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Research paper

RECOVERY OF THE DAMAGES OF A WELDED STEEL STRUCTURE OF A COAL-RELOADING BRIDGE: METHODOLOGICAL APPROACH

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Abstract: *In present paper, the methodological approach to the analysis of the causes of failures and to recovery of the damages has been presented using, as an example, the fracture and damage of a welded steel structure of a reloading bridge. The approach presented can be applied to various types of similar structures, and its application in preventive maintenance would contribute to extension of exploitation life of the reloading bridges.*

Key words: *reloading bridge, welded steel structure, damage, recovery*

1. INTRODUCTION

Due to their specific performances and capacities, coal-reloading bridges are vital components of a system for indoor transport and supply of coal in thermal power plants in Serbia.

Because of extremely strict requirements concerning realization of projected capacity and safety of operation, design and calculation of vital parts of the coal-reloading bridges – supporting structure and motion drive – are a complex task.

Fig.1. Coal-reloading bridge Metalna 300

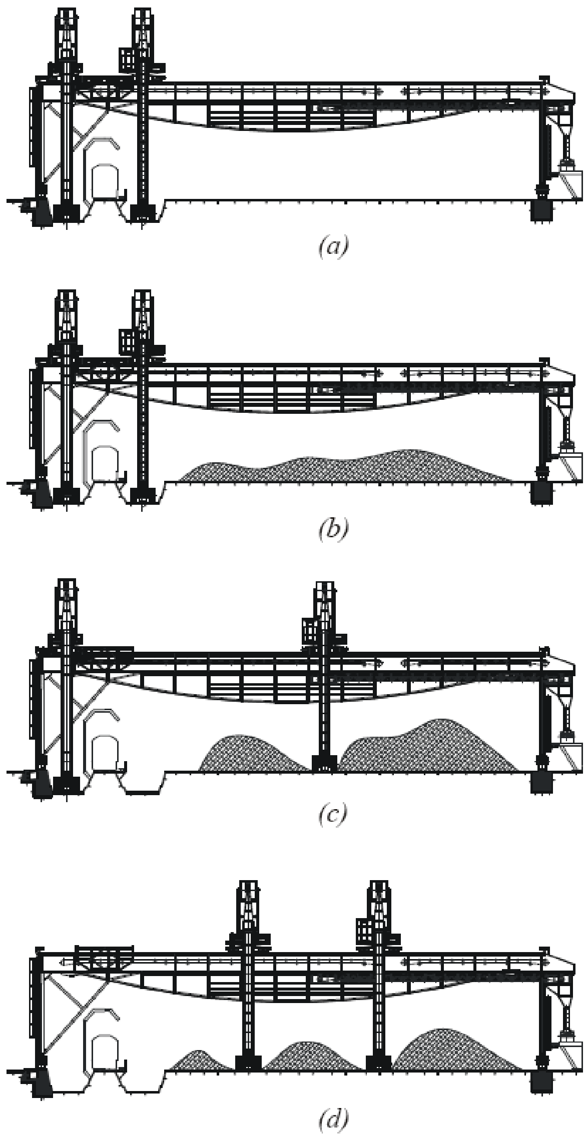

Fig.2. Working regimes coal-reloading bridge [1]

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Continuous exploitation under severe operating conditions leads to relatively frequent failures of the sub-systems of the coal-reloading bridges. In addition to direct material loss, the failures of these machines cause indirect loss due to interruption of operation of the system, which often significantly exceeds the direct one. Among the causes of these failures, the omissions of the project engineers in loading analysis, modelling, response analysis and inadequate exploitation and maintenance are highly ranked.

Four reloading bridges of 50-m span and 300-t capacity are used for the necessities of an outdoor coal warehouse of the Thermal Power Plant KOLUBARA A (TPP Kolubara A). During their exploitation, interruption of operation due to defects of the supporting structure [2,3] occurred relatively frequently, and in extreme cases even the structure failure occurred, which has most frequently been attributed to omissions in the technology of manufacture and/or irregular handling. In Fig. 1 and 2, coal-reloading bridge Metalna 300 at the outdoor coal warehouse of TPP Kolubara A and working regimes coal-reloading bridge is shown, respectively.

2. TECHNICAL DIAGNOSTICS

Accurately conducted procedure of technical diagnostics, as in references [4, 5], protects the system parts against sudden damages, and provides safe operation for the operators and rational techno-economical exploitation and maintenance. Technical diagnostics should be conducted based on three main principles:

- the scope of testing and measurement should result from the case study of exploitation of reloading bridges, including expert knowledge on its construction and operating conditions;
- testing and measurement should be conducted according to the specific procedure, using adequate equipment by highly skilled personnel;
- testing results should be presented so that the conclusions include exploitation of production technical systems and disposability of testing personnel and team experts with adequate experience and knowledge in the field of design, construction, assembling, exploitation, maintenance, safety, fracture mechanics, etc.

3. THE FACTORS AFFECTING DAMAGES

Premature failure or damage of the structural parts and components of the reloading bridges occur when a large number of technological, metallurgical, design and exploitation factors, simultaneously affects them, as shown in Fig. 3.

Favourable design solutions that would ensure driving safety of the parts and structural integrity of the reloading bridges can be achieved only if their behaviour in various modes of operation is completely known [6].

In exploitation of the reloading bridges, fatigue of the assemblies and their integral parts occur. Degradation of the material properties and/or deformation of the components can develop more rapidly due to omissions in exploitation and overhaul; therefore, for systematic control of the processes that might create conditions for system failures, periodical or continuous diagnostic measurements [7] and periodical testing are necessary.

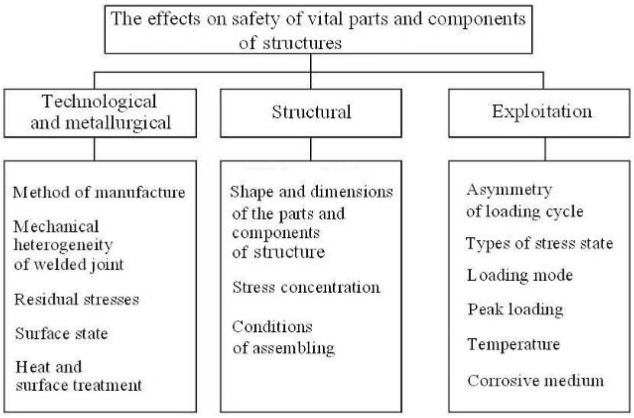

Fig.3. Factors affecting safety

4. ESTABLISHMENT OF DAMAGES

Reloading-bridge structure is exposed to low-cyclic dynamic loading. Such a loading on the reloading bridge under consideration induced fatigue fracture of the supports (feet) of the reloading bridge, Fig. 4, detected by visual inspection.

Fig.4. Damaged structures

The damages can be detected during regular or special inspections by applying the methods of non-destructive testing, using the software technological standards [8] or by measurement of the strains at macro or micro level [9,10].

5. DAMAGE ANALYSIS

Failures of a structure in operation are unavoidable, so that the designers should consider it. To avoid unexpected failures and protect integrity of a structure or some of its components, appropriate experimental and theoretical analyses supported by modelling and numerical analysis are necessary. Fracture mechanics makes it possible to predict behaviour of a structure in presence of a crack, and thus to access safety and reliability of a structure exposed to loading under operating conditions [11].

The analysis of the damages and fractures of vital parts makes it possible to establish their cause in order to eliminate it, which is the process requiring systematic approach to the problem, Fig. 5.

Correct consideration of the effects of loading range on structural life requires the procedure of hybrid design, consisting of the experience acquired by laboratory testing and knowledge on the behaviour in exploitation, both of which should be implemented in the procedures for numerical assessment [12, 13, 14].

The system for continuous diagnostics can be established based on investigation of the failures and causes of defects of specific assemblies of the reloading bridges by applying the fault-tree analysis (FTA), critical point of failure by applying failure mode and effects analysis (FMEA) and indexes of reliability obtained by analysis of input data for actual conditions of exploitation.

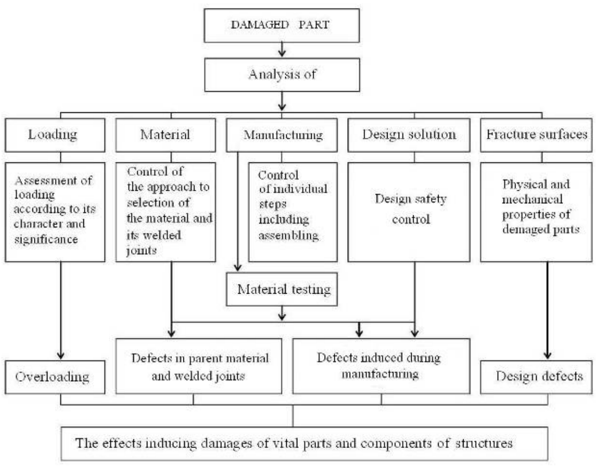

Fig.5. Analysis of damages and failures

The analyses of damages and fractures of the parts and components of supporting structures provide important information for improvement of the methods for design and construction of vital parts and components of supporting structures and for improvement of properties of the existing materials and technologies for their processing and development of new materials as well. In addition, the analyses of damages and fractures enable development of new technical solutions and testing methods already in the prototype phase.

6. DATA FROM DATABASE

The data on loading, parent material and its welded joints properties, manufacturing technology, physical and mechanical properties of registered damages and anticipated preventive measures against damages and destruction can be obtained from corresponding databases, the structure of which is shown in Fig. 6.

The databases of realized investigations [15] of adequate structures provide numerous possibilities for detailed analysis of behaviour of vital parts and components of supporting structures. It should enable establishment of variations of mechanical properties of the materials, parts and welded joints of the structures when varying a large number of the factors of influence; at the same time, some undesirable effects should be reduced to acceptable value, i.e. constructional solution should be favourable as a whole.

The data on loading, properties of parent material and its welded joints, technology of manufacture, technical and physical properties of registered fractures and anticipated preventive measures against damages and destruction should be imported into corresponding database. The databases should also include the data collected by testing of previous structures of adequate supporting structures.

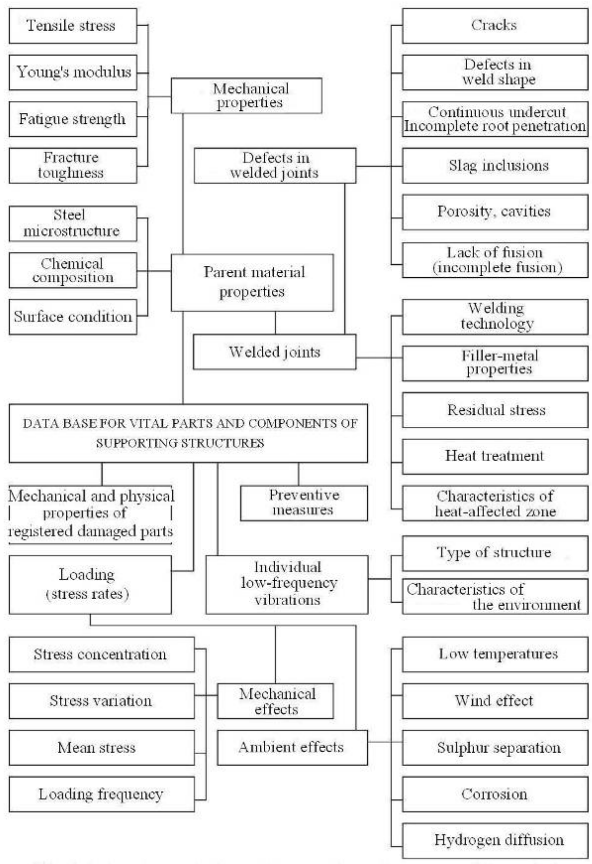

Fig.6. Database structure

The recoveries and reconstructions of similar structure that have already been completed [16, 17] provide useful information on methodology of recovery/reconstruction.

To detect and solve the causes of the problems, it is necessary to apply numerical experimental diagnostics of strength of the components [16].

Experimental measurements should provide the data on loading of the structure in exploitation, deflection, elongations, stress and acceleration. It meand that they define input loading necessary for calculation and verify the results of calculation. The application of FEM calculation enables minimisation of the scope of measurement [17].
Quick and reliable assessment of integrity and applicability of vital parts and components of supporting structures of the loading bridges is possible only by creation of the database and foundations for development of software.
The existing software packages enable more effective use of the database, as well as analysis of individual factors of influence, development of the methods for improvement and search for variant solutions in all phases of design and development of the structure.

7. DOCUMENTATION AND PREPARATION FOR RECOVERY

Documentation for recovery of the damages was prepared based on conducted testing and analysis, where traditional calculation based on permissible stresses, calculation of FEM and analysis of experimental measurements using the data from the database is understood. This documentation includes corresponding drawings, Fig. 7, calculations and welding technology with anticipated tests and NDT methods before, during and after recovery.

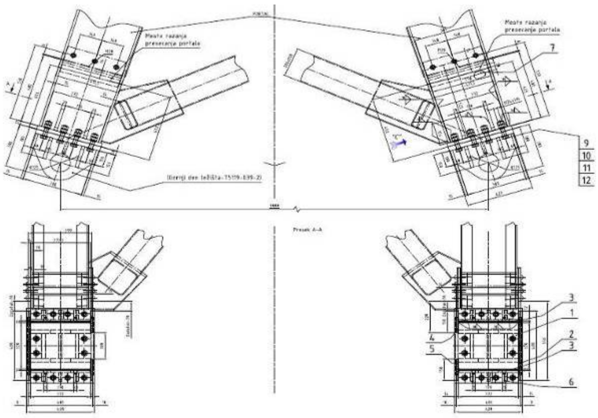

Fig.7. Extract from documentation

An integral part of the welding technology is a procedure containing the sequence of all operations preceding recovery. These are, first of all, supporting of the structure, cutting of damaged supports and preparation for welding, Fig. 8 and 9.

Fig.8. Cutting of damaged supports

Fig.9. Preparation for welding

8. QUALITY CONTROL OF RECOVERY

For the necessities of quality control, 100% visual testing was conducted before, during and after welding. After welding, welded joint of the supports of reloading bridge was 100% tested by applying magnetic particle testing and ultrasonic testing.

8.1. Visual optic testing (VT)

It is used for detection of the defects of any type that may be observed on the surface and the cause of their initiation. It is applied regardless the method to follow, as it is possible to detect the defects and thus to avoid the application of other, more expensive NDT methods. It is also used for selection of the critical spots on the object shat shall be subsequently tested by applying some other NDT methods. It is often repeated on the same objects, too (e.g. before and after cleaning, or before and after anti-corrosive protection). There are great possibilities for its automation and application at the spots that human eye cannot reach.

8.2 Testing with Magnetic Particles (MT)

This method is based on outflow of waste magnet flux induced by presence of surface or sub-surface defects and flaws such as cracks, notches, inclusions and other types of sharper planar defects. The advantages of this method are moderate costs that it requires, and the fact that when properly conducted it provides very good sensitivity in detection of surface defects, and with proper selection of the parameters of sub-surface flaws as well. The disadvantages are the limitation of application on ferromagnetic materials only, as well as possible necessity of demagnetization after termination of testing. The most frequent application is that for detection of the cracks and other sharp defects in welded joints, castings and forgings.

8.3 Ultrasonic testing (UT)

This method is based on recording of the variation of sound resistance induced by presence of the cracks, voids, inclusions and physical separation in the material in general.

The advantage of this method is its applicability even in case of very thick materials; it is excellent for detection and location of the cracks and other defects and suitable for automation. It is considered that its main disadvantage is the necessity of a contact medium on the surface to be tested, as well as the requirement that the surface on which the sonde moves should be relatively smooth (as required by polishing to metal shine).

The most frequent application is that for detection and accurate determination of the defects of sheets, welded joints (butt and angle-welded), steel castings and forgings, if allowed by their geometric configuration. The application of this method in testing of the materials with high damping of ultrasonic energy (high-alloy austenitic steels, cast bronze and alike) is aggravated and is possible only under special conditions.

As the above-specified control and testing methods did not reveal any inadmissible defects in preparation, welding process and welded joints, Fig. 10 and 11, there was no need for their repair after recovery, so that the structure was released and put into trial operation.

Fig.10. Control and NDT during recovery

Fig.11. NDT after recovery

9. MODEL OF MAINTENANCE SYSTEM AS PREVENTIVE MEASURE

Technological process of loading, transport and unloading of coal including reloading bridge, belt conveyor and coalbunker requires special organization of the maintenance system. Organization of the system for maintenance of the reloading bridges depends, in the first place, on their size, shape and structure, number of employees, experience of the experts in the maintenance system, corresponding databases for maintenance and previous testing of the driving aggregates and supporting structures with various types of reloading bridges. In Fig. 12, organizational model of the maintenance system of the reloading bridges as a preventive measure against damages is shown.

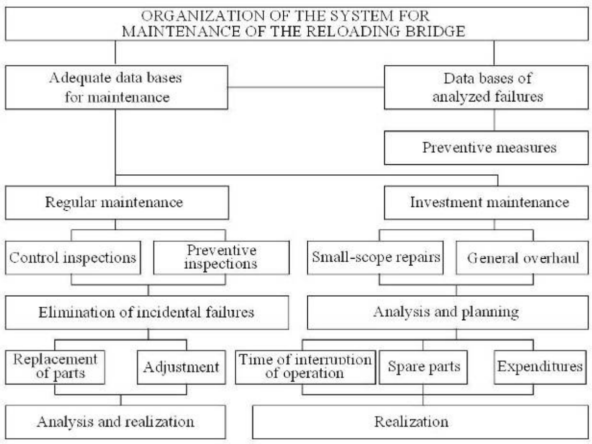

Fig. 12. Organizational model of maintenance system for reloading bridges

The reloading bridges require constant control of the state of and behaviour of the structure through the control centre using the system for monitoring, updating, report and analysis of measured characteristic parameters, both technical/technological and diagnostic [18, 19]. Based on the parameters obtained, the activities related to specific assembly of the reloading bridge are defined.

10.CONCLUSION

Only the testing of reloading-bridge structures under operating conditions makes it possible to assess their state completely. This testing provides the data necessary for comparison of quality and assessment of structures, assessment of the effect of volumetric operation of individual parts and components on carrying capacity and determination of simultaneous operation of driving units and structure as well.

The results presented in this paper and realized investigations provide great possibilities in detailed analysis of behaviour of vital parts and components of supporting structures of the reloading bridges in order to determine the variations of mechanical properties of the materials, parts and welded joints of the structures when varying a large number of the factors of influence and at the same time to produce the structures of higher safety or to reduce some undesirable effects to acceptable value, i.e. to realize favourable constructional solution for a reloading bridge as a whole.

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