IIW SUBCOMMISION XV-E: 55 YEARS

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This paper gives a brief review of the activities of Sub-commission XV-E "Tubular Structures". Sub-commission XV-E is a sub-commission of Commission XV "Design, Analysis and Fabrication of Welded Structures" of the International Institute of Welding (IIW) and is the committee which initiates and coordinates the International Symposia on Tubular Structures (ISTS). The first symposium was held in 1984 in Boston, USA and the current one in Singapore is the 17th Symposium. Further, the committee initiates and discusses new research related to the design, behavior, static strength and fatigue strength of welded joints in structures made of circular, rectangular and other-shaped hollow sections, and drafts design rules for IIW and ISO (International Organization for Standardization) on this topic. For example, the "Static design procedure for welded hollow-section joints - ISO 14346: 2013", and the "Fatigue design procedure for welded hollow section joints - Recommendations - ISO 14347: 2008".

Keywords: Tubular structures, hollow sections, behavior, static design, fatigue design.

1 Introduction

The Sub-commission XV-E is a Sub-commission of Commission XV "Design, Analysis and Fabrication of Welded Structures" of the International Institute of Welding (IIW) and is the committee which deals with welded tubular joints. Therefore this paper focusses on the behavior and design of welded joints. Subjects like bolted joints, (concrete-filled) columns and architectural design are not within the scope of this paper.

Initial investigations on the static strength of circular hollow section (CHS) joints were carried out by Jamm (1951) in the Federal Republic of Germany. These were followed by investigations by other pioneers like Bouwkamp (1957, 1964) with many investigations on the static and fatigue behavior of circular hollow section joints in the USA. Further, by Sammet (1963) in the German Democratic Republic, by Kurobane (1964), Kanatani (1966) and Togo (1967) in Japan. Also in this period investigations on the fatigue behavior were published by Bader (1963). Further work was reported by Hlãvacek (1970) from Czechoslovakia. Other developments in this period can be found in the IIW doc. XV-153-63 by Toprac and Noel (1963) and the books of Wanke (1966) and Brodka (1968).

The research on rectangular hollow section (RHS) joints started later, initially by Redwood (1965) at the University of Bristol, who soon after moved to Canada.

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2 Period 1968 to 1973 (Toprac)

Prof. Toprac

The developments in Tubular Structures led in 1964 to the initiation of an IIW-XV study group "Tubular Joints" and in 1968 to the Sub-commission XV-E under chairmanship of Prof. Toprac from the University of Texas, USA. Under the umbrella of the Sub-commission a worldwide collection of data on circular hollow section joints in Japan and in the USA was made, see Natarajan and Toprac (1968, 1969). Also, work on stress distributions in joints and their fatigue behavior was initiated, for example see Noel, Beale and Toprac (1973). Taking account of the available evidence, Marshall and Toprac (1973) formulated a basis for tubular joint design. The available information can also be recognized in the earlier API (American Petroleum Institute) and AWS (American Welding Society) recommendations for circular hollow section joints. In this period the work was mainly focused on circular hollow section joints for inclusion in offshore codes.

Initial work on RHS joints was published by Bettziche (1969) in the Federal Republic of Germany. This was followed by several PhD projects at the University of Sheffield, see for example Mee (1971) with empirical design equations reported by Eastwood and Wood (1971). Based on a reanalysis, improved initial design equations were published by Davie and Giddings (1971).

3 Period 1973 to 1980 (Hauk-Dutta)

Prof. Hauk

Mr. Dutta

Under the chairmanship of Prof. Hauk (1973-1981) from Mannesmannröhrenwerke AG, F.R.Germany, a direct coordination was made with CIDECT (Comité International pour le Développement et l'Etude de la Construction Tubulaire), an international organization of major hollow section manufacturers. This could be easily established since Prof. Hauk became also Chairman of the Technical Commission of CIDECT. In this period Mr. Dutta, under Prof. Hauk, heading the research group of Mannesmannröhrenwerke AG, initiated many research projects sponsored by the European Coal and Steel Community (ECSC) and CIDECT on the static and fatigue behavior of hollow section joints. In this period the main focus was on the development of data for the static behavior of CHS and RHS joints and the fatigue behavior of RHS joints.

The ECSC-CIDECT sponsored research programs were mainly carried out in Germany at the University of Karlsruhe by Mang and Bucak, in The Netherlands by Wardenier at Delft University of Technology and TNO Building and Research, in the UK at the University of Nottingham by Davies, Coutie and Packer, and at British Steel by Giddings and later on by Yeomans.

Further, in Poland research was carried out by Brodka, Czechowski and Szlendak at Mostostal. In Japan by Kato and Akiyama at the University of Tokyo, by Kurobane and Makino at Kumamoto University, and by Kanatani, Tabuchi and Kamba at the University of Kobe. In

Canada it was undertaken by Redwood from McGill University, and by Korol from McMaster University. In the USA research was done by Marshall of Shell Oil, Yura at the University of Texas at Austin, Sherman at University of Wisconsin-Milwaukee, Graff at the University of Houston and by Zettlemoyer from ExxonMobil Upstream Production Research Co.

In this period, all evidence on the static behavior of CHS and RHS joints, and on joints between hollow section braces and I- or H-section chords, was collected and reanalyzed. See for example Akiyama et al. (1974), Marshall (1974, 1977), Wardenier and Stark (1978), Packer (1978), Kurobane et al. (1980), Yura et al. (1980), Kurobane (1981), Packer and Haleem (1981), Coutie et al. (1983). Also special topics like Knee joints (Mang et al. 1980), haunched joints (Korol and Mansour 1979) and joints in triangular girders (Redwood and Harris 1981) were considered. Mang et al. (1978) even presented, already, data for hollow section joints in high strength steel. Further, the fatigue behavior of RHS joints was investigated (Noordhoek et al. 1980, Wardenier and Dutta 1981).

Besides the above developments a large extensive European offshore program was started on the fatigue behaviour of tubular joints with participation of (in alphabetical order) Denmark, France, Germany, Italy, The Netherlands and the UK, in close cooperation with Norway and Canada. This offshore research program developed a lot of evidence on the fatigue behavior of large-size tubular joints and related aspects like size effect, determination of hot spot stress, corrosion fatigue, and weld improvement methods. The results were discussed in ECSC Working Groups but also in the joint meetings of IIW Commissions XIII and XV.

The increased offshore activities with increased research led to many conferences, besides the existing "Offshore Technology Conference (OTC)" which started in 1969. For example "Behavior of Offshore Steel Structures (BOSS)" started in 1976, "Steel in Marine Structures (SIMS)" started in 1978. "Offshore Mechanics and Arctic Engineering (OMAE)" started in 1981, and later on the "International Society of Offshore and Polar Engineering (ISOPE)" started in 1991. A closer cooperation with the underlying committees of this work was established in the next period, see Sections 4 and 5.

4 Period 1981 to 1991 (Wardenier)

Prof. Wardenier

Under the Chairmanship of Prof. Wardenier (1981-1991) from Delft University of Technology, the main focus of the Sub-commission was to develop improved international-consensus design recommendations, see Section 11.2. The Sub-commission, initially with members Dutta, Hicks, Kato, Kurobane, Mang, Marshall, Mouty and Wardenier, was in this period extended with Messrs. De Back, Davies, Giddings, Packer, Tomkins, Ryan and Zettlemoyer, and later on with Niemi and Yeomans replacing Giddings. Through these members a closer connection was made with other relevant commissions, like AISC (American Institute of Steel Construction), API, CIDECT, ECSC and DoE (Dept. of Energy).

The first edition of the "Design recommendations for hollow section joints under predominantly statically loading", IIW Doc. XV-491-81, was published in 1981 and updated in

1989 in the second edition, IIW Doc. XV-701-89. Background information can be found in the various books in Section 11.3 (e.g. Wardenier 1982, Packer and Henderson 1992, 1997, Puthli 1998, Dutta 2002, Wardenier 2002) and the Design Guides in Section 11.4 (Wardenier et al. 1991, Packer et al. 1992) and their references. Further, the first edition of the "Recommended fatigue design procedure for hollow section joints", IIW Doc. XV-582-85, was published in 1985. These recommendations served as a basis for uniform design recommendations in the 90s in Eurocode 3, post-2000 for AISC, and many national standards.

Due to the activities of IIW Sub-commission XV-E, the topic of Tubular Structures was selected by IIW for the IIW Annual Assembly International Conference in 1984 in Boston. For his immense contributions in the field of Offshore Tubular Structures, Mr. Marshall from Shell Oil was elected and honored by IIW to give the keynote Houdremont Lecture (Marshall 1984), see Section 11.5.

After this successful IIW conference on Tubular Structures in Boston, the IIW Sub-commission XV-E felt that there was a need for such a conference every two or three years, in combination with the Annual Assembly of the IIW. Prof. Kurobane from Kumamoto University organized a following successful international meeting on Safety Criteria of Tubular Structures in combination with the IIW Annual Assembly in Tokyo, 1986. A third successful symposium was organized in 1989 by Prof. Niemi and Prof. Makelainen in Lappeenranta, Finland. As a result of the excellent cooperation between Sub-commission IIW-XV-E and CIDECT and their common interests, the fourth ISTS (1991) symposium in Delft, organized by Prof. Wardenier, was supported by both organizations.

In this period Mr. Dutta from MannesmannröhrenWerke AG, F.R. Germany, was Chairman of the Technical Commission of CIDECT and initiated, in cooperation with members of IIW Sub-commission XV-E, the publication of several Design Guides on static and fatigue design of hollow section joints. The static design guides for joints were all based on the IIW (1989) design recommendations and are shown in Section 11.4.

Although in this period many IIW-XV-E documents and other reports and publications were published and discussed in the Sub-commission, because of space only some are included in Section 11.1; i.e. on reliability (Kremer and Packer 1985), on CHS and RHS joints (Giddings and Wardenier 1986) on fatigue (Efthymiou 1988, van der Vegte et al. 1989) and on fillet welds (Frater and Packer 1990). Many further references can be found in the references of the various books and design guides in Sections 11.3 and 11.4.

5 Period 1992 to 2002 (Packer)

Prof. Packer

Under the chairmanship of Prof. Packer (1992-2002) from the University of Toronto the Sub-commission was extended with new members: Le Franc, Puthli, Grundy, Choo, Lee, van der Vegte and Farkas/Jãrmai. The Sub-commission continued to discuss new information from many research projects, for example on:

- Multiplanar joints (Makino, Paul, van der Vegte, Lee, Coutie, Yu, Liu)
- Beam-to-column connections (Kamba, de Winkel, Lu)
- Plate-to-CHS joints (Makino, Wardenier)

- Deformation limit (Lu, Wardenier, Zhao)
- Overlap joints (Chen, Dexter, Lee, Liu, Wardenier)
- Thick-walled joints (Choo, Qian)
- CHS stiffened joints (Choo, van der Vegte)
- Joints with concrete-filled chords (Packer, Choo)
- Knee joints (Kärcher, Puthli)
- Fatigue (Marshall, Buçak, Herion, Mang, Puthli, Romeijn, Karamanos, van Wingerde, Packer, Wardenier and research from ECSC offshore programs and other scources)
- Ductility and material aspects of cold-formed sections (Kosteski, Packer)
- For Plate-to-CHS joints Makino et al. (1996) provided an updated database and Kamba and Tabuchi (1994) made a database for CHS joints in moment resisting frames.
- Dier and Lalani (1998) presented new code formulations for CHS static strength included in ISO 19902.
- Wilkinson and Hancock (1998) presented new proposals for class 1 RHS section limits.
- Kosteski et al. (2003) presented results on the notch toughness of RHS members.

Importantly, the Sub-commission decided to include, besides the peak load, an additional deformation limit of $3\%d_0$ or $3\%b_0$ as an ultimate limit state to avoid an additional check or excessive deformation at the serviceability load level. The background can be found in Lu et al. (1994) and confirmation can be found in Zhao (2000).

The second edition of the "Recommended fatigue design procedure for welded hollow section joints, Part 1 – Recommendations and Part 2 – Commentary", International Institute of Welding, IIW Doc. XV-1035-99/XIII-1804-99, was published in 1999. Background for these recommendations can be found in van Wingerde et al. (1997a, 1997b) which is for CHS joints based on the work of Herion (1994), Romeijn (1994) and Karamanos et al. (1997).

In this period the following successful International Symposia on Tubular Structures (ISTS) were organized:
- The fifth ISTS (1993) in Nottingham was organized by Dr. Coutie and Dr. Davies from the University of Nottingham, UK.
- The sixth ISTS (1994) in Melbourne was organized by Prof. Grundy and colleagues from Monash University, Australia.
- The seventh ISTS (1996) in Miskolc was organized by Prof. Farkas and Prof. Jãrmai from the University Miskolc, Hungary.
- The eighth ISTS (1998) in Singapore was organized by Prof. Choo and Dr. van der Vegte from the National University of Singapore.
- The ninth ISTS (2001) in Düsseldorf was organized by Prof. Puthli and Dr. Herion from the University of Karlsruhe, Germany.

In this period Prof. Wardenier from Delft University of Technology was elected and honored by IIW for his work in the field of steel structures to give, in 1992, the keynote Houdremont Lecture at the IIW Annual Assembly in Madrid, see Section 11.5.

Dr. van Wingerde (Delft University of Technology / University of Toronto) received in 1993 the Henry Granjon Prize at the IIW Annual Assembly in Glasgow, UK for his studies on fatigue of welded RHS joints;

Prof. Kurobane

The IIW Sub-commission XV-E decided to start, from the eighth ISTS, the Symposium with a "Kurobane Lecture" in the form of a keynote address and an award in honor of the prodigious contribution by Prof. Kurobane to the knowledge of Tubular Structures.

Prof. Yoshiaki Kurobane, born in 1931 in Osaka, got his doctoral degree in 1958 from Osaka University, worked at Osaka University and Kumamoto University and stayed at the University of Texas and the University of Queensland as a Visiting Professor. He was appointed in 1971 as full Professor at Kumamoto University. He retired in 1997 from Kumamoto University, after which he continued as Professor at Sojo University until 2005. He passed away in 2009.

Prof.Kurobane was, since 1969, a member of IIW Commission XV and Sub-commission XV-E. His work in the field of Tubular Structures is legendary and the work of his team in Kumamoto forms the basis of the international design recommendations of the IIW (1989) and CIDECT (1991) for circular hollow section joints.

Prof. Kurobane delivered the inaugural "Kurobane Lecture" at ISTS8 in Singapore in 1998. The subsequent Kurobane Lecturers up to ISTS16 are listed in Section 11.6.

6 Period 2003 to 2014 (Zhao)

Prof. Zhao

Under the chairmanship of Prof. Zhao (2003-2014) from Monash University, Melbourne, the Sub-commission concentrated on the development of updated IIW recommendations for static design and for fatigue design and using these as a basis for the development of ISO standards.

In this period the Sub-commission was extended with new members: Chen, Gardner, Heidarpour, Herion, Iglesias, Nussbaumer, Ochi, Schafly and van der Vegte.

The third edition of the "Recommendations for fatigue design procedure of welded hollow section joints and components", IIW Doc. XV-1254r4-07, was published in 2007 as ISO 14347. Note: Alternative SCF equations for CHS joints are used in ISO 19902 based on Efthymiou (1988).

Also, the third Edition of the "Static design procedure for welded hollow section joints – Recommendations", initially published in 2008 as XV-1281r1-08 and later superseded by IIW Doc. XV-1402-12, was published as ISO 14346 in 2013. Note: Alternative equations for the static design of circular hollow section joints are used in ISO 19902, see Dier and Lalani (1998).

In this period, updates were also published for the CIDECT Design Guides 1 and 3, see Wardenier et al. (2008) and Packer et al. (2009). These were based on the drafts of these IIW (2008/2012) and ISO 14346 (2013) recommendations.

For fatigue design, the background information for the third edition of the IIW recommendations was nearly the same as for the second edition. For static design, however, many re-analyses were carried out for the third edition of the IIW recommendations which are summarized in the following background publications:
- General and philosophy: see Zhao et al. (2008) and van der Vegte et al. (2008a)
- CHS T, X and K gap joints: see van der Vegte et al. (2007a, 2008b, 2014) and Qian et al. (2008).
- CHS overlap joints: see Qian et al. (2007) and Wardenier (2007c).
- CHS plate-to-CHS joints: see Wardenier (2008a)
- Comparison with other codes: see Wardenier et al. (2008b) and Pecknold et al. (2007)
- RHS T, X and K gap joints: see (Wardenier et al. (2010)
- For RHS overlap joints: see Chen et al. (2005) and Liu et al. (2005)
- For chord stress effect in RHS joints: see Wardenier et al. (2007a, 2007b).

In this period Choo et al. (2005) performed nonlinear analysis of tubular space frames and reported that large differences were observed between the results of various researchers and the actual test data. Further, CHS joints stiffened by collar or doubler plates were investigated by Choo et al. (2004). The component method came again under discussion (Weynand et al. 2006) but it was felt that it was not yet sufficiently mature for the design of hollow section joints. Further, the ductility of cold-formed sections received more attention, see Kosteski et al. (2003), Puthli and Herion (2005), Packer et al. (2010) and Puthli and Packer (2013). Based on Puthli et al. (2013) the Sub-commission decided to decrease the minimum permitted section thickness for hollow section joints to 1.5 mm.

In this period Prof. Packer from the University of Toronto was elected and honored by IIW for his excellent work on hollow section joints to give, in 2006, the keynote Houdremont Lecture at the IIW Annual Assembly in Québec City, see Section 11.5.

Furthermore, Mr. McFadden (University of Toronto) received in 2014 the Henry Granjon Prize at the IIW Annual Assembly in Seoul, Korea for his study on weld design for RHS joints.

The following successful International Symposia on Tubular Structures (ISTS) were organized:
- The tenth ISTS (2003) in Madrid was organized by Mr.Jaurrieta and colleagues of the Instituto para Construcción Tubular, Spain.
- The eleventh ISTS (2006.) in Québec City was organized by Prof. Packer and Dr. Willibald of the University of Toronto, Canada.
- The twelfth ISTS (2008) in Shanghai was organized by Prof. Chen and colleagues of Tongji University, China.
- The thirteenth ISTS (2010) in Hong Kong was organized by Prof. Young of the University of Hong Kong, China.
- The fourteenth ISTS (2012) in London was organized by Prof. Gardner of Imperial College, UK.

In this period the number of papers submitted to the ISTS Symposia from outside the traditional sources, such as Europe, North America and Japan, increased considerably – especially from China, Australia and Brazil.

7 Period 2015 to present (Ummenhofer)

Prof. Ummenhofer

Under the chairmanship of Prof. Ummenhofer (2015-now) from KIT Karlsruhe the Sub-commission was extended with members Morris and Fleischer.

The Sub-commision discussed the modifications included for hollow section joints in Eurocode 3 and subsequent background documents by Puthli and Wardenier. The effective width terms in the equations for brace shear of RHS overlap joints have been simplified, see Wardenier et al. (2016). Based on the discussions on plate-to-CHS joints and using the recent evidence in Voth and Packer (2012a, 2012b, 2012c, 2016) a new proposal was formulated by Wardenier et al. (2018) which has been adopted in Eurocode 3. For the chord stress influence functions of hollow section joints a lower limit of 0.4 or 0.3 was agreed.

In this period the following successful International Symposia on Tubular Structures (ISTS) were organized:

- The fifteenth ISTS (2015) in Rio de Janeiro was organized by Prof. Batista of the Federal University of Rio de Janeiro and Profs.Vellasco and Lima of the State University of Rio de Janeiro, Brazil.
- The sixteenth ISTS (2017) in Melbourne was organized by Dr. Heidarpour and Prof. Zhao of Monash University, Australia.

Dr. Tousignant (University of Toronto) received in 2018 the IIW Henry Granjon Prize at the IIW Annual Assembly, Bali, Indonesia on weld design for CHS joints.

7.1 Items which require further analysis

- Chord sidewall buckling

Based on the collected information and proposed design approach by Kuhn et al. (2019), the data of Yu (1997) and recent data presented at this symposium, an improved less-conservative criterion with an improved angle function for chord side wall buckling of RHS joints has to be formulated.

- Open RHS chord end length for RHS joints

Fan and Packer (2017) determined the minimum distance from a brace to a chord open end for application of "traditional" RHS joint strength rules, providing chord face plastification governs. However, this "end distance requirement" still needs to be generalized to accommodate additional limit states.

Hollow section joints in high-strength steel

Currently hollow section joints in high-strength steel are a hot item but the proposed modifications are contradictory. It is already known for a long time that welded joints in higher strength steel show lower effective lengths than mild steel, see Rolloos (1969). Thus, fracture may be governing for joints in higher-strength steel grades whereas plastic failures were governing for similar joints in lower-strength steels.

The current design equations are related to the yield strength but for fracture the ultimate strength actually governs. Since fracture becomes more dominant for joints in high-strength steel, it may have been better to compare the resistance based on the ultimate tensile stress f_u. The following conclusions from existing research clearly show that a thorough analysis is required which could be the task of the Sub-commission.

Mang et al. (1978), Kurobane and Makino (1987), Liu and Wardenier (2004), and Puthli et al. (2013) all indicated, related to yield, material factors in the order of 0.9 for S460 and about 0.8 for S690.

Lalani et al. (1993) and Noordhoek et al. (1996) found, for CHS joints, that the yield stress should be limited to $0.8f_u$ with f_u being the ultimate tensile stress.

Björk and Tuominen (2016), Tuominen and Björk (2016) state for RHS joints, and Lan et al. (2017) and Lee et al. (2018) state for CHS X joints loaded in compression, that up to S700 no material factors are required.

Sedlacek and Müller (2001) already indicated that the effect of secondary bending moments in lattice girders should be one of the crucial research themes for the safe use of high-strength steels. Björk et al. (2015) also state that for RHS joints in high-strength steel secondary bending moments have to be considered in the design. They found secondary bending stresses in RHS K gap joints of 45% to 64% of the axial stresses, which agrees with the values of 40-60% found by Wardenier (1982).

Wilkinson and Syam (2014), Mohan and Wilkinson (2015) and Becque and Wilkinson (2017) conclude for RHS joints in S450 that, for plastic failure modes no material factor or yield stress limit is required. For failure modes related to fracture or ductility or liable to brittle failure the material factor of 0.9 and the yield stress limit of to $0.8f_u$ should remain.

Ladendorf et al. (2018) studied RHS N joints in S700 numerically and concluded that, based on yield, a material factor of 0.8 is required and further for fracture failures a partial factor of 1.25 or based on yield a yield stress limit of $0.8f_u$. Further, the secondary bending effects should be taken into account.

Thus, from the available data it can be concluded that some conclusions are contradictory and require more detailed analysis. Further, in analysing the data, all important factors have to be considered, i.e. definition of resistance, (change in) failure mode, mean strength in recommendation, scatter in data, deformation capacity, welding, secondary effects, etc.

8 IIW-XV-E, ISO recommendations, Design Guides and books

The IIW and ISO recommendations developed by IIW-XV-E are summarized in Sections 11.2 and 11.3. ISO 19902 is not drafted by IIW XV-E but has been added because it gives the latest draft for the international recommendations for circular hollow section joints currently used in the offshore industry.

9 The way ahead

Currently, the main focus is on the behavior of tubular structures made of high-strength steel. Here, the same warnings apply as in the early period of tubular structures made of the lower-strength steels. Welded tubular joints require an integrated approach, considering design, material selection, fabrication, welding and inspection (Marshall 1984). The design includes more than stress analysis calculations to dimension the structural elements.

The designer must understand the behavior and the demands he or she places on the material to be used, especially with regard to local ductility beyond yield and the deformation capacity of the joint. Again, a thorough review and understanding of all available data of high-strength steel joints is required.

10 Acknowledgment

Appreciation is extended to all members and past members of IIW Sub-commission XV-E for their enthusiasm and contributions by presenting discussion documents and papers. Further, I would like to express my sincere thanks to my successors and friends Jeff Packer and Xiao-Ling Zhao for their friendship, discussions and help in collecting the information for this paper.

Last, but not least, I would like to thank my previous "tubular PhD team" in Delft (van Wingerde, van der Vegte, Romeijn, Panjeh Shahi, de Winkel, Lu and Yu) for their excellent contributions, along with the excellent guidance of Mr. de Koning †, Dr. Liu †, and Prof. Puthli (later University of Karlsruhe). Without them, we could never have contributed so much. Also my thanks go to Prof. Choo and Dr. Shen and staff at the National University of Singapore for their excellent collaboration and friendship.

11 References and literature

In the selected references, preference is given to background papers and publications which serve as background for the IIW, ISO or CIDECT recommendations, or which give additional information. The author apologizes that not all important literature could be included, but more detailed references are given in the books in Section 11.3, the Design Guides given in Section 11.4, and the IIW and ISTS keynote lectures given in Sections 11.5 and 11.6.

11.1 *Selected Publications*

Akiyama, N., Yayima, M., Akiyama, H. and Otake, F., *Experimental study on strength of joints in steel tubular structures.* Journal of Society of Steel Construction, JSSC, Vol. 10, No. 102, 1974 (translation from Japanese).

Bader, W., Geschweisste Rohranschlüsse und Abkant-Hohlprofile bei dynamisher Beanspruchung. Schweisstechnik, No. 12, Berlin, 1963.

Becque, J. and Wilkinson, T., *The capacity of grade C450 cold-formed rectangular hollow section T and X connections: An experimental investigation,* Journal of Constructional Steel Research, Vol. 133, 2017, 345–359.

Bettziche, P., *Konstruktieve Gestaltung von Knotenpunkten aus Vierkanthohlprofilen*. Studienhefte zum Fertigbau, Nr. 12, Vulkan Verlag, Essen, 1969.

Billington, C.J., *Application of high strength steels in design of fixed offshore structures*. IBC Conference on safe design and fabrication of offshore structures, London, 1993.

Bouwkamp, J., Tests on experimental gusset plate connection for large tubes TNO-IBBC report-57-1075, Delft, The Netherlands, 1957.

Bouwkamp, J.G., *Concept on tubular joint design.* Journal of the Structural Division, Proceedings ASCE, Vol. 90, No. ST2, 1964.

Björk, T. and Saastamoinen, H., *Capacity of CFRHS X joints made of double grade S420 steel.* Tubular Structures XIV, Taylor & Francis, London, 2012.

Björk T., Tuominen N. and Lähde T., *Effect of secondary bending moment on K-joint capacity.* International Symposium on Tubular Structures ISTS-15. Rio de Janeiro, 2015.

Björk T. and Tuominen N., Rules on high strength steel (RUOSTE), Report RFSR-CT-2012-00036, Part Tubular joints. Publications Office of the European Union, 2016.

Chen, Y., Liu, D.K. and Wardenier, J., *Design recommendations for RHS-K joints with 100% overlap*. Proceedings 15th International Offshore and Polar Engineering Conference, Vol. IV, Seoul, 2005.

Choo, Y.S., Liang, J.X. and Vegte, G.J. van der, *An effective external reinforcement scheme for circular hollow section joints.* Proceedings ECCS-AISC Workshop 'Connections in Steel Structures V', Bouwen met Staal, Zoetermeer, 2004.

Choo, Y.S., Qian, X.D. and Foo, K.S., *Nonlinear analysis of tubular space frame incorporating joint stiffness and strength.* Proceedings 10th International Conference on Jack-up Platform Design, Construction and Operation, City University, London, 2005.

Coutie, M.G., Davies, G. Bettison, M. and Platt, J., Development of recommendations for the design of welded joints between steel structural hollow sections or between steel structural hollow sections and H sections. Final report, Part 3, ECSC contract 7210.SA/814, University of Nottingham, 1983.

Davie, J. and Giddings, T.W., Research into the strength of welded lattice girder joints in structural hollow sections. CIDECT Report 5EC/71/7/E, 1971.

Dier, A.F. and Lalani, M., *New code formulations for tubular joint static strength.* Proceedings 8th International Symposium on Tubular Structures, Singapore, Tubular Structures VIII, Balkema, Rotterdam, The Netherlands, 1998.

Eastwood, W. and Wood, A.A., *The static strength of welded joints in structural hollow sections*. Constructional Steelwork, 1971.

Efthymiou, M., Local rotational stiffness of unstiffened tubular joints. Report RKER 85.199, KSEPL, Shell, Rijswijk, 1985.

Efthymiou, M., *Development of SCF formulae and generalized influence functions for use in fatigue analysis.* Proceedings Offshore Tubular Joints Conference, Surrey, 1988.

Fan, Y. and Packer, J.A., *RHS-to-RHS axially loaded X-connections near an open chord end*, Canadian Journal of Civil Engineering, Vol. 44, 2017, 881-892.

Frater, G.S. and Packer, J.A., Design of fillet weldments for hollow structural section trusses. CIDECT Report 5AN/2-90/73, University of Toronto, 1990.

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