Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

DESIGN S-N CURVES FOR T-, K-, AND X-CONCRETE-FILLED STEEL TUBULAR JOINTS

I. MUSA, F. R. MASHIRI, and X. ZHU

School of Computing, Engineering and Mathematics, Western Sydney University, Sydney, Australia.

High stress concentration at the weld vicinity in welded steel tubular joints results in fatigue failure. Researchers have tried finding an effective method to reduce these stresses. Although concrete filling of the steel tubes has been used to reduce stresses at the joints in the recent two decades, the fatigue performance of concrete filled tubular joints is not yet fully understood. This paper summarizes research on the fatigue strength of concrete-filled steel tubular T- , K-, and X-joints. Based on available experimental results, the nominal stress and hot spot stress design S-N curves for concrete-filled steel tubular joints have been derived. The least squares method is used in the derivation of the design S-N curves according to the American Society for Testing and Materials (ASTM) specifications.

Keywords: Experimental, Hot spot stress, Nominal stress range, Stress concentration factor, Fatigue tests, CFST joints.

1 INTRODUCTION

Steel tubular members are widely used in offshore structures and infrastructure entities such as oil platforms and bridges. The tubular members are exposed to repetitive loading from sea waves, wind and traffic. Repetitive loading causes deterioration of the structural members through crack initiation and propagation which is called "Fatigue". Fatigue strength has always taken most attention in the design of steel tubular members. Due to geometric discontinuity at the connected steel tubular members, high stress concentration exists at the joint. The location of high stresses is usually the location of fatigue crack initiation. In the last century a large amount of research was conducted on empty (non-filled) steel tubular joints which resulted in development of various fatigue design guidelines such as ABS (2003), API (1993), AWS (1996), and CIDECT (Zhao *et al.* 2000). Since the beginning of the current century, researchers have effectively used concrete filling of the steel tubes to reduce stress concentration at the joint. The filling concrete absorbs some of the applied energy which results in less stress concentration by reducing tube wall deformations. Among fatigue life estimate methods, the Hot Spot Stress method has been successfully used in estimating fatigue life of tubular members. The maximum stress in the joint due to specific loading format is the hot spot stress in the joint. The maximum stress concentration factor (SCF) is the ratio of the hot spot stress to the applied nominal direct stress. In this method, the maximum SCF is multiplied by the nominal stress range at the joint to provide the hot spot stress range. The resultant hot spot stress range along with an appropriate S-N design curve is used to estimate the fatigue life of the joint. Hence, this method depends on the accurate prediction of SCF.

This paper summarizes the experimental research conducted on three different types of concrete filled steel tubular (CFST) joints. These joints include CFST T-joints, K-joints and X-joints. Through the review, the research gap is sought and highlighted. Based on current fatigue experimental results, S-N design curves for concrete filled steel tubular (CFST) joints are derived.

2 CONCRETE FILLED STEEL TUBULAR T-JOINTS

2.1 Fatigue Life Estimate in CFST T-Joints

Jardine (1993) conducted fatigue tests on two repaired CFST T-joints. These two circular T-joint specimens were previously fatigue damaged. The specimens were repaired and then the chord was filled with concrete. Fatigue tests for the repaired specimens were conducted under constant amplitude sinusoidal axial loading on the brace member with a stress ratio (R) equal to -1. Compared to the Department of Energy Department of Energy (1990) design S-N curve for non-filled T-joints, fatigue test results for the repaired specimens showed that concrete filling the chord had no impact on the fatigue resistance of the T-joints. The reason was the repair performed on the joints, since it was uncertain that the repaired weld was the same as that of its undamaged condition.

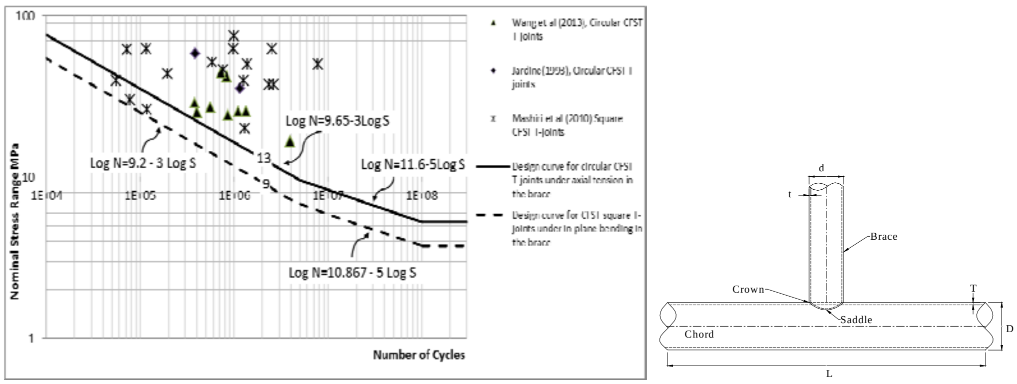
Wang *et al.* (2013) conducted fatigue tests on concrete filled chord steel circular T-joints under axial loading in the brace. Ten specimens were subjected to destructive fatigue tests under cyclic axial force in the brace with constant amplitude from tension to tension. It was indicated that the fatigue behavior of concrete filled T-joints was better than that of non-filled T-joints when subjected to same axial force range or nominal stress range in the brace.

Mashiri *et al.* (2010) investigated the fatigue strength of concrete-filled chord square hollow T-joints under in-plane bending in the brace. Fatigue S–N data were obtained from fatigue testing results of seventeen concrete filled chord square tubular T-joints subjected to constant stress amplitude cyclic in-plane bending load in the brace. The results were compared to those for empty square hollow section T-joints from previous research.

The fatigue life of concrete filled tubular T-joints between the first visible crack and the total loss of strength was quite short (Wang *et al.* 2013). In the paper, the ratio of the number of load cycles at the total loss of strength (N_f) to the number of load cycles at the first visible crack (N_c) was between 1.02 to 1.12. This is due to the high stress range applied in the tests. Applying higher stress range after the first crack is initiated results in lower fatigue life.

2.2 Nominal Stress Range Design Curve for CFST T-Joints

Fatigue data obtained in the research done by Jardine (1993), Mashiri *et al.* (2010) and Wang *et al.* (2013) are used in deriving design S-N curves for T-joints based on the nominal stress range in the brace (Classification Method). The results are shown in Figure 1. The least squares method is used in deriving the design S-N curve for circular CFST T-joints according to ASTM E739-10 specifications, where the number of cycles (N) is the dependent variable and the stress (S) is the independent variable. The slope of the proposed S-N curve is taken as 3 in the analysis, similar to the design S-N curves in AS4100-1998. The design curve for circular CFST T-joints in Figure 1 is the mean minus two times of the standard deviation curve.



b) Design Curves a) Circular T-joint

Figure 1. Nominal stress range design curves for CFST T-joints.

3 CONCRETE FILLED STEEL TUBULAR (CFST) K-JOINTS

3.1 Fatigue Life Estimate in CFST K-Joints

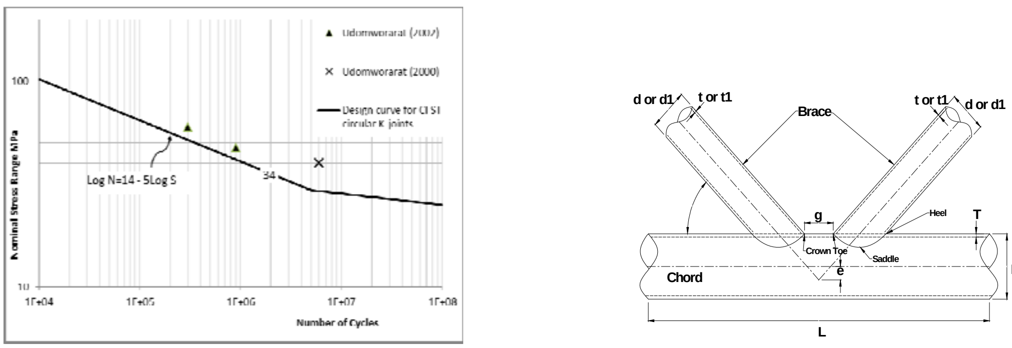
Udomworarat *et al.* (2000) conducted fatigue tests on two concrete filled chord steel circular K-joints subjected to constant amplitude loading. Fatigue life between the number of load cycles at a 5mm crack (N_c) and the total failure (N_f) in the concrete filled specimens was quite long. The ratio N_f/N_c was about 5.5. Fatigue strength in terms of hot spot stress and the number of cycles to failure of the specimens were plotted along with the design curve by United Kingdom Department of Energy (1990). Generally, it was found that concrete filling the chord increased the fatigue life of the joints.

Udomworarat *et al.* (2002) carried out an experimental study on the fatigue performance of concrete-filled steel tubular K-joints used for a high speed train bridge. Fatigue tests performed for two concrete filled chord circular K-joints under constant cyclic loading applied axially to the chord. The fatigue lives of the concrete filled specimens were considerably greater than that of the non-filled specimens. It was found that fatigue life assessment of tubular joints using JSSC (1995) design curves was possible.

Fatigue life of CFST K-joints between the first visible crack and total failure was quite long unlike what was found in CFST T-joints above (Udomworarat *et al.* 2000; 2002). The reason is because of the lower applied stress range. The fatigue life after crack initiation is highly influenced by the applied stress range, and the higher applied stress range after crack initiation makes the lower fatigue life.

3.2 Nominal Stress Range Design Curve for CFST K-Joints

A nominal stress range design S-N curve for K-joints (Classification Method) is developed based on fatigue data in Udomworarat (2000) and Udomworarat (2002). The proposed design S-N curve is shown in Figure 2. Due to lack of data, a deterministic lower bound curve is chosen as a design curve. The design curve has a detail category of 34 and a slope of 5 as is typical for lattice girders. The reliability of the proposed design S-N- curve in Figure 2 cannot be confirmed due to lack of experimental data. Hence further fatigue tests are necessary to establish a reliable design curve for CFST K-joints.



a) Design curve

b) Circular K-joint

Figure 2. Nominal stress range design curve for CFST K-joints.

4 CONCRETE FILLED STEEL TUBULAR X-JOINTS

Qian *et al.* (2014) examined the fatigue performance of concrete filled chord steel tubular X-joints. Two full scale specimens were subjected to two constant-amplitude cyclic loading. The crack propagation life (fatigue life between crack initiation and total loss of strength) was quite long. It was about 50–93% of the total fatigue life. For comparison, fatigue test results for CFST X-joints along with a design S-N curve according to AS4100-1998 are shown in Figure 3.

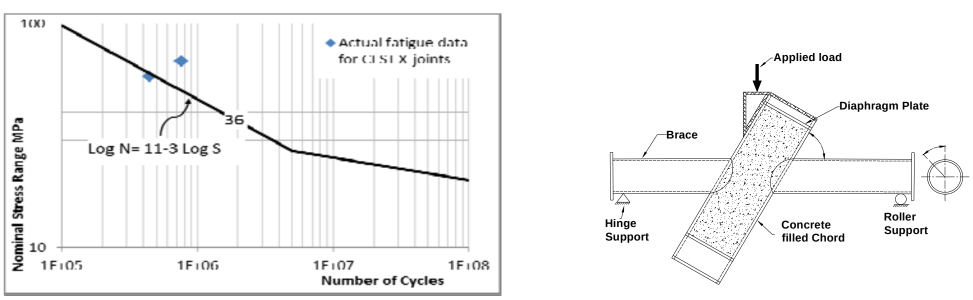


Figure 3. A concrete-filled chord X-joint and a design S-N curve according to AS4100-1998.

5 HOT-SPOT STRESS DESIGN S-N CURVES

In the Hot Spot stress method, the maximum hot spot stress in the joint is related to the number of cycles to failure. Hence for the same wall thickness, one curve can be fitted for different joint geometries. Hot spot stress design S-N curves for three different wall thicknesses are developed based on fatigue data obtained in the research above. The S-N design curves are shown in Figure 4. The least square method is used in developing the S-N design curves according to ASTM E739-10 specifications, where the number of cycles (N) is the dependent variable and the stress (S) is the independent variable. The design curves in Figure 4 are the mean minus two standard deviations curves.

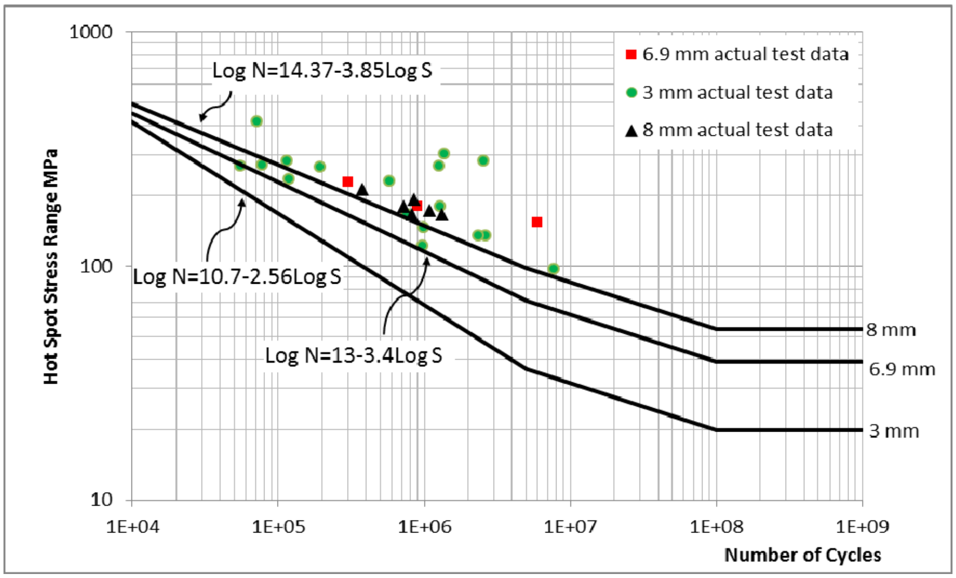


Figure 4. Hot spot stress design curves.

6 CONCLUSIONS AND DESIGN RECOMMENDATIONS

Fatigue tests conducted on concrete filled steel tubular T-, K- and X-joints have been reviewed in the literature. The following remarks have been obtained:

- Fatigue test results in concrete filled T-joints obtained by Jardine (1993) contradict results obtained by other researchers on similar joints. This is due to the fact that the specimen has been repaired in Jardine’s research.
- In general, the fatigue life of concrete filled tubular joints has been improved by concrete filling the chord.
- Higher applied stress range in fatigue tests leads to higher hot spot stresses which lead to lower cycles before crack initiation and higher crack propagation rate. Hence the applied stress range in fatigue tests plays a major rule in fatigue life estimate of the tubular joints.

- The research conducted so far on concrete filled tubular joints is insufficient. Further research is required to build a solid and comprehensive understanding of the behavior of concrete filled tubular joints and to have sufficient results for producing reliable guidelines.
- Parametric equation for estimating stress concentration factors (SCFs) in CFST T- and K-joints have not been reported in literature. Hence, a comprehensive study is required for deriving SCF equations in CFST joints.
- Fatigue research on concrete filled tubular joints under variable amplitude is required to be performed to understand the difference between behavior under constant and variable amplitude loading.

References

ASTM E739-10, *Standard Practice for Statistical Analysis of Linear or Linearized Stress-Life (S-N) and Strain-Life (ε-N) Fatigue Data*, ASTM International, West Conshohocken, PA, 2010.

ABS American Bureau of Standard. *Guide for the fatigue assessment of offshore structures*. Houston: American Bureau of Shipping, 2003.

API. American Petroleum Institute, *Recommended practice for planning, designing and constructing fixed offshore platforms.* API RP2A-LRFD, Washington D.C, 1993.

AWS. American Welding Society, *Structural welding code-Steel*. ANSI/AWS D1.1-96. Miami: American Welding Society, Inc., 1996.

Department of Energy, *Offshore installations: guidance on design, construction and certification.* HMSO. UK, 1990.

Jardine, B., *Fatigue Life Enhancement of Tubular Joints by Grout Injection.* Offshore Technology Report-Health and Safety Executive OTH 92 368, 1993.

JSSC, *Fatigue Design Recommendations for Steel Structures,* 1995.

Mashiri, F. R. and Zhao, X.-L. Square hollow section (SHS) T-joints with concrete-filled chords subjected to in-plane fatigue loading in the brace. *Thin-Walled Structures* 48(2), 150-158, 2010.

Qian, X., Jitpairod, K., Marshall, P., Swaddiwudhipong, S., Ou, Z., Zhang, Y., and Pradana, M. R., Fatigue and residual strength of concrete-filled tubular X-joints with full capacity welds. *Journal of Constructional Steel Research* 100: 21-35, 2014.

SA, 4100-1998 Steel Structures, Standards Australia. Sydney, 1998.

Udomworarat, P., Miki, C., Ichikawa, A., Komechi, M., Mitsuki, K., and Hosaka, T., Fatigue Performance Of Composite Tubular K-Joints For Truss Type Bridge. *Structural Mechanics and Earthquake Engineering JSCE* 19(2), 65-79, 2002.

Udomworarat, P., Miki, C., Ichikawa, A., Sasaki, E., Sakamoto, T., Mitsuki, K., and Hosaka, T., Fatigue and ultimate strengths of concrete filled tubular k-joints on truss girder. *Journal of Structural Engineering ASCE* 46(3), 1627-1635, 2000.

Wang, K., Tong, L., Zhu, J., Zhao, X., and Mashiri, F., Fatigue Behavior of Welded T-Joints with a CHS Brace and CFCHS Chord under Axial Loading in the Brace. *Journal of Bridge Engineering ASCE* 18(2), 142-152, 2013.

Zhao, X., Herion, S., Packer, J., Puthli, R., Sedlacek, G., and Wardenier, J., *Design guide for circular and rectangular hollow section joints under fatigue loading.* CIDECT Publication. Germany: TUV-Verlag, 2000.