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Estimation of Residual Life and Proposed Adjustments for Extending the Life of an Overhead Travelling Crane

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Abstract The evaluation of structures in contemporary times has taken on a more significant role. The current financial situation is forcing owners or operators to extend the life of existing structures and equipment. The operator is faced with two major challenges: the need to extend the continued safe operation of assets and their cost-effective maintenance. This paper looks at the estimation of residual life of an overhead travelling crane and proposes modifications that can be carried out to increase its life span.

Keywords: *residual life, overhead travelling crane, fatigue*

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1. Introduction

Especially in the field of fatigue assessment the word failure is widely used, but often has a different meaning. Depending on the redundancy of the cracked element, a fatigue crack will spread in different ways. In a small non-redundant component the crack spreads in an exponential manner, starting slowly and progressively accelerating. In a large redundant component the crack growth will show a long period of stable crack growth due to a redistribution of the load to the surrounding structure. Theoretically, the end of fatigue life is reached when fracture of the remaining net section occurs. In fact, defining failure, in particular in the domain of fatigue, is difficult. Therefore, the failure criterion for a fatigue crack can either be: an unacceptable change in the component stiffness, a given crack size, net section yielding or, in certain cases, brittle fracture which occurs after a critical crack length is reached.

In assessing existing structures, emphasis is placed on its safe operation during its life span as specified by the manufacturer. A Structures serviceability assessment is primarily based on:

- The results from the evaluation of risks and load stress (effects) that can be expected;
- Consideration of the nature of the materials and geometry (shape) in relation to the current state of the structure.

Each evaluation of the structure is accompanied with the need to determine the acceptable level of risk as they must be in accordance with the current applicable design standards for the structure.

Evaluation methods, resp. structure assessment, can be divided into four phases [6,9,10]:

Phase I: Preliminary assessment. Aim is to remove all existing doubt regarding the safety of the structure utilizing simple methods and identification of critical components or parts of the structure. This is done by collecting information on the structure such as engineering drawings, design calculations, structure diagnostics, etc. Assessments are carried out by professionals.

Phase II: Detailed investigation. Aim is to update the information of the structure and carry out an evaluation of the individual components of the structure to determine the reduction in safety. This is carried out with a quantitative control while the structure is in operation, utilizing the latest load bearing values, durability as well as creating more accurate evaluation models. Technical experts and specialists are required to carry out this assessment.

Phase III: Expert investigation. A team of experts should be invited to provide their conclusions derived from the evaluation and should provide suggestions for eliminating potential risk of the loss of the structures reliability. They may provide additional assessments for utilizing specific tools (i.e. probability methods, fracture mechanics, etc.) as well as further discussion in order to assist in decision making.

Phase IV: Corrective actions. The aim is to propose measures that seek to improve operational safety of the structure. Various measures may be adopted such as increased monitoring of structure, reduction in load bearing, change in use, strengthening sensitive components, rehabilitation and similar. The availability of measures to be taken are the results of the structure's assessment and must provide proof of the adequacy of the measures to ensure its safety.

2. Assessment of the Cranes Condition

The steel structure of the crane is welded from strength council 37 rolled material. The basic parameters of the crane were taken from drawings. A Schematic diagram of a crane bridge structure is shown in Figure 1.

During a complex examination, the verification of the strain gauge measurement was carried out, calculation and assessment of the state of stress, and the changes in stress levels during simulated and actual operations. The assessment of the cumulative fatigue degradation and additional wear on the steel structure of the crane was also carried out. The analysis was conducted on two cranes. According to the crane operator, crane No. 1 was used 90% of capacity in comparison to crane No. 2, Table 1 [1,3]. The comparison of the aforementioned cranes is listed in Table 1 with the significant results from the analysis.

Simultaneously, with the expert assessment of the cranes strain gauge measurement, it was determined that the dynamic load is greater than the dynamic load of the currently valid standard. The assessment of the accumulation of fatigue degradation revealed the complete exhaustion of fatigue life of the steel structures of the crane's main beams. Welds in the flange connections and vertical beams found below the rails have been degraded in specific areas. No suitable technical measures for fixing broken welds were available.

The conclusion of the analysis noted that the continued operation of the crane under current operating conditions is not recommended and that it is not possible to consider any technical measures for fixing degraded welds nor replacing damaged parts with new ones. Further opinion was provided for other possible crane operations with reduced load capacity of 150 tonnes. Limited operations were recommended with regular monitoring of the welds together with drilling holes in the areas with cracks to prevent their spreading.

Despite the limited load capacity and execution of technological measures against the spread of cracks, the spreading of cracks continued as well as the formation of new cracks with a total length of 2500 mm on a single beam in an area of significant stress. For this reason, the crane was removed from operation [2,3,4].

Observed facts on the quantity of cracks and their size are documented in Figure 2. In both cases, the cracks are found along the longitudinal weld and the direction of the cross section weld is found in Figure 2.

Within the scope of the technical condition of the crane, an inspection of the structure was performed after a year. The results of the finding reveal fatigue cracks over the entire active length of the main beams on the side of the crab rails. The main beam profile has opened from the degradation of the weld at the junction of the flange and web (Figure 3). This condition presumes that the beams are stressed just as open cross section beams. This can result in a disproportionate increase in tension and cause the collapse of the crane, therefore it was necessary to remove the crane from operation.

Table 1. Comparison of Crane Condition

Crane number	Exp. Detected dynamic lift factor	Exp. Determined geo. characteristics (mm3)	Residual fatigue life
1	1.57	0.918.108	0 After lifespan
2	1.22	1.07.108	93 548 Operating cycles

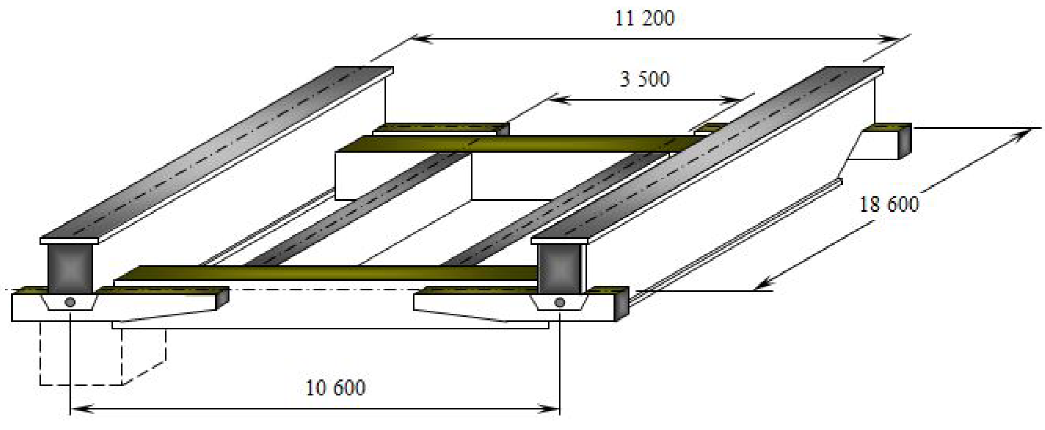

Figure 1. Schematic of the overhead travelling crane structure

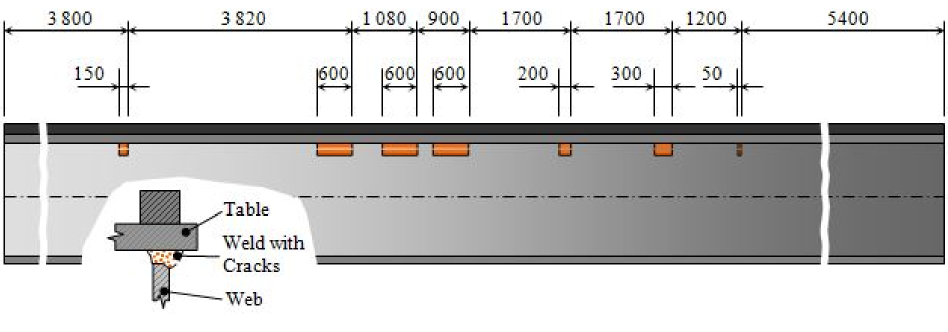

Figure 2. Length of cracks on beam structure

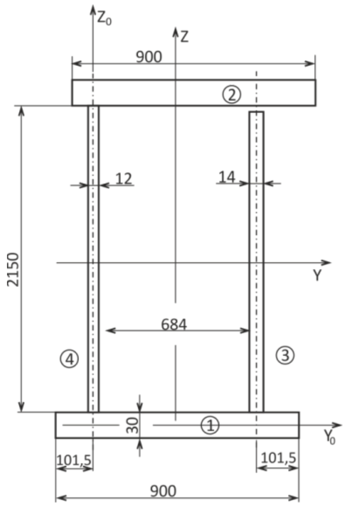

Figure 3. Open profile of the main beam

Specifying internal strength variables were arrived at by using derivative relations during confined flexing. The task was divided into two parts, the load factor of the open profile beam after the degradation of the weld from the forces of its own weight caused during hoisting activity and the forces of pressure on the crab wheels on the rails. The maximum bimoment is formed during the midrange spread, the value of its chosen boundary condition is

$$B_{(1/2)} = \frac{ql}{2}\left[1 - \frac{1}{\cosh\,(pl/2)}\right] + \frac{M}{2p}\tan\,(pl/2), \qquad (1)$$

in which

$$p_2 = \frac{GJ_k}{EJ_\omega} = 1{,}524 \cdot 10^{-10}\ mm^{-2}, \qquad (2)$$

where $J_k = 19\ 449\ 653{,}3\,mm^4$, $J_\omega = 4{,}907 \cdot 10^{16}\ mm^4$, $G = E/2(1+\mu)$.

Bimoment corresponds to presented values

$$B = 5{,}035 \cdot 10^{12}\ Nmm^2$$

and tensions along the axis of the beam's web in the degraded area

$$\sigma = 162\,MPa.$$

If we consider that tension from the bimoment in the area of the crack can reach up to 162 MPa, this observed fact clearly confirms that the beam needs to be closed. Welding cracks even after potential grooving, from a technological perspective was not possible without taking apart the crane.

The material properties of the structure were determined based on metallurgical analysis, tensile strength and uniaxial and impact strength tests. The sample was taken from the crane beam's web relating to material quality 11 375.1.

2.1. Proposal to Modify Beam Cross-section

The damaged weld between the web and table on the side of the crab rails of the main cat head is replaced by welding of a formed plate shown in Figure 4. Calculations of cross-section characteristics were required for assessing the structure for fatigue for this type of cross-section modification [1,7].

2.2. Load Bearing Capacity on Fatigue

To assess beam fatigue, it is necessary to determine the design strength of the symmetrical and vanishing cycle as well as the asymmetrical cycle.

For the production group K453 and operational group J5, the basic design strength according to norms is $R_{\text{fat}(-1)}$, where $R_{\text{fat}(0)} = 2 \cdot R_{\text{fat}(-1)}$ and

$$R_{\text{fat}(\kappa)} = \frac{R_{\text{fat}(0)}}{1 - \left(1 - \frac{R_{\text{fat}(0)}}{0{,}9 \cdot R_m}\right) \cdot \kappa}. \qquad (3)$$

The condition of tension limits based on norms is

$$\left(\frac{\sigma}{R_{\text{fat}(\kappa)}}\right)^2 < 1{,}1. \qquad (4)$$

Accounting for forces of motion

$$\tau_{\text{fat,t}(\kappa)} = \frac{R_{\text{fat,t}(\kappa)}}{\sqrt{2}}. \qquad (5)$$

Afterwards, condition of stress limit is

$$\left(\frac{\sigma}{R_{\text{fat}(\kappa)}}\right)^2 + \left(\frac{\tau}{\tau_{\text{fat,t}(\kappa)}}\right)^2 < 1{,}1. \qquad (6)$$

Results from the assessment of the beam fatigue show that by substituting condition (6) the value of the shear stress does not significantly influence the condition of the fatigue stress limit and therefore can be neglected.

The auxiliary hoist beam is not suited to fatigue. In the calculation, it was anticipated that the crab auxiliary hoist functions with a 50 000 kg load and moves along the auxiliary hoist beams.

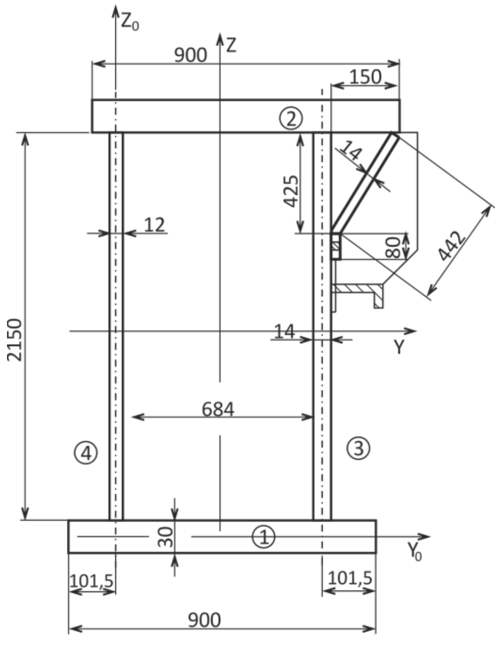

Figure 4. Alteration of the main beams cross section

The beam of the main hoist for notch fatigue is not suitable based on the norms of the technical life span of 200 000 to 600 000 operating cycles.

With adequate reserves, the joint weld in the considered spot of the main beam is suitable for spectrum S3, notched group K4, but for the operational group J4 under tab 13 STN 27 0103 should correspond to the number of cycle in the timeframe of the lifecycle of a crane $N_1 = 20\,000$ to 200 000 cycles. This is confirmed by the analysis using experimental methods as well as the occurrence of cracks after a 30 year operating cycle (more than 300 000 operating cycles).

After the proposed correction, the critical point is still located in the notch group K4 (subject to the required quality of welds), which corresponds to the number of cycles $N_1 = 20\,000$ and a 2 year operational technical lifespan.

Other welded joint of the casing beam of the 200 tonne main hoist can be classified into the notch group K333.

2.3. Calculation of Fatigue Resistance in area of main beam after modification

Proceed by STN 27 0103 with spectrum SP within the operating group J5 and notch group K3.

Table 2. Tension values after the alteration of the cranes beams

	Main hoist beam 200t after alteration
σ_{max} $[MPa]$	124,4
σ_{min} $[MPa]$	38,5
τ_{max} $[MPa]$	12,1
κ	0,309
$R_{fat(-1)}$	63,6
$R_{fat(0)}$ $[MPa]$	106
$R_{fat(\kappa)}$ $[MPa]$	131
$\left(\sigma / R_{fat(-1)}\right)^2 < 1{,}1$	0,902<1,1
	suitable

Adaptive biasing forces are neglected due to low tension.

The welded spot of the beam on the main hoist is suited to the number of cycles during its technical life span $N_2 = 200\,000$ to 600 000 cycles. Since the crane has already completed more than 300 000 cycles, it is not recommended for other welded joints to be in operation for more than two years, even if no faults have been detected. The beam of the 50 tonne auxiliary hoist has reached its life span based on the calculation.

With the modification of the main beam's profile with welded plates as well as taking into account previous operations of the steel structure, it can be concluded that the crane is operation capable as a whole for up to two years based on the current operating conditions requiring regular checks and inspections [1,5].

3. Conclusion

In the field of engineering, there are frequent cases where structures that are past their operational life span, or their abrupt end of life was not accounted for, require the extension of their life span to account for the manufacturing of a new structure or the repair of an existing one. It is dealt with either by limiting the extent of the bearing capacity, such as reducing the impact of dynamic effects or the replacement of critical nodes of the load bearing parts of the structure. It concerns structures which require more than 10 month to produce their replacement. The prediction of residual lifespan forms a key question for the further operation of the structure.

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