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Behavior, strength, design criteria, and fabrication considerations for connections continue to be among the most active research areas, as has been demonstrated in previous current steel structures research articles. So is composite construction, for buildings as well as bridges, and some of these studies are expanding the current knowledge base as well as design considerations very significantly. New structural elements and forms have especially been considered by European bridge designers.

Design for seismic effects and the issues of performance-based design are now being supported actively in several countries. The European Union and a number of its universities and affiliated research laboratories are specifically looking to expand steel construction into regions where traditional approaches have utilized various forms of masonry and reinforced concrete. Robustness is a major concept in these developments, and the failures that have been observed in some recent earthquakes emphasize the need for increased attention to structural systems, components, and connection details. Quality at all levels of the industry and within the regulatory bodies of the various countries continues to be a concern.

Design and construction standards groups in a number of locales around the world are aggressively looking for novel criteria that will help enhance their competitive position in the market. Regional standards solutions such as the Eurocodes and the joint Australia-New Zealand codes are now being looked at in various regions in Asia. It appears that research findings are brought to the design profession at an accelerated pace, and this is often facilitated by increased cooperation between architects, engineers, materials suppliers, and construction firms. This cooperative model was conceived in the United States many years ago, and it has now been widely adopted around the world. It has been carefully expanded in numerous countries, with Japan as a key example.

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References are provided throughout the paper, whenever such are available in the current public domain. However, most of the work presented is still in progress, and reports or publications have not yet been prepared.

FATIGUE BEHAVIOR OF TUBULAR STRUCTURES IN COMPOSITE BRIDGES

This is a major, multiyear research project being conducted at the Swiss Federal Institute of Technology (EPFL) in Lausanne, Switzerland, with Professor Manfred Hirt as the director. The project has a number of subproject components, as detailed in the following.

Fatigue Behavior of Welded Circular Hollow Section Connections: Figure 1 shows one of the bridges that have been built in Switzerland, using tubular truss beams.

These bridges are light and elegant, with high flexural and torsional stiffness and strength. Prefabrication efficiency is high, and the need for transverse diaphragms is less than for traditional girder bridges, due to the lateral stiffness of the truss.

Fig. 1. Bridge with tubular truss beams.

However, the connections are often complicated and difficult to fabricate, especially for trusses that utilize circular hollow structural sections (CHSS). A typical example of such a connection is shown in Figure 2.

The key issue for the tubular beam truss bridge is the fatigue resistance of the structure; specifically, the response of the connections. The chord and the web members exhibit a significant variation of stiffness, nonuniform stress distribution, and a complex three-dimensional behavior that are critical for the fatigue performance. Professor Hirt has noted that much of the research work for such connections has been conducted within the offshore oil-drilling platform industry, with an entirely different set of performance and design considerations. The offshore-based criteria have tended to be very conservative and clearly not directly applicable to bridge structures.

For the tubular truss beam connections, the fatigue behavior was examined through a series of large-scale tests, finite element parametric analyses, and linear elastic fracture mechanics fatigue life predictions (Schumacher, 2003). The results showed that although the so-called hot-spot stresses could be significantly lower than those predicted by current design codes, it was also demonstrated that the fatigue strength was lower. Modified stress concentration factors have been determined for a range of CHSS K-type connections; these factors are now being utilized in design. Finally, the study has given indications on size effects, specifically by looking at CHSS wall thickness, connection geometry, and different loading cases. It is anticipated that improved design criteria will be developed, in particular by providing better size effect correction factors.

Fig. 2. Truss connection with circular hollow structural sections.

Fatigue Behavior of Cast Steel Nodes in Tubular Bridges: Attempting to resolve some of the problems associated with welded tubular connections, designers have used cast steel nodes for the joints of tubular space trusses, and this is now gaining attention from bridge engineers as well. The cast node replaces the central part of the connection, but the tubular members still have to be welded to the node. The EPFL study of the cast steel elements focused on determining the fatigue resistance of the nodes as well as the complete joint (Haldimann-Sturm, 2005). The full-scale tests that were conducted showed that the fatigue strength was governed by the welds, in all of the configurations that were examined.

The current work aims at optimizing the joint, meaning that the analysis incorporates a certain level of defect in the node, to match the node strength to that of the welds. It has been determined that the node defects can be very large before the joint strength is not controlled by the welds. Further, the node does not fail in a brittle fracture. Based on an approximate stress concentration factor, the design procedure has been greatly simplified, and parametric evaluations have been done. The work continues to focus on improving the fatigue strength of the welds to a level that is comparable to that of the cast steel nodes. Data are also being developed to determine allowable cast node defect sizes. One possible solution that has been identified involves the use of a backing ring, which has a much higher fatigue resistance than the traditional joint.

Probabilistic Study of Fatigue in Post-Weld Treated Tubular Bridge Structures: Post-weld treatment as a means to improve fatigue performance continues to be the subject of several investigations around the world. The EPFL study of Walbridge (2005) offers an interesting approach, attempting to develop system reliability criteria to allow a designer to assess the fatigue life of the structure. Using a linear elastic fracture mechanics approach, multiple potential crack sites are examined, including the effects of treatment intensity, quality, and timing. The probabilistic models show that post-weld treatment in the form of weld peening can be efficient. However, the degree of treatment is an issue for actual bridge structures, especially because it is so difficult to control the amount of peening that is done. Current results show that the treatment will be more efficient if it is applied in the field as opposed to in the fabrication shop right after the welding has been completed. But the researcher also notes that the economic benefits are highly variable, in part because it is extremely difficult to define realistic measures for the amount of treatment, as well as to ensure uniformity in the process of treatment.

EVALUATION OF SEISMIC RESPONSE OF STRUCTURES AND ELEMENTS

Earthquake Protection of Historical Buildings by Reversible Mixed Technologies: This is a very substantial, recently started, three-year research effort that involves 14 institutions in various European and Mediterranean countries. The project is funded by a special program under the European Commission. Professor René Maquoi of the University of Liège in Liège, Belgium, is in charge of the numerical analyses that are part of the project, including evaluations of actual historical buildings.

This project emphasizes the development of seismic protection measures for a large number of buildings, including some very old structures. The primary objective is to develop sustainable methodologies for the use of reversible mixed technologies in the seismic protection of existing structures. The term "reversible mixed technologies" involves the use of various materials and special devices, with particular emphasis on easy disassembly and removal, if necessary. At the same time, it is intended that the use of different materials and techniques will lead to optimum response and structural safety during seismic events. Finally, the project aims at developing a proposal for codification of these technologies, to satisfy and complement current European design standards.

Large Cyclic Deformation Capacity of Steel Members: This project has been conducted at Kyoto University in Kyoto, Japan, under the direction of Professor Masayoshi Nakashima.

Welded built-up tubular columns are used extensively in Japanese building and bridge structures, in part because of their perceived as well as actual behavior when subjected to the kind of large deformation demands that accompany earthquakes. Large *experimental* cyclic deformation data are very limited, however, and the project undertaken by Professor Nakashima focused on response characteristics in terms of maximum strength, plastic deformations, strength degradation,and ultimate failure mode (Kurata, Nakashima, and Suita, 2005).

The tubular columns used in the study had various levels of width-to-thickness ratios and axial load ratios. The column bases were fixed to reflect typical construction details. As expected, it was found that both of the primary test parameters were critical to the performance of the test specimens. For example, with an axial load ratio of 0.3, the column had lost its strength before the end rotation reached 0.025 to 0.03 radian. This rotation level is used as a measure for suitably ductile structural members. Figure 3 shows one of the columns after the completion of the test.

ENHANCED STRUCTURAL RESPONSE THROUGH METHODS, MATERIALS, AND DEVICES

Robust Structures by Joint Ductility: This is a major, three-year project conducted jointly by three European universities [Liège, Belgium (Professor Maquoi); Stuttgart, Germany (Professor Kuhlmann); Trento, Italy (Professor Zandonini)], in close cooperation with a German consulting firm and one of the European steel companies. Funding is provided by the European Commission through the Research Fund for Coal and Steel. The overall aim of the project is to provide disproportionate ("progressive") collapse criteria for steel and composite structures, including simple rules and recommendations.

The concept of robustness has gained a great deal of attention around the world, following several major incidents that may be characterized as disproportionate collapse. The key performance demand is to prevent local or overall collapse through material ductility; connection, member stiffness, and ductility; and structural system function. Force redistribution is achieved through connection and member local yielding, even under exceptional loading and deformation demands.

The work at the University of Liège is led by Professor René Maquoi. This component of the project focuses on analytical, numerical, and experimental evaluations of the performance of a one-story, four-bay composite frame as well as a number of other composite and industrial building structures when these buildings have sustained the loss of a column. These efforts complement certain ongoing projects in the United States and England.

Passive Control Design through Tuning of Structural Properties of Elastoplastic Damping Devices: This work has been conducted by Professor Kazuhiko Kasai at the Tokyo Institute of Technology in Tokyo, Japan.

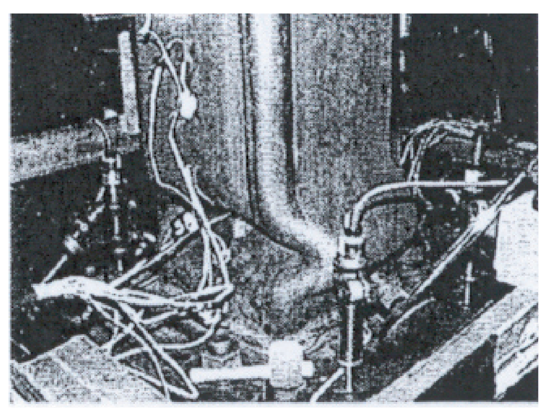

Fig. 3. Failure mode of heavy-welded, built-up column.

Japanese researchers and construction companies have devoted significant effort to the study and development of structural control devices and mechanisms, including active and passive damping measures. In the current examination, Professor Kasai has focused on a single-degree-of-freedom (SDOF) idealization of multistory buildings, including the use of a so-called control performance curve (Kasai and Ito, 2005). The frame is assumed to behave elastically. The curve characterizes the seismic performance of the frame as a function of stiffness parameters, ductility demands, and response spectra. The curve is used to determine the preferable balance of stiffness between the damping device and other elements of the model. It is reportedly especially effective for structures with a variable stiffness distribution over the height of the building.

Capacity of Semicompact Steel Shapes: This study is conducted by the University of Graz in Graz, Austria and the University of Liège in Belgium, in collaboration with a German consulting engineering firm. The Graz effort focuses on the cross-sectional behavior of the shapes, while the group at Liège concentrates on the member response. The shapes in question come from a group that are defined by the Eurocode as "semicompact," meaning that only some of the compactness criteria of the code are satisfied by the shapes in the representative steel grades. The actual capacities are expected to exceed those specified by the codes.

The aim of the project is to expand and improve the use of rolled and welded built-up shapes in industrial and multistory buildings, bridges, masts, towers, etc. The current code requires the semicompact shapes to be designed by elastic criteria. However, preliminary testing and numerical simulation have demonstrated that inelastic or even fully plastic behavior is feasible. To this end, 24 tests on beam columns under biaxial bending will be performed, using W-shapes and rectangular and square hollow structural sections. A numerical model will be developed for use in an extensive parametric study. This will, in turn, provide the basis for the development of a suitable design methodology for semicompact members.

COMPOSITE MEMBERS

Deformation-Based Approach to Determine the Minimum Degree of Partial Shear Connection in Composite Beams: This study has been conducted by Professor Mario Fontana at the Swiss Federal Institute of Technology (ETH) in Zürich, Switzerland.

Considering that the construction process sometimes governs the size of the steel shape for composite beams, only a small portion of the additional bending strength that is provided by the composite action is actually needed. In consequence, the shear transfer demand at the steel-concrete interface is limited and rarely equals the amount associated with full (100 percent) interaction. On the other hand, the flexural stiffness of the composite beam is significantly affected by the interaction between the slab and the steel, and long-term deflections in particular may be a problem for low degree of interaction beams. Since interface slip is a major measure of the beam behavior, low degrees of interaction impose severe deformation demands on the shear connectors.

The model that has been developed by Professor Fontana takes into account the actual load-slip behavior of the shear connector, as well as the geometry of the beam and the distribution of the superimposed load (Bärtschi and Fontana, 2005). It can therefore accommodate different types of shear connectors, although the headed stud is by far the most common. Even connectors with very small deformation capacity may be used under certain conditions, although it is recommended that short- and long-term beam deflections need to be examined very carefully. But the descending portion of the load-slip curve for the shear connector must be known, and the use of pushout tests will not suffice to define the curve.

DECISION THEORY APPLIED TO STEEL STRUCTURES

Decision-Making Tools for Steel Structures Engineering: This study has been conducted by Professor Siegfrid Stiemer of the University of British Columbia in Vancouver, BC, Canada.

Presenting an overview of currently available methods for decision making in various fields of endeavor, Professor Stiemer proceeds to develop suitable tools specifically adapted to steel structures and their design and fabrication. This complements the early work of Steven J. Fenves and others at the University of Illinois in the 1960s and 1970s and emphasizes the importance of decision theory to all areas of engineering. The study also details current software and associated methods of analysis.

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