Theoretical and experimental studies on the resistance structure of a metallurgical overhead travelling crane in operation

C. Pinca-Bretotean, A. Josan, A. Dascal, and G. Chete

***Abstract*—**The paper's purpose is to study the stresses and strains state in the resistance structure of a travelling crane which operates in the steelwork of an integrated iron and steel plant, from ten years. This has been realised through theoretical analysis, based on the resistance structure modelling, using the finite element method, and by experimental measurements, based on electric resistance tensometry. The results of comparative interpretation of the theoretical and experimental studies provide a complete picture of the stresses and deformations found in the resistance structure of an overhead travelling crane, enabling us to understand the behaviour in operation of the resistance structure and, if oversized, to redesign it.

***Keywords*—**Experimental, resistance, structure, theoretical.

I. INTRODUCTION

The rational design and proper operation of the metallurgical equipments have a favourable effect on increasing the efficiency of the technological processes sustained by these equipments. The process of making metallurgical equipments, regardless of their intended purpose, addresses directly to two departments: design and execution. Because of this, we aim to correlate the calculation with their specific characteristics in operation [1], [5], [7].

The resistance structures of the metallurgical equipment, designed and tested using the classical methods of Strength of materials, lead in most cases to over sizing [1], [9]. Due to the current trend of getting machines with lower weights, but without affecting the strength, rigidity and stability, it is necessary to optimize their size [2]-[6]. This leads to an optimum correlation between the deformed state of the structure and material consumption [2], [4], [7].

The decisions regarding the possibilities to optimise the resistance structure belonging to metallurgical equipment require knowledge of its behaviour under the action of operating strains. In this regard, the characterization of the resistance structure response to external strains can be done in terms of quality and quantity. The qualitative aspect refers to the stresses and movements corresponding to the analyzed strain state, and the quantitative one refers to the determination of their values. In order to ensure a better use of the equipment, these quantities must fall within the required limits [2], [7].

The complex process of analyzing the behaviour of resistance structures of the metallurgical equipment under operating loads is achieved using theoretical and experimental methods of investigation [5], [15]. The theoretical study methods are based on the resistance structure modelling, which in turn is based on the analysis using the finite element method. In order to validate the theoretical study, certain industrial experiments should be carried out to highlight the behaviour of the structure resistance in the assembly whose part it is [6]. The experimental analysis is performed to determine the stresses and deformations in the resistance structure of the equipment in operation, and their distribution in the areas of stress concentrators. These are considered critical areas, which will be given special attention either in operation or in case of equipment redesigning [2], [7], [8]. The metallurgical equipment design procedures are highly standardized and most effort and time are spent on interpreting and implementing the available design standards [9], [10]. The research of the resistance structures stresses for the elevating and conveying plants, represents a very important stage for the design of some installations according to the reliability imposed by the norms and standards in the field [9]-[14], [18]. DIN-Taschenbuch and F.E.M Rules offer design methods and empirical approaches and equations that are based on previous design experience. DIN norms generally state standards values of design parameters and F.E.M. rules are mainly an accepted collection of rules to guide metallurgical equipment designers. It includes criteria for deciding on the external loads to select the components [9],[13],[14]. There are many published studies on structural and component stresses, safety under static loading and dynamic behaviour of cranes [15]-[18].

In this study, the calculations apply the F.E.M. rules and DIN standards, which are used for the cranes [9],[14],[18]. A solid model of the metallurgical travelling crane is generated with the same dimensions as in the calculation results. Then static analysis is performed, using finite element method. Before starting the solutions, the boundary conditions are applied as in practice. Next, we are going to perform experimental measurements in static regime, to highlight the behaviour in operation of the structure, which involves determining the state of stresses and deformations by applying resistance tensometry methods. The complex process applied to analyse the behaviour of the metallurgical equipment resistance structures under operating loads, using theoretical and experimental methods of investigation, highlights the strength

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reserves of the structure, which can be taken into account for size optimization, in case of redesigning it. On the other hand, the modality to assess the structure response to operational actions, and the interpretation of its complex behaviour phenomenon under loading, are significant factors on which the further operation of the construction depends.

II. ANALYSIS PROCEDURE

The overhead travelling cranes are equipments serving the technological processes in metallurgy [1]. Their design includes two basic sequences that refer to the resistance structure and equipment mechanisms, both being conducted based on the regulations in force. [9]-[18]

In the analytical calculations, the behaviour of the resistance structure under operating loads is studied based on simplifying assumptions: the structure material is considered homogeneous and isotropic, the strains and geometrical characteristics of the sections are taken into account through certain values, which in reality can differ from those taken into account in the calculations, [6], [13] The safety of the resistance structure is also influenced by the presence of some imperfections and deviations caused by the factors originating from the manufacturing process of metal components, along with their execution and installation in the structure assembly. The effect of these imperfections and deviations is overlapped by the effect of some strains specific to the working conditions found in the steelworks, [5],[11],[20]. Some of the adverse effects, caused by the faulty operation of the resistance structures of the metallurgical equipments, are: consolidation and changes in the resistance structures of the overhead travelling crane, changes in the operating regime of the overhead travelling crane, increase of its lifting capacity. Also, depending on the specifics of the technological process realised by the metallurgical equipment, its operation can produce shocks and vibrations whose transmission to the resistance structure components can cause their displacements and deformations, phenomena that adversely affect the overall behaviour of the structure under the operating loads, [5].

For these reasons, redesigning the resistance structure of an overhead travelling crane, after a certain period of operation in the steelwork of an integrated iron and steel plant, involves assessing the behaviour in operation of the resistance structure of the equipment.

Based on the rules in force, in redesigning the resistance structures of the metallurgical equipment it is accepted the semi-probabilistic computing concept, and the calculation method related to this concept is the Limit State Method [18]. Principle, this method consists in providing reasonable elements and resistance structures strength as a whole, for reaching limit states. Reaching these limit states would involve either loss of ability to meet the operating conditions, or generate hazards for humans or property, [19].

The use of this method in the calculation of metallurgical equipment resistance structure involves:

- observance of the structure design and calculation rules (sizing and testing) applied to the resistance structures of the metallurgical equipment;
- proper execution of the structural elements, in accordance with the standards in force;
- proper operation of the resistance structure, consistent with the design conditions approved;
- periodic check of the resistance structure behaviour, according to the design-established rules.

Metallurgy industry develops certain technological processes whose features need the use of all equipments of the assemblies – these equipments belong to the hardware category [1]. The most appropriate equipments we use in this domain are the cranes, because they provide some advantages, such as: they could adjust according to the features of the technology process, they could lift up and transport a large range of weights, they do not need too much space, and are used for a large range of activities [1]. The sub-installation is the most important element of the strength structure when assembling the cranes, because it should provide the lastingness, stiffness during transportation and assembling, easy maintenance during use, and its elements should adjust to the dynamic use of the equipment [5], [20].

In this paper, we checked the way of reaching the limit state at normal operation of the resistance structure of an overhead travelling crane which operates in the steelwork of an integrated iron and steel plant from ten years. The method allows resistance structure calculation for an overhead travelling crane in the design stage, and also after a certain period of construction operation, under the influence of various operating loads [5].

Adopting the limit state method to calculate the strength structures of the metallurgical equipment involves assessing their response to external stresses, both qualitatively and quantitatively. The qualitative aspect refers to the modalities used to assess the physical quantities corresponding to the analyzed strain state (displacements and stresses), and the quantitative one refers to the determination of their values.

In this regard, the quantitative characterization of the response received from the resistance structure of the overhead travelling crane subjected to study, that is the assessment of the stress state in one of its principal beams, was conducted in this paper in two modalities: theoretical studies about the resistance structure modelling, using the finite element calculation program COSMOS/M, [21], and experimental measurements based on electric resistance tensometry [22].

Taking into account the above-mentioned aspects, the study conclusions have been made by analysing the experimentally determined results compared with those obtained by modelling, using the finite element method.

The goals have been reached by searching:

- the geometrical aspect of the principal beam behaviour, which is part of the resistance structure of the analysed overhead travelling crane, by interpreting the measured deformations comparatively with those calculated;
- the physical aspect of the analysed principal beam behaviour, by studying the correlations between the experimentally obtained stresses and those analytically determined.

III. CONSTRUCTIVE ANALYSIS OF THE OVERHEAD TRAVELLING CRANE

The crane we are analyzing is able to lift up to 100 KN, and the items are lift up to 17.3 m. It is made up by the following main sub-installations: strength structure – 1, trolley - 2, the translation mechanism - 3, the electric installation and additional elements - 4, fig. 1.

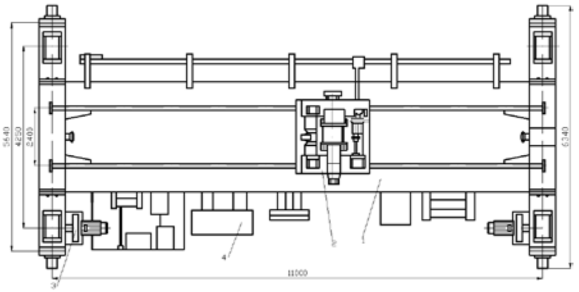


Fig. 1 The assembly of the travelling crane

The design values used in the crane analysis from F.E.M and DIN standards are given in I [9],[14],[18].

I. Crane property values

Handling Capacity	100 KN
Lifting height	17,3 m
Gauge	11 m
Distance between axes	4,25 m
Trolley velocity	10 m/min
Travelling crane velocity	63 m/min
Total duration of use	U4
Load spectrum class	Q3
Appliance group	A5
Loading type	H
Dynamic coefficient	$\psi = 1{,}15$
Amplifying coefficient	$\gamma c = 1{,}11$

All the subassemblies are mounted on the resistance structure, the mechanisms are electrically operated from the control room fixed on the resistance structure, and for lifting the loads, the crane trolley is equipped with a hook shank. The resistance structure is made of two symmetric, caisson-type main beams, and two cross beams (right end beam, left end beam). The connection between the main and cross beams is realised by welding, creating a closed, statically indeterminate structure. The caisson section is realised by welding the constituent elements. These are 8 mm-thick steel strips, for sides, and 6 mm-thick for the upper and lower flange, respectively. The main beams have, at the ends, dimensions reduced along the height, unlike the cross beams which are made with constant section. Looking from the point of view of construction, we found that the resistance structure of the overhead travelling crane represents about 75% of the total equipment weight, which represents a rather high percentage and requires dimensional optimization. In this paper, we analysed the possibility to obtain a size optimisation without losing the stability and rigidity of the resistance structure under the operation strains.

IV. THEORETICAL ANALYSIS OF THE RESISTANCE STRUCTURE

The theoretical analysis of the studied overhead travelling crane resistance structure dealt with the following problems:

- structural composition of the overhead travelling crane in terms of geometry of the structure and its elements;
- analysis of the static load schemes of the resistance structure;
- modelling of the overhead travelling crane resistance structure, for its spatial calculation;
- analysis of the state of stresses and deformations in the resistance structure elements;
- presentation of the theoretical study results.

The results of the performed theoretical analysis will allow us to assess the behaviour under operation strains, in terms of optimization possibilities of the overhead travelling crane resistance structure.

In this study, the finite element modelling is carried out by means of the Cosmos package, [21], [23], which has shell type elements with three or four nodes per element and six degrees per node in the finite elements library, which secure a very good calculation accuracy, with deviations under 4% related to the exact methods of calculation, [24]- [26].

The analysis of the strength structure of the crane using finite elements have been calculated all the stresses and strains tensor from the structure nodes and from the centroids of the finite elements.

In the analytical calculus, we adopted a spatial calculation scheme, the results obtained in this way being confirmed by assessing its behaviour in operation. The spatial calculation has been conducted on the basis of numerical modelling, and the final results were presented in two ways:

• in terms of quality, involving a comprehensive and local presentation of the distribution of stresses and deformations, and the visualization of various parameters according to certain imposed directions;

• in terms of quantity, which involves finding the stresses and deformations, which allows plotting the variation of the studied quantities and comparing them with those experimentally determined.

The solid model of the overhead travelling crane is presented in fig. 2.

Analyzing these data, it results a series of conclusions regarding the behavior of the resistance structure of the crane. We have selected some values we have considered important from amongst the analysis of the folders which contained the results. The beams of the resistance structure of the travelling crane are made of OL 37 then, the analysis of stresses and strains is more effective if we use the theory of the specific form modifying energy (stated by von Misses) as a determining factor for reaching the limit stages [5].

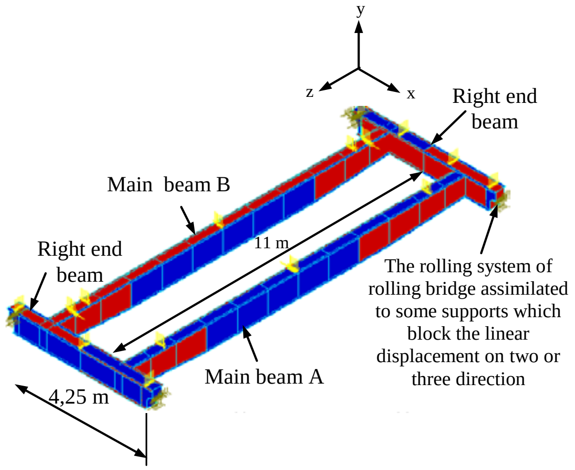


Fig. 2 Solid model of the resistance structure of the travelling crane

The theoretical analysis of the overhead travelling crane resistance structure has been presented in detail in [26]-[30].

Bigger values of the equivalent stresses (within the admissible limits) occur in the central areas of the main beam A, in fig. 3.

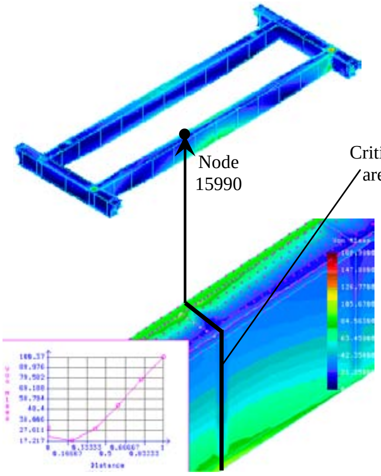


Fig. 3 Diagram variation of von Misses equivalent stresses at the middle of the main beam A

The maximum equivalent stress calculated according to the theory of the specific form modifying energy is $\sigma_{\text{von Misses max}}$ = 182, 89 MPa and is recorded in the node 15104 placed, on the lateral external surface of the main beam A, near the connection with the right end beam. This size exceeds the allowable stress for the case I of loading according to Bach, for the steel OL 37, $\sigma_{\text{von Misses max}} > \sigma_a$ (σ_a = 150 MPa), fig.4.

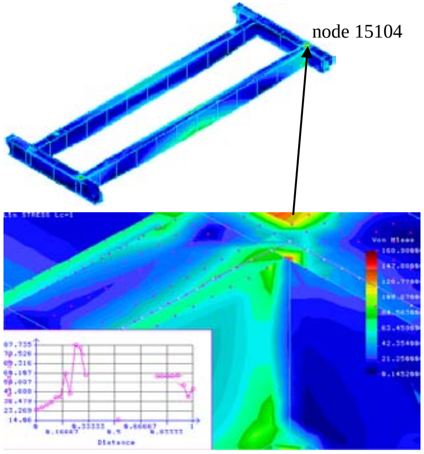


Fig. 4 Diagram variation of **v**on Misses equivalent stresses at the level of the outside edge of the main beam A and right-end beam

Extreme value of principal stresses σ_2 is occur in the 1732 node and normal stress σ_x occur in node number 1809, fig. 5.

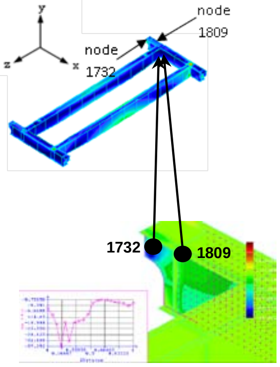


Fig. 5 Diagram variation of extreme value of principal stresses σ_2, and normal stress σ_x

The location of these nodes in the resistance structure, obtained by numerical modelling, is shown in II. The extreme values of the shear stresses τ_{zy}, τ_{xy} are shown in fig. 6.

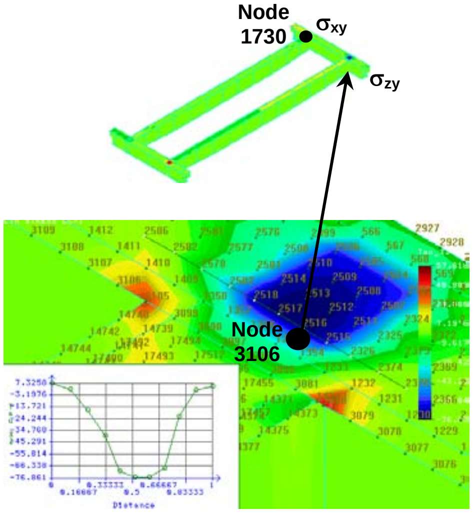


Fig. 6. The extreme values of the tangential stresses τ_{zy} , τ_{xy}

After a thorough analysis of results files, we selected several values we considered significant both for stresses because they generate critical areas within the resistance structure of the travelling crane. Thus, the most requested areas are presented in fig.7.

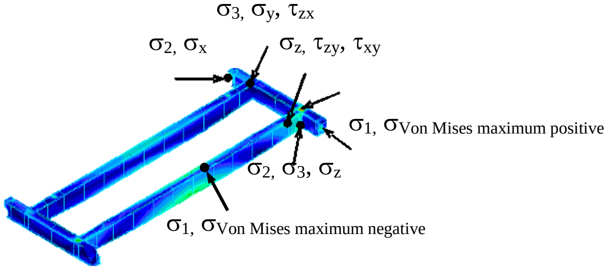


Fig. 7 The critical areas of the resistance structure

The extreme values of the principal stresses σ_1, σ_2, σ_3, normal stresses σ_x, σ_y, σ_z, tangential stresses τ_{xy}, τ_{zy} , τ_{zx} and von Mises stresses, $\sigma_{\text{von Mises}}$ are presented in II.

According to this it results that the connection between the right end beam and the main beam A is a critical area for which have to be taken measures of improving the constructive solutions in order to decrease the peaks of stress which appear. In III we can see the minimum and maximum values of the displacements, considering four distinct values for the nominal load. Fig. 8 shows the image of the structure deformed under the action of the highest value of the rated load.

The displacement we have seen that the highest values are recorded at the middle of the opening of the longitudinal beam I, fig. 9. We find the highest displacement in case of 15992 node, which reaches u_{rez}= 20,87 mm. The components of the linear displacement according to all three directions of the global axis system are: u=15,18 mm, v =3,75 mm and w=0,075 mm.

II. The extreme values of stresses, obtained from the analysis with finite element method

Analysis component	Area where the value has been recorded	The extreme recorded size (MPa)
	Principal stresses	
σ_1	The midlle of the main beam A, superior	182.89
σ_2	The extremity of the right end beam, on the lower flange	81.92
σ_3	The connection of the main beam A with the right end beam, on the lower flange	-192.554
	Tangential stresses	
τ_{xy}	The connection of the main beam B with the right end beam, on the lower flange	- 46.996
τ_{zy}	The connection of the main beam A with the right end beam, on the upper flange	- 76.85
τ_{zx}	The connection of the main beam B with the right end beam, on the upper flange	30.73
	Normal stresses	
σ_x	The connection of the main beam A with the right end beam	132.164
		-133.064
σ_y	The extremity of the right end beam	-182.226
	The connection of the main beam B with the right end beam	179.63
σ_z	The connection of the main beam A with the right end beam on the upper flange	155.315
	The connection of the beam A with the right end beam on the lower flange	-145.691
	Equivalent stresses von Mises	
$\sigma_{von\ Mises}$- max. negative	The midlle of main beam A, superior	- 168.98
$\sigma_{von\ Mises}$- max. positive	The connection of the main beam A with the right end beam	182.89

III. Value of maximum and minimum displacement of main beam A

Load Q (10^3 N)	Maximum displacement (mm)	Minimum displacement (mm)
10	8.413	0.221
37.5	15. 317	0.457
60	17.591	0.561
74	20.1832	7.64

Also, the area of the right end beam near the global axis system needs special attention in order to improve the product and to eliminate any possible tension peak.

The conclusion obtained after the analyzing using finite element method are:

- the mid area of the main beam A is critical for which action will be taken to improve the state of stress and deformation if the strength structure is redesigned;
- the main critical area of the travelling crane is represented by the connection between the main beam A and the right end beam;
- for the maximum value of the load, the maximum displacement is recorded in the middle of the main beam A.

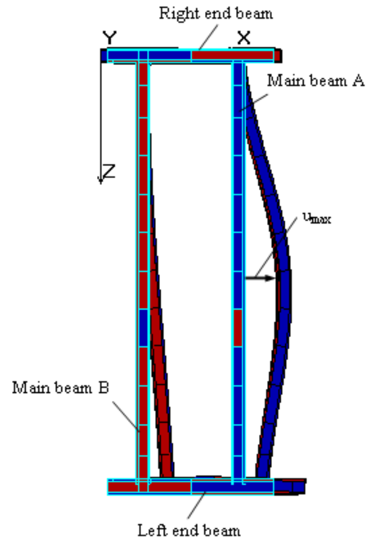


Fig. 8 Deformation of the resistance structure under the action of the maximum rated load

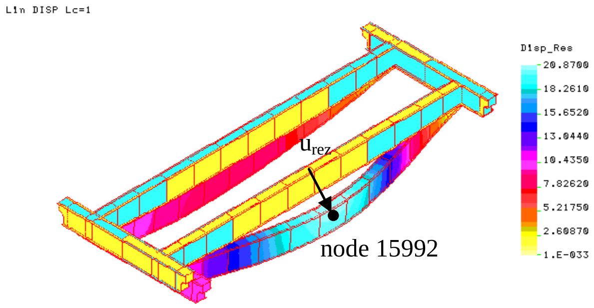


Fig. 9 The rolling bridge in strain state under the action of the nominal loads

The analytical methods for analysing the behaviour of the resistance structure of the overhead travelling crane under the action of the operation loads can be successfully applied only if there are practical means of analysis. Thus, in order to validate the analytical study previously conducted, some industrial experiments should be carried out to highlight the behaviour of the resistance structure of the equipment that has worked for ten years in the steelwork of an integrated iron and steel plant. The industrial experimental analysis is conducted to determine the stresses, more precisely to determine their distribution in the resistance structure, in order to find the areas with stress concentrators, which are considered critical areas and which will be given particular attention either in operation or in case of redesigning the structure. The experimental determination of stresses, along with the analytical study, provide a complete picture of the stress state in the resistance structure of the overhead travelling crane, allowing the dimensional optimization where redesigning it.

V. THE PROGRAM OF EXPERIMENTAL DETERMINATIONS

The program of experimental determinations by electric resistance tensometry aimed at determining the values of stresses and displacements corresponding to the stress state of the resistance structure of the overhead travelling crane in operation. This includes the following steps:

- preparation in laboratory of the measurements;
- selection of equipment, materials and accessories needed for the experimental determinations;
- establishing the conditions for measurements inside the steelwork where the analysed overhead travelling crane is working;
- selection of tensometric methods, preparation of the related operation and experimental determinations planes, according to the design of the resistance structure;
- carrying out the experimental determinations, based on electrotensometric measurements, followed by experimental data processing;
- preparation of the final table results;
- critical analysis and interpretation of the obtained values.

VI. EXPERIMENTAL DETERMINATIONS

The statically indeterminate spatial structure of the overhead travelling crane with the lifting capacity of 100 KN and lifting height of 17.3 m, being in operation for ten years in the steelwork of an integrated iron and steel plant, analyzed by analytical methods based on the finite element method, (the results presented in the subsection IV), has also been studied experimentally, by using the electric resistance tensometry method.

The object if of experimental determinations consists in determining the displacements corresponding to the stresses states, under the conditions of overhead travelling crane operation, and the maximum absolute values of stress for certain hypotheses considered, either at the level of the upper flange, or the lower flange of the caisson belonging to the main beam "A". The resistance structure scheme for experimental determinations, made using the electric resistance tensometry method, is presented in fig. 10.

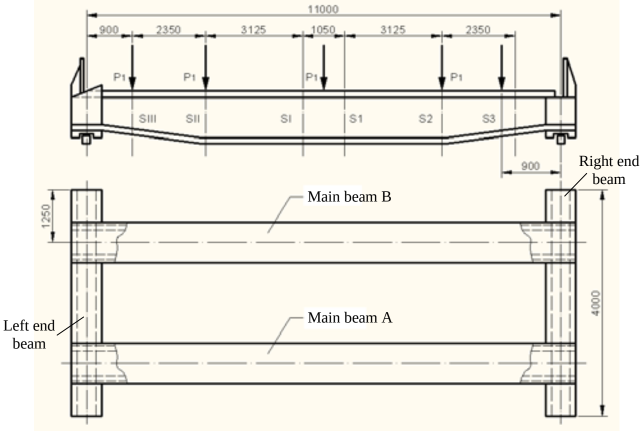


Fig. 10 The resistance structure scheme prepared for carrying out experimental determinations

For loading the overhead travelling crane, we used steel ingots with known weight. So, the loads used for experimental measurements are presented in III. We neglected the tare weight of the metal construction and other mechanisms mounted on the crane, and the loads were considered to have the point of application in the geometric centre of the trolley. The positions of the geometric centre of the trolley were marked with P_1, P_2, P_3, P_4, and P_5. The analysed resistance structure was subjected to stress in static regime, with the loads Q_i (i = 1.3), applied increasingly up to exceeding the limit load. The investigated sections are noted with S_{III}, S_{II}, $S_{I,}$ S_1, S_2, and $S_{3\ .}$ fig. 11.

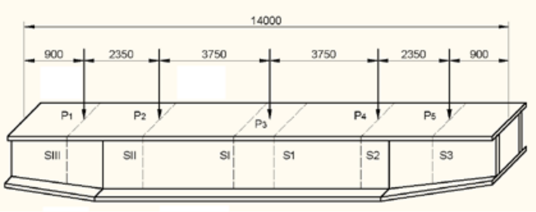


Fig. 11 Presentation of the caisson afferent to the main beam A, the sections where the experimental determinations are carried out, and the positions of the geometric centre of the trolley

The degrees of freedom imposed to the supports and the positions of those six sections on the main beam A, part of the resistance structure of the overhead travelling crane for which the experimental determinations were performed, are presented in fig. 12. It is stated that the sections SI^* and $S1^*$, located on the main beam B, have been explored as a witness. This is the reason for which the experimental determinations for the main beam B have been carried out only in two sections.

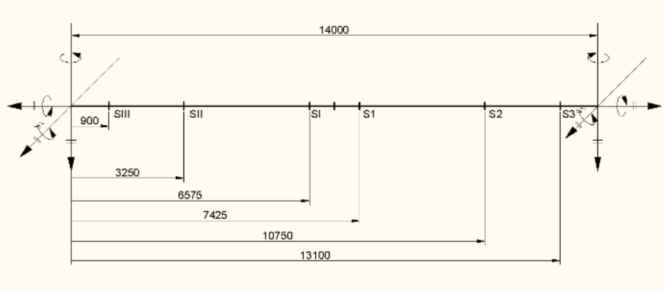


Fig. 12 The explored sections positions on the resistance structure of the overhead travelling crane

Two strain gauges were placed within each of the six analysed sections, on the upper flange and, respectively, on the lower flange of the main beam A, at 120 mm from the ends of the side wings of the caisson, fig. 13.

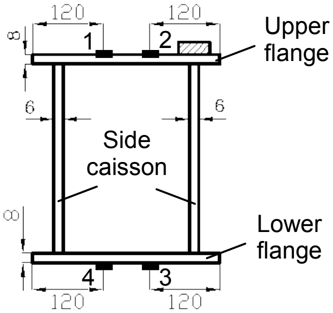
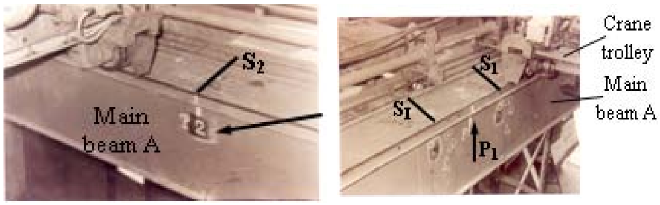


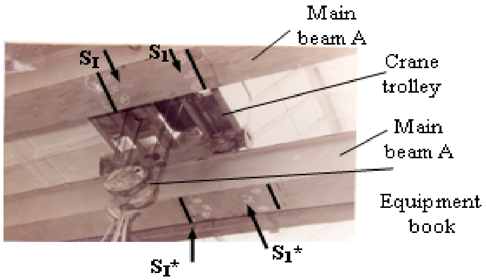
Fig. 13 Positioning of the electrical strain gauges on the upper and, respectively, on the lower flange of the caisson afferent to the main beam A

The experimental determinations have been carried out in the positions P_1, P_2, P_3, P_4, and P_5, with successive application of the loads $Q_{0,}$ Q_1, Q_2, and $Q_{3,}$ every time making records in the sections S_{III}, S_{II}, $S_{I,}$ S_1, S_2, and $S_{3.}$ These sections and the measurement points P_i (i = 1…5), during the experimental determinations, are presented in fig. 14.



a – marking of the section SII and position P2 of the geometric centre of the trolley on the main beam A

b – marking of the sections SI and, respectively, S1, and position P1 of the geometric centre of the trolley



c - marking of the witness sections SI^* and $S1^*$ on the main beam B

Fig. 14 Marking of the analysed sections and positions of the geometric centre of the trolley on the resistance structure of the overhead travelling crane, in order to determine the industrial experiments

In order to perform experimental determinations based on electrotensometric measurements, [22], [31], we carried out tensometric apparatus balancing, as follows:

a. For static measurements with the load Q_0, the trolley being empty, for the strain gauges placed within the sections S_1, S_2, S_3 the balancing was realised in the position P_1 of the Q_0 load, and for the sections S_{III}, S_{II}, S_I the balancing has been realised in the position P_5 of the load Q_0.
b. For static measurements with the loads Q_1, Q_2, Q_3, the balancing was realised with the load Q_0 placed in the point where it was made the loading.

The experimental determinations led to:

- plotting the stress variation diagrams in those six analysed sections;
- plotting the deformation variation diagrams along the main beam A;
- quantitative and qualitative study of the correlations between the analytically obtained results and those determined experimentally.
- critical analysis of the experimental results compared with those obtained with the finite element program.

At each loading step, we measured the specific deformations to be used for calculating the normal stresses in the direction in which the measurements were carried out. So, on the upper flange and, respectively, on the lower flange of the caisson, we plotted the specific stresses, taking into account the quantities measured with the resistance strain gauges placed in the points 1and 2, respectively, 3 and 4, fig. 15. Laterally, we plotted the variation diagrams of the specific stresses in the lateral sections of the caisson, based on the results obtained from the arithmetic means of the measured stresses, for each of those six analysed sections.

The stress variation diagrams in the cross section are used to find the stress state in the upper and lower flanges of the main beam A.

Analysing all the diagrams, we found differences between the records afferent to the same section of the upper flange compared with the lower flange, but not significant. This is due to measurement errors, that is. the recording errors, inherent in any electrotensometric measurement.

Regarding the stress distribution in the cross sections, the worst loading case was recorded for the main beam A, towards the area of connection with the right end beam. In fig. 15, we presented the variation diagram of the specific stresses in the section S2, in the loading hypothesis Q_3 in P_4, this being the worst loading situation for which we obtain the maximum values of the specific stresses.

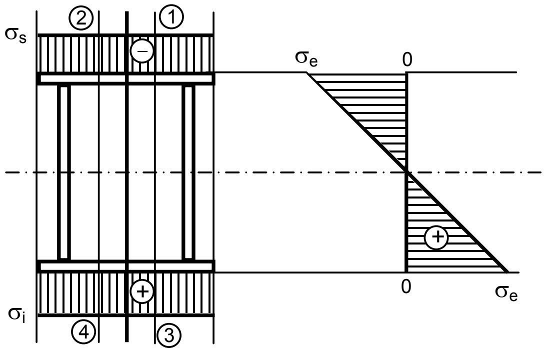


Fig. 15 Variation diagram of the specific stresses in the side sections of the caisson, hypothesis Q_3 in P_4

With the experimental data obtained, we plotted the variation diagrams for the deformations along the main beam A, using the Excel program. We realised the quantitative and qualitative study of the correlations among the analytically obtained results and those determined experimentally, in order to find:

- the geometric aspect of the main beam A behaviour, by qualitative interpretation of the measured deformations compared with the calculated ones;
- the physical aspect of the main beam A behaviour, by studying the correlations among the stresses obtained experimentally and those determined analytically.

The comparative study of the above mentioned aspects has been conducted based on four loading hypotheses, considered to be significant: Q_0 in P_1 (Fig. 16), Q_1 in P_2 (Fig. 17), Q_2 in P_3 (Fig. 18), Q_3 in P_4 (Fig. 19). In these diagrams:

- 1-2 E represents the variation diagram of deformation for the upper flange, along the main beam A, plotted with the experimentally determined values, and 1-2 A for the analytically determined values;
- 3-4 E represents the variation diagram of deformation for the lower flange, along the main beam A, plotted with the experimentally determined values, and 3-4 A for the analytically determined values.

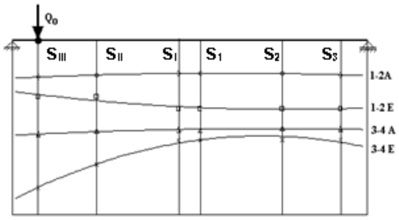


Fig. 16 The strength variation diagram along the main beam A, drawn up based on the analytically and experimentally obtained results, hypothesis Q_0 in P1

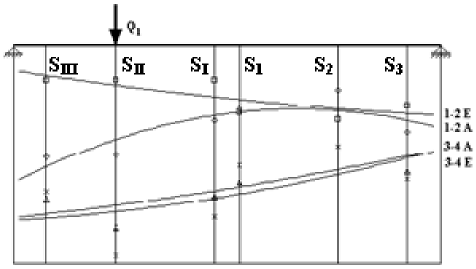


Fig. 17 The strength variation diagram along the main beam A, drawn up based on the analytically and experimentally obtained results, hiypothesis Q1 in P2

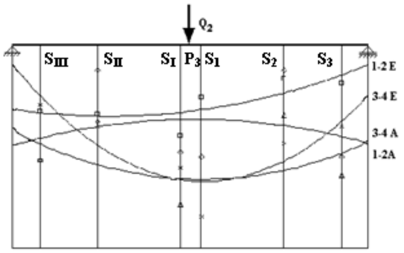


Fig. 18 The strength variation diagram along the main beam A, drawn up based on the analytically and experimentally obtained results, hiypothesis Q_2 in P3

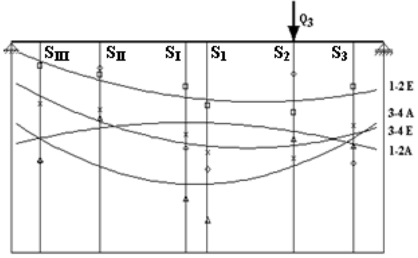


Fig. 19 The strength variation diagram along the main beam A, drawn up based on the analytically and experimentally obtained results, hiypothesis Q_3 in P4.

As a common element of the diagrams determined analytically and experimentally, we found significant increases of the vertical displacements in the areas of concentrated force action, directly applied on the resistance structure. On the other hand, the displacement variation generally keeps the same shape. This shows that the calculation scheme is properly modelling the beam behaviour in terms of displacement rigidities. In the same sets of diagrams we found the existence, within the same cross sections, of certain differences between the records afferent to the upper flange (in the points marked with 1 and 2) and those afferent to the lower flange (in the points marked with 3 and 4). To explain these differences, we made the assumption that among the four components of the cross section, realised as a closed caisson, it was also manifesting the spatial collaboration phenomenon. The consequences of this phenomenon would be the mitigation of the adverse effect of twisting caused (due to the deviation from the vertical axis of symmetry) by the loading resulted from the load suspended in the hook, transmitted to the higher level in point 1.

Regarding the physical aspect of the principal beam A behaviour, some significant differences has been found in the following cases:

- On the cross section, in the upper flange, which confirms the collaboration between the hearts and flanges of the caisson section;
- In the longitudinal direction of the beam, where remarkable quantitative differences are seen towards the cross sections located in the surrounding areas of the supports, especially in the loading cases when concentrated forces are found in these sections.

VII. COMPARATIVE STUDY BETWEEN THE ANALITYCAL AND THE EXPERIMENTAL RESULTS

The behaviour under load of the resistance structure of the overhead travelling crane, analyzed based on the spatial collaboration calculation, revealed that adopting a computational model of the structure implies the acceptance of simplifying assumptions that provide a certain degree of approximation to the analytical results. In these conditions, for verifying the correctness of assumptions and thus the validity of the chosen calculation method, we used the comparative analysis applied to the analytical and the experimental results. If the object of the comparative analysis is a piece of equipment which has already been in use for a long period of time, we can obtain information regarding the complex phenomenon of its behaviour under the operation loads. Based on this analysis, we can assess the reliability of the equipment and/or we can perform dimensional optimizations in order to redesign it. Given this aspect, the conclusions of the theoretical and experimental studies were formulated in this paper based on the finite element method in conjunction with those obtained from the electro-tensometric measurements.

IV. Comparative values of the maximum stresses obtained analytically and experimentally in the upper and lower flanges of the principal beam A

Sr. no.	Analysed sections	Maximum stresses Caisson upper flange (N/mm²)		Maximum stresses Caisson lower flange (N/mm²)	
		Theoretically	Experimentally	Theoretically	Experimentally
Hiypothesis Q_0 in P_1					
1.	**S III**	37.1	65	41.7	56
	S II	27.9	43	27.8	33
	S I	21.8	56	45.3	49
	S1	39.1	33	30.1	36
	S2	20.0	48	22.7	23
	S3	31.9	76	39.7	48
Hiypothesis Q_1 in P_2					
2.	**S III**	51.7	65	57.8	65
	S II	45.5	39	31.1	33
	S I	37.8	46	47.4	51
	S1	49.8	67	30.8	33
	S2	45.7	49	39.7	43
	S3	79.8	86	69.1	76
Hiypothesis Q_2 in P_3					
3.	**S III**	47.3	130	52.6	148
	S II	30.7	65	31.7	87
	S I	39.1	86	35.2	130
	S1	40.1	172	43.7	172
	S2	29.6	86	27.1	130
	S3	42.6	96	49.6	130
Hiypothesis Q_3 in P_4					
4.	**S III**	89.9	172	88.1	189
	S II	91.7	130	110.6	176
	S I	101.7	143	120.4	130
	S1	107.8	197	81.5	143
	S2	74.6	86	98.7	160
	S3	111.8	172	99.8	150
Hiypothesis Q_3 in P_5					
5.	**S III**	97.6	187	151.2	180
	S II	75.7	86	98.7	101
	S I	96.5	172	126.7	172
	S1	101.8	154	99.7	105
	S2	87.4	97	96.6	105
	S3	96.5	150	91.7	147

The comparative analysis applied to the analytically determined stress values and the experimentally determined ones revealed noticeable differences between the current values and the extreme values. We can notice that the maximum absolute values determined experimentally exceed the values of the stresses determined analytically using the finite element method, for all the load cases, either in the upper flange or in the lower flange of the caisson afferent to the strut "I". This aspect is shown if the fig. 20 respectively 21, for the load hypothesis Q_2 in P_3.

In IV, we presented the comparative values of the maximum stresses obtained analytically and experimentally in the upper flange and, respectively, in the lower flange of the main beam A.

This observation reveals that the behaviour of the resistance structure in operation differs quantitatively from the adopted model. According to this, the resistance structure is oversized and has significant resistance reserves. But, from the qualitative point of view, the real structure in operation behaves almost identically with the adopted model, which confirms the validity of the model used in the analytical study.

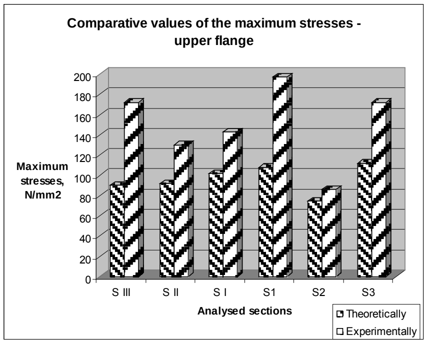


Fig. 20 Maximum stresses determined analytically and experimentally in the analysed sections located in the upper flange of the caisson afferent to the main beam "A", hypothesis Q_2 in P_3

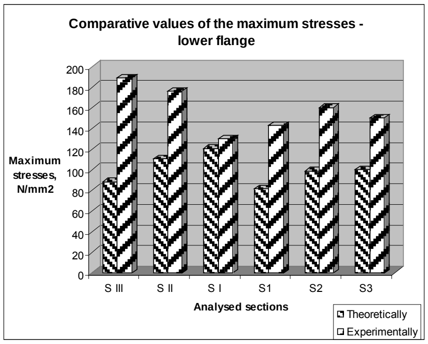


Fig. 21 Maximum stresses determined analytically and experimentally in the analysed sections located in the lower flange of the caisson afferent to the main beam "A", hypothesis Q_2 in P_3

The fact that the hearts and flanges of the caisson are working together can be seen in both flanges of the strut I, as evidenced by comparing the experimental and analytical charts plotted for all the load cases. Thus, in terms of response to the operation strains, the main beam "A" behaves differently compared to its physical model adopted in the analysis with the finite element method. This difference in behaviour can find its justification in the simplifying assumptions taken into account (concerning the strains and their groupings), or in the composition and abutment of the resistance structure. Regarding the strains and their groupings, we may include the allowed simplifications to establish the application points of the concentrated forces; these ones were considered to be applied in the positions corresponding to the geometric centre of the trolley. In reality, the forces determined by the load suspended in the hook are transmitted by strongly pressing the wheels in the sections of contact with the rail. Regarding the structure abutment, we mentioned the effects generated by the operating conditions specific to the overhead travelling crane.

The operation behaviour assessment for the resistance structure of the overhead travelling crane with the rated load of 100 KN and lifting height of 17.3 metres has been made after testing it at the limit state of normal operation, according to the standards in force, [10], [11], [14], [18] based on the analytical results presented in detail in [26]-[30] and the experimentally results presented in this paper. So, the limit state of normal operation of the overhead travelling crane resistance structure was tested in terms of stresses and displacements. The test results highlighted the fact that, in the loading situation considered for the analysed overhead travelling crane, which operates in the steelwork of an integrated iron and steel plant, the limit state conditions of normal operation are met, and the analysed resistance structure has significant reserves of strength. This makes possible further dimensional optimization.

VIII. CONCLUSIONS

All modeling revealed that the operation mode of the structure varies according to the calculation pattern adopted from a quantitative point of view, and behave identically from a qualitative point of view. Different quantitative behavior revealed that the resistance structure has inseminated strength reserve, so it may be subject to dimensional optimization by reducing the thickness of plate beams without exceeding allowable material strength; the same qualitative behavior confirms the validity of the model calculation. In case of resistance structure, choosing a certain calculation pattern has a quantitative and qualitative influence on the structure components' state of application, with direct implications on the process of optimization. All results of this study can be conducted as a basis for developing the software used for tracking down the travelling crane strength structure and for redesigning it. Adopt a calculation model is quantitative and qualitative influence on the state of application components of the strength structure of travelling crane in use after a relatively long time.The results of the undertaken studies and experimental research can be used as basis to develop programs for monitoring the behaviour in time of the overhead travelling crane resistance structure, and to realise lifelike physical models of the real resistance structure, aimed at redesigning it.

The study of the stresses within the strength structure of the travelling crane allows us to make a study of size improvement in order to reduce the material consumption, by reducing the caliber of the caisson without decreasing the required material resistance.

A much more complete analysis of this issue is possible if using it within a dynamic environment.

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