MODERN STEEL CONSTRUCTION

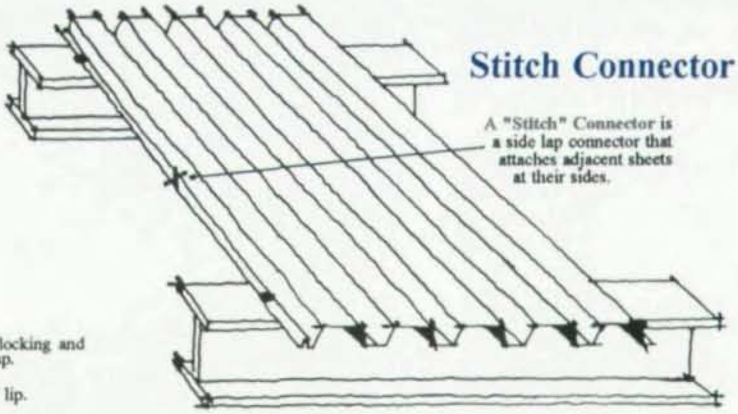
February 1995

$3.00

Heat Straightening

deck connection terms

Stitch Connector

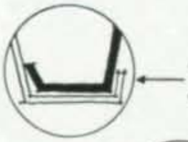


A "Stitch" Connector is a side lap connector that attaches adjacent sheets at their sides.

Side Lap Types

- *Common names include:* interlocking, button punch, and bayonet side lap.
- Can be button punched, welded, or screwed.
- Horizontal return on "female" lip.

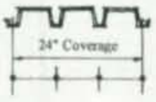
- *Common names include:* interlocking and button punch and bayonet side lap.
- Can only be button punched.
- No horizontal return on "female" lip.



- *Common names include:* overlapping, barge and foot, and nestable.
- Can be welded or screwed.

- Provides adjustment when required.

Typical Frame Fastener Layouts
for roof deck



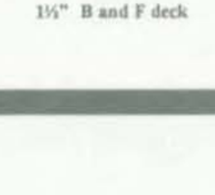
24/4 pattern

3" N deck

- **Note:** In general the nomenclature is "cover width"/(number of welds).

30/6 pattern
30/4 pattern
30/3 pattern

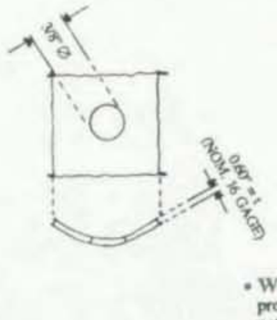
1½" B and F deck



36/9 pattern
36/7 pattern
36/5 pattern
36/4 pattern
36/3 pattern

1½" B and F deck

Welding Washer



- Welding washers are to be used on deck products lighter than 22 gage (0.028"). Do not use welding washers on side laps.

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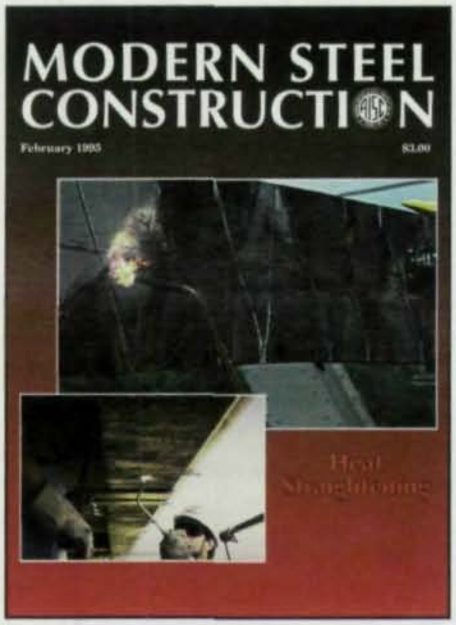
MODERN STEEL CONSTRUCTION

Volume 35, Number 2 February 1995



Heat straightening can be a useful and economical alternative for repairing damaged steel. A report on the science of engineered heat straightening begins on page 32.

Features

Departments

Modern Steel Construction (Volume 35, Number 2). ISSN 0026-8445. Published monthly by the American Institute of Steel Construction, Inc., (AISC), One East Wacker Dr., Suite 3100, Chicago, IL 60601-2001.

Advertising office:Facinelli Media Sales, 2400 E. Devon Ave., Suite 257, Des Plaines, IL 60618 (708) 699-6049.

Subscription price:
Within the U.S.—single issues $3; 3 years $85.
Outside the U.S.—single issues $5; 1 year $36; 3 years $100.

Postmaster: Please send address changes to Modern Steel Construction, One East Wacker Dr., Suite 3100, Chicago, IL 60601-2001.

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Combining Work With Play

A MAJOR BROUHAHA IS BREWING AT AISC. ON ONE SIDE ARE THE TRADITIONALISTS—the extremely serious engineers who are constantly trying to expand their capabilities and improve their skills. On the other side is a more laid back group who realize that while the fabricated structural steel community is important, there are other things that are just as important.

No, I'm not talking about LRFD and ASD. Believe it or not, I'm referring to the National Steel Construction Conference. And, in my opinion, both groups should be able to happily co-exist.

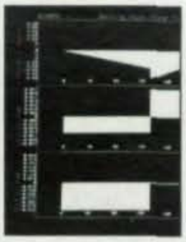
The first group is the traditional NSCC attendee. He wants to get up at 6:00 in the morning, meet some colleagues for some shop-talk, and then hit the seminars—non-stop until 6:00 that evening. And then he wants to meet with some more colleagues to talk about the latest engineering or fabrication trends. The second group is the rest of us. Yes, we want to hear interesting and informative seminars. And yes, we want to be able to meet and network with our colleagues. But we also want to bring our families and combine business with pleasure.

Fortunately, this year's NSCC should provide the perfect meeting ground for both groups. Yes, the show will feature the usual menu of wonderful seminars and lectures on such subjects as: how to reduce structural steel costs; new concepts in industrial building design; designing connections for structural tubing; how to protect your firm from lawsuits; improved fabrication equipment & methods; new flame straightening technology; and avoiding field painting failures. And it will provide time and opportunity for engineers, fabricators, detailers, contractors, educators and architects to get together and discuss their industry. But unlike last year's show in Pittsburgh (a nice place to live, but let's face it, not one of the top vacation destinations in the U.S.), this year's NSCC is being held in the major tourist destination of San Antonio. So in addition to the many educational opportunities at the conference, there also is the opportunity for sightseeing and family fun—ranging from the history of the Alamo to the excitement of Splashtown Water Park.

Complete programs were mailed with this issue to all Modern Steel Construction subscribers. But if you didn't get one, just call 312/670-5420 or fax a note to 312/670-5403 and AISC will be happy to send one out to you. Registration is only $320 ($270 for AISC members) and you should make your hotel reservations by April 16.

I hope to see you on the Riverwalk in May. **SM**

How to get from here



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to here.

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Steel Interchange is an open forum for *Modern Steel Construction* readers to exchange useful and practical professional ideas and information on all phases of steel building and bridge construction. Opinions and suggestions are welcome on any subject covered in this magazine. If you have a question or problem that your fellow readers might help you to solve, please forward it to *Modern Steel Construction*. At the same time, feel free to respond to any of the questions that you have read here. Please send them to:

Steel Interchange
Modern Steel Construction
One East Wacker Dr., Suite 3100
Chicago, IL 60601-2001

Answers and/or questions should be typewritten and double-spaced. Submittals that have been prepared by word-processing are appreciated on computer diskette (either as a Wordperfect file or in ASCII format).

The opinions expressed in *Steel Interchange* do not necessarily represent an official position of the American Institute of Steel Construction, Inc. and have not been reviewed. It is recognized that the design of structures is within the scope and expertise of a competent licensed structural engineer, architect or other licensed professional for the application of principals to a particular structure.

Information on ordering AISC publications mentioned in this article can be obtained by calling AISC at 312/670-2400 ext. 433.

The following responses from previous Steel Interchange columns have been received:

Specifications currently exist which require minimum pretensioning loads for slip critical connections. There is, however, no guidance regarding minimum pre-loading of anchor bolts which occur at column bases. While in most situations this issue is academic since the anchor bolt nut and thread projection are below the plane of the concrete slab on grade and are eventually embedded in concrete at the slab isolation joint, there are instances where the nut and thread projection remain exposed. Is tightening the nut to "snug tight" and tack welding the nut to the bolt thread the only solution in preventing the nut from backing off?

In general, anchor bolts are selected from material meeting ASTM A307 specifications. A307 specifications require material that conforms to the A36 specification. The lower strength of this material compared to high-strength bolts, such as A325, does not lend itself to high pretension loads for a given bolt diameter. When your anchor requirements call for resistance to high tension or conditions where slippage due to shear is not permitted then pretensioning using high strength bolts may be used. Other methods, such as shear keys may be used to prevent slip. High-strength anchor bolts are heat treated and quenched which increases their load carrying capabilities. A307 bolt material is not treated and therefore cannot be expected to produce high, consistent preloads for a given bolt diameter.

In most cases anchor bolts are used in locations where a small clamping force in conjunction with the combined friction from deadweight and or shear keys is all that is required to resist the occasional shear and tensile forces. The design tension loads at column bases are usually a result of large wind forces that the structure seldom experiences with the presence of large dead loads. Therefore, the net tension that the anchor bolts experience does not exceed the clamping force that results from "snug tight" tightening of the nuts. Kulak, Fisher, and Struik in their book Guide to Design Criteria for Bolted and Riveted Joints indicate that this clamping force from "snug tight" nuts in A307 anchor bolts is not very great and should not be considered to have any influence on the connection design. The preloads that result from "snug tight" nuts on A307 bolts are usually in the elastic range (somewhere in the sloping portion of the stress-strain curve) where minor variations in the starting point, amount, and accuracy of the nut rotation have a greater influence on the amount of preload. On the other hand, pretensioning high-strength bolts to the specified values actually stretches the bolt (called set) and produces a large, constant clamping force that is basically unaffected by the conditions at the starting point of nut tightening (snug tight).

Tall, lighter structures where large lateral and tensile forces frequently occur depend on their anchor bolts to carry tension and prevent upward or horizontal movement at the foundation interface. Other examples would be anchor bolts used for large equipment foundations, such as paper machine foundation anchor bolts. In these cases, high-strength anchor can be specified and pretensioned to resist any large dynamic and thermal loads. These loads can produce large, lateral forces that are present at all times. These "slip critical" connections are designed to prevent any slip which can cause misalignment in the precision equipment. These anchors are usually pretensioned to meet the equipment supplier' specifications.

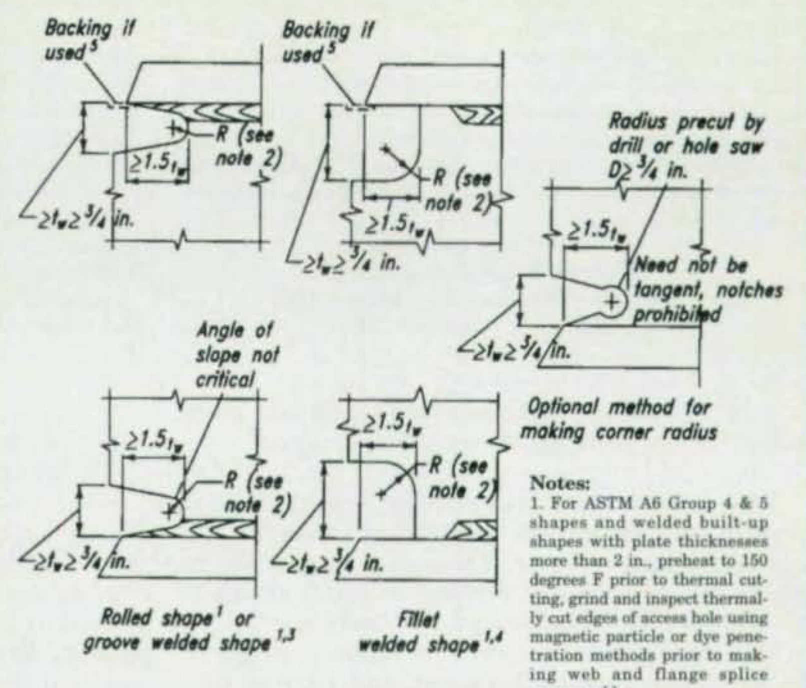
Another method of preventing loosening of a "snug tight" anchor bolt nut (besides tack welding) is to furnish two nuts and torque the second nut against the first nut.

Robert R. McGlohn
Rust Engineering Company
Birmingham, AL

STEEL INTERCHANGE

The AISC Manual includes examples and figures in the connection sections, some of these connections include weld access holes in the beam member. What are the dimensioning requirement for these weld access holes? They are not given in the example problems.

All of the examples and details in the manual follow the requirements of the AISC Specification for Structural Steel Buildings. Section J1.6 of the LRFD Specification and Section J1.8 of the ASD Specification include requirements for beam copes and weld access holes. These dimensioning requirements are for all weld access holes and copes. The commentary to each section includes drawings which demonstrate this weld access hole and cope geometry. The figure at right is repeated from the AISC Commentary.



Notes:
1. For ASTM A6 Group 4 & 5 shapes and welded built-up shapes with plate thicknesses more than 2 in., preheat to 150 degrees F prior to thermal cutting, grind and inspect thermally cut edges of access hole using magnetic particle or dye penetration methods prior to making web and flange splice groove welds.
2. Radius shall provide smooth notch-free transition; R greater than or equal to 3/8-in. (typical 1/2-in.).
3. Access opening made after welding web to flange.
4. Access opening made before welding web to flange.
5. These are typical details for joints welded from one side against steel backing. Alternative joint designs should be considered.

NEW QUESTIONS

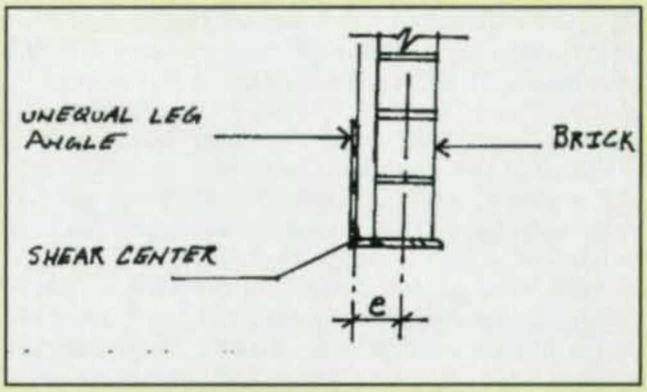
Listed below are questions that we would like the readers to answer or discuss.

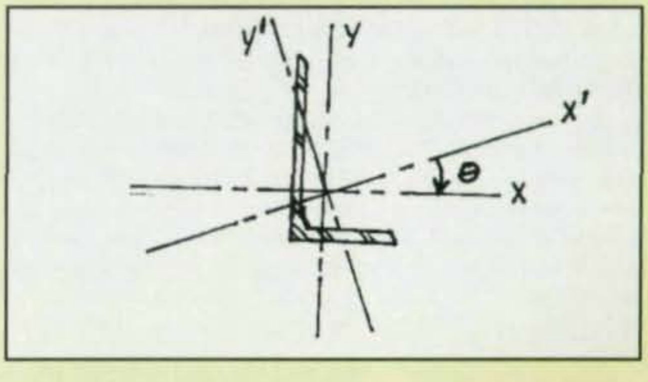
If you have an answer or suggestion please send it to the Steel Interchange Editor, Modern Steel Construction, One East Wacker Dr., Suite 3100, Chicago, IL 60601-2001. Questions and responses will be printed in future editions of Steel Interchange. Also, if you have a question or problem that readers might help solve, send these to the Steel Interchange Editor.

Is the method of determining the flexural design strength of a single angle with unequal legs as outlined in the Specification for Load and Resistance Factor Design of Single-Angle Members, (December 1, 1993) valid when the angle is not loaded through its shear center?

If the method is valid, what effect does the load eccentricity to the shear center have on the flexural strength?

If the method is valid and M_n has been determined about the principle axes, should the moment (M_u) about the x-axis be broken into its components about the minor and major axes by multiplying the moment (M_{ux}) by the sin θ or by cos θ?





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CHAPARRAL STEEL

This bi-monthly column deals with legal matters of interest to designers, fabricators and contractors. We solicit your comments, concerns, suggestions and questions, both as to individual issues and subjects that you would like to see treated in this column. Some of the issues that we plan on covering in the future include: contract provisions; OSHA standards; employment law; alternative dispute resolution; and dealing with the EPA. Comments should be sent to: Modern Steel Construction, One East Wacker Dr., Suite 3100, Chicago, IL 60601-2001.

YOUR WORST NIGHTMARE

"Mr. Jones, there are two people in the lobby to see you. Mr. Reich from OSHA and Ms. Blau from the EPA," your receptionist says over the intercom.

You put down the phone, take a deep breath and prepare to go out to the lobby to face the regulatory equivalent of an earthquake, flood and fire. For most people, an OSHA or EPA inspection is the health, safety and environmental regulatory equivalent of an IRS tax audit. The odds of having either are about the same. But while no responsible businessperson would even think of not paying taxes or keeping tax records, there are still some businesses owners that think they can afford to attempt to avoid compliance with OSHA or EPA regulations. If you are prepared, you will survive the unpleasant experience. If not, it can literally put you out of business. Indeed, for some health, safety or environmental violations, it can put you in jail.

In preparation for a possible inspection, you should take several steps.

•First, you have to become familiar with and come into compliance with the substantive health, safety and environmental requirements that apply to your operation. Admittedly, this is no small task since these regulations are constantly expanding and being revised at the Federal level, which sets off a ripple effect at the State and local levels. Keeping up with these requirements can be particularly difficult for small businesses. Fortunately, help is out there. Various publishing houses (such as Thompson, Government Institutes and others) have generalized compliance guides. More focused are the educational bulletins and other materials issued by AISC and other trade associations. In addition, AISC is sponsoring a series of environmental compliance workshops around the country in 1995 (more information will be available on these workshops at a later date—fax 312/670-5403 for info). Also, the EPA has a small business ombudsman (800/368-5888), as well as hotline numbers for specific environmental issues.

•Second, you should ensure that your record keeping system is in place and organized. One of the most fertile areas for OSHA citations is your paperwork. Both OSHA and EPA have countless regulations requiring written plans; every regulation requires records to be kept and many require certifications—of plan adequacy, of training held, and of qualifications of individuals. This mass of paper should not only be organized and tamed, it should be cleansed regularly. For example, some EPA regulations require you to keep records for three years. In certain instances, older records, if maintained, can be the basis for a non-compliance citation. (Care should be taken here, as this class of record can sometimes prove your compliance.) Beyond the records required to be kept are those audits, minutes of health, safety and environmental meetings, notes, memoranda, and similar papers in the file that are generated in the normal course of business. These impulses need to be muted, since they can be used to show you knew of a problem, an unsafe condition, or environmental emission, but failed to take action. Your files should include a paper trail—a written response—that shows why a certain suggestion was not adopted, why some proposal was impractical, infeasible or unnecessary. Finally, you should have a records retention policy and system. Periodically, clean both your hard copy and electronic files.

•Third, you should ensure that your employees have receive mandated train-

Kenneth G. Lee, Esq. os with the Washington, DC, office of Goldberg & Simpson, P.S.C., and concentrates in the area of construction law.

ing. One of the records you will want to have is a log of attendees at training sessions, a description of the subjects covered, who led the training, and the amount of time spend in the session. During the course of an inspection, an employee may be asked about training and give a less than desirable answer. Training logs, particularly with sign-in sheets, can rebut the erroneous impression given by such an employee's comment.

KEEP A BRIDLE ON YOUR TONGUE. MORE COMPANIES GET HUNG ON WHAT THE EMPLOYER SAYS DURING THESE INSPECTIONS, THAN ON THE RECORDS OR WHAT THE EMPLOYEES SAY

Once these steps are taken, you're ready for an inspection. You go out and greet Reich and Blau. Do you have to let them in? OSHA and EPA have recently announced a policy of "multi-media" inspections. A quarter of all inspections are targeted to be joint, multi-media in the near future. That means you may get both OSHA and EPA, and the EPA may have a specialist for just air, one for just water, and somebody else for SARA 313. Congress, in many of the environmental statutes, has given EPA the right of entry. In certain statutes, for example the Clean Air Act, refusal of entry is itself a violation of the Act, which can trigger fines and other penalties. For the OSHA inspector, on the other hand, you can demand a warrant. This is a company policy matter that you should consider. If the inspection is identified as part of a criminal investigation, immediately consult legal counsel.

After greeting Reich and Browner, they will want to have an opening conference. This will be the time to lay out the scope and nature of the inspection. A couple of important things to remember: More companies get hung on what the ***employer*** says during these inspections, than on the records or what the employees say. ***Keep a bridle on your tongue.*** Statements like, "Yeah, that's a problem we've been trying to fix," show both knowledge and failure to bring into compliance. Too often employers attempt to justify or explain away situations during the inspection. The inspection is just that, an inspection. The arguing about what it means comes later.

During the inspection, stay with the inspectors. Send prepared individuals with inspectors if you get a multi-media team. Keep a record of what is occurring—use a hand-held recorder, a stenographer or even a video camera. Take the same measurements, photographs, samples and other observations that the inspector takes.

After the walk-through, there will be a concluding conference. Again, be careful what you say. Refer to things observed as a "situation" or a "condition", not as a "problem." Do not agree when the inspector says that something is "unsafe," or "polluting" or a "violation." Remember, the inspection is to observe. The characterization of what is observed comes later, unless you have already agreed with the inspector.

There are a number of practical tips on how to survive an OSHA and EPA inspection. Because of the increased number of inspections planned by OSHA and EPA, the increased fines and penalties associated with these inspections, and because of the increased complexity of health, safety and environmental regulations, AISC has planned a series of 10 regional hands-on, one-day intensive workshops to assist companies in the steel production, fabrication and construction industries. These workshops will not only cover the regulatory requirements, but how to comply, providing hand-outs and workbooks that can form the basis for that compliance. Recognizing that these issues have Federal, State and local parameters, the workshops will be presented by recognized health, safety and environmental experts who can address all levels. AISC will present more information about these workshops in the coming months.

If prepared, at the end of the session you may hear (though it's unlikely): "Excellent facility, keep up the good work." Simply thank Reich and Browner and say: "Goodbye."

SHORT COURSE ON BRACING AND BUCKLING

AISC, IN CONJUNCTION WITH THE STRUCTURAL STABILITY RESEARCH COUNCIL, is offering a short course on *The Bracing of Steel Structures*. To be held in San Antonio immediately following the National Steel Construction Conference, the course includes five sections: Column & Frame Bracing; Lean-On Systems; Torsional Bracing; Beam Buckling; and Beam Bracing.

Faculty for the course includes Joseph A. Yura of the University of Texas—Austin and Todd Helwig of the University of Houston. The course begins Friday, May 19, at 5:30 p.m. and continues on Saturday at 8:30 a.m. through 11:30 a.m.

Cost for the seminar is $200 ($175 for AISC or SSRC members). For more information, contact Robert Lorenz at 312/670-5406 (fax: 312/670-5403).

The National Steel Construction Conference is scheduled for May 17-19 in San Antonio. In addition to its traditional audience of structural engineers and fabricators, the NSCC is opening its doors to construction managers in 1995. The conference will feature four professional tracks: Construction Management; Steel Fabrication; Structural Engineering; and Engineering Management. In addition, the conference will include a product exhibition with nearly 100 booths.

"We wanted to expand the conference to involve more of the construction industry," explained Franklin B. Davis, chairman of the AISC NSCC Committee and president of Precise Fabricating. "It's an exciting change that will put more life and spirit into the program."

While seminars are assigned to a specific track, show organizers stressed that there is no additional charge for crossing from one track to another. Registration for the show costs $320 ($270 for AISC members) and includes admission to all seminars and general sessions, as well as the trade show. To receive a registration packet, write AISC, One East Wacker Dr., Suite 3100, Chicago, IL 60601-2001 or call 312/670-2400.

Speakers this year include:

- Duane Miller (Lincoln Electric Co.) on welding inspections;
- Jim Scotti (Brown and Root) and Peter Van Nort (H.B. Zachry) on team building/partnering;
- David Harwell (Central Texas Iron Works) on bar coding;
- J.J. Suarez (Belcan) on quality management;
- *Eric S. Kline (KTA-Tator) and*

David Boyd (The Vulcan Group) on paintings and coatings;

- Ken Lee (Goldberg and Simpson) on recent EPA legislation;
- Jim Blackburn (Vernon Tool Co.) on hollow structural section fabrication;
- Tom Webb (Fibre-Metal Products Co.), Joe Derkitch (National Research) and James Morton on new developments in fabrication equipment and methods.
- R. Richard Avent (Louisiana State University) on flame straightening technology;
- Holley Fisk, Phil Fortune and Tag Wilson on how to protect your firm from lawsuits;
- Donald Buettner (Computerized Structural Design) on steel erection awareness;
- Bob Shaw (Steel Structures Technology Center), A.J. Julicher, and John T. Holcomb (Berlin Steel Co.) on the inspection of welded and bolted joints;
- Jim Notch (Notch & Associates); John Nagel (AFCO) and Jim Neil on reducing structural steel costs;
- Jim Rowland (Bethlehem Steel) on industrial buildings;
- Stan Rolfe (University of Kansas), John Bell (Nucor), and Peter Wright (Chaparral Steel Co.) on what structural engineers need to know about fracture mechanics, metallurgy and weldability;
- Michael Engelhardt (University of Texas); Tom Sabol (Englekirk & Sabol); and Jim Malley (Degenkolb Associates) on research applications of from the Northridge Earthquake;
- R.M. Korol (McMaster University) and Donald Sherman (University of Wisconsin) on new developments in using structural tubes.

New AISC Publications Phone Number

Beginning February 1, AISC will offer a new toll-free number for ordering publications. The new phone number is **800/644-2400**. AISC's main office number remains **312/670-2400**.

EXPRESSING THE STRUCTURE

A true design synthesis between architect and engineer resulted in a stunningly successful retail project in Florida

Exposed steel played an important role throughout the project, including the main entrance, corridors and courts.

By Robert P. Wingard, AIA, and Craig E. McElroy, P.E.

ALL TOO OFTEN, DESIGN BECOMES A TUG-OF-WAR BETWEEN ARCHITECTS AND ENGINEERS, with architects creating images and then expecting structural engineers to dream up some way to make them work. But with the Brandon Town Center, a new regional mall outside Tampa, the architect and structural engineer were clearly on the same side.

The new retail center, which opens this month, is an expansive new single-level retail center anchored by four department stores and a 650-seat food court. Nearly 1,800 ft. in length, the project occupies more than 175,000 sq. ft. in the public areas. Architect for the project was RTKL Associates Inc. of Baltimore and structural engineer was Paul J. Ford and Company of Orlando. Developer is Chicago-based JMB Retail Properties Co.

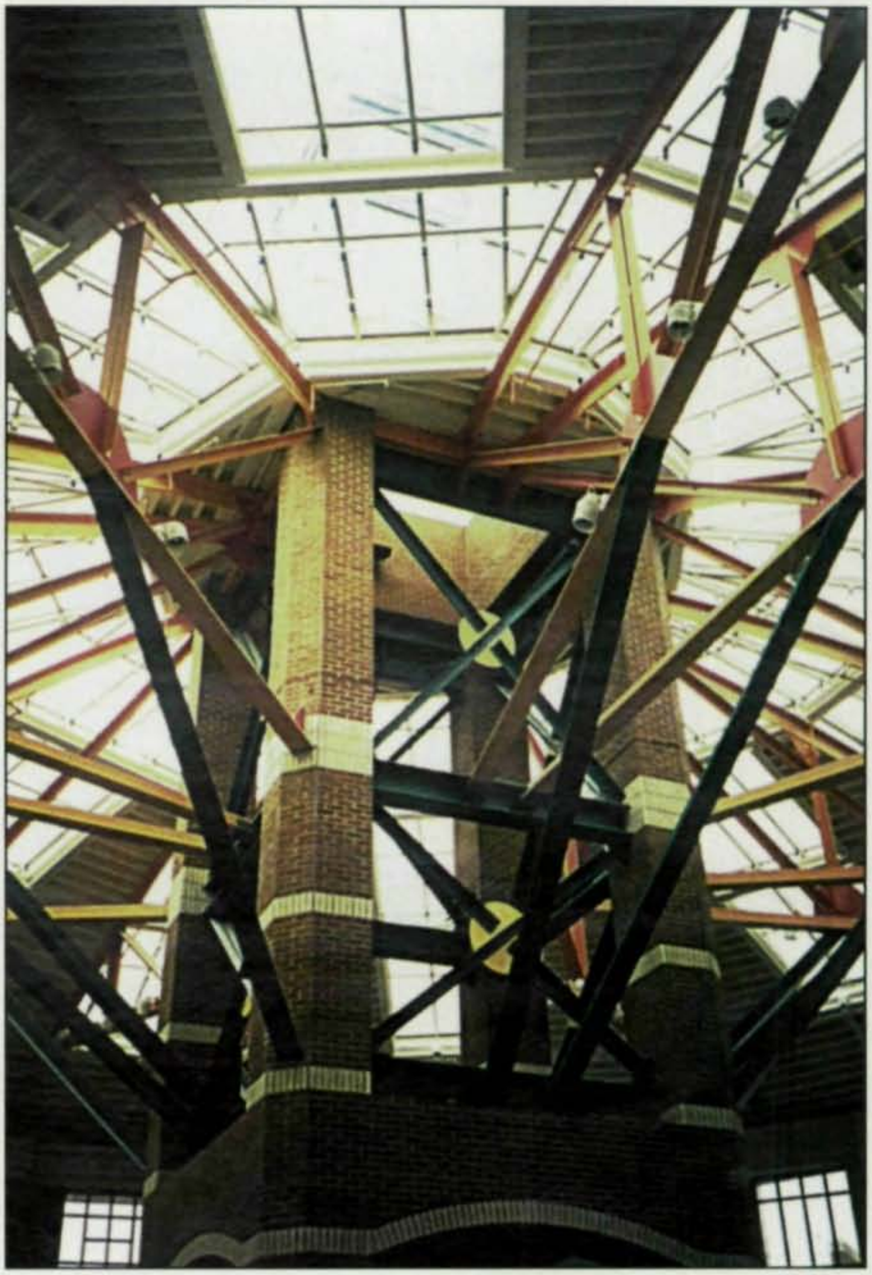
DESIGN CONCEPT

The city of Brandon is a rapidly expanding bedroom community east of Tampa along the developing I-75 corridor. Though only a half-hour's drive from the Gulf of Mexico in a part of Florida known as "cattle country", Brandon has the look of an inland town with its fairly flat landscape organized into expansive fields and forests. With palm trees the exception rather than the rule, white pointed church steeples poking above the trees, and red brick buildings instead of the normal pastel stucco and terra cotta tile expected in a Florida community, Brandon seems more like a northeastern village than a sun-drenched semi-tropical town.

It was this New England-like atmosphere that initially inspired the design for Brandon Town Center. The exterior of the project features four 60-ft. tall towers that link four barrel-vaulted roof segments to the large vaulted central court. A fifth tower, 76-ft. high, rises above the food court's segmented dome roof. Red brick, accented by bands of tan and white, along with standing seam roofing and exposed steel entry, complete the exterior.

The project's interior theme is loosely based on an industrial, factory-like concept. Dominant materials include red brick piers and column enclosures, combined with heavily stylized curved trusses and exposed structural steel painted off-white with light green accents. Initially envisioned as dark green, the steel was changed to the less industrial off-white color during design development to avoid giving the project too much of a factory appearance and perhaps misrepresenting it as a value-oriented or outlet center.

The original design also called for minimal visible connection detail between the stylized trusses and support members. As part of the design refinement, the architects and structural engineers worked together to achieve a more straightforward approach. Both disciplines agreed that the bold curvature of the trusses and the spaces beneath them would be even more successful if the structural design were simplified and the connections left exposed. To the architects, this became a "celebration" of the structure; to the engineers, it was an opportunity to share authorship for a large potion of the visible project design.



UNCOMMON APPROACHES

As with most shopping centers, the majority of the building is a warehouse-like space with few interruptions to the modular bays and basically flat roof. Framing for these areas is typically steel joists at 6-ft. on center supported by joist girders with 30-ft. bays at the tenant areas. The joists and joist girders are rigidly connected to the columns to provide moment frames for wind stability. Additional capacity is provided in bays pre-identified as locations for individual tenant rooftop mechanical units.

In contrast to the simple design of the tenant spaces, the public spaces provided a design challenge to the both the architects and engineers. These extra-high areas were designed to attract attention and feature varying individual section profiles and an emphasis on aesthetics—primarily expressed through an exposed structure.

Brandon Town Center's public spaces have seven different sectional profiles: typical (main mall) courts; end courts; department store side courts; central court; food court; tower courts; and entrance malls. Though similar in some aspects, each of these areas demanded a different approach to design, both of the space itself and the structure surrounding it.

For instance, in the typical (main mall) court, the lease line is straight on one side but curved on the other to create an asymmetrical layout. Mall width and structural span vary from 30 ft. to 48 ft. The section for these areas is asymmetrical as well, with curved trusses creating height at the straight side for clerestory windows and a lower flat ceiling at the curved side. The trusses are 4-ft. deep with cantilevered W36 beams at 30 ft. on center and $7^1/_2$-in. long span metal deck. Rather than vary the length of each truss to maintain equal distance from the lease lines, the profile of the truss was kept constant and the cantilevered length of the W36 beam became the variable. By allowing the more costly truss element to be repeated, this design was achieved more economically.

The end courts are similar to the typical courts with one major exception: The maximum span increases from 48 ft. to 50 ft. to provide room for a water feature. Here, the curved trusses were allowed to complete more of the arc, ending at a lower point than in their mall counterparts. This helped maintain the maximum height of the public space at the same level as the main mall, meaning that previously resolved architectural details and design issues (such as the relationship between hanging

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CHANNEL RINGS THE HARD WAY (X-X Axis)	INSIDE DIA.	10	**13" × 50 lb./ft. Channel**
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TEE RINGS STEM OUT	INSIDE DIA.	12	**12" × 81 lb./ft. Tee**
TEE RINGS STEM UP	MEAN DIA.	13	**10.5" × 83 lb./ft. Tee**
ANGLE RINGS HEEL IN	INSIDE DIA.	14	**8" × 8" × 1" Angle**
ANGLE RINGS HEEL OUT	OUTSIDE DIA.	15	**8" × 8" × 1" Angle**
ANGLE RINGS HEEL UP	MEAN DIA.	16	**8" × 8" × 1" Angle**
SQUARE & RECTANGULAR TUBE RINGS	INSIDE DIA.	17	**16" Square Tube** **20" × 8" Rectangular Tube**
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RAIL RINGS BALL OUT	INSIDE DIA.	21	**ASCE 100# Rail** **Bethlehem 175# Rail**
RAIL RINGS BALL UP	MEAN DIA.	22	**ASCE 100# Rail** **Bethlehem 175# Rail**

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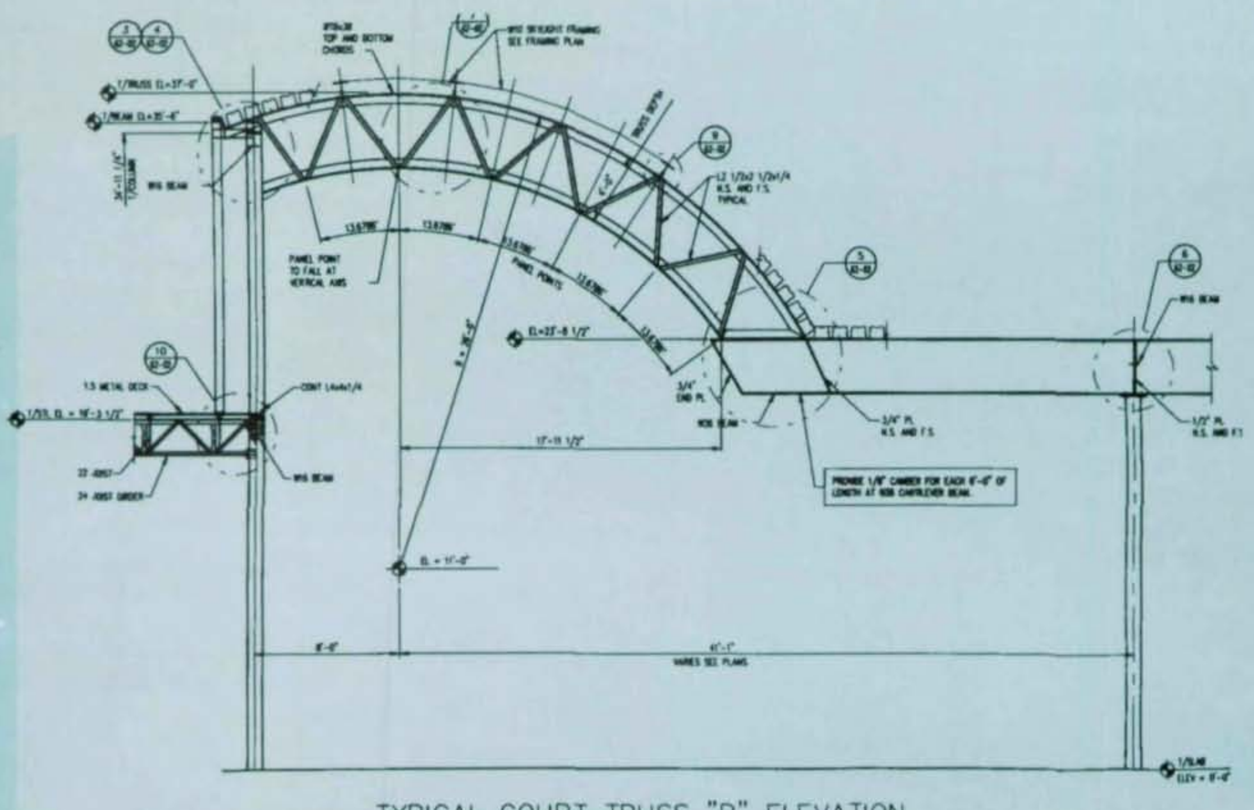


TYPICAL COURT TRUSS "B" ELEVATION
SCALE: 1/4" = 1'-0"

light fixtures, single-side only clerestory windows and tree sizes) did not have to change.

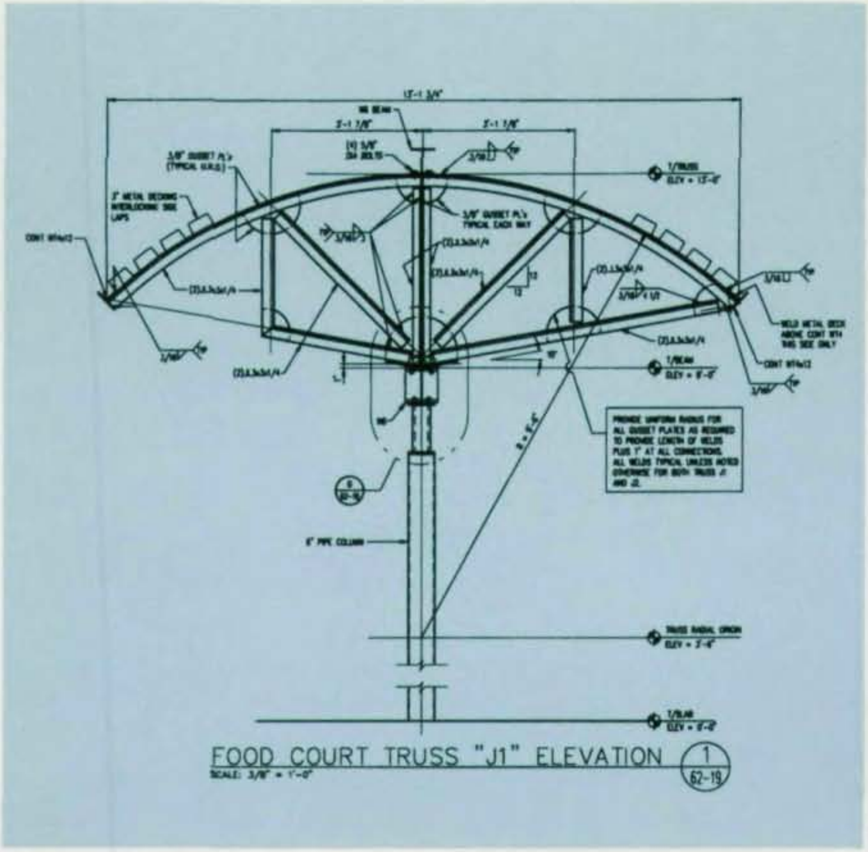
The two department store side courts are completely symmetrical in section and plan but retain the curved truss as part of the design. Here the trusses are carried by cantilevered W36 beams at both ends, which permit the same arc radius as the asymmetrical trusses and again promotes economy through repetitive components.

The 80-ft.-wide by 300-ft.-long central court is the most dramatic of the common areas and features a 60-ft.-high barrel-vaulted roof. The court is designed as the "heart" of the project—the place where special events and a variety of seasonal activities will take place. It also exhibits the most dramatic structural design as it fulfills the design requirements for a light and airy space that maximizes the feeling of height.

A prominent row of columns with 3-ft.-4-in.-diameter banded brick masonry enclosures marches through the space at the midpoints of the 80-ft. long trusses spaced 30-ft. on center. This combination of unique, umbrella-like trusses supporting the roof and the line of columns was conceived as a row of trees under a canopy of foliage. To further the concept, the columns are discontinued 14-ft. below the bottom of the trusses and branch out with "limbs" in the form of WT8x33.5 diagonal braces extending in two directions to support the trusses. A W16 beam running at the center of the trusses also is supported by WT8 braces to stabilize the entire structure for the 100 mph design wind velocity perpendicular to the span.

UNDER THE DOME

The food court is circular in plan with individual tenants arrayed along the circulation



path surrounding the large seating area. At the center, the tallest of the five towers punctuates the roofscape. The brick-clad food court tower also serves as the central support for 12 trusses that radiate outward to form the segmented dome roof over the vast seating area. Since this tower is square, all the trusses are attached at various angles, requiring careful coordination for a clear and logical fit with the masonry. At their outer ends, the trusses are supported by columns clad as brick piers in a curving masonry.

Another special feature of the food court is the exposed steel and metal deck min-canopy framing the individual food tenants. This miniature version of the central court structural scheme also provides a framework for tenant signage and lighting.

Up Above

Aside from the food court, there are four other towers. Two of these are triangular in plan and serve to introduce the department store side courts. The other two are square and join the typical (main mall) courts to the central court. All feature 60-ft.-diameter central skylight courts. To maintain unimpeded storefront visibility, the towers are wrapped with a 7-ft.- to 9-ft.-high brick masonry wall just above the court trusses and are completely visible through the shed-skylights the trusses support. Above the brick is glass curtain wall; the tower is capped by a pre-manufactured pyramidal skylight.

All of the towers were designed with a combination of X-bracing and moment connections for horizontal stability. With a maximum height of 76-ft., special consideration also was given to controlling drift during high wind velocities.

Connection Concerns

Since all of the connections in the common areas are exposed to view, they were designed not only for strength but for aesthetics. Most of the gusset plates are curved with a carefully designed, slightly oversized, radius. Bolt spacing and edge distances also were specified on the drawings. The connection details were so complete that the steel detailer, Southern Steel Detailers, was able to use the structural engineers' drawings, with only minimal modifications, as part of the shop drawings submittal.

Through this coordinated detailing of the visible connections, the engineer enabled the architect to control the appearance of the finished product with exceptional precision. In fact, as part of the overall interior color scheme, the gusset plates are painted in bright accent colors for emphasis and contrast.

Another benefit of the close attention to details was the smoothness of the fabrication and erection process, as well as numerous construction economies. General contractor on the project was the Hardin Construction Group of Atlanta and steel fabricator was AISC-member E&H Steel Corporation.

Project architect Robert F. Wingard, AIA, is an associate vice president at RTKL Associates Inc. and is based in the firm's Baltimore office. RTKL is a full-service architecture/engineering firm with a multi-dicipline staff of 500 and additional offices in Dallas, Los Angeles, Washington, London, Tokyo and Hong Kong. Craig E. McElroy, P.E., is project manager for Paul J. Ford and Company, structural engineers, with offices in Orlando, Atlanta and Columbus, OH.

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Bridges With Unequally Spaced Girders

A proposal to use refined analysis methods for calculating live load distribution factors would reduce costs by as much as 10% to 34%

By Yohchia Chen, P.E., Ph.D.

WHILE BRIDGE DESIGN IS TYPICALLY BOTH SIMPLER AND LESS EXPENSIVE WHEN EQUAL GIRDER SPACING IS UTILIZED, there are instances—such as staged construction during bridge replacement, widening of an existing bridge and utility constraints—where unequal girder spacing is required.

The simple formulas for estimating live-load distribution factors contained in the 1992 AASHTO code are intended for use with bridges with uniform girder spacing and generally result in conservative bridge designs, especially for bridges supported by W-shape girders. In contrast, the new bridge design code (1994 AASHTO-LRFD) would take advantage of refined analysis methods for predicting distribution factors.

These factors were recently shown, in a study by this author, to have particular advantages for bridges with unequally spaced girders. In this study, a finite element-based refined method was employed in an attempt to derive more accurate live-load distribution factors. Comparisons of maximum flexural distribution factors for interior I-shaped girders determined from various methods are shown on the opposite page.

Numerical Studies

Table 1 and Figure 1 summarize the bridge studies; bridge girders are summarized in Table

Table 1: Summary of Bridge Studies

Bridge Case	S1 (ft)	S2 (ft)	S3 (ft)	S4 (ft)	A (ft)	B (ft)
1	8	8	8	-	4	4
2	6	10	10	-	3	3
3	10	6	10	-	3	3
4	8	8	8	-	4	4
5	6	10	10	-	3	3
6	10	6	10	-	3	3
7	8	8	8	8	4	4
8a	6	6	10	10	3	5
8b	4	4	12	12	2	6
9a	10	6	6	10	4	4
9b	12	4	4	12	4	4
10a	6	10	6	10	3	5
10b	4	12	4	12	2	6
11a	6	10	10	6	4	4
11b	4	12	12	4	4	4
12a	4	4	12	12	2	6
12b	6	6	10	10	3	5

Table 2: Summary of Girder Sizes

Bridge Case	G1	G2	G3	G4	G5
1	W36x300	W36x300	W36x300	W36x300	-
2	W36x393	W36x393	W36x393	W36x393	-
3	W36x300	W36x300	W36x300	W36x300	-
4	W36x150	W36x150	W36x150	W36x150	-
5	W36x170	W36x170	W36x170	W36x170	-
6	W36x150	W36x150	W36x150	W36x150	-
7	W36x300	W36x300	W36x300	W36x300	W36x300
8a & 8b	W36x439	W36x439	W36x439	W36x439	W36x439
9a & 9b	W36x328	W36x328	W36x328	W36x328	W36x328
10a & 10b	W36x328	W36x328	W36x328	W36x328	W36x328
11a & 11b	W36x439	W36x439	W36x439	W36x439	W36x439
12a & 12b	W36x232	W36x232	W36x232	W36x232	W36x232

REFINED METHOD:

Equation One:

$$DF = \frac{N_L M_{comp}}{\sum M_{comp}}$$

where N_L is the number of loaded traffic lanes, M_{comp} the composite girder moment, and ΣM_{comp} is the total composite girder moment.

Equation Two:

$$M_{comp} = \sigma_{comb} S_{b,c}$$

where $S_{b,c}$ is the composite section modulus at the bottom of the girder and σ_{comb} is the combined stress at the bottom of the girder computed by:

Equation Three:

$$\sigma_{comb} = \frac{P}{A} + \frac{M}{S_{b,nc}}$$

where P is the axial load computed at the center of gravity (c.g.) of girder, M the bending moment at the c.g. of girder, A the cross-sectional area of girder, and $S_{b,nc}$ is the non-composite section modulus at the bottom of girder.

1992 AASHTO CODE:

Equation Four:

For interior I-shaped girders with N_L greater than or equal to 2:

$$DF_{int} = \frac{S}{5.5}$$

$$when\ S \leq 14\ feet$$

where S is interpreted as the "average" center-to-center girder spacing across the bridge.

1994 AASHTO CODE:

(For interior girders)

Equation Five:

$$DF = 0.5[0.15 + (S/3)^{0.6} (S/L)^{0.2}]$$

Table 3: Maximum Flexural Distribution Factors for Interior Girders

Case	1992 AASHTO (1)	1994 AASHTO (2)	Refined Method (3)	RF x (3) (4)	(4) / (1)	(4) / (2)
1	0.73	0.62	0.58	0.58	0.79	0.94
2	0.79	0.72	0.62	0.62	0.78	0.86
3	0.79	0.62	0.57	0.57	0.72	0.92
4	0.73	0.70	0.61	0.61	0.84	0.87
5	0.79	0.82	0.71	0.71	0.90	0.87
6	0.79	0.70	0.62	0.62	0.78	0.89
7	0.73	0.62	0.56	0.56	0.77	0.90
8a	0.73	0.62	0.48	0.48	0.66	0.77
8b	0.73	0.62	0.61	0.55	0.75	0.89
9a	0.73	0.62	0.54	0.54	0.74	0.87
9b	0.73	0.62	0.50	0.50	0.68	0.81
10a	0.73	0.62	0.56	0.56	0.77	0.90
10b	0.73	0.62	0.53	0.53	0.73	0.85
11a	0.73	0.62	0.60	0.60	0.82	0.97
11b	0.73	0.62	0.62	0.62	0.85	1.00
12a	0.73	0.62	0.62	0.56	0.77	0.90
12b	0.73	0.62	0.49	0.49	0.67	0.79

2. The bridges were assumed to be single span, simply supported and non-skewed.

In modeling a bridge system using the finite element technique, consideration must be given to the number of elements per span, aspect ratio (element length/element width) for quadrilateral element, relative vertical distances between the centers of various elements, and torsional stiffness.

In this study, the generalized shell elements that couple bending with membrane action were used to model the bridge deck/slab. The shell elements are proportioned so that the maximum aspect ratio always remains at two-to-one or less. However, for bridge girders and diaphragms (C15x33.9 applied at the end supports and quarter points), standard beam elements were employed. The bridge barriers were not modeled, though, since they have negligible effects on live-load distribution. Modeling efforts also were made to see how many elements are needed transversely and longitudinally. As a result, it is recommended that two transverse slab three different methods are summarized in Table 3. As can be seen, the simplified methods of lateral load distribution are generally more conservative, especially the method currently used (i.e. Equation 4), than is the refined method. Use of the refined method yields cost savings of 10% to 34% depending on the girder situation. The empirical formula adopted in the 1994 AASHTO-LRFD Code gives a good approximation for only about one-third of the bridge cases studied.

In conclusion, for bridges with non-uniform girder spacing, a refined analysis method is recommended for predicting lateral distribution of live loads. Significant cost savings also can be expected for the exterior girders. This proposed refined method is applicable to any bridge system.

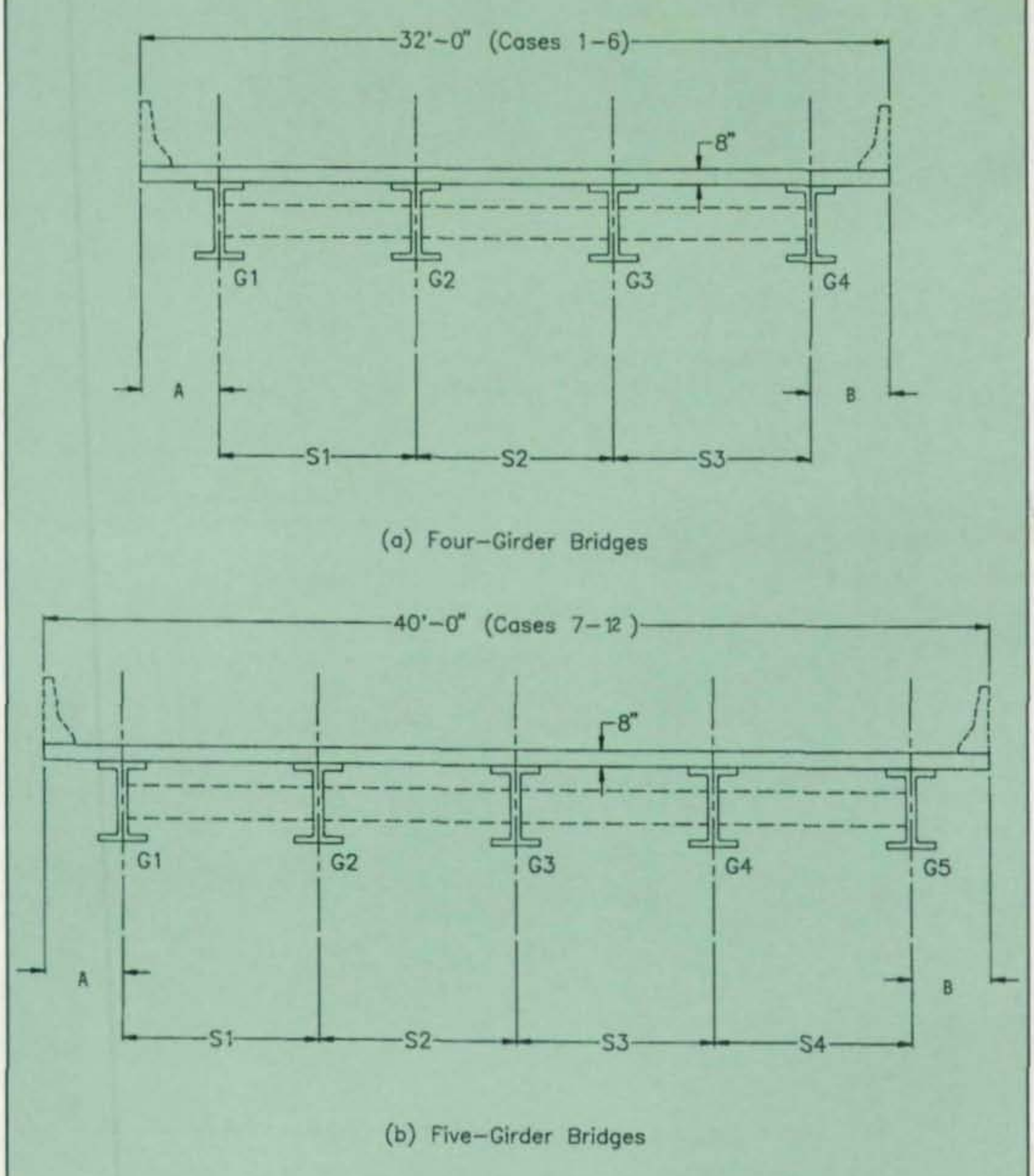

Figure 1: Overall cross sections of the bridge systems

elements between two adjacent girders and twelve divisions along the bridge span be used. The composite action between the deck and girder is affected by using the rigid links/elements attached at the c.g.'s of the structural components.

AASHTO HS20 trucks were tested on each bridge until the maximum flexural effect on girders was achieved. The following elastic properties were used:

E_{steel} (Young's modulus) = 29,000 ksi; υ_{steel} (Poisson's ratio) = 0.3; $E_{concrete}$ = 3,122 ksi; and $\upsilon_{concrete}$ = 0.17.

CONCLUSIONS

The maximum flexural distribution factors obtained from the

Yohchia Chen, P.E., Ph.D., is with the Department of Civil Engineering at PennState-Harrisburg. *Financial support for this study was provided by the University and bridge information was given by Dr. S. Tabsh.*

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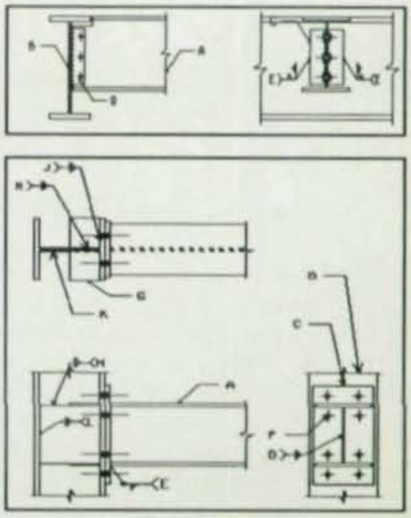

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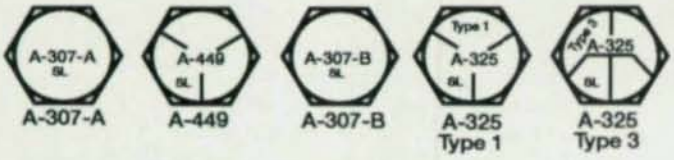

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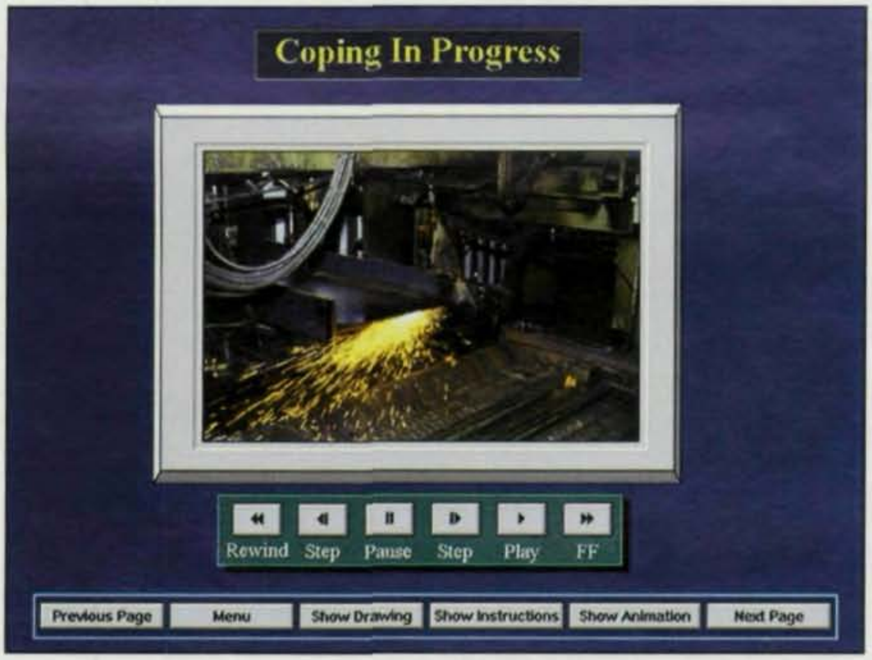
Multimedia Technology And The Steel Industry

By Abbas Aminmansour

Most fabricators and engineers have already made the initial leap into the computer world. Now, the steel industry must prepare itself for the next generation of tools: Multimedia. Many people are already familiar with some multimedia applications, such as the latest versions of the Sega and Nintendo Entertainment Systems, where full-motion video and audio is combined with the more traditional text and graphics of a personal computer.

But the benefits of multimedia go far beyond mere game playing. Multimedia programs may have the most capability as educational tools. For example, a multimedia program could be used for the initial training of an operator of new fabrication equipment or to help an engineer better understand connection design.

Typically, multimedia programs or applications are interactive, requiring user's involvement in the learning process. This interactivity along with potentials offered by the media used allow for better, easier, and longer lasting understanding and comprehension of the subject matter than traditional methods of education and training. The more senses of the user involved in the learning process, the better the understanding of the material. For example, seeing and hearing is a more effective way to learn than just hearing alone. In addition, being actively involved in the learning process increases this effectiveness even further. According to IBM, researchers believe that an average learner has short term retention of about 20% of what (s)he hears, 40% of what (s)he sees and hears, and 75% of what (s)he sees, hears, and does. Multimedia technology allows developers to take advantage of this fact as well as the flexibility, effectiveness, and innovations in a number of technologies to produce tools that enhance the teaching/learning process in a variety of fields.



Aminmansour is in the process of developing a multimedia program to teach structural steel design.. Shown above is a screen capture from the program's working model.

Multimedia applications allow active, individualized, hands-on learning, self-paced instruction and very close to real world experience. They allow random access, immediate feedback and automatic or manual review. Video segments, animations, and other forms of information may be reviewed as many times as necessary for the user to fully understand and comprehend the material.

A major advantage of the multimedia technology is that while it allows for development of more effective tools, the user need not know anything about the technology itself. A well designed and developed multimedia program is very easy to install and run. That is one reason why we see more and more of these tools appearing in such places as shopping malls, tourist information centers, museums, and automobile repair shops where the users are likely to be not familiar with computer and other technologies involved in multimedia. In fact, the casual user is often not even conscious of the fact that they are using a very sophisticated computer program when they touch a screen to view additional information on tourist sites.

While developing multimedia

programs is time consuming and expensive, the benefits are tangible and immediate. For instance, a learner utilizing a multimedia program will typically spend less time in training and becomes more productive earlier due to a better and quicker understanding of the subject matter. Also, there will be less use of equipment and material. Further, there is less chance of the worker potentially endangering anyone's life as a result of working with equipment that he may be totally unfamiliar with. Also, the multimedia teaching tool is ready for use by others continuously and without any change in its effectiveness or losing any of its benefits. As soon as one person is finished going through the material, the system is ready for the next person. Simply put, a right combination of this technology, instructional design, expertise in a subject matter, and creative minds could result in tools which not only improve learning and retention of a subject, but they do so in a more effective and entertaining way.

Multimedia has many potential applications in steel construction and related fields. It may be used to develop tools for education, from teaching the basics of engineering design to engineering students to refresher courses for practicing engineers and others. Students can now learn practical and real world issues during their education. For example, most college graduates may not even have had a chance to study a steel connection in detail. Some cannot recognize a partially restrained connection from a fully restrained one even if they saw one. All they might have seen in school are line drawings that represent these types of connections. Utilizing multimedia technology, tools can be developed that not only allow the students to see the details of a connection, but see for instance how the size and orientation of the joining members and elements affect the design, fabrication and assembly of the connection.

Another area in which multimedia technology offers great potential benefits is in training. Imagine workers learning how to carry out certain processes and procedures in a steel mill or learn how to operate new equipment or simulate different conditions including potentially dangerous ones, before even touching the equipment for the first time or using any material. Or how about training workers for safety issues in the job environment and updating their knowledge periodically with minimal expense and effort.

Multimedia can also be combined with other useful technologies for easier and more effective ways to access or present information. For example, you may have online access to many resources such as codes, references, and design aids including tables, charts, plots, etc. right at your fingertips while working on your computer. Data bases, case studies, and other useful information may be accessed in different formats for quicker solutions to problems. An example of use of multimedia technology in research is showing actual

ELECTRONIC PUBLICATIONS

Some fledgling multimedia efforts are already available for structural engineers and fabricators:

• Last year, AISC introduced LRFD on CD to accompany the new 2nd Edition LRFD *Manual of Steel Construction*. LRFD on CD includes, page-by-page, the entire manual. It's advantage is that key words are hypertext linked, which allows a user to double-click on one word and immediately find other references elsewhere in the manual. In addition, powerful search functions are available to quickly locate any word or equation in the Manual. And finally, the CD-ROM includes complete copies of each issue of Engineering Journal published in 1992 & 1993 as well as more than 50 drawings (.dxf files) taken right from the manual. For information on ordering the CD, call 312/670-2400 (after February 1, call 800/644-2400) or for more information circle number 10 on the reader service card in the back of this magazine.

• The monthly *Journal of Protective Coatings & Linings* has issued JPCL Archives, a CD-ROM featuring the first 10 years (120 issues) of the magazine. Users can search by any combination of key words, authors, article titles and issues. For more information, contact: JPCL, 2100 Wharton St., Suite 310, Pittsburgh, PA 15203-1951 (phone 800/837-8303) or circle number 97.

• The National Institute of Building Sciences offers a series of disks containing standards and technical information from more than 125 government agencies, professional societies, and associations, including AISC, AWS, ASTM, and FHWA. The information is available for an annual subscription fee of $970; contact NIBS at 1201 L Street N.W., Suite 400, Washington, DC 20005 (phone 202/289-7800) or circle number 98.

behavior of a member or system in the form of video while displaying the theoretical or predicted behavior of the parts along with the pertinent formulas, plots, and other information at hand. The possibilities are simply many. Just think about what you do in your profession every day, and very likely you can think of some of those tasks that can be performed more effectively using multimedia technology.

While running a multimedia program, the computer serves as a control center and the software provides the capability to manage the direction, type, and speed at which the information is being presented. In response to the user selecting menu items, pushing buttons, or responding to questions, the program may displays certain information or make intelligent decisions as to what should happen next.

In terms of hardware, it takes very little to run a multimedia application. Typically, the recommended minimum system configuration for running multimedia software is a 386-33MHz (or equivalent) computer with four megabytes of Random Access Memory (RAM)—though a 486 or faster system with at least eight megabytes of RAM is much preferred. Playing audio files requires a sound card and speakers, but in most cases, video files may be played without any additional hardware requirements. Needless to say, running large video segments in large windows and with high frame per second (fps) counts and high resolutions and more colors will require a heftier machine.

Due to their relatively large size, most multimedia applications are distributed on CD-ROM's. Consequently, a CD-ROM drive may also be necessary to run such programs. However, today, CD-ROM drives are very common on new computers and fairly inexpensive to add to existing ones (usually less than $300 for a double speed CD-ROM drive with sound card and speakers). Additional requirements, such as display and hard disk size requirements depend on the specifics of the multimedia software to be used.

Most computer vendors now offer "multimedia capable" systems in pre-configured packages. While the cost of such systems depends on their particular configuration, quality, and capabilities, today one can buy a basic system with the capability to run basic multimedia applications for about fifteen hundred dollars or less. Obviously, more requirements and better quality and capabilities can rise the cost up to several thousand dollars for a system.

While running multimedia programs takes fairly little, developing one requires much more time, money, and know-how. However, it seems like the cost of computer hardware and software keep going down every day while their capabilities go up. Still, developing multimedia programs is a major task which should not be taken lightly.

There is good news, however. We all do not need to spend lots of time and money developing our own multimedia programs. After all, most of us use books, references, software, and other aids developed by others and find them easy and economical to use. Multimedia applications should be viewed the same way as other tools we currently use. The point to remember is that we should not hesitate to utilize multimedia and other technologies in our work when appropriate.

Abbas Aminmansour is president of Hybrid *Information Technologies in State College, PA and a faculty member with the Architectural Engineering Department at Penn State University. He is currently developing a multimedia program to help students learn about steel design (a working model was previewed at last year's National Steel Construction Conference.)*

ENGINEERED HEAT STRAIGHTENING COMES OF AGE

Established procedures for heat straightening result in safe, reliable and economic repairs

Figure 1: Vee heat in progress at the Mississippi River bridge near Greenville, MS.

By R. Richard Avent, P.E.

HEAT STRAIGHTENING OF DAMAGED STEEL HAS PROBABLY been a part of the fabricator's tool kit since the invention of the oxy-fuel welding and cutting apparatus. Reported repairs extend at least 40 years into the past. The process, however, has remained primarily an art, learned by trial and error in the fabricating shop, and passed from one craftsman to the next. In addition, a small number of contractors have specialized in the art of heat straightening and travel the world to perform emergency repairs on damaged structures.

While engineers have appreciated the work of the more competent craftsmen, the lack of a clear scientific basis for the method has limited its use.

Until recently, scientific information on heat straightening has been limited. The engineering criteria that did exist was often found in obscure sources and sometimes provided contradictory information. As a result, engineers faced with the dilemma of selecting the most viable repair scheme for damaged steel structures tended to avoid heat straightening. Two key questions have been consistently voiced: Do heat-straightening procedures exist that do not compromise the structural integrity of the steel? And, if so, how can such repairs be engineered to insure adequate safety of the structure both during and after repair?

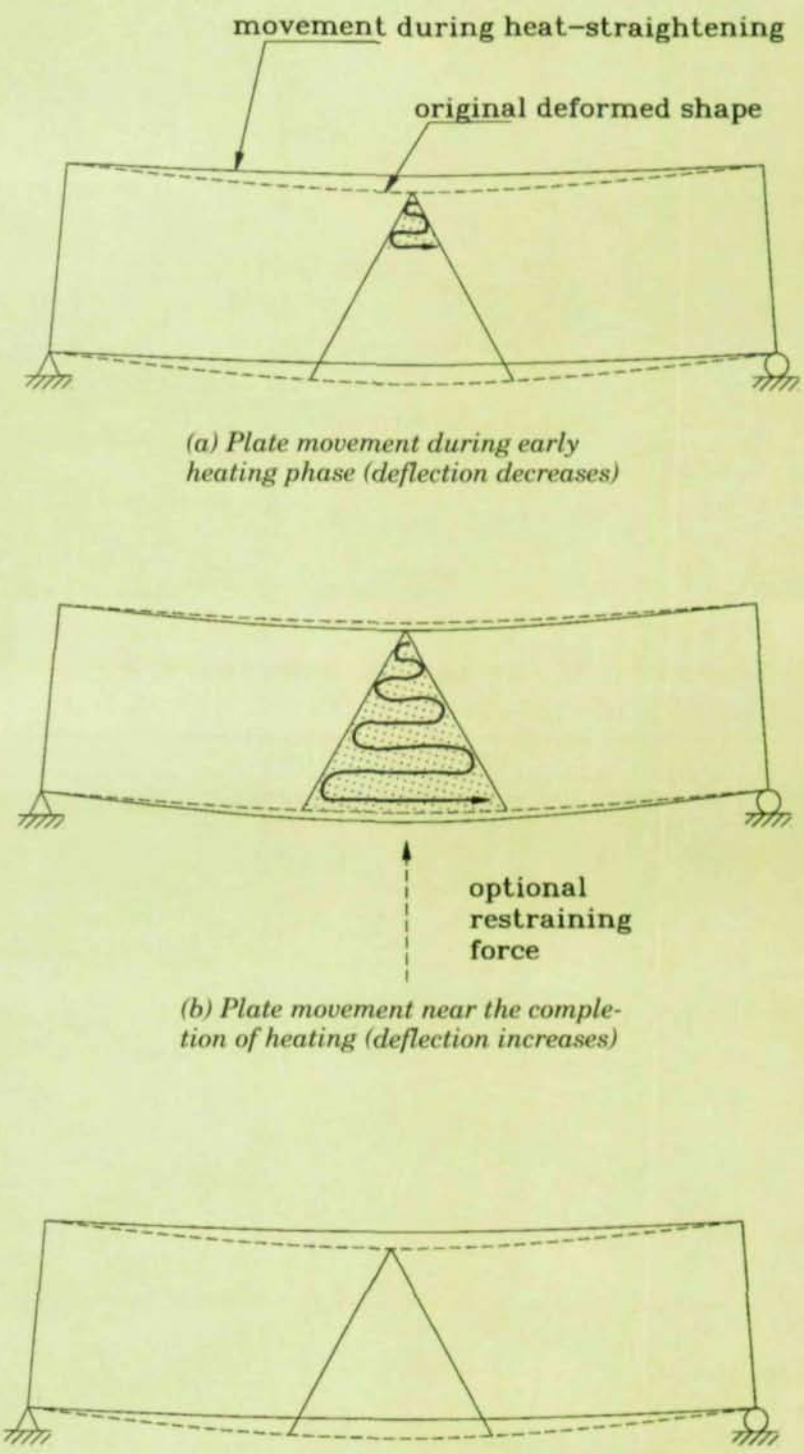
I have been conducting analytical and experimental research on heat straightening since 1985. As a result of more than 1,000 bench scale tests on small rolled shapes, 20 full-scale girder tests and several field repairs, a protocol for heat straightening repair has been established.

Basic Concepts

Structural damage typically consists of a combination of strong and weak axis bends of the plate elements forming the rolled or built-up shape. Vee, strip, and line heats are the fundamental heating patterns with vee heats playing the dominant role. The plate element in Figure 2 illustrates the process. The heating begins at the apex of the vee with the torch gradually moved across and down the vee in a serpentine motion so that the entire vee area is eventually heated. Heats in progress are shown in Figure 1.

The basic mechanism of heat straightening is to create plastic flow, causing expansion through the thickness (upsetting) during the heating phase, followed by elastic longitudinal contraction during the cooling phase. This upsetting can be accomplished in two ways. First, as the heat progresses toward the base of the vee, the cool material ahead of the torch prevents unrestrained longitudinal expansion of the heated material leading to upsetting through the thickness. However, as illustrated in Figures 2a-b, some longitudinal expansion does occur, which results in a temporary change in displacement (decreasing at beginning of heat, and increasing near the end of heating). After cooling, the net degree of damage is reduced, as shown in Figure 2c, so that the net effect is a reduction in the damage curvature in the immediate vicinity of the vee as the vee closes slightly. Repetitive cycles of heating and cooling are required

Figure 2:



(a) Plate movement during early heating phase (deflection decreases)

(b) Plate movement near the completion of heating (deflection increases)

(c) Final position after cooling (deflection decreases)

to remove all damage.

A second method of producing the desired upsetting (usually in conjunction with the vee heat) is to provide a restraining force. The role of the restraining force is to reduce or prevent beam movements, which tend to favor longitudinal expansion during the heating phase. For example, if a restraining force is applied that generates a bending moment tending to close the vee as shown in Figure 2b, the upsetting effect will be increased through the flexural constriction of free longitudinal expansion at the open end of the vee. A restraining force is usually applied externally, but sometimes the structure itself provides restraint through internal redundancy.

Heat Straightening Rolled Shapes

For structural shapes, the typical damage falls into one of four categories that requires certain combinations of vee, strip and line heats (Figure 3a). For example, a wide flange shape subjected to various types of damage can be straightened using the heating patterns indicated:

1. Damage as a result of bending about the strong axis (Category S) requires the vee and strip heat pattern shown in Figure 3b;
2. Weak axis damage (Category W) requires the pattern in Figure 3c;
3. Twisting damage (Category T) requires the pattern in Figure 3d;
4. Local bulging (Category B) is heated as shown in Figure 3e.

For all cases, the general order of heating is line, vee and strip.

Engineered Repairs

The key to safe, reliable heat-straightening repairs is to control certain specific parameters. The vee depth is usually taken as the full depth of the plate element except for Category B, which may require half-depth vees. The vee angle should gen-

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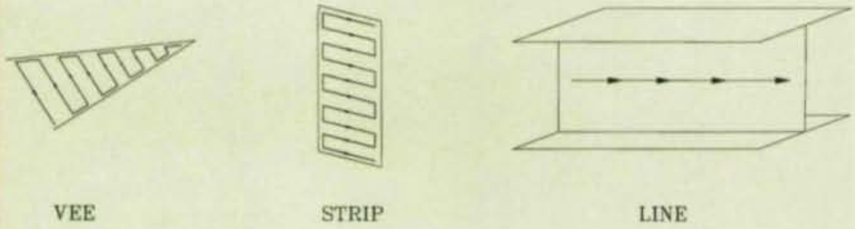
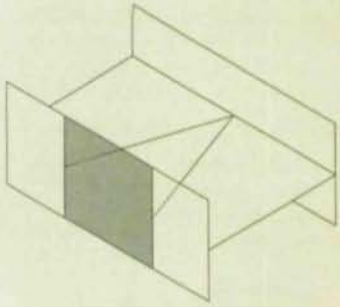
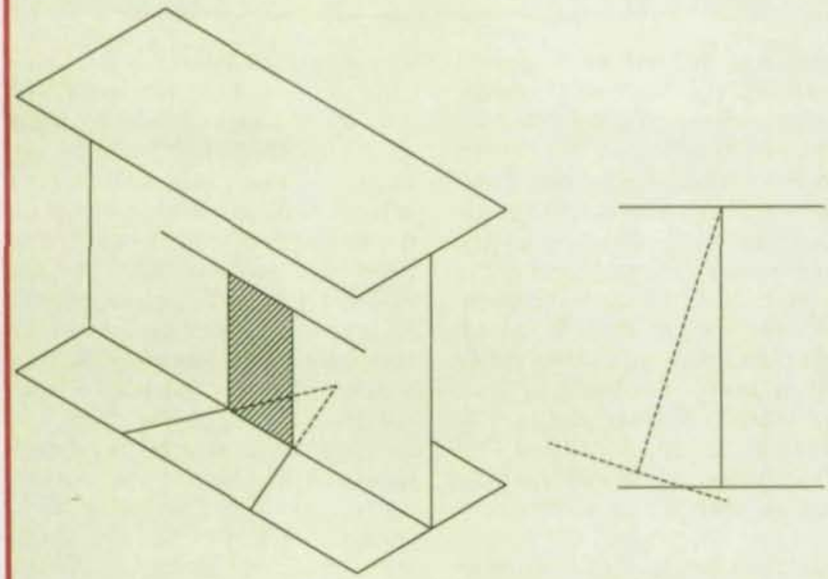
Figure 3: Heating Patterns For Wide Flange Shapes



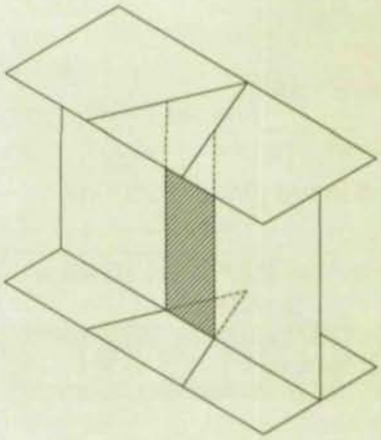
(a) Torch patterns for vee, strip and line heats



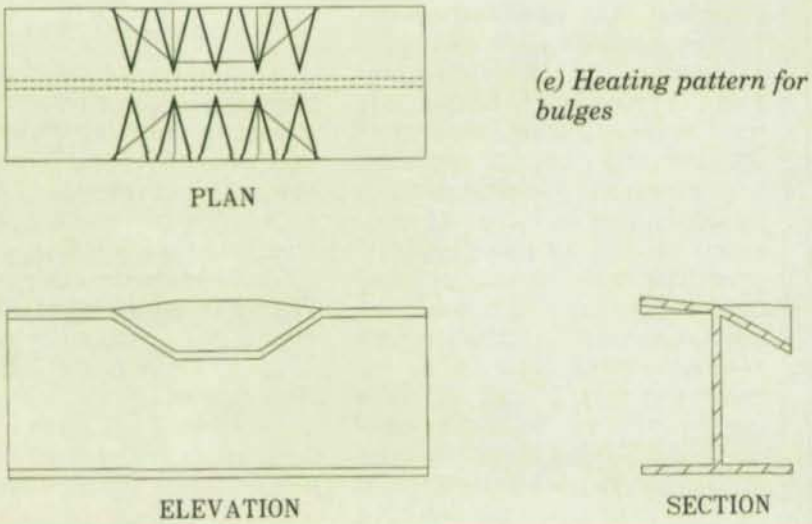
(b) Heating pattern for strong axis damage



(d) Heating pattern for twisting damage



(c) Heating pattern for weak axis damage



(e) Heating pattern for local bulges

erally not exceed 20 degrees. Control of the heating temperature is critical and should be limited to 1200 degrees F for carbon and low alloy steels and 1100 degrees F for constructional-alloy steels. Temperature crayons and contact pyrometers can be used to monitor temperature. However, at 1200 degrees F steel takes a satiny silver color that a trained observer can quickly learn to recognize.

One of the most critical factors is the applied restraining force. Research has shown that the use of jacks to apply restraints can greatly shorten the number of heating cycles required. However, over-jacking can result in a brittle fracture during or shortly after heat straightening. To prevent such a sudden failure as illustrated in Figure 4, jacking forces should always be limited. The recommended procedure is to calculate the bending moment capacity of the damaged member and limit the moment resulting from applied jacking forces to one-third of this value. Very few practitioners take this precaution and, thus, brittle fractures are not uncommon. It is strongly recommended that jacks be gauged and calibrated with the maximum force limitation computed. Of course, the jacking forces should always be applied in the direction tending to straighten the beam.

In general, all yield zones and only yield zones should be heated with either line, strip or vee heats. Since yield zones may extend 3 ft. or more, successive heating cycles require the vee to be shifted sequentially over the entire zone. With proper control of jacking forces and heating temperature, temporary shoring is not required. There also is no recognized limit as the degree of damage that can be repaired. Research has shown that strains up to 100 times the initial yield strain can be safely heat straightened. Even repetitive damage that has not been previously heat straightened may be re-shored, although this process should not be repeated more than once.

Examples Of Repair

A common type of damage is the result of over-height vehicle impact to the steel girders of an overpass. I have worked with the Iowa Department of Transportation to develop a heat-straightening training program for their maintenance personnel. The final phase was to conduct a repair of a damaged bridge of I-80 near Davenport. The facia girder, in which the lower flange more than 7 in. of permanent deflection, was successfully repaired, as shown in the before and after photos (Figure 5).

Figure 4 (opposite page): Fractured lower flange of a composite steel girder resulting from over-jacking during heat straightening.
Figure 5a (above): Damaged I-80 overpass in Iowa prior to heat straightening repair.
Figure 5b (right): I-80 overpass near completion of repairs.

A second example is the Mississippi River Bridge in Greenville, MS, in which the through truss cross bracing had excessive localized damage from a crane boom that broke its mooring while being transported over the bridge. (Before and after views are shown in Figure 6).

Safety & Economic Impact

If heating temperatures and jacking forces are controlled, heat straightening does not significantly change the strength characteristics of the material. For example, data is available for hundreds of tests in which the percent change of key parameters before and after heating have been measured. For yield stress, there tends to be a small increase averaging 13% after heating. Similar increases have been found for maximum tensile strength. The modulus of elastic-

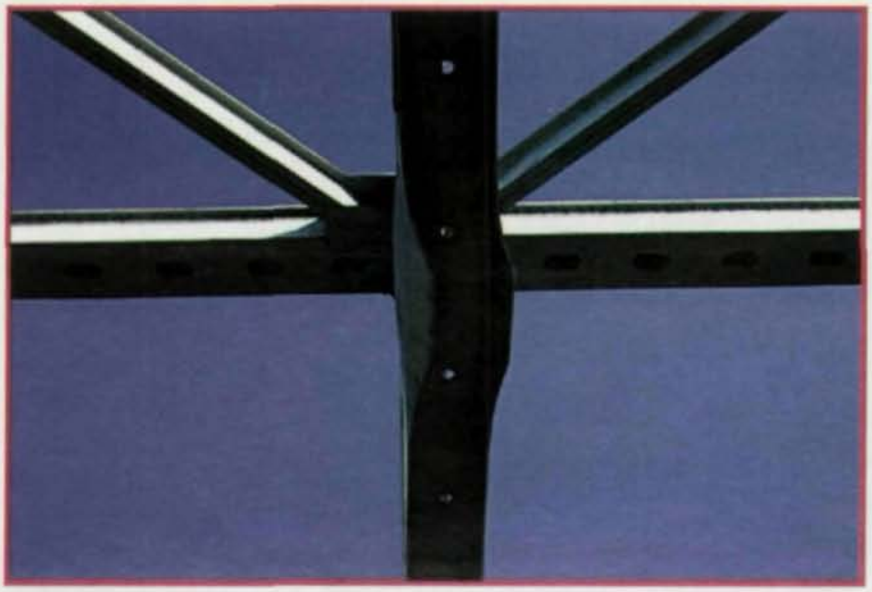


Figure 6a (above): Damaged cross brace on Mississippi River bridge near Greenville, MS.

Figure 6b (opposite page): Cross brace after completion of heat straightening.

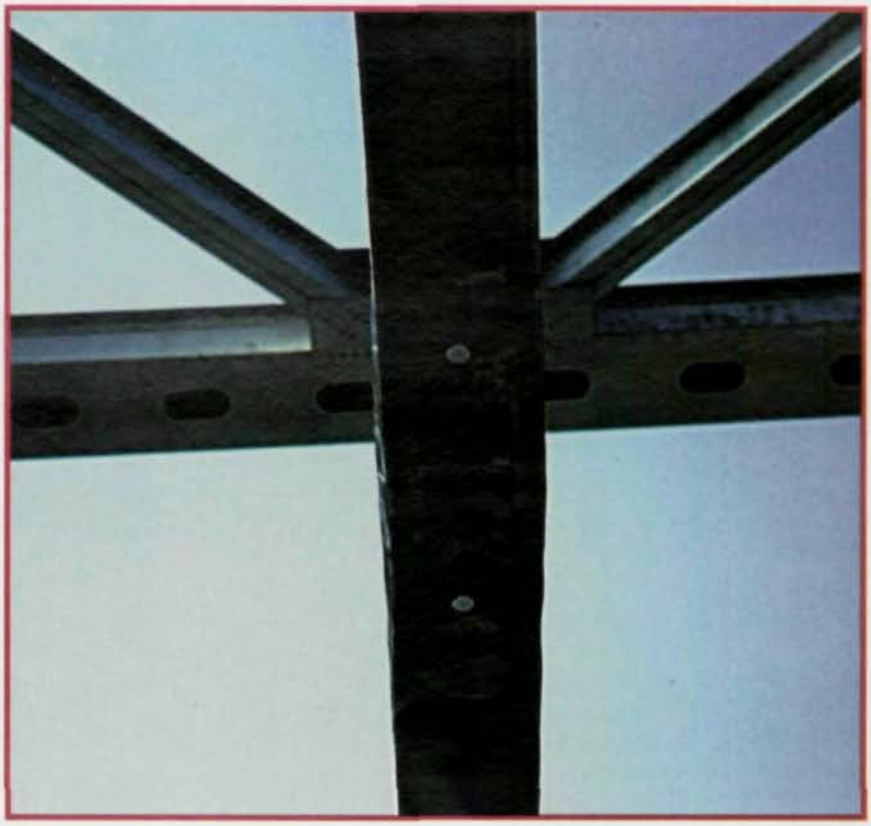
ity after heating decreases slightly by 4%. Ductility has the greatest change, decreasing by an average of 20%. Fracture sensitivity, as measured by the Charpy V-notch test, shows little change before and after heating.

The cost of heat straightening tends to be quite low when compared to alternatives such as replacement of all or part of a girder. A typical bridge project with one to three damaged girders typically requires less than a week to complete. While traffic is usually diverted from the lanes directly over the girders, the rest of the bridge can remain open. Costs typically range between \$20,000 to \$30,000. IDOT's in-house repair of the single girder in Figure 5 was less than \$10,000. A heat straightening specialty contractor's estimate was \$20,000. Replacement would have exceeded \$100,000.

Research has reached the

point that a prototype engineer's guide to heat straightening was presented and published at AISC's National Steel Construction Conference in 1992 and more information will be presented at the 1995 NSCC in San Antonio in May (For more information on the upcoming NSCC, please call the American Institute of Steel Construction at 312/670-5420). The emphasis on future research is to conduct field repairs in which the response to heat straightening is closely monitored. The LSU research team is seeking candidate bridges and other structures that can be repaired by heat straightening as part of this continuing research.

R. Richard Avent, P.E., Ph.D., is a professor in the Department of Civil and Environmental Engineering at Louisiana State University.



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