Technical safety measures when performing works at heights on the stairs

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Abstract. Works at heights are a hazardous activity. The most common in industrial and economic activities works at heights are carried out on the stairs. Injury statistics in the Russian Federation indicate that when performing work at heights, the proportion of injuries is about 25 percent of their total number. A large number of injuries are recorded in everyday life from falling when performing work at heights from the stairs. Falling down the stairs is the second leading cause of industrial accidents in the US construction industry. A significant part of these incidents occurs at the construction sites and during operation when using extension ladders. Injuries from falling down the height, including down a ladder, are usually severe. About 70% of injuries are with serious consequences. When working with portable ladders, the most common cause of falls and injuries is the stairs’ sliding. The article presents the engineering solutions aimed at eliminating the sliding of the upper part of the stairs during works on the support. An assessment of these engineering solutions for various options for their application volumes has been performed.

1. Introduction
Works at heights are a hazardous activity. The most common in industrial and economic work activities at heights are carried out on the stairs.

The statistics of injuries in the Russian Federation suggests that the injuries’ proportion when working at height is about 25 percent of injuries from their total number [1]. A high proportion of injuries in everyday life from falling down. Falling down the stairs is the second leading cause of industrial accidents in the US construction industry. A significant part of these incidents occurs at construction sites and during operation when using the extension ladders [2–3].

Injuries from falling down a height, including ladder, are usually severe and fatal [3, 5]. About 70% of injuries on stairs occur with portable stairs, and the most common reason for falling is that the stairs slide under the user [4, 6].

2. Problem urgency
When falling down the stairs, the human factor plays a great role. Therefore, technical safety measures when performing work at heights on the stairs are inherently an object of increased attention within the professional risk management system framework. Safety measures that exclude the human factor influence are of priority.
The attached ladders and step-ladders’ design should exclude the possibility of shifting and overturning them during the operation. At the lower ends of ladders and step-ladders there should be shackles with sharp tips for installation on the ground. When using the stairs and stepladders on smooth supporting surfaces (parquet, metal, tile, concrete), the covers made of rubber or other non-slip material should be applied on the lower ends. When installing a ladder in the conditions when it is possible to displace its upper end, the latter should be reliably fixed to stable structures.

When performing the work on the stairs on towers of aerial lines and electric power transmission lines (hereinafter AL and EPTL), the upper part of the staircase - the stringer abuts against the support. Since the support of the AL and EPTL is either of the circular cross section or trapezoidal, when installing the ladder there is a small adhesion area and it has a small stability degree.

Technical means to ensure the working safety of the installed on the lower ends of the stairs (metal shackles and shoes made of non-slip material) covers are quite widely represented. But there are very few nozzles on the top of the stairs when performing work on a support in mass production.

3. Discussion (theoretical part)

The purpose of the work is to increase the work safety at heights when using ladders to climb the supports of the AL and EPTL. Explanatory Dictionary of Efremova T.F. contains the definition of stairs. Staircase (n) - a structure in the form of a steps or beams series for lifting and lowering. GOST R 58752-2019 Means of conditioning. General technical conditions, gives the definition of stairs - a structure designed for workers to access the work area at a height and perform short-term jobs. The ladder consists of a stringer (position. 1) and steps (position. 2) (Figure 1).

![Figure 1. Scheme of the stairs’ installation to the support](image)

When performing work at heights from the stairs on the supports of the AL and EPTL there is a technical feature that affects the safety of such work.

Wooden poles AL and EPTL have a diameter at the apex (upper cut) of 12 to 25 cm. Reinforced concrete poles have a trapezoidal shape. Metal supports are round or multifaceted (position 5).

When installing the stairs to the support, the lower part rests on the ground or floor with the ends of the stringer, the upper part a step to the support. In order for the staircase to be stable, various anti-shift tools are used below: metal tips if the staircase is installed on the ground; rubber anti-slip nozzles for
ceramic and concrete substrates (Figure 1, item 3). The nozzles are used above to prevent the stairs from moving. All these means are directed against lateral displacement and sliding of the ladder from the support, which are the most common cause of the employee falling down the ladder [4].

Since the supports’ surface is round or trapezoidal, in most cases the support engagement plane with the ladder is the point of contact from the steps (Figure 1, position 4). When installing the stairs to the support, there is a small adhesion area. Touch occurs at the contact point. When lifting a person, the load on the support has a direction N (Figure 1, N). In case of the load redistribution in one of the parties $F_1$ or $F_2$ more $F_{adh}$ - the staircase loses balance. So that the balance is not lost, it is necessary that when climbing the stairs, the load is distributed in the direction N. Another way to increase the stairs’ stability is to keep it from two sides from the bottom. But this method has several disadvantages: 1) the human factor, which may have negative consequences; 2) it is not always possible (the absence of an additional two employees).

4. Methods (Research Methods. Work Methodology.)

One way to increase the stairs’ upper part stability is to use nozzles on its upper edge. Depending on the method of coupling with the support, the ability to adjust the clutch area, as well as the presence of built-in safety systems, various types of nozzles are used.

In the Russian Federation, Germany and many other countries, the KRAUSE nozzle for pole / tower support is the most common commercially. The KRAUSE pole / tower nozzle is designed to attach the stairs with rungs to poles with a diameter of 100–250 mm, and can be used on the stairs with an internal width of 300–400 mm. In addition to the KRAUSE pole / tower nozzle, there are others that are not commercially available, but in certain cases have safety advantages when working at heights.

Let us consider the available nozzles on the stairs. Between 2017 and 2020, the patents for the following utility models were received:
- Stair nozzle with anchor point [7];
- Stair nozzle U- universal unregulated [8];
- Stair nozzle U- universal adjustable [9];
- Stair nozzle U- shaped not adjustable with anchor point [10];
- Nozzle on a ladder with a ring circuit [11], in which the ring circuit is an anti-slip device

We will systematize the existing nozzles on the stairs. Firstly, the nozzles can be systematized by the method of coupling with the support, since the better the adhesion, the less the possibility of the ladder with the nozzle sliding off the support. Table 1 summarizes the methods for attaching a ladder to a support in terms of reliability and functional design.

Table 1. Systematization of methods for attaching a ladder to a support for reliability and functional performance

| The method of attaching the ladder to the support in functional design | Reliability and functionality of coupling with a support |
|--------------------------------------------------|--------------------------------------------------|
|                                                   | The presence of a device for coupling the upper edge of the stairs against moving | Fastening the upper edge of the stairs to the support by the nozzle on the stairs | Safety at work at heights |
| Ladder without nozzle                             | -                                               | -                                               | -                        |
| Ladder with anti-slip nozzle                      | +                                               | -                                               | -                        |
| Ladder with nozzle and ring circuit               | +                                               | +                                               | -                        |
| Ladder with nozzle and anchor point               | +                                               | +                                               | +                        |

Adjustment of the nozzle makes it possible to increase the adhesion area. Anchor loop, anti-shear chain - these are the engineering solutions that provide reliable adhesion of the ladder to the nozzle and
supports. The presence of the anchoring in the nozzle makes it possible to provide insurance when climbing to a height. Adhesion reliability to the support is ensured by the following factors:

1. When attaching the upper edge of the stairs by the nozzle, the adhesion will be ensured by the reliability of the individual elements of the nozzle. Namely: the attachment reliability of the nozzle with the ladder, the strength of the nozzle itself, the attachment reliability of the nozzle to the support.

The condition for the structure subject’s operability to force loading, in general case, is that the structural strength $R$ expressed in units should be greater than the load $N$ perceived by this structure. Denoting their difference as safety factor $Z$, we write this condition as:

$$ Z = R - N \geq 0 $$

Since our design consists of several elements, in our case this formula will look like:

$$ Z = \sum_{i=1}^{n} R_i - N \geq 0 $$

where $n$ – is the number of structural elements.

2. When installing a ladder with a nozzle to a support, the adhesion force of the nozzle with the support will depend on the free movement degree between the nozzle and the support (the nozzle adhesion area to the support) and the friction force of the mating surfaces.

In Table 2, the nozzles are systematized according to the adhesion reliability method to the support.

**Table 2.** Organizing nozzles according to the coupling method with the support

| Name of nozzles                           | Support girth adjustment | Adjustment of adhesion area with support | Support fixing |
|-------------------------------------------|--------------------------|------------------------------------------|----------------|
| Pole / Support KRAUSE                     | +                        | -                                        | -              |
| Stair nozzle with anchor point [7]        | +                        | -                                        | +              |
| Nozzle on a ladder U - shaped universal non-adjustable [8] | -                        | -                                        | -              |
| U-shaped stair nozzle universal adjustable [9] | +                        | +                                        | -              |
| U-shaped stair nozzle non-adjustable with anchor point [10] | -                        | -                                        | +              |
| Ring circuit ladder nozzle [11]           | -                        | -                                        | +              |

5. Results (experimental results)

The safest nozzle on the upper edge of the stairs in operation will be the structure that is fixed to the support. The shift of the upper end of the stairs in this case is possible only if the integrity of the structure itself is violated. The nozzle with an anchor point in its composition will ensure the working safety at heights. But a nozzle with an anchor point inherently may not be suitable in all cases. For example, if the support has fastening of communication lines (power lines) in several places located at different distances in height. In this case, do not raise the anchoring from below - the suspension will interfere.

Other nozzle designs that are not rigidly fixed to the support will have some degree of safety, which will depend on the nozzle clutch module, depending on its design.

The adhesion modulus and its direction are determined from the body motion equations, in particular, from the equilibrium equations of the body at rest. However, experience has shown that traction $F_{adh}$ cannot exceed a certain limit value $F_{max}$. In our case, the adhesion force limiting value will depend on:

1) movement freedom degrees of the nozzle with the ladder relative to the support;
2) friction forces between the nozzle and the support.

The “nozzle-support” system can generally have such a number of freedom degrees that is the sum of the freedom degrees that make up our system, minus those freedom degrees that are limited by the internal connections [12].
In general, for a spatial model, the freedom degree is determined by the formula:

\[ m = 6(n - j - 1) + \sum_{i=1}^{j} f_i, \]

where

- \( m \) is the number of freedom degrees;
- \( n \) is the number of system links;
- \( j \) is the total number of moving parts;
- \( \sum_{i=1}^{j} f_i \) is the sum of all freedom degrees in the system.

The sliding friction force acts in those cases when the body moves or is moved [13-14]. The friction force is equal to the product of the sliding friction coefficient and the support reaction force and is calculated by the formula:

\[ F_{fr} = \mu * N, \]

where

- \( \mu \) is the friction coefficient;
- \( N \) is the support reaction force.

The reaction force of the supports is:

\[ N = m * g, \]

where

- \( m \) is the body weight (in our case, the mass of the nozzle with a ladder and a person moving up);
- \( g \) is the gravity force.

Then the formula will look like:

\[ F_{fr} = \mu * m * g \]

With an increase in body weight and coefficient of friction, the force of friction increases. The friction force does not depend on the area of the contacting surfaces.

Thus, the adhesion force of the nozzle with the support will be equal to:

\[ F_{ah} = F_{fr} = \mu * m * g \]

**Summary**

Empirically, it can be concluded that the stability of the nozzle with the ladder will be the higher, the greater the nozzle friction coefficient, which depends on the material of the nozzle, and the less freedom degrees of movement in the bundle “nozzle-support”, which depend on the nozzle design. These empirical laws are largely supported by engineering practice.

At present, in order to ensure and evaluate occupational safety, the priority is a risk-oriented approach. To assess risk, the mathematical models that can compare and evaluate risk are used [15].

This mathematical model gives us the most effective engineering development solutions’ understanding in the development of nozzles on stairs against shifting its upper part and can be used in risk assessment when performing works at heights using stairs.

Thus, ensuring the work safety at heights when working on stairs is one of the important measures in the labor safety system [16].

There are various engineering solutions that can ensure the working safety at heights using stairs. There is no universal effective engineering solution to ensure the working safety at a height from the stairs. In different situations, the most effective engineering solutions may be different.

The development of technical safety measures has a greater potential, since it excludes the human factor in this process.

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