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FEATURES OF THE PLACEMENT OF DUMPS DURING THE DEVELOPMENT OF UPLAND DEPOSITS: QUALITY MANAGEMENT IN INDUSTRIAL AND MANUFACTURING ENGINEERING

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A B S T R A C T

The purpose of this paper was to determine the specifics of the placement of dumps during the development of upland deposits and to develop recommendations to improve quality management in industrial and manufacturing engineering during the development of mineral resource deposits. As a result of the performed research, it was proved that the placement of dumps during the development of upland deposits requires more calculations for planning and ensuring stability than for dumps located on a horizontal surface. Assessment of the stability of dumps on the slope is a key component of ensuring the safety of dumps. One of the main factors affecting the stability of dumps on an inclined base is the bearing capacity of the base. When planning the area for the dump, the bearing capacity and strength of the base rocks are calculated. The article describes a method for determining the loading of the dump depending on the bearing capacity of the base of the dump of overburden rocks. The features of the placement of overburden dumps during the development of upland deposits are revealed, taking into account the planning of the base for the dump, depending on the strength characteristics of the base and the slope angle. The theoretical significance of the results obtained is due to their rethinking of the essence of the development of mineral resource deposits from the position of quality management in industrial and manufacturing engineering. The practical significance of the authors' developments is that the authors' methodology of determining the load of the dump depending on the carrying capacity of the base dump of overburden rocks will allow improving quality management in industrial and manufacturing engineering of the development of mineral resource deposits.

1. INTRODUCTION

This paper focuses on the scientific and practical problem of the quality of the development of mineral resource deposits. The placement of dumps of overburden rocks during the open development of upland deposits is one of the complex problems during

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storing of dumps of overburden rocks on mountain slopes.

The main requirements set to the placement of dumps on a mountain slope are as follows: sufficient capacity in case of small size of occupied land areas, minimal distance from the place of loading of rocks (overburden mines), placement on areas without mineral deposits at industrial scale, and absence of limitations for the development of mine works. A mandatory condition for the placement of dumps is ensuring production and environmental safety (Eremin, 2003; Khramtsov et al., 2018). Dumping is accompanied by the deformation of dumps, which depends on the qualities of overburden, in particular, lumpiness and humidity. Also, deformations in a dump depend on the engineering and geological features of the rock of dumps and their bases, such as:

- Presence of weak or heavily cracked rock at the base of dumps;
- Geometrical parameters of the slope on which the dump is moved;
- A small distance from the dump to the quarry;
- Level of crushing of rock;
- Natural division of rock into fractions and self-levelling of dump escarpments;
- Change in strength characteristics of rocks in the dump in time (resistance to the shift grows due to compaction or reduces during moisturising of rocks of the dump and the base);
- Emergence in water-bearing rocks of the dumps and their bases of pore pressure, which is an important factor in the development of various landslides.

Dumps are in a stable state (no landslides or going down) until there is a sufficient internal connection in their environment that forms them. A granular medium’s ability to keep slopes stable is defined by the total resistance to a shift.

In calculations of the stability of bulk materials, methods of determining the resistance to a shift are developed – as measures that characterise the possibility of shift deformations. These methods are mainly brought down to a comparison of all forces that strive toward causing movement and forces that hinder this, The main condition for the successful solution to a task on the stability of dumps consists in a clear understanding of the physical essence of resistance to the shift, which is a consequence of friction between separate factions of bulk material and between particles and a solid base of the dump.

During contact between bulk material and solid surface, each particle adjoining it, depending on various conditions, can move with a slide, rolling, and rotation. The total area of friction consists of many separate elements and is predetermined by the discreet character of the contact between bulk material and the base. Deformations of the shift of bulk material on the surface disseminate to a large depth due to the transfer of movement from one layer to another. The movement of separate particles in the near-contact zone takes place along the vector of relative speed and with various angles to it, which lead to the relative movement and mixing of particles. At that, the shift of the part is intermittent.

The mobility of the particles of bulk material is determined by the density of their packaging, the least value of which is at the border between a solid surface and bulk material. The farther from the surface, the larger the density of the packaging; at a certain distance from it, the density reaches a constant value.

Particles of bulk material in the border region form certain structural formations, in which they are in a certain equilibrium state. To move these particles to another state, it is necessary to make additional effort. As long as the total value of shearing is lower than the resistance force, there will be no relative movement of particles within this structural formation.

During the growth of shearing, there comes a moment when friction forces cannot oppose the particles’ moving to a new equilibrium state, which conforms to a higher level of acting forces. There appear new, more stable structural formations, which are characterised by higher density, an increased number of contacts, and better grip between the particles.

During structural transformations, a certain share of particles can – under the influence of tangential forces – perform rotational motion. Since the friction of rolling is much lower than the friction of sliding, the emergence of rotational motion leads to a sharp reduction of the total resistance force, as a result of which the shift of bulk material in relation to solid surface increases (displacement leap). At that, more border structural formations are destroyed against the background of an increase in shifting forces.

Thus, displacement leap leads to structural transformation in the near-contact zone, increasing the density of packaging of bulk material and reducing the particles' ability to perform rotational movement, which is replaced by sliding. The structure of bulk material becomes stronger and more resistant to shifting forces, which takes place due to an increase in the factual area of the contact between the material and the surface. Resistance grows up to a point that the material’s movement along the surface stops. Further increase in shifting forces (which is peculiar for the exploitation of dumps) leads to the recurrence of the cycle. At first, a gradual shift with elastic character takes place, and then – a breakdown and displacement leap, during which the transformation of the structure in the near contact zones continues with an increase in the density of packaging and resistance forces. Numerous repetition of the process leads to a limiting state when the transformation of the structure is finished, and only the possibility of sliding movement of bulk material along the surface remains.

An increase in shearing (tangential stresses) until the resistance limit leads to the next phase – the phase of continuous movement (sliding) along the slope with constant shear force. At the initial moment of sliding, the shear force equals the maximum value of resistance for the given condition of the given bulk material and the underlying surface. At that, the following types of relative motion of bulk material along the slope are possible (Kozhogulov et al., 2016):

- Without any visual changes in the structure of near contact zome that formed as a result of the first phase;
- With the emergence of a border layer of bulk material with a certain gradient of relative speed as to the depth;
- With the emergence of a layer of material with zero relative speed near a solid surface.

The second type of motion is the most frequent one; it appears with normal pressures and roughnesses of underlying surface, which fluctuate in a rather wide range. The relative speed of particles adjacent to the underlying surface is smaller than the speed of remote particles. With distance from the surface, the speed of particles grows up to a certain constant value, and the velocity gradient between separate layers reduces from a certain maximum value at the border down to zero. Assessment of the stability of a dump is a task on the balance of a body on an inclined surface under the influence of gravity and resistance. The stability of the dump is defined by force. The slope is in balance (rest) if resistance forces at the border of the division of bulk material are sufficient for the neutralisation of shear forces (Kozhogulov et al., 2021; Kozhogulov et al., 2016):

$$\tau_n = \tau_o + P_n tg\varphi$$

where τ_0- effective grip force, φ — the angle of internal friction, P_n — effective normal pressure.

Among the physical properties of bulk material, resistance to shift is most complex and depends on many factors. The above formula is approximate but has a sufficient degree of precision for practical purposes. The values τ_0 and φ in the given case depend on the density, snowboundness, and humidity of bulk material and can change within a large range even for the same material. The body of the dump consists of a range of layers: for each layer, a margin line at which this formula works can be built.

The resistance force for the entire dump is calculated with the use of several margin lines. Their combination at one scale allows determining the possibility of drawing an average margin line for the entire dump. The precision of the calculation of the stability of the dump largely depends on the precision of the determination of shift resistance of the bulk material of which the body of the dump consists.

Shear forces in the dump at a mountain slope and the motion of dump mass are predetermined by gravity, the pressure of water that filters through the dump, and occasional shaking during blasting operations in the quarry when shear resistance in any dimension of the dump turns to be sufficient for neutralisation of these forces. Melting and moisturising of bulk material during the spring and summer period significantly reduce the value of shear resistance, the seasonal fluctuations of which in the body of the dump are rather difficult to study but must be researchers to solve the task on stability.

Thus, the issues of quality management in industrial and manufacturing engineering were studied in detail in the existing literature, but the specifics of upland deposits have not been sufficiently studied and are unclear. This is a literature gap, which is filled by this paper. The above predetermined the importance of this research and its goal, which is connected with the identification of the features of the placement of dumps during the development of upland deposits and the development of recommendations to improve quality management in industrial and manufacturing engineering of the development of mineral resource deposits.

This goal is achieved by solving two research tasks. The first task is to determine the level of risk of the collapse of dumps and the value of the stability of dumps for the quality of industrial and manufacturing engineering during the development of upland deposits. The second task consists in specifying the methodological issues of planning and ensuring the stability of dumps during quality management in industrial and manufacturing engineering. The paper's originality consists in the clarification of the features of the quality of developing upland deposits and the offer of the novel methodological approach to quality management in industrial and manufacturing engineering of the development of mineral resource deposits through the stability of dumps.

2. LITERATURE REVIEW

This paper is based on the scientific provisions of the theory of the development of deposits, which are reflected in the following published works. Ukey and Pardeshi (2023) substantiated – by the example of semi-arid upland deccan traps in India – the high geoscientific and geoheritage value of waterfall calc tufa. Cai et al. (2023) pointed to the importance of monitoring, calculation, and simulation methods for ground subsidence induced by coal and the development of mineral resource deposits.

Wang et al. (2023) proved – by the example of Lijiahao Coal Mine – the dynamic evolution law of fissures in shallow-buried and short-distance coal seam mining. Gao et al. (2023) substantiated the mechanical behaviour of coal under true triaxial loading test connecting the effect of excavation- and mining-induced disturbances.

This paper focuses on the issues of assessment and quality management of industrial and manufacturing engineering, which is the research topic of this study. The issues of quality management of industrial and manufacturing engineering were studied in detail and reflected in multiple published works by such authors as Cardoso et al. (2022), Gomes and Cardoso (2020), Krebish and Berberoglu (2020), Shcherban et al. (2023), and Yüksel and Ersöz (2023).

Qi et al. (2023), Xie et al. (2023), and Zhang et al. (2023) stated that dumps located on a horizontal surface have a low risk of collapse. This means that for dumps that are located on a horizontal surface, the stability of dumps is insignificant to the quality of industrial and manufacturing engineering. At that, the level of risk of collapse of dumps and the value of the stability of dumps for the quality of industrial and manufacturing engineering during the development of upland deposits have been not sufficiently studied in the literature, which is a literature gap.

Content analysis of the existing literature - Adeigbe and Rahaman (2020), and Azev and Popov (2020) – also showed that quality management in industrial and manufacturing engineering of the development of mineral resource deposits is conducted based on the following methods. 1st method: environmental management of quality. This method is presented by Yang et al. (2023); the authors suggested assessing the ecological environment quality in rare earth mining areas based on improved RSEI.

In their turn, Yang et al. (2022) developed – by the example of Dongguashan (China) – the methodological recommendations for quality evaluation of wasteless mining based on intuitionistic fuzzy set and VIKOR. Yang et al. (2021) substantiated such criterion of the quality of the development of mineral resource deposits as urban and rural high-quality development based on ecological restoration of coal mining subsidence areas. Christiansen et al. (2022) suggested evaluating the quality of environmental baselines for deep seabed mining. Rezmerița et al. (2022) substantiated the necessity for urban air quality monitoring in a decarbonization context, with a case study of a traditional coal mining area, Petroșani, Romania. Chaulya et al. (2022) substantiated – by the example of an international heritage site in India – the air quality impact assessment and management of mining activities.

2nd method: soil exploration. Delgado et al. (2022) recommended assessing soil quality from areas of great mining interest using the grey clustering method. Guo et al. (2022) suggested analysing the interaction between vegetation and soil quality in coal mining subsidence areas.

Du et al. (2022) considered the contrast between an increase in quantity or a quality improvement, proving, by the example of China, that soil pollution control can promote green innovation in China's industrial and mining enterprises. Dai et al. (2022) offered a monitoring system for air quality and soil environment in mining areas based on the Internet of Things. Liu et al. (2021) proved – on the example of Loess Plateau in Northern Shaanxi Province – the necessity for consideration of physicochemical properties and quality assessment in the coal mining area.

3rd method: automatization for labour safety. In particular, this method involves the remote development of deposits of mineral resources with the help of robotised systems, manipulators, and other smart technologies. Rafiei et al. (2022) created an augmented remote operating system for scaling in smart mining applications and the development of mineral resource deposits.

Zhang et al. (2020) offered methodological recommendations for intelligent monitoring and simulation of the whole life cycle of the coal mining process and water quantity and quality in coal and water coordinated development under large data. Yang et al. (2019) proved mine water quality variation during the overhaul of fully mechanized mining equipment in Shenfu mining area (China).

Thus, the performed literature review showed that the methodological issues of planning and support of the stability of dumps during quality management in industrial and manufacturing engineering have not been sufficiently elaborated, which is another literature gap. Certain issues of the stability of dumps during the development of deposits were disclosed in scholarly works. Thus, Zelayeva et al. (2021) discovered prerequisites for creating a bucket to improve the quality of selective coal mining.

Ren et al. (2021) proved the influence of management on vegetation restoration in coal waste dumps after reclamation in semi-arid mining areas, examining ShengLi coalfield in Inner Mongolia, China. Bi et al. (2021) substantiated the shifts in arbuscular mycorrhizal fungal community composition and edaphic variables during the reclamation chronosequence of an open-cast coal mining dump.

Wang et al. (2021) proved the existence of shifts in the composition and function of soil fungal communities and edaphic properties during the reclamation chronosequence of an open-cast coal mining dump. Ribeiro and Flores (2021) proved the occurrence, leaching, and mobility of major and trace elements in a coal mining waste dump, based on the case of Douro Coalfield, Portugal.

To fill the discovered gaps, we specified the features of the placement of dumps during the development of upland deposits from the position of stability as a component of quality and developed scientific and methodological issues of quality management in industrial and manufacturing engineering during the extraction of mineral resources through the provision of the stability of dumps during the development of upland deposits.

3. METHODOLOGY

3.1. Order of the research

The following two tasks are solved in this research. 1st task: to determine the level of risk of collapse of dumps and the value of the stability of dumps for the quality of industrial and manufacturing engineering during the development of upland deposits. To solve this task, we identify the dependence of the area of the dump's base on the pressure of stored overburden rocks. We also determine the dependence of the value of the carrying capacity of the base dump on the tensile strength of the soil.

2nd task: to specify the methodological issues of planning and ensuring the stability of dumps during quality management in industrial and manufacturing engineering. To solve this task, we determine the dependence of the area of the dump's base on the dump's pressure on the base. We assess the influence of the carrying capacity of the base on the dump's area with an inclined base. We find the height of the dump depending on the strength properties of the base. We identify the value of the coefficient of stability of surface sediments on the slope and the carrying capacity of the base.

3.2. Methodological basis for measuring and management of risks for the stability of dump

The main factor that influences the stability of a dump is the relief of the base and the strength properties of the rock and base. The relief also defines the character of surface runoff. The hydrogeological conditions of the slope determine its humidity, the growth of which leads to deformations of the dump and its base due to hydrodynamic or hydrostatic pressure of underground waters (Popov et al., 2010; Kozhogulov et al., 2021).

One of the factors that determine the secure placement of dumps is the climate of the area, atmospheric precipitation, snowboundness, and iciness, even daily air temperature (Agafonov & Porshneva, 2020; Kadyralieva, 2013; Asilova & Usenov, 2008). Negative temperatures lead to the iciness of the rock of the dump, and following melting leads to an increase in the initial humidity by 10-15%. The stability of dumps depends on the carrying capacity of the rock base, i.e., the limit load that soil can withstand at the set area without destruction.

The carrying capacity of the base depends on the features of overburden rocks and the level of groundwater, and is calculated according to the following formula (FSUE CDP, 2006):

$$F \leq \gamma_c F_u / \gamma_n$$

where F- equivalent calculation load on the base;
F_u – the strength of marginal resistance (equivalent base load limit); $F_u = Q/S$, where Q – the weight of dump weight and S - an area of the base dump;
γ_n – coefficient of reliability, which is accepted as 1.2, 1.15, and 1.10.

The pressure of the dump on the inclined base is calculated according to the following formula:

$$P = Qcos\alpha / S$$

where α- angle of slope.

Technological factors that influence the stability of dumps include the height and configuration of dump slopes, the length and speed of motion of the dump front, and the rate of backfilling of the dump (Kadyralieva and Kozhogulov, 2022; Shpakov and Yunakov, 2018). To determine the maximum area of the base at which the stability of the dump is preserved, it is necessary to find the pressure of dump masses on the base and the conditions at which this base is not deformed. The following conditions are accepted during the calculations (Table 1).

Table 1. Conditions during calculations

No.	Parameter	Measuring unit	Value
1	The volume of the dump	m^3	76,923,077
2	Weight of the dump	t	$90*10^6$

Source: Authors.

The area of the base for the dump was set from $5*10^5$ m^2 to $43*10^5$ m^2 with a step of $2*10^5$ m^2.

To calculate the carrying capacity of the base for the dump, the reliability coefficient was accepted as 1.1 (γ_n) and γ_c=0.8.

Tensile strength of the rock base for the dump during compression $\sigma_{сж}$=175 MPa; $\sigma_{сж}$=75 MPa, $\sigma_{сж}$=30 MPa. To assess the influence of the angle of the slope on the choice of parameters of the area for the base on the slope, the angle of the slope was set from 0^0 to 30^0 with a step of 5^0 (Figure 1).

a) b)

Figure 1. Placement of overburden rocks, a) dumps on the horizontal surface (photo by Vyacheslav Bukharov), b) on the inclined surface (photo from Shpakov and Yunakov, 2018).

4. RESULTS

4.1. Determination of the level of risk of collapse of dumps and the role of stability of dumps for the quality of industrial and manufacturing engineering during the development of upland deposits

To solve the first task of this research, we determine the level of the risk of collapse of dumps and the role of stability of dumps for the quality of industrial and manufacturing engineering during the development of upland deposits. The results of calculations with the set values of the weight of overburden rocks and qualities of the base of the dump are given in Figures 2, 3, and 4 and Tables 1 and 2.

We performed an analysis of the data of the calculation of the area of the dump's base, located on the horizontal surface, which is the minimum for forming a dump with the known pressure on the dump. We revealed the area of stored overburden rocks with the strength of overburden rocks equalling 30 MPa, which equals $30*10^5$ m^2 and is shown in Figure 2.

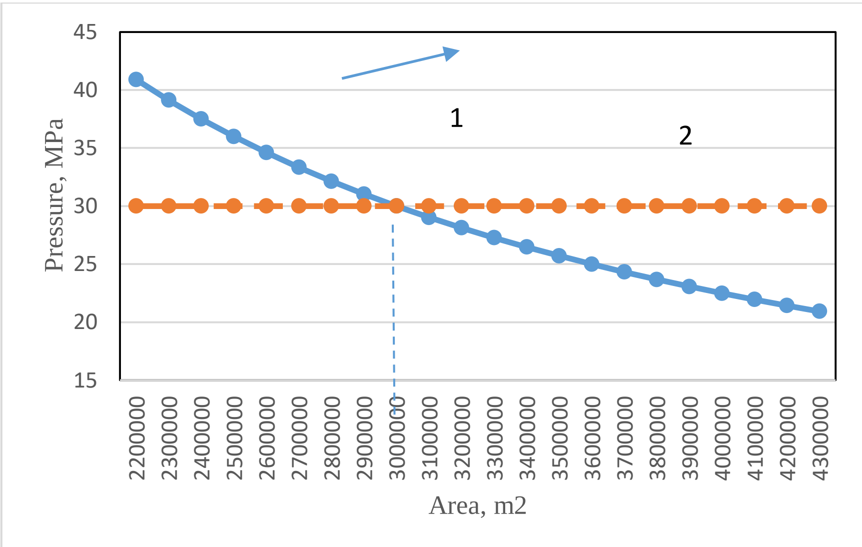

Figure 2. Dependence of the area of the dump's base on the pressure of stored overburden rocks.

1- the pressure of the dump on the base with the known area and weight of overburden rocks, 2- the value of base compression strength.

It was revealed that a further increase in the volume leads to the loss of the stability of the base.

To assess the dependence of base compression strength on the carrying capacity, we performed calculations. The results of the analysis of these calculations are given in Figure 3.

We assessed the influence of tensile strength on the carrying capacity of the base and revealed that, with equal values of the volume and area of the dump, the values of carrying capacity grow by 2.5 times for weakly fractured rock and by 6 times for strong rock, compared to the heavily fractured base. These values have been also confirmed for areas of the base of the dump depending on the strength of the rock.

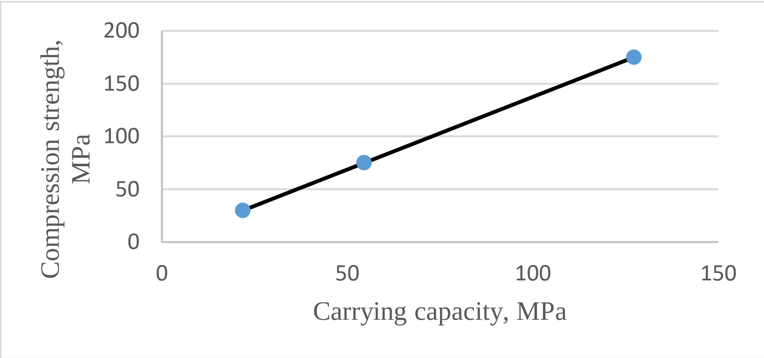

Figure 3. Dependence of the value of the carrying capacity of the base dump on the soil's tensile strength.

4.2. Methodological issues of planning and ensuring the stability of dumps during quality management in industrial and manufacturing engineering

To solve the second task of this research, we specified the methodological issues of planning and ensuring the stability of dumps during quality management in industrial and manufacturing engineering. To determine the area of the dump's base with the set values of tensile strength, we performed calculations, which results are shown in Figure 4.

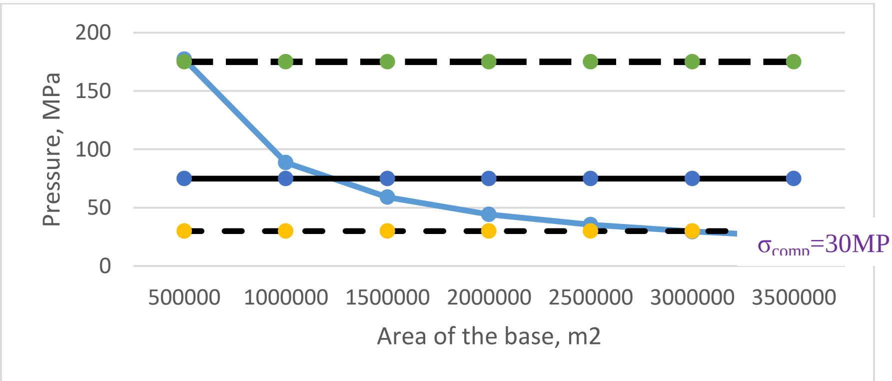

Figure 4. Dependent of the area of the dump's base on the dump's pressure on the base with the set values of compression strength limits

Analysis of the results obtained showed that dumps for strong rock can be placed at the area of at least $5*10^5$ m^2, on a weakly fractured base on the area of at least $12.5*10^5$ m^2, and a heavily fractured base – on the area of at least $30*10^5$ m^2 with the equal volume of overburden rocks.

Analysis of the results of the calculation of the influence of the angle of the slope on the area of the base for the dump is given in Table 2. Table 2 shows the dependence of the values of the dump's pressure on the base (***P***) and the carrying capacity of the base (***F***) on the angle of the slope with the set area of the dump.

Table 2. Influence of the carrying capacity of the base on the dump's area with an inclined base.

S, m^2	***Slope angle, degrees***									
	5		***10***		***15***		***20***		***30***	
	P, MPa	***F, MPa***	***P, MPa***	***F, MPa***	***P, MPa***	***F, MPa***	***P, MPa***	***F, MPa***	***P, MPa***	***F, MPa***
$5*10^5$	179	130	177	129	174	126	169	123	156	113.37
$10*10^5$	89.66	65.21	88.63	64.46	86.93	63.22	84.57	61.51	77.94	56.69
$15*10^5$	59.77	43.47	59.09	42.97	57.96	42.15	56.38	41.00	51.96	37.79
$20*10^5$	44.83	32.60	44.32	32.23	43.47	31.61	42.29	30.75	38.97	28.34
$25*10^5$	35.86	26.08	35.45	25.78	34.77	25.29	33.83	24.60	31.18	22.67
$30*10^5$	29.89	21.74	29.54	21.49	28.98	21.07	28.19	20.50	25.98	18.90
$35*10^5$	25.62	18.63	25.32	18.42	24.84	18.06	24.16	17.57	22.27	16.20

It was revealed that storing overburden rocks on an inclined surface up to 20 degrees slightly affects the carrying capacity of the base and dump pressure on the base. If the values of the angle of the slope are above 20 degrees, it is necessary to increase the area of the base for the dump.

To determine the ultimate height of the dump with the set values of the base's strength, we performed the calculation, the analysis of the results of which is shown in Table 3.

Table 3. Determination of the height of the dump depending on the strength qualities of the base.

σ, MPa	**S, m^2**	**h, m**
175	$5*10^5$	136
75	$12*10^5$	56
30	$30*10^5$	22

where h – the height of the dump.

We assessed the influence of the strength of the dump's base on its height. It was revealed that it is possible to place a dump with a height of up to 136 meters on strong rocks; up to 56 meters – on weakly fractured rocks; and up to 22 meters – on heavily fractured rocks, with an equal volume of overburden rocks.

To check the estimated data, the calculations of the coefficient of stability of surface sediments on a slope and the carrying capacity of the base for a dump were performed at a deposit in Kyrgyzstan. The results of the calculation are shown in Table 4.

Table 4. Values of the coefficient of stability of surface sediments on a slope and the carrying capacity of the base.

Object	Area for the dump, m^3	The angle of the slope, degrees	Coefficient of stability	The pressure of the dump on the base F, MPa
Low-grade ore store	140,484	17	1.52	37.90
Off-balance ore store	118,675	11	2.39	41.20
Dump 1				
Section 1	501,796	19	1.27	52.12
Section 2		15	1.74	
Section 3		15	1.74	
Dump 2				
Section 4	296,398	20	1.28	74.29
Section 5		5	5.32	
Dump 3				
Section 6	65,815	20	1.28	58.92
Section 7		5	3.797	
Section 8		11	5.32	

Based on the analysis of the results obtained, it was determined that on the slopes of the steepness of 20^0, the soils of the base for the dump on the slope are in the state of ultimate equilibrium and that it is necessary to increase the area of the base for dump 2 at the selected section, which confirms the calculated data.

To ensure the safety of works during the formation of dumps, we identified the carrying capacity of the base for the dump. The carrying capacity of the base was determined for the total weight of the dump without division into tiers. Since the calculated resistance of rubbly and grus soils of the base for the dump is 60 MPa (Sorochan, 1985), the area of the base for **dump 2** should be increased in the selected section.

5. DISCUSSION

This paper contributes to the literature through the development of scientific provisions of the theory of the development of deposits, continuing the discussion in the works by Cai et al. (2023), Gao et al. (2023), Ukey and Pardeshi (2023), and Wang et al. (2023). The scientific novelty of the results obtained is shown in Table 5, in comparison with the existing works.

As shown in Table 5, unlike Qi et al. (2023), Xie et al. (2023), and Zhang et al. (2023), during the development of upland deposits, dumps are peculiar for a high risk of collapse. There was formed an evidence base, which proved with facts the scientific provisions of the works of Bi et al. (2021), Ren et al. (2021), Ribeiro and Flores (2021), Wang et al. (2021), and Zelayeva et al. (2021) and allowed substantiating that, unlike dumps that are located on a horizontal surface, during the development of upland deposits, the stability of dumps is critically important and determines the quality of industrial and manufacturing engineering.

Also, the authors' scientific developments strengthened the methodological tools of planning and ensuring the stability of dumps during quality management in industrial and manufacturing engineering. It is suggested that quality management in industrial and manufacturing engineering be performed with the help of a new – proprietary – method of determining the dump's load depending on the carrying capacity of the base dump of overburden rocks.

The proprietary approach includes calculation formulas and calculation parameters, as well as an analysis of the results obtained. The maximum area allocated for the dump has been established, depending on the volume of the rocks being shipped and the bearing capacity of the base. The maximum slope angle affecting the bearing capacity of the blade base has been determined, more than which the area of the blade base should be increased. The influence of the compressive strength limit on the height of the blade at the calculated base area is estimated. The dependence of the area of the base of the dump on its pressure on the base at the values of compressive strength for strong, weakly fractured and strongly fractured rocks is revealed.

Table 5. The scientific novelty of the results obtained compared to the existing works

Sphere of comparison	Provisions of existing literature	New scientific results obtained in this paper
Level of the risk of collapse of dumps (value of the stability of dumps for the quality of industrial and manufacturing engineering)	Dumps located on the horizontal surface are peculiar for a low risk of collapse (the stability of dumps is insignificant for the quality of industrial and manufacturing engineering) (Qi et al., 2023; Xie et al., 2023; Zhang et al., 2023)	During the development of upland deposits, dumps are peculiar for a high risk of collapse (stability of dumps is critically important and defines the quality of industrial and manufacturing engineering)
Methodological tools for planning and ensuring the stability of dumps during quality management in industrial and manufacturing engineering	Quality management in industrial and manufacturing engineering is performed based on the following methods: • Environmental management of the quality (Chaulya et al., 2022; Christiansen et al., 2022; Rezmerița et al., 2022; Yang et al., 2021; Yang et al., 2022; Yang et al., 2023); • Soil exploration Dai et al., 2022; Delgado et al., 2022; Du et al., 2022; Guo et al., 2022; Liu et al., 2021); • Automatization (Rafiei et al., 2022; Yang et al., 2019; Zhang et al., 2020).	The authors' methodology of determining the load of the dump depending on the carrying capacity of the base dump of overburden rocks was developed to improve the quality management in industrial and manufacturing engineering

Source: Authors.

It was substantiated that the recommended approach is preferable for the quality of the management of industrial and manufacturing engineering during the development of upland deposits of mineral resources, to which a limited effect is applied by the existing methods, such as environmental management of the quality (unlike Chaulya et al., 2022; Christiansen et al., 2022; Rezmerița et al., 2022; Yang et al., 2021; Yang et al., 2022; Yang et al., 2023); soil exploration (unlike Dai et al., 2022; Delgado et al., 2022; Du et al., 2022; Guo et al., 2022; Liu et al., 2021); automatization (unlike Rafiei et al., 2022; Yang et al., 2019; Zhang et al., 2020).

Thus, an increase in scientific knowledge was ensured by proving the specifics of upland deposits of mineral resources, which, as was shown in this paper, differ from deposits that are located on a horizontal surface. The theoretical value of this new approach is that it allows for the fullest, most precise, and most correct determination of the quality of development of upland deposits of mineral resources. The applied value of this approach lies in its allowing the improvement of the practice of quality management in industrial and manufacturing engineering during the development of upland deposits of mineral resources.

6. CONCLUSIONS

The main conclusion of this work is that in addition to the standard criteria of the quality of the development of mineral resource deposits – such as production waste, consequences for soil, and labour safety – upland deposits have another criterion of the quality: stability of dumps. Therefore, quality management in industrial and manufacturing engineering during the development of upland deposits of mineral resources must include measures to ensure the stability of dumps for their safe placement. This research allowed obtaining the following results:

- Specifics of the placement of dumps during the development of upland deposits in the open way were revealed: relief of the base and strength properties of rock; climate of the area and hydrogeological conditions, bearing capacity of the dump's base and geometric characteristics.
- The influence of the strength of rock on the bearing capacity and height of the dump, angle of slope and area of the base for the dump was assessed.
- It was found that during the placement of dumps of the volume up to $77*10^5$ m^3 on a weak base, the stability of the base is ensured on the area that exceeds $30*10^5$ m^2.

- The dependence of the area of the dump's base on the strength of the rock base was determined. A weakly fractured base requires a 2.5 times larger area compared to strong rock; 6 times larger – for a strongly fractured base, accordingly.

The theoretical significance of the results obtained lies in their rethinking the essence of the development of deposits of mineral resources from the position of quality management in industrial and manufacturing engineering. Due to this, the paper opened a new view of the study of upland deposits of mineral resources – through the lens of the stability of dumps, which is substantiated as a serious risk and decisive factor of quality.

The practical significance of the authors' developments is that the authors' methodology of determining the load of dumps depending on the carrying capacity of the base of the dump of overburden rocks will allow improving quality management in industrial and manufacturing engineering in the development of mineral resource deposits. The managerial significance of the new methodology lies in its allowing increasing effectiveness in managing the risks of the quality of industrial and manufacturing engineering of the development of mineral resource deposits.

The developed methodological recommendations will be useful during the development of upland deposits of mineral resources in countries which experience is covered in the paper's literature review – Kyrgyzstan, Russia, China, and India. Romania, and Portugal – and in other countries in which such deposits are developed. To sum up, it should be noted that a limitation of the results obtained is their theoretical and methodological direction. Thus, to deal with this limitation, future studies in continuation of the scientific discussion should approbate the developed methodology by the example of the existing deposits of mineral resources.

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