio of area internal to crevice and area external to crevice. Experimental data generated include: rate of swelling of crevice by corrosion product, pH within crevice, electrochemical potential within crevice, current flow between interior and exterior of crevice and the electrochemical impedance of the material within the crevice. The most rapid corrosion rates were observed upon drying of the crevice and again upon rewetting of the crevice. Access of oxygen to the crevice interior appeared to be an important parameter controlling the rate of corrosion within the crevice.

PROBLEM OPPORTUNITY

Although much is known about crevice corrosion of stainless steels, little is known of the principles governing crevice corrosion of mild steels. Examples of severe crevice corrosion of structural steels has been noted in bridges.

The research being carried out is fundamental in nature and it is hoped that the principles uncovered will be useful to designers seeking to minimize corrosion in structures such as bridges.

IMPORTANCE

Visits to bridges in Pennsylvania and in New Jersey indicated many examples of severe crevice corrosion. Portions of bridges sent to Fritz Laboratory for examination also showed examples of severe crevice corrosion.

COMMUNICATION OF RESULTS

(1) Graduate student Mark Ingle should complete work on this program and will summarize the research in a Master's thesis in January 1989.

(2) A first disclosure of the research will be made in a presentation before The Electrochemical Society in Chicago in October, 1988. A formal manuscript will be prepared for publication before the meeting.

(3) A poster presentation of the research will be made by Mr. Ingle at the Gordon Conference on Corrosion in July 1988.

PROJECT PERSONNEL

Principal Investigator:	Henry Leidheiser, Jr., Prof.
Co-Principal Investigator:	Richard Granata, Research Scientist
Graduate Student:	Mark Ingle, Dept. of Materials Science and Engineering

Summary of ATLSS Project C3

Use of Acoustic Emission for Structural Monitoring and Ultrasonic Sensors

ABSTRACT - Protocols are being developed for the effective utilization of acoustic emission technology for the monitoring of laboratory and real structures. New sensors are being investigated as to their usefulness for evaluating structures. In addition, advanced NDE methods will be applied to test structures in the ATLSS facility.

PROJECT OBJECTIVE - To evaluate existing and new sensor technology for use in the performance assessment of large structures.

APPROACH - The application of existing acoustic emission (AE) technology to laboratory and field structures will be investigated. Protocols will be developed for the successful application of AE for monitoring civil structures. In addition, NDE techniques, such ultrasonic imaging and polyvinylidene fluoride transducers, will be evaluated on simulated and real structures. Finally, NDE sensing technology will be applied for the development of a real-time process-controlled fusion-welding process.

IMPORTANCE - The prediction of useful life of existing structures and the construction of long life new structures is highly dependent upon the development and application of NDE technology.

EVALUATION - This project is being divided into sub-projects and each sub-project will be individually evaluated using the criteria of (1) significance of the goals of the sub-project in relation to the goals of the entire ATLSS project and (2) progress in achieving the desired sub-project objectives.

PROJECT PERSONNEL -

John D. Wood, Professor, Materials Science and Engineering
J. Karl Campbell, Graduate Student, Master of Engineering Candidate, Materials Science and Engineering
Stephen M. French, Graduate Student, Master of Engineering Candidate, Materials Science and Engineering
Daniel P. Henkel, Graduate Student, Ph.D. Candidate, Materials Science and Engineering

EXTERNAL ADVISORS -

Physical Acoustics Corporation: Adrian A. Pollock

Federal Highway Administration: Charles H. McGogney

Johns Hopkins University NDE Center: Robert Green