Technological process of buildings construction as regards occupational risks

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Abstract. Relative statistical indicators of injuries in construction are higher than the general rate for all types of economic activity. In this paper, the assessment has been made of the occupational risks during buildings construction with consideration to the peculiarities of technological stages. The occupational risks were assessed with regard to the probability of danger and seriousness of consequences. The highest risks were revealed for the following works: land plot fencing, demolition of the existing buildings, foundation excavation, trenching for communications, erecting outer walls of buildings, and wiring. The most frequently occurring accidents are falling from height and electric injuries. Namely these risks require putting more focus on them and using individual approach when trying to minimize them.

1. Introduction

Construction enterprises, like all other companies within the market economy environment, are exposed to various risks. In the process of construction the importance of this or that risk changes depending on the stage of construction; for instance, at the stage of engineering, the most significant are financial and legal risks, and at the stage of construction – the production and technological ones. The results of a construction enterprise’s activity are influenced by the following:

- political risks, such as changes to taxation rates, laws, by-laws, raised customs tariffs and duties on imported construction materials, what may lead to a situation when expenses exceed profits;
- economical risks, such as wrong choice of the area of development, lack of demand for apartments, high construction costs, penalties and fines for failure to meet the construction deadlines;
- natural risks, such as floods, earthquakes, hurricanes, and other natural catastrophes;
- production and technological risks, such as operational failures of machines, mechanisms and transportation vehicles, breakdown of the systems of power and water supply, low quality of materials, parts, structures and equipment not allowing to use them as designed, reworking the improperly performed construction and assembly due to violations of technology, unforeseen works and removing of various defects, unstable quality of raw materials and materials, insufficient reliability of technology, outdated technology of construction-and-assembly and
finishing works, lack of power reserves, staff turnover and difficulties with hiring qualified work force, quality of labour conditions, risks of occupational injuries caused by not following the labour safety requirements, as well as fire safety and sanitary-and-hygiene norms and regulations, etc.

The construction occupational injuries have the highest rate and features the worst cases in Russia. In 2016, according to Rostrud (Federal Service for Labour and Employment) data, 20% of fatal accidents were registered namely in the construction sector. Relative statistical indicators of injuries in construction are higher than the general rate for all types of economic activity. Table 1 shows absolute and relative statistical indicators of occupational injuries in the Russian Federation as per Rosstat (Russian Federation Federal State Statistics Service) data [1] over the period of 2012-2016.

| Table 1. Injuries Statistics for Russia (Rosstat). |
|--------------------------------------------------|
|                                                   |
| Average number of listed employees, thous., peop. |
| In all types of economic activity                 |
| 2012 2013 2014 2015 2016                         |
| In construction                                   |
| 21687.1 21291.8 21663.8 20924.2 20806.9          |
| 1557.0 1488.7 1463.6 1325.5 1206.7               |

| Number of the injured, peop.                     |
| In all types of economic activity                |
| 2012 2013 2014 2015 2016                         |
| In construction                                   |
| 40373 35587 31336 28240 26744                    |
| 3832 3310 2711 2371 2157                         |

| Number of fatal injuries, peop.                  |
| In all types of economic activity                |
| 2012 2013 2014 2015 2016                         |
| In construction                                   |
| 1820 1699 1456 1288 1290                         |
| 359 320 282 255 213                             |

| Injuries frequency rate, $K_n$                  |
| In all types of economic activity               |
| 2012 2013 2014 2015 2016                         |
| In construction                                   |
| 1.9 1.7 1.4 1.3 1.3                              |
| 2.5 2.2 1.9 1.8 1.8                            |

| Fatal injuries frequency rate, $K_{ncm}$        |
| In all types of economic activity               |
| 2012 2013 2014 2015 2016                         |
| In construction                                   |
| 0.084 0.08 0.067 0.062 0.062                    |
| 0.231 0.215 0.193 0.192 0.177                   |

Professional injury risks for construction workers are related to the specifics of work, including working at height (falling from roofs, scaffolds, stairs, etc.), earthwork (collapsing of trenches, operation of earth-moving equipment), use of hoisting machinery (cranes and builder’s hoists), use of electrical equipment and hand tools, as well as of transportation vehicles on a construction site. Construction sites are often messy and cluttered, what contributed to the occurring of accidents.

All the stages of construction works feature sources of dangerous and hazardous occupational factors, and therefore, the technogenic risks. At present, to assess the injury risks, a sufficient number of models have been elaborated, which use both apriori and aposteriori information on injuries.

In this paper, the assessment has been made of the occupational risks during buildings construction with consideration to the peculiarities of technological stages [2-7].

2. Objects and Methods of Research

Construction organisations of the Irkutsk Region were chosen as the objects of research. 5,974 construction organisations operate on the territory of the Irkutsk Region. The annual scope of the accommodation constructed by these organisations exceeds 50 thous. sq.m.

Traditionally the occupational risks are assessed as a combination of the probability of danger and seriousness of its consequences [3,4], i.e. quantitatively, using the following formula

\[ R = PW \] (1)
where \( R \) is the risk of injury; \( P \) is the probability of danger explained by the presence of dangerous and hazardous occupational factors; and \( W \) is the seriousness of consequences of danger.

In this paper, the quantitative criterion of the danger probability \( (P) \) was ranged in seven categories of the possibility of risk occurring (Table 2), and calculated as per method [3] using the formula of probability of cumulation of overlapping events.

**Table 2. Quantitative Criterion of Possibility of Risks.**

| Category of Possibility of Risks | Ranging Criterion | Description |
|----------------------------------|------------------|-------------|
| 1. Minimum                       | \( 0 < P < 1 \)   | Insufficient possibility. It is near to impossible to predict the occurrence of such a factor |
| 2. Low                           | \( 1 \leq P < 2 \) | The possibility remains low. Such conditions are formed in certain cases, but chances are very little |
| 3. Medium                        | \( 2 \leq P < 3 \) | The possibility is medium. The conditions for that may suddenly become reality |
| 4. Significant                   | \( 3 \leq P < 4 \) | The possibility is high. The conditions for that form quite regularly and (or) within a certain period of time |
| 5. Very significant              | \( 4 \leq P < 5 \) | The possibility is very high. The suitable conditions have been inevitably forming for quite a long period of time |
| 6. Unacceptable                  | \( 5 \leq P < 6 \) | The possibility is unacceptably high. The suitable conditions are sure to form during quite a long period of time |
| 7. Critical                      | \( 6 \leq P \leq 7 \) | The possibility is critical |

The quantitative criterion of the seriousness (gravity) of the danger consequences \( W \) as assessed as per the effect on workers, as well as the damage (harm) inflicted to the material-and-production environment. The seriousness criterion was also ranged in seven categories (Table 3).

**Table 3. Quantitative Criterion of Seriousness of the Danger Consequences.**

| Category of Seriousness of Consequences of Risks | Ranging Criterion | Description |
|--------------------------------------------------|------------------|-------------|
| 1. Acceptable                                    | \( 0 < W < 1 \)  | Almost no health risks. No impact on equipment or on the course of work |
| 2. Insignificant                                 | \( 1 \leq W < 2 \) | Little harm, micro-injuries. Insignificant impact on equipment or on the course of work |
| 3. Medium                                        | \( 2 \leq W < 3 \) | Insufficient impact on equipment or on the course of work |
| 4. Significant                                   | \( 3 \leq W < 4 \) | Significant harm, which requires long-term treatment |
| 5. Grave                                         | \( 4 \leq W < 5 \) | Accident with grave consequences leading to permanent disability |
| 6. Very grave                                    | \( 5 \leq W < 6 \) | Group accidents with grave consequences; fatal accident |
| 7. Catastrophic                                  | \( 6 \leq W \leq 7 \) | Several fatal accidents |
The total seriousness of consequences of risks $W$ was taken as equal to the maximum value for certain type of works.

The value of $R$, determined for the certain type of works, referred to risk category [3].

The risk categories include: minor ($R < 7$), low ($7 \leq R \leq 14$), medium ($14 \leq R < 28$), significant ($28 \leq R < 42$), high ($R \geq 42$).

The risks categorised as “insignificant” and “low” are considered to be acceptable and controlled in compliance with the measures existing within the organisations. The risks under the categories of “medium”, “significant” and “high” are considered to be unacceptable; and special measures need to be elaborated to control them depending on the risk criterion: reducing the impact of hazardous factors on the workers’ health and on the material-and-production environment, and taking preventive actions.

3. Results and Considerations

The risks values were calculated for all types of construction works, and the results were consolidated into Tab. 4.

Table 4. Determining Risks for Each Type of Works of the Main Stages of Buildings Construction.

| No. | Works Type                  | Dangerous and Hazardous Occupational Factors                  | P   | W   | Total |
|-----|-----------------------------|-------------------------------------------------------------|-----|-----|-------|
| 1   | land plot fencing           | - moving machines and mechanisms;                           | 2   | 4   | $P_1=0.93$ |
|     |                             | - high level of noise;                                       | 3   | 2   | $W_1=5$ |
|     |                             | - high level of infrasonic vibrations;                       | 2   | 1   | $R_1=32.5$ |
|     |                             | - sharp edges, burrs and coarseness on surfaces;             | 2   | 2   |       |
|     |                             | - impact of natural factors;                                 | 3   | 2   |       |
|     |                             | - falling of fencing                                        | 2   | 5   |       |
| 2   | demolition of the existing buildings | - moving machines and mechanisms;                          | 2   | 4   | $P_2=0.95$ |
|     |                             | - dust and gas pollution of air in the work zone;            | 2   | 1   | $W_2=6$ |
|     |                             | - high level of noise;                                       | 3   | 2   | $R_2=40.2$ |
|     |                             | - high level of infrasonic vibrations;                       | 2   | 1   |       |
|     |                             | - sharp edges, burrs and coarseness on surfaces;             | 1   | 2   |       |
|     |                             | - high level of vibrations;                                 | 2   | 2   |       |
|     |                             | - impact of natural factors;                                 | 3   | 2   |       |
|     |                             | - collapsing of facility parts on workers                    | 2   | 6   |       |
| 3   | clearing work               | - moving machines and mechanisms;                           | 2   | 4   | $P_3=0.91$ |
|     |                             | - dust and gas pollution of air in the work zone;            | 2   | 1   | $W_3=4$ |
|     |                             | - high level of noise;                                       | 3   | 2   | $R_3=25.6$ |
|     |                             | - high level of infrasonic vibrations;                       | 2   | 1   |       |
|     |                             | - sharp edges, burrs and coarseness on surfaces;             | 2   | 1   |       |
|     |                             | - impact of natural factors;                                 | 3   | 2   |       |
| 4   | rerouting of engineering networks | - sharp edges, burrs and coarseness on surfaces;             | 2   | 1   | $P_4=0.75$ |
|     |                             | - impact of natural factors;                                 | 3   | 2   | $W_4=5$ |
|     |                             | - workplace is high above the ground;                        | 2   | 5   | $R_4=26.2$ |
|     |                             | - electrical shock;                                          | 1   | 5   |       |
| 5   | laying of temporary roads   | - moving machines and mechanisms;                           | 2   | 4   | $P_5=0.7$ |
|     |                             | - high level of infrasonic vibrations;                       | 2   | 1   | $W_5=4$ |
|     |                             | - impact of natural factors;                                 | 3   | 2   | $R_5=19.8$ |
| 6   | marking out building’s axes | - impact of natural factors;                                 | 3   | 2   | $P_6=0.43$ |
|     |                             |                                                             |     |     | $W_6=2$ |
|     |                             |                                                             |     |     | $R_6=6$ |

Earthwork

| 7   | foundation excavation      | - moving machines and mechanisms;                           | 2   | 4   | $P_7=0.96$ |
|     |                             | - dust and gas pollution of air in the work zone;            | 1   | 1   | $W_7=5$ |
|     |                             | - high level of noise;                                       | 3   | 2   | $R_7=33.7$ |
|     |                             | - high level of infrasonic vibrations;                       | 2   | 1   |       |
| Process of Building Construction | | |
|-------------------------------|---|---|
| 8 trenching for communications | sharp edges, burrs and coarseness on surfaces | 2 |
| | workers falling into foundation trench | 2 |
| | toppling over of equipment | 2 |
| | clumps of soil flying off | 2 |
| | impact of natural factors | 3 |
| 9 foundation work | moving machines and mechanisms | 2 |
| | dust and gas pollution of air in the work zone | 1 |
| | high level of noise | 3 |
| | high level of infrasonic vibrations | 2 |
| | sharp edges, burrs and coarseness on surfaces | 2 |
| | workers falling into foundation trench | 2 |
| | toppling over of equipment | 2 |
| | clumps of soil flying off | 2 |
| | impact of natural factors | 3 |
| 10 erecting outer walls of buildings | moving machines and mechanisms | 2 |
| | high level of noise | 3 |
| | high level of infrasonic vibrations | 2 |
| | sharp edges, burrs and coarseness on surfaces | 2 |
| | workplace is high above the ground | 2 |
| | electrical shock | 2 |
| | high level of ultraviolet radiation | 2 |
| | explosion of gas bottle | 1 |
| | walls falling on workers | 2 |
| | impact of natural factors | 3 |
| 11 roof assembly | sharp edges, burrs and coarseness on surfaces | 2 |
| | workplace is high above the ground | 2 |
| | impact of natural factors | 3 |
| 12 assembly of internal partition walls | dust pollution of air in the work zone | 2 |
| | sharp edges, burrs and coarseness on surfaces | 2 |
| | structures crumbling down | 1 |
| 13 installation of metal-plastic windows | workplace is high above the ground | 2 |
| | dust pollution of air in the work zone | 1 |
| | high level of noise | 2 |
| | impact of natural factors | 3 |

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| Assembly of Buildings’ Engineering Equipment | | |
| Bringing Service Lines to Building | | |
| 14 water | dust and gas pollution of air in the work zone | 2 |
| | high level of noise | 3 |
| | high level of infrasonic vibrations | 2 |
| | impact of natural factors | 3 |
| 15 sewerage | dust and gas pollution of air in the work zone | 2 |
| | high level of noise | 3 |
| | high level of infrasonic vibrations | 2 |
| | impact of natural factors | 3 |
| 16 wiring | dust and gas pollution of air in the work zone | 1 |
| | high level of noise | 2 |
| | high level of infrasonic vibrations | 2 |
| | impact of natural factors | 3 |
| | electrical shock | 2 |
| Schedule number | Description | Risk Level |
|-----------------|-------------|------------|
| 17              | light wiring | 2          |
| 18              | laying of sewerage pipes | 2          |
| 19              | heating arrangement | 2          |
| 20              | arranging cold and hot water supply | 2          |
| 21              | arranging of floor cement screed | 2          |
| 22              | internal finishing works | 2          |
| 23              | external finishing of façade | 2          |
| 24              | performing repairs in public rooms | 2          |

- workplace is high above the ground; 2
- dust pollution of air in the work zone; 2
- sharp edges, burrs and coarseness on surfaces; 2
- electrical shock 2
- laying of temporary roads; 2
- trenching for communications; 2

All values within the range of 0 to 14 are acceptable and do not require mitigation measures. The values within the range of 14 to 28 correspond to the medium level of risks. The values exceeding 28 mark the high degree of risks and require special control and immediate elaboration of measures.

The chart data show that the works which require the introduction of risks control actions include:

a) site preparation stage (hereinafter the works are numbered as per Table 4):
   - land plot fencing;
   - demolition of the existing buildings;
   - clearing work;
   - rerouting of engineering networks;
   - laying of temporary roads;
   - foundation excavation;
   - trenching for communications;

b) construction process:
   - foundation work;
   - erecting outer walls of buildings;
   - roof assembly;
   - installation of metal-plastic windows;

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   - roof assembly;
   - installation of metal-plastic windows;

b) construction process:
   - foundation work;
   - erecting outer walls of buildings;
   - roof assembly;
   - installation of metal-plastic windows;
performed repairs in public rooms.

The most dangerous ones from among the listed works, i.e. those with the highest risk level, are the following:

- land plot fencing;
- demolition of the existing buildings;
- foundation excavation;
- trenching for communications;
- erecting outer walls of buildings; and
- wiring.

The high level of danger of these types of works as compared to other types is explained by high probability of risk with grave consequences causes by:

- moving machines, structures crumbling down;
- toppling over of equipment;
- structures crumbling down, falling from height; and
- risk of electrical shock.

4. Conclusion

Having performed a comparative assessment of professional risks at different stages of construction, we revealed that practically each type of works at each buildings construction stage features hazardous and dangerous occupational factors of technogenic character, the occurrence of which leads to most unfavourable consequences; high-danger works (such as works at the stages of construction site preparation, and in the direct construction process) are paid more attention with regard to Safety Regulations, than works on bringing electricity to a building, or on arranging its internal communications networks.

The assessment of the injuries risks during buildings construction shows that the most frequently occurring accidents of technogenic character are falling from height and electric injuries. Namely these risks require putting more focus on them and using individual approach when trying to minimize them.

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