

Organization of safe execution of works with the use of trapping nets

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Abstract. The organization of ensuring safe execution of building and assembly works when erecting and reconstructing buildings (structures) of various purposes based on the application of trapping nets to prevent industrial injuries in case of human or items falling from height is presented. Structural layout of a safety (catching) device with pivotally mounted brackets and a freely hanging net was considered. Appearing dynamic loads in case of items falling on trapping nets depending on impact acceleration were theoretically identified. It was found out that a trapping net with pivotally positioned brackets additionally reduces deceleration loads in relation to devices with rigidly fixed brackets and their use is more effective for cases of men falling with insignificant forward velocity. Bench and shop tests of trapping devices were carried out with the purpose of checking compliance of selected theoretical models, selection of developed options of designs and schematic diagrams, differentiation of reaction of capron and lavsan net materials from action of impulse loads. Test key results confirming matching of experimental data with presented theoretical models were showed. It was established that dynamic overloads depend both on a bracket position angle as well as on a place of an item falling into net, the value of pitch of deflection of net cloth made of lavsan and capron materials is almost similar and characteristics of values of their displacement under dynamic loads from a falling item are identical.

1 Introduction

Execution of building and assembly works at height is connected with the use of various protection equipment that also includes trapping devices with net materials preventing chance of getting injured in case of people or items falling from structures of buildings being erected.

Key elements of such a trapping device are metal brackets and synthetic nets. Brackets are installed with support elements on building structures to which nets are fixed with ropes or metal frames. [1,2]

Preliminarily, based on study conducted, the following key parameters of trapping de-

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vices – bracket necessary reach ensuring guaranteed trapping of items falling from different heights, and also acceptable distances between brackets that most likely exclude collision of such items with them were identified. It was also established that the distance (reach) of a trapping device from the border (edge) of a building structural element, encasement or scaffolding, where workstations placement is possible, to net extreme point vertically must not exceed 7 m. And bracket reach must be at least 3.5 m, and optimal distance between brackets should be 6 m. [3,4]

At the same time, when items fall on trapping device, it is necessary to take into account such factor as possible occurrence of dynamic overloads characterized by dependency of values of effective acceleration to gravitational acceleration that may cause trapping devices structural damage, injury to a fell labor and other unintended effect. Impact action occurs from falling on surface of a trapping device the value of which depends on the rate of velocity change by end value over a particular period of time. [5]

The most important objective with account to various structural layouts of trapping devices, is the selection of a structural layout ensuring minimum overloads. [6]

2 Analysis

To study occurring dynamic interaction of a falling item and trapping net, let's consider the following possible layouts of trapping devices:

- with rigidly fixed brackets and freely hanging or fixed on frame net;
- with pivotally fixed brackets and freely hanging net.

In the first case, brackets are installed so that the bracket angle of deflection remains constant in trapping (brackets possible elastic deformations are neglected) and the net is located on some height from bracket attachment basis.

The carried out studies and tests of trapping devices with rigidly fixed brackets and freely hanging or fixed on frame net showed that it is preferable to install brackets for reducing dynamic loads with maximum possible angle to horizontal plane with observance of required condition for ensuring trapping of a falling item. [7, 8] Therefore trapping devices made by such layout must probably have long brackets with nets fixed at insignificant height from site of operations. If an item is falling from height H with zero initial vertical velocity, average body acceleration during braking action (a) can be evaluated as

$$a = \frac{2gH}{u_{\max}}, \quad (1)$$

where u_{\max} – fell item maximum center – of – gravity shift;

g – gravitational acceleration, m/sec^2 .

Based on this, when using trapping devices with rigidly fixed brackets for various options of falling, values (a) may reach about 20 g , which is quite acceptable for falling items not causing destruction of structure and nets of device, but does not exclude possible injury to men. [5]

This causes a necessity to consider second layout of the trapping device when a bracket is pivotally installed on support fixed on building structure. Net is attached to the bracket with contour rope (figure 1), with examination of rate of acceleration in case of men falling on trapping device made by such layout. Net pull-up by this layout is done at account of bracket own weight.

By changing net width d initial angle of bracket installation α_0 can be changed. Such method of net fastening allows obtaining some additional slowdown path in relation to the above considered cases. [9]

3 Statement of problem

When a falling body gets on net, bracket start going up, the body wastes energy for taking brackets up, and the net deflects. Upon reaching of some value of the body center-of-gravity shift u_{max} , braking forces will start influencing on the body from the part of net cloth and the task resolves itself to cases that were discussed above. Let's consider that additional slowdown path u_{max} ,

To confirm compliance of trapping devices operation theoretical investigation with net materials, their testing was required.

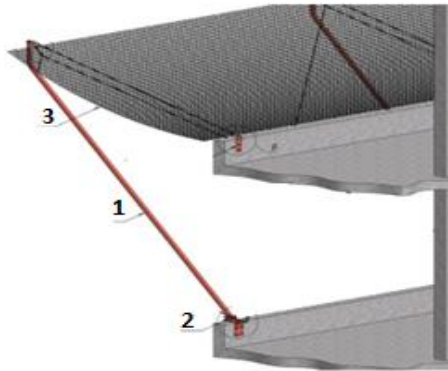


Fig. 1. Trapping net with pivotally installed bracket
 1- bracket 2 – bracket support mounted on building structure 3 - net

4 Results

If a body center-of-gravity got on net at the distance d from the point of its attachment to the wall, coordinate of center-of-gravity x, y can be found from system of equations: [10]

$$\begin{cases} x^2 + (y-h)^2 = d_1^2 \\ (L \cos \alpha - x)^2 + (L \sin \alpha - y)^2 = (d-d_1)^2 \end{cases} \quad (2)$$

Here α – bracket angle of ascent after item falling on net;

α_0 – initial angle of bracket installation.

From system (2) it follows that minimum value y_{min} is reached at $tg \alpha = \frac{g}{x}$, and

$$y_{min} = \frac{L}{h} \left(L - G - \sqrt{L^2 - 2GL + Q} \right)$$

$$G = \frac{(L^2 - (d-d_1)^2) + Q}{2L}; Q = d_1^2 - h^2;$$

Thus, additional slowdown path is identified from the following expression

$$u_{max} = y_0 - y_{min} \quad (3)$$

where $x_0; y_0$ – initial coordinates of a falling item center-of-gravity

$$y_0 = h - \frac{d_1}{d} (h - L \sin \alpha_0)$$

Therefore, in case of freely installed bracket, slowdown path of a fell item is increased by value identified by ratio (3). Results of calculation of u_{max} are presented on Figure 2, made for bracket $L = 3.5$ m. Considered were cases of bodies falling with various forward velocities (distance of item falling point on the net from the point of net attachment to wall was taken successively: $\frac{d}{4}$; $\frac{d}{2}$; $\frac{3}{4}d$). It turned out that use of trapping devices with nets on freely installed brackets is especially effective in cases of items falling with insignificant forward velocity, and u_{max} — decreases with increase of d_1 , insignificant angle of bracket installation α_0 and increased angle of installation value h .

To identify the item complete slowdown path caught by trapping device with freely installed bracket, it is necessary to consider diagram on Figure 2 together with diagrams of Figure 3, when the item is motionless in relation to net or diagrams of Figure 4 when a body is moving along the net.

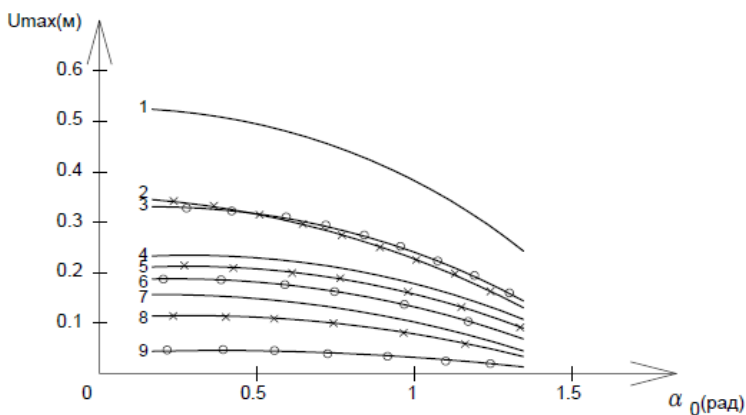
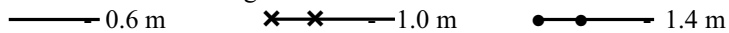


Fig. 2. Diagram of item additional slowdown path in case of its falling on net depending on angle α_0 of 3.5 m long freely installed brackets

Values of curves corresponding to item points of fall on the net

$$1, 3, 6 - \frac{d}{4}; \quad 2, 5, 8 - \frac{d}{2}; \quad 4, 7, 9 - \frac{3}{4}d$$

Designations of net attachment height from bracket base



Diagrams on Figure 3 and Figure 4 were made based on theoretical computations performed. [5] Let's assume that, for instance, it is necessary to evaluate acceleration of an item that hit a trapping device center with $L = 3.5$ m, $h = 1$ m, $x = 0.4$ rad. and that remained motionless in relation to the net.

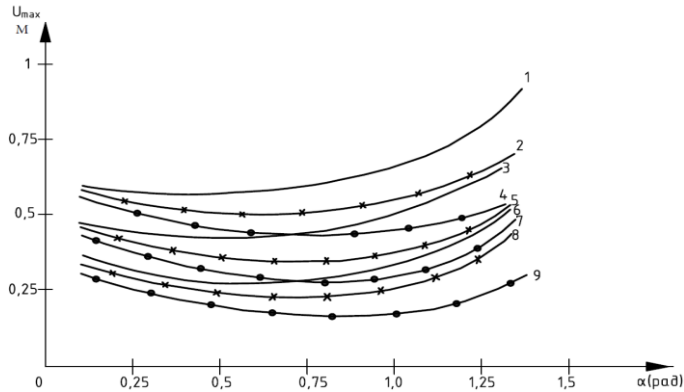


Fig. 3. Graph of dependence of maximum displacement u_{\max} on bracket installation angle α in case of item movement along the net.

Values of curves 1, 2, 6 correspond to bracket length 3.5 m

Values of curves 3, 5, 8 correspond to bracket length 3.0 m

Values of curves 4, 7, 9 correspond to bracket length 2.5 m.

Designation of net mounting height from the bracket basis

————— 0.6 m ×××× ——— 1.0 m ●●●● ——— 1.4 m

By Figure 2 respective value of additional slowdown path is found $u_{\max} = 0.35$.

The bracket raised by some level $\Delta\alpha$, and

$$\operatorname{tg}\Delta\alpha \approx \frac{u_{\max}}{x_0}.$$

For this case $x_0 = \frac{L}{2} \cos \alpha$.

Substituting numerical values, we find that $u_{\max} = 0.21$, consequently $\alpha = \alpha_0 + \Delta\alpha = 0,61$. On Figure 3 on a curve corresponding $L = 3,5\text{M}$ and $H = 1\text{M}$, it was established that for $\alpha = 0,61$ $U_{\max} = 0,56\text{M}$. The complete slowdown path is $U_{\max} = 0,56\text{M} + 0,35\text{M} = 0,91\text{M}$, and acceleration of a body that fell from height 6 m

$$a = \frac{2gH}{U_{\max}} \approx 10g$$

Thus, trapping devices with freely installed bracket allow reducing overloads down to values of about 10g.

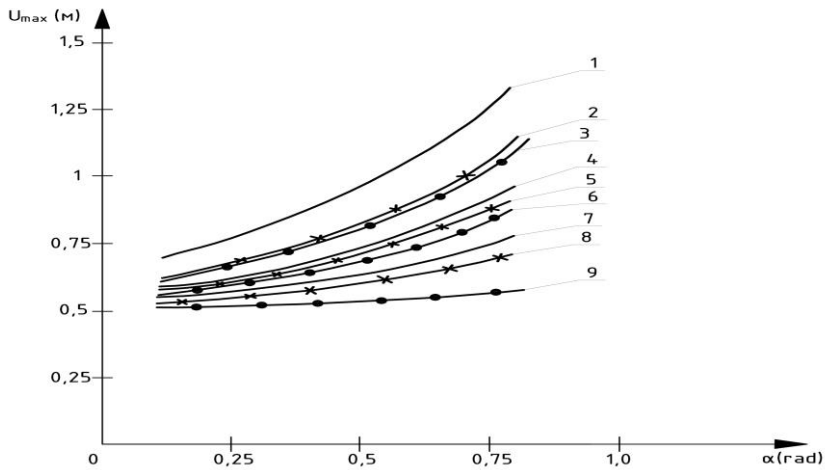


Fig. 4. Graph of dependence of maximum displacement u_{\max} on bracket installation angle α in case of item movement along the net.
 Values of curves 1, 2, 6 correspond to bracket length 3.5 m
 Values of curves 3, 5, 8 correspond to bracket length 3.0 m
 Values of curves 4, 7, 9 correspond to bracket length 2.5 m.

Designation of net mounting height from the bracket basis

————— 0.6 m ××× 1.0 m ●●● 1.4 m

Herewith, it is expedient to select longer brackets that should be installed at the maximum possible angle to capture the falling object, and the net should be fixed at the lowest permissible height from the brackets.

A trapping net with a pivotally mounted bracket allows to more reduce braking overloads by 1.5 times in relation to devices with rigidly fixed brackets.

However, use of a device with freely hanged brackets does not exclude the possibility of trapped item hitting a building wall and does not provide acceptable reducing of dynamic load when it hits different places of the net. [11]

Compliance of the performed trapping devices operation simulation was checked by tests corresponding to working conditions of construction operations successively in two stages. Individual methodology and test program were prepared for each stage.

At the first stage, bench tests were performed with focus on:

- experimental testing of theoretical models and developed options of trapping devices design
- study and selection of trapping devices schematic diagrams;
- study of reactions of different net materials to action of impulse loads.

A special bench was designed and made for performing tests at this stage. The bench allowed installation of brackets with different spacing, change installation angle, use nets made of various synthetic fibers, measure negative accelerations and the value of a falling item shifting, as well as strains and tensions in metal structures and flexible connections.

To perform bench tests, trapping devices with rigidly and pivotally installed brackets with nets hanged on them were mounted. As net materials used were nets with protective cloth size of 6 x 5.2 m and 12 x 5.2 m with 50 mm mesh made of rope with diameter 3.1 mm of two types, first were made with capron, and others – lavsan fibers. A 100 kg mannequin was selected as a falling weight based on possible weight of workers wearing full outfit. The mannequin was lifted to the required height by telfer equipped with a device with remote control ensuring load engagement and unstrapping in spatial points necessary for tests.

Main results of bench tests proved compliance of experimental data with presented theoretical models:

- brackets sizes and angles of their installation actually guarantee trapping of falling items under extreme conditions of tests;
- probability of falling items colliding with brackets is possible, which indicates installation of additional nets above brackets to increase safety;
- selected net mesh size 50 mm ensures trapping of almost all manual construction tools used in erecting building of different purpose and small items;
- dynamic overloads depend both on bracket installation angle, as well as on a place of an item falling into net.

In experimental test on bench, different structural layouts of trapping devices were tested with rigidly and pivotally fixed brackets with nets attached to them.

Tests performed allowed establishing a number of essential factors affecting trapping devices performance characteristics.

So, rigid fixation of brackets in case of a man falling into net excludes his colliding with a building wall vertical plane, which is possible with pivotally fixed brackets. At the same time, dynamic load with pivotally fixed brackets was lower than in structures with rigidly fixed brackets and matched results of theoretical studies carried out.

Comparative analysis of nets made of lavsan and capron materials showed that net cloth pitch of deflection of these net types is almost the same and characteristics of values of net shifting under dynamic loads from a falling item are identical.

Bench tests confirmed the necessity of installing additional small net above brackets due to the possibility of colliding them in case of a man falling. Besides, it was found out that the most optimal in mounting and fixation in operating position are 6 m long nets.

The purpose of second stage tests was the testing of reliability, convenience and labor intensity of mounting-dismantling of trapping nets in general and key components mounting assemblies, identification of performance indicators, identification of strength properties of strains and tensions in key structural units, and also measurement of accelerations when a falling item touches the net.

To perform the second stage with account to results of bench tests, technical documentation was updated based on which prototype models of trapping nets were tested directly under production conditions on construction site. Here, the distance between brackets above which small 0.6 m wide net was installed, was taken as equal to 3 m.

Identification of tensions and strains in trapping device structural components under dynamic loads for experimental updating of computation results was carried out with strain measurement method with the use of ohmic resistance electric sensors (resistance strain gages) with data recording with direct-writing oscillograph.

During tests, structures state was constantly monitored, and residual deformations, components damage and their connections were considered to be maximum allowed.

Measurements of occurring bending stress and compression strain in brackets and ropes, and also accelerations in the process of an item falling on net were made during tests. All the listed factors in item falling in stipulated by testing methodology in various points of trapping device were recorded simultaneously.

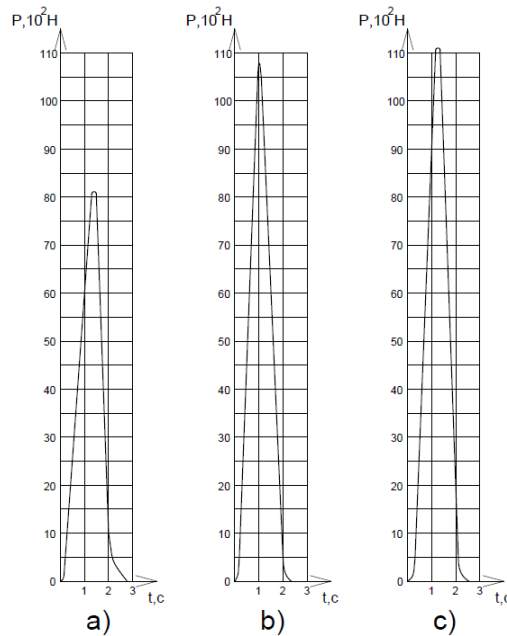


Fig. 5. Oscillogram of dynamic strains appearing when an item falls on trapping net: a) on net center b) in the point closest to building on net center between brackets c) in the point closest to building on the center of small net above bracket

The tests provided values of dynamic strains on the basis of strain measurement appearing when trapping device catches a falling item. So, for instance, Figure 5 presents an oscillogram of dynamic strains appearing when an item falls on trapping net in points located on the net center, as well as in points closest to building on net center between brackets and small net above bracket. Analysis of oscillograms showed that in case of falling even from low height, loads of about 10000 N appear, and strain value in many instances depends on the point of net that a falling item hit. Possible range of strains reaches 30%.

5 Findings

Based on tests performed, it is possible to make the following main conclusions:

- trapping devices using synthetic nets allow improvement of safety of works at height;
- trapping nets with suggested design parameters fully ensure trapping of a falling item;
- when an item falls on trapping nets dynamic overloads of about 10 g allowing creation of safe conditions for execution of building and assembly works at height while erecting buildings and structures;
- were proved results of previously carried out theoretical elaboration showing that reducing of negative accelerations at account of synthetic nets elastic properties does not ensure possible slight injuries in case of men falling on a trapping device;
- decrease of dynamic loads own to safe for humans in case of falling causes the need in designing and use of special shock-absorbers.

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