Loads in Rope Access System when Working at Heights

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Abstract. The statistics of injuries in Russian Federation put accidents in heightworks in the first place. Heightworks using rope access (RA) are considered. The purpose of this study was to determine the safety margin of RA anchors when used by specialists for increasing the safety of heightworks. The values of peak loads arising in the anchor during ascending using the two rope clamps technique and when descending using descender are determined. The empirical results of loads in the RA are presented to increase the competence of safety specialists when working at heights. The results showed that the loads in the RA can reach up to 544% of the load created by a specialist in a static position. The loads upon the point exceeded the worker’s weight by 5.44 times due to the dynamic nature of the impact of the displacement technique. The values of peak forces at anchor points obtained when performing work using RA should be taken into account by high rise work safety specialists, when drawing up work and rescue plans, planning the method of performing work in rope access systems.

1. Introduction
Currently, heightworks are in request in various sectors of economic activity, both economically and technologically. At the end of December 2018, the order of the Ministry of Labor of Russia dated December 20, 2018 No. 826н, which introduced amendments, and clarifications to the existing rules on labor protection when working at heights [1] (hereinafter referred to as the Rules) came into force starting from the introduction of the Rules into effect, and this was in 2014, they have been already updated twice. This is the first aspect that shows the urgency and relevancy of the issue of safety work at heights. The second aspect, which is even a more important one, is the statistics of accidents. The term “heightwork” on the one hand is not correct since it does not relate specifically either to the industry or to the technological process, but simply refers to finding an employee in the hazardous environment while performing work. If we consider just accidents and approach the matter from the side of the safety criterion, then the above term may denote a separate block of work that needs to be paid attention to and demand exclusive standards in the field of labor protection. In Russian Federation, the occurrence rate of industrial injuries during heightworks is in the first place [2-5]. This type of injury, due to the fall of a person from a height, occupies 30% of all severe and “lethal” statistics, and if we consider cases with a fatal outcome, then the percentage will be over 35% [6-13]. The rules, in turn, affect all types of heightworks, treating them as a separate block, and grouping them according to different types. As a part of our work, we want to make out accurately the performance of various types of work at heights with the use of rope access (hereinafter referred to as RA) [5,14-20] in support-free space. From the point of view of the RA volumetric ratio to the volume of all types of heightworks, the percentage will not be high, but from the point of view of the safety and the presence of an employee during the execution of the production task in a support-free space, it will be the most dangerous, [5] as well as
requiring maximum professional competence [21-25]. In the production environment, RA is mainly used in facade work, in arborism, on structures where stationary access systems are absent (figure 1), and are also widely used in the oil and gas complex for servicing oil platforms (figure 2). In addition, the use of RA techniques is often implemented during rescue operations. [26].

There given [16] a comparative analysis in the work, which shows that the risk of the safety system failure, taking into account the worker’s mistakes when using the two-rope system is 46 times less than when hanging on one rope; the main components of the safety system when applying RA (figure 3) are mentioned. At present, personal protective equipment (PPE) against falls from a height used when performing any types of heightworks, including the RA, is subject to mandatory certification and is regulated by the requirements of TR CU 019/2011 “On personal protective equipment safety.” Within the framework of the above regulations: “The components and connecting elements of the safety and restraint systems must withstand a static load of at least 15 kN, and slings made of synthetic materials — at least 22 kN.” Accordingly, the anchor devices included in the RA must be designed for a load of at least 15 kN. If we start from the specialized GOST EN 795 “Occupational Safety Standards System (OSSS). Personal protective equipment against falls from a height. Anchor devices. General specifications. Test methods” (hereinafter referred to as GOST EN 795) for anchor devices, the minimum strength of these products should not be less than 10 kN.

The purpose of this study is to determine the safety margin of RA anchor devices when it used by specialists for increasing the safety of heightworks. In order to do this, it is necessary to determine the values of peak loads arising in the anchor during ascending using two rope clamps technique and when descending using descender, as well as developing empirical results of loads in the RA to increase the competence of safety specialists [1] when the working is at heights.
Figure 3. Components of the safety system when hanging on one rope (a) and on two ropes (b).
1 – harness; 2 – lanyard; 3 – connector; 4 – positioning device; 5 – working rope; 6 – anchor; 7 – lanyard with energy absorber; 8 – connector; 9 – fall arrester; 10 – safety rope; 11 – anchor device

2. Methods
The studies were conducted in the laboratory, on a certified stand for testing PPE preventing a fall from a height [27]. The specialist climbed and descended with the help of a certified rope complying with GOST EN 1891 “Occupational Safety Standards System (OSSS). Personal protective equipment against falls from a height. Low tension core ropes. General specifications. Test methods” using techniques presented in figure 4 and figure 5. The working rope was connected to the anchor in the form of a high-frequency strain gauge complying with GOST R 12.4.206-99 “Occupational Safety Standards System (OSSS). Personal protective equipment against falls from a height. Test methods”, which recorded the load magnitude. The length of the rope on which the ascent and descent were made was 4.0 m. The study was carried in the context of two weight parameters of the user: 70.5 kg is the mass of the equipped specialist and 95.5 kg is the mass of the equipped specialist with the load on his back.

Figure 4. The rope descending technique: 1 – anchor; 2 – descender; 3 – working rope

The descending technique is a regulation of the friction of the rope on the descender, thereby allowing the specialist to control the speed he needs to descent. The ascending technique, in turn, is the alternate loading of two rope clamps, the chest one and the handle one, installed on the lanyard. The specialist,
being on the chest rope clamp, moves the handle rope clamp up and stands on the foot loop, and then he moves up the chest rope clamp again.

**Figure 5.** The rope ascending technique: 1 – anchor; 2 – chest rope clamp; 3 – working rope; The handle rope clamp is closed by the specialist’s hands

The test was divided into basic blocks:
- smooth ascend without additional load;
- smooth ascend with an additional weight of 25 kg;
- quick ascend without additional load;
- quick ascend with an additional weight of 25 kg;
- smooth descent with a stop without load;
- smooth descend with a stop with an additional weight of 25 kg;
- quick descent with a stop without load;
- quick descent with a stop with an additional weight of 25 kg;
- an abrupt loading of the chest clamp in the fall - an imitation of a small breakdown at the moment of load distribution between the clamps.

3. Results

Figure 6 shows the anchor point loading diagram when making a quick descent with a sharp stop in several sections. Maximum peak load $F_{\text{max}}$ made up 3.76 kN, which is 544% of the load created by a specialist through his weight.

Figure 7 shows the anchor point loading diagram during a quick ascend without load. The maximum peak load value made up 1.84 kN, which is 266% of the load created by the specialist through his weight.

Figure 8 shows two diagrams of descent for comparative analysis, smooth descent and with abrupt stops. We see in figure 7 that the difference in the load on the anchor point, when performing the same technical method, may differ by 3.38 times.
Figure 6. Anchor point loading diagram during quick descent with an abrupt stop

Figure 7. Anchor point loading diagram during a quick ascend without load
Figure 8. Comparative analysis of two diagrams of descent, a smooth one and with abrupt stops

Full results of loading are given in the table 1.

Table 1. The value of anchor point loads in absolute terms and as a percentage of the weight of the specialist/loaded specialist.

| Test No. | The performed technique                                      | Load on the anchor point, kN | Percentage of the load created by the specialist’s own weight (the weight of the loaded specialist),% |
|----------|---------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------|
| 1        | Smooth ascend without additional load                         | 1.04                          | 150.7                                                                                           |
| 2        | Smooth ascend with an additional weight of 25 kg             | 1.82                          | 193.6                                                                                           |
| 3        | Quick ascend without additional load                         | 1.80                          | 260.8                                                                                           |
| 4        | Quick ascend with an additional weight of 25 kg             | 2.33                          | 247.8                                                                                           |
| 5        | Smooth descent with a stop without load                      | 1.11                          | 160.8                                                                                           |
| 6        | Smooth descent with a stop with an additional weight of 25 kg| 1.65                          | 175.3                                                                                           |
| 7        | Quick descent with a stop without load                       | 3.76                          | 544.9                                                                                           |
| 8        | Quick descent with a stop with an additional weight of 25 kg | 4.51                          | 479.8                                                                                           |
| 9        | An abrupt loading of the chest clamp in the fall — an imitation of a small breakdown at the moment of load distribution between the clamps | 3.22                          | 466.6                                                                                           |

4. Discussions
It can be seen from the presented results that the load values fluctuations in the anchor with different techniques for performing RA techniques vary in the range of 150.7—544.9% of the load created by the
weight of a specialist in a static position. The loads upon the point exceeded the worker’s weight by 5.44 times due to the dynamic nature of the impact of the displacement technique.

The obtained values of the maximum loads on the anchors with various options for performing descent/ascent fit the standard range, which is presented by the normative documents in Russian Federation to the anchors. If we consider the minimum requirements for anchors in accordance with GOST EN 795 (10 kN), then the margin of safety from the maximum peak values obtained as a result of the experiment was $K_3 = 2.21$. At the same time, it is necessary to clarify that the maximum impact weight was only 95.5 kg, the workers of the greater weight category were not taken into account, as well as the rescue works. In the process of rescue work, when an injured person is evacuated, two people are on the same line of the rope at once, this is the rescuer himself and the injured person connected to the rescuer’s descender, as a result of which the impact weight on the system may be more than 200 kg. Permissible, safe loads on the human body in safety systems when working at heights is considered to be no more than 6.0 kN [17], while the opening of shock-absorbing systems can usually begin in the range of 2.5 kN [17].

5. Conclusions
The values of peak forces at anchor points obtained when performing work using RA presented in the work should be taken into account by third grade heightwork specialist, when drawing up work and rescue plans, as well while planning the method of performing work at heights with the application of RA.

We believe that it is necessary to conduct more extensive studies of the loads arising in RA, in situations of using these systems by “heavy” workers, with an estimated mass of 150 kg, as well as in rescue situations. It is necessary to form a manual that will help improve safety already at the planning stage on the basis of the data obtained.

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