Experimentální Analýza Napětí 2010
Experimental Stress Analysis

Experimental stress analysis of critical locations in vicinity of frame welds of hospital sickbeds

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Abstract: Hospital sickbeds are being used not only for accommodation of patients, but also for ensuring the optimum position of inpatients during handling, therapy and connected investigations. Safety and reliability of the sickbed frames is one of the essential conditions for everyday use. An investigation programme on prevention of potential fatigue failures of welded joints between sickbed shackles and cross girders of the frame was carried out. The problem of the weld joint between the shackle and frame consisted in very different thickness of the two parts, the shackle thickness being approximately 10 mm in comparison with very thin wall of the cross girder resulting in potential weld imperfections. Fatigue cracks could be then initiated as a result of cyclic loading during road transport, when frames are usually stacked on each other, particularly in countries with poor quality of pavement. Results of experimental static and dynamic strain/stress measurement near the locations of welds are presented and discussed considering potential weld imperfections. Taking account of possible actual loading resulting of mass of inpatients and another person sitting on the bed, which was simulated by a sequence of model loading with different mass, limit states of stresses were determined. A positive effect of reinforcing structure element introducing compression stresses to prevent fatigue crack growth and potential failures is demonstrated.

Keywords: Fatigue cracking, Welds, Thin-walled girders, Experimental stress analysis, Hospital sickbeds

1. Introduction

Hospital sickbeds belong to fundamental medical equipment being daily used in numerous hospital departments. No hospital can exist without this basic device enabling to accommodate inpatients and to perform necessary care. In spite of that hardly anybody think about hospital beds, a lot of development and progress has been recently made in their construction. Advanced sickbeds namely enable to select and optimise various positions in both head and foot inpatient zones, which are very important for inpatients´ recovery process [1]. An ideal bed height considerably helps to nursing staff when taking care of inpatients, whilst an optimum height choice is important for a prevention of inpatients´ falls [2]. Besides these useful and recently already essential sickbed functions, the beds have to be absolutely safe and

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reliable not only to prevent any additional inpatient injury in the hospital, but also to prevent any restrictions in operation of important hospital departments [3].

The paper contains the most important result of a case study connected with an occurrence of cracks in essential structural elements of sickbed frames, having arisen in welds between bed frame cross girders and plates attaching the frame to the positioning hydraulic cylinder – Fig. 1. The critical welds are indicated by arrows (compression zones), whereas the cracks arose in zones of tension loading – at the bottom opposite to the arrows. The cracks occurrence was observed in several cases after transport of the bed frames on bad quality roads, when beds were stacked on each other. Attention was paid particularly to quality analysis of the welds. In the second part of the paper, extensive experimental static and dynamic stress analyses were carried out to evaluate actual possible strains and stresses occurring in the critical sites. A prototype strengthening device to prevent possible fatigue cracking was then proposed and its positive effect on reduction of dynamic stresses was demonstrated.

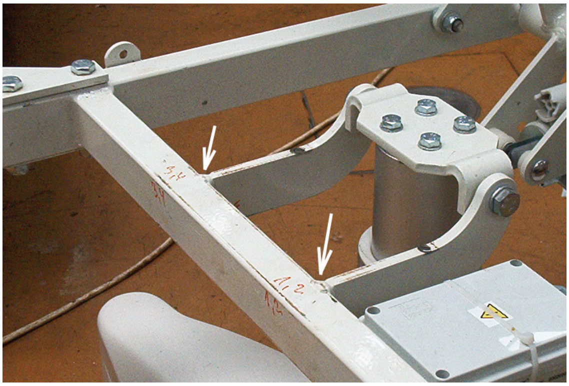

Fig. 1. Sickbed frame with welds between cross girder and plates, the critical welds being indicated by arrows (compression zones).

2. Case study of cracks in bed frame welds

As mentioned above, quite distinct cracks were observed in several frames after the road transport under the severe conditions. It should be mentioned that the welds were very difficult to make, because they connected quite thick plates of the 40 x 8 mm cross section to thin walled profile 30 x 40 mm of the bed cross girder, the wall thickness only being 2 mm.

Issues connected with microstructure and properties of welds in general are quite complicated and so a great number of works have been recently published in the literature, either form the field of numerical predictions or experimental evaluation. Welding of thin walled structures or joining thick and thin walled parts by welding are characteristic by particularly specific problems. When two pieces of pipe are namely welded together, residual stresses arise in the vicinity of the weld owing to the circumferential welding of the pipes. Residual stresses are attributed to the elastoplastic response of the object towards the transient thermal stresses generated by the thermal cycle. They can be a major source of cracking and fracture problems in welded structures [4].

Possible distorsions occurring during welding represents another group of problems [5]. If the whole structure is stiff enough an does not enable distorsions, high resisual stresses occur which can affect fatigue strength very negatively. The weld quality and properties are connected with numerous parameters like thickness of the welded parts, heat input, heat losses through convection and radiation, affecting temperature distribution during the welding process, whereas cooling phase is of a particular importance [6-8].

A sample of the weld delivered to the laboratory was sectioned and metallographical analysis carried out. Macro view of the perpendicular cut of the weld is in Fig. 2 showing the 2 mm thick wall of the girder (horizontal position in Fig. 2) and the 8 mm thick plate – vertical. bottom part of Fig. 2. The right part of the weld is of a relatively good quality unlike the left part, where imperfections were found.

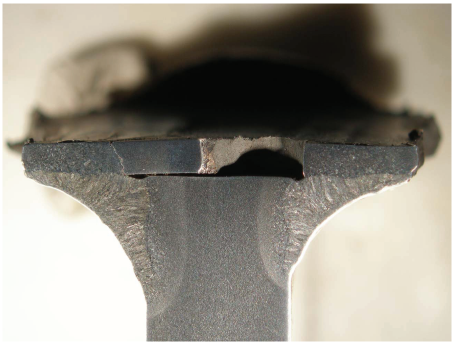

Fig. 2. Macro view of perpendicular cut of weld.

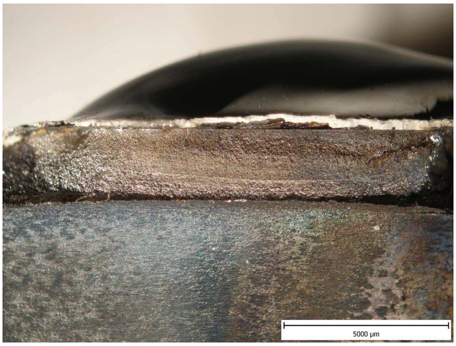

Fig. 3. Fracture surface with gradual fatigue crack propagation.

Fractographical analysis showed that crack propagation was gradual, i.e. of fatigue type – Fig. 3. However, fatigue crack propagated under the contribution of existing technological welding cracks and other defects including microstructural ones. Welding cracks were found particularly in heat affected zone along boundary between fine grain and Widmannstätten structure, which is typical for low carbon steels, if overheating is followed by fast cooling – Fig. 4. The cracks likely arose as a result of residual stresses. Besides these technological cracks, melting zones in the thin walled girders were found, usually containing further cracks at their boundaries – Fig. 5. It is therefore evident that the welding parameters were not ideally optimised.

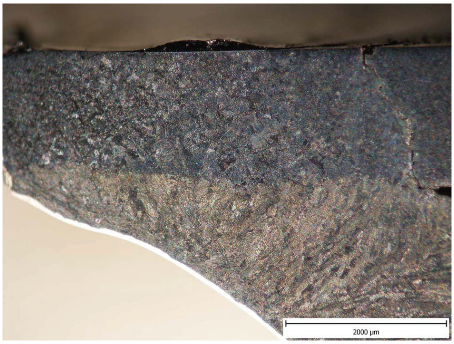

Fig. 4. Crack in profile wall at heat affected zone margin.

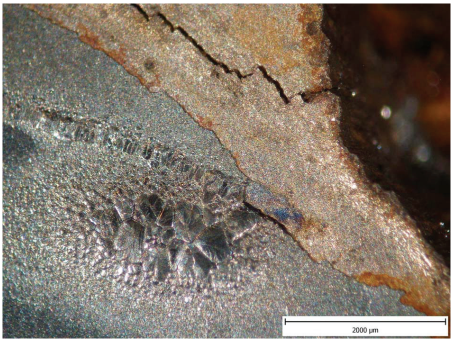

Fig. 5. Coarse melted structure with technological crack at zone boundary.

3. Experimental strain measurements in welding zones

Evaluation of complex stress concentration factors near welds is a complicated task. Therefore, despite of possibilities of recent computational methods, stresses near welds are often determined from strain distribution obtained during strain gauge measurement [9]. A similar method was used in this work, too.

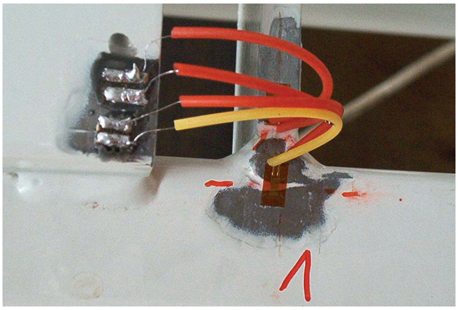

Fig. 6. Position of strain gauges 1 and 2.

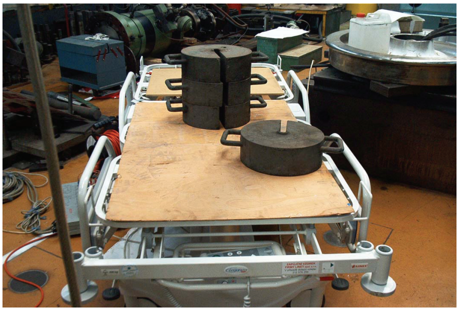

Fig. 7. Simulation of inpatient 150 kg mass and 50 kg visitor.

Total number of 7 strain gauges (SGs) were bonded near the welds. SGs of numbers 1, 3 and 5 were bonded over the weld at the position of maximum stress concentration, at the boundary between weld elevation and the girder. SGs of numbers 2, 4, 6 and 7 were bonded on the 8 mm thick plate surface approximately 10 mm from the weld. These SGs were of reference type, because theoretical stress at their positions could be easily calculated. Example of positions of SGs 5 and 6 is in detail view in Fig. 6. SGs 1, 2 and 5, 6 were on the plate near the right sickbed side, SGs 5, 6 and 7 near the left bed side.

Loading of the sickbed was simulated by 50 kg masses gradually laid down on the bed. An example of “the inpatient” laying at the centre and “visitor” sitting on the left foot side of the bed is in Fig. 7.

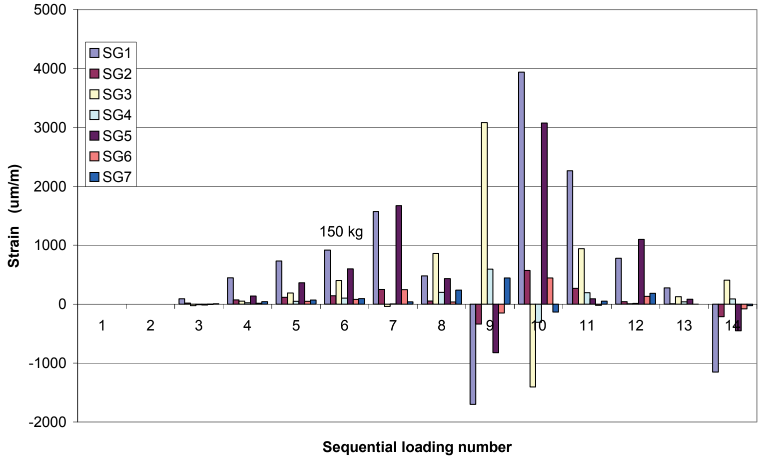

Fig. 8. Results of static strain measurement.

Evaluated results of strain measurement are in Fig. 8. I follows from Fig. 8 that even if a fairly heavy inpatient of 150 kg mass sits at the bed centre (measurement No. 6 in Fig. 8), maximum strains correspond to almost 1000 μm/m. i.e. to 200 MPa, if 210 GPa E-modulus is considered. Much worse situation occurs when visitors takes seat beside, resulting in 4000 μm/m maximum strain corresponding to stress higher than 800 MPa. The strain values might be affected by hidden cracks and defects in the weld, it is true. However, it does not change the fact that such strain/stress values are inaccessibly high.

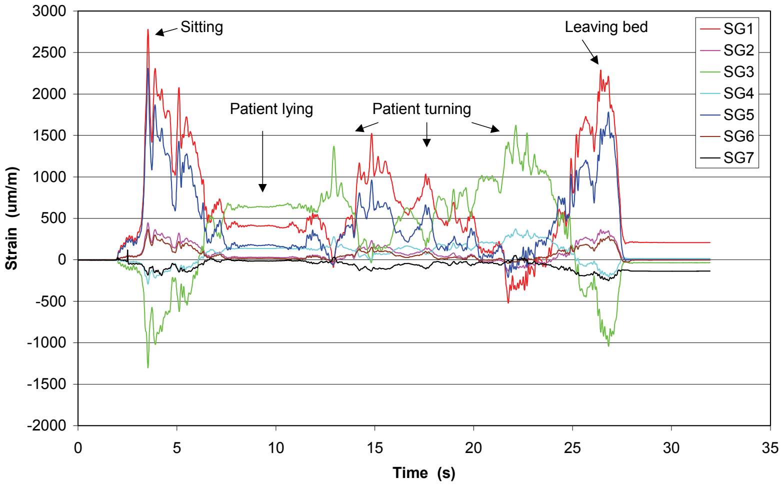

Fig. 9. Dynamic strain measurement record.

Dynamic measurement was performed during a short time sequence simulating dynamic movements of a person of 90 kg mass. The sequence included: (i) standard inpatient sitting down – on the right bed side, (ii) inpatient laying, (iii) inpatient turning, (iv) leaving the bed using the right side.

Dynamic measurement is documented in Fig. 9. The dynamic measurement confirmed that the maximum stresses in the welds occur when the bed side is loaded. Then the stresses can reach values up to 5-times higher in comparison with quiet inpatient laying in the bed centre. Moreover, further 30 % loading has to be added due to some dynamic peaks which usually occur. The results have to be considered for fatigue life estimations.

4. Proposal of weld strengthening method and evaluation of its effect

To prevent possible fatigue failures of the bed frames and to avoid possible problems connected with crack occurrence in operation, several versions of prototype strengthening tool was designed, optimised and attached to the weld vicinity – Fig. 10. The device consisted in two plates further strengthen by welded ribs. An important part were two screws enabling to gradually introduce compressive external preliminary stresses. SG measurement enabled to optimise amount of the static pre-stressing, which corresponded to more than 1 1/2 of screw turns.

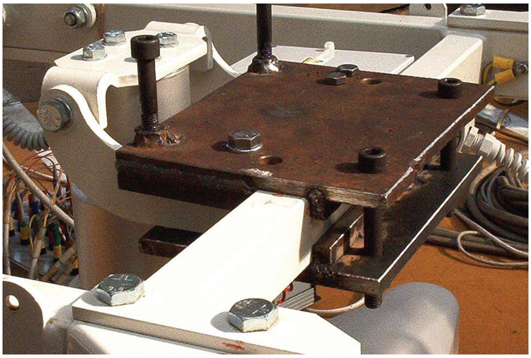

Fig. 10. Strengthening prototype grips with pre-stressing screws.

A similar loading sequence as in Fig. 8 was applied using the strengthening and pre-stressing tool. Results are shown in Fig. 11, where the SG device was set to zero after the pre-stressing application. The effect of the strengthening was considerably high, maximum strain changes were reduced to approximately 400 μm/m, which was a reduction by one order. The corresponding stress range is approximately 40 MPa, which can be considered as acceptable and safe.

The prototype design and pre-stressing method were overhand to the bed manufacturer as a basis for the final design of the strengthening part to be used in operation.

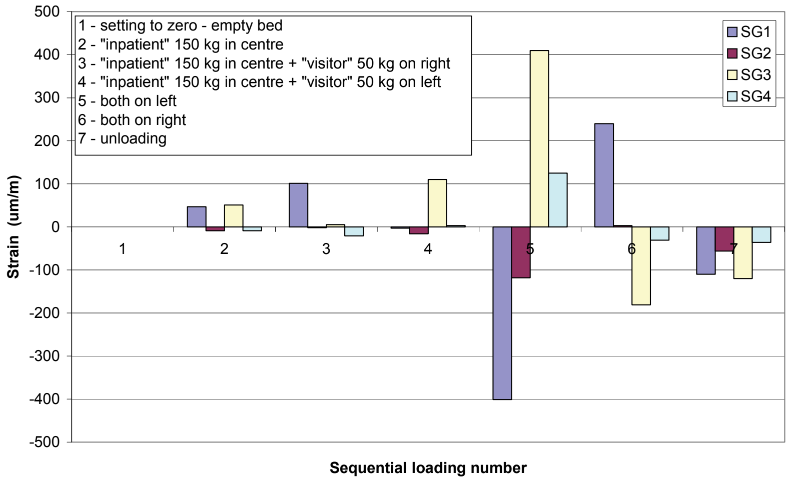

Fig. 11. Strain measurement after application of strengthening grips.

5. Conclusions

The most important results of the investigation performed with the aim to find causes of crack occurrence in sickbed frame welds and to find preventing solutions can be summarised as follows:

- Fractographical and metallographical analyses of fracture surfaces and welding areas showed significant imperfections in weld quality affected by the combination of rather thick plate welded to thin-walled cross girder. Coarse-grained melted structure with connected technological cracks was present in the welds.
- Strain gauge measurements near the welds confirmed and occurrence of unacceptable stresses, which could be affected by a presence of hidden cracks and defects in the welds. It was shown that loading of bed sides is the most critical introducing more than 5-times higher stresses in the welds in comparison with a symmetric loading. Dynamic forces connected with sitting down of the inpatient caused further 30 % increase of the stresses.
- The optimised version of the strengthening tool with application of compressive pre-stressing resulted in a significant reduction of operational stress range, namely by one order, which could be considered as safe, acceptable solution.

Acknowledgement

The works was supported by the grant MSM 2579700001 of the Czech Ministry of Education, Youth and Sports.

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