# FATIGUE ASSESSMENT OF BWE BOOM MEMBERS AND JOINTS IN ORDER TO ASSESS THEIR REMAINING LIFETIME

## OCENA ZMĘCZENIOWA ELEMENTÓW WYSIĘGNIKA WIELONACZYNIOWEJ KOPARKI KOŁOWEJ W ASPEKCIE ICH WYTRZYMAŁOŚCI

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*The paper deals with a new method to establish the fatigue resistance of the constitutive elements of BWE boom (members and joints) based on local surface hardening. The hardness increase with the number of variable load cycles was determined on samples collected from critical parts of BWE boom elements, and, based on this, the in situ hardness in critical points of the analysed structure has been correlated with the age of the BWE. In this manner, we obtain an image of the degree of fatigue along the boom and some dependencies of as a function of the age (which is correlated with the number of cycles, number of working hours, quantity of excavated material) on a fleet of BWE-s with different age. The age of the BWE-s has been also correlated with the number of faults and number of faults involving the load carrying structure.*

***Keywords: fatigue, hardness, bucket wheel excavator, remaining lifetime***

*W artykule opisano metodę ustalania wytrzymałości zmęczeniowej elementów składowych wysięgnika wielonaczyniowej koparki kołowej w oparciu o miejscowe utwardzenie powierzchni. Wzrost twardości wraz z liczbą cykli zmiennego obciążenia wyznaczono na podstawie pomiarów krytycznych elementów wysięgników koparek pracujących w rumuńskich kopalniach odkrywkowych. Twardość in situ w punktach krytycznych analizowanej struktury została skorelowana z wiekiem wielonaczyniowej koparki kołowej. Przedstawiono uzyskane wyniki stopnia zmęczenia elementów wzdłuż wysięgnika i niektórych zależności wynikających z wieku, który jest skorelowany z liczbą cykli, liczbą godzin pracy, ilością wykopanego materiału. Przedstawiono również korelację wieku koparek z ogólną liczbą usterek i liczbą usterek związanych z konstrukcją nośną.*

***Słowa kluczowe: analizy numeryczne, analiza układów wieloczłonowych (MBS), górnictwo, koparki wielonaczyniowe***

### FATIGUE ESTIMATION USING HARDNESS MEASUREMENTS

Using surface hardness measurements on structural elements with a long history of cyclical loading as an indicator of the fatigue is relatively new in the analysis of structures, subject of this kind of loading. The representative structures subject of this approach are mainly the metallic bridges, and in past time the load carrying structures of huge earth-moving machines, such as Bucket Wheel Excavators.

It was determined that the fatigue resistance coefficient decrease can be correlated with Brinell Hardness (HB) increase in the case of steel. The relation between the fatigue resistance coefficient (fatigue ratio) and Brinell Hardness has been statistically determined as in fig. 1.

In our approach, three types of measurements were considered, as follows.

Joint hardness and tensile strength measurements on samples made by the same kind of steel as the BWE boom elements, revealing an increase of surface hardness increase in the proximity of breakage relative to the hardness in the body of the sample.

Hardness and strength measurements on samples obtained from the BWE boom members, which where replaced during renewal of the respective structural element after failure.

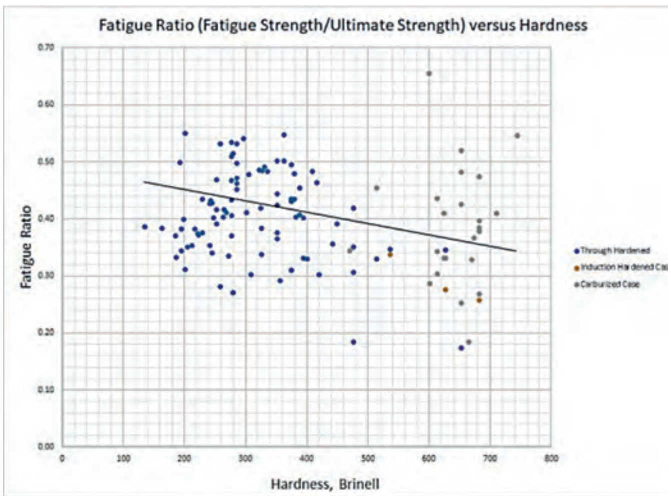


Fig.1. Brinell Hardness increase with fatigue resistance coefficient decrease , according to https://barfatigueblog.org/2017/08/08/hardness-versus-fatigue-strength/

Rys. 1. Wzrost twardości Brinella wraz ze współczynnikiem wytrzymałości zmęczeniowej wg https://barfatigueblog.org/2017/08/08/hardness-versus-fatigue-strength/


Fig. 2. Brinell Hardness relative increase as a function of operating hours
Rys. 2. Wzrost twardości Brinella w funkcji godzin pracy

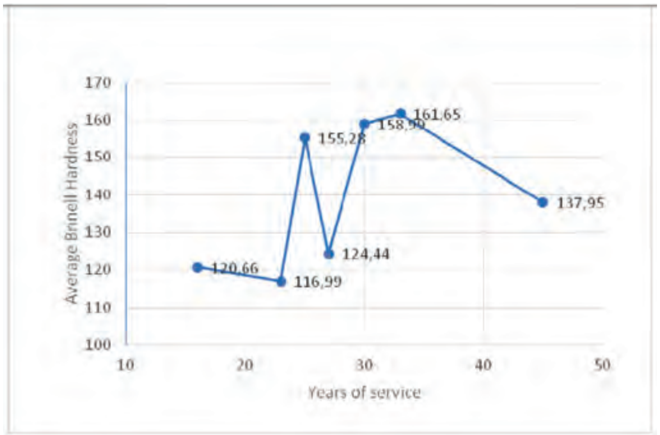


Fig. 3. Evolution of average hardness according to the length of service
Rys. 3. Zmiana średniej twardości w zależności od czasu pracy maszyny

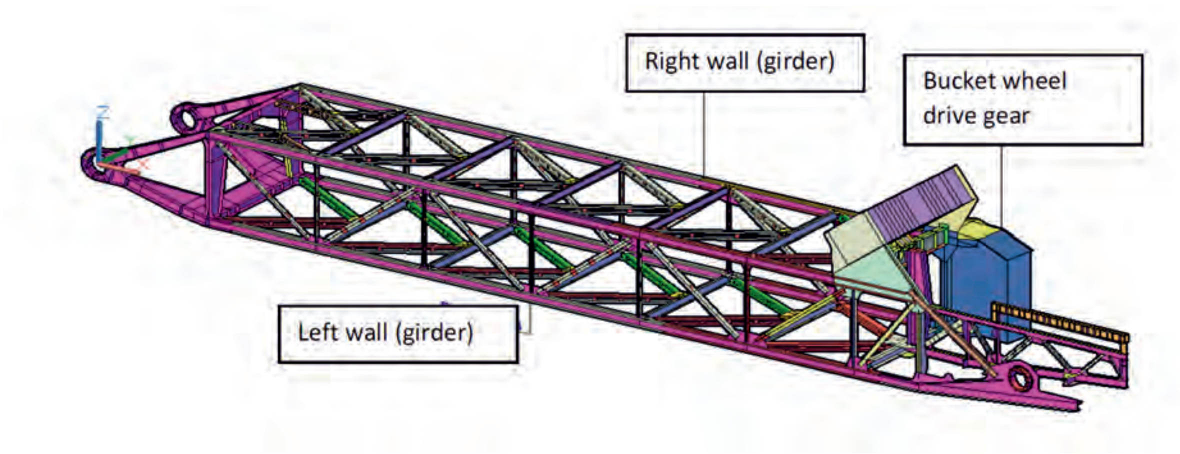


Fig. 4. Constructive elements of a bucket wheel boom
Rys. 4. Elementy konstrukcyjne wysięgnika koła czerpakowego

Tab. 1. Results of hardness measurements on the bucket wheel boom of E1400-30/7 excavators
Tab. 1. Rezultaty pomiaru twardości na wysięgniku koła czerpakowego koparekE1400-30/7

| No | Equipment/mine | Operating hours[hr] | Year of start | Average hardness [HB] |
|---|---|---|---|---|
| 1 | E14-07 -Rosiuta-Motru | 50400 | 2000 | 120.66 |
| 2 | E14-04-Pinoasa-Rovinari | 51313 | 1991 | 155.28 |
| 3 | E14-03-Pinoasa-Rovinari | 64220 | 1989 | 124.44 |
| 4 | E14-08-Rosiuta-Motru | 69264 | 1993 | 116.99 |
| 5 | E14-04 Tismana-Rovinari | 72815 | 1986 | 158.99 |
| 6 | E14-02-Rovinari Garla | 95925 | 1983 | 151.65 |
| 7 | E14-02-Tismana - Rovinari | 115684 | 1971 | 137.95 |

Fig. 5 . Hardness measuring points
Rys. 5. Punkty pomiarowe twardości

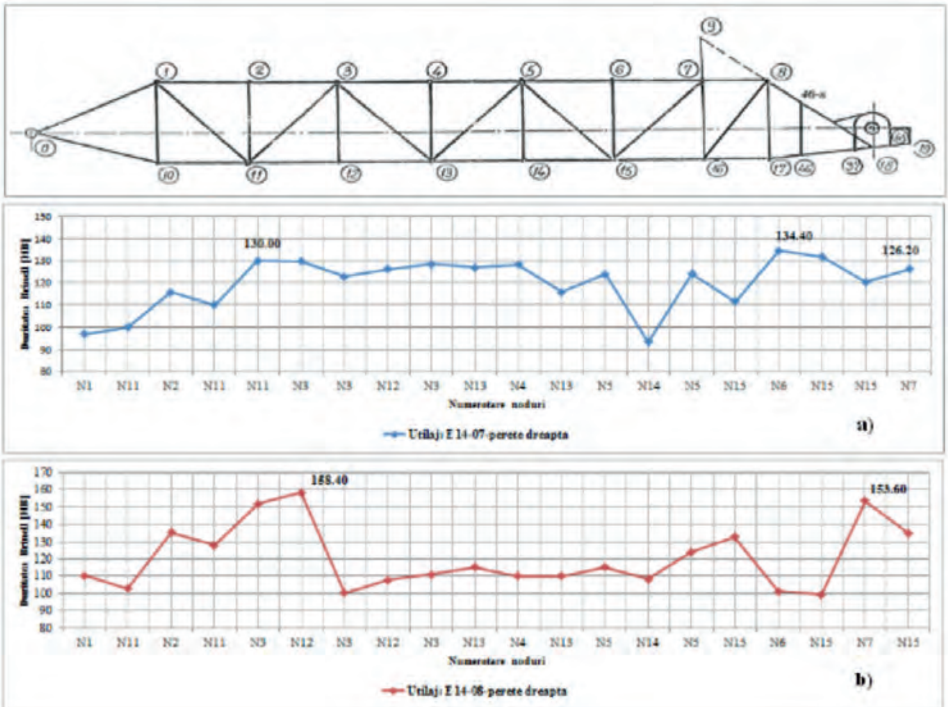


Fig. 6. Distribution of hardness on the boom's right wall of excavators E14-07, E14-08
Rys. 6. Rozkład twardości po prawej stronie wysięgnika koparek E14-07, E14-08

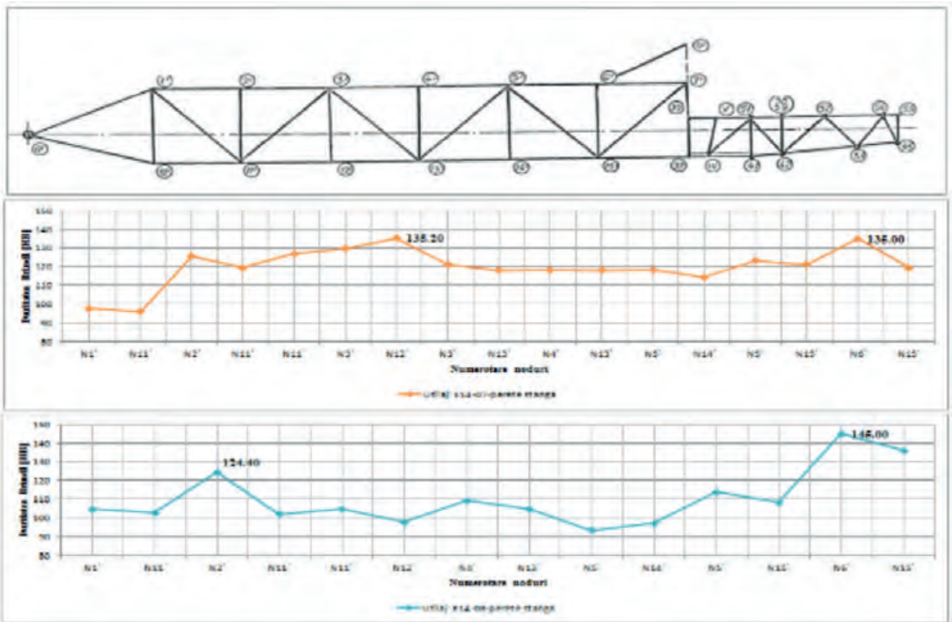


Fig.7. Distribution of hardness on the boom's left wall of excavators E14-07, E14-08
Rys. 7. Rozkład twardości po lewej stronie wysięgnika koparek E14-07, E14-08

In situ hardness measurements on selected points of constitutive elements of boom, using portable non-destructive hardness measurement devices , the points being selected on the basis of FEM analyses and fault history of the given BWE.

Hardness based mechanical properties decay analysis is a less-used method of investigating structural features in mining machinery, but it can provide some properties that evolve over time in materials in the load-carrying structure of the machine.

The hardness increase with the number of variable load cycles – determined from the overall working hours -was determined on samples collected from critical parts of BWE boom elements.

The average Brinell Hardness variation of samples collected from BWE boom elements related to samples made from the same kind of steel, in original state, has been plotted, according to fig. 2.

The hardness relative increase is significant leading to the conclusion that the hardness can be considered as an indicator of fatigue resistance, i.e. for the assessment of remaining lifetime of remaining lifetime of the structure in cause.

We extended the hardness measurement on a batch of 7 machines type ERc1400-30/7 from different open pits from Oltenia coal basin, on the same subassembly, respectively, the bucket wheel boom, the data being synthetized in table 1.

In the fig. 3, the average hardness has been plotted in correlation with the age of service of different BWE -s from which the samples were collected. It can be observed that the general trend of HB is increasing, the last point value is due to the fact that the steel is other kind than the rest of BWE-s , other deviations are due to the averaging and different load history ( less operating hours at same age).

Nevertheless, the differences of hardness between different elements of the boom structure can provide useful information about the fatigue level of different structural parts, for the identification of those in which the probability of expected failures is greater. This is very useful for sensors placement location for state monitoring.

To measure the hardness we used a portable device in the MIC 20 range to perform measurements on both sides of the boom, right/left wall, according to figure 4. The hardness measurement was performed after a mechanical pre-cleaning of the sampling area, at the lower/upper part of the diagonal strut, as in figure 5.

We performed the hardness measurement on two machines type E 1400-307, 07 and 08, from the same open pit, under approximate temperature and excavation conditions to assess the hardness for which the structural properties of the materials are close. After processing the data, we have compiled and illustrated in figures 6 and 7.

From the figures we can find that in average the decay of properties is not affected by the operating time between excavators, but it is a clear difference between left and right wall (girder).

Also, the graphs indicates a difference between the joints (nodes) which shows an asymmetry between left and right and a concentration of hardening at the extremities of the boom relative to middle segment.

This fact, with correlation with other analyses can be useful for deriving a complex, multifactorial discrimination method of detecting the most vulnerable parts of the boom.

## INFLUENCE OF THE AGE OF BWE ON FAULTS FREQUENCY

The carrying structure of BWE suffers in time degradation by fatigue that affects the functionality of these machines, degradations that can be generated jointly by corrosion, due to the environment of working area, by the remaining deformations of the elements , generally caused by accidental crashes or by the fall of material blocks on the structure, cracks in structural elements which may occur due to overloading to non-conforming welds, decrease of fatigue resistance of materials.

The degradations that may occur over time on mobile heavy-duty machinery may be disposed of in the form of punctual charts of type defects for these machines. These charts have been drawn up after conducting the technical expertise of 25 machines used in lignite open pits or coal deposits.

The evolution of faults in the load carrying structure of

Tab. 2. Faults occurred at some representative BWE s relative to age, throughput and operating hours
Tab. 2. Usterki maszyn w powiązaniu z ich wiekiem, urobkiem oraz godzinami pracy

| Machine | Age of the machine [years] | Type faults | Faults | Throughput 1000[cm+t] | Operating hours |
|---|---|---|---|---|---|
| 04 Pinoasa | 25 years | 9 | 13 | 44,129.884 | 51313 |
| 03 Pinoasa | 28 years | 9 | 12 | 52,518.749 | 64220 |
| 04 Tismana | 31 years | 10 | 13 | 56,622.949 | 72815 |
| 02 Rovinari-Garla | 34 years | 10 | 12 | 82,433.395 | 95925 |
| 02 Tismana | 45 years | 19 | 27 | 96,506.447 | 115684 |

*@ load carrying system involved faults*

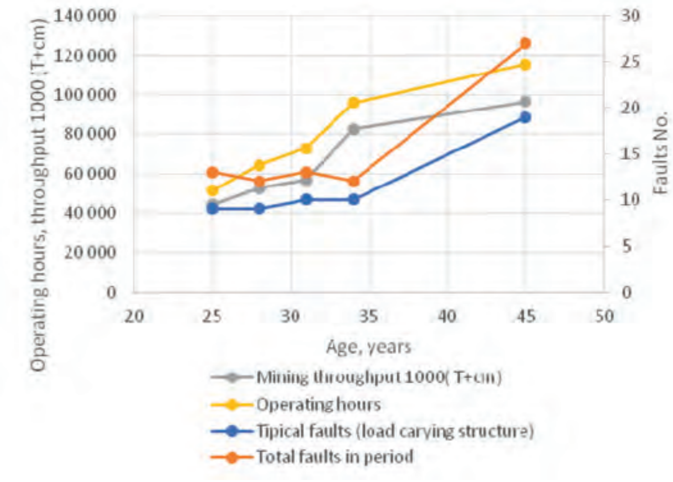


Fig. 8. Main Correlation chart
Rys. 8. Wykres głównych korelacji

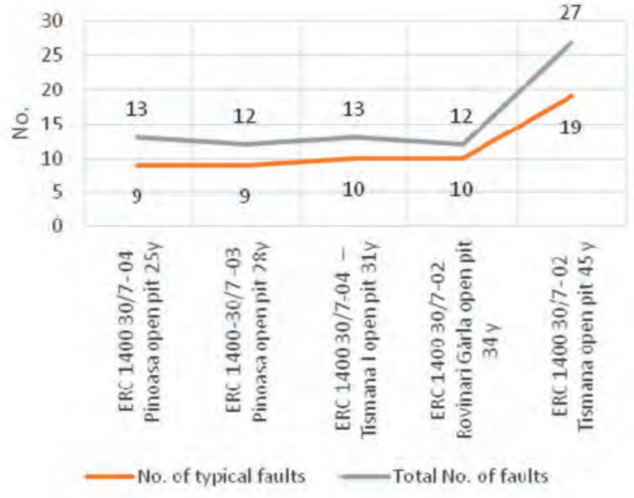


Fig. 9. The damage chart according to the age of the machine
Rys. 9. Awarie w zależności od wieku maszyny

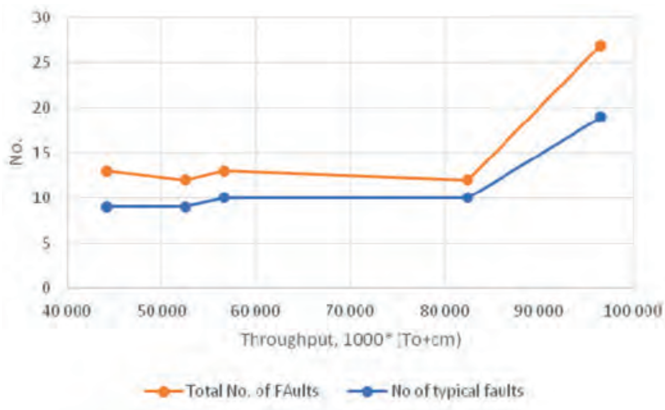


Fig. 10. The damage chart according to the throughput
Rys. 10. Awarie w zależności od ilości wydobytego materiału

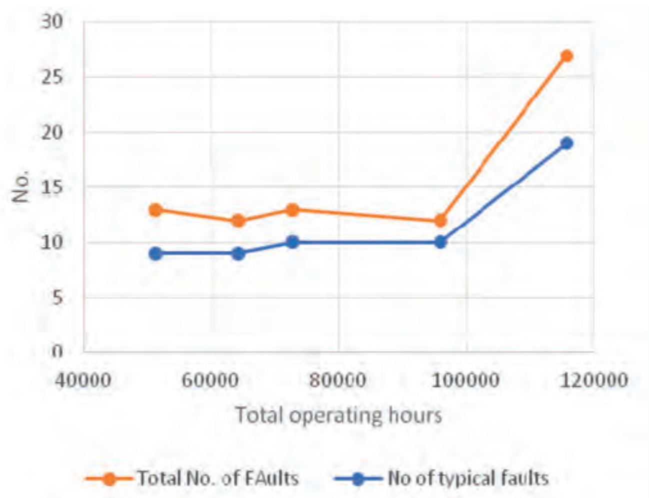


Fig. 11. The damage chart according to the operating hours
Rys. 11. Awarie w zależności od godzin pracy

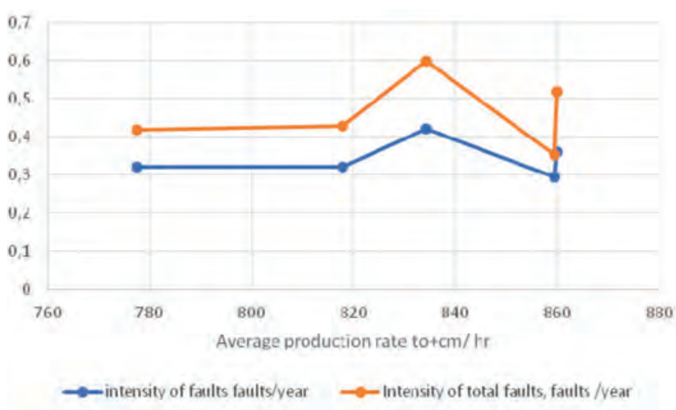


Fig. 12. Correlation Intensity of Faults vs production rate
Rys. 12. Korelacja intensywności awarii i wydajności

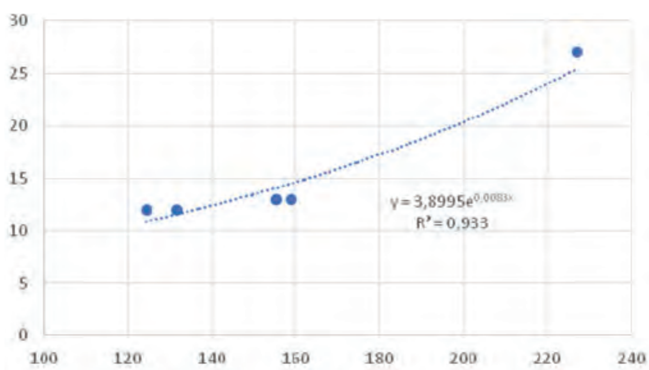


Fig. 13. Correlation Intensity of Faults vs hardness growth
Rys. 13. Korelacja intensywności awarii i wzrostu wytrzymałości

some of these ERc1400-30/7 type machines operating in the open pits from CEO, resulted from an in-situ analysis carried out in 2016, is presented in table 2.

The data from table 2 shows that the number of faults was almost constant for a period of about 30 years, after which they grow.

In figures 8 to 12 different correlations between operating hours, failures occurred, throughput, rate of failure, production rate are presented.

By correlating the fault intensity with hardness growth, we can forecast the expected faults number dependence on the average hardness, as in the figure 13.

## CONCLUSION

• Hardness based mechanical properties decay analysis is a useful method of investigating structural features change in mining machinery, and it can provide some information on the properties that evolve over time in the components of the load-carrying structure of the machine.

• The hardness relative increase with the duration of service is significant, leading to the conclusion that the hardness can be considered as an indicator of fatigue resistance, i.e. for the assessment of remaining lifetime of the structure in cause.

• Different correlations between operating hours, failures occurred, throughput, rate of failure, production rate were derived, which are useful for state monitoring of the BWE carrying structure.

• By correlating the fault intensity with hardness growth, it i possible to forecast the expected faults number dependence on the average hardness.

• The differences of hardness between different elements of the boom structure can provide useful information about the fatigue level of different structural parts, for the identification of those in which the probability of expected failures is greater, which is useful for deciding the sensors placement location for state monitoring.

• The results, in correlation with other analyses can be useful for deriving a complex, multifactorial discrimination method of detecting the most vulnerable parts of the boom.

• The method presented itself is a new way to expertise and assess the state of the BWE-s and to forecast the remaining lifetime reserve.

## ACKNOWLEDGMENT

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Architectural details of Wrocław