Experimental Methods of One-floor Steel Constructions' 
Seismic Stability – Analysis of Results

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Abstract. The article discusses several particularly significant questions related to seismic stability of steel frames. The tests produce the result of steel frame endurance under different loads, implying the condition of structure’s weakening. The paper presents the study of natural seismic noise indices fluctuations, displacement amplitude, noise decrease under various designs and implication of the dynamic loads. The issue of the impact made on the dynamic characteristic of changes are represented in the article’s sections, as well as the review of possible experimental methods of determining the endurance of the frames under seismic loads. The paper represents the empirical study of artificially damaged steel frames performance under the dynamic load, calculation of the extent of steel frame joints displacement, the degree of changes under natural and artificial seismic noise with load implication. The work aims at objective conclusion of frame performance, and states that loads and artificial damages modeling produces ineffective results for estimating the performance of frames in real/natural conditions, due to the fact that the effect made by frame’s connection nodes and the base was not taken into consideration. The paper implies further research in the area, with regard to the joint functioning of the foundation base and the frame under the dynamic load.

1. Introduction

1.1. The purpose and objectives of experimental studies

Experiment in the theory of seismicity can be considered one of the essential sources of information. On the one hand, it serves to verify the reliability of the proposed theoretical hypothesis and calculation method, on the other it allows to determine the design dynamic characteristics of the structure, estimate the sustaining capability of the structure under seismic effects, define the design scheme of structures, determine endurance characteristics of the bearing elements’ materials. [1]

The empirical studies solved the following tasks:

a) Definition of the dynamic characteristics of the frame and the identification of the stress-strain state of the elements of the frame during horizontal dynamic effects.

b) Estimation of the resulting impact made on the dynamic and stress-strain state of the frame elements under condition of damaged individual elements.
It should be noted that the simulation taking into account the dynamic similarity is an expensive and time-consuming procedure, so we offer a detailed description of experiments represented in the scope of existing technical literature, the advantage of modelling performed by the scholars lies in the fact that:

- models’ construction time period is considerably shorter than that of the full-scale object
- it is possible to achieve the desired degree of damage up to the destruction of models
- it is possible to study the mechanism of damaging the bearing frame under the application of dynamic loads of any kind (harmonic impact, explosion, ram), etc.

1.2. Research model designs

Tests of the steel frame model of a one-floor industrial building with pre-stressed tapes of a wall fence.

In order to identify the pre-stress on the stress-strain state of the elements of the steel frame of a one-floor building, its dynamic characteristics multiple comprehensive tests were carried out with the use of the models.

The 1:10 scale model was a fragment of a one-floor building consisting of seven transverse frames, a system of horizontal and vertical communication, and a covering. The columns are of solid structure, the composition of their cross section is stepwise. Particularly, the upper part of the column is of smaller section, compared to the rest of the column, thus creating a step. The joints of the columns with the foundations and roof trusses are rigid.

The taken crane beams possess composite cross-section with a developed upper belt to provide the ability to handle the horizontal loads from the bridge crane.

The horizontal and vertical connections are constructed with the use of pipes, and the struts situated on the level of the upper corner trusses follow from the corners.

The effect of constant and snow loads on farms were simulated with the use of steel sheets (1.148 kN/m² and 1.722 kN/m²). The crane bridge weight ranged from 3.041 to 8.437 kN.

Pre-stressed steel strips with a thickness of 0.1 mm and a width of 400 mm, which were attached to beams located between the columns, were taken as wall fencing. Tension control was carried out using strain gauges and indicating gages. As a result of the preliminary tension of the tapes, the wall fence turned into a plate with reinforced ribs.

Model testing was carried out in the conditions of free and forced vibrations. Free oscillations of the model were created by withdrawing from the dormant state by a blow and pulling, followed by a destruction of the load. This method allowed to reveal only the first frequency of natural oscillations. Therefore, the focus was on analyzing the behavior of the frame structure in the mode of forced oscillations created by a specially made vibratory machine of inertial action with two eccentrics.

Consequently, resulting from the experiment, practical conclusions were made. Tests of the model with implication of longitudinal vibrations has showed that the dynamic stresses in the vertical connections along the columns were twice as large for the framework with pressurized tapes, and 1.2 times smaller in the horizontal crosswise connections along the lower truss belt if compared to the framework with the condition of absent prestress on the 3rd tape.

It has been revealed that with the longitudinal vibrations of the frame simulation, the pre-stressed ribbons of the shadow fence are actively involved in the work and alleviate some degree of the inertial load on the frame of the building, while unloading the vertical ties between the columns and the horizontal links between the trusses. Calculations have shown that the rigidity of the frame resulting from the prestressing of the wall fence tapes increases by 75-80%, the decrement of the frame oscillations increases by 40-70%, and the displacements decrease by 3-4 times.

Study of the model built on the basis of the steel frame of a one-floor industrial building for horizontal dynamic effects examination.
The tests of the framework model, the geometry of which is made in compliance with the law of similarity with real frameworks of projects are of the greatest interest. Further sections of the paper will examine this experiment in more details.

1.3. Description of the construction model of a steel frame of the one-floor industrial building

Experimental studies [9], [10] were carried out on a model built on the basis of a fragment of a steel frame of a one-floor building, equipped with a bridge crane with a lifting capacity of 30 tons and a weight of 860 kg, constructed with the use of 1:10 size ratio scale of the natural object.

Figure 1. Attachment nodes of crane structures to columns and design of framework model.

A general view of the model of the steel frame of a one-floor building is shown in figure 1. The model portrayed represents a frame span of 3 m and an interval of 0.6 m. The beam of the frames is presented by a building truss with parallel chords and a height of 0.3 m. The frame of the model was combined into a spatial block with vertical and horizontal links, crane beams, struts/extensions, bolted together according to the standard design solutions. A rigid connection, and the connection of columns with the foundation was completed with the used of anchors embedded in the foundation. The connection of the crane girders between themselves and with the columns was carried out by means of studs. [11]

The overhead crane part and crane part of the columns, as well as the crane girder I-beam were composed of steel sheets. The cross section of the elements of chords and braces of the trusses were made of single angles. Vertical crane connections cross, constructed with pipes with a diameter of Ø10x1.2. The spacers between the columns and the extensions along the tent were also made of single corners, and the horizontal and vertical inter-truss connections of the framework were made of steel pipes Ø8x1. All joints of trusses were welded on the plates. Steel plates were used to fasten the elements of ties, spacers, stretch marks and metal plates that simulate the load on the floor together. [12]

Figure 2. Joints of model: a) pairing truss with column; b) coupling column with concrete foundation.
The main and end beams were made of channel with flanges inside. Wall filling in the form of expanded clay-concrete panels was constructed on a scale of 1:10 to the size of natural object taking into account the geometry, the percentage of reinforcement and material properties. The bottom row of panels was based on curved profiles that imitated the crane beams. The fastening of the panels to the columns was carried out at the four corners with the help of special clamps, which were inserted into the body of the panels and tightened with nuts. The ribbon window opening was taken in height $h_0=36$ cm. [13] The experiment was conducted on the roof of two types: lightweight and heavy. [14]

2. Methods
After Both the research methods adoption and implementation and measuring equipment choice were based on the purpose and objectives of the experiment provided for dynamic studies respectively.

The main conditions for the correct conduction of seismic noise simulation include the selection of the oscillations’ stimulant, the exposure range on which the noise simulation would be applied to test the impact made on the frame and its size, as well as intensity. Vibroelectrodynamic stands, vibroplatforms and vibratory machines have been widely used to create a vibration load [15].

In Russia, for dynamic studies of both real life buildings and models, the most common practice is the use of vibration machines, which allows to develop inertial forces equal to or higher than 8 earthquake magnitude number. [16]

A special vibration directional machine has been used to conduct empirical testing of the model. The experiments were undertaken with account of the model parameters, specifically the assumed basic frequency of its natural oscillations and the amplitude at which the values of dynamic stresses are sufficient for registrations. In the vast majority of cases in order, to estimate the amplitude-frequency characteristics, the modes of smooth or step change of the vibrator machine revolutions are used. Modes of regulation of vibrator machine revolutions make it possible to minimize the influence of effects that distort the reaction of a building during the passage of resonant oscillations due to the oscillatory process being nonstationary. [16]

In the work for the purpose of studying the spatial forms of oscillations and the construction of amplitude-frequency characteristics, the most optimal mode of smooth-step change in the frequency of the disturbing force was chosen. The essence of the latter lies in the fact that in between the undertaken steps, the frequency of the disturbing force changes smoothly with exposures equal to 2-3 seconds until the oscillatory process is fixed on station at each step. [17]

Structural damage was simulated artificially by turning off the bolted connections of the frame elements and reducing the cross-sectional area of structural elements with cutouts in appropriate sizes. For measuring relative deformations, single-element loop-based strain gauges of paper with a 5 mm base of HP type were used as primary transducers. In the columns of the bond unit (A - II, A - 4), the A-axis voltage varied from the axial compressive loads. In the course of transverse vibrations of the framework model in columns along the A axis, dynamic moments were also measured in six characteristic sections. [18]

3. Results
The purpose of experimental studies of the behavior of the frame with its horizontal vibrations was to determine the dynamic characteristics — natural frequencies and modes of vibration and the stress-strain state of the frame elements.

Dynamic tests of the one-floor frame building model were performed in two stages: [19]

Stage I - overview of the operation of a framework model with specific damage to structural elements during its axial compressive vibrations.

Stage II - the study of the work model of the frame with the specific damage to structural elements during its transverse vibrations.
Experimental studies were divided into two series - A and B, respectively, in the presence of a light and heavy roof. In turn, each series was divided into 2 groups: 1 and 2, which, respectively, subdivided into 1a and 1b (2a and 2b).

3. 1. Test Series A.

The research of the influence of various damage to structural elements on the dynamic characteristics and stress-strain state of a frame model with a lightweight roofing.

Group 1a.
1. The performance of the frame in the original condition undamaged structural elements.
2. The operation of the framework model in case of damage caused to the elements of vertical links.
3. The operation of the framework model in case of damage to the elements of interfarm communications of both bond units and the absence of an overhead crane.
4. Model’s performance in the presence of a bridge crane with interfarm bond damage.
5. The operation of the framework model without an overhead crane in the presence of damaged elements of the overcrane connections of both blocks.
6. The work of the model containing damaged elements of the crane and over-crane connections of both communication units in the absence of a bridge crane.

Conclusion on the tests of the series A.
1. It has been established that significant reductions in the frequencies of natural vibrations (by 19-21%) can be observed in cases of damage to the elements of interfarm, crane and crane connections (up to 31%) in comparison to the values obtained during testing of the undamaged frame and the absence of a bridge crane.
2. It was revealed that damage to structural elements when testing a frame without a bridge crane affects the nature of the amplitude-frequency dependence to the significant extent. Therefore, in the case of damaged crane and crane connections, the amplitude of displacement increased by 50%.
3. It has been shown that damage caused to the elements of the overhead crane and under crane connections in the presence of a bridge crane make considerable impact on the dynamic characteristics of the framework. Thus, in the condition of damaged over crane connections, the frequency of free vibrations has decreased, simultaneously with oscillations’ decrement by 15% and 23%, respectively, compared to results obtained in condition of damaged crane connections equal to decline by 19% and 27%.
4. It was revealed that in the presence of a bridge crane, damage to structural elements does not significantly affect the amplitudes of frame’s displacements. Only in the case of damage caused to the inter-truss bonds, there was observed to be a growth by 28% compared to the values of displacements obtained during testing of the undamaged framework.

3.2. Test Series 2A

The equations 1. The operation of the frame model in the case of damage caused to the spacer elements and in the absence of an overhead crane. 2. Frame’s performance in the conditions of damaged elements of the spacers and in the absence of the bridge crane. 3. Framework model’s effectiveness while containing damaged elements of braces and horizontal connections along the lower chords of the trusses. 4. The operation of the framework model with damaged elements of horizontal connections in the absence of a bridge crane and its presence. 5. Performance of a frame model with a wall crane and damage caused to wall filling elements.

Conclusion on tests 2A.
1. Damage to horizontal connections and struts along the tent, both in the presence and absence of a crane, has a slight effect on the dynamic characteristics and stress-strain state of the structural elements.
2. When horizontal links are damaged, the frame movement at the level of the coating increases by 38-42%.
3. If the elements of horizontal connections are damaged in the bonding unit, the stresses increase by 15-17% in the elements of inter-truss connections and in the frame elements adjacent to the communication unit (in the spans and elements of horizontal connections along the lower chords of the trusses).

4. In the absence of a bridge crane, damage to wall panels (mainly, in the place of their attachment to the frame) does not reduce the frequency of free longitudinal vibrations of the frame, but reduces the decrement of vibrations by 8% and 4%, respectively, and, at the same time, leads to an increase in oscillation of amplitudes by 3%.

5. In the presence of a bridge crane, damage to wall panels leads to a decrease in natural frequencies and vibration decrements by 8% and 23%, respectively, and 16% increase in vibration amplitudes.

3.3. Test series 1B

1. The work of the frame undamaged structural elements. 2. Performance of the frame with wall filling with or without a bridge crane. 3. The work of the frame containing damaged elements of vertical links. 4. The work of the frame containing damaged elements of the inter-truss connections of both blocks and the absence of a bridge crane. 5. Frame’s capabilities under condition of damaged over-crane and under-crane connections in the presence of a bridge crane.

Conclusion on testing group 1B.

1. In the case of damage caused to the elements of vertical connections of the model (in the absence of a bridge crane), the frequencies of the longitudinal free vibrations of the framework have changed slightly (by 7–9%), while the values of the logarithmic decrement of vibrations decreased by 18–42%.

2. In the presence of a bridge crane, damage to the elements of vertical links has led to a slight increase in the frequencies of free vibrations of the frame 1 (by 5-7%). The values of the amplitude of oscillations have increased in average by 28%.

3. It was revealed that damage caused to one of the elements of vertical connections in the coupling side leads to a redistribution of pressure on capabilities of the remaining elements of the connections. At the same time, there can be seen an improvement in the stress state in the columns of the bond unit, since the adjacent to the link block columns are loaded. organization).

3.4. Test series 2B

Headings, With damaged spacer elements. 1. In the absence of a bridge crane. 2. In the presence of a bridge crane. With damaged elements of horizontal connections.1. In the absence of a bridge crane.2. In the presence of a bridge crane. With wall filling with damaged wall panels.1. In the absence of a bridge crane.2. In the presence of a bridge crane.

Conclusions on testing group 2B.

1. In the model of a building frame, in the absence of a bridge crane, damage to the spacers of horizontal links in the coupling unit and mounting points of the wall panels of the frame significantly changes the dynamic characteristics and stress state of the frame elements. Thus, the frequencies of free longitudinal vibrations have increased by 20-25% (in comparison to an intact frame) under condition of damaged horizontal links and struts, have decreased by 10% in the case of damage to attachments to the frame of wall panels.

2 In the presence of a bridge crane, similar degree of damage to the frame elements led to an increase in the natural frequencies and the logarithmic decrement of oscillations, by 29–33% and 14–17%, respectively.

3. It has been shown that in the absence of a bridge crane, damage to horizontal links in the coupling unit does not significantly affect the dynamic characteristics of the framework model. Thus, the frequency and the logarithmic decrement of oscillations decreased compared with tests of the framework
without damage, respectively, by 3% and 7%. However, there was a decrease in displacement amplitudes, which was 22%. When damage increased by 10%, the angle of twist coating.

4. In the presence of a bridge crane and damage to horizontal connections, the dynamic characteristics of the framework’s model have remained almost unchanged (figure 2, 3, 4). At the same time, the bending moments in section A (figure 2-4) of column A-4 of the linking block are significantly reduced (by 47%).

![Figure 3](image)

**Figure 3.** Plan of damage to structural elements with nodes of application of dynamic mass

5. It was revealed that the 20-40% reduction of cross sections of elements of roof trusses (simulation of corrosive wear) does not affect the dynamic characteristics of the framework model and the stress state of its elements.

6. It has been established that, in the absence of a bridge crane, damage to horizontal links in the coupling unit does not significantly affect the dynamic characteristics, the twist angle of the coating, and bending moments in the columns of the framework model. At the same time, the amplitude of displacement has decreased by 9%.

![Figure 4](image)

**Figure 4.** Plan of deflection indicators and strain gauges when testing frame for longitudinal horizontal oscillations.
7. In the presence of a bridge crane and damage to horizontal connections, the frequencies and
decrements of vibrations decreased by 5% and 7%, respectively. Compared to the values obtained when
testing the undamaged frame, the bending moments in the columns of the frame remained unchanged.
Only in section (A) there was a significant decrease in the bending moment from the bridge crane at the
end of the. In the condition of damaged elements of horizontal links, the dynamic characteristics and
bending moments in the columns have changed slightly. At the same time, compared with the test results
of the undamaged frame, the angle of coating’s twist has increased by 10-12%.

8. It was revealed that the reduction of cross sections of elements of construction farms by 40%
(modeling of corrosive wear) does not affect the dynamic characteristics and the stress-strain state of
the frame elements.

4. Conclusion
As result of multiple test run on the model of the steel frame of the one-floor industrial building, we can
draw the following conclusions:

- in case of longitudinal vibrations of the frame, damage to structural elements leads to a decrease in
the natural frequencies and damping decrements;
- the most considerable reductions in the frequency of oscillations were observed when the elements
of the block of vertical links were damaged by 19–20%;
- under the condition of damaged structural elements of the framework, the displacement amplitudes
significantly have increased - up to 50%;
- damage to the structural elements in the absence of the bridge crane as a whole has unload the
elements of the block of ties (vertical ties and columns);
- in case of a heavyweight roof and damaged elements of vertical connections, the frequencies of free
vibrations of the frame have increased slightly (by 5–9%), and the values of the logarithmic vibration
decrement have decreased by 10–29%;
- it was found that, in condition of transverse vibrations of the frame, damage caused to the elements
of horizontal bonds in the coupling block resulted in insignificant changes in the frequencies of the
decrements to oscillation amplitudes (by 3-7%). With these damages, the twist’s angles of the model
cover have increased by 10-14%.

Taking into account the challenge imposed by the seismic on structures, we have concluded that the
joint work of the frame with the base is not fully considered. On this basis, we have concluded that
experiments have apparently proven to be insufficient.

However, the solution to the problem of the foundation compliance plays an important role for the
development of construction in seismic regions. Using the knowledge and research of recent years, we
concluded that the use of metal structures is increasingly used in a variety of intended and constructive
forms of construction of buildings and structures. And it is at our stage that it is important to do the
necessary research to solve the problem of increasing the seismic resistance of steel structures.

The experimental results do not allow to predict the behavior of the structure in real seismic
conditions.

It should be emphasized that the joint work of the frame with the base is not taken into account. [20]

It can be assumed that the effectiveness of the use of prestressed metal structures in seismic areas
can increase, in particular cases under the condition of simultaneous application of other anti-seismic
measures. Therefore, there is a possibility of future field research implementation.

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