MODEL FATIGUE TEST OF BOLTED JOINT OF A STRUT OF BRACING TO THE BUCKET WHEEL LATTICE GIRDER OF THE LARGE ROTARY EXCAVATOR

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Failure of bolted joint of a diagonal strut of bracing to the bucket wheel lattice girder occurred during the proof test of the large rotary excavator. In-service inspection after failure revealed that the joints were not tightened according to the specification and several openings for bolts had been repaired by welding after initial machining, due to manufacturing error. In order to investigate the cause of the failure, a full scale model fatigue test of bolted joint was performed. Total model length was more than 2000 mm, and the connection was provided 8 bolts (M24) of steel strength class 10.9 in 800 mm long active part of the model.

INTRODUCTION

During the test work of the bucket wheel excavator SchRs 1760 of the theoretical digging capacity of 6000 m^3 per hour there happened a sliding on the connection at one of the diagonal struts of the lower chord bracing belonging to the bucket wheel lattice girder. All connections of the steel structure are prfomed with high tension friction grip bolts. This sliding extended its influence to the other nearest connections.

The commission for examining the failure discovered many irregularities in production and errection of the main steel structure, as follows:

- improper height of the web of the I type the bracing struts,
- improper angle of the flanges to the web,
- improper distance between the gusset plates,
- repair of the position of the bolt openings (holes) by poor welding,
- sometimes there had been applied unsufficiant torque moment to the bolts in the connection or hadn't been applied any,
- poor sealing of the pretightened connection.

After the repair of connections of the bracing struts of the bucket wheel lattice girder, step by step, excavator was put into operation without problems. In order to ascertain the real reasons of failure and the fatigue life of this kind of joint, the Goša Industry decided to carry out fatigue testing.

EXPERIMENT

The test had been performed on 500 kN MTS servohydraulic testing

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machine with extra high 1000 kN frame Figure 1. The loading spectrum, defined according to operating conditions and available loading specification in the sinus form, with special attention paid to critical conditions. In view of the possibilities of testing machine, it has been decided to test the model in its real size.

The choice of specimen and its design is determined by the facilities of the hydraulic testing machine, on which the testing was carried out. It has been decided to construct a specimen of characteristic joint with most frequent defects which might occur in the real construction. Several bolt opening were repaired by welding. Surfaces which was stressed by friction have corroded and the sand blasting was not done. The torque moment of the bolt was carried out according to the documentation. Figure 2a shows the construction of the first design of the specimen. The central part of the specimen of length cca 800 mm is designed according to the construction documentation with above mentioned defect. The remaining (dummy) part of specimen is adapted for the fixing devices.

Calculation of working loadings into testing loadings. On the basis of construction documentation and calculations for critical girders, (1), the load spectrum of the excavator was obtined, Table 1. This table gives minimum and maximum values of loadings, as well as the number of cycles in 12 types of operation for the period of 40 and 25 years. Since values of maximum loading in different blocks, exceed the capacity of testing machine, all the blocks of the loading spectrum are calculated to the equivalent number of cycles of the corresponding block loading (F^{eq}_{max} = 450 kN and F^{eq}_{min} = 116 kN). The maximum load of this block is determined by the capacity of the testing machine, and the minimum load is determined by the amplitude of load which corresponds to the maximum amplitude of load spectrum e.q. F^{eq}_{a} = 167 kN.

The calculation of testing spectrum is done by "S-N" equation, because, with given testing loadings, testing is carried out under elastic deformation (2). Table 2 gives the loading spectrum of the excavator on the basis of one year life. The mentioned equation is:

$$\left(\frac{N_{eqi}}{N_{i}}\right)^{b} = \frac{S_{aeq}\,(S_{f} - S_{mi})}{S_{ai}\,(S_{f} - S_{meq})} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

S_{ai} - amplitude of i-th load block

S_{mi} - mean stress of i-th load block

N_{i} - number of cycles of i-th load block

S^{eq}_{a} - stress amplitude of an equivalent block = F^{eq}_{a}/A = 334 MPa

S^{eq}_{m} - mean stress of an equivalent block = $(F^{eq}_{max} + F^{eq}_{min})/2A$ = 566 MPa

N^{eq}_{i} - equivalent number of cycles of i-th load block

S_{f} - fatigue strength coeficient = 9 200 MPa, (2)

TABLE 1 - Loading spectrum of the excavator

No	Types of operation	Time [%]	40 Years = Day	25 Years = Day	cycles for 40 Years N 40	cycles for 25 Years N 25	F_{max} [kN]	F_{min} [kN]	ΔF [kN]
1	Moving forward	1.	0.4 146.	0.25 91.25	42048	26280	473.	350.	123.
2	Moving backward	1.	0.4 146.	0.25 91.25	42048	26280	473.	350.	123.
3	Upper left cut	15.	6. 2190.	3.75 1368.75	630720	394200	471.	375.	96.
4	Upper right cut	15.	6. 2190.	3.75 1368.75	630720	394200	267.	171.	98.
5	Left horizontal	15.	6. 2190.	3.75 1368.75	630720	394200	554.	437.	117.
6	Right horizontal	15.	6. 2190.	3.75 1368.75	630720	394200	344.	227.	117.
7	Lower left cut	15.	6. 2190.	3.75 1368.75	630720	394200	615.	480.	134.
8	Lower right cut	15.	6. 2190.	3.75 1368.75	630720	394200	414.	280.	134.
9	Slant lower left cut	2.	0.8 292.	0.5 182.5	84096	52560	686.	354.	334.
10	Slant lower right cut	2.	0.8 292.	0.5 182.5	84096	52560	538.	204.	334.
11	Slant upper left cut	2.	0.8 292.	0.5 182.5	84096	52560	546.	245.	301.
12	Slant upper right cut	2.	0.8 292.	0.5 182.5	84096	52560	397.	96.	301.

b - fatigue strength exponent = - 0.0845 (2)

A - critical cross-section surface of specimen = 50 cm^2

From the obtained results one can see that the types of operations 1 - 8 with small loading amplitudes can be neglected.

The first test was finished by fracture of the dummy part due to poor design of the model. After 250,000 cycles the specimen was broken which corresponds to the life of 30 years. The fracture happened on the bent parts of flange where the welding was done in order to join the two flanges. Figure 2a shows with an arrow the place of fracture. This is classical example of high stress concen- tration which is provoked by the cold bending deformation of flange and HAZ by welding on the place of high local stress.

The reconstruction of the specimen was done as shown in Figure 2b. Reconstruction was done only on the dummy part of specimen. Testing was continued under the same conditions. It was stopped after 1.41E6 cycles corresponding to 172 years of life, as there were no cracks. Having in mind the safety factor, the exploitation age of this construction and the allotted financial means, it has been decided to increase load to - 45 kN / 450 kN; R = -0.1. In order to find the "bad" place of the specimen as soon as possible, load was increased. After 130 000 cycles there was no fracture. Load was again increased to - 450 kN / 450 kN; R = -1. After 64 000 cycles fatigue crack occurred on the dummy part of specimen. The fatigue crack is marked by an arrow in Figure 2b. The cause of fracture was again the stress concentration and HAZ.

TABLE 2 The load spectrum of the excavator tranformed into the equivalent spectrum corresponding to one - year of exploitation

No	Types of work	S_a^{eq} (MPa)	S_{ai} (MPa)	S_f (MPa)	S_m^{eq} (MPa)	S_{mi} (MPa)	b (1)	N_i (cyc/y)	N_i^{eq} (cyc/y)
1	Moving forward	334.	123.	9200.	566.	823.	-0.0845	1051.	0.011
2	Moving backward	334.	123.	9200.	566.	823.	-0.0845	1051.	0.011
3	Upper left cut	334.	96.	9200.	566.	846.	-0.0845	15768.	0.009
4	Upper right cut	334.	98.	9200.	566.	439.	-0.0845	15768.	0.007
5	Left horizontal	334.	117.	9200.	566.	992.	-0.0845	15768.	0.117
6	Right horizontal	334.	117.	9200.	566.	572.	-0.0845	15768.	0.065
7	Lower left cut	334.	134.	9200.	566.	1095.	-0.0845	15768.	0.674
8	Lower right cut	334.	96.	9200.	566.	846.	-0.0845	15768.	0.009
9	Slant lower left cut	334.	334.	9200.	566.	1042.	-0.0845	2102.	4112.369
10	Slant lower right cut	334.	334.	9200.	566.	742.	-0.0845	2102.	2682.150
11	Slant upper left cut	334.	301.	9200.	566.	791.	-0.0845	2102.	838.825
12	Slant upper right cut	334.	301.	9200.	566.	492.	-0.0845	2102.	554.750

ΣN_i^{eq} = 8188.997 cyc/year

CONCLUSION

Testing was carried out according to the demands of the Goša Industry. The construction proved to be safe from the point of view of fatigue life. Due to limited time and funds, Laboratory for Fracture Mechanics at the Faculty of Technology and Metallurgy, University of Belgrade, which did all these experiments with the cooperation of the Aeronautical Institute - Belgrade, were not able to extend the test program to the crack growth rate detection.

REFERENCES

(1) Berechnungsgrundlagen für Großgerate in Tagebauen DIN BG 86

(2) Fatigue Design Handbook, Vol 4, ASME, 1985.

Fig. 1 Extra long frame for 1000 kN load

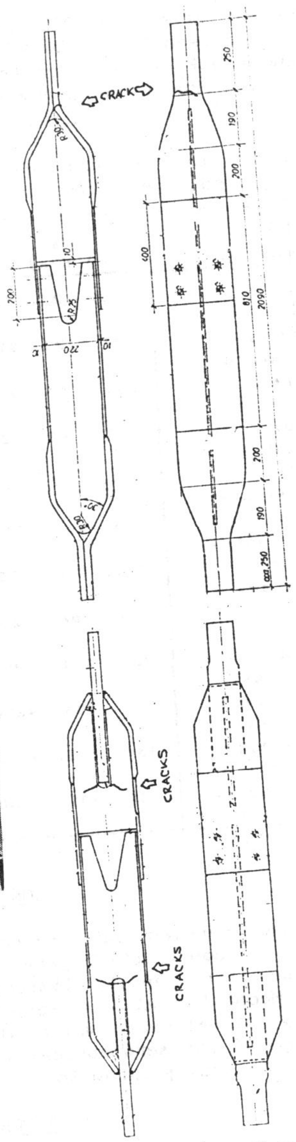

Fig.2a. First design of specimen
2b. Reconstructed specimen