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FATIGUE DAMAGE AND REPAIR OF 250 kN PORTAL CRANE IN SHIPYARD

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ABSTRACT

The paper presents fatigue damage analysis and repair procedure that was carried out after the cracks at 250 kN portal crane were detected. After few years of crane service, fatigue cracks occurred at several critical points – bottom of the tower and both legs of portal. Previous attempts of repair by simple welding of cracks were not successful, because new cracks were detected soon after the repair. When cracks reached the critical length, the exploitation of the crane was stopped and detailed analysis was carried out. The results of numerical analysis and strain gauge measurements showed the source of a crack propagation – high stress concentration due to inappropriate design of portal details. FEM models also showed that stress concentration could be reduced by applying the additional stiffeners. Having in mind this fact, critical crane areas were redesigned. Later measurements and examinations showed that this repair was successful – after two years of intensive service new cracks were not detected.

KEYWORDS: Fatigue cracks, repair, welding, FEM

INTRODUCTION

General rules for design the machine parts against fatigue are well known for many years, but still now the examples of inappropriate design can be found. This paper describes such example – heavy portal crane in shipyard: unusual portal box construction made of steel plates, Figure 3. The cracks occurred at transition areas from vertical to horizontal supports on both legs, growing from the corners and bringing into danger the whole construction, Figure 1. First cracks were detected soon after the crane was placed in the shipyard, so the allowed carrying capacity was reduced from 250 kN to 50 kN, but the cracks continued to grow. First attempt of repair by simple welding did not solve the problem – new cracks were detected in the same areas soon after the repair. When the cracks reached the critical values, the crane was stopped to avoid the risk of total failure. In order to find the source of crack initiation and growth, the complete manufacturer's documentation and calculations were checked. It was found that calculations were performed by using the simple beam elements, without taking into account the stress concentration, and the influences of inertial forces and wind were underestimated. Those facts led us to perform the complete static and fatigue analysis, to measure the real stresses during the typical manoeuvres of the crane, and to redesign the critical places to avoid stress concentration. The results of this work including the later stress measurements are presented in this paper.

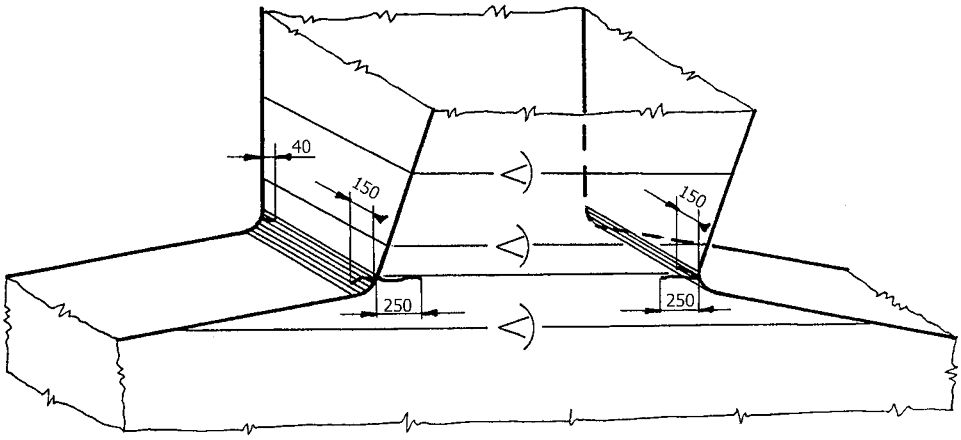

Figure 1: Detected cracks (measures in millimetres)

MEASUREMENT OF STRESSES, COD AND ACCELERATION

To determine the dynamic behaviour of the construction strain gauges, two induction transducers for displacement and capacitive transducer for acceleration were applied. Test load was 50 kN, and there were no wind during the measurement. All data were recorded during the typical working cycles of the crane and results were presented by great number of diagrams.

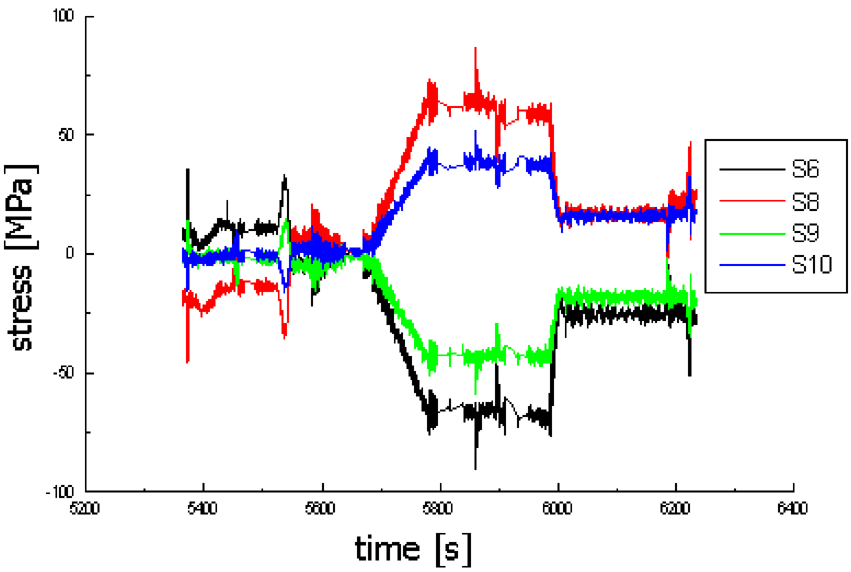

Figure 2: Measured stresses during typical manoeuvres

Based on the analysis of these diagrams, some general conclusions can be set:
- the highest measure stress amplitude were about 150 MPa, but in practice stresses can be higher, because of several reasons: - strain gauges were not attached at the places of highest stress concentration (access is not possible because of cracks)
- stress concentration factor α_k is about 2, what is not theoretical maximum
- during the measurement, the secondary stresses that reached up to 20 MPa were recorded, not connected with the nominal stresses, probably caused by swinging of the tower
- crack opening displacements reached 1.5 mm, what according to the Fracture Mechanics COD – concept indicates the stress of about 200-300 MPa

- measured values of acceleration were up to 0.2 m/s^2, what is acceptable, but during the test the crane was driven very carefully – in every day's use, with the influence of wind, these values can be higher.
- it is interesting to notice that the stresses were mostly caused by the manoeuvres of the crane – stresses caused by the loads were not significant. This result could be expected, because the maximum allowable load (250 kN) is less then 10% of the own weight of the construction.

FEM ANALYSIS

Finite Elements Method was used to determine the global stress distribution and to find out the weak points of construction that could cause high stress gradients and stress concentration. Linear elastic model and 3D-Plate elements with four or three nodes and six degrees of freedom was used.

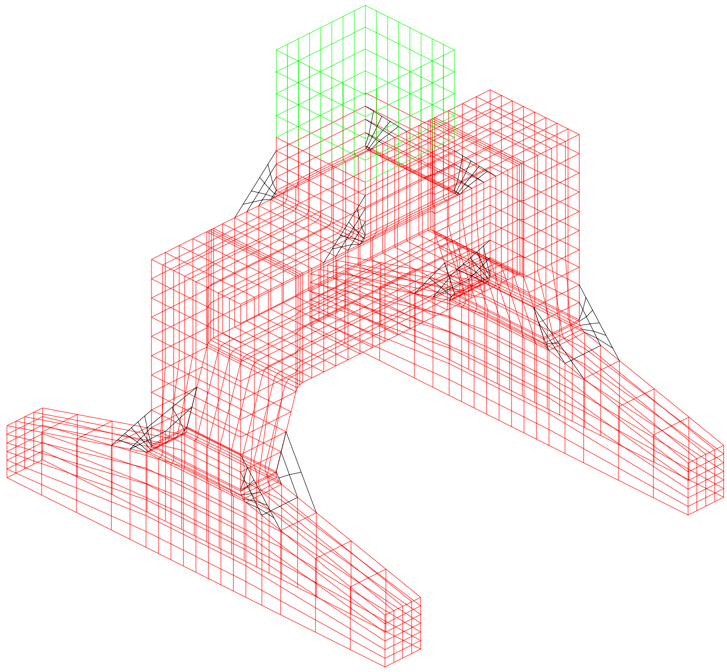

Figure 3: FEM model of the lower part of the crane (Variant with stiffeners)

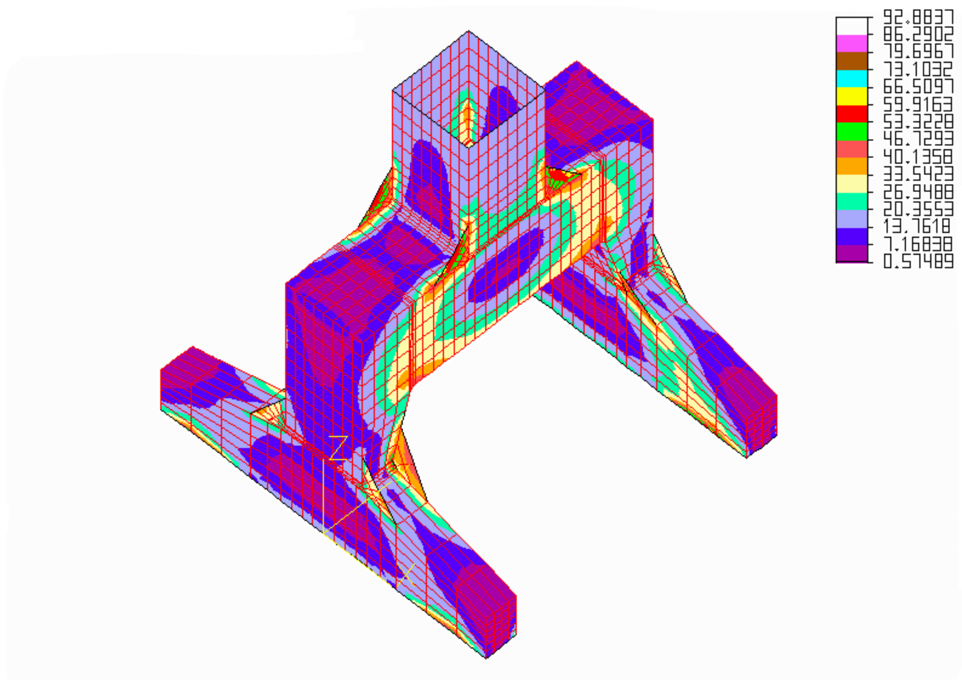

Figure 4: Typical stress distribution – visible areas of stress concentration

The geometry of the lower part of the crane was defined by 2191 elements (2327 elements in variants with stiffeners) were used, Figure 3. Boundary conditions were defined as follows:
- all six degrees of freedom on the nodes at the bottom contour of model were constrained,
- concentrated forces and bending moments are distributed along the nodes on the top of the model, representing the own weight of upper part of the crane and particular load case.

The complete analysis included 17 variants, with various loads, with or without stiffeners , with different orientation of crane branch and including the weight of construction. Typical results of FEM analysis are shown on Figure 4.

REPAIR PROCEDURE

Strain gauge measurement and FEM analysis showed the source of crack initiation – high stress concentration in the transition areas from vertical to horizontal part of the supports. At critical points those stresses exceeded the fatigue strength of material and caused the crack initiation and growth. Variable loads cannot be avoided, so the only solution was to redesign the critical areas in order to redistribute the local stresses. FEM analysis also showed the best way for redistribution of high stresses: application of triangle stiffeners that fit the existing construction (Figure 4 and Figure 5). Those stiffeners were welded by using MAG process. The heat treatment was used to minimize the residual stresses and fatigue limit of welds was increased by grinding the weld toes and roots.

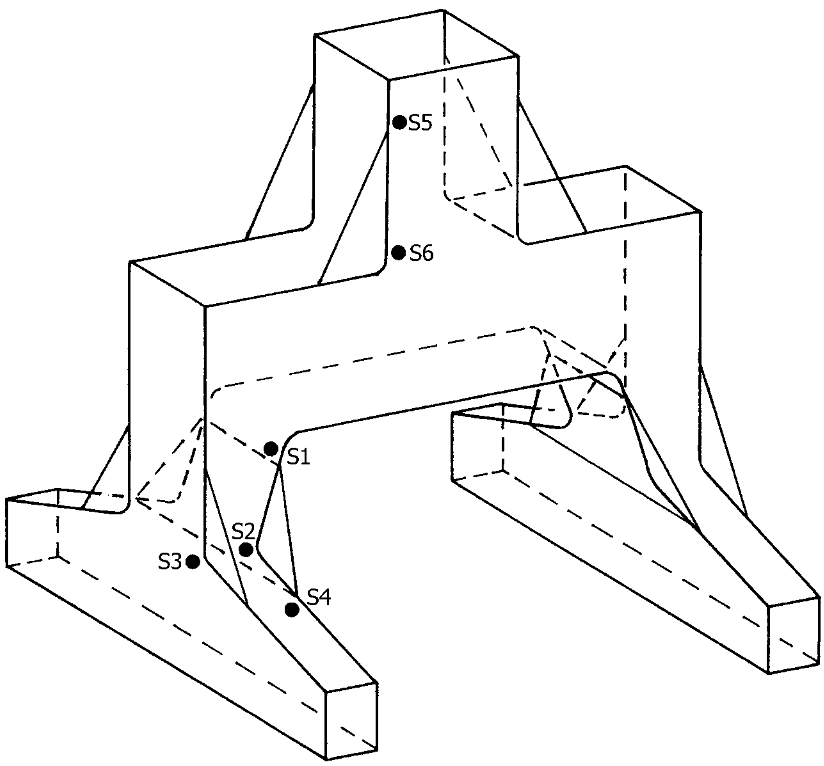

Figure 5: Positions of attached strain gauges

After the repair was completed, stresses at critical points were measured once again and compared to the values predicted by FEM. Places where strain gauges were attached are shown on Figure 5, and the results are shown in Table 1. Presented results are approximate, because the strain gauges cannot be attached perfectly at the same positions. According to data from Table 1., it is clear that the stresses at critical points are significantly lowered, especially in critical areas. All the stresses are under the fatigue limit, so the main source for crack growth is removed.

TABLE 1
COMPARISON OF STRESSES BEFORE AND AFTER REPAIR

Strain gauge	S1	S2	S3	S4	S5	S6
Max. stress without stiffeners (MPa)						
Measured	Not measured	Not measured (crack)	50-100	30	50	150
FEM	100	360	110	60	50-60	300
Max. stress with stiffeners (MPa)						
Measured	100	120	20	30	70	50-70
FEM	100	180	15-20	60	60-80	100

CONCLUSION

The paper illustrates the danger of inappropriate design in the case of variable loads. Sharp transition from vertical to horizontal plates at crane leg caused the initiation and growth of fatigue cracks that brought into danger the whole construction.
By replacing the plates that contained cracks and applying the stiffeners at the places of cracks initiation, the sources of fatigue damages are removed and the maximum stresses at redesigned construction are lowered to approximately one half of previous values. Having in mind important role of the own weight of construction and inertial forces, the application of electrical devices connected to all actuators was suggested. The purpose of these devices is to turn on the actuators gradually, without jerks, what will generally minimize the influence of inertial forces. Later examinations of the crane construction approved the success of this repair – two years after repair no new cracks were detected.

REFERENCES

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