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Members
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Ref: RP 86-18, "Weld Profile and Thickness Effects on Fatigue of Tubular Welded Joints" - Annotated References

Gentlemen:

A list of annotated references for the project, referred to above, is enclosed for your evaluation. Efforts will be made to acquire the references marked with asterisks, together with other relevant references, as the project progresses.

With best wishes and kind regards.

Yours sincerely,

M. Arockiasamy D.V. Reddy

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RP 86-18

# WELD PROFILE AND THICKNESS EFFECTS ON FATIGUE OF TUBULAR WELDED JOINTS

## Annotated References

(1) S. Berge, and K. Engesvik, "Effect of Plate Thickness in Fatigue of Transverse Fillet Welds", Proc. Int. Conf. on Steel in Marine Structures, Special Plenary Sessions, Vol. I, Paris, France, 1981.

Transverse, non-load carrying fillet welds in structural steel with plate thicknesses varying from 12.5 to 60 mm were tested in axial tension in air. The fatigue strength was found to decrease significantly with increasing thickness. Two analytical models were used for fatigue life estimation using i) the weld toe angle, and ii) the weld toe angle and notch radius as the primary parameters.

(2) M.B. Gibstein, "Fatigue Strength of Welded Tubular Joints Tested at Det Norske Veritas Laboratories", Proc. Int. Conf. on Steel in Marine Structures, Special Plenary Sessions, Vol II, Paris, France, 1981.

The paper reports the results of the fatigue tests, carried out at Det Norske Veritas. A S-N curve based on 11 fatigue tests is presented. The paper also describes

fatigue crack propagation measurements through the wall thickness of the test models. The results of corrosion fatigue tests carried out on two T-joints are also presented.

(3) D. Radenkovic, "Stress Analysis in Tubular Joints", Proc. Int. Conf. on Steel in Marine Structures, Special Plenary Sessions, Vol III, Paris, France, 1981.

The S-N curve approach is shown to be a complement to the empirical approach based on fracture mechanics. The Marine Technology Research program funded by the ECSC contributed significantly to understand the fatigue behavior of tubular joints.

(4) W. Schutz, "Procedures for the Prediction of Fatigue Life of Tubular Joints", Proc. International Conf. on Steel in Marine Structures, Special Plenary Sessions, Vol III, Paris, France, 1981.

Results from the Dutch, U.K., Norwegian, French, and German fatigue programs are presented and the fatigue life prediction methods, i.e. Miner's rule, the relative miner rule and Paris' and Forman's equations are discussed.

(5) P.J. Haagensen, "Improvement of the Fatigue Strength of Welded Joints", Proc. Int. Conf. on Steel in Marine Structures, Special Plenary Sessions, Vol III, Paris, France, 1981.

A survey of research work within ECSC and Norway, on fatigue strength improvement has been reported. The test results are compared with the existing weld design codes.

(6) J. de Back, "Strength of Tubular Joints", Proc. Int. Conf. on Steel in Marine Structures, Special Plenary Sessions, Vol III, Paris, France, 1981.

The fatigue behavior of plate specimens tested in ECSC-Offshore Steels Program is reported; the effects of environment (air, seawater, cathodic protection), loading conditions (constant amplitude, stress ratio), welding parameters, and plate thickness are studied, and the influence of test results on the design curve is discussed.

(7) Offshore Installations: Guidance on Design and Construction, Department of Energy, HMSO, London, 1984.

(8) "Rules for the Design, Construction, and Inspection of Offshore Structures", Det Norske Veritas, 1977.

(9*) Regulations for the Structural Design of Fixed Structures on the Norwegian Continental Shelf, Norwegian Petroleum Directorate, 1977.

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* - will be acquired during the project

(10) American Welding Society, Structural Welding Code-Steel, AWS D1, 1-84.

(11) American Petroleum Institute, Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, API RP 2A, 15th ed., Dallas, 1984.

The fatigue design rules currently used (7, 8, 9, 10, 11) are based on S-N data obtained from laboratory tests with different plate thicknesses.

(12) J. de Back and G.H.G. Vaessen, "Effect of Plate Thickness, Temperature, and Weld Toe Profile on the Fatigue and Corrosion Fatigue Behavior of Welded Offshore Structures", Part II, ECSC Final Report, Delft Univ., Technology, 1984.

The results of the second ECSC-program on fatigue of offshore steel structures are presented including the corrosion fatigue testing of welded tubular T-joints. Welded T-plates were tested under four point bending to assess the effect of plate thickness, weld geometry, and sea water temperature. The increase in plate thickness from 16 mm to 70 mm reduced the fatigue endurance by 62% with a stress range of 120 N/mm2. The thickness effect was observed to level off at higher stress ranges. A smaller weld angle was found to contribute only a slight increase of fatigue life for the as welded specimens. Weld toe grinding contributed a more pronounced improvement in

fatigue life. Allowance for the thickness effect based on fracture mechanics computations is considered by the DnV code in the fatigue analysis.

(13) J. de Back, and G.H.J. Vaessen, "Fatigue and Corrosion Fatigue Behavior of Offshore Steel Structures", ECSC Final Report, Delft Univ. Technology, 1981.

The Dutch part of the ECSC-Offshore Steels Research Program on tubular joint fatigue is presented in which a number of parameters, i.e. environment, loading conditions, weld parameters, and plate thickness have been taken into account.

(14) A. Bignonnet, H.P. Lieurade, and L. Picouet, "Improvement of the Fatigue Life for Offshore Welded Connections", Proc. Second Int. Conf. on Welding of Tubular Structures, Boston, Pergamon Press, 1984, pp. 271-278.

An improved weld procedure and a global post weld improvement technique were developed to improve the fatigue behavior of tubular T-joints. To simulate the hot spot region of a tubular T-joint, a T-shaped welded plate joint was used for fatigue testing in three-point bending. The effects of improved weld profile on fatigue life of the joint are compared with that of a conventional joint.

(15) J.G. Hicks, "A Comparative Review of Fatigue Design Rules for Tubular Structures", Proc. Second Int. Conf. on Welding of Tubular Structures, Boston, Pergamon Press, 1984, pp 431-437.

There are a number of design rules for tubular structures subjected to fatigue loading conditions. The rules most widely accepted in offshore industry are, those of U.K., British Standards Institution (BSL), API, AWS, and DnV codes. The paper discusses the differences between the various rules, particularly in the high-cycle region.

(16) F. Mung, and O. Bucak, "Fatigue Behaviour of Welded Tubular Joints Design Proposal and Background Information", Proc. Second Int. Conf. on Welding of Tubular Structures, Boston, Pergamon Press, 1984, pp. 471-491.

The draft of Eurocode 3, Part 9, is illustrated with background information in the form of S-N curves, plotted from test results, on K and X joints.

(17) J.G. Wylde, "Fatigue Crack Growth in Welded Tubular Joints", Proc. Second Int. Conf. on Welding of Tubular Structures, Boston, Pergamon Press, 1984, pp. 561-571.

The paper discusses the results of fatigue tests carried out in the U.K. as part of the Department of Energy's 'UKOSRP' program. The characteristics of fatigue crack development were found to depend on joint type and mode of loading. Initially fatigue cracks propagated more rapidly along the surface of the specimen than in the through-thickness direction with a low crack aspect ratio.

(18) U.S. Coast Guard, "Long Term Corrosion Fatigue of Welded Marine Steels, Ship Structure Committee Report, SSC-326, 1984.

The report presents mathematical models to quantify the environmental and loading variables on fatigue crack initiation and propagation. The initiation model utilized the local stress-strain approach with a modified Neuber rule. The propagation model was based upon the fracture mechanics approach.

(19) O. Vosikovsky, and A. Rivard, "Effect of Thickness on Fatigue Life of Welded Plate T-Joints", Report PMRL 85-65 (TR) Department of Energy, Mines and Resources, Ottawa, 1985.

The experimental work carried out on welded plate T-joints, with thicknesses varying from 16-103 mm is reported; the joints were tested at constant amplitude loading in the following three stress ranges: 100, 150 and 200 MPa. The fatigue crack growth was monitored by multiprobe AC potential drop and beach marking techniques. The study indicated that the total fatigue life is significantly reduced as plate thickness increases.

It is suggested that the thickness effect can be correctly predicted by fracture mechanics if the same initial defect size is assumed for all the thicknesses.

(20) P.W. Marshall, "Allowable Stresses for Fatigue Design", Proc. Boss '82, McGraw Hill, 1982, pp 3-25.

The paper reviews the development and the basis for fatigue allowable stresses considering fatigue S-N curves, stress concentration-factors, sensitivity to approximations, and reliability considerations.

(21) D.R.V. Van Delft, C. Noordhoek, and J. de Back, "Evaluation of the European Fatigue Test Data on Large-Size Welded Tubular Joints for Offshore Structures", Proc. Offshore Tech. Conf. Paper No. OTC 4999, Houston, 1985, pp. 351-359.

The results of about 200 fatigue tests on welded large size tubular joints, which were carried out as a part of an extensive European Offshore Research Program, are analyzed using multiple linear regression analysis. The effect of specimen size, loading mode, joint type, environment, etc. are studied. The scatter of the results around the S-N curve could be reduced considerably if the scale effect is taken into account.

(22) M. Lalani, I.E. Tebbett, and B.S. Choo, "Improved Fatigue Life Estimation of Tubular Joints", Proc. Offshore Tech. Conf. Paper No. OTC 5306, Houston, 1986, pp. 133-146.

This paper presents unpublished results of over 50 elastic tests on large scale steel tubular joints. The results are used for the reliability analysis for fatigue life estimation. Comparisons with existing parametric SCF formulae are made and their reliability examined.

(23) S.M. Nerolich, P.E. Martin, and W.H. Hartt, "Influence of Weld Profile on Fatigue of Welded Structural Steel in Seawater", Corrosion Fatigue, ASTM, STP 801, 1983, pp 491-507.

The paper addresses quantification of the weld geometry for selected specimens and undercuts as basic parameters which influence the fatigue and corrosion fatigue behavior of structural steel in seawater. The study includes a finite element analysis which was performed in order to obtain the elastic stress concentration factors in the hot spot region.

(24) M. Arockiasamy, G.S. Bhuyan, and K. Munaswamy, "Finite Element Analysis of Stress Concentration in Tubular T-Joints", Final Report DSS Contract OSU 83-00033, Department of Energy, Mines and Resources, Dec. 1984, pp 129.

The report describes the analytical investigation of stress distribution in tubular T-Joint for axial and in-plane bending load cases. The results of the study on distribution of surface stresses along the brace-chord interaction including the through-thickness variation and hot spot stress concentration factors are presented, and compared with those reported in the literature. The effect of shallow weld toe cracks on stress redistribution is discussed.

(25) J.E. Merwin, "Fatigue in Welded Tees", Report to Shell Oil Co., Rice University, Houston, 1986.

An experimental investigation to determine the effect of plate thickness and weld profile on the fatigue life of welded tee connections in air is described. Three plate thicknesses 1/2", 1", and 2" were chosen and the weld profiles used were AWS Basic, AWS Alt#1 and AWS AlT#2 for 1/2", 1" and 2" size respectively. The average fatigue life was found to increase with decreasing plate thickness even though the weld profiles appeared better for the thick plates. The data indicated that the plate thickness is a more important parameter than the weld profile in determination of fatigue life.

(26*) Engesvik, K. and Wold, P.T., "A Fracture Mechanics Analysis of the Fatigue Capacity of a Welded Joint", Report SK/R 48 Div. of Marine Structures, The Norwegian Inst. of Tech., 1979.

(27) T.R. Gurney, "The Influence of Thickness on the Fatigue Strength of Welded Joints", Second Int. Conf. on Behavior of Offshore Structures, Aug. 1979

It has been shown by fracture mechanics, that the fatigue strength of welded joint decreases with increasing plate thickness. The paper outlines the reason for this effect and discusses the influence of joint size on the stress intensity factor for transverse non-load-carrying fillet welds.

(28) J.G. Wylde and A. McDonald, "The Influence of Joint Dimensions on the Fatigue Strength of Welded Tubular Joints", Second Int. Conf. on Behavior of Offshore Structures, Aug. 1979.

The paper describes the preliminary results of static and fatigue tests on welded tubular joints. The specimens tested were tubular T-joints ranging in diameter from 168 mm to 1830 mm and in wall thickness from 6 mm to 76 mm. The specimens were tested under axial loading, in-plane bending and out-of-plane bending. Fatigue strength was found to decrease with increase in joint dimension.

(29) T.R. Gurney, "Basis of Fatigue Design for Welded Joints", IABSE Report, Vol. 37, 1982.

The paper considers the general form of the S-N curves which should appear in fatigue design rules for welded joints. It is agreed that, for as-welded joints, they should be based on stress range using all the available test results.

(30) T. Iwasaki, and J.G. Wylde, "Recent Research on the Fatigue Performance of Welded-Tubular Joints", International Conf. on Offshore Welded Structures, London, Nov. 1982, Paper No. 44.

This paper discusses the results of fatigue tests carried out on welded tubular joints in Europe and Japan. The fatigue data obtained from the two programs are compared and differences in the S-N curves discussed. The parametric equations available for the prediction of stress concentration factors in tubular joints are reviewed. Finally, the fatigue results are compared with the relevant current fatigue design S-N curves.

(31) D.W. Hoeppner, and W.E. Krupp, "Prediction of Component Life by Application of Fatigue Crack Growth Knowledge", Engr. Fract. Mech. Vol. 6, 1974, pp. 47-70.

The concept of fatigue crack propagation is discussed as it relates to life prediction. Since the use of propagation concepts assumes the presence of a minimum detectable initial flaw size, this concept is discussed as it relates to the fatigue process. The relative roles of fatigue crack initiation and propagation are presented. A detailed list of the development of fatigue-crack growth 'laws' is then presented. Examples of the use of the crack-growth 'laws' and the fracture mechanics concepts are presented illustrating the application of fatigue-crack growth prediction.

(32) D.R.V. Van Delft, and O.D. Dijkstra, "The Calculation of Fatigue Crack Growth in Welded Tubular Joints Using Fracture Mechanics", Proc. Offshore Tech. Conf. Paper No. OTC, 5352, Houston, 1986, pp. 573-582.

A fracture mechanics model for calculating the fatigue crack growth in welded tubular joints is established. The model incorporates the various aspects of fatigue crack growth calculations available in the literature. The results estimated from crack growth model are compared with the actual fatigue crack growth in a large scale welded tubular joint specimen. The fatigue results of specimens used by other researchers are also compared with calculated results.

(33) S.J. Maddox, "An Analysis of Fatigue Cracks in Fillet Welded Joints", International Journal of Fracture, Vol. II, No. 2, April 1975, pp. 221-243.

Available literature references were used to estimate the stress intensity factors for cracks with low a/2c values. The effect of the weld stress concentration factor was incorporated in the $\Delta K$ computations.

(34) C.L. Tsai, "Fitness-for-Service Design of Fillet Welded Joints", ASCE Struct. Divn. Vol. 112, No. 8, Aug. 1986, pp. 1761-1780.

The paper describes the philosophy of "fitness for service" to suggest a new acceptance criteria for weldments on the basis of service requirements. A design methodology is developed based on the definition of 'Equivalent Effective Weld Size' and 'Design Load Reduction Factor'. Among the discontinuities studied, undercut is the most critical type, followed by centerline notch, overlap, convexity and concavity.

(35*) Clayton, A.M., "Effect of Weld Profile on Stresses in Tubular T-Joints", Interim Technical Report UKOSRP 2/03.

(36*) Marshall, P.W., "Problems in Long Life Fatigue Assessment for Fixed Offshore Structures", ASCE Water Resources Convention, San Diego, Preprint 2638, 1976.

(37*) Johnston, G.O., "Influence of Plate Thickness on Fatigue Strength", Welding Institute Report 3549/3/1978.

(38*) Todoroki, R., "Effects of Toe Profile Improvement on Corrosion Fatigue Properties of Welded Joint", International Institute of Welding Document XIII-875-78, July 1978.

(39) C.C. Osgood, Fatigue Design, Pergamon Press, 1982.

(40) Recho, N. and Brozzetti, J., "Design Fatigue Life of Welded Cruciform Joints", Proc. IABSE Colloquium Lausanne, Fatigue of Steel and Concrete Structures, 1982, pp. 140-151.

This paper attempts to determine the coefficients of the Paris law based on the classical S-N curve and establish a simple fracture mechanics model for the evaluation of design fatigue life of cruciform welded joints.

(41*) G.S. Booth, "Constant Amplitude Fatigue Tests on Welded Steel Joints Performed in Air", Paper III/P4, European Offshore Steels Research Seminar, Cambridge.

(42*) K. Nagai, et al, "Studies of the Evaluation of Corrosion Fatigue Crack Initiation Life for Welded Joints of Mild Steel in Seawater", Paper 3JWS-43, Third Int. Symp. of the Japan Welding Society, Tokyo, 1978.

(43) K.M. Engesvik, and T. Moan, "Probabilistic Analysis of the Uncertainty in the Fatigue Capacity of Welded Joints", Eng. Fract. Mech., Vol. 18(4), 1983, pp. 743-762.

This paper presents the results of a study of the uncertainty in the fatigue capacity (constant amplitude fatigue life) of welded steel joints, due to uncertainties related to geometrical and material parameters. A linear-elastic fracture mechanics model and the Paris-Erdogan law of crack propagation were adopted. The main parameters were treated as stochastic variables. The uncertainties associated with the basic variables were transformed into a measure of uncertainty of the fatigue capacity by employing the Monte Carlo simulation technique. The probabilistic fracture mechanics analysis provided a sufficient sample of data to allow a test of analytical probability distributions to the fatigue life.