

Diagnostics of steel structures with the dynamic non-destructive method

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Abstract. The method of the assessment of steel structures mechanical properties is considered with the nondestructive test by conical indentation. The nondestructive evaluating of the steel mechanical properties in real structures is widely spread in many applied problems. Dynamic indentation method is one of the most effective because of compatibility and accuracy. For this purpose, the static and dynamic problem of axisymmetric elastic-plastic truncated cone indentation is solved, and the results are compared with finite element analysis and experimental data. The method of nondestructive evaluating of mechanical characteristics is suggested and devise of the realization of the method is tested at real structures. The method is tested on steel railway bridges that are being operated for more than 60 years. As a result, zones with lower strength values were identified, and recommendations for strengthening the design were given.

1 Introduction

One of the main goals in civil engineering is to improve the quality of buildings and structures, and to ensure their reliability. There are many accidents of oil and gas pipelines have become more frequent because of the strength failure of the material. Evaluation of mechanical properties of metal structures for various purposes is one of the most important instruments at any stage of their design and operation. The most important mechanical properties are yield strength, ultimate strength, elongation, Charpy impact strength and hardness. It needs to know these characteristics at all stages of the life cycle structure [1,2] and at any point. Non-destructive testing methods are prioritized especially for existing structures [3]. Recent researches show the possibility of assessment of the parameters of creep of materials for subsequent calculations [4].

The quality management of structures is an effective way of ensuring the reliability of buildings and construction objects that specifies the strict compliance of the characteristics of materials with the requirements of design project at each stage of the technological process. In the process of operation, the structures are exposed to a number of influences: power, shock, heat and others [5]. The properties of materials change under the circumstances, and the further changing must be thoroughly monitored directly on the structure at all stages of the product life cycle: design, manufacture and operation.

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The procedure for mechanical properties determining in structural steel using indentation test with spherical indenter was considered in [6,7]. For investigating mechanical properties in steel weld zone, the indentation approach was applied in [8,9]. Instrumented indentation tests were performed across the weld zone and the mechanical properties (E , H , σ_y , and n) were then determined from their load-depth data. It should be noted that the spherical indenter is very sensitive to the degree of surface roughness and gives a large error on rough asperity.

However, existing methods for assessing the mechanical state of materials do not match modern requirements for express testing on real structures. The of accuracy and the range of the applicability do not allow the use of express methods outside laboratories. Determination of the yield strength, tensile strength and elongation require equipment for uniaxial tensile testing, determination of C_V Charpy V-notched absorbed energy and fracture toughness or crack resistance - complex laboratory equipment and qualified personnel. Thus, a new method has to be developed for express estimation of the steel structure mechanical state at any point.

2 Materials, methods and device for mechanical properties assessment

Theoretical and experimental data obtained in [10] allow us to consider the problem of control of mechanical properties (MP) of materials in a wider aspect. The organization of any kind of design diagnostics is associated with the measurement of MP structural elements. In this case, these properties are determined by the manufacture and testing of special samples. Since such samples cannot be cut from an already manufactured structure, their properties cannot be measured, and the condition of the structure is uncertain.

The most important structural elements are undergone by complex processing (thermal, mechanical, chemical), after which the properties of the material vary greatly, and their values need to be known at the design, manufacturing and operation stages.

In [10] we introduced a device for MP assessment by impact conical indentation.

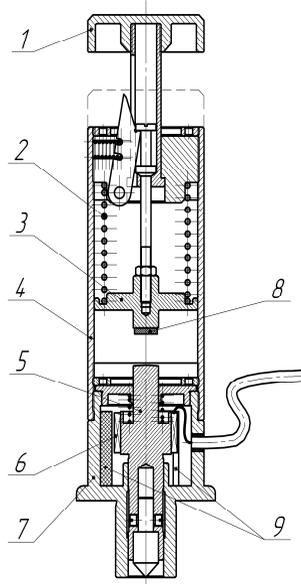


Fig.1. The devise for mechanical properties measurement: 1 - handle; 2 - spring; 3 - striker; 4 - body; 5 - indenter holder; 6 - sensor; 7 - body part; 8 - damper; 9 - sensor part.

operation to the present they experienced cyclic loading from the passing railway trains. The bridges are made of bridge steel, which for 70 years of operation was corroded and could change its properties due to fatigue damage.



Fig. 3. The general view of steel structure of Novocherkassk railroad bridge

3 Results and discussion

Analysis of the results of the tests of the steel structure of highway overpass (Figure 2) presented in Table 1 allows us to conclude the following. Minimum values of mechanical characteristics were observed at the metal at point 1 with $\sigma_{\text{yield}} = 363$ MPa, $\sigma_u = 496$ MPa, $\delta_5 = 17\%$.

Mechanical characteristics correspond to those stated in the project documentation.

Table 1. The mechanical properties of the steels selected for impact tests

Point name (Figure 2)	Mechanical characteristics			
	HB	Yield strength, MPa	Ultimate strength, MPa	Elongation, %
1	2	3	4	5
Point 1	177	363	496	17
Point 2	178	368	499	17
Point 3	190	403	531	15
Point 4	179	369	501	17
Point 5	220	512	632	7
Point 6	202	446	571	12
Point 7	182	380	511	16
Point 8 (207	463	586	11
Point 9	199	431	557	13

Table 2. Mechanical characteristics of the elements of the right truss of the first span of the bridge in Novocherkassk

Designation of the measuring point	HB	σ_r , MPa	σ_B , MPa	δ_5 , %	KCU, J/mm ²
Right farm (I - 1)					
H P 0-1'(0) bottom, load	129	289,8	447,3	23	14
H P 0-1'(0) bottom, unload	114	230,5	385,9	29	18
X P 0-1'(0) bottom, load	135	324,7	477,1	19	13
X P 0-1'(0) bottom, unload.	127	281,5	439,7	24	15
X P 0-1'(0) top, load	128	285,6	443,5	23	14
X P 0-1'(0) top, unload.	127	283,5	441,6	23	14
X P 0-1'(0) top, load.	135	324,7	477,1	19	13
X P 0-1'(0) top, unload.	131	303,1	459,0	21	14
Longitudinal beam					
Longitudinal 1 (right), top	131	303,1	459,0	21	14
Longitudinal 1 (right), plate	135	327,2	479,1	19	13
Longitudinal 1 (right),bottom	131	300,8	457,0	22	14
Longitudinal 1 (слева), top	128	285,6	443,5	23	14
Longitudinal 1 (слева), bottom	124	266,0	425,0	25	15
Longitudinal 2 (right), top	129	289,8	447,3	23	14
Longitudinal 2 (right), plate	131	303,1	459,0	21	14
Longitudinal 2 (right), bottom	125	271,6	430,4	25	15
Transversal beam					
Transversal 1 H	127	283,5	441,6	23	14
Transversal 2 H	126	275,5	434,1	24	15

Given that bridges were operated without stopping traffic, the only acceptable method is non-destructive testing by portable devices. The measurements were carried out in the zones of the lower belt of trusses, the main longitudinal and transverse beams.

The determination of the mechanical characteristics in each mentioned element of the span structure was carried out in all elements entering the element under consideration in two sections: at the end of the element (non-stressed zone) and in the most stressed section along the first row of rivets.

The tests were carried out in the zones between the rivets of the extreme transverse row, where it was possible, and in the zone above this row. In the cross sections of the elements where the tests were carried out, the numbers of the rolling elements and the measurement points in the stressed and non-stressed zones were taken into account.

In longitudinal and lateral beams, the mechanical characteristics of the metal of rolling elements were determined in the middle sections in accordance with the scheme.

4 Conclusions

The method of non-destructive testing based on the impact indentation of a conical indenter is considered on the example of steel structures of the road overpass of the Rostov-Arena stadium and steel structures of bridges across the Don river. An important feature of the considered structures is that the road overpass has just been built, and the bridges across the don river were built 70 years ago and operated all this time without stopping.

Results of impact indentation of a conical indenter for several kinds of steels allowed to determine the main mechanical characteristics at various points of structural elements. The

elements with the lowest strength characteristics are determined. This approach allows regular studies of mechanical characteristics on real structures [11,12,13] and draw conclusions about their work capacity.

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