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MODAL RESEARCH CONSTRUCTION OF SELECTED ITEMS LATTICE HARBOR CRANES

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Abstract

Dockside cranes must retain adequate strength requirements that will not endanger the safety of their use. This may cause the fact that the impact of vibration on the structure exposed to horizontal forces caused by the transport of goods loading and transverse forces caused by wind can be dangerous for the correct operation of the machine. In addition, there are often consequences of climate-related environment, with fatigue - dynamizującymi destruction of the object. Dynamic loads may cause effects so devastating or catastrophic lead to their destruction [1,6,9,13,21].

Recognizing the need to improve methods for testing of lifting equipment for the purpose of assessing their condition and assess the safety factors in this paper attempts to study the destruction of the structural element of the lift with the help of theoretical methods of modal analysis [4,8,12,21].

Keywords: *modal analysis, frequency vibrations, diagram stabilization, vibrate*

1. Introduction

Modal analysis is widely used to prevent damage due to vibration infrastructure, structural modification, update the analytical model, or the control of the state, and also is used for vibration monitoring of structures in aerospace and civil engineering mechanics [22,25].

Traditional experimental modal analysis (EAM) uses input (excitation) and output (response) and is measured to estimate the modal parameters, consisting of modal frequencies, damping and mode shapes. But traditional EAM has some limitations, such as:
- In the traditional EAM, artificial excitation is normally carried out to measure the frequency of oscillation;
- A traditional EAM is usually conducted in a laboratory environment, but in many cases the true state of degradation may differ significantly from those examined in the lab.

The results of the analysis of the truss element, which is equivalent to the components used in the construction crane transport using a theoretical modal analysis in Inventor computing environment.

2. Vibrations in the record structure

One of the basic criteria used in the design of modern crane structures are dynamic properties of the structure. They have a direct impact on system vibration, noise emission, fatigue strength and stability of the structure. Analysis of dynamic properties, in most cases encountered in practice is made on the basis of the behavior of the construction model.

The quality of the analysis depends on the reliability of the model, measured compliance behavior of the object and the model subjected to disturbance of the same kind. Model design can be created in the process of transformation of analytical formalism used to describe the system dynamics or the results of experiments performed on the real object [6].

Dynamics is a branch of mechanics involved in the movement in terms of macroscopic bodies, including the reasons causing the movement. So dynamic is the science of vibration structure, geometrically unchanging, by conservative form of balance. The aim is to determine the dynamic response of structures (displacements, stresses) treated any dynamic load. Dynamic load is a load whose value, direction, phrase or place touchdowns change over time [2,9,13,22].

The main problems in the design phase structure should be mentioned inter alia:

• determination of static and dynamic loads acting on individual nodes and elements of design,
• determine the stress distribution in selected areas of computed design,
• selection of the most loaded elements and to estimate their fitness
and durability (operational reliability).

The most difficult undertaking, therefore, is to set the course, the nature of change and the extreme dynamic loads in the proposed structure. The accuracy of the designation of the status of these charges will depend on the correctness of the design calculations carried out, and as a result the reliable operation, as well as operational advantages and cost of fabrication.

The first step in analyzing the dynamics is usually determining the frequency vibrations of structural elements (ie. The spectrum of vibration elements or team). Typically, it is observed that random vibrations with these frequencies in the structure are subject to rapid-borne. But always the risk of a build-up of vibration, when external impact in their structure will also contain the force of frequencies close to the natural frequency of the structure.

The most dangerous states of dynamic loads associated with the extreme values of the stresses arising in the area of lowest resonant vibration frequencies of their own structure. Dynamic high loads may result, for example. During a high-speed (displacement) in the environment of the construction, the impact of climate, wind, temperature, or passing vehicles. Usually occurring at the change in load structure nodes are transient processes
about fading amplitude.

When determining the dynamic load structure may be used physical methods and mathematical modeling - Figure 3.1. Physic modeling methods are used for the test structural models in positions of laboratory and during specially prepared test polygon. Laboratory studies allow for significant shortening of time for a test polygon. It is also easier to keep the repeatability of test conditions. However, each of these methods is very costly and time consuming [14,71,81].

Most often to describe the structural dynamics apply structural models are built in accordance with the finite element method. This method is based on discretization of the continuous distribution of parameters, assuming certain assumptions, eg. Related to the line deflection modeled element. However, they constructed in this way models, in particular for analysis of the dynamics give the results approximate whose use is very limited. They require some fine-tuning based on knowledge of the properties measured on a real object.

Fig.1. Analysis of synthesis and the physical model is not always easy

The structural model can be used to determine the model of another kind, for example. Modal model which is a set of natural frequencies, damping factors and their corresponding mode shapes - with suitable coordinate transformation model. This model allows prediction of the behavior of construction at any forcing. Modal model can be defined on the real object based on the results of the experiment identification. It is one of the most frequently identified real model building structures used
using vibration [16].

Use of the information contained in the image of a vibration (described by estimators determined vibration) of interest to us masonry element or building structure is the area of interest for the diagnosis of structural vibration known in short as the DDK. At the same this area was located the main issues presented study.

In this study the vibration signal is the basis of the study design destruction and masonry, and many ancillary procedures for solving the task at excelling in the field of vibration engineering construction. Many times further in this work will be cited and extended messages from the vibration and noise - well already mastered in mechanical engineering - especially in terms of specification, acquisition signals, determining the vibration estimators and statistical processing of results for the destruction of selected studies of mechanical structures or masonry.

System vibrations generated by a breach of the equilibrium position of the object, which then moves under the action: the elastic forces, gravity and the friction is called the free vibration. In systems with one degree of freedom violation position of equilibrium is characterized by the initial conditions: the initial position x0 and the initial speed. If the layout has only one degree of freedom (one mass m) and has a linear elastic characteristic (k) and a damping (c) - figure 2, and it receives a harmonic driving force F (t), then the equation of motion is expressed as the formula:

$$m\ddot{x} + c\dot{x} + kx = F(t) \qquad (1.1)$$

This is the equation of harmonic oscillation or vibration equation of harmonic oscillator.

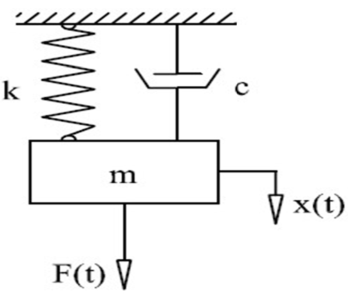

Fig.2. The system of one degree of freedom for translational movement

It shows that the vibration own system with one degree of freedom are completely determined by the vibration frequency. The amplitude of the vibration depends on the initial conditions, and the frequency of its own and the oscillation period of them are independent. The solution of this equation (displacement) is:

$$x = A\sin(\omega_0 t + \varphi) \qquad (1.2)$$

Differentiating this equation is obtained vibration velocity:

$$\overset{*}{x} = A\omega_0 \cos(\omega_0 t + \varphi) \qquad (1.3)$$

which is also a periodic function of time with the same period as the offset. On the other hand, differentiating the speed obtained by the vibration magnitude:

$$\overset{**}{x} = -A\omega_0^2 \sin(\omega_0 t + \varphi) = -\omega_0{}^2 x \qquad (1.4)$$

It is a periodic function of time with the same period as offset and speed. The acceleration is proportional to displacement and is directed opposite to the shift, which is constantly directed to the equilibrium position.

The parameters a, v, x - these are the parameters of the process of vibration, which argues that oscillations well describe the state of the structure.

In the low frequency structures can be modeled discrete systems with several degrees of freedom, and often with one degree of freedom. Discrete circuitry in contrast to the continuous distribution is characterized by a point mass, stiffness, damping and dimensions of these elements play no role. The number of degrees of freedom specifies the number of independent coordinates to be made for a clear description of the traffic (the number of degrees of freedom equal to the number of the masses in the system). In practice, the system shown in Figure 2 may be model:

- heavy construction m dampers (k, c) secured to the foundation a high molecular weight.
- working machine (vehicle) weighing m dampers (k, c) moving the perfect equality of the road,
- high building construction (large chimney, mast) exposed to the wind.

In the first approach can be a lot of systems modeled system with one degree of freedom, and his property look towards mathematical description and analysis of the equations that describe it. You can also explore the property using the parameters of vibration ($\ddot{x}$ $\dot{x}$ x) that as a result the mathematical description of model solutions interchangeably describes the same property, but from the side of the measuring system vibrations.

In commercial practice generally measured vibrations, avoiding complicated theoretical considerations.

- The use of vibration in the study of building construction quality results
  for the following reasons:
- Vibration processes reflect the physical phenomena occurring
  in structures (deformation, stress cracks), which determine the degree of destruction (fitness) and correct functioning, which results from the nature of the spread of vibration process;
  ease of process measurement of vibration in normal operation of the facility, without having to shut him out of traffic and special preparation allows indestructible assessment of the state of destruction;
- Vibration processes are characterized by high speed transmission of information
  per unit time by the formula Shanon'a:
  C = F 〖g〗 _2 (1 + N_s / N_z) (1.5)
  dependent on the spectral width of the process F and the ratio of useful signal power to the noise power Ns interfering Nz;
- Vibration processes are characterized by a complex structure of the time, amplitude

and frequency, which provides for the proper processing of the evaluation of the whole structure, as well as single elements.

During operation of the structure due to the existence of a number of external factors (force environment force of other structures) and internal (aging, wear, cooperation of elements) in the structure followed by disturbances of equilibrium states, which propagate in the elastic - material which is built structure. Disorders are dynamic and keep the conditions of equilibrium between the state of inertia, elasticity, damping and extortion. This causes the dissipation of energy as a result of waves, the diffraction, reflection, and the overlap. The existence of sources and the spread of the disorder is causing the vibration of structural elements and the surrounding environment.

3. Model effects of vibration

1. As a result, the existence of the input and execution states representing transformation processes taking place in the structure, formed a number giving a measure of symptoms characteristic contained in the processes starting from the structure. These processes are also the basis for building a model of signal generation, determining the method of construction, operation and destruction of the object state changes [16].

TRANSITION MODEL FEATURES vibration signals
for the building structure under random failures

1. As the structure is uniquely defined by the signal characteristic $\varphi_i(t,\theta)$, generated separately at each forcing. This signal changes over time dynamic (short) "t" and the evolution in their spare time (long) "θ".

2. The signal characteristic is a complex process determined φ_o and accidental "n", while the intensity and rate of change characterizes the destruction of the structure. So while the i-th extortion signal is generated:

$$\varphi_i(t,\theta) = \varphi_0(t,\theta) + n_i(t,\theta) \qquad (1.6)$$

3. Converted into a signal which is characteristic mapping of internal interactions - the destruction of the material - is perceived as $y(t,\theta)$, and in the simplest case is a response to test material with characteristics $h(t,\theta)$ to force $x(t,\theta)$. Considering the vastness of space (dimensions) "r" construction can write:

$$y(\theta,r) = \sum_{i=1}^{\infty} \varphi_i(t,\theta,r) * h(t,\theta,r) * \delta(t - iT) \quad (1.7)$$

4. The processes of construction output (selectively) influence back upon the processes of destruction and continue on the state of the building (element) by the positive feedback disruptive, distorting the original signal $\varphi_i(t,\theta)$.

5. For a fixed value of the life of θ_i = const all building objects are treated as linear, stationary systems, the properties of which clearly describes the impulse response h (t, θ_i , r) or its Transform: Laplace operators H (p, θ_i , r) or Fourier spectrum H $H(j\omega,\theta,r)$.

Described a string of assumptions leading to the signal generation model can be represented as a block model, as shown in Figure 3.

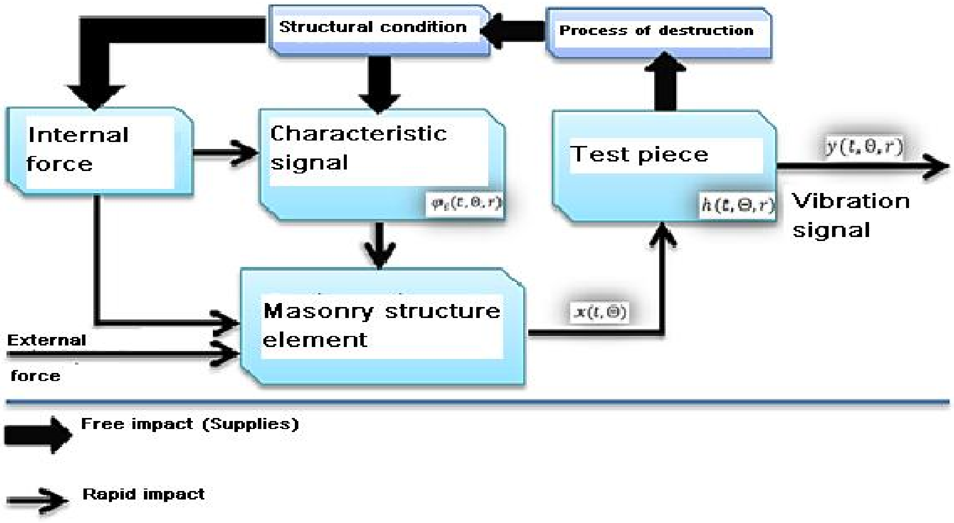

Fig. 3. Model pass through the test piece walled

The signal output any point of collection you can express approximately formula [16]:
$y_k(\Theta,r) = \sum_{i=1}^{k} a(k)h_i(t,\Theta,r) * [u_i(t,\Theta,r) + n_i(t,\Theta,r)]$ (1.8)
Where:
Pulse transition function h (*) are recorded material destruction of property,
A (k) gives different weights aggregation associated with space collection "r".

The present interpretation of the output signal y(t,θ,r) is the general case of excitations objects of batch true, but not always so simple as in Figure 4, which shows the formation of excitations from the random effects of wind on high buildings, chimneys, towers and record responses in the form of a complex vibration signal.

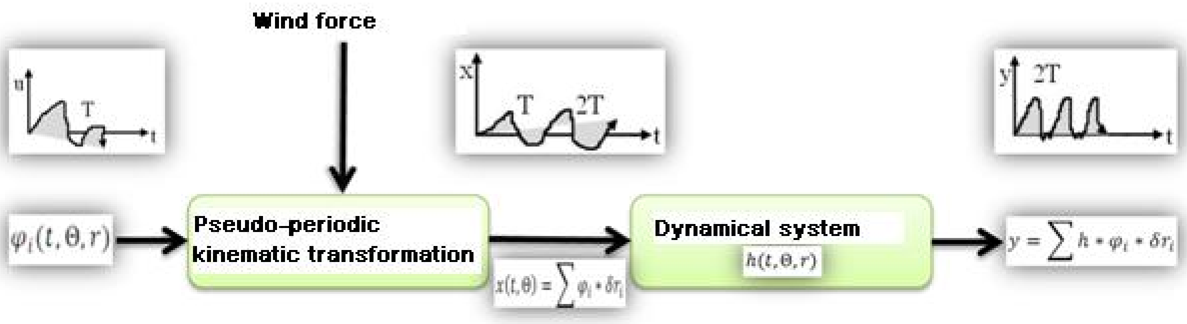

Fig. 4. Transformation signal which φi (*) in the output signal y (*) as a model generation of the signal in buildings by applying to environmental [16]

The received output signal at any point of the structure is the weighted sum of the responses to all elementary events φ_i (t,θ,r), acting always in the same sequence in different points of the dynamic system of the pulse transfer function h h(t,θ,r). These effects add up and are further transformed along different axes of reference, with the change of signal reception "r" is also connected with the change of the transmittance.

Model passage of the vibration signal by the test structures or masonry components in practice featured a function of the FRF - marked out in an experimental modal analysis as the ratio of the exciting force vibration amplitude of the vibration acceleration on the exit. Inverse function FRF is transmittance H (f), defined as the ratio of response to extortion.

It features transition process model developed by the vibration test materials further used to assess changes in the degree of degradation of the structure or masonry, studying vibration signals pass through different structures masonry elements and segments.

4. Identification of simple and complex

The dynamics is the study of how things change over time and the forces that are causing these changes [14,22]. The aim of the study is to understand the dynamics of the principles of operation, changes in dynamic loads and predict the correct behavior of the system. The need for knowledge of system dynamics due to the increasing requirements for structures. With the increase of burdens, increased requirements for durability and reliability, as well as the need for in many cases indestructible assess the degradation of old buildings, the significance of dynamic analysis of structures.

Analysis of the dynamics of the system consists of the following steps:

- Stage I - the precise arrangement of its essential features and building the physical model whose dynamic properties are reasonably consistent with the properties of a real object;
- Phase II - analytical description of dynamic phenomena as reflected physical model, which is to find a mathematical model of differential equations that describe the movement of the physical model;
- Phase III - study of the dynamic properties of a mathematical model on the basis of the solution of differential equations of motion, determine the expected traffic;
- Stage IV - take design decisions, ie. The adoption of physical parameters of the system, with the modernization adapted to expectations. The synthesis and optimization, leading to achieve the required dynamic properties of the structure.

The following procedure is based on knowledge of the system model and conclusions the actions models depend on their quality. Construction of the models involved in the identification, which identifies real systems with their models.

Figure 5 shows the steps for the study of the dynamics of the system with an indication of feedback for improving the physical model and to compare the project with the construction done. In developing the study of structural dynamics tasks they are extensively used flowcharts. They are designed to show the sequence of events or their mutual relationships, help show complex systems using block diagram dependencies and relationships between parts of those systems. Complex systems can thus be studied separately to finally put this together. For each block can be given a mathematical model describing the dynamic properties and diagram shows the path fusion blocks and corresponding models, enabling analysis of the dynamic properties of the entire system.

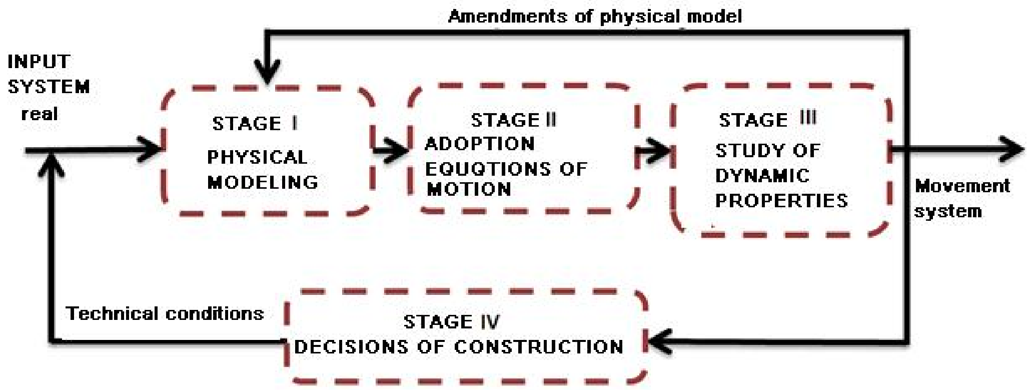

Fig. 5. Stages of system dynamics study

Obtaining a physical model of the building is the first step in its dynamic analysis. In many cases, the resulting system will dynamic system of elementary, primary, called the system or the model with one degree of freedom. The procedure for reaching the actual object to the replacement of a dynamical system, often called a model is the first step to dynamic analysis. The importance of this step for all dynamic analysis let them spell out the fact that for one object you can think of an infinite number of models, from very simple to extremely complex, and for this no one cannot give a sufficiently precise sought object property. So modeled procedure, which is coming to a replacement model of the object should be analyzed on the example and draw general conclusions methodical. The sum of the guidelines provides: a model of discrete linear, with several degrees of freedom, stationary determined.

The next step in the analysis of dynamic object is to apply the laws of mechanics and physics to obtain the differential equations of motion. Analysis of solutions to these equations as a function of the model parameters gives knowledge of the dynamic properties of the model. The conclusions of the analysis of the behavior of the model should continue to be confronted with the results of the experiment on the subject. In case of significant differences, we change the model so far to get consistent behavior of the object and its model. This requires additional full knowledge and skills of the experiment.

During the analysis of the dynamic state can seek answers in terms of:

- assess the stability of the system;
- amplitudes of vibration or forces occurring;
- describe steady-state or transient processes;
- determine the resonance frequencies.

Depending on the purpose of analysis of dynamic object put different requirements on built models and their evaluation is carried out using various experimental methods.

Changes in the degradation of the construction of buildings reported a vibration signal reflected in fluctuating levels of vibration or a change in transmittance, or FRF from the point of extortion to the collection point.

Quality tests the state of degradation is carried out using the methods for identifying a single or complex, using for evaluation of changes, respectively, resonance frequency, amplitude and attenuation coefficients in those frequencies.

Identification straight

In most applications, use of the identification line, where the determined change in the value m k, c, or change the parameters characteristic of amplitude - frequency (spectrum). For simple identification tasks to be [7,8,16]:

- determination of the structure of the model, the value and the interconnections between elements of the mass (m), spring (k) and dissipative (c);
- determining amplitude characteristics - frequency systems or only a certain set of parameters.

Transmittance module value $|H(\omega)|$ determined from the quotient of the amplitude response of forcing harmonics to the amplitude of the force. The transmittance owns: the force - displacement is as follows [16]:

$$|H_{xF}(\omega)| = \frac{x_0}{F_0} = \frac{1}{m\sqrt{(\omega_r^2 \omega^2)^2 + (2\xi\omega\omega_r)^2}} \tag{1.9}$$

$$\mathrm{tg}\,\varphi = \frac{2\xi\omega\omega_r}{\omega_r^2 - \omega^2} \tag{2}$$

Form transmission system with one degree of freedom completely define two parameters: the resonant frequency $f_r = \frac{\sqrt{\frac{k}{m}}}{2\pi}$ and the degree of attenuation $\xi = \frac{c}{c_{kr}}$. Both of these parameters are easily measured: the first position of the resonance peak on the frequency axis dimension f_r, the second from a height of the resonance peak, as:

$$H_r = \left|H(f)\right|_{f=f_r} = \frac{1}{2k\xi} \qquad \text{hence } x_{0r} = F_0 H_r = \frac{x_{st}}{2\xi} \tag{2.1}$$

wherein: $x_{st} = \frac{F_0}{k}$ is the static deflection of the spring under the force F_0.

Changing the resonance peak may be due to only a change in rigidity or mass in the system, and the change in the amplitude of the resonant oscillations may result from a change of force F_0, the stiffness k or the degree of attenuation ξ.

By measuring the position of the resonance frequency fr and amplitude at this frequency $\boldsymbol{x_{0r}}$ you can decide to change or stationary transmission system, and thus the behavior of the physical parameters m, k, c same object model.

A similar approach can be applied to systems (real engineering structures), provided that resonances are sufficiently spaced apart. Such a system can then be considered as weakly coupled to a set of systems with one degree of freedom tuned to different frequencies $\Delta F \rangle\rangle\ 2\xi f_r$.

Research transmittance change reflects the dynamic properties of the structure can be carried out using three methods:

- Using pulse test (hammer blow);
- By means of a harmonic (signal generator);
- Using a random test (stimulation of multiple resonances simultaneously).

In each of these cases specific design constraint corresponds to a vibration signal output for using the FFT spectrum of the vibration is determined, wherein the determined resonant frequency and amplitude at this frequency.

Identification complex

For complex systems, often nonlinear used for the identification design - modal analysis. As a result of modal analysis obtained modal model, which is an ordered set their own rate, the corresponding coefficients of damping and mode shapes. Based on the knowledge of modal model can predict the response object for any disorder in both time and frequency domains.

In practice the following types of modal analysis [14]:

• theoretical, which requires the solution of their own problems to the adopted structural model of the object,

• experimental requiring controlled identification experiment, during which the forced oscillation of the object and measures the force and measure the response in one or a plurality of points arranged on the test object,

• operational, based on operational experiment, in which measurements are made only system response in a number of measurement points, while the movement of the subject is due to the actual operating extortion.

In further discussion of this study nature and use of modal analysis methods in the study of destruction of masonry forms the basis of a study. There also are given details concerning the suitability of modal analysis to differentiate the state of degradation of construction (masonry element) using the vibration signal.

5. Analytical Tool in Autodesk Inventor environment

Modal study aims to determine dynamic properties truss elements commonly used in the construction of harbor cranes to indicate possible opportunities to diagnose and even modify these properties through structural changes which would ensure a high quality of these objects. To perform a modal analysis lattice design was created three-dimensional model of the selected item. On truss structures consist of the types of profiles or profiles related links disjointed or inseparable. Similarly, implemented in Inventor software. Modeled the selected element truss port cranes, which have been linked by geometric relations, according to the nature of the cooperation between these elements. This created an element analyzed by the module "Stress Analysis". This analytical module is one of the subsystems of computing Inventor and comes with the possibility of using the finite element method in order to carry out theoretical modal analysis. Preparations preceding calculation step include:

• define how to support the test piece,

• conversion of the bonds resulting from the assembly and method of assembling blocks of individual elements to a form suitable to carry out and determine the number of mode shapes.

Depending on the type of connection existing between the elements of the construction they have been replaced by so-called contact. bound for static and spring-type contacts for flexing. Contact is related to bonding material equivalent to combined elements such as.: welds. In contrast, the spring-type contact allows you to enter between adjacent surfaces spring element stiffness coefficient, which is determined by the user. When modeling overlooked is the phenomenon of suppression
in the case of flexing, which results in that the model is greatly simplified. Figure 6 shows the actual and modeled a structural model of the crane tested using theoretical modal analysis.

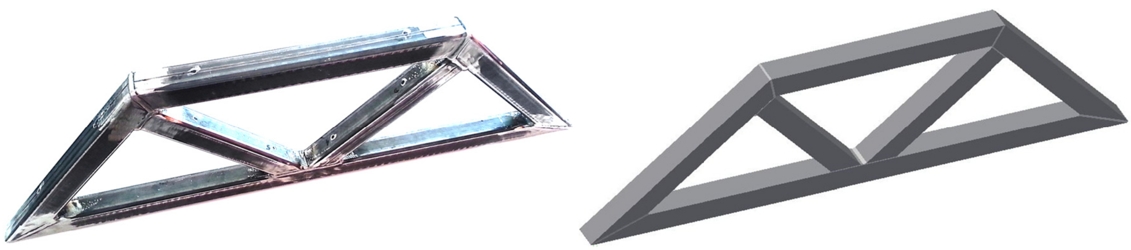

Fig.6. Actual and theoretical model tested truss element

Yes, element created in Inventor subjected to simulation calculations, which generates a report. The report contains information on the task analyzed and presented in graphical form simulation results. The results are presented in the form of layers' maps, graphically depicting the characters of free vibration test system with a dynamic array with the frequency corresponding to these forms of vibrations. The program also allows to carry out an animation obtained deformations that occur during the free vibration of each of the observed character.

6. Test results

In the framework of the implementation of theoretical calculations using the method of modal analysis we generated characteristic resonance frequency for a given element, which are summarized in Table 1. During the simulation limited number of designated natural frequency to 20.

The resulting simulation of frequency and forms of vibrations help to identify the most vulnerable areas of dynamic mechanical structure. This knowledge can be used to modify the structure in order to improve its rigidity in sensitive areas. This information also can be used to determine the current state of technical knowledge of the structure in case of possible previous states implement adequate diagnostic procedures. Below graphically shows a few examples of the form of vibrations.

Tab. 1. List of natural frequencies generated by means of theoretical modal analysis

F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]
71,29	289,40	345,10	350,83	792,55	904,46	995,99	1063,37	1063,84	1168,01
F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]
1273,96	1373,37	1577,62	1702,82	1814,78	1847,73	1930,23	2076,51	2290,80	2357,98

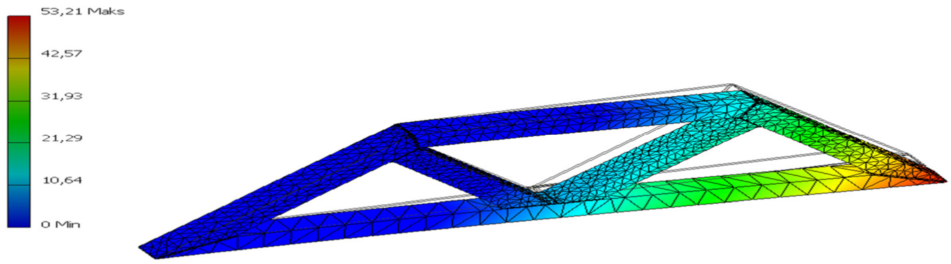

Fig. 7. The bending vibration of the grid welded at a frequency of 71.29 [Hz]

Figure 7 shows a first embodiment of vibration at a frequency of 71.29 [Hz]. Low frequency vibrations in particular should pay attention to engineers. They usually have a very significant impact on the stability of the whole structure. In the case of the analyzed object that has been left-restrained form of this is a flexural.

Truss structures in theory are treated mostly as a type of thin-walled structures. In these constructions, in addition to the bending stresses occur much more dangerous stresses derived from a constrained torsion sometimes also called bi-moment. Therefore, in the case of these structures are important inherent vibrations on the steering or flexural nature. Usually such forms of vibration of this nature are somewhat higher frequencies.

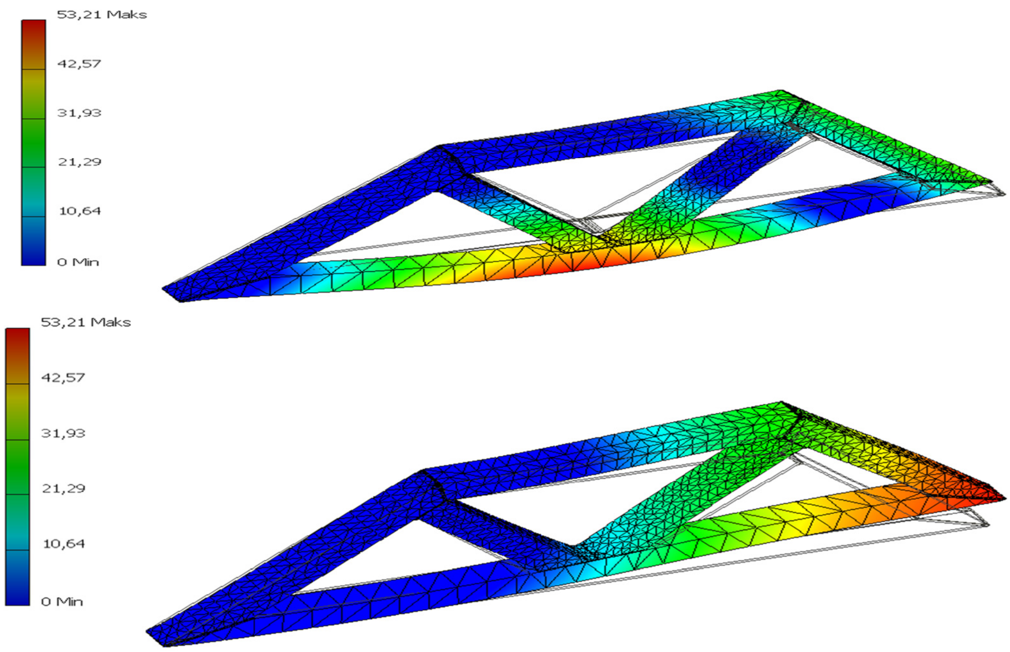

Fig. 8. Examples of two new form of vibrations truss of a flexural frequencies sequentially 289.40 [Hz] and 345.10 [Hz]

A first aspect of vibrations of a flexural appeared at a frequency of approx. 1000 [Hz]. This character can be triggered both normal stress, in the midst of which may appear Constrained

twisting, as well as the tangents that can be induced by transverse (shear) or torque.
The free torsional metal profiles can be defined as a certain deformation, by which the distance of the two sections before and after the deformation is the same. This would mean that the elongation of individual fibers and longitudinal stresses are zero.

The situation is different in the case of a constrained torsion, wherein the distance between two cross-sections before and after deformation is very different and the individual longitudinal fibers change their original length.

In the analyzed example we were not observed among 20 normal modes including at incorporating the form of a torsion or flexural similar to the definition of a constrained torsion.

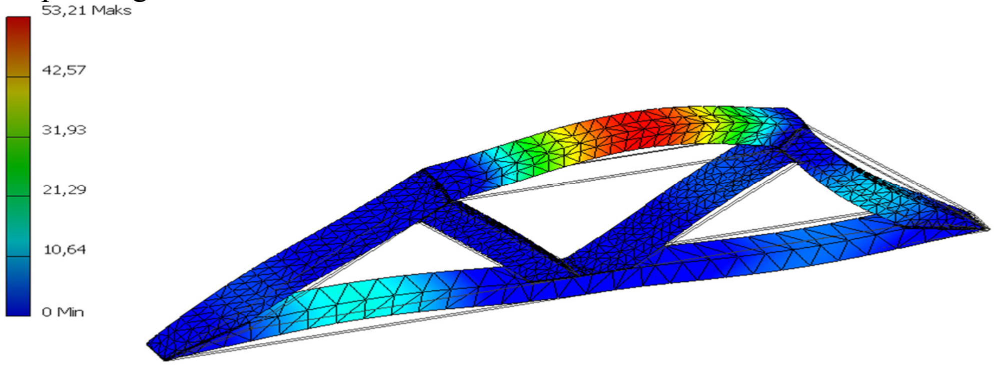

Fig. 9. The first embodiment of a vibration torsion at a frequency of 995.99 [Hz]

Meticulous and precise analysis of the form of vibrations allows very precise knowledge of the dynamic state of mechanical objects. However, this requires a combination of knowledge from several other fields of engineering.

7. Conclusion

The research results point to the fact that it is possible to distinguish between material properties, which affects the ability to distinguish their mechanical properties. The study also confirmed the usefulness of Inventor software to research using theoretical modal analysis performed on modeled construction of port cranes.

The presented results of research can be carried out following consequential inference:

- generated resonance frequency for modeled lifting the test piece,
- noted that the change in operating conditions of the lifting element increases the resonance frequency, which proves the usefulness of this method for the assessment of degradation in the quality of construction,
- it highlighted the importance of a particular character of the form of vibrations of the sensitivity of the lattice structure.

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