

WORK SAFETY AND ERGONOMICS AT THE WORKPLACE AN EXCAVATOR OPERATOR

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Abstract: Ergonomics plays an important role in shaping safe and hygienic working conditions. Its main purpose is to increase the productivity of work in a way to not cause adverse health effects for the employee. In the article the profession of excavator operator, taking into account the scope of activities performed the qualifications and skills necessary to perform this profession were described. In the further part of the work, hazards occurring in the working environment of the excavator operator were identified. Then, selected ergonomic factors influencing the comfort of earthmoving machine operator were analyzed, in particular those that could cause excessive strain on the musculoskeletal system. Authors of the work focused primarily on discussing the construction and equipment of the excavator cabin as those elements that fundamentally determine the safe, ergonomic and comfortable work. The measurable effect of the work is to propose preventive works reducing the negative impact of these factors on the human body.

Keywords: ERGONOMICS, OCCUPATIONAL HEALTH AND SAFETY, EXCAVATOR OPERATOR, WORKING ENVIRONMENT

1. Introduction

In Poland, Labor Codex [14] regulations oblige employers to provide employees with safe and healthy working conditions with appropriate use of the achievements of science and technology. This obligation can be implemented in many ways, for example by appropriate organization of work, ensuring compliance with health and safety rules, or responding to all the needs of adapting measures ensuring protection of life and health of people to changing working conditions. The obligation to provide health and safety at work also rests with the constructors and manufacturers of machines and other devices constituting work equipment. They should protect the employee from the negative impact of work environment factors, in particular: injuries, excessive vibrations, vibration, radiation, electric shock, the action of hazardous chemicals or other harmful work factors. In addition, these machines and devices should meet the technical requirements contained in Polish Standards [12, 13] and take into account the principles of ergonomics.

Ergonomics deals with issues related to the adaptation of the material environment and working conditions to the anthropometric possibilities, needs and limitations of man. It focuses on the proper shaping of the workplace, which will ensure the maximum possible work efficiency, at the lowest possible human biological cost [16]. Therefore, ergonomic solutions are characterized by proper adjustment to human anthropometry, comfort or lack of negative impact on the human body. The aesthetics are also important factor. The application of ergonomic principles at the workplace can bring many benefits, among which one should distinguish: improvement of productivity and quality of work, reduction of the workload, reducing the number of errors, increasing the safety of performed work (reducing the incidence of occupational diseases and reducing sickness absence) and increasing job satisfaction, which can also affect better motivation to work [7, 16].

In this article, considerations were taken in the field of work safety and ergonomics as excavator operator. Work related to the operation of this type of machine is heavy and physically demanding work. The excavator operator is exposed to many threat related to both the operation of the machine and the work environment. In addition, the operator's nuisance is related to the seated position of the body and the monotony of the activities performed, which can cause excessive strain of the muscular and skeletal systems. For this reason, it is necessary to adapt the basic working environment, which is the excavator cabin to human anthropotechnical conditions. The basic parameters of the excavator cabin in the field of safety and ergonomics include: protection against the effects of overturning (ROPS - Roll-Over Protective Structures) and falling objects from the height (FOPS - Falling Object Protective Structures), the position of the cabin in the machine, lighting, seat and the arrangement of control elements. Providing ergonomic working conditions affects the operator's safety, reduces the risk of accidents in which other people can

participate, and ensures the comfort of the employee. It is also important to equip the operator with appropriate personal protective equipment, depending on the place of work and working conditions.

2. Excavator operator profession

2.1. A description of the work and the way it is performed

The excavator operator is a profession consisting in the provision of services in the field of specialized earthworks and auxiliary works related to construction and mining. The basic duties of the machine operator include excavation, loading and handling of earth masses, loosening and transporting of spoil, sorting and deployment of materials in the landfill. In addition, the operator performs reloading and transport work, as well as cleaning works. The machine operator is also obliged to control its technical condition, replace operating fluids and remove minor defects [5, 8, 11]. The full scope of duties of the excavator operator is presented in Table 1.

Table 1: Responsibilities of the excavator operator

| Before making earthworks |
|---|
| <ul style="list-style-type: none"> – preparation of the machine with equipment for earthworks, their repair and maintenance in accordance with the Operation Manual; – transporting the machine to the place of work; – preparation of the work area and works front in accordance with the rules and regulations of health and safety, ergonomics, fire protection and environmental protection; – getting acquainted with the survey of work, geodetic guidelines; – checking the technical condition of the machine and setting the levers and working units in the correct position. |
| During earthworks |
| <ul style="list-style-type: none"> – leveling the area using a excavator ; – excavation, ground loosening using a excavator; – arranging and sorting of backhoe work products; – controlling the quality of work performed; – performing works in accordance with the technological requirements specified for a given process and machine type; – reliable tracking of the machine environment in order to avoid collisions with other vehicles and objects and objects, as well as accidents involving people; – quick response to incorrect machine operation. |
| After making earthworks |
| <ul style="list-style-type: none"> – replacement of operating fluids and removal of minor defects in the excavator; – performing maintenance work; – reporting to the management about any observed defects and other irregularities related to the operation of the machine, removal of which is beyond the capabilities of the operator; – participation in acceptance and technical tests carried out after machine repairs; – preparing a daily report on the work performed; – cooperation with people supervising the work; – transporting the machine to the place of its garage. |

2.2. Working environment

The working environment of the excavator operator are construction sites, gravel pits, sand pits, quarries, mines and machine parking spaces. The excavator operator works both inside and outside the cabin, therefore it is exposed to changing weather conditions. It should be emphasized that the ambient temperature has a important impact on the working conditions and the quality of the works performed. The operator works in a one- or three-shift system. The excavator operator is exposed to such dangerous and harmful factors as: noise, vibration, air dust, explosion, fire or electric shock. In addition, the work of the operator is associated with health threat associated with diseases of the musculoskeletal system and rheumatic diseases [8].

According to the International Occupational Risk Safety Data Sheet, the following hazard factors exist in the backhoe operator's work environment:

Factors that can cause an accident

- microclimate (cold, hot);
- fire, explosion;
- falls from a higher level to a lower one;
- slips and falls at the same level;
- lifting weights.

Physical factors

- crushing;
- collision;
- lighting;
- noise;
- vibration;
- electric current.

Chemical factor

- dust;
- chemical substances.

Ergonomic, psychosocial and work organization factors

- sitting body position;
- stress;
- work monotony.

In addition, among the threats at the excavator operator's position, you can indicate [11]:

- improper technical condition of the machine;
- terrain conditions when carrying out earthworks;
- failure to comply with traffic regulations;
- failure to comply with the safety rules during operation, inspection and repair of the machine;
- servicing the excavator without the required qualifications.

Incorrect operator behavior, improper work organization or work positions, as well as poor technical condition of the machine can cause accidents at work.

2.3. Education, qualifications and health and psychophysical requirements necessary to work in the profession of a excavator operator

The profession of a excavator operator can be carried out by a person who has: a minimum of 18 years, primary education, a current medical certificate stating that there aren't contraindications to the profession issued by a medical doctor and completed a specialized training and obtained a positive exam result. In addition, candidates starting the training should have at least one month's work experience in a position related to technical and operational servicing of machines in a given specialty. Otherwise, they are obliged to complete additional practical training [5, 8, 11].

In Poland, the legal basis for the training and qualification of machine operators and other technical equipment for earthworks (including excavator), construction and roadworks is the Regulation of the Minister of Economy of September 20, 2001 on health and

safety at work while using machines and other technical, construction and road equipment (Journal of Laws No. 118, item 1263) [10]. According to this document confirming the right to operate a backhoe loader and other working machines is the "Book of the working machine operator" with an appropriate entry regarding the type of allowances received, issued by the Institute of Mechanized Construction and Rock Mining. These rights in Poland are valid indefinitely. The basic requirement, necessary to undertake work in the profession of a backhoe loader operator, is to have the right to move the vehicle on public roads (driving license category B or T).

These rights can also be recognized in other European Union countries, depending on whether the occupation of the excavator operator is classified in the given country as a regulated or unregulated profession. In the case of a regulated profession, official recognition is required, which is carried out by the competent authorities of the target country. In addition, when there are major differences in the field of education or occupation, the recognition of professional qualifications is associated with an adaptation traineeship or an aptitude test. In turn, if in a given European Union Member State, the profession of an excavator operator is an unregulated profession, then the employer decides about employing an employee and recognition of his professional qualifications, pursuant to Directive 2005/36 / EC [2].

Based on the database of regulated professions [3], it can be concluded that the occupation of an excavator operator is a regulated profession in Norway, Iceland, Ireland and Bulgaria. In these countries, exercising the profession of an excavator operator by persons who have obtained their professional qualifications in another EU member state is possible only after the official recognition of professional qualifications.

The work of the excavator operator is characterized by high requirements regarding knowledge and driving skills, because even a small error can cause huge losses and expose to loss of life and health of people. In addition, servicing this type of machine requires the ability to concentrate, perceptive and reflex. Due to the specifics of the work performed, the excavator operator should demonstrate accuracy, reliability, care for safety, as well as technical abilities and manual dexterity.

Good health is required of the operator of the working machines, in particular the absence of defects in the organs of sight, hearing, movement and disturbances of balance, combined with resistance to long-lasting effort. Because the operation of work machines is a heavy and exhausting work, especially due to psychophysical loads. In addition, people undertaking the job of a backhoe operator should demonstrate the ability to cope in stressful and crisis situations.

The health contraindications preventing work in the discussed occupation include diseases of the musculoskeletal system (spine), heart disease, circulatory and respiratory system. Additionally, it should be noted that the exclusion for performing occupations related to driving vehicles is diagnosed dependence on alcohol and psychoactive substances. Due to strict health requirements, employees should undergo periodic medical and psychotechnical tests [11].

3. Analysis of selected ergonomic factors at the profession of a excavator operator

The excavator operator performs most of its duties in a sitting position. A working place is used when [4]:

- work requires high accuracy and precision over a longer period of time;
- a high degree of body and balance stability is required;
- all necessary items for work are located in an easily accessible place and do not require lifting above 150 mm;
- work does not require the use of high force and carrying loads over 4.5 kg;

– precise foot control is required.

The sitting, forced position of the operator's body causes that employees performing this profession are exposed to the ailments of the skeletal and muscular system. Diseases of the musculoskeletal system are characterized by one of the largest sickness absence of vehicle drivers.

In addition, in the working environment of the excavator operator, a significant risk factor for the health of employee is the work monotony, which causes of excessive strain certain parts of the body used to carry out professional activities. This factor may contribute to a decrease in concentration, and consequently, be the cause of an accident.

The excavator operator usually performs its work in the open air, in various weather conditions. Depending on the season, it is exposed to low or high temperature, high humidity, rain or snow. The indicated weather conditions may cause diseases of the lower and upper respiratory tract, disturbances of concentration and influence visibility (snow, bright sun).

The indicated factors have a fundamental impact on the safety, ergonomics and comfort of the excavator operator. Therefore, the cabin of the working machine should be characterized by appropriate construction and equipment.

3.1. Protective structure of the excavator cabin

The cabin is the basic equipment for earthmoving machinery (including excavator). Its main purpose of the application is to increase the safety and comfort of the operator during the work. The cabin protects the operator primarily against excessive noise, physical load and atmospheric factors. In addition, the floor of the cabin lined with a special mat allows to minimize the level of vibration. The ergonomics and operator comfort can also be influenced by such solutions as: rear side windows opening completely or partially improving ventilation, heated seat, or fresh air / recirculated air heater.

The basic requirement that must be met by currently offered excavator is to equip the cab with protective structures: ROPS (Roll-Over Protective Structures) and FOPS (Falling Object Protective Structures). The purpose of these constructions is to ensure an appropriate level of safety for the machine operator. The ROPS protective structure protects the worker from the effects of machine rollover during work. Its basic elements include: frame, brackets, mounting, support sockets, bolts, screws and suspension. Requirements that should be met by such a construction are set out in the standard PN-EN ISO 3471:2009 Earth-moving machinery -- Roll-over protective structures -- Laboratory tests and performance requirements [13]. The second type of protective construction is FOPS construction, which protects the operator from the effects of falling from the height of objects. Basic guidelines in this respect are specified in the standard PN-EN ISO 3449:2009 Earth-moving machinery -- Falling-object protective structures -- Laboratory tests and performance requirements [12].

In order to adequately protect the operator from hazards, the ROPS / FOPS protective structures should not be modified in any way. It is forbidden to weld, drill, cut or assemble parts. In the situation when the machine overturns or damages the cabin structure, it should be replaced with a new one. Assembly and dismantling of the cabin may only be carried out by specialized services. In addition, the machine should not be additionally loaded by mounting additional parts or adherence to the maximum weight guidelines indicated on the cabin. The operator is also obliged to carry out periodic inspections of the technical condition of the cabin, which are aimed at eliminating cracks, loosening screws and other damages. It should be emphasized that proper operation, systematic control [6, 9].

3.2. Visibility and lighting in the excavator cabin

The assurance of good visibility of the work field is of great importance in the work of the excavator operator. For this purpose, it is necessary to optimally place the cab in the working machine. In modern excavators, lift cabins are mounted, which allow changing its position from side to side, forward and backward, providing the operator with sufficient visibility during work. In addition, when constructing machines, certain positioning parameters of the eye ellipse are assumed and a reference line is set. The vehicles are constructed in such a way as to ensure the widest possible and the best visibility, taking into account the position of the posts, which is particularly important when performing precise tasks.

The level of visibility is not only influenced by the proper cabin construction and its location, but also by the equipment in the appropriate quality and size of the glass. Large, rounded windscreens and wide side windows guarantee visibility in all directions. A good solution used by machine manufacturers are also appropriately tinted glass protecting against excessive light (sunlight).

The operator of the excavator works at different times of the day, sometimes also in the evening and at night. Therefore, lighting is required to ensure proper visibility and operator comfort. The currently produced machines use lighting, which is characterized by high luminous efficiency. Correct lighting not only improves visibility, but also reduces the psychophysical load of the operator and increases the level of work safety.

3.3. Entering and exiting the excavator cabin

The safety of the excavator operator depends not only on the structural elements inside the cab. The external parts of the cabin are also important. Some of them include entry levels. They should guarantee safe entry and exit of the cabin, which is why they are made of non-slip materials. The correct operator behavior is also very important. Before entering or exiting the cab, make sure that the machine is stopped and properly parked. When entering and exiting the excavator, be facing the machine and use three support points (fig. 1). In addition, it is forbidden to use the rudders of the machine or steering wheel as handles [1, 9].



Fig. 1. Support points on the inside of the excavator's cabin [1]

3.4. Seat (armchair) of the excavator operator

Work in a sitting position is much less physically aggravating as opposed to a standing position. Nevertheless, long-term sitting of operators in the cabin may negatively affect the load on the lumbar spine. Therefore, long-term sitting is difficult for a man. It can cause spinal pain syndrome, flabbiness of the abdominal and back muscles, pressure on internal organs, as well as breathing difficulties. Therefore, the most important influence on shaping the correct position of the working machine operators is the seat (armchair). It should be properly adjusted to ensure work comfort and reduce operator fatigue. In addition, the height of the seat should be set so as to ensure free access of the operator to the rudders of the machine. In addition, the optimal seat height should allow the brake pedal to be fully depressed while the back touches the backrest [1]. An example of a excavator seat is presented in fig. 2.

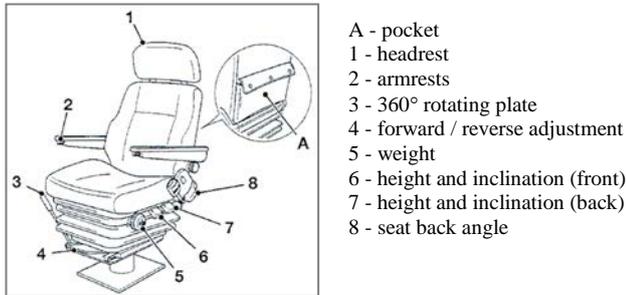


Fig. 1. Construction of the operator's seat [9]

In terms of ergonomics, the basic elements of the seat include [4]:

- **headrest** – is intended to hold the head of the machine operator, and consequently prevents spinal injuries during sudden head movement backwards. It also affects the comfort of work, allowing a comfortable head support;
- **armrests** – they provide additional support for the body and allow relief of the neck and shoulder section; they affect the stabilization of the upper limbs, which is necessary in the operator's work. In addition, armrests help in sitting and standing, lining them with a soft fabric protects against an ulnar injury;
- **seat height** – it should be adjusted to ensure proper access to machine control devices and proper leg placement (thighs should be placed horizontally and the leg should be vertically);
- **forward / reverse position adjustment** – allows you to adjust the optimal position of the driver's seat with respect to the pedals and control and monitoring elements; it affects the safety and comfort of the operator's work, without causing any postural loads; in addition, the adjustment of the forward / back position together with the seat height adjustment provides the operator with adequate leg space, which also reduces the effects of static load and discomfort. For machine operators, the optimal height of the recess in a sitting position should be 70 cm (but not less than 66 cm);
- **rotary plate** – it allows to change the position of the operator's seat to any angle;
- **backrest reclining angle** – determines the pressure on the intervertebral discs; Increasing the inclination angle means that the greater part of the operator's weight is transferred to the backrest, which reduces the compressive force acting on the disks. The optimal inclination of the backrest should be 100° – 110°
- **the angle of the seat panel** – increasing the inclination angle of the seat plate allows you to maintain proper contact with the backrest and prevents the sliding of the operator; however, a larger inclination angle is not conducive to the proper lordosis (bending) of the spine.

3.5. Ergonomic arrangement of control elements

Performing by the operator of a excavator specific earthworks is associated primarily with the operation of control devices. Ensuring their optimal position, in accordance with the employee's anthropometry, influences the safety and comfort of work, and makes it more efficient and less stressful.

Machine manufacturers must make the following rules when making decisions regarding the arrangement of control devices [4]:

- quick operations requiring high precision are done with fingers or hands; therefore, buttons, tilting switches and rotary knobs are preferred for this type of operation;
- operations requiring strength and relatively lower precision are best done with upper limbs (with arm involvement) and lower limbs; for this type of operation it is best to use levers, cranks, handlebars and pedals;

- control elements should be such that they can be easily reached (in the optimal motor zone); manual controls should be arranged with the elbow and the shoulder.

The control devices, which should be compatible with the movement stereotype, are important in efficient and safe driving of the excavator. This means that the movement of the control device forward, up, to the right corresponds to positive effects (activation, start-up, parameter increase). On the other hand, the movement of the control element towards oneself, downwards, to the left causes negative effects (switching off, stopping, reducing the parameter). In addition, vehicles should pay special attention to the unification of the location of control devices, which means that a group of devices should always have the same location and move in the same directions [4].

The optimum position of control elements in vehicles requires taking into account the dimensional relations between the operator and the control station. In addition, the design of the site should take into account the user's reach zones. Control elements in the cab space are located in three zones: first, second and third degree. Table 2 presents their distribution and general characteristics.

Table 2: Comfort service zone in the excavator cabin

| COMFORT SERVICE ZONE IN THE EXCAVATOR CABIN | |
|---|--|
| ZONE 1 device operation does not require detaching the shoulders | <ul style="list-style-type: none"> – light switches; – direction; – sound signal; – hand brake; – on / off switch; – tool control levers; – wiper; – sprinklers. |
| ZONE 2 device operation does not require detaching the lumbar region from the backrest | <ul style="list-style-type: none"> – blower on / off switch; – air conditioning control; – sun visors; – cabin light buttons; – electric lighter. |
| ZONE 3 device operation takes place within limited comfort, but does not interfere with other elements | <ul style="list-style-type: none"> – engine cover openings; – handles for opening windows; – window latches; – seat adjustment elements; – the main circuit breaker of the electrical system. |

Safe and comfortable driving also requires proper positioning of the steering wheel in relation to the pedal. The tests [15] carried out indicate that there is a relationship between the position of the pedal relative to the seat and the resistance posed by the pedal, and the time and value of moving the foot while driving. In addition, the value of the pressure on the pedal and its duration is correlated with the load on the lower limbs. Prolonged peeling on the pedal with excessive force contributes to reducing the accuracy of control, and thus lowering the level of safety of work. In addition, performing this activity may cause lower limb and above all knee disorder.

In order to reduce the load on the knee joint, it is necessary to properly position the seat in relation to the pedal so that the angle in the knee joint is between 120° – 130°. In this angle range the load value is low and the pressure force is highest [15].

3.6. Personal protective equipment for excavator operator

Personal protection means are aimed at eliminating the danger resulting from the threat associated with the technological process or the work environment. They are usually used when other methods of protection are inadequate [7].

Personal protection measures very often affect the ergonomics and comfort of work. Some of them may cause employees to feel

uncomfortable and therefore it is necessary to strive to minimize their wearing time. It is recommended that the use of personal protection measures is only due to the working conditions and needs at a given place of work. In addition, to ensure the maximum possible level of employee protection, places and areas of use should be clearly marked. The basic means of personal protection at the excavator operator position include:

- protective helmet;
- protective gloves;
- respiratory mask;
- safety glasses;
- hearing protectors;
- safety shoes;
- protective mask;
- dust mask;
- protective clothing;
- clothing ensuring visibility (reflective vest);
- safety harness.

Summary

Based on the reading of this article, the following conclusions and final statements can be formulated:

1. The profession of a excavator operator may be carried out by a person who is 18 or older, has basic or vocational education, completed specialist training and passed the exam with a positive result, and received a "Book of a working machine operator" with an appropriate entry regarding the type of entitlements received.

2. The excavator operator is exposed to many dangerous and harmful factors, among which the highest level of occupational risk is characterized by: noise, vibration, electric shock or dust.

3. The work of an excavator operator is a tedious and tiring work, requiring perceptiveness, continuous concentration, precision, as well as dexterity of upper and lower limbs. In addition, the machine operator works in a sitting, forced position, which means that their ability to change the position of the body is small. In addition, he performs a monotypic work, which also affects the load on the skeletal and muscular system of the employee and the decrease in concentration that can cause accidents.

4. The direct position of the excavator operator's operator is the space of the machine's cabin in which he spends most of the day's work. Its construction and equipment depends on the comfort and safety of the employee and other people in the immediate vicinity. Therefore, all elements of the cabin should be adapted to human anthropogenic conditions, be characterized by easy and intuitive operation, and be appropriately located.

5. In terms of ergonomics, the protective structure of the cabin against the effects of overturning (ROPS) and falling from the height of objects (FOPS), operator's seat (seat), cab position and lighting guaranteeing proper visibility as well as the arrangement of control devices are of great importance. In addition, the safety and comfort of the operator's work also depends on his behavior, how to operate the machine, compliance with the general rules of health and safety and the use of protective measures.

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