Current Steel Structures Research

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The American Institute of Steel Construction has published its flagship technical periodical, the *Engineering Journal*, four times every year since 1964. Emphasizing contributions that focus on the practical applications of structural steel research and development, the journal is commonly found in the libraries of practicing structural engineers and structural steel fabricators. A number of the findings that have been published over the years eventually have been adopted into the AISC specifications for the design of steel building structures, transforming state-of-the-art research results into usable, economical and above all practical criteria for steel design.

As would be expected, most of the research work that has been presented in the *Engineering Journal* has been conducted by individuals at various U.S. universities and research organizations, and an appreciable number also reflect studies conducted in U.S. design offices. Clearly, such individuals are cognizant of American design philosophies and requirements, facilitating the translation from theory to practice.

Nevertheless, research knows no international boundaries, and very significant studies have been conducted all over the world for years. Solutions may find application in many locations, and it is primarily a matter of effective communication to ensure that researchers and other practicing professionals are aware of what is being done and what such work may mean for design and construction in their own locales. However, even today, with efficient electronic communication and close contacts between researchers, it is all too common that research is being done without knowledge of related work of recent and especially not-so-recent vintage. Clearly, there is never any reason for duplicating work or to "re-invent the wheel".

This paper is the beginning of a new tradition for the *Engineering Journal*. Reporting on important work underway all over the world, each issue will present information about ongoing international studies and what they may imply for future practice in design and construction. The application focus will obviously be for U.S. structural steel designers and fabricators, but this works both ways: engineers from all walks of the profession, anywhere, would be remiss in their duties if they do not pay attention to all developments that may enhance their technical prowess and offer better and more economical solutions for their clients.

The subject matter to be presented in each issue will address hot-rolled steel and composite construction as it applies to buildings and bridges. The topics may vary somewhat from one issue to the next, but subjects such as steel materials, member and frame performance and stability considerations, connections, composite construction and structural systems will likely appear on a regular basis. Details of approaches and findings will be provided as much as feasible, and the locations of researchers and their institutions will be identified whenever possible. But it is emphasized that the material presented reflects work that is currently underway.

Reidar Bjorhovde is the Research Editor of the AISC *Engineering Journal.*

CONNECTIONS

Simple Beam Connections in Combined Shear and Tension

This study reflects a major experimental program carried out at the University of New Brunswick in Fredericton, NB, Canada, under the leadership of J.L. Dawe and Susan Guravich.

Specifically, a total of 111 tests of five common shear connections were conducted to examine the interaction, if any, between shear and tension. It is noted that no other tests of connections under this loading combination have been conducted. The connection types were (a) header angle, (b) double angle ("knife angle"), (c) single angle, (d) shear tab and (e) shear end plate. All specimens were subjected to an initial rotation of 0.03 radians, which was maintained for the duration of the test. In addition, the connections were loaded by a shear force of a magnitude between zero and the full design value, and tension was then applied to determine the tensile capacity of the connections in the presence of realistic shear force levels. Additional tests for pure shear and pure tension were run to determine the capacities of the connections under such end-point, single type of loading conditions.

The test results indicate significant differences in serviceability, ductility, shear-tension interaction and ultimate tensile strength of the connections. For example, header angles reached high ultimate tension loads but also exhibited unacceptably high levels of deformation before failing. Shear end plates behaved similarly, but with smaller tension

deformations. Double ("knife") angle, single angle and shear tab connections all demonstrated excellent tensile capacity in the presence of shear, including high strength and serviceability, although the double angle connection had the smallest combined shear and tension capacity. The single angle and the shear tab exhibited the least amount of interaction between shear and tension.

Overall, the test program has demonstrated that simple connections such as those tested can sustain significant amounts of tension in combination with the design shear capacity.

Influence of Weld Imperfections on Earthquake Performance of Welded Moment Resisting Connections Using Full Strength Fillet Welds

A series of large-scale connection model tests with artificial imperfections in fillet welds were carried out at the Welding Centre of the Heavy Engineering Research Association of New Zealand, under the leadership of Messrs. Short, Woerner, Voegele and Moll.

Using hot-rolled shapes as well as welded built-up shapes for the connection members, they were tested under simulated earthquake loads with imperfections that varied in size and location within the welds. Other parameters included weld size, filler metal composition, beam flange thickness and panel zone deformation.

Overall, the results showed that connections failing by a ductile overload were able to perform adequately with imperfections of up to 10 percent.

Seismic Response Characteristics of Semi-Rigid Connections

This study is being performed at the Technical University Santa Maria in Valparaiso, Chile, under the direction of Carlos Aguirre.

Chile suffers numerous earthquakes every year, and the design and fabrication community pays very careful attention to strength, deformation and energy absorption demands for all types of connections, including connections used in structures for Chile's substantial mining industry. The project aims at quantifying the rotational and strength characteristics for a variety of connections, but semi-rigid (partially restrained (PR)) connections are the main objects of the study, primarily because these have been found to exhibit significant energy absorption capacity. The connection properties will be incorporated into software for frame analysis. At this time commonly used PR connections are being developed into a database, for use with appropriate frame analysis software.

Influence of Column Web Stiffening on Seismic Behavior of Beam-to-Column Connections

This experimental and analytical study has been conducted at the Technical University of Timisoara in Romania, under the direction of Dan Dubina.

Twelve full-scale connections were tested, using five different types of panel zone strengthening; these were compared to the performance of an unstiffened connection. All of the specimens were able to develop the design moment resistance while undergoing rotations larger than 0.04 radians. Using statically based design models in accordance with criteria developed by Krawinkler as well as Eurocode 3, the correlation between tests and analyses was generally very good, although the theoretical connection stiffnesses were always higher than those determined from the tests.

The results show that the most efficient web stiffening was provided by doubler plates welded to the column flanges, not connected to the column web. This is in agreement with similar U.S. connection research, where doubler plates welded to the column web tend to lead to failure in the web material in the vicinity of the welds.

Seismic Performance of Buckling-Restrained Brace-to-Gusset Plate Connections

The testing for this project will commence in January 2005. The work is being conducted at the National Center for Research on Earthquake Engineering of Taiwan, under the direction of K.C. Tsai, in close cooperation with American researchers Mahin, Roeder and Sabelli.

The project aims at validating analytical models for buckling restrained brace (BRB) to gusset plate connections, including the BRB to column base connection, using a two-story prototype building with perimeter moment resisting frames and two BRB frames in the transverse direction. The building has been designed for bi-directional ground acceleration, with translation about two axes as well as torsional displacement. Only one such BRB frame will be physically tested, using a pseudo-dynamic procedure. The test also will impose in-plane and out-of-plane deformation demands on the BRB to gusset and column base connections.

Some Other Connection Studies

The performance of various connections subjected to seismic effects is being investigated in France at INSA—Rennes, and in New Zealand at the University of Auckland.

The Heavy Engineering Research Association (HERA) of New Zealand has conducted a study to develop a damage avoidance seismic-resisting system, involving partial isolation of the floor system from moment-resisting frames. Although initially unsuccessful, the work has led to the

development of special connections that limit the extent and amount of damage that is likely to occur under seismic conditions. Design and detailing requirements for these "self-centering sliding hinge joint" connections have been developed; full-scale testing will eventually be conducted.

MATERIALS

A number of projects are currently underway at several universities in Europe, to examine performance criteria for members and connections using steel with yield stress as high as 100 ksi. These include a project at the Norwegian Institute of Technology examining ductility and moment redistribution requirements for high-strength beams with bolted connections (P. K. Larsen, Director) and a project at the Technical University of Luleå in Sweden aiming at providing inelastic design criteria for Eurocode 3 for steels with yield stress between 65 and 100 ksi (B. Johansson, Director). Eurocode 3 is currently limited to steels with yield stress less than 65 ksi (460 MPa).

A project at the Technical University of Delft (F.S.K. Bijlaard, Director) is addressing the applicability of high and ultra-high strength steels (yield stress between 100 and 140 ksi) for civil engineering structures, including factors such as the yield-to-tensile ratio, deformation capacity and weldability, as well as fabrication considerations for such steels. It is anticipated that these types of steels may be suitable for truss-like structures and other tension applications, for which deflection considerations will not govern the structural performance.

COMPOSITE CONSTRUCTION

Lateral-Torsional Buckling of Beams During the Erection Stages of a Building

This is a study being conducted at the University of Liège in Belgium, under the direction of René Maquoi, with support from the steel company Arcelor and design software being developed by a company in the German city of Aachen.

The project focuses on a new type of partially encased composite beams, where concrete is placed in between the flanges of hot-rolled wide-flange shapes. The presence of concrete increases the bending and torsional stiffness of the members, and fire resistance is also enhanced. The concrete is placed in the beam at an off-site location and the beam with the partially cured concrete is then erected in the structure after a few days.

However, since the strength and stiffness of the concrete nominally do not reach design levels until after 28 days, the stiffness of the partially encased beam during the erection of the structure may be so low that lateral-torsional buckling is a realistic limit state at this stage of construction. An analytical procedure has been developed whereby a relative slenderness of the beam is found, using the plastic moment capacity of the bare steel member and the buckling moment of the encased beam to arrive at the lateral-torsional buckling curve for the beam. The approach takes into account the stiffness contribution of the concrete at any given time, and determines whether the steel deck for the slab provides sufficient bracing or whether additional temporary bracing is needed.

Composite Action and Confinement Effects in Tubular Steel-Concrete Columns

This study has been conducted at Chalmers University of Technology in Gothenburg, Sweden, under the direction of B. Kliger.

Focusing on the interaction between the materials in concrete-filled steel tubes (CFT), the primary aim of the study was to examine the use of high-strength concrete, the confinement efficiency of the steel tube for such concrete, and how the axial load is transferred and carried by the composite column. Among the most important results, it was found that it is feasible to use high-strength concrete and still achieve ductile response of the member. It was also determined that high-strength concrete requires the use of a tube with thicker wall than what is common for lower strength concrete. Finally, the enhanced strength of the column is most pronounced for short columns under concentric loading, as would be expected.

Structural Behavior of Horizontal Shear Studs

This study has been conducted at the University of Stuttgart in Germany, under the direction of Ulrike Kuhlmann.

The project has developed strength and performance criteria for studs that are attached horizontally to edge plates as well as vertical plates within the slab of composite beams. The edge condition was the major consideration, recognizing the limited force transfer region for normally (vertically) placed studs in such areas of a composite floor system. In brief, the major finding is that whereas horizontal studs have adequate shear transfer capacity, the strength is less than or at best equal to that of normally oriented connectors. The design criteria that have been developed are very complex, but have already been adopted into Eurocode 4 for the design of composite structures. Additional work will address the fatigue behavior and strength of horizontal studs in bridge decks and similar locations.

Development of Composite Beam and Slab Panel Fire Design Procedure

This project is an activity of the New Zealand Heavy Engineering Research Association (HERA), under the direction of Charles Clifton.

The current project is the second stage of work which demonstrated that secondary beams can be left unprotected by fire protection materials, whereas primary beams—including slab panel edge supports—must be protected. The study now is incorporating the influence of supports deforming as a result of fire temperatures, to determine whether the edge support girders can be left unprotected. The initial findings indicate that such is the case, and work is now proceeding to develop design and detailing procedures for unprotected support girders.

FRAMES AND STRUCTURAL SYSTEMS

Simulation-Based Design of Slender Structures

This is a project being carried out at the Hong Kong Polytechnic University under the direction of S.L. Chan.

The project focuses on unusually tall and slender structures such as certain high-rise frames, long-span roofs, scaffolds and transmission line towers. Using a simulation-based approach with advanced and second order analysis techniques, the study has three main areas of interest, as follows:

1. To substantiate the application of the effective length method for slender frames, recognizing that although the K-factor has certain application limitations, it can be reliable and efficient in combination with simulation-based design.

2. To develop a consistent design philosophy for the design of structures under extreme loads and unconventional events such as fire, seismic loads and blast. Traditional prescriptive approaches cannot cover adequately conditions that evolve under such loads.

3. To address the design demands of structures such as long-span trusses and trusses with tension rods or prestressed cables, including considerations for the use of structures in high-strength or ultra-high-strength steel.

Seismic Retrofitting of Framed Structures Using Steel Braces

This is a project being undertaken at the National University of Cuyo in Mendoza, Argentina, under the direction of F. Crisafulli. The study focuses on the use of ductile bracing elements that derive a major component of the ductility from a reduction of the cross-sectional area at one of the ends of the brace. In some ways this follows the philosophy of reduced section beam-to-column connections, in that the major ductility demand is removed from the immediate vicinity of columns and other structural members.

Pseudo-Dynamic Tests of a Full-Scale 3-Story, 3-Bay Buckling Restrained Braced Composite CFT Frame

This project is being carried out at the National Center for Research on Earthquake Engineering of Taiwan under the direction of K.C. Tsai, with collaborative involvement from American researchers Goel, Roeder and Mahin.

A full-scale, three-story three-bay buckling restrained braced (BRB) composite concrete-filled tube (CFT) frame was tested by pseudo-dynamic loading protocol, using ground motions from the 1999 Chi-Chi and the 1989 Loma Prieta earthquakes. The structure is 40 ft tall with a 23 ft × 10 ft footprint, with 7-ft-wide composite slabs for the beams. It is thought to be one of the largest frames ever tested.

In the first test one of the gusset plates buckled at a load that was closely approximated by a magnitude predicted using the Whitmore model, although the effective length factor to be used had to be 2.0 instead of the traditional 0.65. After stiffening of the free edges of all of the gusset plates of the frame, the BRBs performed as expected. Following the application of six simulated earthquakes, all of the BRBs had fractured or buckled, but the beam-to-CFT connections remained intact. All BRBs sustained cumulative plastic deformations larger than 200 times the yield displacement before failure occurred. Future studies will focus on the flexural demands for the BRB connections as well as stiffening methods for the gusset plates.

STEEL AND COMPOSITE BRIDGE STRUCTURES

Competitive Steel and Composite Bridges by Innovative Steel Plated Structures

Commonly referred to as the ComBri project, this is a major, three-year study being undertaken by nine universities, industrial organizations and associations in five European countries (Belgium, France, Germany, Spain and Sweden). The project is funded by the Research Fund for Coal and Steel, and is managed by the German "Society for the Study of Steel Applications."

The overall aim of the ComBri project is to promote and develop the use of advanced steel plated structures in bridges, recognizing the increased strength and ductility of steel, optimizing member and bridge deck cross sections, innovative use of various types of longitudinal stiffeners and web systems and improved fabrication and erection procedures.

MIKTI Composite Bridge Research Program

This is a French national research effort involving general contractors, public and private owners, research laboratories and design offices. Twenty percent of the four-year, 4 million euro funding is provided by the French govern-

ment, the remaining eighty percent comes from private sources. The project is scheduled for completion in 2005.

The primary research subjects are:

1. Efficient decks for small bridges
2. Prefabricated composite decks with innovative connection systems
3. Utilization of various forms of tubes for members, including connection details
4. Reliability and maintenance of composite bridges, including efficient and accurate methods of inspection

Rehabilitation of Fatigue-Damaged Orthotropic Steel Bridge Decks

This is a project being conducted at the Delft University of Technology under the direction of F.S.K. Bijlaard.

Due to the increase of heavy traffic patterns in the Netherlands and other European countries as well as the development of "super single" and "super-super single" truck tires, orthotropic steel bridge decks are being subjected to much larger stress ranges and longer lives than what they were designed for. This is heavily influenced by the thickness and properties of the finishing layers for the decks. The study aims at developing economic repair methods and strategies for the damaged orthotropic decks.

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