Fatigue Strength of Welded Stud Joint with respect to Various Steel Plate Thickness

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1. Research Objectives

Hybrid pontoon and caisson structure used at coast and offshore are build from multiple layers of thin steel plate; forming the box of steel shell where large quantity of studs are welded onto it and embedded into concrete on external side. In present, strength characteristic between stud diameter and steel plate thickness is not yet being considered for the design of hybrid pontoon and caisson. This research is carried out with aim to establish fatigue design method for offshore hybrid structure by conducting experiment on series of test specimens under two objectives.

1) Study on fatigue strength for thin steel plate welded with studs
2) Study on fatigue strength for thin steel plate welded with group of studs

2. Outline of Test Specimen

Steel plates are of type JIS:SS400; studs are of material called Si-Killed Steel.

(a) Steel plate welded with studs

Specimen consists of 700 × 80 mm steel plate welded with two different stud diameters (Fig-1). Stud diameter, d of 13, 16, 19, 22 mm and plate thickness, t of 6, 12, 22 mm are used.

(b) Steel plate welded with group of studs

Two different types of specimen (type A and type B); each consists of 620 × 210 × 9 mm steel plate welded with six studs of 13 mm diameter (Fig-2).

3. Test Procedures

Fatigue tests for steel plate welded with studs and steel plate welded with group of studs are conducted using Shimadzu test machine model EHF-U50. Minimum load is set to zero and axial tensile cyclic load is applied at 480 cycles per min (8 hz) to one end of steel plate with the other end fixed. For specimens with group studs, the steel plate is clipped at both ends with two slices of steel plates using 3 bolts at each end before load is applied. During testing, maximum and minimum loads are automatically kept constant at the preselected values.

4. Test Results and Evaluations

14 specimens from various combinations of stud diameter and steel plate thickness are tested for steel plate welded with studs while 6 specimens are tested for steel plate welded with group of studs. All specimens failed by crack line perpendicular to longitudinal axis at weld toe. At $N_f = 2\times10^6$ cycles in Fig-3, it can be seen that fatigue strength for group of studs (at passing-through crack state) is lower compare to one stud. This shows that fatigue strength will decrease with increasing number of stud welded on steel plate. All test results meet the minimum requirement for JSSC Class E design curve.

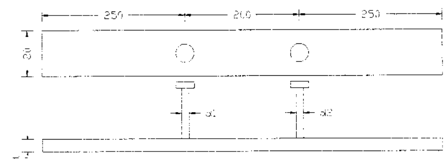
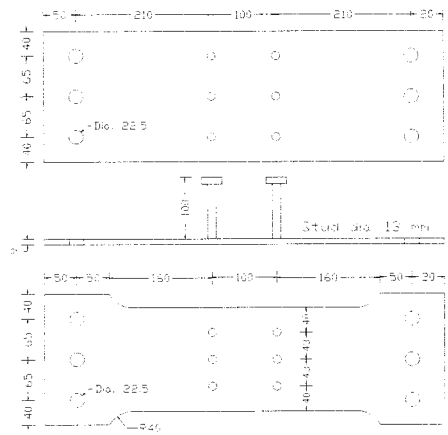


Fig-1 : Dimension of plate welded with studs



Plan view : type A (above); type B (below)
Fig-2 : Dimension of plate welded with group studs

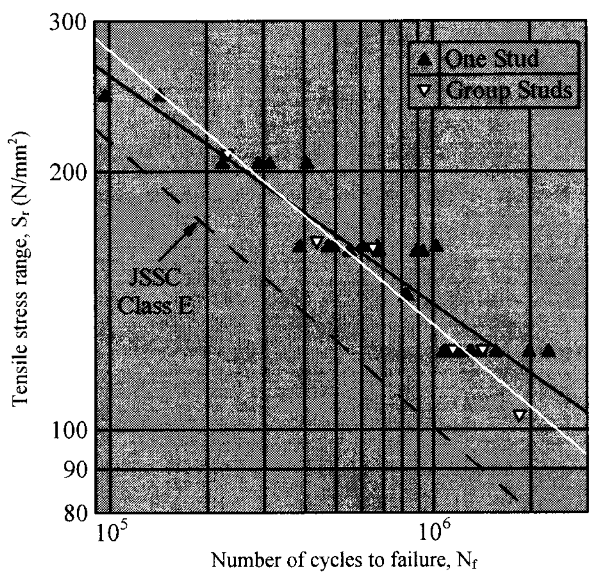


Fig-3 : S-N curve for one stud and group of studs

In Fig-3 mean value of fatigue strength, μ = 116.35 N/mm^2 is obtained at $N_f = 2\times10^6$ cycles and standard deviation is calculated for all one stud data, σ = 11.91 N/mm^2. Using statistic equations below, value of μ and σ at probability of failure, 2.5% of normal distribution as suggested by JSSC are obtained for number of studs, n = 1, 5, 10, 15, 20 and 25 as shown in Fig-4.

$$p_{\min}(x) = n[1-\Phi(\frac{x-\mu}{\sigma})]^{n-1}\phi(\frac{x-\mu}{\sigma})\frac{1}{\sigma}$$

$$P_{\min}(x) = 1-[1-\Phi(\frac{x-\mu}{\sigma})]^{n}$$

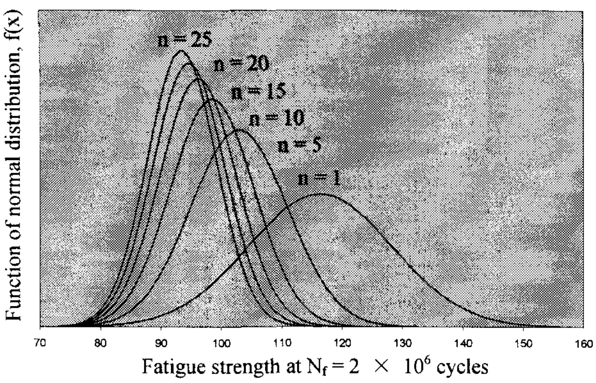


Fig-4 : Normal distribution for number of studs, n

From Fig-4, it can be seen that the fatigue strength decrease exponentially; μ and σ decrease with increasing number of studs. Using equation above, number of studs that would not fall below Class E curve (S_r = 80 N/mm^2; N_f =2×10^6 cycles) is calculated and the result gives n = 23. This shows that maximum number of studs that can be welded in a row for an area of steel plate surface in the direction of force is 23 studs (n ≤ 23). The result is illustrated in Fig-5 for n = 23.

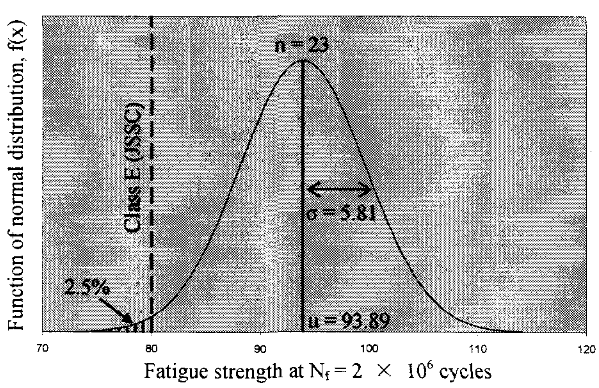


Fig-5 : Normal distribution for n = 23

5. Design Formula Using d/t Ratio

Test data obtained for one stud as shown in Fig-3 are used to modify normal S-N equation by introducing ratio d/t (d = stud diameter; t = plate thickness). Since this research deals with high cycle fatigue, minimum cycles are set to 1×10^5. For design purpose, using probability of failure, 2.5% of normal distribution as suggested by JSSC, propose design equation for steel plate welded with stud is given with 2 conditions.

$$S = [305(\frac{d}{t})^{-\frac{3}{19}} - 22](\frac{N}{10^5})^{-\frac{1}{3}}$$

Conditions : 1) $N \geq 1 \times 10^5$ cycles
2) $d/t \leq 4.67$

6. Finite Element Method (FEM)

Software analyses are performed using LUSAS finite element analysis for steel plate welded with stud. Model is built in 3D (368 × 80 × 6 mm) with stud diameter of 16 mm. The plate is fixed in y-direction and tensile load of 100 N/mm2 is applied. C_p and C'_p are the critical points for maximum stress (Fig-6). Stress distribution in x-direction shown in Fig-7 show maximum stress (211 N/mm^2) concentrates on the edge of weld collar with factor as high as 2.1.

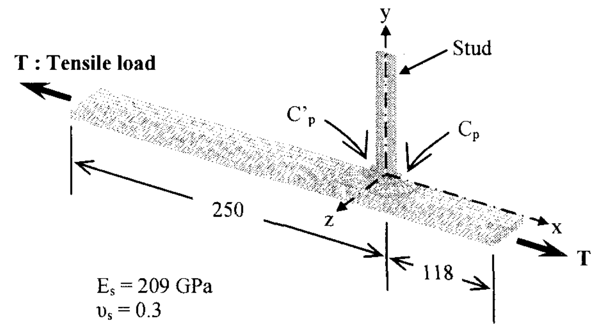


Fig-6 : Finite element mesh division (half model)

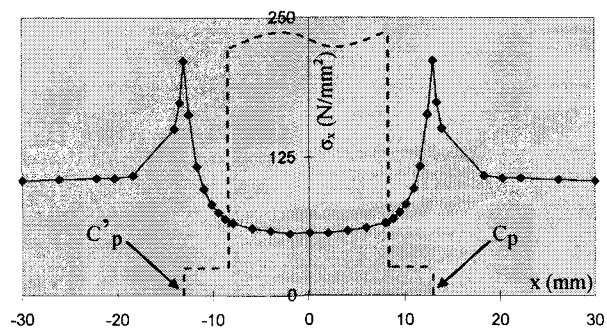


Fig-7 : Stress distribution in x-direction

7. Summary

a) For steel plate welded with studs, fatigue strength at 2×10^6 cycles for one stud is higher than group studs. Maximum number of studs that clear JSSC Class E curve is 23 studs (n ≤ 23).
b) Design equation for steel plate welded with stud on 2 conditions (refer section 5) is proposed :

$$S = [305(\frac{d}{t})^{-\frac{3}{19}} - 22](\frac{N}{10^5})^{-\frac{1}{3}}$$

c) Stress analyses show maximum stresses occur at weld collar edge with concentration factor of 2.1.

<References>

1) Kajikawa, Y., and Maeda, Y., "Fatigue Strength of Flange Plate with Stud Shear Connector Subjected to Combined Tension and Shear," Journal of Civil Engineering, Vol. 362, No. I-4, pp. 285-292, 1985.
2) "Fatigue Design Code for Steel Structures (in Japanese)," Japanese Society of Steel Construction (JSSC), pp. 6, 1993.