Current Steel Structures Research

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This issue of "Current Steel Structures Research" for the *Engineering Journal* focuses on a selection of research projects at three of the leading universities in Europe. The descriptions will not discuss all of the current projects at the schools. Instead, selected studies provide a representative picture of the research efforts and demonstrate the importance of the schools to the home countries and indeed to the efforts of industry and the profession worldwide.

The universities and many of their structural steel researchers are very well known in the world of steel construction: University of Coimbra in Coimbra, Portugal; Karlsruhe Institute of Technology in Karlsruhe, Germany; and University of Naples, Federico II, in Naples, Italy. Other projects at some of these institutions have been discussed in previous research papers, but the studies that are presented in the following reflect major, long-time efforts in a number of areas of the construction industry of Europe. Much of the work is tied to the research programs of the European Union and its member countries, and the collaboration among universities in several countries for many of the projects is very impressive. All of the projects are multiyear efforts, emphasizing the need for careful planning and implementation of research needs and applications, including the education of graduate students and advanced researchers. Naturally, and as always intended in the United States as well, the outcomes of the studies focus on design standards and industry needs. The magnitude of the economic impact of the work cannot be overemphasized.

In true forward-looking fashion, the researchers at these institutions have been active for many years, as evidenced by their leading roles in the design standards development efforts of Europe, the well-known Eurocodes. Specifically, for steel construction, Eurocodes 3, 4 and 8 are reflected in the applications of the results, addressing the design of steel structures, composite structures and structures subjected to seismic effects, respectively. Large numbers of English-language technical papers and conference presentations have been published, contributing to a collection of studies that continue to offer solutions to complex problems for designers as well as fabricators and erectors. Not the least important, some of these efforts complement ongoing work in the United States and elsewhere. The broad sharing of knowledge that is taking place promises significant results, not the least because of issues of finances and the sheer cost of research.

References are provided throughout the paper, whenever such are available in the public domain. However, much of the work is still in progress, and in some cases reports or publications have not yet been prepared for public dissemination.

SOME CURRENT RESEARCH WORK AT THE UNIVERSITY OF COIMBRA IN COIMBRA, PORTUGAL

For many years the University of Coimbra has been one of the leaders in international academia, due to its being the fifth oldest university in the world. Its leadership role in structural engineering is, of course, of much more recent date, but the faculty has pursued an aggressive development of technical programs and research facilities. There have been numerous principal contributors, and the faculty of the Department of Civil Engineering of the university, with the leadership of Professor Luis Simões da Silva as chairman for several years, has been very active in the development of solutions to many technical problems. In particular, Professor da Silva and his colleagues have conducted extensive studies of the performance of steel and composite frames and bridges, connections for steel structures, response of steel structures to fire effects, strength and performance of wind towers for the energy industry, and extensive evaluations of sustainability.

In a development that is somewhat similar to the research centers of the National Science Foundation in the United States, the national research foundation of Portugal provided funding in 2007 for the establishment of the Institute for Sustainability and Innovation in Structural Engineering (ISISE), to be operated as a joint effort of the University of Coimbra and the University of Minho. Administratively, the institute was organized into three research areas: (1) steel and mixed construction technology, (2) structural concrete and (3) historical and masonry structures. With strong research groups in various areas, the University of Coimbra will focus on area 1, the University of Minho will focus on area 3 and area 2 will be shared by the two institutions. Researchers from related university areas will also participate, to the effect that support will be provided from architectural, mechanical and metallurgical engineering.

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For steel and composite construction at Coimbra, particular emphasis has been placed on behavior and strength of connections as well as members and structures, including fire and other extreme effects; and sustainability; life-cycle engineering; and monitoring and maintenance. Bridges, buildings and special areas of construction such as wind towers form the central activities. The research team includes 13 faculty members, 10 collaborators from other university departments and industry, 2 technicians and 28 doctoral graduate students. The physical testing facilities are excellent.

Economical and Safe Design of Steel Joints Subjected to Natural Fires: This three-year project (2009–2012) is sponsored by the European Commission, with a total budget of €1.7 million ($2.5 million), and is shared among the University of Coimbra as the lead institution, receiving €300,000 ($430,000); the University of Manchester, United Kingdom; the Technical University of Luleå, Sweden; the Technical University of Prague in the Czech Republic; and Corus Tubes, United Kingdom. The project director is Professor Luis da Silva.

The research work has focused on the development of component-based design methods for composite connections, in particular connections between composite beams and columns. Composite columns in European design practice are most commonly concrete-filled hollow structural sections (HSS) or partially encased open sections. The intent is that the connections will be designed to the same level of fire resistance as the frame, adhering to the requirements of Eurocode 3, Part 1-2 (CEN, 2005b; Franssen and Vila Real, 2010).

Numerical models have been developed, and fire tests have been conducted with components, individual connections, structural subassemblages and demonstration structures. As an example, Figure 1 shows the model for the assemblage of a steel beam and a concrete-filled HSS while subjected to the high temperatures of a natural fire (Carvalho Lopes et al., 2010).

Robustness of Car Parks against Localized Fire: This three-year project (2008–2011) is sponsored by the European Commission with a total budget of €1.3 million ($1.9 million), of which €250,000 ($360,000) is for Coimbra. The funding is shared among the University of Liège in Belgium as the lead institution; the University of Coimbra; Imperial College, London; ArcelorMittal, Luxembourg; CSTB and CTICM, France; and Greisch Ingenierie, Belgium.

It is interesting to note that steel has not been the construction material of choice for parking garages in Europe, which has been a recurring issue in the United States (although it is less of an issue than 40 years ago). In Europe the particular problem has been the response of garage structures to highly localized fires, which was the specific problem that led to the full scale fire test in a parking garage in Scranton, Pennsylvania, in 1972 (Gage-Babcock et al., 1973; Harris, 1979).

The project aims at developing a general philosophy for the design of robust structures for "exceptional" events, to include practical guidelines. Examples of the testing that is being done for composite structures are given in Figures 2

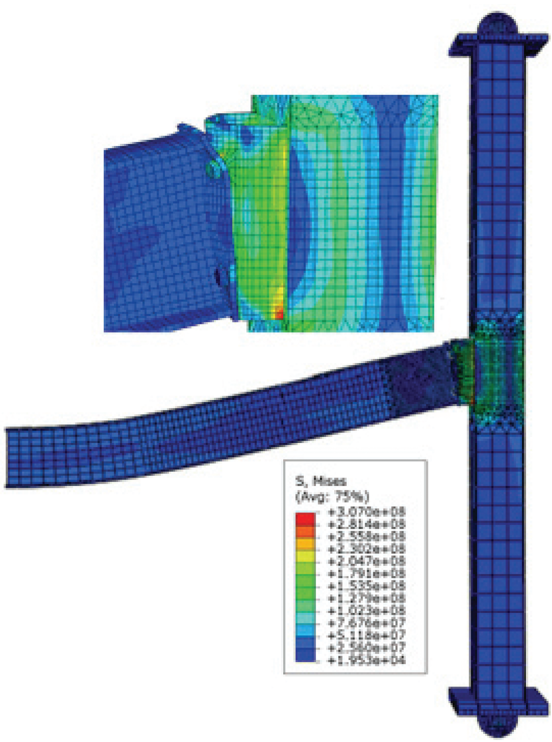


Fig. 1. Subassemblage model of steel beam and HSS composite column. (Figure courtesy of Professor Luis da Silva)

Fig. 2. Fire testing of a full-scale beam-to-column connection. (Figure courtesy of Professor Luis da Silva)

and 3, which show a connection being tested for fire temperatures (Figure 2) and the testing of an assemblage that includes the connection of Figure 2, as well as the two-span slab that is part of the original frame (Figure 3) (Haremza et al., 2011).

Fig. 3. Fire testing of a structural composite subassemblage. (Figure courtesy of Professor Luis da Silva)

Sustainable Steel and Composite Bridges in the Built Environment: This three-year project (2009–2012) is sponsored by the European Commission with a total budget of €1.5 million ($2.2 million), of which €280,000 ($400,000) is for Coimbra. The budget is shared among the University of Stuttgart in Germany as the lead institution; the University of Coimbra; LCPC—Laboratoire Centrale des Ponts et Chaussées, France; SETRA, France; BAST, Germany; ArcelorMittal, Luxembourg; Dillinger Hüttenwerke, Germany; Ramböll, Sweden; and Brisa, Portugal. The project director is Professor Ulrike Kuhlmann, University of Stuttgart.

The project focuses on the development and presentation of well-defined sustainability benefits of composite highway bridges, including highly effective and advanced structures and systems and cost-effective and environmentally friendly construction with long-life structures. A holistic approach is used, combining life-cycle assessment, life-cycle costing and life-cycle performance analyses to demonstrate the advantages of steel for bridges. As an example, Figure 4 gives a flowchart for the various operations of a life-cycle analysis (Gervásio and da Silva, 2010).

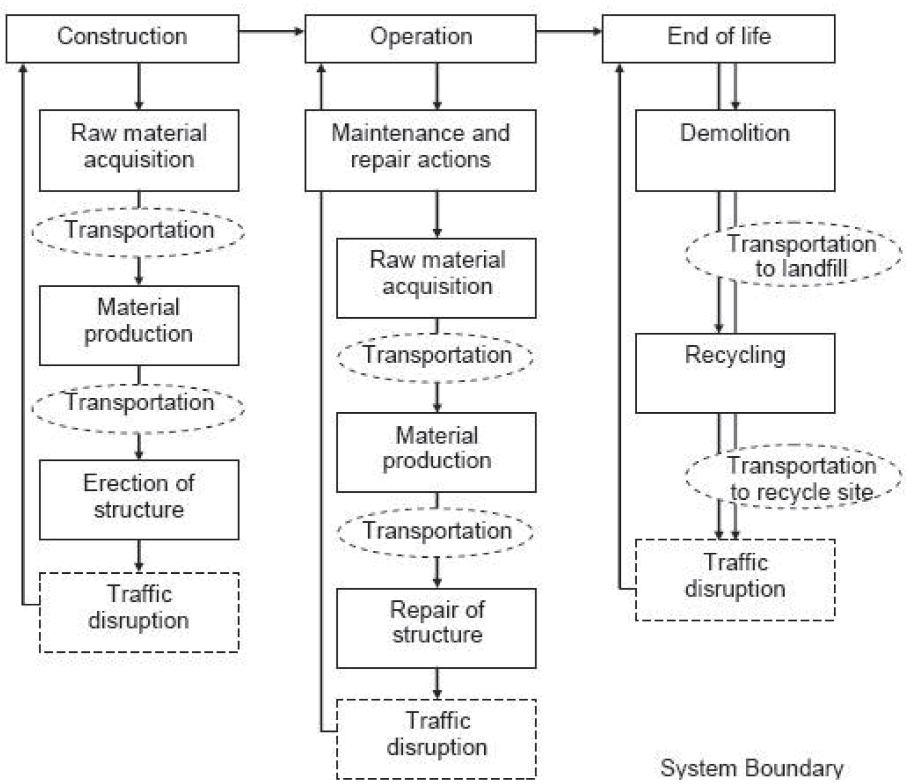


Fig. 4. Flowchart for life-cycle analysis. (Figure courtesy of Dr. Helena Gervásio)

High-Strength Steel Towers for Wind Turbines: This is a very major project that has been funded by the European Commission for two 3-year periods (2006–2009 and 2010–2013). The total financial support is €2.7 million ($3.9 million), with €434,000 ($630,000) allocated for Coimbra, with the Technical University of Luleå of Sweden as the lead institution. The other project participants are the University of Aachen in Germany; the University of Coimbra; the University of Thessaloniki, Greece; Martifer Energy Systems, Portugal; Rautaruukki, Finland, and Germanischer Lloyds, Germany. The project director is Professor Milan Veljkovic of the Technical University of Luleå.

The overall objective of the projects has been to demonstrate and improve the competitiveness of steel towers to support multi-megawatt wind turbines. The optimized design of a steel tower is based on an analysis of the criteria that govern wind tower design. Specifically, fatigue is a major consideration, and a more economical design would involve the use of high strength steel. One solution provides for an improvement of the flange detail that has traditionally been used to splice tower segments. Another suitable splice solution would be to use a friction type (slip-critical) joint to allow higher strains in the shell (Veljkovic et al., 2010; Matos et al., 2011). Another design limitation is the potential for the shell buckling that may take place in the tower wall, for which the strength is strongly related to geometric imperfections. New solutions for steel and hybrid tower stability and using foundations with steel micropiles are being developed. A bolted connection for the tower splice will be used, as illustrated in Figure 5.

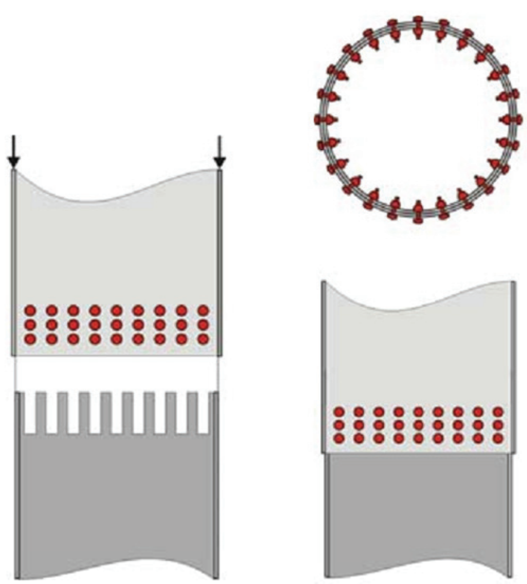


Fig. 5. Bolted slip-critical splice for a wind tower. (Figure courtesy of Professor Luis da Silva)

SOME CURRENT RESEARCH WORK AT KARLSRUHE INSTITUTE OF TECHNOLOGY IN KARLSRUHE, GERMANY

The University of Karlsruhe, one of the old, excellent German universities, educated large numbers of engineers and conducted extensive research in all areas of engineering and science. A few years ago, the government of Germany conducted an evaluation of its universities and identified certain institutions as being particularly capable. The University of Karlsruhe was one of a very small number of schools that was designated as an *elite university,* and thus the name of the institution was changed to Karlsruhe Institute of Technology (KIT). The research teams of some of the engineering departments subsequently changed their names to specific centers, and the KIT Research Center for Steel, Timber and Masonry (RCSTM) is now the unit that addresses all study subjects in these areas. Professor Thomas Ummenhofer is the director of the RCSTM.

The research and laboratory staffs are substantial, without giving a number of positions here. Laboratory and computing facilities are excellent, including a very high-capacity universal testing machine.

Detection of Cracks in Steel Components by Means of Ultrasound Excited Thermography: This project has been sponsored by the German Research Foundation. The director is Professor Thomas Ummenhofer; the primary researcher has been Dipl.-Ing. Robin Plum.

Detection of cracks in steel members and connections is a significant issue for many types of structures, whether the cracks have been caused by fatigue-type loading, fabrication techniques or other effects. Once the cracks have been identified, the possible solutions are generally fairly well defined, whether specific repairs are needed (or not, as the case may be) or whether changes in design methods and approaches may be warranted.

Developments over the last several years have indicated that active thermography methods—specifically, ultrasound applications of the technique—may be particularly suitable for structural purposes. Rubbing or "clapping" of crack surfaces as prompted by sound waves in the medium produces heat, which can be detected by an infrared camera. The equipment and applications of the procedure are illustrated in Figure 6. This is the primary focus of the current KIT project, to be applied to heavy structural members. Figure 7 shows an application of the method to detect a fatigue crack in a heavy rolled shape (IPE 500).

The primary objective is to determine the depth of the crack. In addition, it is important to determine the ultrasound frequency and the crack opening displacement, which can then be correlated to the state of prestressing (Plum and Ummenhofer, 2009). Finally, finite element simulations of the thermographic structural problem are developed to assess

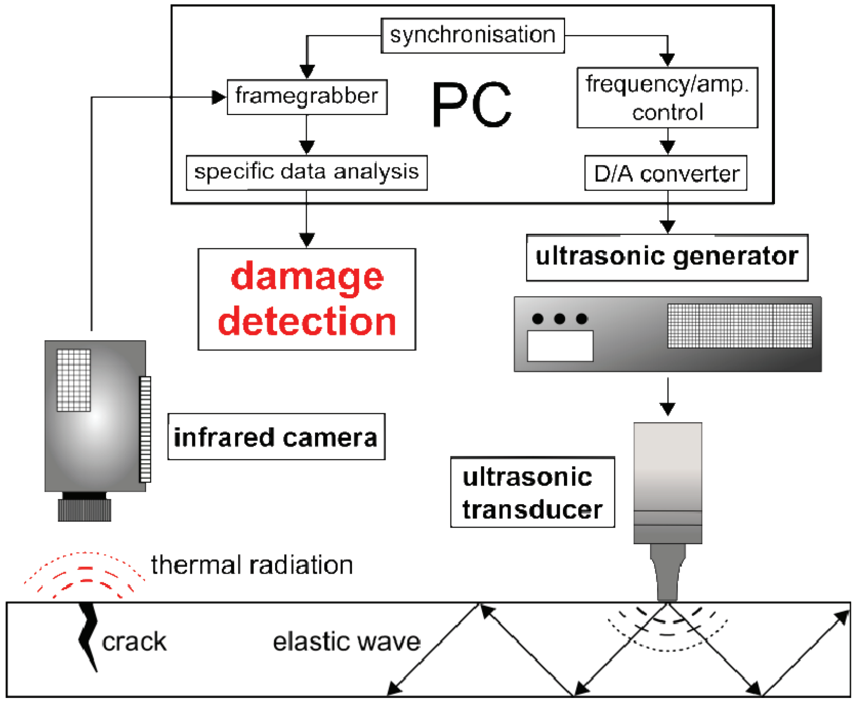


Fig. 6. The principle of ultrasound excited thermography. (Figure courtesy of Professor Thomas Ummenhofer)

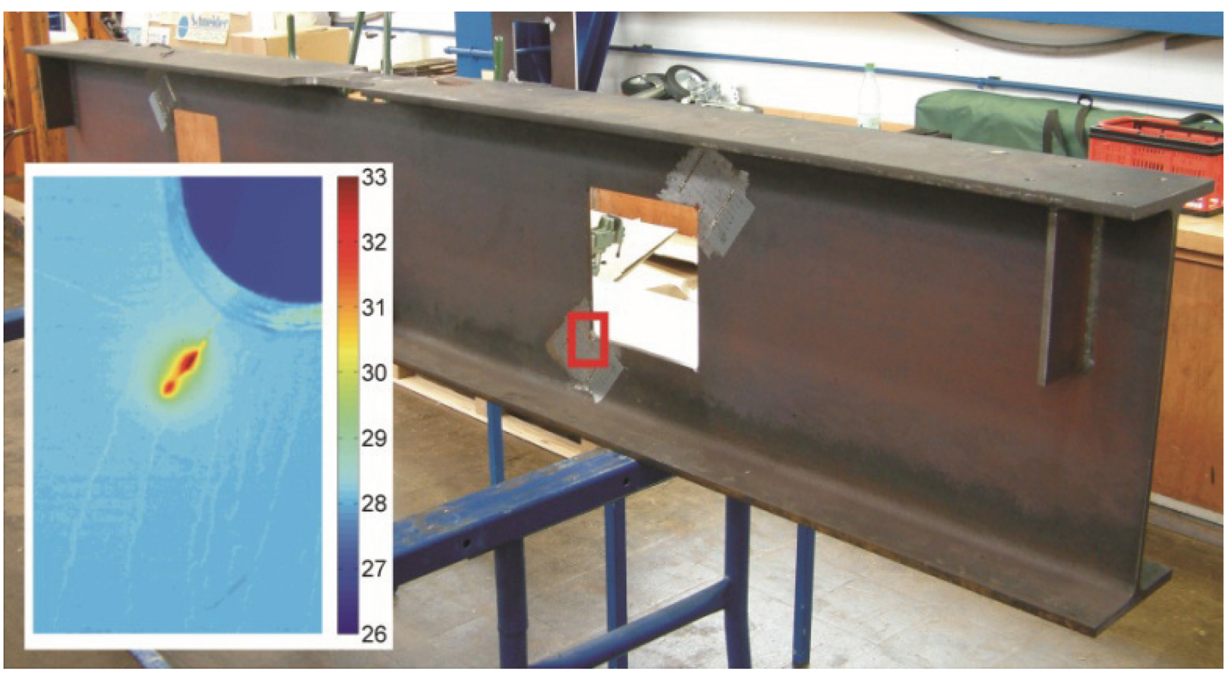


Fig. 7. Thermographic detection of a fatigue crack in a heavy-girder IPE 500. (Photograph courtesy of Professor Thomas Ummenhofer)

the accuracy of the experimental results and to improve the understanding of the physical effects of the process (Plum and Ummenhofer, 2010).

Adhesive Bonded Cast Steel—Structural Steel Connections: This project has been sponsored by the German Federation of Industrial Research Associations. It has been managed by KIT in cooperation with the University of Applied Sciences of Munich and the Fraunhofer Institute for Manufacturing Technology and Advanced Materials. The director is Professor Thomas Ummenhofer; the primary researcher has been Dipl.-Ing. Matthias Albiez.

Tubular members are being used for many structural applications, and the connections are often very complex and almost always have to be welded. For bridges and certain industrial applications, the complexity of the welded joints may promote fatigue cracking, and the cracks are often discovered only after the structure has been completed. Attempting to avoid complex welds, the project aims to develop connection solutions that utilize cast details of tubes and other shapes, and welds will be replaced by adhesive connections. This avoids the high temperatures associated with welding as well as the shrinkage that accompanies weld cooling. Providing cast steel details that allow for more uniform stress distributions and gradual force transfers between the connection elements, the solution with adhesives is likely to resolve a number of fabrication and structural performance issues.

The project will address the following subjects:

1. The adhesives currently available will be evaluated to determine their ability to satisfy the "boundary conditions" for the joints, including conditions for curing, strength and force transfer across the joint. The long-term stability of the adhesive will also be examined, including any organic effects.

2. A manufacturing process will be developed that uses a semi-automatic injection device that is suitable for the deposit of the adhesive in the (often narrow) gap between a cast node and the HSS. It is anticipated that the HSS sizes will range from 100 to 500 mm in diameter (4 to 20 in.).

3. The strength and behavior of the adhesively bonded joint will be determined for static, dynamic and thermal loads, including aging effects.

4. Above all, a joint will be developed that provides the necessary redundancy and alternate load paths in the case of a local failure.

5. Practical design approaches will be developed.

An example of a potential joint is shown in Figure 8.

Optimization of Supporting Structures for Offshore Wind Energy Converters: This project has been sponsored by the German Federation of Industrial Research Associations. It has been managed by KIT in cooperation with the Federal Institute for Materials Research and Testing (BAM) of Germany. The director is Professor Thomas Ummenhofer; the primary researcher has been Dipl.-Ing. Philipp Weidner.

Foundation structures for offshore structures in general and now also for the wind farms that are being developed in many areas of the world need novel evaluations of their strength and behavior. The structures have to be designed for all of the relevant offshore effects, including fatigue, for the often very heavy, elaborate and complicated joints. The project will examine all of these procedures, including tower construction and methods of maintenance. Underwater repair of welds must also be taken into account; it is anticipated that such will often be conducted using the HiFIT device developed at KIT. The device uses post-weld high-frequency hammer peening of the weld toe to reduce residual stresses and thus improve the performance of the weld. Material thicknesses in the range of 30 to 60 mm (1¼ to 2⅜ in.) are anticipated for the structures; the analysis and repair procedures will be evaluated for short- and long-term performance. Figure 9 shows various typical tower support and mast solutions.

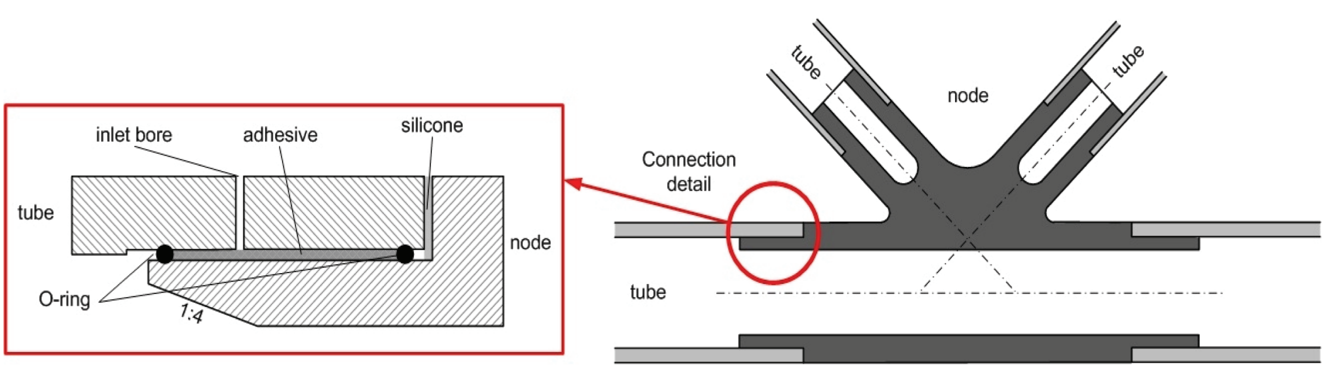


Fig. 8. Potential connection detail with cast steel elements and adhesive joints. (Figure courtesy of Professor Thomas Ummenhofer)

SOME CURRENT RESEARCH WORK AT THE UNIVERSITY OF NAPLES, FEDERICO II, IN NAPLES, ITALY

The University of Naples, Federico II, is one of the premier universities in Europe for the study of seismic effects. For many years Professor Federico Mazzolani conducted extensive evaluations of the seismic performance and strength of steel connections and frames as well as bridges; he has also done major studies of aluminum structures. For all practical purposes, he was the "father" of Eurocode 8 (CEN, 2004), the seismic design code for European countries, and has provided numerous links with industry and the code developers in North and South America as well as Asia. Now retired, his successor is Professor Raffaele Landolfo, who continues to lead an aggressive research and development effort.

High-Strength Steel in Seismic-Resistant Building Frames: This is a major three-year (2009–2012) project that has been funded by the Research Fund for Coal and Steel of the European Commission. The work is carried out as a joint effort among numerous European universities, led by the University of Naples, Federico II. The partners are the University of Timisoara, Romania; the University of Liège, Belgium; the University of Stuttgart, Germany; and the University of Ljubljana, Slovenia, along with a number of industry participants from various European countries. The project director is Professor Raffaele Landolfo.

Using typical multi-story frames in mild steel and high-strength steel, the mild steel is used for elements and connections that will serve as the major sources of ductility and energy absorption for the frames. The high-strength elements are used for members that will supply the principal portions of the elastic strength of the frames. The major activities of this project can be summarized as follows:

1. Select suitable structural systems and provide the designs of the frames.
2. Evaluate the seismic performance of the frames.
3. Assess the welding needs for the connections and other elements of the structures, taking into account the seismic performance requirements.
4. Perform prequalification tests of moment-resistant bolted beam-to-column connections.
5. Perform prequalification tests of moment-resistant welded beam-to-column connections.
6. Develop guidelines for conceptual design and performance-based design of the steel frames with members and connections in two steel grades.
7. Evaluate the technical and economical efficiency of the designs with two steel grades as compared to designs using a single grade of steel.

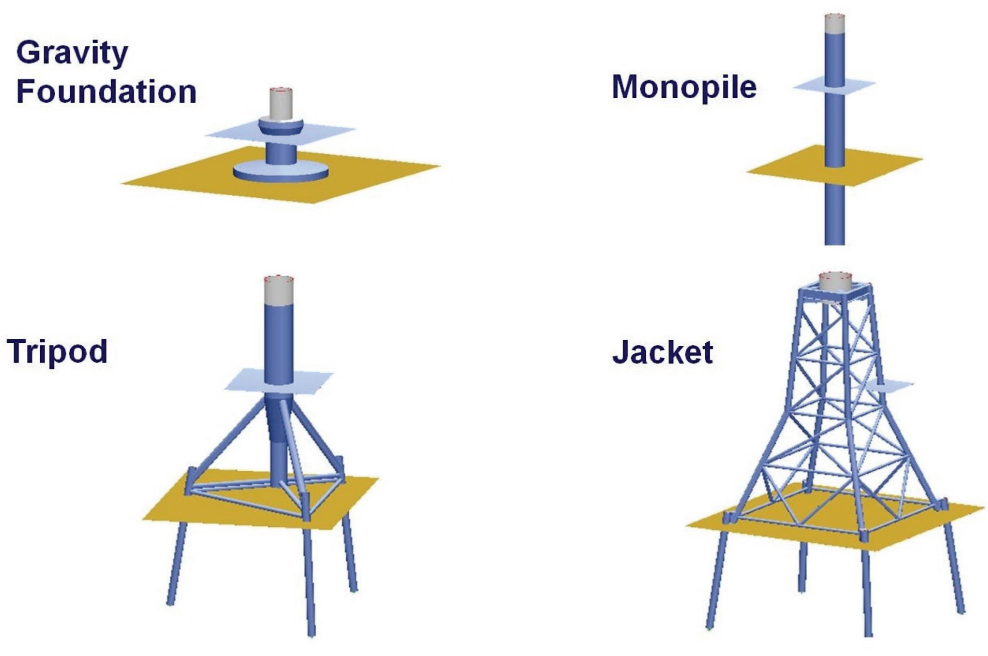


Fig. 9. Various offshore wind tower underwater structures. (Figure courtesy of Professor Thomas Ummenhofer)

The primary efforts of the University of Naples, Federico II, focus on the design and numerical analyses of a comprehensive set of frames combining two grades of steel. The performances of moment-resistant frames (MRF), concentrically braced frames (CBF), eccentrically braced frames (EBF) and dual MRF and CBF as well as dual MRF and EBF are examined.

The designs have been force-based, using the criteria of Eurocode 8, with special evaluations where the designs fail the requirements of EC8 (CEN, 2004): (1) the influence of ground-motion characteristics on ductility demands and (2) estimating the strength requirements for the nondissipative (elastic) structural members. It is anticipated that improved design procedures will be developed for frames with multiple grades of steel, taking into consideration the performance abilities of the various elements of the frames (Tenchini et al., 2011; Cermelj and Beg, 2011; Comeliau et al., 2011).

Displacement-Based Seismic Design of Steel Structures: This is a major three-year (2010–2013) project that has been funded by the Research Fund for Coal and Steel of the European Commission. The work is carried out at the University of Naples, Federico II. The project director is Professor Raffaele Landolfo.

The use of displacement-based design (DBD) methods and codes has been explored by numerous researchers over the years (Priestley et al., 2007). It is felt that a successful implementation offers the best approach to arrive at practical performance-based design criteria—in lieu of the force-based approaches that are common today. The DiSTEEL project, as it is called at the University of Naples, Federico II, aims at developing a suitable DBD procedure and performance criteria for moment-resisting frames with various types of beam-to-column connections. Thus, full-strength moment (rigid) connections, full-strength flexible connections and partial strength bolted connections will form the original basis, as illustrated in Figure 10. The connection classifications will be done in accordance with the criteria of Eurocode 3 (CEN, 2005a).

Figure 11 illustrates the fundamental characteristics of the DDBD method (Priestley et al., 2007). Significant additional research work is being conducted, but much must still be explored for the most suitable approaches (Della Corte et al., 2010).

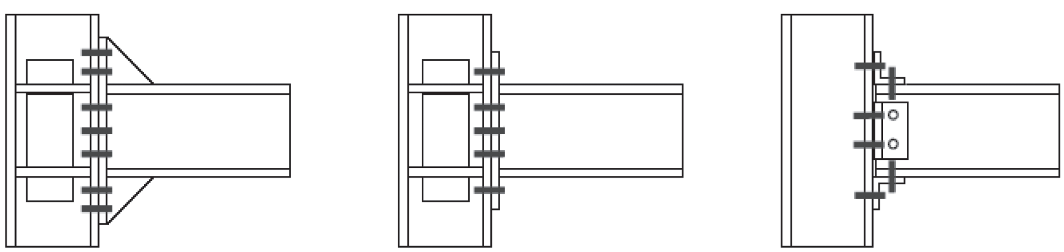
The DiSTEEL project is organized in accordance with four primary areas:

1. A detailed review of the literature will be performed to collect experimental data. The data will be classified such that it will be possible to identify how the hysteretic behavior is influenced by the connection details.

2. The experimental data will be examined and codified according to Eurocode 3 and by finite element models. This information will be used to develop simple design-oriented equations that can be used to determine the magnitudes of the connection rotations at the yield and ultimate limit states.

3. Sample moment-resisting frames will be designed in accordance with the codified force-based procedures and the direct DBD (DDBD) method that has been developed. The results will be used to validate the DDBD.

4. Nonlinear dynamic analyses will be performed for the sample frames in order to determine the reliability and efficiency of the DDBD method as contrasted with current force-based procedures.



(a) *(b)* *(c)*

Fig. 10. Beam-to-column connections to be used in the DiSTEEL analyses: (a) full-strength rigid joints; (b) full-strength flexible joints; (c) partial-strength joints. (Figure courtesy of Professor Raffaele Landolfo)

Laboratories University Network of Seismic Engineering: This is a major three-year (2010–2013) project that has been funded by the Civil Protection Department of the government of Italy.

The network is a consortium of 10 Italian universities that conduct research in seismic engineering. The aim is to provide advice to various government and other institutions with regard to seismic issues, dealing with all aspects of new and old construction, seismic risk and damage following earthquakes, and to assess the efficiency of new tools of design and construction.

The consortium involves several research units; the operation headed by Professor Landolfo focuses on extending the current seismic regulations and codes to cold-formed steel systems (Landolfo et al., 2010). The following are the principal areas of effort:

1. Numerical and experimental studies will be performed to assess the local behavior of cold-formed profiles, connections, panels and walls.
2. The results of the numerical analyses will be evaluated by a parametric study to determine the seismic behavior of elements of various geometries, materials and seismic input.
3. Upgraded specifications and design tools that are suitable for use by designers will be developed. For example, seismic design procedures that will allow shear wall components to be defined in a few steps are likely to be very useful to industry.

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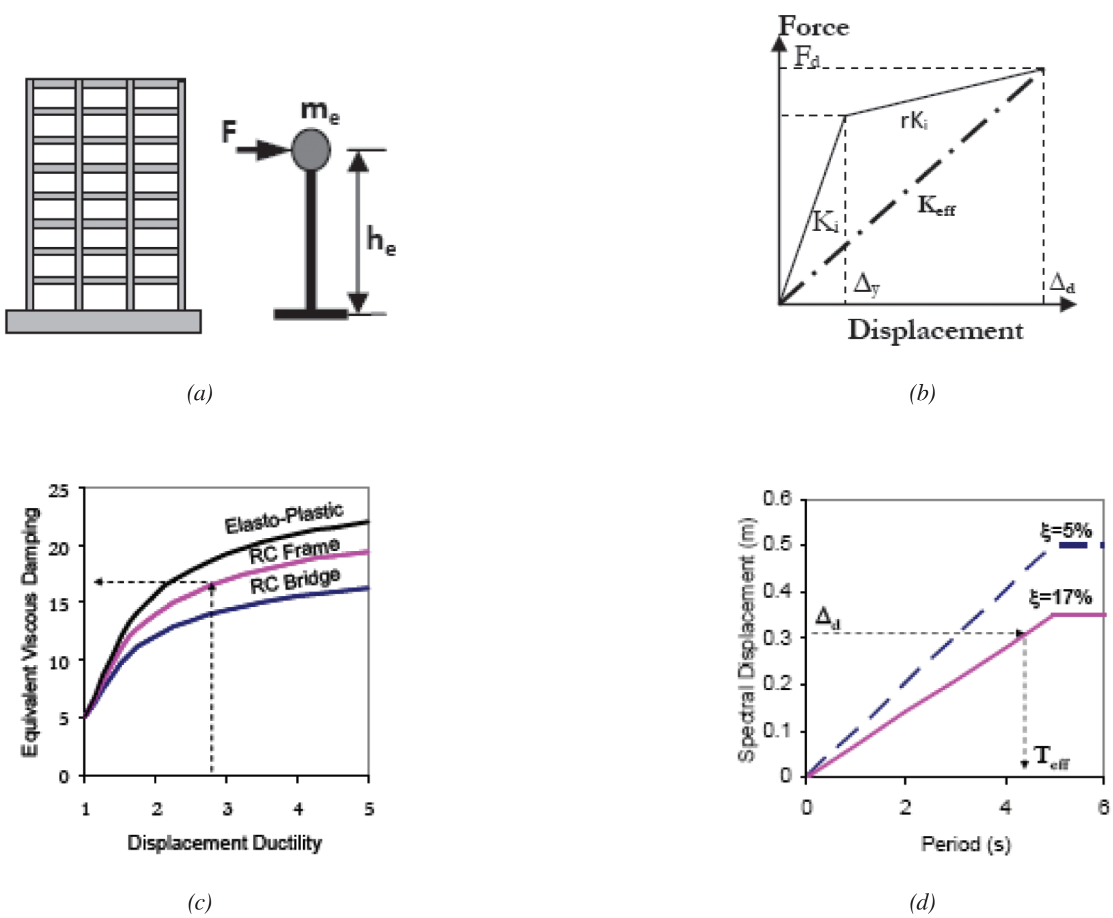

Fig. 11. Characteristic features of the direct displacement-based design method: (a) SDOF representation; (b) effectiveness, k_{eff}; *(c) equivalent viscous dampling; (d) dispacement spectrum. (Figure courtesy of Professor Raffaele Landolfo)*

REFERENCES

Carvalho Lopes, F.R., Santiago, L., Simões da Silva, L. and Santos da Silva, J.G. (2010), "Numerical Assessment of Structural Assembly between Steel Beam and CFT Column under Fire," *Proc. Urban Habitat of Constructions under Catastrophic Events* (COST C26 Workshop, Naples, Italy), CEN, Brussels, Belgium.

CEN (2004), *Eurocode 8: Design of Structures for Seismic Resistance—Part 1: General Rules, Seismic Actions and Rules for Buildings*, Comité Européen de Normalisation, Brussels, Belgium.

CEN (2005a), *Eurocode 3: Design of Steel Structures—Part 1-1: General Rules and Rules for Buildings*, Comité Européen de Normalisation, Brussels, Belgium.

CEN (2005b), *Eurocode 3: Design of Steel Structures—Part 1-2: Structural Fire Design*, Comité Européen de Normalisation, Brussels, Belgium.

Cermelj, B. and Beg, D. (2011), "Numerical Analysis of Welded Stiffened and Welded Cover-Plate Beam-to-Column Joints with Fully Encased Wide-Flange Columns," *Proc. Eurosteel 2011,* August 30–September 2, Budapest, Hungary.

Comeliau, L., Demonceau, J.F. and Jaspart, J.F. (2011), "Non-Dissipative Joints in Seismic Resistant Building Frames Bolted Beam-to-Column Joints," *Proc. Eurosteel 2011,* August 30–September 2, Budapest, Hungary.

Della Corte, G., Landolfo, R. and Mazzolani, F.M. (2010), "Displacement-Based Seismic Design of Braced Steel Structures," *Steel Construction—Design and Research*, Vol. 3, September, pp. 134–139.

Franssen, J.-M. and Vila Real, P. (2010), *Fire Design of Steel Structures*, Eurocode Design Manuals, European Convention for Constructional Steelwork (ECCS), Brussels, Belgium.

Gage-Babcock & Associates (1973), "Automobile Burn-Out Test in an Open-Air Parking Structure," Report No. 7328, Gage-Babcock and Associates, Westchester, IL.

Gervásio, H. and Simões da Silva, L. (2010), "Lifetime Analysis of Highway Composite Bridges," *Proc. International Symposium on Steel Structures: Culture and Sustainability,* September 21–23, Istanbul, Turkey.

Haremza, C., Santiago, A. and Simões da Silva, L. (2011), "Experimental Behaviour of Heated Composite Joints Subject to Variable Bending Moments," *Proc. Eurosteel 2011,* August 31–September 2, Budapest, Hungary.

Harris, Leslie (January 1979), "1979 Update of the Survey of Fire Experience in Automobile Parking Structures in the United States and Canada," Marketing Research Associates, Teaneck, New Jersey.

Landolfo, R., Fiorino, L. and Iuorio, O. (2010), "A Specific Procedure for Seismic Design of Cold-Formed Steel Housing," *Advanced Steel Construction*, Vol. 6, No. 1, pp. 603–618.

Matos, R., Fontoura, B., Rebelo, S., Jesus, A., Veljkovic, M. and Simões da Silva, L. (2011), "Fatigue Behaviour of Steel Friction Connections—Experimental and Numerical Results," *Proc. Eurosteel 2011,* August 31–September 2, Budapest, Hungary.

Plum, R. and Ummenhofer, T. (2009), "Ultrasound Excited Thermography of Thick-Walled Steel Load-Bearing Members," *QIRT Journal*, Vol. 6, No. 1, pp. 79–100.

Plum, R. and Ummenhofer, T. (2010), "Structural-Thermal FE Simulation of Vibration and Heat Generation of Cracked Steel Plates due to Ultrasound Excitation Used for Vibrothermography," *Proc. QIRT Conference 2010,* Quebec, Canada, pp. 763–770.

Priestley, M.J.N., Calvi, G.M. and Kowalski, M.J. (2007), *Displacement-Based Design of Structures*, IUSS Press, Pavia, Italy.

Tenchini, A., Rebelo, C., da Silva, L., Serra, M., Landolfo, R. and D'Aniello, M. (2011), "Seismic Performance of High Strength Steel Building: Dual-Frame Analysis," *Proc. Eurosteel 2011,* August 31–September 2, Budapest, Hungary.

Veljkovic, M., Feldmann, M., Naumers, J., Pak, D., Rebelo, C. and Simões da Silva, L. (2010), "Friction Connections in Tubular Towers for Wind Turbines," *Stahlbau*, Vol. 79, No. 9, pp. 660–668, in German.