# Ultrasonic Measurement of Residual Stresses in Welded Railway Bridge

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## ABSTRACT

The residual stresses have a significant effect on the process of the initiation and propagation of the fatigue cracks in welded elements. In this paper the results of the residual stress measurement in the zones of welded elements of the railway bridge span are presented. An ultrasonic method and portable computerized device for uni- and biaxial residual stress measurement were used in this investigation. The residual stresses were measured in the main wall of the bridge span near the ends of welded vertical attachments before and after application of improvement treatment, directed on the beneficial redistribution of the residual stresses. The computer simulation showed that such redistribution of the residual stresses cause a 45% increase in the limit stress range for this type of welded element. The dependency of the fatigue life of welded elements on the possible variations of the residual stress level is also analyzed.

## INTRODUCTION

In many cases the residual stresses are one of the main factors, determining the engineering properties of structural components. This factor plays a significant role in fatigue of welded elements. For example, at a symmetric cycle of loading, the influence of residual stresses on fatigue life of butt and fillet welds can be compared with the effects of stress concentration [1-4]. For that reason, the residual stress analysis is a compulsory stage in the process of design of structure elements and in the estimation of their fatigue life under the real service condition.

In modern standards and codes on fatigue design [4,5] the data presented correspond to the fatigue strength of real welded joints including the effect of welding technology, type of welded connection (stress concentration) and welding residual stresses. Nevertheless, in many cases there is a need to consider the influence of welding residual stresses on the fatigue life of structural components in details. These cases include: the using of the results of fatigue testing of relatively small welded specimens without high tensile residual stresses, analysis of the effect of the such factors as overloading, spectra loading and application of the improvement treatments.

The application of an ultrasonic non-destructive method and the instruments based on it for residual stress measurement showed that for many cases this technique is very efficient and allows to measure the residual stresses both in laboratory conditions and in real structures for a wide range of materials [6-8]. The advanced ultrasonic method and new portable device were used for the residual stress measurement in the zones of welded elements of the railway bridge span.

## ULTRASONIC METHOD AND DEVICE FOR STRESS MEASUREMENT

The ultrasonic method of stress measurement is based on the acoustic-elasticity effect, according to which the velocity of elastic wave propagation in solids is dependent on the mechanical stresses. The acoustic relationships are the theoretical grounds for the development of acoustic methods of stress measurement and in investigations of physical-mechanical properties of materials by means of the ultrasound [6-8].

For the measurement of residual stresses in a material with known mechanical properties, the propagation velocities of the longitudinal ultrasonic wave and shear waves of orthogonal polarization are determined.


FIGURE 1. Ultrasonic device with transducers.

The mechanical properties are represented by the proportionality coefficients, which can be calculated or determined experimentally under the uni- or biaxial loading of a sample of the considered material.

The change of the acoustic wave velocity in structural materials under mechanical stresses amounts to tenths of a percent. Therefore the equipment for practical application of ultrasonic method for residual stress measurement should be of high resolution, reliable and fully computerized. For this purpose, a novel instrument (Figure 1) and supporting software for residual stress analysis were developed based on an advanced ultrasonic methodology [7].

Quartz plates measuring from 3×3 mm to 8×8 mm in cross-section are used as acoustic transducers. The measured levels of residual stresses are averaged through the plate thickness.

**Technical Characteristics of the Measurement Unit**

The developed method and equipment allow one to determine:

- magnitudes and signs of uni- and biaxial applied and residual stresses for a wide range of materials;
- stresses, strains and forces in bolts (pins);
- acoustoelastic coefficients for wide range of materials.

The main technical characteristics of the equipment:

- stresses can be measured in metals with wall thickness: 3 - 150 mm;
- error of stress determination (from external load): 3 - 8 MPa;
- error of the residual stress determination: 0.1 $\sigma_y$ MPa;
- error of the measurement in bolts (pins) 25 - 1000 mm long:
    - stresses: 10 - 15 MPa;
    - strains: 0.05 mm;
    - forces: 0.5 kg;
- supply line:
    - voltage: 110/220 V;
    - frequency 50 Hz;
- power consumed: 20 W;
- independent power supply (accumulator battery 12 V);
- overall dimensions: 300x200x150 mm;
- mass 6 kg.

**Supporting software for residual stress analysis**

The supporting software (SS) for residual stress analysis was created and adapted to the developed instrument. It allows storing of the ultrasonic measurement data, calculation and drawing of distribution of residual stresses and usage of the designed method and equipment with standard PC's.

The original part of the SS includes the possibility to assess through calculations the influence of the residual stresses and their redistribution under the effect of various improvement treatments and cyclic loading on the service life of structural components without having to perform time- and labor-consuming fatigue tests. The program package enables to calculate the fatigue life of structural components after application of heat-treatment, vibration treatment, overloading, ultrasonic peening and other improvement treatments.

The SS allows to analyze the effect of residual stresses, both by using as the initial data the generalized fatigue curves presented in the international and national standards and codes on fatigue design of structural components or using the original experimental results of fatigue testing.

## RESULTS OF RESIDUAL STRESS ANALYSIS

The residual stresses were measured in the main wall of the bridge span near the ends of two welded vertical attachments (Figure 2). In many cases such places are the zones of origination and propagation of fatigue cracks in welded bridges. The residual stresses were measured in welded elements before and after application of improvement treatment, directed on the beneficial redistribution of the residual stresses.

The measured levels of tensile residual stresses near the welds before application of improvement treatment reached 200-240 MPa. Such high tensile residual stresses are one of the main factors leading to the origination and propagation of the fatigue cracks in welded elements.

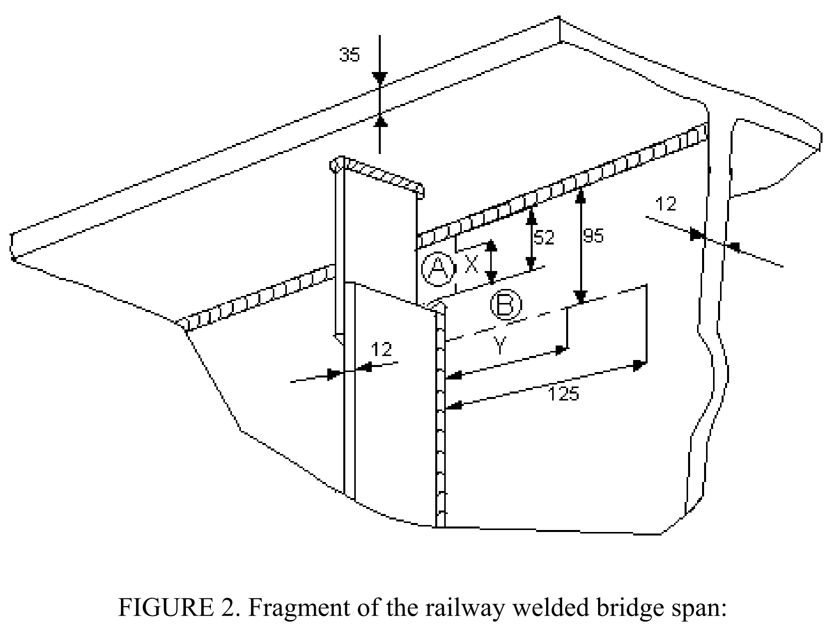


FIGURE 2. Fragment of the railway welded bridge span:
A and B – zones of residual stress measurement.

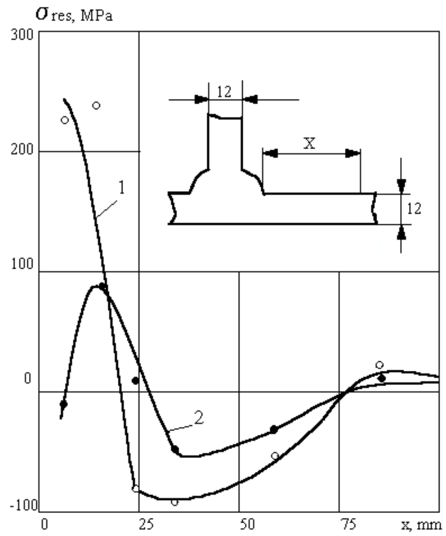


FIGURE 3. Distribution of residual stresses near the fillet weld in the railway bridge span: 1 and 2 – before and after application of the improvement treatment.

The results of residual stress measurement in the main wall near the end of the fillet weld before and after application of improvement treatment are presented in Figure 3. The level of tensile residual stresses near the weld reached in this case 240 MPa. The application of the improvement treatment caused the redistribution of the residual stresses near weld zone from initial level to -10 MPa.

The computer simulations showed (Figure 4) that such redistribution of the residual stresses cause a 45% increase in the limit stress range ($N=2\times10^6$ cycles) for this type of welded element: from 85 MPa to 123 MPa. Figure 4 also shows the dependency of the welded joint fatigue life on the possible variation of the residual stress level. A 50 MPa deviation of the residual stress level leads to a 6% (8 MPa) change in the limit stress range in this case.

## SUMMARY

The advanced ultrasonic method, portable device and supporting software were used for non-destructive residual stresses analysis in welded elements of railway bridge span. The results of measurement showed that the tensile residual stresses near the welds reach 200 - 240 MPa. These stresses are one of the factors leading to the origination and propagation of the fatigue cracks in considered welded elements. The application of the improvement treatment caused the significant redistribution of residual stresses and 45% increase in limit stress range of considered welded element.

The developed ultrasonic technique and software may be used for residual stress analysis in construction industry, shipbuilding, bridge building, aerospace and

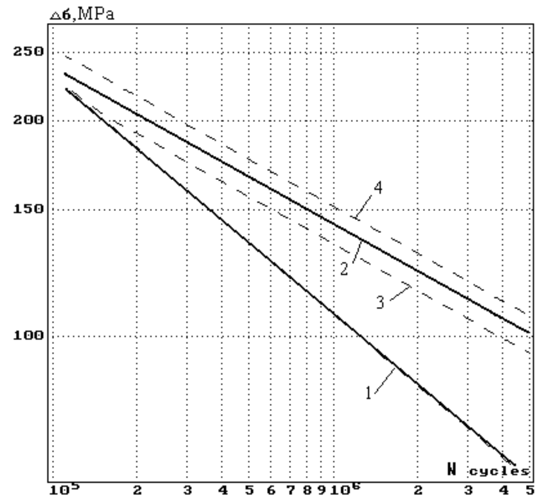


FIGURE 4: Fatigue curves of fillet welded joint with different level of residual stresses: 1, 2, 3 and 4 – 240, -10, 40 and -60 MPa.

nuclear industries, oil and gas engineering and in other areas during manufacturing, in service inspection and repair of structural elements.

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