Experimentální Analýza Napětí 2009
Experimental Stress Analysis

COMBINED CONNECTIONS IN HEAVY CARRYING STRUCTURES AND THE FAILURES CAUSED BY THEIR IMPROPER FUNCTIONALITY

František Trebuňa [1], František Šimčák [2], Jozef Bocko[3] & Miroslav Pástor [4]

Abstract: The contribution is a continuation to the discourse on EAN 2008 in Ostrava that concerned to safe operation of casting pedestal on the base of results gained by the methods of experimental mechanics. After detection of failures was on the base of previous analysis realized further examination not only by the numerical methods, but also by the methods of experimental analysis. These analyses were realized during operation as well as in laboratory conditions. The results show that combined connections that preserve transmission of forces especially under non-proportional loading distribution to individual parts of connections influence not only functionality of connection, but also excessive loading of structure.

1. Introduction

In workplaces, especially metallurgical and machinery companies are often used equipments that have carrying structures completed, with respect to their dimensions and mass, from several parts. If during operation of such equipments arise dynamic loading, it is appropriate for assembling of structure use combination of sunk keys and bolted connections. An example of such combined connections is a casting pedestal (Fig.1), which serves for transportation of steel in ladles of converter into operation container of continuous casting line.

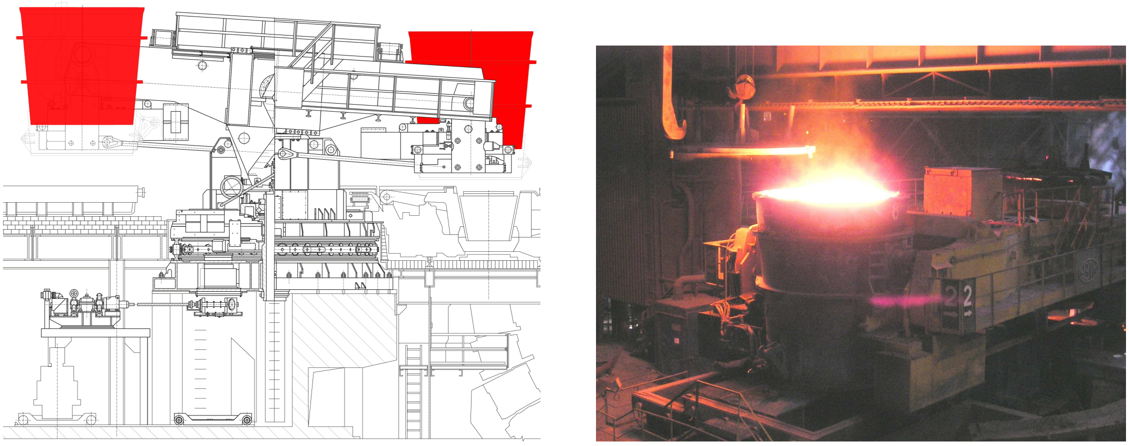


Figure 1: *Casting pedestal with casting ladles.*

[1] Dr.h.c. mult. Prof. Ing. František Trebuňa, CSc.; Technical University in Košice, Department of Applied Mechanics and Mechatronics, Letná 9, 04082 Košice, Slovakia, frantisek.trebuna@tuke.sk
[2] Prof. Ing. František Šimčák, CSc.; Technical University in Košice, Department of Applied Mechanics and Mechatronics, Letná 9, 04082 Košice, Slovakia, frantisek.simcak@tuke.sk
[3] doc. Ing. Jozef Bocko, CSc.; Technical University in Košice, Department of Applied Mechanics and Mechatronics, Letná 9, 04082 Košice, Slovakia, jozef.bocko@tuke.sk
[4] Ing. Miroslav Pástor, PhD.; Technical University in Košice, Department of Applied Mechanics and Mechatronics Letná 9, 04082 Košice, Slovakia, miroslav.pastor@tuke.sk

During operation of casting pedestal the sunk keys and bolted connections were often released. It caused non-proportional loading of individual parts of connections and remarkably influences not only their functionality, but also it caused extraordinary loading of carrying structure of casting pedestal. As a result of this process it was necessary to realized stress analysis of carrying elements of pedestal under operation loading by analytical, numerical and experimental methods [1,2,3], to evaluate functionality of combined connection and to suggest modifications with the aim to increase pedestal lifetime. After providing modifications and after approximately one year operation was realized new experimental analysis of stress state in pedestal and on the base of theory of failure accumulation was assess the residual lifetime.

2. Combined connection of carrying structure of casting pedestal

Main supporting part of casting pedestal is the traverse consisting of two beams (Fig. 2) jointed with middle part with arms for toothing by bolts and sunk keys (Fig. 3). During the operation of casting pedestal are in hinges A, B or C, D placed the ladles by hinging supporting baskets. Process of casting results to the following loading combinations of traverse: hinges A, B - full ladle, hinges C, D - ladle with rest of steel; hinges A, B - full ladle, hinges C, D - without ladle; hinges A, B - without ladle, hinges C, D - ladle with rest of steel. Due to symmetry of pedestal are the hinges A, B and C, D interchangeable. For the solution was considered weight for full ladle 280 000 kg, weight for empty ladle 70 000 kg and weight for ladle with the rest of steel 120 000 kg.

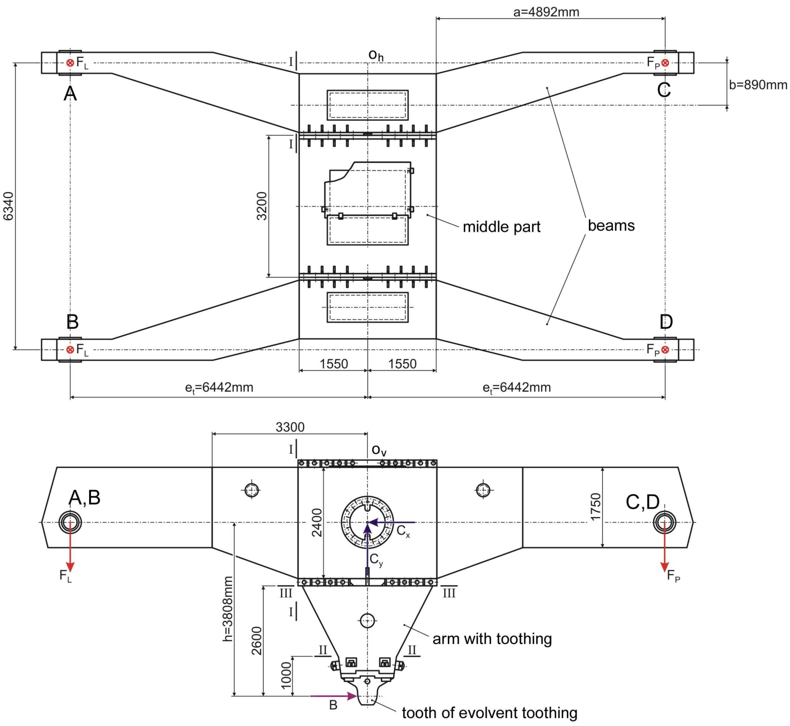


Figure 2: *Traverse of casting pedestal.*

During the casting are in hinges of traverse placed ladles in above given combinations. Transportation of liquid steel from converter to container is realized by turning of casting pedestal (together with traverses) around vertical axis o_V (Fig. 2) by 180°. Full ladle in hinges A, B (reserve position) is transported to hinge positions C, D (casting position). Ladle in hinges C, D (mostly with rest of steel) is moving to reserve position from which is taken (hinges C, D are without ladle). Short time before steel casting from ladle in hinges A, B full ladle is given to hinges C, D and the process repeats. During operation the traverse of casting pedestal provides rickety rotational movement still by 180° around axis o_V . During the casting traverse provides additional rickety rotational movement around horizontal axis o_H so that ladles are moved in vertical direction. Rotational movement around vertical axis o_V is realized by rollers on which whole casting pedestal (Fig.1) lies, rotational movement around horizontal axis o_H is realized by teeth on the arms with toothing and four hydraulic pistons [7].

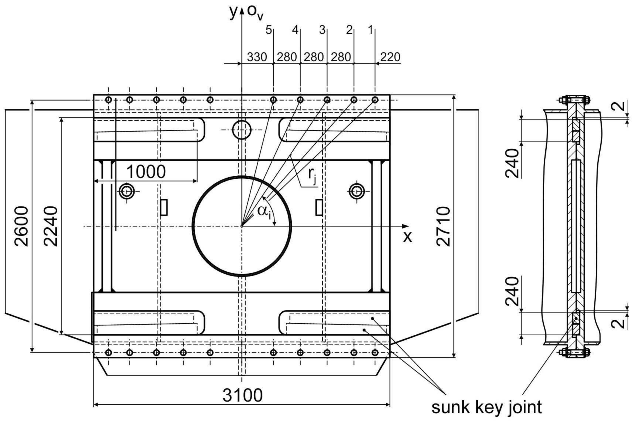


Figure 3: *Bolted and wedge joints of the traverse and middle part structure.*

Traverse beams are are connected with the middle part of traverse by sunk keys and bolted connections (Fig.3).

Bolted connection of traverse beam and the middle part of pedestal consists of twenty bolts M48 (Fig.4), sunk keys consists of four pairs of sunk keys (all together eight sunk keys according to Fig.5).

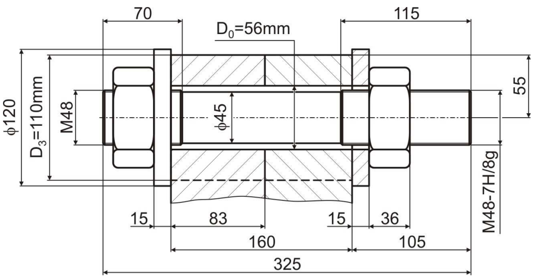


Figure 4: *Bolted connection of traverse beams with the middle part of pedestal.*

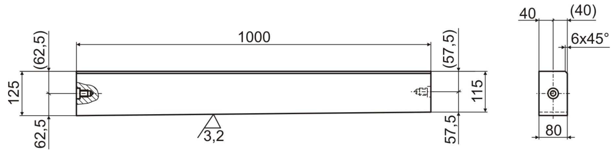


Figure 5: *Shape of sunk key.*

Analysis of stress states in the area of connections of traverse beams with the middle part of pedestal was accomplished by the finite element method. In Fig.6 is detail of equivalent stresses in location of traverse beam and middle part of pedestal connection during manipulation with one full ladle (280 000 kg). In Fig.7 are fields of principal stresses σ_1 (Fig.7a) and σ_3 (Fig.7b) in location of combined connection. In this figure is seen evident shift of traverse beam with respect to middle part.

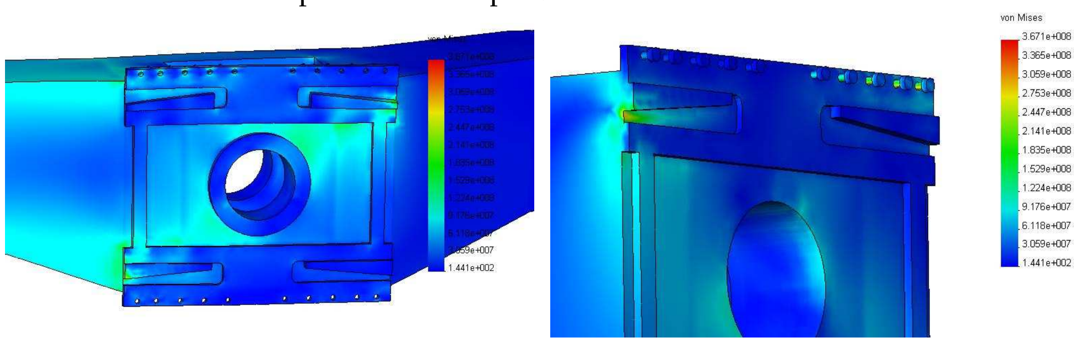
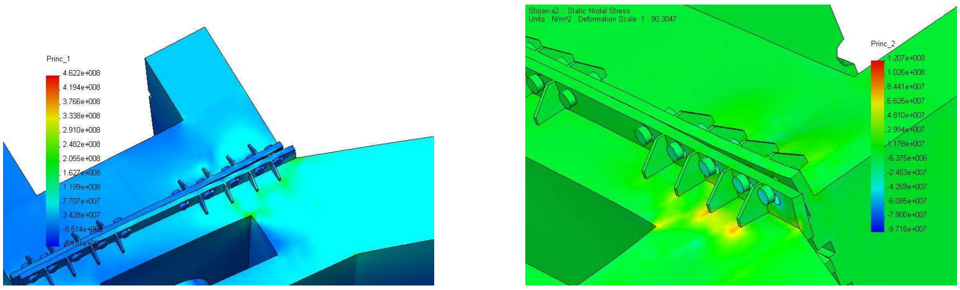


Figure 6: *Detail of equivalent stresses in location of middle part and transverse beam connection.*

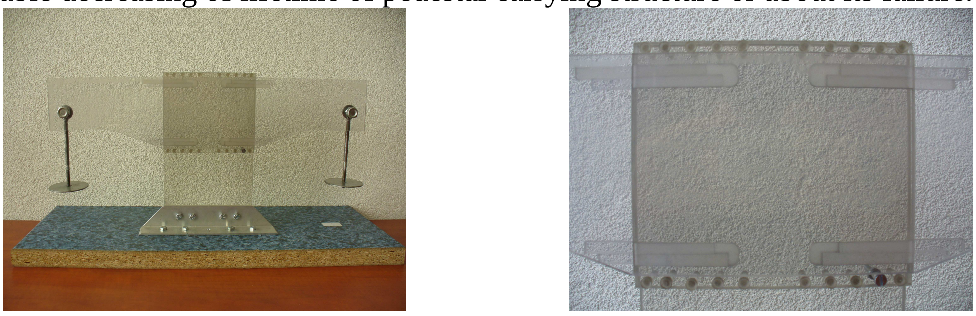


a) b)

Figure 7: *Fields of principal stresses in location of bolted connection of transverse beams and middle part.*

3. Verification of loading transfer to bolted connections and sunk keys pairs by the method of trasmission Photoelasticimetry

Due to releasing sunk keys that transfer the main part of loading there occurred significant change in stress distribution. It was the reason for giving the pedestal out of operation, which was necessary for reinsuring functionality of sunk keys. It was necessary to analyze these changes and the analysis itself was provided by analytical, numerical and experimental methods. From the variety of experimental methods was for determination of strain and stress states chosen the Photostress method, which uses models made of optically sensitive material (Fig.8). Model of carrying part of casting pedestal was made of optically sensitive material PSM-1 with stress – optic coefficient 7kPa/fringe/m, Young’s modulus E = 2,5 kPa, Poisson ratio μ = 0,38; thickness 6,25 mm, producer Vishay M-M. During the process of design were used the similarity methods. On the model in question were simulated regimes that included also extraordinary load combinations that can adjudicate about remarkable decreasing of lifetime of pedestal carrying structure or about its failure.



a) b)

Figure 8: *Unloaded model of casting pedestal. a) whole view, b) detail of sunk keys and bolted connections.*

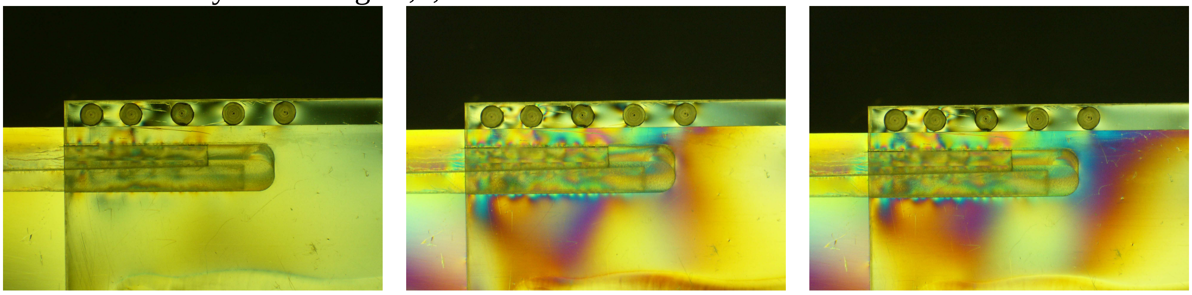
The measurements were realized for fixed sunk keys, one pair of released sunk keys and for two pairs of released sunk keys.

Process of loading was chosen according to Table No.1.

Table 1

Measurement No.	**Loading of model [N]**	
	Left side	**Right side**
1	50	0
2	125	0
3	125	50

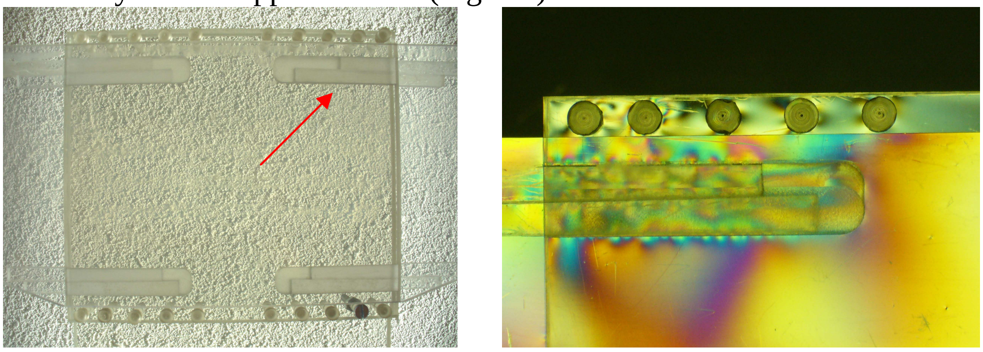
Measurement No.1 represents operation regime with empty ladle on the left side of casting pedestal Measurement No.2 represents operation regime with full ladle on left side of casting pedestal. Measurement No.3 represents operation regime with full ladle on left side and empty ladle on the right side of casting pedestal. Details of isochromats near combined connection on upper left boundary of traverse beam during measurements No. 1, 2, and 3 with inserted sunk keys are in Fig.9a,b,c.



a) b) c)

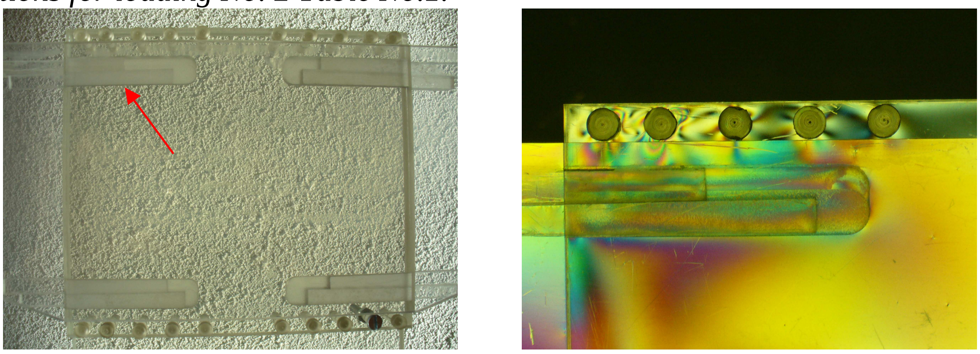
Figure 9: *Detail of sunk keys and bolted connection near upper boundary of traverse beam under loading. a) 50 N – 0 N, b) 125 N – 0 N, c) 125 N – 50 N.*

In Fig.10b are the details of isochromats near combined connection on upper left boundary of traverse beam for released pair of sunk keys on upper right side (Fig.10a). In Fig.11b are fields of isochromats at the same location of traverse beam after releasing of a pair of sunk keys on the upper left side (Fig.11a).



a) b)

Figure 10: *Measurement for released sunk keys on the right upper side (Fig.10a), b) detail of connections for loading No. 2 Table No.1.*



a) b)

Figure 11: *Measurement for released sunk keys on the left upper side (Fig.11a), b) detail of connections for loading No. 2 Table No.1.*

Photoelastic measurements with a model were realized also for a case of releasing two pairs of sunk keys. The same procedure of measurement was repeated also for change of loading of left and right side. On the base of analysis of isochromats can be assessed influence of releasing of sunk keys to stress distribution in beam and in middle part of pedestal as well as to redistribution of loading between sunk keys and bolted connection.

4. Conclusions

In the paper are given some results of stress analysis of combined sunk keys and bolted connections on the casting pedestal that were gained by numerical and experimental methods of mechanics. Complex analysis of measurement results have shoved that the bolted connection transfers approximatelly 20% of loading. This result well corresponds with the results reached by analytical solution and supports a fact that extraordinary attention have to be given to sunk keys.

Stresses and accordingly also supperponed values of isochromat fringes increased linearly. From the analysis is obvious that portion of load transfered by sunk keys decreased for one released sunk keys and accordingly increased the portion of load transfered by bolted connection.

This fact allows writing a claim that by releasing of pair of sunk keys will be gained answer to questions about increased stress levels in critical locations of carrying structure of casting pedestal. For that reason it is necessary to prevent taking out of all pairs of sunk keys by locking of upper sunk keys, by modification of bolted connection (change of prestress in bolts), or by improving of manipulation procedures with ladles on the pedestal

Acknowledgement

The contribution was elaborated with the support of grant agency VEGA, projects No.1/0004/08 and 1/4163/07.

References

[1] Pástor, M.: Metódy experimentálnej mechaniky ako nutná súčasť pre určovanie životnosti nosných prvkov. Doktorandská dizertačná práca. December 2008.

[2] Trebuňa, F., a kol.: Analýza a určenie životnosti liaceho stojana na ZPO2 U.S.Steel Košice. Záverečná správa. TU Košice, august 2007.

[3] Trebuňa, F., a kol.: Analýza a určenie životnosti liaceho stojana na ZPO2 U.S.Steel Košice. Potvrdenie zostatkovej životnosti resp. navrhnutie riešení na jej predĺženie na základe opakovaného merania po roku. Záverečná správa. TU Košice, máj-august 2008.

[4] Trebuňa, F., Šimčák, F.: *Odolnosť prvkov mechanických sústav*. Emilena, Košice, 2004.

[5] Trebuňa, F., Šimčák, F.: *Príručka experimentálnej mechaniky*. Typopress Košice, 2007

[6] Trebuňa, F. a kol. : Ensurance of casting pedestal operation on the base of results gained by the method of experimental mechanics. In: Experimental Stress Analysis *2008* : 46th international conference, Horní Bečva, Czech Republic, June 2-5, 2008 : Book of contributions. Ostrava : VŠB TU, 2008. 4 p. ISBN 978-80-248-1774-3.