“Development of Cast Modular Components for Steel Construction”

Interim Research Progress Report

to

The National Science Foundation
American Institute of Steel Construction
Steel Founder’s Society of America

PI: Robert Fleischman, University of Arizona

Industry Partners (Representative):
American Institute of Steel Construction (*Thomas J. Schlafly*)
Steel Founder’s Society of America (*David R. Poweleit*)
Interim Report - September 30, 2004

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NSF INTERIM REPORT

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APPENDICES

Appendix 1:

Appendix 1-A: SF/SC Task Group Meeting
Appendix 1-B: Principal’s Meeting
Appendix 1-C: AISC/NIST Research Review Meeting
Appendix 1-D: AISC Research Committee Meeting
Appendix 1-E: Fabricator Site Visit

Appendix 2:

Appendix 2-A: Research Meeting #1
Appendix 2-B: International Workshop on Construction Applications for Castings
Interim Report - September 30, 2004
PI: Robert Fleischman, University of Arizona
Industry Partners (Representative):
American Institute of Steel Construction (Thomas J. Schlafly)
Steel Founder’s Society of America (David R. Poweleit)

This document is an interim report for the project “Development of Cast Modular Components for Steel Construction”. The time period covered in this report is from September 2003 to September 30, 2004. The project described in this report is being carried out by researchers at the University of Arizona (UA), in collaboration with two industry partners: the American Institute of Steel Construction (AISC), the Steel Founder’s Society of America (SFSA).

Introduction
The overall objective of this project is to improve the reliability and economics of steel construction in the United States through the use of modular cast components. Structural steel applications are being identified where the use of modular construction can: (1) improve economy and/or reliability of a component; (2) eliminate difficult or costly fabrication and/or difficult or dangerous erection; and, (3) permit the use of steel construction in situations previously unexplored for practical reasons.

Summary of Progress
An industry team, the Steel Founders/Steel Construction joint task group (SF/SC TG), has been organized to spearhead this effort. The SF/SC TG is comprised of AISC and SFSA staff, SFSA foundry members, AISC fabricators and erectors, and practicing structural engineers and architects. The SF/SC TG has held 4 meetings to date in support of this effort. Through this process, the SF/SC TG identified promising applications for the use of modular cast components. Of these, a subset has been further defined that require research and development. Trial designs have been conceived for these applications and were the subject of vigorous discussion on the potential benefit, practicality and economics. The outcome of these discussions has focused the research on two specific areas: connections for hollow structural sections (HSS) and connections and modular systems for seismic bracing systems (CBFs, EBFs, MRFs). An international workshop was held in July 2004 to further focus the needs and possibilities in these areas. Concepts for these applications are currently being developed into prototypes through extensive analytical research, with experimental verification and families of designs to follow.

Personnel Participating in the Project:
Dr. Robert B. Fleischman, Project PI, University of Arizona
Yong Pan, Graduate Researcher, University of Arizona
Nathan J. Palmer, Graduate Researcher, University of Arizona
Olivia Ramirez, Undergraduate Researcher, University of Arizona
Thomas J. Schlafly, Director of Research, AISC
David R. Poweleit, Project Engineer, SFSA
Raymond W. Monroe, Executive Vice President, SFSA

Project Activities Timeline:
August 22 2003  -  Notification of Award
August 27 2003  -  Submission of budget revisions (10% cut)
September 11 2003 -  SF SC Meeting, Chicago IL
September 30 2003 -  UA- SFSC Meeting, Rosemont IL
October 1 2003   -  NIST Workshop, Gaithersburg MD
December 19 2003  -  1st Research Meeting, AISC Headquarters, Chicago IL
February 2 2004   -  Trial Design: HSS Concepts for Westinghouse School
April 11 2004    -  Meeting with AISC Fabricator Member, Mesa AZ
June 7 2004      -  Meeting with Seismic Design Consultants, SF CA
July 9 2004      -  International Workshop, Kansas City MO
September 30 2004 -  First Interim Project Report
1. Meetings with Industry Partners and Other Professionals:
Phase I: Identification of Applications

FALL 2003   (These meetings w/industry partners occurred prior to Research Meeting #1)

SF/SC Task Group Meeting:
AISC Headquarters, Chicago IL September 11, 2003
The objective of the meeting was to create a “starting point” for the project by identifying an initial set of promising applications for steel castings in steel construction. The attendees of this meeting were David Poweleit, Raymond Monroe of SFSA; Tom Schlafly of AISC, Dave Eckmann Senior Architect at OWP/P Chicago and Fred Haas, Steel Erector (Private Consultant). The group focused on applications where the use of steel castings could provide significant potential benefit structurally, economically or architecturally. Two compelling issues in favor of steel castings were identified at the meeting: the high cost of welding and the need to meet construction tolerances (See Appendix 1-A1). These two issues, as well as constructability and aesthetics, shaped the concepts identified by the group. The outcome was a set of sketches of rough concepts (See Appendix 1-A2).

DOCUMENTS PRODUCED:
Minutes Summary.................................................................Appendix 1-A1
Initial Concepts.................................................................Appendix 1-A2

Principal’s Meeting:
Embassy Suites, Rosemont IL September 30, 2003
The attendees of this meeting were Robert Fleischman (PI) of UA, Tom Schlafly of AISC, and David Poweleit and Raymond Monroe of SFSA. In the meeting, the rough concepts identified in the SF/SC TG meeting were presented to the PI (See Appendix 1-B1). Each concept was discussed in depth, including structural/construction benefits, casting strategies, and fabrication/erection issues. Considerable supplemental discussion surrounded to the roles and interaction of SFSA and AISC members in developing sound and marketable products (See Appendix 1-B2).

DOCUMENTS PRODUCED:
Meeting Agenda.................................................................Appendix 1-B1
Minutes Summary...............................................................Appendix 1-B2

AISC/NIST Research Review Meeting:
NIST Headquarters, Gaithersburg MD October 1, 2003
The PI, Robert Fleischman, was invited to make a presentation on the project at the National Institute of Standards and Technology (NIST) at a joint NIST/AISC meeting (See Appendix 1-C1). This meeting was sponsored by the Building and Fire Research Laboratory at NIST, in cooperation with AISC, as a follow-up to their workshop on automated steel construction (See Appendix 1-C2). The purpose of the meeting was to investigate the development of new technologies to facilitate automating the steel construction process. Desired outcomes included the development of a research roadmap. The PI was asked to make a 30-minute presentation on the project for the purpose of identifying possible collaboration with the NIST effort. Thus, the presentation focused on cast modular connectors for automated construction (Appendix 1-C3). Follow-up discussion centered on the possibility of making this topic the primary scope of the research. This decision was tabled until RM #1 (See p4) and the AISC Research Committee (See p3).

DOCUMENTS PRODUCED:
Meeting Agenda.................................................................Appendix 1-C1
Summary of the NIST Workshop on Automated Steel Construction ........................................Appendix 1-C2
PI presentation ........................................................................Appendix 1-C3

Development of Modular Connectors
1. Meetings with Industry Partners and Other Professionals:
   Phase II: Refining of Concepts

SPRING 2004: (These meetings were held after Research Meeting #1 in preparation for international workshop)

**AISC Research Committee Meeting**

NASC, Long Beach CA

March 24, 2003

In accordance with consensus from the project Research Meeting #1 (described in the next section) and the possibilities raised at the NIST Research Review Meeting, the industry partners representatives and the PI agreed that the next logical step for the project would be a workshop to flesh out one or more of the following topics: (1) development of a modular structural system with facilitated erection capabilities using cast components (See Appendix 1-D1); (2) cast modular components for HSS space and plane truss applications; and (3) cast modular components for seismic bracing systems. The PI put forth a proposal to hold such a workshop in a project presentation during the AISC Research Committee meeting at the 2004 NASCC in Long Beach, CA. The research committee supported the idea of a workshop and strongly endorsed the final two areas for workshop topics.

**DOCUMENTS PRODUCED:**

Proposed workshop agenda for modular system ...................................................... Appendix 1-D1

**Fabricator Site Visit**

Able Steel Fabricators, Mesa AZ

April 11, 2004

Following the development of trial designs for cast components for HSS connections, the UA research team visited AISC member Able Steel Fabricators for a day-long meeting to discuss welding issues. The UA team met with Mark Fultz, Operations Manager and Terry Seibel, Quality Control Manager/Certified Welding Inspector. The UA team brought CAD drawings and design sketches of cast modular concepts for HSS and seismic resistant systems. Within the context of these cast designs, the Able Steel team indicated preferred welding procedures, specifications and surface preparation techniques. As a result of this meeting, preliminary welding interface details for the cast modular components for HSS were developed (See Appendix 1-E1).

**DOCUMENTS PRODUCED:**

Discussion on WPS for Cast Modular HSS Connections .............................................. Appendix 1-E1

**Meetings with Industry Experts**

PEER Center, UC-Berkeley CA

June 5, 2004

Rutherford and Chekene, Oakland CA

June 6, 2004

Degenkolb Engineers, Inc. San Fransisco CA

June 7, 2004

One of the consensus items emanating from Research Meeting #1 was that the cost competitiveness of modular cast solutions could be enhanced in situations where costs for special detailing were already present, such as blast or seismic detailing. In preparation for the project workshop, the PI met with members of the earthquake engineering community during a west coast swing in June. These discussions centered primarily around design and construction issues pertaining to seismic bracing systems including new systems (BRBFs), and recent test results on CBFs at UC-Berkeley and EBFs at UT-Austin. Included in these discussions (with both practitioners and researchers) were intersections requiring complicated fabrication or costly welding, observed failure modes (in tests) that were either unexpected, brittle or both; and the interplay of the two - complex fabrication and failure modes. Initial discussions took place as to the manner in which cast modular components could be used to address these issues. The content of these discussions were used to inform the agenda for the session on modular seismic bracing systems in the upcoming international workshop (See next section).
2. Research Meetings and Workshops

Research Meeting #1:
AISC Headquarters, Chicago IL
December 19, 2003

Project Research Meeting #1 (RM#1) was held in December 2003. The agenda (See Appendix 2-A1) was structured around the rough concepts identified in the September SF/SC Task Group Meeting. The UA research team created three-dimensional realizations of the concepts during October/November 2003. At RM#1, these realizations were presented to a large interdisciplinary industry panel comprised of eighteen experts from steel design, fabrication, erection and casting, in addition to industry partner representatives from AISC and SFSA. The objective of RM #1 was to generate discussion on the potential of modular construction in the context of specific designs, and set the physical scope of the project by selecting the most promising applications through consensus based on industry wide input. UA graduate researcher Nathan Palmer presented approximately 25 cast modular concepts (See Appendix 2-A2) covering the range of structural applications identified by the SF/SC TG. Examples of a few of the concepts presented appear below in Fig. 1. The consensus of the group was that most of the concepts, while providing the potential for improved structural behavior through new and interesting configurations, would have difficulty competing from an economic standpoint as stand alone connections (See Appendix 2-A3). It was emphasized that cost competitiveness of modular cast solutions could be enhanced in situations where costs for special detailing were already present, such as blast or seismic detailing, or in cases where difficult and/or expensive connections are a primary reason for limited use, such as connecting structural tubing (HSS) in steel construction. The consensus was to focus specifically on: (1) families of modular HSS connections, and (2) modular seismic bracing systems. In each case, the current fabrication process for the application should be studied and the difficulties and potential for expensive procedures associated with each connection determined. Then, cast connections should be developed that reduce or eliminate the expense and difficulties of the traditional connection, while improving the structural performance. It was suggested that benchmark structures be identified where cost comparisons could be performed and develop connection options for tubular structures.

[Images of cast modular concepts]

FIGURE 1:
Cast Connecting Concepts

DOCUMENTS PRODUCED:
Meeting Agenda.................................................................Appendix 2-A1
Presentation........................................................................Appendix 2-A2
RM1 Minutes Summary....................................................Appendix 2-A3
International Workshop on Construction Applications for Castings:

Hilton Airport, Kansas City MO

July 9, 2004

An international workshop for the project was held on July 9, 2004. Among the 23 attendees were steel construction representatives (engineers, erectors, fabricators, architects, general contractors), steel founders and researchers from all regions of the United States, and Canada and Japan. On the basis of consensus from Research Meeting #1 and the AISC Research Committee Meeting, the focus of the workshop was on applications in two broad construction categories: HSS and seismic bracing systems (See Appendix 2-B1). The objective of the workshop was to endorse the research direction, and prioritize and finalize the specific applications for cast modular component prototype development in these two construction categories.

In the first morning session, the PI provided background information on this project, previous projects and ongoing parallel efforts (See Appendix 2-B2a). This presentation included slides of the first-ever implementation of a modular construction framing system recently developed by ConXTech (Bob Simmons, President) and tested for seismic code approval at the PI’s laboratory (See Appendix 2-B2b). The stand-alone concepts developed for RM #1 were also reviewed as several of them have direct applications or could be modified for the two construction categories (See Appendix 2-B2c). The second morning session covered the use of cast components for HSS. This session began with a review of current use of cast components for HSS, primarily in Europe and Canada provided by Dr. Jeffrey Packer of the University of Toronto (See Appendix 2-B3a). Following this, the PI presented the current state of cast modular HSS connection research in three parts (See Appendix 2-B3b): (1) comparisons of benchmark planar and space trusses using traditional connections and cast modular nodes as developed by the UA research team; (2) Cast modular HSS connecting concepts including nodes and attachments, discrete and variable angles; and (3) Weld interface details including sleeves, butt joints and collars. A discussion session ensued resulting in the following consensus for cast modular components for HSS:

1. Focus on planar and space trusses of regular geometry
2. Maintain the architectural feel of smooth contoured surfaces.
3. Develop a catalog of components to fit typical conditions
4. Develop node configurations rather than cast attachments
5. Preferable interface detail is the single depth/diameter; variable gage detail.

The early afternoon session, focusing on seismic systems, began with a presentation by Dr. Hideshige Matsuo of Hitachi Metals on their cast seismic components, HIBLADE and HIBASE (See Appendix 2-B4a). Following this, the PI presented the current state of cast seismic bracing system research (See Appendix 2-B4b), including the benchmark structures (plans, details) that are being used. A discussion session ensued resulting in the following consensus for cast modular seismic bracing systems:

1. Focus on eccentric braced frames first, then concentric braced frames
2. Develop EBF designs based on set link lengths
3. Develop designs for central links and end (column) links
4. Develop designs for the brace-to-column and beam-to-column connections as these also require an immense amount of fabrication and field welding.

The late afternoon session involved review of discussion and consensus on each topic and creation of a list of action items. The conclusion reiterated by the group was that tubular trusses (planar and space), as well as eccentrically braced frames possess the foremost potential economically and architecturally. The majority of traditional trusses utilize medium-to-small diameter/width tubular members, thus providing natural relationships for developing a catalog. Eccentrically braced frame links require a vast amount of welding and fabrication that could be eliminated by using a cast link. The action items coming out of the workshop were: (1) develop a catalog of cast connectors fitting a wide range of lengths, depths and loadings for tubular planar and space trusses; and, (2) develop cast modular connectors to improve the reliability and reduce fabrication in seismic bracing systems.

DOCUMENTS PRODUCED:

Workshop Agenda………………………………………………………………………..Appendix 2-B1
Workshop Session #1 (Fleischman, Simmons) ………………………………..Appendix 2-B2a, B2b, B2c
Workshop Session #2: (Packer, Fleischman)…………………………………..Appendix 2-B3a, B3b
Workshop Session #3 (Matsuo, Fleischman)…………………………………..Appendix 2-B4a, B4b
Workshop Minutes……………………………………………………………………..Appendix 2-B5

Development of Modular Connectors -5-
3. Research Progress-Development of Prototype Concepts

Casting Concepts for HSS Connections

Designs for HSS Moment Frames

A benchmark structure for evaluating cast modular concepts for HSS moment frame was identified by SF/SC TG member Dave Eckmann of OWP/P. The structure, Westinghouse High School in Chicago, was a OWP/P project in the pre-bid phase in February 2004. The design calls for a circular steel tube frame for support of a glass façade. A sketch of a trial cast piece was drafted (See Figure 2a) and forwarded to the UA team for structural development, and to the SFSA and AISC partners for economic evaluation of the casting, fabrication and erection process. The UA team performed finite element analyses to develop the trial dimensions for the prototype structure detail (See Figure 2b) and developed four concepts to meet different erection schemes, some of which are shown in Figures 2c and 2d. Discussion of the architectural requirements and erection considerations resulted in the selection of Concept 2 (shown in Figure 2c) with welding details and erection procedures to be specified. Economic evaluation resulted in a unit price for the casting ranging from $300-$800 for 25+ pieces (as determined by SFSA) and for the fabrication fluctuating from a few hundred to several hundred dollars depending on shop capabilities and experience (as per AISC). Casting costs will depend upon the stipulated surface finish, inspection and material.
HSS Space Frame Connecting Concepts
The cast modular node approach will allow the elimination of certain branch preparation in the welding process including:

- Fish mouth (See Fig 3a) or bird mouth cuts
- Mitered cut
- Flare-bevel weld fit-up for equal width branch and chord members

These procedures can be costly, particularly for circular HSS sections. In addition to elimination of potentially difficult and expensive fabrication, the cast modular node approach also removes the weld from the critical region. Further, by redistributing the material at the joint, casting geometry can be used to eliminate certain HSS truss connection failure modes (See Fig. 3b), including:

- reduction in chord size by eliminating primary failure modes A, B (& mode F for deep chords)
- develop branch member to full capacity (yield/buckling strength)
- Increase buckling strength by decreasing effective length factor, K
- Promote the use of overlap connections without costly fabrication and the use of gap connections by eliminating shear failure in the gap (See Fig. 3c)

If the branch member is fully developed, modes C & D must be carefully addressed, including evaluating:

- the viability of fillet welds
- the need for a more compact branch member
- the impact on decreasing effective length

The casting geometry can be used effectively in a number of ways:

- Increase section thickness uniformly
- Non-uniform “fine-tuned” section
- Cast integral stiffeners, diaphragm
- Insert cast stiffeners, diaphragm
- Additional section using collar or saddle

Figure 3a

Figure 3b: Failure modes A-G for HSS truss connections (Packer & Henderson, 1997).

Figure 3c: Chord Shear Failure (Packer & Henderson)
This provides the cast modular approach for HSS trusses with three levels (See Fig. 4):

**Level 1 Solution:** Cast Attachment
- cast collar, attachment, or insert added to chord
- minimizes main member pieces, cutting operations
- traditional (welded/bolted) connections
- supplements local strength to eliminate failure modes to develop (or nearly) member strength

The Level 1 Solution eliminates difficult welds and branch preparation. The Level 1 Solution adds (per joint) a small casting and one shop weld – likely a fillet weld, and will provide a modest reduction in weight.

**Level 2 Solution:** Cast Node
- full node placed between chord pieces
- traditional (welded/bolted) connections
- eliminate failure modes to develop member strength

The Level 2 Solution eliminates difficult welds and branch preparation. The Level 2 Solution adds (per joint) a large casting and 2 shop welds – likely full penetration welds; cutting of chord pieces, and multiple section sourcing. The level 2 solution, however, will significantly reduce the truss weight.

**Level 3 Solution:** Enhanced Cast Connector
- This type of connector possesses features to enhance the connecting process:
  - Field splice
  - Facilitated erecting
  - Housing of secondary elements

The following tables show the potential weight savings that can be realized by eliminating failure modes A and F.

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**Benchmark Truss Structure**
Benchmark structures are used to evaluate the potential impact of using cast components. Three benchmark structures are used for planar truss example:
1. AISC HSS Design Manual Example (small member truss)
2. Chicago Board of Trade, Cross Truss T4 (medium member truss)
3. Chicago Board of Trade, Super Truss T2 (large member truss)

Considerable weight savings can be realized simply by replacing open sections with tubular sections (See Tables 1-3). Further weight savings are achieved by using cast modular nodes, though these are partially offset by added fabrication steps.

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Table 1: Connection Design for Examples

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</table>

Table 2: Weight Savings for Examples

Table 3: Weight Savings for Examples
Weld interface detail

The inherent difficulty of connecting closed sections, without sacrificing structural integrity, is primarily resolved by means of welding. Welding remains the method of choice, especially when full member capacity much be reached. However, other issues such as maintenance/preservation and aesthetics also play major roles in the decision. Shown below are some viable weld interface details that may make connecting tubular members to castings an efficient task with improved reliability. Many of the details are based on a fabricator’s recommendations (listed below).

![Complete or partial penetration groove weld with beveled casting](image)

Figure 5: Complete or partial penetration groove weld with beveled casting

**Recommendations from Fabricator:**

- Fillet welds are the most desirable. They are economical, strong enough to develop the full member, easy, and no special inspection is required.
- Prep-work on circular members (fish-mouth) is more expensive than the bevel on rectangular members.
- Special inspection is required on all full-penetration welds and is expensive.
- When welding circular members to spherical shapes, preparation is needed to get a good weld. That is, the “beam” may need to be beveled to get a good fit and a good weld.
- The square groove weld is a good weld but it likely requires special inspection which is expensive. The beveled-type insert is fine for a weld, but the range of application may be limited because if the gap gets too large, unnecessary welds may have to be made to fill in the gap.
• It was suggested to use a casting such that the tubes fit inside so a fillet weld can easily be made around the outside.
• Castings would seem less economical for smaller trusses. The best opportunities are likely fish-mouth type connections on large or deep trusses.

After meeting with ABLE Steel Fabricators, Inc., the initiative was to develop a cast connection that incorporates fillet welds, in order to reduce fabrication costs. One such casting to accomplish this is shown in figure 6d. Figures 6a through 6b are favorable alternatives that were selected at the international workshop in Kansas City, MO.
Cast Connectors for Seismic Bracing Systems

The research on cast components for seismic bracing systems begins with developing a system for eccentrically braced frames. The development process revolves around prototype structures and details based on actual designs. A major objective of the cast modular system is to eliminate welding, thus it is envisioned that the modular system will incorporate pinned connections wherever possible. For this reason, the prototype structure was used to evaluate the effects of different arrangements of pinned joints. On the basis of these analyses, a set of possible erection schemes and cast details were determined. Nonlinear finite element analysis is being used to optimize these designs. Full scale testing of the most promising concepts will follow.

Prototype Structures
The prototype structures encompass three seismic lateral force-resisting systems: (1) Eccentric braced frames (EBFs); (2) Special concentric braced frames (SCBFs); and (3) Buckling-restrained braced frames (BRBFs). The structural drawings used to create the prototype structures were provided by an industry partner. The drawings provide geometry and details considered typical of current construction.

Figure 7a shows the elevation for the prototype EBF: in this case, the lateral force resisting system is an eight story frame typical of current center link construction. Figure 7b shows the prototype SCBF. EBF construction.

![Figure 7a](image1.png)

![Figure 7b](image2.png)
Figures 8a through 8d show some of the welded details used for EBF links, brace to column connections, BRBF brace gusset connections. These typical details will be studied and utilized to develop the most cost effective and efficient cast alternatives. The primary cost consideration will be amount of field welding and shop welding, whereas efficiency will be based on optimizing the cast shape to eliminate stress concentrations and premature fracture. Improved ductility and general behavior will also be a consideration.
Study on EBF Pinned Connecting Configurations
The prototype structure was analyzed with pin connections utilized in various locations. The use of pin connections in the modular approach could significantly reduce costs by eliminating field welding and facilitate erection of the brace sub-assemblies. The effect of pinned connections at the brace ends and beam ends was evaluated.

A total of seven different models of Prototype Structure A were analyzed and compared. Each model had a different end condition for the braces, beams, or a combination of both. In terms of stiffness, all models with pins at the tops of the braces will yield a larger drift (7%) when compared to the fixed end condition. If the pins are at the bottoms of the braces or at the ends of the beams (near the column), a slight increase in deflection (1%) will occur.
Changes in member restraint also affect the other structural members in the frame. The beam moments are significantly influenced by the end condition at the top of the brace. If the brace is pinned at the top, beam moments near the shear link may increase up to 35%. Column moments were also seen to increase slightly when the beams were fixed at the column, and the end conditions of the braces were varied. Shear and axial loads remained comparable throughout the seven models.

It was decided that “pinning” the tops of the braces may increase the beam moments too much, so casting concepts will be created for models with pins at the bottoms of the braces, and pins at the ends of the beams (near the column), or a combination of both. Pins in the beam near the shear link overload the braces and do not effectively utilize the rest of the structure, thus pins in these locations will not be considered.

Results from the sensitivity study showed that the effect of changing boundary conditions is most critical in the beams at the link interface.
The braces and columns of the structure are also affected, but the effects were not such as to cause concern about the members’ structural integrity if strain hardening of the links was to occur. With that said, it was decided to proceed with the boundary condition that has the least effect on global stiffness and member unity ratios. From Figures 9a and 9b above, the boundary conditions explored in trial 6 proved to have the lowest combined effect on unity ratios and one of the lowest effects in global stiffness. Potential concepts that would foster use of the aforementioned boundary conditions were then devised (see next section). The intent of pursuing these concepts and boundary conditions is to reduce fabrication costs and ease the erection process.

**Cast Modular Components**

Several cast modular component concepts have been created within AutoCAD. These components fit into one or more of the erection schemes identified (See p. 18). The Level 1 Concepts shown below are pinned components that provide the required boundary conditions within straightforward erection schemes. Such connections would eliminate field welds at most locations, eliminate stiffeners and attachments and lead to shorter erection times.

**Level 1 Concepts**

![Figure 1: Strong-axis Brace Pin](image1)

![Figure 2: Weak-axis Brace Pin](image2)

![Figure 3: Single Piece Beam Pin (SPBP)](image3)

![Figure 4: SPBP Configuration](image4)
Figure 5: Dual Piece Beam Pin (DPBP)

Figure 6: DPBP Configuration

Figure 7: Single-sided Column Node

Figure 8: Dual-sided Column Node

Figure 9: Continuous Link Element

Integrally cast bracing connections (not shown for clarity)
Structural Evaluation of Components relative to traditional

Nonlinear finite element analyses of traditional EBF links and the cast components are in progress. The analyses of the traditional details serve as the control for a baseline for evaluation of the new forms. The analytical modeling began with 2D (planar) isolated links, extended to a 2D frame subassemblage analysis, and then was extended to a 3D model. Large strain capabilities are used to examine the state of plastic strain at large ductility demands.

Isolated link Model: (a) Discretization (deformed shape); (b) Equivalent Stress

Frame Sub-Assemblage Model: (a) Full frame discretization; (b) Link Region Subassemblage

Plastic Strain Contours: (a) Isolated Model; (b) Sub-assemblage Model.
Shear vs. Deformation Plots: (a) Comparisons of Models; (b) Shear spring model calibration.

3D Sub-Assemblage Model: (a) Full frame discretization; (b) Link Region Subassemblage.

3D Contours: (a) Von Mises Equivalent Stress; (b) Equivalent Plastic Strain.
EBF Erection Schemes

Erection schemes have been developed to meet aspects of the entire construction process, including transport, availability of materials, tolerances, constructability and safety. Two possible erection schemes using pinned cast components for the brace, beam and column connections are shown below. Shop and field tasks for each phase of construction are indicated. Figure numbers given correspond to the concepts shown previously in the section on cast modular components. These are in schematic form only and are for the purpose of seeing components, operations and sequence.

**Erection Scheme 1**

**Shop Tasks:**
1. Weld modular brace end nodes (Fig. 7 & 8) to columns segments
2. Weld brace pin connectors to the lower end of the brace members (Figure 1)
3. Weld cast link element (Figure 9) with beam segments
4. Weld beam pin connectors (Figure 3, 5) onto the free ends of the beam

**Field Tasks:**
1. Erect Multi-tier Columns
2. Locate braces and pin in place
3. Slide beams into place and pin
4. Weld braces at underside of cast link element
**Erection Scheme 2**

**Shop:** Weld cast column nodes to columns (Figures 7 & 8)
- Weld Brace Pin Castings to the ends of the lower level braces (Figure 1)
- Weld cast pin connectors (Figure 3 or 5) onto ends of the beams
- Weld cast Interface Node (Figure 10 or 13) onto beam segments

Weld Braces to Interface Node

**Field:** Erect Columns

- Assemble (weld/bolt) two of the angle shaped segments (joined in shop) with their respective replaceable link (Figure 11 or 14), on the ground.
- Lift beam/link/brace assembly into place and pin in four locations
**Level 2 Link Element Concepts**
The objective of the level two concepts is to be able to replace the link while being able to assemble the links and beams on site (on the ground). One concept involves field welding (figures 10-12) while the other suggests the possibility of field bolting. Again, these elements are conceptual schematics – considerable further work is required to create a structurally efficient shape that can be cast, that can be attached securely, reliably and economically, and that can be erected easily.

![Cast Interface Node](image1)

![Potentially Replaceable Cast Link](image2)

![Replaceable Link Assembly](image3)
**Interim Report - September 30, 2004**

“Development of Cast Modular Components for Steel Construction”

PI: Robert Fleischman, University of Arizona  
Industry Partners (*Representative*):  
American Institute of Steel Construction (*Thomas J. Schlaflly*)  
Steel Founder’s Society of America (*David R. Poweleit*)

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SF/SC Meeting Minutes  
September 11, 2003

Location:  AISC Headquarters, Chicago IL
Attendees:  Tom Schlafly  American Institute of Steel Construction
            David Poweleit  Steel Founder’s Society of America
            Raymond Monroe  Steel Founder’s Society of America
            Dave Eckmann  OWP/P Architects, Inc.
            Fred Haas  Independent Steel Erector Consultant

Notes:

• Discussed the value in building a “notebook” for castings in architecture
  o Web due to availability and ease of updating would like be better than publishing as an AISC design guide
• Discussed not doing full-scale tests on new casting applications
  o Typically only engineering calculations are done for new applications in buildings
• Discussed need for cost savings in cast “hardware” applications
• Reviewed potential applications for GOALI project (sketches of applications in PPT)
  o Additional parts that would facilitate erection automation, modular connection, flexible geometry to accommodate building tolerances, or plug-in place would all be good candidates
  o Pursuing applications utilizing clamping forces (like in scaffolding) would require additional proof of performance
• Tom mentioned NIST project to reduce cost for steel erection (automation)
• Steel construction issues:
  o Biggest cost is welding
  o Biggest issue is tolerances
  o Footprint is a concern (both in terms of erection area, and for connections – keeping connections the same size as the connecting pieces is more aesthetically desirable and need to ensure room is not taken away from flooring or utilities)
• All loading is known for buildings; thus, would be available for FEA

Actions:

• Collect data on existing and conceptual applications of castings in architecture for web notebook (DP)
• Include data on when to use a casting in the web notebook (DP)
• Get costs for modular connectors (DP/TS)
• Create solid models, run FEA and solidification analysis, make prototype castings, and get costs for potential applications (DP/TS/RF)
• Look into self-locking hardware applications for cast connector ideas – eliminate bolts/welds (RF)
DEVELOPMENT OF CAST MODULAR COMPONENTS FOR STEEL CONSTRUCTION
UA – AISC – SFSA
Principal’s Meeting
September 29, 2003
Radisson O’Hare, Rosemont IL

Agenda:

1. Review main points of the proposal
2. Review budget and update on budget modifications
3. Review timeline: focus on first 2 months
4. Review Connection Candidates
   a. Improved Fabrication
   b. Automated Construction
   c. Seismic Details
5. Construction issues
6. Casting Issues
7. Economic Issues
8. Discuss tasks for Industry Partners
9. Schedule Research Meeting #1
Development of Cast Modular Components for Steel Construction
UA – AISC – SFSA

Principal's Meeting
September 29, 2003
Radisson O’Hare, Rosemont IL

Participants:
Robert Fleischman (University of Arizona)
Tom Schlafly (American Institute of Steel Construction)
Dave Powelleit (Steel Foundry Society of America)
Raymond Monroe (Steel Foundry Society of America)
William Gibb (NorthStar Cast Steel Foundry)

Minutes
- Proposal objectives and research plan reviewed
- Budget reviewed and modifications updated
- Timeline reviewed w/focus on first 2 months
- Construction issues
  - RM: improve fabrication; improve erection; design to improve; can engineering time be saved?
  - TS: can save a lot; EOR does all seismic calculations (connection engineering is 15% of the total cost of the seismic design)
  - TS: NIST – 25% off steel erection times – started a project to locate items in the field – standard connections won’t work – might be a nice fit
  - TS: Stack up tolerances in the building – use cast geometries – scheme to control tolerances
    - Certain connections to control
    - Certain connections to accommodate
    - Sweep of a member must be accounted in the aligning scheme
  - TS: Look at the construction practice (overall) – Dave Ruby
  - Insufficient Distribution of labor between engineer, manufacturer, fabrication and erection.

- Casting Issues
  - Be creative – misconceptions – barriers to use
  - RM: Performance – probably greatest concern but easiest to achieve
  - BG: Prove everything – acceptance, modularity, family
  - RM: 30% of casting are tested – railroad
    - FE analysis (efficient from industry standpoint) – solidification
    - FE analysis and solidification – F.O.S.
    - Quality assurance – 1) Q.A.  2) design
    - Be creative and practical
  - RM: SFSA polish a surface that later is machined
  - BG: work through steel founder’s on everything step out of the loop – go through D.P.
    - Quality foundries
    - Big enough list that it is competitive
    - “six” foundries that are already certified
    - leverage other foundries

- Economic Issues
  - RM: slight cost advantage is no big deal – at 10% not good enough, other will simply lower their price; need 40% is needed – need to sell it on reliability – Focus on performance, new directions, or some performance that is currently unavailable
  - TS: costs will be an issue – keep this in the evaluations
  - RM: That is why we need foundry people during the prototype phase; provide a technology advantage
  - TS: Back of the napkin – column bases 50 cents;
  - Need to assemble bigger group – estimates unrealistic
• Discuss tasks for Industry Partners/Transfer

RM: Portfolio of Applications
- Relatively developed but unimplemented (AC)
- Technology transfer: K or Y pipe; FE analytical (proof testing)
- Straightforward but no academic sizzle
- Developed

RM: How do we get these concepts adopted?

TS: Controlling body is the local body: IBC, NFPA 5000. AISC has the CPRP – Connection
Prequalification Review Panel – it will meet next at the end of October in Oakland. Chris Levitt, Ron Hamburger, Jim Malley (Committee Chair).

BG: how do we quantify performance?

TS: AISC doing a better job – historically stay away due to geographic differences - measure $/ton, not necessarily $/connection; may be difficult to communicate

TS: Identify applications – Find one configuration that works; Next step – multiple solutions

RM: Sequence: Potential - Trial - Play it - Larger group
Blank sheet of paper w/ big group – doesn’t really work – people react

TS: Shake the tree when we have a sample; See if we can go after this in Year 2

TS: Keep narrow focus: fabricate bearings and expansion joints
Lot of labor in bridge splices; NSBA (National Steel Bridge Alliance)

• Review Connection Candidates

   Sketches for what we have now - fabrication and parts
   1. Column bases: biggest question for steel solutions
      - 1300  8”x8”
      - misaligned anchor bolts
      - two half moon wedges
      - Base plate – distribute the load from steel to concrete
      - Set the base on shims; plumb on grout
   2. HSS to WF
      - Medium to low
   3. Tubes
      - Don Sherman – HSS Manual
      - 3b -slide on the tube
      - 3c – plug extensions (simple connections)
   4. poor solutions – ¾” pin, clevises; can you use a casting?
   5. skewed connection
      - stability requirement – T/2
   6. K’s, Y’s
      - Fish mouths
         - UT requirements
         - Welds
         - Situations - joint cans
         - Outside looks clean – clean look
         - 30 to 60 degrees
         - clamp to the beam flange and bolt to the beam
         - carry the local and beam weight; location at a variable angle
         - Brain-storming – concrete column can get shifted a little
         - Weak axis wide flange moment connection
         - Connections of steel beams to concrete cores
         - Slab to beams – connect precast HC to beams (stud on steel beams into grouted core)
         - Window washer davit
         - Cone head for a pedestrian bridge

• Schedule Research Meeting #1

   First Research Meeting: Tenatatively Mid-December at AISC Headquarters, Chicago
Appendix 1: C1

AISC / NIST REVIEW MEETING

Research Efforts in Automated Steel Construction

Location: National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899-8610. Building 226 Room B221

Date: Wednesday, October 1, 2003

Purpose: Provide a follow-up meeting from the AISC / NIST Automated Steel Construction Workshop of June 2002. Review NIST research in FY03 and proposed research for FY04. Explore opportunities for research cooperation and collaboration.

Agenda: Wednesday, 10/01/03, 8:30 am – 4:00 pm:

<table>
<thead>
<tr>
<th>Time</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>8:30 am</td>
<td>Start up</td>
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<td>• Welcome (TBD)</td>
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<td></td>
<td>• Self introductions</td>
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<td></td>
<td>• Desired Outcomes and Agenda (Lytle)</td>
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<td>8:45</td>
<td>Presentation #1: Project Review: Performance of Innovative Technologies for Automated Steel Construction / Comp-TRAK / LADAR</td>
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<td>Speaker: Alan Lytle, NIST</td>
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<td>9:15</td>
<td>Presentation #2: Project Review: Data Exchange Standards at the Construction Jobsite</td>
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<td>Speaker: Dr. Kamel Saidi, NIST</td>
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<td>9:30</td>
<td>Break</td>
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<tr>
<td>9:40</td>
<td>Presentation #3: Developments in CIS/2 Data Exchange</td>
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<td>Speaker: Bob Lipman, NIST</td>
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<td>10:00</td>
<td>Presentation #4: New Steel Connection Developments</td>
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<td>Speaker: Robert Fleischmann, AISC</td>
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<tr>
<td>10:30</td>
<td>CIS/2 Demonstration in the NIST RAVE</td>
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<td>11:00</td>
<td>Depart for Building 202</td>
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<tr>
<td>11:15</td>
<td>Automated Steel Construction Testbed Demonstration</td>
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<td>12:00</td>
<td>Lunch: NIST</td>
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<td>1:00</td>
<td>Open Discussion</td>
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<td></td>
<td>Moderator: Alan Lytle, NIST</td>
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<td>Proposed Topics:</td>
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<td></td>
<td>• 2002 Automated Steel Construction Workshop Results – A Look Back Through a One Year Filter</td>
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<td></td>
<td>• Discussion / Comment on NIST Future Research</td>
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<tr>
<td></td>
<td>• Potential Areas for Cooperation / Collaboration / (Site Visits, Pilot Studies, etc.)</td>
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<tr>
<td>4:00</td>
<td>Adjourn</td>
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Report of the NIST Workshop on Automated Steel Construction

by

Alan M. Lytle, Kamel S. Saidi, William C. Stone, and John L. Gross

ABSTRACT: The Building and Fire Research Laboratory of the National Institute of Standards and Technology, in cooperation with the American Institute of Steel Construction, sponsored a workshop on automated steel construction. The purpose of the workshop was to investigate the development of new technologies to facilitate automating the steel construction process. Desired outcomes included a clear definition of issues and constraints, the identification of candidate breakthrough technologies, and the development of a research roadmap. A description of the workshop structure, agenda, and preliminary results are presented.

KEYWORDS: construction automation, automated steel erection

1.0 INTRODUCTION

Productivity, reliability, and safety are the three predominant issues facing the steel construction industry today. In both industrial facilities and commercial buildings, hot-rolled steel members are typically joined together either by welding or using high strength bolts. These processes require a significant amount of skilled labor, and in the case of high-rise construction, constitute one of the most dangerous specialties in the already hazardous construction industry. Inspection is difficult and time consuming, and often, the connections are the weakest link in the resulting structure.

The steel construction industry faces significant challenges to remain competitive. The following two statements succinctly summarize the issue [1]:

“The U.S. construction industry must begin to move away from a nearly exclusive labor-intensive business and towards automation to be competitive in the ever-shrinking global marketplace.”

“Decreasing fabrication and erection time for steel frame buildings, while increasing the safety of workmen during construction are issues that must be addressed, and provides the motivation for automated construction.”

According to the American Institute of Steel Construction (AISC), a 25% reduction in time required to erect a steel frame structure is needed. In response to this stated need, the NIST Building and Fire Research Laboratory (BFRL) and AISC co-sponsored a workshop on Automated Steel Construction at the NIST campus in Gaithersburg, MD on June 6 and 7, 2002. The workshop brought together steel producers, fabricators, designers, erectors, and construction automation experts to discuss factors affecting the steel construction industry and to identify possible courses of action to assist the industry. The desired outcome from the workshop was a clear definition of issues and constraints, identification of candidate breakthrough technologies, and the development of a research roadmap. This report presents information contained in the keynote addresses and results of the working group breakout sessions.

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1 Official contribution of the National Institute of Standards and Technology (NIST); not subject to copyright in the United States.
2 NIST, BFRL, Materials and Construction Research Division, Mail Stop 8611, Gaithersburg, MD 20899-8611; alan.lytle@nist.gov, kamel.saidi@nist.gov, william.stone@nist.gov, john.gross@nist.gov.

Appendix 1: C2
2.0 DETAILED AGENDA

The first presentation was by Dr. Carl T. Haas of The University of Texas at Austin entitled “Automation in Steel Erection” [2]. Dr. Haas’ presentation included a definition of industry problems, possible opportunities for automation, and a review of some previous construction automation research and development activities. Specific opportunities for automation discussed included:

- Robotics and process integration in the fabrication shop
- Materials tracking using radio frequency identification (RFID) tags, bar codes, etc.
- Design of connections for compliant assembly
- Pre-assembly to minimize field connections
- Integrated project processes, databases, and 4-D models
- Positive control of members and subassemblies using manipulator arms, inverse Stewart platforms, etc.
- Automated welding, bolting, adhesion, etc.
- Global positioning and locating systems

Examples of previous applicable research and development presented included:

- Lehigh ATLSS connection [3]
- NIST RoboCrane [4]
- Japanese automated building systems [5,6,7]
- UT Large Scale Manipulator [8]

The afternoon session of day one began with a presentation by the president of National Riggers and Erectors, Inc. (Plymouth, MI), Mr. Robert Dunn, entitled “Steel Erection and Challenges” [9]. Mr. Dunn reviewed the challenges facing the steel industry including safety, quality, workforce aging, and the cost of construction. He then reviewed various elements of the erection process, presented a cost breakdown of those elements, and projected potential cost benefits of various process improvements. Mr. Dunn outlined the following 4 recommendations for application of automation to steel erection and the corresponding potential cost savings:

1. Pre-assembly and/or modularization of roof/floor/wall components can save 10 % to 20 % of ground operations/hoisting costs which constitutes 45 % of total erection cost – a 4.5 % to 9.0 % overall savings.
2. Optimizing crew sizes and using innovative lifting/storage devices can save 15 % to 20 % of hoisting cost which comprises 30 % of the total erection cost - a 4.5 % to 6.0 % overall savings.
3. Use of “snug-tight” bolts in bearing connections can realize savings of from 30 % to 35 % of this cost driver which accounts for 30 % of erection costs - a 9.0 % to 10.5 % overall savings.
4. Semi-automated welding practices can save 2 % to 5 % of overall erection cost.

3.2 Day Two

Dr. Ricles discussed required connection characteristics for automated construction and provided examples of connection ideas for automated construction. Characteristic features required of next-generation beam to column included [10]:

- **Self-alignment** – The connection must be able to guide the beam toward the proper location once contact is made between connection elements located on the beam and column.
- **Tolerances** – The connection must have tolerances which allow for misalignment or out-of-plumbness.
- **Adjustment** – Because of the tolerances that must be built in, it is unlikely that the connection will be precisely in its correct position after erection. Therefore, the connection must have the ability to be adjusted easily.
- **Stiffness, Strength and Stability** – The connection must be strong enough to carry erection loads while possessing a suitable amount of stiffness to control deflections. Furthermore, the connection must be stable enough to allow erection of the structure to continue until the final fastening.
- **Modularity** – The connection should be able to be mass-produced with a standard shop fitting operation and with quick, automatic erection capabilities.

Following the presentation, the workshop participants were divided into 4 groups. The purpose of the last breakout session of the workshop was to brainstorm ideas for new connection technologies for use in steel construction as described in the following tables:
Table 1. List of Helpful/Desired Technologies.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Technology</th>
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<tbody>
<tr>
<td>Most</td>
<td>New connector technology</td>
</tr>
<tr>
<td></td>
<td>3D/4D CAD and data interchange</td>
</tr>
<tr>
<td></td>
<td>Automated welding</td>
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<td></td>
<td>Material tracking technology (logistics)</td>
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<td>Piece movement technology (material handling)</td>
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<tr>
<td></td>
<td>Plumbness technology</td>
</tr>
<tr>
<td></td>
<td>Simpler method for installing and tensioning bolted connections</td>
</tr>
<tr>
<td></td>
<td>Technology to locate components and objects</td>
</tr>
<tr>
<td></td>
<td>Technology to create as-built models</td>
</tr>
<tr>
<td>Least</td>
<td>Jack-up construction technology</td>
</tr>
<tr>
<td>Desired</td>
<td>Deck-sheet sidelap fastening technologies</td>
</tr>
</tbody>
</table>

Table 2. List of Criteria for Ranking the Technologies.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Technology Criteria</th>
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</thead>
<tbody>
<tr>
<td>Most</td>
<td>Cost savings</td>
</tr>
<tr>
<td></td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>Speed/productivity</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td>Minimization of rework</td>
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<tr>
<td></td>
<td>Ease of Use</td>
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<tr>
<td></td>
<td>Durability</td>
</tr>
<tr>
<td></td>
<td>Time until 100% ROI</td>
</tr>
<tr>
<td>Least</td>
<td>Tolerance accommodation</td>
</tr>
<tr>
<td></td>
<td>Make task attractive to labor</td>
</tr>
</tbody>
</table>

Table 5. AHP Results for the Top 5 Technologies and Top 3 Criteria.

<table>
<thead>
<tr>
<th>Criteria (weights)</th>
<th>Quality (0.41)</th>
<th>Cost Savings (0.34)</th>
<th>Productivity (0.25)</th>
<th>Final Weighted Score</th>
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</thead>
<tbody>
<tr>
<td>Connectors</td>
<td>0.20</td>
<td>0.27</td>
<td>0.27</td>
<td>0.24</td>
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<tr>
<td>3D/4D CAD and data interchange</td>
<td>0.25</td>
<td>0.21</td>
<td>0.21</td>
<td>0.23</td>
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<tr>
<td>Automated welding</td>
<td>0.26</td>
<td>0.17</td>
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<td>0.22</td>
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<tr>
<td>Material handling</td>
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<td>0.18</td>
<td>0.15</td>
<td>0.16</td>
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<tr>
<td>Material tracking</td>
<td>0.14</td>
<td>0.17</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>
**Development of Cast Modular Connections for Structural Steel Frames**

Robert B. Fleischman  
Department of Civil Engineering & Engineering Mechanics  
University of Arizona

**Research Efforts in Cast Steel Connections**

- **Past Research Effort**  
  ATLSS Connections
- **Present Research Effort**  
  Seismic Moment Connections
- **Future Research Effort**  
  Cast Modular Construction

---

**Connections for Automated Construction: ATLSS Connections**

Research Program in Modular Construction at Lehigh University  
ATLSS Center

- Developed self-aligning connector for gravity load framing
- Variations on the gravity connection for moment resistance were conceived
- Connector was patented and implemented in actual structures

**Early Version:**  
Modified Double Angle Connection

- Difficult “knife-type” fit
- Rigid body motion “slop” along axis of beam
- Can be knocked out from accidental upward load
- High twisting stress on line welds

---

**Selected Configuration:**  
Chamfered Connection

2D knife-type >> 3D chamfer

- Large target relative to locating object
- Forces tend to align the connector regardless of initial translational or angular error
- Tenon will not stick or jam during insertion
- Wedging forces will tend to secure the connector

**Selected Configuration:**  
Chamfered Connection

Complex-angles in 3D

- Viable manufacturing through casting process
- A shallower taper angle increases the relative size of the target.
Load Transfer Characteristic

- Challenge: The same angled surfaces that are used for engaging, aligning and securing also carry structural forces.

Force Transformation: Beam Shear

- Large (equal and opposite) “opening” forces develop.
- These opening forces increase with steeper taper angles.

Connector Securement: Wedging Action

- First ATLSS Connection: Phase I AC Prototype
  - 1/3 scale prototype
  - Cast mild steel
  - Slotted holes on pads

Tenon Kinematics

- Planar Rigid Body Response Modes

Phase I AC: Shear Loading Experiment

- Rigid Body Kinematics
**AC Failure Mechanism**

- **Planar Models:** Examination of required lateral stiffness

**Response of “Pure” AC**
- Hinging of arms
- Local contact plasticity

**Response of Enhanced AC**
- Load carried by tension and compression struts in flutes
- Tenon pullout failure occurs at strength greater than web

**ATLSS CONNECTOR:**
Phase II Prototype

**Laboratory:** Proof Testing and Concept Validation
First Implementation: Iowa
- Bay took 21 minutes to assemble on ground; 2½ minutes to erect and 5½ minutes to secure (29 min)
- Adjacent (identical) bay erected traditionally in 1 hr. 15 minutes

Second Implementation: Tenn.
- 20’ x 36’ bay
- Moment Connections
  - 30’ x 36’ bay @ 37’ elev.
  - 41’ x 43’ bay @ 59’ elev. (6 pt.)
  - 18’ x 20’ bay @ 109’ elev.
- 34% savings in time realized

Moment-resisting AC alternatives
- AC with flange connectors (WTs)
- Composite AC
- End Plate AC

NSF Research Project:
Development of Cast Modular Components for Steel Construction
Objective: Identify and develop applications where cast modular components can:
  - Improve economy or reliability
  - Eliminate difficult or costly fabrication
  - Eliminate difficult or dangerous erection
  - Facilitate steel construction in new areas

Preliminary Concepts
- AISC and SFSA have conducted meetings to determine trial concepts for exploration. Some include:
  - HSS to WF
  - Window Washer Davit

Modular Connectors with Erection Capabilities
- Alternative concepts from the ATLSS Connection development will be revisited.
Research Plan

The NSF research begins in October 2003 and extends three years. Tasks include:

- Identification of Applications
- Analytical development of concept
- Experimental verification of prototype
- Trial Implementation
- Economic and Constructability Studies
- Design Procedures

Several concepts will be explored. It is envisioned that at least one will involve automated construction features.
Developing a Modular Steel Framing System

Robert B. Fleischman
Department of Civil Engineering & Engineering Mechanics
University of Arizona

Proposal for developing a Modular Steel Framing System

Objective:
Develop a versatile steel framing system absent of field welding or field bolting through the use of modular cast components

Proposed Approach:
Bay lift construction involving:
• quick-connect ground assembly for floor beams to girders
• self-guiding, self-aligning girder-to-column connections
• self-locking mechanisms for connections

Proposed Components:
• Round Tubular Columns
• Rectangular Tubular Girders
• Cast Modular Connection Components
• Variety of Floor Framing Systems
• Variety of Lateral Force Resisting Systems

Modular Connection Components:
Mortise (guide) Pieces
• Shop-welded to tube columns
• Substantial casting piece to provide panel zone stiffness for moment connections
• Simple casting piece for shear connections
• Modularity allows biaxial moment connection
• Self-locking mechanism insert

Tenon (fitting) Piece
• Shop-welded to tube girders
• Composite action can be mobilized for locking

Modular connection components (con’t):
Column Splice
• Casting with multiple conical cavities shop welded inside lower column
• Complementary casting within upper column
• Self-locking device installed in lower column
• Completely hidden connection

Column Base
• Same connection assembly
• Base piece adjustable within embedded trough

Appendix 1: D1
A workshop is required to focus the research effort. It is proposed that this workshop take place as soon as possible, preferably before the end of February 2003. The following slides discuss a proposed agenda and the desired personnel.

**Potential Erection Sequence**
- Tubular column
- Spandrel Drop
- N-S and E-W Bay Drops
- Tubular girder
- Floor beam

**Potential Floor Systems**
- Cast-in-place (bare steel lift ~ 5 tons)
- Cast on ground (topped lift ~ 25 tons)
- Lift-slab?
- Precast

**Lateral Force Resisting System Options**
- Perimeter Moment Frames – both ways
- Distributed Moment Frames – both ways
- Braced Frame – both ways
- N-S Moment frame; E-W Braced Frame
  - Modular, and involving little or no field bolting

**Proposed Agenda for Workshop**
- Choice of members including the use of tubes
- Choice of erection/framing sequence
- Choice of floor systems/lateral systems
- Applicability to a wide range of structures
- Discussion on mill, fabrication, casting and erection tolerances
- Discussion on erection sequence, lift capacities, adjustment, plumbing and field tightening
- Working session to develop a strategy to meet tolerances, adjustment and securing requirements
- Selection of a set of prototype structures

**Workshop on the Development of a Modular Steel Framing System**

The workshop agenda will focus on the following issues, everywhere balancing vision with economic constraints:
Proposed Personnel for Workshop

Redundant expertise (at least three key personnel) in all areas is needed to foster discussion. These areas include:

- Steel founders (3)
- Steel erectors (3)
- Steel fabricators (3)
- Building designers (3)
- Architects (2)
- Institutional representation (AISC/SFSA)
- Steel Mills/Steel Tube Institute Members
- Composite construction expertise
- Structural Researchers (UA)
- Automated construction researchers (NIST)
Participants:
Robert Fleischman (University of Arizona)
Nathan Palmer (University of Arizona)
Yong Pan (University of Arizona)
Mark Fultz (ABLE Steel Fabricators, Inc.)
Terrence Seibal (ABLE Steel Fabricators, Inc.)

Applications Covered: Cast Components for HSS Construction:
- Planar Trusses
- Moment Frames
- Braced Frames
- Space Trusses

Objectives of Cast Modular Approach:
- Improve Fabrication Procedure and Reduce Fabrication Costs
- Promote ease of Construction/Erection through exacting Tolerances and Erection Aids
- Improve Structural Performance through Optimized Geometry

Questions on Fabrication for Discussion:
- Most traditional truss connections involve a mitered cut to the branch member end, and the branches are attached to the chord with fillet welds. Are fillet welds the most desirable?
- If so, can the full member capacity be reached with a fillet weld? Economically?
- Circular members and overlapped connections are often considered to have difficult weld details. How much more expensive is it to prepare the branches and complete the welds in these conditions compared to a rectangular gap connection? A little? Much more expensive?
- Is special inspection of a shop weld common? If so, is there a specific weld involving HSS and is special inspection expensive?

Recommendations on Fabrication from ABLE Steel:
- Fillet welds are the most desirable for welders. They are economical, strong enough to develop the full member, easy, and no special inspection is required.
- The prep-work on circular members (fish-mouth) is much more expensive than the bevel on rectangular members.
- Special inspection is required on all full-penetration welds, and it is expensive.
- When welding circular members to spherical shapes, preparation is needed to get a good weld. That is, the “beam” may need to be beveled to get a good fit and a good weld. However, ABLE has not done any work with spherical balls.
- The square groove weld is a good weld but it probably requires special inspection which is expensive. The beveled-type insert is fine for a weld, but Terry thinks that the range of application would be limited because if the gap gets too large, unnecessary welds may have to be made to fill in the gap.
- Mark suggests using a casting such that the tubes fit inside. That way a fillet weld can easily be made around the outside.
- Both Mark and Terry did not feel that castings would be economical for trusses. However, they believe that the largest improvement can be accomplished with fish-mouth type connections on large or deep trusses.
AISC/SFSA Research Meeting Agenda: Chicago, Dec 19, 2003

Introduction/ Meeting Goals (9:00 am – 9:30 pm):

I.) Morning Discussion (9:30 am – 12:00 pm): Cast Steel Connection Initial Candidates
   A.) Column Splices
      1.) Wide-Flange Column Splices
      2.) Tube Column Splices
      3.) Wide-Flange to Square Tube Column Splices
         • Manually Guided
         • Self-Aligning
         • Self-Locking
   B.) Beam to Column Connections
      1.) Tube to Tube (Square and Round)
      2.) Tube to Wide-Flange Beam
      3.) Weak-Axis Connections
         • Full-Moment Connections, Shear Connections
         • Self-Aligning
         • Seismic
         • Full Node, Connectors
   C.) Bracing/Trusses
      1.) Fixed Angle Gusset Plates
      2.) Variable Angle Gusset Plates
         • Wide-Flanges
         • Tubes
   D.) Column Bases
      1.) Wide-Flanges
      2.) Tubes
         • Pinned Base, Fixed Base
         • Self-Guiding
         • Self-Locking

Lunch: 12 noon – 1pm

II.) Afternoon Discussion (1:00 – 3:30 pm): Modular System for Automated Construction
   A.) Identification of Candidate (prototype) structures
      • Moment frame, Braced frame, Steel core, Staggered Truss, Other?
      • Time and Cost
      • Sequencing
      • Tolerances
      • Plumbing
   C.) Approach:
      • self-guided vs. assisted
      • self-locking vs. secured
      • low tolerance vs. adjustable
      • Stick erection vs bay
   D.) Benefits to self-guided, self-locking, members
      • Time, Cost, Safety
   E.) Integrations with NIST Program
      • Timeline
      • Deliverables
      • Creation of Scaled models
      • Verification of Concept
Development of Cast Modular Components for Steel Construction

Nathan Palmer

Robert B. Fleischman

Department of Civil Engineering & Engineering Mechanics
University of Arizona

Industry Partners

- American Institute of Steel Construction
- Steel Founder’s Society of America

Background

- UA, AISC and SFSA submitted proposal to NSF for $386,000 in January 03
- Objective of proposal is to develop modular cast components for use in steel construction
- Proposal funded at $347,000; Effective date October 2003
- RBF, TS, DP, RM meet October 2003 to outline target areas
- RBF, TS meet with NIST October 2003 to discuss opportunities for modular connections to facilitate or automate the steel erection process
- NP starts on project late October; develops trial candidates in target areas
- Research Meeting #1: December 19, 2003

Meeting Agenda

I. Morning Discussion: Connection Candidates
   A.) Column Splices
      1.) Wide-Flange Column Splices
      2.) Tube Column Splices
      3.) Wide-Flange to Square Tube Splices
         • Manually Guided
         • Self-Aligning
         • Self-Locking
   B.) Beam to Column Connections
      1.) Tube to Tube (Square and Round)
      2.) Tube to Wide-Flange Beam
      3.) Weak-Axis Connections
         • Full-Moment Connections, Shear Connections
         • Self-Aligning
         • Seismic
         • Full Node, Connectors
   C.) Bracing/Trusses
      1.) Fixed Angle Gusset Plates
      2.) Variable Angle Gusset Plates
         • Wide-Flanges
         • Tubes
   D.) Column Bases
      1.) Wide-Flanges
      2.) Tubes
         • Pinned Base, Fixed Base
         • Self-Guiding
         • Self-Locking

II. Afternoon Discussion: Modular System for Automated Construction
   A.) Identification of Candidate (prototype) structures
      - Moment frame, Braced frame, Steel core, Staggered Truss, Other?
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      - Tolerances
      - Plumbing
   C.) Approach:
      - self-guided vs. assisted
      - self-locking vs. secured
      - low tolerance vs. adjustable
      - Stick erection vs bay
   D.) Benefits to self-guided, self-locking, members
      - Time, Cost, Safety
   E.) Integrations with NIST Program
      - Timeline
      - Deliverables
      - Creation of Scaled models
      - Verification of Concept

Initial Candidates

Category A: Column Splices

A.) Column Splices
   1.) Wide-Flange Column Splices
   2.) Tube Column Splices
   3.) Wide-Flange to Square Tube Splices
      • Manually Guided
      • Self-Aligning
      • Self-Locking

A.1 Wide-Flange Column Splices
Candidate A.1.a: Angled Tabs

version 1: guides
• clips permit +/- 2" out of alignment in plan (2-ways)
• erection bolts secure top column
• perform field weld

version 2: connection
• large tabs shop welded to lower column
• clips permit +/- 2" out of alignment in plan (2-ways)
• splice completed with field bolting or welded alternative

Appendix 2: A2
A.1 Wide-Flange Column Splices

Candidate A.1.b: Keyed Splice

- Two complementary pieces: one with notch, one with key
- Shop welded to columns
- Fits range of column sizes with same T-Distance
- Key provides shear transfer; novel configuration permits moment transfer thru bolt tension

Candidate A.1.c: Eye Splice

- Flange forces carried in quad-shear
- Individual connector - easy to cast, difficult to align
- Shop welded to each column

Candidate A.1.c: Eye Splice Pin

- Three piece system
- Threaded end of tapered pin for a nut
- Expanding diameter with torque of nut which provides tight fit in eye-hole

Candidate A.1.d: Tendon Splice

- Conical cavity shop-welded to web of bottom column
- Conical tendon shop-welded to upper column
- Tight fit - wedging force to hold in place
- Easy to cast, can be utilized on any size column with scaling adjustment
- Has applications as column base connection
A.1 Wide-Flange Column Splices

Quick Connector Locking Mechanism #1

Description
- Locking “hammer” mechanism that requires a pivoting shear pin
- Hammers form small compression struts which rely on the shear strength of the pin
- Shop welded to bottom column

A.2 Square Tube Column Splices

Candidate A.2.a: Flanged Collar Splice

Description
- Modified baseplate with self-aligning capability regardless of tube wall thickness
- Shop welded (either fillet or full-penetration welds)
- Doubly symmetric hole patterns

Candidate A.2.b: Transverse Pin Splice

Description
- Utilizes easy two-pin connection
- Quad-shear feature
- Columns shop welded to castings
- Holds a somewhat self-aligning feature
- Dimensions are that of the tube (no extrusions)

Candidate A.2.c: Finger Splice

Description
- Multiple “finger joints” which provide 12 shear planes per bolt
- Minimal number of bolt tightening operations required
- Each casting is shop welded to column
- End “fingers” are longer to facilitate alignment
- Can develop full member strength

Candidate A.2.d: Cruciform Splice

Description
- Cruciform shape allows for bolting access
- Two bolts per face loaded in double shear
- All shop welds
- No reduction in moment of inertia or strength
- Pieces can be recessed within dimension of the tube
A.2 Square Tube Column Splices

Candidate A.2.e: Bolted Insert Splice

- Cast insert with recessed nut holders
- Insert has circular core to facilitate alignment
- Insert is tack welded inside upper column prior to construction
- Bottom casting has tapered conical pin as is shop welded to lower column
- Full member capacity is reached through field bolting

Description

A.2 Round Tube Column Splices

Candidate A.2.f: Flanged Collar Splice

- Complimentary top and bottom castings to ensure alignment of bolt holes
- Self-aligning taper
- Tube can be inserted into casting or match diameter of casing to allow for full-pen weld
- Full moment transfer capability

Description

A.2 Round Tube Column Splices

Candidate A.2.g: Knife Plate Splice

- Two castings full-pen welded to tubes
- Taper on bottom casting to help guide into place
- Tube sandwiched between vertical plates to allow for double shear bolting or field welding
- Full moment transfer; increased moment of inertia; alternatively this connection can be recessed for flush joining surfaces
- Casting permits knife plates to be replaced with complementary tapers for easy alignment yet preserving flat faying surface

Description

A.2 Square Tube Column Splices

Quick Connector Locking Mechanism #2a

- Thin cantilevers with triangular “latching” ends
- Cantilevers bend inward (elastically) under gravity load of upper column
- Mortise cut into HSS tube in shop
- Field weld or bolt necessary after erection is completed

Description

A.2 Square Tube Column Splices

Quick Connector Locking Mechanism #2b

- Same concept without cantilever base
- One universal casting
- Shop or field bolted to lower column
- Shorter cantilever extending from end of tube

Description

A.3 WF to HSS Column Splices

Candidate A.3.a: Bolted Plate Splice

- Bottom base-plate shop welded to WF with center aligning hole
- Top base-plate shop welded to HSS tube and slips into aligning hole of bottom plate; while “saddling” WF with
- Bolting pattern directly in line with tube faces which puts bolts in tension
- Nut locations are recessed and will hold nuts while tightening bolts from below

Description
A.3 WF to HSS Column Splices
Candidate A.3.a: Bolted Plate Splice

Initial Candidates
Category B: Beam to Column Connections
Beam Column Connections
1. Tube to Tube (square)
2. Tube to Wide-Flange Beam (square and round)
3. Weak-Axis Connections
   - Full Moment Connections, Shear Connections
   - Self-Aligning
   - Seismic

B.1 Square Tube Beam to Square Tube Column Connections
Candidate B.1.a: Simple Ledge
Description
- Cast ledge is shop welded to column
- Tube beam must be prepared by drilling hole of proper diameter in bottom face
- Simply supported
- May be required to field weld tube onto ledge

Candidate B.1.b: Full Moment Collar
Description
- Resists moment thru bearing surfaces
- Collar has sufficient inherent stiffness to avoid diaphragm plates in tube
- Collar can be welded to column or may serve simultaneously as a column splice
- Inserting fixtures can be adapted to fit tubes and WF’s

B.2 Tube column to WF Beam Connections
Candidate B.2.a: Full Moment Collar
Description
- Resists moment thru bearing surfaces
- Node can be welded to column or can serve simultaneously as a column splice
- Inserting fixtures can be adapted to fit tubes and WF’s
- No loss of moment of inertia through beam adapter section
B.3 Weak-Axis Connections
Candidate B.3.a: Welded Adapter

Description:
- Adapter is inclined to allow for weld access
- Bottom adapter is shop welded to column
- Top adapter is shop welded to beam
- Combination allows for any size beam
- Field welds required at bottom flange and at the top adapter/column interface

B.3 Weak-Axis Connections
Candidate B.3.b: Bird’s Eye Connector

Description:
- Easy field pin connection (dual shear)
- Can develop full strength of flange
- Connector is shop welded to flange
- Rests on a seat provided by connectors that are shop welded to column

B.3 Weak-Axis Connections
Candidate B.3.b: Bird’s Eye Connector 1

Description:
- Concept shown with a full-pen weld to the web
- Casting incorporates weld-access hole

B.3 Weak-Axis Connections
Candidate B.3.b: Bird’s Eye Connector 2

Description:
- Concept shown with a shop fillet weld between offset tab and the web
- Also allows for welding underside of flange

B.3 Weak-Axis Connections
Candidate B.3.c: Full Moment Quarter Node

Description:
- Resists moment thru bearing surfaces
- Connector can be shop or field bolted to column
- Inserting fixtures can be adapted to fit tubes and WF’s
- No loss is moment of inertia in beam adapter
- Connector is confined within flanges

Initial Candidate
Category C: Bracing Connections
Initial Candidates
Category D: Column Bases

Description:
- Typical base-plate with four tie-down holes and a tapered centerpiece
- Cast studs which hold nut from rotating and are shop welded to bottom of base-plate
- After studs are welded, column base can be cast in concrete

Initial Candidates
Category D: Column Bases

Description:
- Complimentary top base-plate with prepared WF for welding and a tapered centerpiece
- Top and bottom base-plates will align and tie-down rods can then be tightened

Initial Candidates
Category D: Individual Tie-downs

Seismic Design

Double-Arm
Guide plates

Conclusion

These modular connection concepts represent an initial set of designs for the use of castings to facilitate steel construction. These individual designs will be modified, pursued or abandoned or new designs will be developed based on industry input.
Participants
Robert Fleischman (University of Arizona) Nathan Palmer (University of Arizona)
Tom Schlafly (American Institute of Steel Construction) Todd Alwood (American Institute of Steel Construction)
Raymond Monroe (Steel Foundry Society of America) Dave Poweleit (Steel Foundry Society of America)
John Zils (Skidmore Owings & Merril) David E. Eckmann (OWP/P Architects Inc.)
Fred Haas (Private Consultant) Jeff Wise (Atchison Casting)
William Gibb (NorthStar Cast Steel) Teresa Derian (NorthStar Cast Steel)
Ken Murphy (ACIPCO) Alan Holtz (Spuncast)
Tim Hays (Harrison Steel) Geoff Curtis (Harrison Steel)
Gilbert Catherwood (A.G. Anderson Ltd.) Vasile Ionescu (A.G. Anderson Ltd.)
George Hartay (Falk Corp.) Joe Rondinelli (Falk Corp.)
Tim Wade (Spokane Industries) Raj Reddy (Southwest Steel Casting)
Hal Davis (Sivyer Steel) Scott Montino (McConway & Turley)

Meeting Minutes

Overview
RM: castings were prevalent in construction in the 1940’s – fabricators got better – today casting are used only for specialty items.

TS: In general two major opportunities envisioned
• Economic advantage
• Architectural advantage

i.e. if it doesn’t beat it architecturally, it needs to beat it economically

Application 1: WF Column Splices

General comments:
Gravity vs. tension splices:
1. gravity load
2. column in moment frame – more robust to carry moment/uplift

Fabrication:
Often bolted though tough to drill holes in thick flange

Erection:
Safety issues – two tier construction (i.e. 26’ in the air); joint needs to be able to take the moment caused by a man hanging off the end (sitting on a 4’ stub)
TS: Get the hook off, get a beam on near the top
FH: 5 men in the raising gang – Must remove the rigging; the iron worker needs to be there to align it; adjustment is attained with 2 erection bolts; keep the column plumb for final bolting – Steel with a concrete core further needs vertical adjustment.

Fastening:
What is done now (i.e. in the context of gravity splices):
temporarily bolted
welded to meet the strength of the weaker column (is this tension splice?)
TS: Gravity column connection – keep it from shifting
construction loads – not big relative to structural loads

**Estimating:** steel erection costs \((FH)\)
- 2 men welding in the field – wage rate $120/hr (incl. fringe)
- 1 man welding in the shop – wage rate $50/hr
 (+ quality control: humidity, different position, deposition rate)

**Typical Members:**
- Most buildings are 1-3 story with little field welding;
- Changing column size is not an issue
- Industrial buildings – bolt columns using splice plates
- Taller buildings typically have columns of different sizes
  - Inside to inside face is constant \((RM)\)
  - Use shim plates to joins columns of different flange thicknesses
  - Columns depth transitions are expensive but rare (same with WF to tube)

**Castings:**
- The more complicated, the better the use of casting; lot of shape and a lot of complexity
- Replace the welding with a casting; transfer welding operations to the shop

**A.1.a Bent guide plates (erection aid)**

**Features**
- Provides stability
- 3 foot pocket should keep the column

**Issues**
- Can bend a plate much easier than one can cast
- \(TS\): can’t weld a cast piece in the shop much quicker than an ironworker does in the field. i.e. a casting added in the shop needs to eliminate the field erection

**Overall Comment on Erection:**
An opportunity does exist with the construction method: Save the erector the time of getting the people to the point

Self-alignment and (at least) temporary attachment
Ironworker to guide it without needing to fasten it; the weight should secure

A tight fit cast joint will not permit you to erect because everything would need to straight/square

**A.1.b (keyed fitting for bolted flanges)**
Nice solution for larger columns

**Comments:**
1. double the welding
2. 90% of the splices do not require tension splices

Shear transfer may not be a big deal in a typical column splice/moment connection – might be an issue in a bridge girder splice \((JZ)\)

Architect – internal drain system \((DE)\)

There is added complexity in this connection
Want something big and rough – sell a product at a ¼ price of hamburger
Make the building go where you want

Butt plate splice: Tolerances may be an issue (from a casting standpoint)
Investment casting instead of machining – steel is 30 cents/pound

Column bases – shear key – braced column bases take shear into the concrete

Cast leveling piece – mating piece above

**D.E.** may not get enough repetition

How are the casting and construction tolerances married (**JZ**)
Casting and construction tolerances are similar (**RM**)

**A.1.c (Eye bar with tapered pin)**
Can modify it for identical castings top and bottom (**RM**)
Must eliminate interference when lining up the slot

**FH.** All the shop welding is not desirable

Is the pin a casting? Not necessarily. The pin may be 20 lbs – a concern is the iron worker carrying these pins around (or dropping one)

The cost effectiveness of the assembly is questionable –
Doubling the weld; adding a casting and yet still requiring a field connecting operation

**A.1.d (web tenon and mortise splice)**
Is the cone necessary on both sides?
Try a one sided cone – this will permit access for the mechanicals
This connection may work better upside down
Offshore used a connection like this for stabbing points – 1000 pounds
The OSHA loads are unrealistically small
Cast the mortise with a base for bolting; hence adjustment – this will also allow shop alignment of the mortise (make the casting base so it fits the inside dimension)
The connector must develop minimum capacity for axial, moment and shear (**JZ**)

This one was viewed to have some promise

**A.1.e (Quick connects)**
Economics will rule

**A.2.a (Tube splice)**
**RM** – collar (channel-shaped that fit on either side of the tube)
**DE** – column splices are not so common for HSS members – a typical application is Walmart stores – 30’ columns; joist girders sitting on a bolted cap plate
**DE** – primarily for aesthetics – simple, clean lines – visually driven; architectural – often exposed-thus the collar may be viewed by architects as a bit too clunky
**JZ** – tubes aren’t being used in high rise construction, this may be because of difficulty with making the connections; it may be a frequency vs. cost issue – it may be used more if there were better options – tube steel is more expensive pound for pound than rolled shapes
TS - Right now tubes are typically field welded – it is often a difficult fit up – weld without backup, bevel cut into branch – fish mouth – for 2D and 3D trusses
Some people thought the inner sleeve idea wasn’t bad

A.2.c (Teeth splice)
12 1 1/8" bolts – may be attractive for a beam flange (TS)
it’s been done
if it doesn’t line up…

A.2.d (cross fitting)
What if fitting gets bent along the way (TS)
Be careful to avoid dust ledge – HSS advantage is no dust ledge

A neat project may be to examine concrete filled tubes
WF to tube – can be used to punch through the roof- penthouse

B (Beam to Column Connections)
General comment: DE sees steel tube construction as the real opportunity – they want a clean connection – have the members melt into each other – thinks a big opportunity is to allow straight, square-cut segments to be joined by cast pieces – this may not require very much R&D as the castings may simply be the shape needed to join
Economics –
– fabrication cost
– erection cost
– detailing cost
– architecture

Tube to tube trusses – don’t see them often because they are so expensive, mostly planar
Create a family of tube-to-tube connections
HSS is most efficient but expensive to connect

Centrifugal tubes welded to spheres – modular space frames; cast tubes with taper at end to fit into receptacles in the sphere

Typical HSS rectangular is 42 ksi; round A53B – up to 5/8” thick
centrifugal can be up to 125 ksi: any O.D., I.D. – cast it up to 10” thick

Tube trusses typically have top and bottom chords the same size, diagonals smaller (80% of diameter – typically for welding purposes) – panel points at 45 or 60 degrees
DE – architects prefer smaller sections – blend from larger to smaller

Nodes are used on offshore platforms – standard hardware off the shelf

HSS is used in smaller sections and in shorter buildings, not used that much for large applications – no big market for that at this time

B.2 (moment connections)
Node idea seems heavy – not castable as one piece – a parting line approach seems more feasible

Ring with a flange; lower ledge (JZ) instead of an upper and lower ring
**B.3.a (weak axis connection)**
Don’t want plates on both sides – inside stays the same
Ray likes it
Wouldn’t sit on the shelf
Weak axis – 4 fillet welds
Weak axis connection is not very common – cantilever; typically continuity plates

Make the connection on both sides

**B.3.c (eye pin)**
Why not make the pin big enough
Just a glorified tee stub
Make sure the eye does not get up into the deck
Why not use stiffened hooks instead of the eye and pin?

**Truss Connections:**
*(JZ)* – gusset plate and double angles
Staggered truss uses a tube-to-tee connection –
standard angles – cut or grind to change the angle 5 degrees

The central pin with bolts – do one or the other; not both
Get rid of the loose pieces
Make the hole a taper
Half of the sleeve in the casting

Cast the plate with an undulating surface – it can slip into many orientations (Channel lock pliers)

**Base Plate:**
Faster and easier to erect

Big problem – anchor bolts are mislocated– less often screwing up the pattern; more often pattern in the wrong place *(JZ)* – almost every building has mislocated anchor bolts

Cast product – the pattern should be good
Need something to move within a couple of inches can be off by 4-5”

**ACTION ITEMS:**

*FH*: steel fabricator
Need input from:
1. fabricator
2. erector
3. structural engineer

Need to find friendly fabricator and a friendly erector to spend time with the UA team
Need to discuss construction (fabrication, layout, erection sequence) of staggered truss

DE will provide:
- typical tube connections details
- typical plans/sections/elevations of buildings
- examples of the European construction

Will flip through last 12 months of Modern Steel Construction
Summary Agenda

Workshop: Development of Cast Modular Components for Steel Construction

Date: July 9, 2004
Time: 9am-4pm
Venue: Hilton Kansas City Airport (Airport shuttle is available and hotel information is attached)
Location: Kansas City, MO
Room Rate: $ 78.00/night (Negotiated for the event)

Research Institution, Sponsor and Industry Partners:
University of Arizona (UA)
National Science Foundation (NSF)
American Institute of Steel Construction (AISC)
Steel Founder’s Society of America (SFSA)

Workshop coordinated by Viji Kuruvilla, Genesis Quality Systems

Participants
Design Consultants, Fabricators, Erectors, Researchers, Founders, Architects, Producers
(see attached participant list)

Objective: To select most promising application(s) for research and development through consensus of industry-advisory panel for project “Development of Cast Modular Components for Steel Construction”

Dress: Business Casual

9:00 am: Introduction/ Meeting Goals
9:00 am – 9:30 am: Background: Cast Modular Components
9:30 am – 10:00 am: Review of Initial Project Stages
10:00 am – 10:15 am: Break
10:15 am – 12:00 am: Working Session for Research Thrust A: HSS
12:00 pm – 12:30 pm: Lunch
12:30 am – 2:15 pm: Working Session for Research Thrust B: Seismic
2:15 pm – 2:30 pm: Break
2:30 pm – 3:15 pm: Industry-guided Activities
3:15 pm – 4:15 pm: Open Working Session for Topics A-B as Required
4:15 pm – 4:30 pm: Consensus on Applications for Development
4:30 pm: Conclusion
Workshop Agenda

Objective: To select the most promising application(s) for research and development through consensus of the industry-advisory panel for project “Development of Cast Modular Components for Steel Construction”

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4:30 pm: Conclusion

History of Current Research Effort

• AISC and SFSA were independent research partners on RBF’s NSF CAREER AWARD to develop cast modular connections for seismic resistant steel frames (1998-2002)
• AISC and SFSA begin a dialogue on opportunities for castings in steel construction – fall 2002
• RBF invited to joint meeting of AISC and SFSA where it was agreed to pursue NSF GOALI funds for this purpose – Dec 02
• UA, AISC and SFSA submitted proposal to NSF in January 03
• Proposal successful; funding date moved to October 2004

A stipulation of the grant is to work closely with AISC and SFSA to develop industry consensus on the approach and application(s) developed.

Research Plan Proposed

• Objective of proposal is to develop modular cast components for use in steel construction.
• Applications are to be identified where cast modular components can:
  • Improve economy or reliability
  • Eliminate difficult or costly fabrication
  • Eliminate difficult or dangerous erection
  • Facilitate steel construction in new areas
• Several concepts are to be discussed initially. One or more promising applications will be developed. These can take the form of:
  • A comprehensive system (e.g. modular building)
  • A unique application (e.g. new bracing detail)
  • A family of components (e.g. nodes for HSS bridges)
Proposed Research Plan

Research tasks associated with developing a concept:
• Identify a concept associated with a promising application (AISC)
• Analytical development of concept into prototypes
  • Structural Analysis Solid Modeling (UA)
  • Solidification Simulation Solid Modeling (SFSA)
• Experimental verification of prototype
  • Prototype Creation (SFSA) & Specimen Fabrication (AISC)
  • Full-scale Experimentation (UA)
• Economic/Constructability Studies (AISC/SFSA)
• Trial Implementation/Design Procedures (AISC/SFSA)

The research plan was largely based on the successful development of concepts in previous research on connections for seismic design and for automated construction.

First Session: Background

1. Background (Fleischman): (9:00 am – 9:30 am)
   a. Description of Current Research Effort
      – AISC/SFSA Joint Task group
      – NSF GOALI Grant
      – Proposed Research Approach
   b. Previous research efforts
      – Modular Nodes for Seismic Resistant Design
      – Modular Connections for Automated Construction
   c. Parallel Efforts
      – ConXtech Framing System
      – NIST Research in Automated Construction

Northridge Earthquake, January 17, 1994

• More than 100 Special Moment Frames (SMFs) suffered extensive brittle fractures.
• Among many reasons cited as contributors to the failures, it was agreed that this connection’s inherent configuration is not conducive to ductile behavior, and the situation is exacerbated by placing the weld region at this location.

Proposed Solution: NSF CAREER Award 01-96120

- Specially configure the connection region for optimal seismic performance.
- Eliminate the field weld from the critical structural regions.

Traditional rolled shapes do not have the versatility in form to meet this objective.

It is, however, a natural application for the use of steel castings.
Design Methodology

<table>
<thead>
<tr>
<th>PH-MN</th>
<th>PZ-MN</th>
<th>MC</th>
<th>PT</th>
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<td>Beta Prototype</td>
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<tr>
<td>Design Methodology</td>
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</tbody>
</table>

Cast Modular Connections for SMFs

Panel Zone Dissipator Modular Node

PZ-MN

Field Weld

Panel zone weak relative to beam

Filleted cruciform

Field Weld

Column Flange Kinking in Connection

FEMA 350 minimum ΨP relative strength

Implied allowable column flange curvature value

Deformation of Panel Zone: Traditional Joint

Kinking of Column Flange

Beam Plastic Hinges

Column Flange Kinking in Connection

Weaker panel zone relative to beam

Proposed Full Joint Mechanism

Appendix 2: B2a
Experiment Subassemblage

Industry Partner

• Able Steel Fabricator Inc., Mesa AZ

PZ-MN Prototype

Industry Partner

• Varicast, Inc., Portland OR

PZ-MN-01 Monotonic Test

\[ P_y (EXP) = 70 \]
\[ P_y (FE) = 76 \]

Subassemblage Rotation (rad)

PZ-MN-02 FEMA Cyclic Test

Qualifying Drift Angle for Strength Degradation

Survived 12 additional cycles at max amplitude

Appendix 2: B2a
Bolted Cast Modular Connector (MC)

Objective – Dissipate seismic energy in the connector rather than in main members.
- Shop-weld or bolt to beam
- Field bolt to column

Bolt Prying of Traditional Tee-Stub

T = Q + P

Comparison of Plastic Damage Regions: Connector vs. Traditional Connection

MC Half-scale Prototype Castings

Specimen prepared with pull plate and strain gages

Global Results: MC vs. WT

Strain Distribution Along Arm
Comparison of Constant Amplitude Tests

Conclusions

Steel castings have shown great promise as special energy-dissipating details in steel moment frames in high seismic zones. These modular designs exhibited:

- Superior ductility w.r.t. traditional connections
- Stable and efficient energy dissipation
- Increasing strength due to work hardening
- Reliability and repeatability
WORKSHOP:
Development of Cast Modular Components for Steel Construction

Hilton Kansas City Airport
Kansas City MO
July 9 2004

Coordinator: Viji Kuruvilla, President
Genesis Quality Systems

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   c. Parallel Efforts
      - ConXtech Framing System
      - NIST Research in Automated Construction

NIST Research on Automated Construction

<table>
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<tr>
<th>Ranking</th>
<th>Technology</th>
<th>Most</th>
<th>Desired</th>
<th>Important</th>
<th>Quality</th>
<th>Speed/productivity</th>
<th>Safety</th>
<th>Minimization of rework</th>
<th>Ease of Use</th>
<th>Durability</th>
<th>Time until 100%</th>
<th>Tolerance accommodation</th>
<th>Task attractive to labor</th>
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<tbody>
<tr>
<td>Least</td>
<td>Jack-up construction technology</td>
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<tr>
<td>Least</td>
<td>Deck-sheet fastening technologies</td>
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</tbody>
</table>

The structural system is made feasible by replacing standard fabrication with state-of-the-art manufacturing:

- robotically welded
- innovative fixturing
- precision machining
- straightening

These processes enable holding tolerances of .006 of an inch.

Modular Framing System

- 3D moment connection
- 100% factory welded
- Precisely-aligned space frame
- Stable prior to field bolting
- No field welding
- No bracing or guying

ConXtech was conceived and developed by Robert J. Simmons, Founder and Chief Executive Officer, of RJS & Associates

121,000 sq. ft “state-of-the-art” production facility: Hayward, CA

- Welds up to 80 foot HSS columns in the flat position
- Automatic fixturing method that removes sweep in HSS columns during the root and filler welding operation
- Robots successfully complete full penetration welds
- Precise cutting of I-beams in specified lengths
- Numerous custom tools and fixtures, which minimize labor, maximize precision and increase throughput
- Three CNC steel milling machines operating on a “lights out” basis

Weld in ConXtech’s facility takes 6 minutes, costs $10 who inspections required beyond ConXtech’s QC. Field weld may take 3 hours, cost $150 and incur a 30-minute inspection process.

Appendix 2: B2b
The ConX Structural Frame System

- **Inner-collar plates**
  - precisely machined to include self-aligning, self-seating connector
  - factory fillet welded to each face of an 8" HSS column at floor level specified by the architect
- **Outer-collar plates**
  - robotically welded at each end of WF at the precise length to accommodate the architectural grid
  - precisely machined to include a slot contoured to the same shape as the tapered boss on the inner-collar plate
  - drilled along the exterior edges to receive diagonal bolts

Result: exactly match construction plans without the need for human layout, cutting or fitting. Precision allows ancillary products including electrical, plumbing, HVAC and fire protection systems to be pre-designed and pre-fabricated.

Used for residential/mixed-use buildings because of the significant cost penalty and design constraints required to align vertical load paths through multiple occupancies. The ConXtech system distributes the load across the podium, eliminating the need to align concrete columns below the podium with the structural columns above and the need for expensive transfer beams.

Special “Column Lander” designed for positioning and plumbing
Overall Construction Time

- 150 pieces of steel were erected at Santana Row on day one by union iron workers who had never before seen the ConX system
- ConX estimated to reduce one month of traditional steel construction to one week
- Bolting safely takes place after deck is poured

Structure is already stable – columns are attached to base plates after the erection process has been completed
Santana Row: Four-story 47,000 sq.ft. residential building on podium over four levels of retail and parking erected in 3-weeks (April 2004)

ConXtech chosen to replace wood frame structure that burned down in 2002 in the largest fire in San Jose’s history

ConXtech System Advantages

- Substantial overall reduction of on-site labor
- Lower construction and overhead costs
- Dramatically reduces overall construction time
- Safer work environment due to minimal on-site welding, vertical access to roof by stairs on day 1
- Clean efficient construction environment for all trades
- Drastic reduction in special inspection costs
- No requirement to align columns below podium with columns above
- Standard wood code limited to 65 ft. ConXtech system allows for up to 8 floors in Seismic Zone IV without shear walls, brace frames.
- Reduction in liability and risk offers significant potential to reduce insurance costs
Second Session: Review of Initial Stage

Timeline: Preliminary Stages

- TS, DP, RM develop rough set of applications
- RBF, TS, DP, RM meet October 2003 to outline target areas

Rough Set of Applications

Appendix 2: B2c
Rough Set of Applications

Timeline: Preliminary Stages
• TS, DP, RM develop rough set of applications
• RBF, TS, DP, RM meet October 2003 to outline target areas
• RBF, TS, DP, RM meet October 2003 to outline target areas
• RBF, TS, DP, RM meet October 2003 to outline target areas
• RBF, TS, DP, RM meet October 2003 to outline target areas
• NP develops trial candidates in target areas November 2003
• Research Meeting #1: AISC December 2003
  • Initial Concepts Presented
  • Focused on joining a piece with a complementary piece
  • Most forms were splices – and could easily be extended to joints

Initial Concepts: HSS Bolted Field Splices
Candidate: Flanged Collar Splice
- Indentation for tapered lip
- Tubes inserted for fillet weld around perimeter

Description
- Complimentary top and bottom castings to ensure alignment of bolt holes
- Self-aligning taper
- Tube can be inserted into casting or match diameter of casting to allow for full-pen weld
- Full moment transfer capability

Initial Concepts: HSS Bolted Field Splices
Candidate: Keyed Splice/Connection
- Two complementary pieces shop welded to columns of same T distance: one with notch, one with key
- Key provides shear transfer and self-aligns bolt; novel configuration permits moment transfer thru bolt tension
- No preparation to WF before welding

Description
- Three erection bolts in tapered "knife" web for alignment
- Shear transfer provided by tapered pin and bushing
- Pin end threaded to lock - torque of nut provides tight fit

Initial Concepts: WF Bolted Field Splices
Candidate: Eye Splice
- Two solid pieces that ensure alignment
- Three erection bolts in tapered "knife" web for alignment
- Shear transfer provided by tapered pin and bushing
- Pin end threaded to lock - torque of nut provides tight fit

Description
- Easily modified for full-moment connection
Initial Concepts: HSS Brace Pin Connection
Candidate: Transverse Eye and Pin

Description:
- Utilizes easy two-pin connection
- Quad-shear feature
- Columns shop welded to castings
- Holds a somewhat self-aligning feature
- Dimensions are that of the tube (no extrusions)

Initial Concepts: HSS Bolted Field Splices
Candidate: Multi-Shear-Plane Finger Splice

Description:
- Multiple “finger joints” providing in casting in shop welded to column up to 12 shear planes per bolt
- Minimal number of bolt tightening operations required
- End “fingers” are longer to facilitate alignment
- Can develop full member strength

Initial Concepts: HSS Bolted Field Splices
Candidate: Cruciform Splice

Description:
- Cruciform shape allows for bolting access
- Two bolts per face loaded in double shear
- All shop welds
- No reduction in moment of inertia or strength
- Pieces can be recessed within dimension of the tube

Initial Concepts: HSS Bolted Field Splices
Candidate: Conical Tenon Splice

Description:
- Conical cavity shop-welded to web of bottom column
- Conical tenon shop-welded to upper column
- Tight fit – wedging forces to hold in place
- Easy to cast, can be utilized on any size column with a scaling adjustment
- Has applications as column base connection

Initial Concepts: HSS Col to Beam Connection
Candidate: Full Moment Collar

Description:
- Resists moment thru bearing surfaces
- Collar has sufficient inherent stiffness to avoid diaphragm plates in tube
- Collar can be welded to column or may serve simultaneously as a column splice
- Inserting fixtures can be adapted to fit tubes and WF’s

Initial Concepts: HSS Col to WF Beam Conn
Candidate: Full Moment Collar

Description:
- Resists moment thru bearing surfaces
- Node can be welded to column or can serve simultaneously as a column splice
- Inserting fixtures can be adapted to fit tubes and WF’s
- No loss of moment of inertia through beam adapter section
Initial Concepts: Weak-Axis Moment Conn
Candidate: Bird’s Eye Connector

- Concept shown with a shop fillet weld between offset tab and the web
- Also allows for welding underside of flange
- Easy field pin connection (dual shear)
- Can develop full strength of flange
- Connector is shop welded to flange
- Rests on a seat provided by connectors that are shop welded to column

Description
- Thin cantilevers with triangular “latching” ends; long and short protrusion
- Cantilevers bend inward (elastically) under gravity load of upper column
- Slots cut into HSS tube in shop
- Field weld or bolt necessary after erection is completed

Initial Concepts: Locking Mechanism
HSS Quick Connect Lock

- Locking “hammer” mechanism that requires a pivoting shear pin
- Hammers form small compression struts which rely on the shear strength of the pin
- Shop welded to bottom column

Description
- Complimentary top base-plate with prepared WF for welding and a tapered centerpiece
- Top and bottom base-plates will align and tie-down rods can then be tightened

Second Session: Review of Initial Stage

1. Review of Preliminary Stage of Project: (9:30 am – 10:00 am)
   - Initial Concepts
     a. Target Areas
     b. Rough Concepts
     c. Conceptual Realizations
   - Outcome: Targeted Research Thrusts
     - Applications for HSS
     - Bracing Elements
       - Seismic Details
         → Thrust A: HSS
         → Thrust B: Seismic Bracing
       - Modular Systems for Facilitated Erection
   - Challenges and Issues
     - Construction Issues
     - Casting Issues

Category D: Column Bases
APPLICATIONS OF STEEL CASTINGS WITH HOLLOW STRUCTURAL SECTIONS

Jeffrey A. Packer
Professor
University of Toronto

Steel Steel Nodes in Tubular Structures

Aix-en-Provence TGV Station, France

The renaissance for cast steel began in 1972 with the roof of the Olympic Stadium in Munich, Germany.

Recent developments (particularly in Europe) with cast steel products show that it is possible to achieve the same strength, toughness, weldability and corrosion resistance as for rolled steel products.

Casting allows connections to be shaped according to the demands of internal forces, thereby avoiding large stress concentrations.

The design of welded tubular connections under dynamic loading is very influenced by their fatigue behavior. Thus, castings are ideally suited to bridge structures.

CIDECT Design Guides

Fabrication: 1998
Fatigue: 2000

Cost: Welded versus Cast Tubular Joints

A dramatic 8-storey atrium using steel castings with tubes

Appendix 2: B3a
**Finishing of Steel Castings**

Castings with steel may have rough surfaces requiring finishing.

---

**Bridges using Cast Steel Joints**

<table>
<thead>
<tr>
<th>Bridge Structure</th>
<th>Year</th>
<th>Bridge Type</th>
<th>Bridge Length [m]</th>
<th>Bridge Width [m]</th>
<th>Bridge Span [m]</th>
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<tr>
<td>Ripshorster bridge</td>
<td>1997</td>
<td>pedestrian</td>
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<td>Zirndorfer bridge</td>
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<td>13.2/8.8</td>
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<td>1996</td>
<td>highway</td>
<td>45</td>
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**Material used in Cast Steel Bridge Joints**

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<td>S 355 GS</td>
<td>197.7 to 325.9</td>
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<td>S 355 GS</td>
<td>273 and 406.4</td>
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<td>Bridge across river Wurm</td>
<td>S 355 GS</td>
<td>267 and 457</td>
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<tr>
<td>Humboldthafen bridges</td>
<td>S 355 GS</td>
<td>267 and 457</td>
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**Highway Bridge over River Traun (2000)**

[Image of highway bridge over river Traun]

---

**Humboldthafen Railway Bridges, Germany (2000)**

[Image of Humboldthafen Railway Bridges]
Recent Literature


Friedrich Wilhelms-Hütte GmbH: www.fwh.de
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PART II: Working Sessions

Hilton Kansas City Airport
Kansas City MO
July 9, 2004

Coordinator: Viji Kuruvilla, President
Genesis Quality Systems

Challenges and Issues

Steel construction is a mature industry with tight profit margins and serious consequences for non-performance. A key feature of steel construction is its versatility – any modular solution must be able to provide a distinct improvement without significantly adversely impacting cost or versatility.

Third Session: Working Session on HSS

Working Session Research Thrust A: HSS: (10:15 am – 12:00 am)

a. Castings in HSS construction (Intro by Packer)
   - Use (10 minutes)
   - Issues (10 minutes)
   - Opportunities (10 minutes)

b. Trial Concepts for HSS (25 minutes)

c. Discussion (50 minutes)

Large Castings for HSS

(Courtesy Sheffield Forge)

Appendix 2: B3b

-1-
Large Castings for HSS
(Courtesy Sheffield Forge)

Potential Applications for Castings in HSS

HSS Applications
• Planar Trusses
• Moment Frames
• Brace Frames
• Space Frames
• New Systems

Modular Castings for HSS

Casting geometry can be used to eliminate HSS truss connection failure modes
• Increase section thickness uniformly
• Non-uniform “fine-tuned” section
• Cast integral stiffeners, diaphragms
• Integral cast stiffeners, diaphragms
• Additional section using collar or saddle
• The cast modular node approach will also allow for the elimination of certain branch preparation including:
  • Fish mouth or bird mouth cuts
  • Minimum cut
  • Difficult fit-up for flare-bevel welds for equal width branch and chord members
This is particularly helpful in round HSS

Round Gap K Connection Failure (from Packer & Henderson)

Modular Castings for HSS

• Cast modular parts could:
  • Allow reduction in chord size by eliminating primary failure modes A, B & mode F for deep chords, and/or
  • Develop branch member to full capacity (yield/buckling strength)
  • Increase buckling strength by decreasing effective length factor, K
  • If branch member is fully developed, modes C & D must be carefully addressed, including evaluating:
    • the viability of fillet welds
    • the need for a more compact branch member
    • the impact on decreasing effective length

Round K connections: Promote the use of overlap connections without costly fabrication and the use of gap connections without the weak failures

Cast Component Types for HSS

• A “Level 1” Solution: Cast Attachment
  • Cast collar, attachment, or insert added to chord
  • Supplementary welds required
  • Improved connection strength
  • Improved strength to eliminate failure modes

• A “Level 2” Solution: Cast Node
  • Traditional weld/bolted connection
  • Eliminate failure modes to develop member strength

• A “Level 3” Solution: Enhanced Cast Connector
  • Possesses some feature to enhance the connection
    • Field splice
    • Facilitated erecting
    • Housing of secondary elements

Impact on Shop Costs: Cast Components for HSS

• Economics of a “Level 1” Solution:
  • The approach will add (per joint):
    • 1 smaller casting
    • 2 shop welds – likely FPW
  • The approach will eliminate:
    • Difficult welds (flare, fish-mouth or bird-mouth type welds)
    • Branch preparation (no special equipment required)
    • Significant reduction in weight

• Economics of a “Level 1” Solution:
  • The approach will add (per joint):
    • 1 larger casting
    • 2 shop welds – likely FPW
    • Cutting of chord pieces
    • Multiple section sourcing
  • The approach will eliminate:
    • Difficult welds (flare, fish-mouth or bird-mouth type welds)
    • Branch preparation (no special equipment required)
    • Significant reduction in weight due to chord optimization
Issues to Consider: Cast Components for HSS

Issues to consider in the Development:
- Overall Cost
- Reliability
- Ease of Fabrication
- Structural Efficiency
- Deflection
- Ease of Construction
- Modularity
- Castability

Type of Cast Component in HSS

Scenarios where castings would provide a large increase in strength:
- Failure Mode A: Chord Face Plastification
- Failure Mode F: Chord Side Wall Buckling

Modular Cast Connections for HSS Trusses

Use of benchmark structures:
- to evaluate potential for use of castings
- begin by evaluating planar trusses

Benchmark Structures:
- AISC HSS Design Manual Example
- Chicago Board of Trade, Truss T4
- Chicago Board of Trade, Truss T2

Benchmark Structure A: HSS Design Manual Example
- Rectangular HSS Truss

-8x8x1/2 Top Chord
-7x7x1/2 Top Chord

Max Deflection = 3.41"

Benchmark Structure A
- Rectangular HSS Truss: Cast attachments

Small weight savings by reducing the chord section (which is controlled by the central compression span), at the field splice; branches fairly optimized

Benchmark Structure A
- Rectangular HSS Truss: Cast nodes

Max Deflection = 3.76"

This centerline calculation ignores the added area due to the node section at each panel point and the rotational rigidity provided by the nodes
Benchmark Structure A: HSS Design Manual Example
- Round HSS Truss

Benchmark Structure B: CBOT T4
- WF chord and 2L Branch Member Truss

With the use of Cast Nodes, Similar Savings can be realized with Round HSS ~ 15-20%

Chicago Board of Trade, Truss T4

Max Deflection = 4" (L/450)

Max Deflection = 5" (L/360)

Appendix 2: B3b
Benchmark Structure B: CBOT T4
• Rectangular HSS Equivalent Truss (Cast node)

Max Deflection = 5 1/2" (L/320)

Benchmark Structure B: CBOT T4
• Round HSS Equivalent Trusses 2:1 (Traditional)

Benchmark Structure C: CBOT T2
• WF Member Truss

Benchmark Structure C: CBOT T2
• Rectangular HSS Equivalent Truss 2:1 (Traditional)
• Rectangular HSS Equivalent Truss 2:1 (Casting)

Interface of Cast Component to HSS
• Issues of Modularity for HSS Trusses
  • Number of joined elements
  • Orientation angle of joined elements
  • Dimension of joined elements
  • Wall thickness of joined elements

• Interface Choices
  • Direct
    • one-to-one
    • variable thickness
    • variable section
  • Flat
  • Discrete angles (0, 30, 45, 60, 90)
  • Continuous

Appendix 2: B3b
Type of Cast Component in HSS

• Level 1 Solutions
  • cast collar, attachment, insert
  • minimizes main member pieces, cutting operations
  • traditional welded connections
  • supplements local strength to eliminate failure modes to (nearly) develop member strength
  • Ample fillet weld length due to casting shape

Level 1: HSS Cast Attachment

• Plane Truss Attachment:
  Flat Interface
  Chord stiffening and strengthening and sufficient weld length provided by arms

Level 1: HSS Cast Attachment

• Space Truss Attachment:
  Flat Interface

Level 1: HSS Cast Attachment

• Plane Truss Attachment:
  Direct Interface

Level 1: HSS Cast Attachment

• Plane Truss Attachment:
  Discrete Interface

Level 1: HSS Cast Attachment

• Inserts
• Diaphragms
**Level 2 Solutions: Interface**

- Full node placed between main member pieces
- Eliminate failure modes to develop member strength

**Weld Preparation Surface**

- Fillet welds
- Cast Bevel for FPW or PPW

---

**Discussion: Able Steel Fabricators**

- Fillet welds are the most desirable. They are economical, strong enough to develop the full member, easy, and no special inspection is required.
- Prep-work on circular members (fish-mouth) is more expensive than the bevel on rectangular members.
- Weld preparation is required on all full penetration welds and is expensive.
- When welding circular members to spherical shapes, preparation is needed to get a good weld. That is, the “bevel” may need to be beveled to get a good fit and a good weld.
- The square groove weld is a good weld but it likely requires special inspection which is expensive. The beveled type insert is fine for a weld, but the range of application may be limited because if the gap gets too large, unnecessary welds may have to be made to fill in the gap.
- It was suggested to use a casting such that the tubes fit inside so a fillet weld can easily be made around the outside.
- Castings would seem less economical for smaller trusses. The best opportunities are likely fish-mouth type connections on large or deep trusses.

**Level 2: HSS Cast Node**

- Section Specific 1:1
- Angle Specific

**PRO:**
- Strong Square Groove Weld

**CON:**
- Need predetermined structures

---

**Level 2: HSS Cast Node**

- Depth Specific
- Angle Specific

**PRO:**
- Range of thickness
- Easy fit-up

**CON:**
- Predetermined structures

---

**Level 2: HSS Cast Node**

- Angle Specific
- Decent PJP Groove Weld
- No obstruction from chord for weld access

**PRO:**
- Fits range of diameters and thicknesses

**CON:**
- Predetermined angles
Level 2: HSS Cast Node

- Fits Range of Diameters and Thicknesses
- Angle Specific
- Decent PJP Groove Weld

PRO:
- Better weld angle, less taper length

Level 2: HSS Cast Node

- Fits One Family
- Angle Specific
- Easy, Economical Fillet Weld
- Eliminates Eccentricities

Level 2: HSS Cast Node

- Each Connection Fits Four Families
- Angle Specific
- Easily Accessible, Economical Fillet Welds and PJP Welds
- No Connection Eccentricity

Level 2: HSS Cast Node

- Fits a wide range of sizes and angles
- Semi-Angle Specific
- Easy, Economical Fillet Welds
- Eliminates Difficult Branch Preparation (especially with round chords)
- Internal Stiffeners improve Behavior

Field-bolted alternative

Level 2: HSS Cast Node

- Fits a wide range of sizes
- Semi-Angle Specific
- Easy, Economical Fillet Welds
- Eliminates Difficult Branch Preparation (especially with round chords)

Appendix 2: B3b -8-
**Level 2: HSS Cast Node**

- Fits a wide range of sizes and angles
- Flare groove field welds

**Field-bolted alternative**

**Level 2: HSS Cast Node**

- Easily used for Space Frame

**Level 3: Enhanced HSS Cast Node**

- Fits a family of round HSS chords and any size branch at many angles
- Easy field connection
- Cast center plate for transverse bracing

**Space Trusses**

**Modular Castings: HSS Moment Connections**

**HSS Moment Connection Failure modes (after Packer)**

- Scenario where castings would provide a large increase in strength:
  - For generic moment connection, can be evaluated when \( b_0 \) and \( h_0 \) are large, \( \beta < 0.85 \), and \( h_1 > h_0 \)

For Example: 10”x10”x1/2” chord and 18”x12”x3/8” branch

\[ \beta = 0.75, h_1 > h_0, \text{to} = 32 \]
Conclusion: Cast Modular Parts for HSS

The potential seems to exist to lower the structure weight by:

- Eliminating failure modes
- More efficient connections
- Improving Effective Length
HIBLADE PROCESS

**Composition**

- HIBLADE on equal Y(10, 30/90)

**Strong Point**

1. **High Quality**
   - Confirmed earthquakeproof by experiment with life-sized specimen
   - Approval to HIBLADE and HIBLADE Process by the Minister of construction in Japan

2. **Shortening of Construction period and Reduction of Cost**
   - Reduction of steel work and welding

**Experiment with life-Sized Specimen**

<table>
<thead>
<tr>
<th>Tensile Experiment</th>
<th>Cross Framed Experiment</th>
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<tr>
<td>HIBLADE</td>
<td>Column</td>
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<tr>
<td>(□40)</td>
<td>Column</td>
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<tr>
<td>(□4 0)</td>
<td>Beam</td>
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</table>

**Result of Experiment**

- **Bending moment (kN m)**
- **Rotation angle (rad)**

High Rotative Distortion in plastic region

**Structural Design of HIBLADE Process**

- **Decision of Column and Beam Size**

\[
\begin{align*}
\text{Strength of HIBLADE} & \\
\text{Pa} & \equiv \frac{Ms}{h_b} \\
\text{Pu} & \equiv \frac{Mp}{h_b}
\end{align*}
\]

(Selective Diagram of HIBLADE)

- **Confirm Shearing Force for Allowable One**

**Process of Steel Work**

1. Assembling of HIBLADE and Wing Beam
2. Insert into Column
3. Welding of HIBLADE and Wing Beam
4. Welding of HIBLADE and Column
5. Welding of Column and Beam
6. Finish

**Example of Construction Work**

- **Column**: □550

---

Appendix 2: B4a
Economy of Time and Money

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<th>Process of Steel Work in Column</th>
<th>Traditional Process</th>
<th>HIBLADE Process</th>
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<tr>
<td>Welding</td>
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<td>○ (fillet welding)</td>
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<td>Ultrasonic flaw detecting</td>
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Cost

Composition of Super HIBASE PROCESS

- Steel column
- Expand Mortar "NX200"
- Anchor bolt "HAB" yield strength ratio ≥70% or less approved by the Ministry of Land, Infrastructure and Transport in Japan
- "HIBASE" on equal with SN490B(JHS) approved by the Ministry of Land, Infrastructure and Transport in Japan
- Anchorage plate
- Unbunded sleeve
- Washer

Type of "SuperHIBASE"

- For Square-shape steel column: □150~1200
- For Round-shape steel column: φ200~1000
- For H-shape steel column: H200~H900

High Rotative Distortion in plastic region:
by Anchor Bolt with Low Yield Strength Ratio

- Specimen: SuperHIBASE for □500, 8 Anchor Bolts
- Theoretical Maximum Strength: 167.4 tf - m
- Rotation angle: 1/25 rad

Anchorage of Anchor Bolt

- By Concrete in Foundation
- By Rising Reinforcement in Foundation

Appendix 2: B4a
Route 1

Calculate the stress of structural flame with numerical value of rotative rigidity in column base, and check the stress for allowable stress in every parts. If pin-connected column base is used in design route 1, the stress can be obtained by other method.

Route 2

Column base with ultimate resistant force ($M_u \geq \alpha \cdot M_{pc}$)

Route 3

Confirm $M_u$ for $\gamma$ times the stress resulted from seismic force

Confirm the ultimate horizontal resistant force for necessary one with $D_s$ added 0.05

Confirm $M_u$ for 2 times the stress resulted from seismic force

Confirm the ultimate horizontal resistant force

Confirm the ultimate horizontal resistant force for necessary one with $D_s$ of structure IV

Appendix 2: B4a -3-
Seismic Bracing Systems

Three types of seismic bracing systems are common currently:
- Special Concentric Braced Frame (SCBF)
- Eccentric Braced Frame (EBF)
- Buckling Restrained Braced Frame (BRBF)

Seismic Bracing Systems

Fabrication
Seismic Bracing Systems

Performance Issues: CBFs
• Net Section Fracture at gusset slot
• Fracture at center of brace
• Buckling of Gusset Plate
• Tearing of Gusset Plate due to bent racking

Performance Issues: EBFs
• Pure “Shear” Fracture along link
• Fracture of weld connecting girder flange to column

Seismic Bracing Systems

Issues that affect modularity:
• Different Member sizes
  • Column
  • Beam/Link
  • Brace
• Different Orientation
  • Bays: 20’-30’
  • Floor to floor heights: 13’-18’
• Full Bent vs Centerline of Bent
• Concentric vs Eccentric trajectory
• Member depths

Issues that affect modularity (con’t):
• Different Force Conditions:
  • Force:
    • Axial Tension/Compression only
    • Moment
    • High Shear
  • High Shear and Moment
  • High Shear, Moment and Axial
• Different Boundary Conditions/Needs
  • Fixity vs Pin OK
  • Accommodate Frame Racking
  • Out-of-plane compliance
  • Concentric vs Eccentric
  • Fit up/Erection/ Tolerance

Level 1 Solutions
• Fits a family of sizes for square or round HSS
• Improved force transfer

Level x Solutions
• Fits a family of sizes for square or round HSS
• Easy field bolting
• Possible shear key to reduce bolting requirements for slip-critical conditions
Level 2 Solutions

- Fits large range of column and beam sizes
- Braces would have a special pin adapter (CBF or SCBF)
- No weld prep to columns, same beam prep
- All shop welds

Level 1 Solutions

- Reduces brace length by 1/2
- Braces would have a pin adapter (CBF or BRBF)
- Possible K reduction
- Shop weld, Field Bolt

Seismic Bracing Systems

The relative advantages and disadvantages of each type of seismic bracing systems are:

- Special Concentric Braced Frame (SCBF)
  - Stiffest
  - Most straightforward
  - Least ductile

- Eccentric Braced Frame (EBF)
  - Mode is very ductile
  - A lot of fabrication

- Buckling Restrained Braced Frame (BRBF)
  - Design for the tension strength
  - Able to use pins

Seismic Bracing Systems: Configurations

The preferred configurations of each type of braced frames have to do with architecture and post-buckling modes among other things:

- Special Concentric Braced Frame (SCBF)
- Eccentric Braced Frame (EBF)
- Buckling Restrained Braced Frame (BRBF)

Level x Solutions

- Fits a family of sizes for square or round HSS
- No cuts, No net section reduction at full P
- All shop fillet welds

Seismic Bracing Systems

The seismic bracing systems involve:

- A lot of fabrication, particularly EBFs
- Are critical structural members
- Performance issues
Seismic Bracing Systems

Fabrication

Level 2 Solutions

- Link is cast in symmetric halves and bolted together at inflection point
- Shear carried by replaceable plate inserts, bolted to the ends of the link
- Design required connection strengths using shear plates (many thicknesses available), not node capacity
- Can fill any gap with spacers or possibly grout (with bonding agent)
- Braces have a range of acceptable angles (provided brace can be miter cut)

EBF Example

1 ½” Plate required for shear
2 - ¾” plate spacers
3” gap in node
Gap should be filled with grout or intermediate spacers

Level 1 Solutions

Alternatives for brace end if casting isn’t used

- 4 L’s welded or bolted to a gusset plate
- 2 T’s welded or bolted to a gusset plate
- 1 WF (provided tubes fit in “T” distance)

Alternatives for brace end if casting is used

- Connect 4 tubes (2 pair) to cruciform shaped casting at beam-column connection (could bolt or weld)
- Can slide pairs in from transverse direction and they will sit on the cruciform
Fifth Session: Industry-guided Activities

1. Industry-guided Activities (Group): (2:30 pm – 3:15 pm)
   a. Prototype Structures/Designs
   b. Constructability/Feasibility/Castability Studies
   c. Economic Studies
   d. Trial Implementations

Sixth Session: Working Session on Seismic Braces

Open Working Session for Topics A-E (as required): (3:15–4:15pm)
   a. Research Thrust C: Seismic Applications
   b. Research Thrust D: Facilitated Erection
   c. Research Thrust E: Revisit Initial Concepts

Final Session: Consensus

Consensus on Applications for Development (Group): (4:15 pm – 4:30 pm)

Conclusion (4:30 pm)

These modular connection concepts represent an initial set of designs for the use of castings to facilitate steel construction. These individual designs will be modified, pursued or abandoned or new designs will be developed based on industry input.
Research Workshop - Cast Steel Modular Connections
Hilton Airport, Kansas City, MO.
July 9, 2004

Participants
Tom Schlaflly, American Institute of Steel Construction
Raymond Monroe, Steel Founders Society of America
Robert Fleischman, University of Arizona
James O. Malley, Degenkolb Engineers
Gary Storm, Ellerbe Becket Engineers
David Eckmann, OWP&P Architects
David McKenzie, SPI International
Gary Bond, Ellerbe Becket Engineers
Kristi Roberts, Turner Construction
Harold Sprague, Black & Veatch
Hideshige Matsuo, Hitachi Metals (Japan)
Mark Holland, Paxton & Vierling Steel Company
David Lidberg, Havens Steel Co.

Viji Kuruvilla, Genesis Quality Systems
Dave Poweleit, Steel Founders Society of America
Jeff Packer, University of Toronto
David Bleiman, Rutherford Chekene Engineers
Gary Bond, Ellerbe Becket Engineers
Scott Metzger, Hills and Carnes
Mike McArthur, Bratton Corp
Ben Barnett, HOK
Bruce Marshall
Mitsu Kusumoto, Hitachi Metals (Japan)
Fred Palmer, Steel Tube Institute
Bob Elmore, ACME Structural

Workshop Minutes

Viji Kuruvilla (VK) started the meeting at 9:05 AM with introductions of each participant. He then detailed the workshop objectives, which includes endorsing the research direction; prioritizing and finalizing the applications for cast modular component prototype development in specific construction categories. The primary sponsor AISC was acknowledged. VJ then introduced Robert Fleischman (RF) to lead the meeting.

PART 1: OVERVIEW (9:10 AM)
RF provided a brief overview of the workshop agenda. The primary topics of focus for the workshop were outlined, that being the use of casting for steel construction applications for: (1) HSS; (2) Bracing systems; and (3) Seismic design. RF acknowledged the industry partners, AISC, Steel Founders Society of America and National Science Foundation.

1.A Summary of Past Research
Background information on this project, previous projects and ongoing parallel efforts were presented in this session. AISC and SFSA were independent partners on RF’s previous project. AISC and SFSA then began discussions to find common applications for R&D, leading to this research. The presentation also included a review of concepts developed for RM #1 and a description of the first implementation of a modular construction framing system recently developed by ConXtech.

1.B The Casting Process
Raymond Monroe (RM) provided background on the casting process. Main points included:
- The steel casting process has improved significantly in recent years
- One can provide components similar to rolled steel from a metallurgical standpoint by using soft carbon steel in the casting process.
- Cast steel can be quenched and tempered.
- Castings, even those that look very complex, are typically an easy item to produce.

Bruce Marshall (BM): What about architectural coatings? For instance, can the same profile be achieved when specified to an SSPC-6?
RM: Standard castings provide a shot blast finish. Other finishes require additional labor and with it the associated added costs.
The second morning session pertained to the use of cast components for HSS: current use was first reviewed; then the cast modular HSS connection research opportunities were discussed.

2.A The use of castings in Europe and Canada

This session was led by Jeffrey Packer (JP), an international authority on tubular construction, in particular the connecting of tubular members. JP provided a history of the use of castings in Europe and Canada. The presentation detailed several large projects in which cast steel components were used to produce aesthetically pleasing structures. These included cast steel designs of:

− Montreal’s Olympic Stadium in 1972, a facility that is still in great use.
− The CDP Capital building in Canada in which the geometry is capable of being duplicated.
− Several bridges in Germany of span lengths between 240-300 meters completed in 2000.

JP listed the steps involved in developing designs and design guidelines for cast components, and the groups responsible, in particular CIDECT: (European) Design guidelines for tubular connections. Rich information on castings for bridges has been produced in Germany.

The typical casting components used in these applications:

− The steel used for castings S 355, Cast Steel (GS 18, GS 13 Mn Ni 64, GS 20 Mn 5 V)
− The diameter-to-thickness ratios used include: (9.2 to 11.1, 12.6 to 23.1; 9.2 to 11.1)
− Tree-type components (T-Y-K) are often used for supports in bridge construction

JP concluded with a discussion of the economics involved in using cast modular components. The costs of cast steel connections become economical when heavy connections are used. A useful resource, the article “To cast or not to cast” (2003 Itnl. Symp. on Tubular Structs.), was referenced.

2.B Cast applications for Hollow Structural Sections (HSS)

RF presented the research on cast modular components for HSS. The presentation occurred in three parts: (1) comparisons of benchmark planar and space trusses using traditional connections and cast modular nodes as developed by the UA research team; (2) Cast modular HSS connecting concepts including nodes and attachments, and at discrete or variable angles; and (3) Weld interface details including sleeves, butt joints and collars. The benchmark comparisons indicated that potential weight savings could be realized by replacing traditional HSS truss connections with modular forms that eliminate connection failure modes, thus bringing design unity ratios near to 1.0. Discussions followed on the advantages and disadvantages of using cast attachments versus nodes, and the preferred weld interface on the basis of soundness, modularity, and ease of construction.

DISCUSSIONS:

Applications –

David McKenzie (DM): When considering the difficulty in TYK joints, it seems the cast steel option is a good choice that would provide value and easy fabrication.
- Cast Nodes will eliminate the TYK welding problem
- Connections are a huge part of the cost of long span roofs

Harold Sprague (HS): would like to see the research get into blast resistant design: strain rate effect ~ 4 milliseconds such as tested at the army materials research laboratory in Aberdeen; the HSS form is excellent for these situations provided the connections hold – castings are currently not being considered

DM: Food processing plants use HSS beams because you can’t paint the back of the angles. A tube-to-tube shear connection using cast attachments would be very useful.

RM: Would like to see cast steel in special projects. Not enough research done yet for use.
Industry Acceptance –
TS: The two industries speak different languages; use different business models; different production sequences; different expectations. What is the best way to overcome this? What tolerances will work for each group, etc? There is a real need to define the product.
RM: Need to overcome the lack of awareness in the industry of the options available
• The parties involved in building construction will need cross-the-board education
• Contractor needs fabricator knowledge/experience to make informed decision
• Contractor likely needs talk to foundry up front
TS: A needed exercise is –
• Fabricators talk w/ foundry
• Go through the dialog
• Create a “primer”

Economics
TS: This approach won’t be competitive for routine tasks- it will be tough to beat the cost of a shear bar. A special need situation is required: significant labor relative to engineering need; seismic design; high-end architecture
DM: There’s a lot of labor built into the T-K-Y cost
TS: We tried to do small economic study on the material & labor costs for HSS T-K-Y – it was difficult - not everyone is familiar with requirements, 6TR, etc. – so replies that indicated little improvement may have been due to lack of knowledge of the process.
• Couldn’t get proprietary information
• Dave Poweleit (DP) to work with us on pricing
• Will the costs come down?
JP: Need to refer to the article “To cast or not to cast”
• Rough rule of thumb – when labor costs 5x material, a casting is competitive
RM – per lb cost: 1$/lb – off the shelf
• Also save the cost of drawings

Design Process –
Mark Holland (MH): How do I start the design process to select cast steel over steel?
For instance, this cast modular node concept for round HSS long span truss:
• How to design it?
• Who will manufacture it?
• What are the scheduling considerations?
See “Component Qualification”, “Manufacture” and “Availability” respectively for responses.

Component Qualification
MH: For instance, what about punching shear caused by cast attachments?
RM: Finite element analysis will be done to evaluate the component.
RF: The development would involve optimizing the casting for all failure modes.
MH: If the cast steel modular component can provide the strength, can first principles applied for steel construction be sufficient to move forward with designing connections?
RF: Two types of cast modular component design options are envisioned:
• Pre-qualified: Standard off-the-shelf items from family of connectors in catalogs
• Custom (case-by-case): specifications and qualification testing protocol provided
Specifications will include:
• inspection requirements
• qualifying of the welders (cast nodes)
• material grade: Casting specs: A27, A418 – being modernized
• A/E casting specifications
Manufacture –
**RM:** There are about 10 foundries
- 8-16 lot piece
- Large capabilities: 10,000 lb for one piece

Scheduling (Availability) –
**MH:** How can you assure the cast steel part is available for our use when needed?
**RM:** What are the fabrication cycle times?
**TS:** Ten weeks
**RM:** Castings can make a 10-week delivery time – some additional time:
- 3-4 weeks tooling
- 3-4 weeks to cast
- 8 weeks total + administrative lead time
- Off the shelf core boxes will save 4 weeks

MH: What about subtle differences in designs?
**RM:** Flexible tooling can be used effectively for the casting-to-tube welding design
**RM:** It is critical that the most common scenarios are selected, so that eventually the components become catalogue items: Get it off the shelf
- Atlas foundry would be able to come up with a catalogue item.
- If you have a master tool and core box, it would only take 4 weeks.
- Rapid prototyping is used to decrease the amount of time in pattern making

Transfer to practice
*Tom Schlafly (TS):* Knowing how to make these connections to provide adequate strength and ductility is good. Quality issues such as internal soundness of cast steel can also be handled. But there are a lot of other issues we have to look into in the course of bringing this product to market: fabrication and evaluation methods, acceptance criteria, welding issues etc.
**RM:** Further, we need to address how to deal with marketing issues.
*Dave Bleiman (DB):* At least in the beginning, the use of the cast components must be part of the project at an early stage – and likely it would have to be a large project.

Fitting/Erection/Aesthetics
**RM:** The modular connectors can be bolted or welded in the shop.
**RM:** From an aesthetic/cleanliness standpoint, prefer cast node inside the tube (others in the room preferred the tube inside the casting); But if casting attachments are outside on both elements, how is it going to be erected?
*Dave Eckmann (DE):* HSS is typically used in exposed situations and thus aesthetics are extremely important for the architect; the cast node must maintain the clean and pure look.
**DE:** For this reason, the added cast attachment approach takes away from primary objective.

Weld interface –
A full penetration weld in conjunction with the cast modular node in effect pre-engineers the difficult portion of the design:
- The load is more defined
- Inspection is required for full penetration welds: 90 degree corner groove weld
- Design community may not want to be restricted to complete penetration welds
- Partial penetration welds may be more appropriate
Develop test criteria to perform the WT – D1.1 qualification
Inspection –
  RM: NDE is performed after the casting process
  Occurs over a range of specifications
  - Radiography
  - UT the inside of the joint
    o Offshore: common to UT joints
    o ATLAS foundry: involved w/offshore
    o rare to UT tapers
    o Irregular castings don’t typically use ultrasound

Tolerance –
  Node: gets rid of mill tolerance of HSS
  ERW – inside: 7/8” to 1 1/8” variation

Case studies –
  Kristi Roberts (KR): Case study on Kemper Arena in Kansas City would provide coverage
  - KR worked on Kemper
  - Architectural exposed structure
  - Many cast connections
  - round tubes, square tubes, WFs
  - asymmetric building
  - Helmut Jahn – architect
  - Structural engineer?
  O’Hare International Airport
  - Saddle points (architect AESS)
  - cut the tubes way back
  - 300 belt sanders
  Miami international airport
  - Pipe trusses

Benchmark HSS Structures -
  Gary Bond (GB): Every project has different complexity. We should take couple of projects to start building member families:
  - Shopping mall and other small projects
  - High rise projects, Roadways, communications
  Mark Holland (MH):
    - 3 stage delivery system: Three different delivery systems
    - Large projects with complicated nodes – Architects contact the engineers for options
    - Steel fabricator with a project having repetitive connections:
      o Sell on the use of cast steel nodes
      o Standard tubular truss implementation
      o Create a jig for prep work
  Trusses: Lot of fabrication work in the truss making would be combined through a modular approach, though symmetry not always present. Details may repeat one time or 16 times. How would this impact the schedule and cost?
  Jim Malley (JM): Need to start with a class of standard trusses
  - Common relationships: larger chord than branch (e.g. 10”x8”)
  - Standard angle: 30 deg; 45 deg
  Mark Holland (MH): Create standard McMaster Catalogue entries for getting cost information, capacity (10”x8”)

Appendix 2: B5
Consensus –
The discussion session resulted in the following consensus for cast modular components for HSS:
1. Focus on planar and space trusses of regular geometry
2. Maintain the architectural feel of smooth contoured surfaces.
3. Develop a catalog of standard set of components
   i. shape
   ii. interface
   iii. prototype
   iv. cost analysis
4. Components are to fit typical conditions
   i. Start with Standard truss geometries
   ii. Typical diagonals
   iii. Regular chord (10”) to branch (8”) member size ratios
   iv. Standard Angle: 30 deg; 45 deg
5. Develop node configurations rather than cast attachments
   i. Nodes for exposed
   ii. Attachments for hidden
   iii. AWS D 1.1 thickness transition (1:2.5)
6. Preferable interface detail is the single depth/diameter; variable gage detail.
   i. Direct branching with variable thickness
   ii. Direct branching with variable section

Sequence
1. Identify Representative structures
   i. Rohn Telecommunication Towers – Harold Sprague
   ii. Miami Pipe Trusses – David McKenzie
   iii. Missouri DOT - Harold Sprague
2. Examine connections
   i. Dream: take a “pile of clay” – mold into a piece of steel with beneficial features
3. Conduct Exercises (SCCC)
   i. Kemper Arena: tube – cost exercise: fabrication and casting
   ii. Fabricators go through the dialog w/ foundry to create a “primer
   iii. Designer/Foundry
   iv. Total Costs: Fab vs. Cast
4. Perform FE analysis
5. Optimize the design
6. Perform experiments
   i. Proof tests
   ii. Fatigue tests (CIDECT guidelines)
7. Trial implementation
   i. AISC find site?
   ii. SFSA identify foundry
8. Create families to cover standard cases
   i. Create standard catalogue entries to provide cost information, capacity
   ii. Beat the bushes – go back to

LUNCH (12:00 PM)
PART 3: MODULAR SEISMIC BRACING SYSTEMS

The first afternoon session, focusing on seismic systems, began with a presentation by Dr. Hideshige Matsuo and Mitsuo Kusumoto of Hitachi Metals on their cast seismic components, HIBLADE and HIBASE.

3.A Castings for seismic systems in Japan

Mitsuo Kusumoto (MK), Hideshige Matsuo (HM):

In Japan, 20% of steel construction uses cast steel connections. Two successful cast products, the HIBLADE and HIBASE, are covered here:

**HiBlade** –

Column-to-beam connection
- Cast connecting part
- Shortens construction period
- Reduces costs
- Provides high plastic rotation capacity

Modularity:
- Family of Sizes
- Fits all standard column sizes
- Separate top and bottom pieces to fit range of depths

Construction Sequence:
- Shop assemble Hiblade and wing beam
- Shop weld Hiblade to wing beam
- Insert on column
- Field weld Hiblade to column
- Field weld beam to column

Economy of time and money:
- Only partial penetration welds are required.

**HiBase** –

Column base
- Square and round shapes and H-shape steel column
- High plastic rotation capacity through anchor bolt with low yield strength ratio.

Components:
- Steel Column,
- Expand Mortar “NX 200”,
- Anchor Bolt “HAB” (Yield strength ratio: 70% or less)
- Hi base on equal with SN 490B

Construction Sequence for Anchorage to foundation:
- Structural design of column base (Route 1,2,3)
- Formation of anchor bolts – parts, brackets, fixing of lower shape plate.
- Filling of expand mortar: (Quick 3, filling, finish)
- Fastening of anchor bolt: (marking, fastening, finish)
3.B The use of castings for Seismic Bracing Systems

RF presented the research on cast modular seismic bracing system, including the benchmark structures (plans, details) and concepts that are being used. Dave Bleiman presented some of his concepts for cast components for SCBF systems. Jim Malley and Dave Bleiman discussed the pertinent issues for these systems:

- Special Concentric Braced Frame (SCBF) – Tensile>>compressive
- Buckling restrained braces (BRBF): tension ~ compression
  - braces, columns, foundations – all smaller
- Eccentric Braced Frame (EBF)
  - becomes little heavier in applications.
- Connections need to be stronger than the member for seismic applications.

Discussions followed on possible approaches to a modular seismic bracing system.

DISCUSSIONS:

Seismic Bracing Systems

SCBFs

Jim Malley (JM):
- Special concentric brace frame is not necessarily the most ductile system, but is the cheapest system out there.
- Gusset plate extends a large portion of the floor-to-floor height

Dave Bleiman (DB):
- Gusset plates get to be 5’ to 6’0 long

JM: Structural Performance
- Post buckling behavior is an issue - zipper columns, etc.
- Gusset plates have experienced tearing, buckled due to frame racking
- Net Section fracture at member slot

Robert Fleischman (RF): Cast components can potentially improve structural performance by:
- Eliminate gusset buckling or tearing
- Problem details can simply be eliminated

Raymond Monroe (RM):
- Don’t cast gusset plates – this type of geometry produces a poor casting.

DB: Alternate Ductile CBF connections:
- CBF gussets can be replaced by pins
- Cast clevis with ADAS device

Mike McArtor (MM):
- You need a way to grab the connections for erection – place to put drift pins.
- For the erection of braces, you need something keep it there until you come back:
  - For a fast erection process you would want to put in some bolts and move on
  - You cannot normally start weld at that point.
- What about hole mismatching. How would you bring those members together?
- What would happen if the brace or the collar slips?

Dave Bleiman (DB):
- There are a number of different ways to approach the gusset plate to beam and diagonal brace system.

Tom Schlafly (TS):
- It could be a pin connection or could be other parts.
- Off the shelf items should be available
EBFs
- Modular Link
- Modular Brace node
- Column/Brace/Beam interface
- Column bases for WF full moment capacity
- Transitions/Splices

**JM:** Base plates, adding stiffeners to provide moment capacity. Lots of fabrication dollars into the base plate. That could be an area for cast steel.

Cast the components with accessories (bracing connections, anchors): the more things you can get for free, the better.

**Modularity**
Need to consider meeting a number of sizes

**JM:**
- We should compare it to what it takes to fabricate in labor and material in steel vs. cast.
- There could be a family of parts can be made in cast steel.
- Consider retrofit vs. new construction

**Other Special Design Cases**
Progressive Blast resistance using Castings
- Moment frame scenario for steel buildings
- SMF w/Side plate/blast
- Side plate connections are bad (It is a welded connections)

*Harold Sprague (HS):*
- For instance in Albuquerque, Moment frames for steel buildings\Blast resistance guide lines\Special moment frames\Missouri DOT Signage structures

**PART 4: Summary/Consensus/Action Items**

**General Questions:**
- In every project, erectors face erection problems when wrong piece are erected. How do you deal with the different scenarios?
- How about accidentally knocking one member off from the connection? Safety issues, OSHA issues?
- How about availability of modular connectors for fabrication due to changes?
- How about quality of castings? How could these parts provide confidence to the owners and users?
- How about testing criteria on welds? Should we look into developing test criterions?
- What if they made a mistake and damaged a cast steel member, how would you replace it in a tight schedule construction?
- Can cast steel part provide a capacity chart?
The late afternoon session involved review of discussion and consensus on each topic and creation of a list of action items. The conclusion reiterated by the group was that tubular trusses (planar and space), as well as eccentrically braced frames possess the foremost potential economically and architecturally. There may be a strong interest in developing family of cast steel connections that can be used in tubular truss fabrications. The majority of traditional trusses utilize medium-to-small diameter/width tubular members, thus providing natural relationships for developing a catalog. Eccentrically braced frame links require a vast amount of welding and fabrication that could be eliminated by using a cast link.

The discussion session for cast modular components for HSS resulted in the following consensus:
1. Focus on planar and space trusses of regular geometry
2. Maintain the architectural feel of smooth contoured surfaces.
3. Develop a catalog of components to fit typical conditions
4. Develop node configurations rather than cast attachments
5. Preferable interface detail is the single depth/diameter; variable gage detail.

The discussion session for cast modular seismic bracing systems resulted in the following consensus:
1. Focus on eccentric braced frames first, then concentric braced frames
2. Develop EBF designs based on set link lengths
3. Develop designs for central links and end (column) links
4. Develop designs for the brace-to-column and beam-to-column connections as these also require an immense amount of fabrication and field welding.

The action items coming out of the workshop were: (1) develop a catalog of cast connectors fitting a wide range of lengths, depths and loadings for tubular planar and space trusses; and, (2) develop cast modular connectors to improve the reliability and reduce fabrication in seismic bracing systems.

The workshop concluded at 5pm. Viji Kuruvilla is thanked for organizing the workshop. Tom Schlafly is thanked for sponsoring the workshop. The participants are thanked for generating stimulating and thoughtful discussion regarding the opportunities for steel cast components in steel construction. These people’s interest and participation are responsible for the success of the workshop.

The meeting minutes were taken by Viji Kuruvilla and edited by Robert Fleischman. Attempts were made to capture the essence of the conversation and may not be verbatim. If in reviewing these notes you find errors, please feel free to contact us so we can make the corrections.