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Development of Effective and Safe Methods of Underground Mining of Inclined ore Deposits Using Artificial Landslide Water-Rock Streams to Deliver Broken ore

Bakirov G.X., KoraboevKh.A.

Lecturer of the Almalyk branch of the Tashkent State Technical University named after Islam KarimovAlmalyk, Uzbekistan
Engineer surveyor State unitary enterprise "State design research institute of engineering survey and construction, geoinformatics of the urban planning cadastre", Tashkent,Uzbekistan

ABSTRACT: Methods using artificial landslide water-rock streams are offered for development of inclined (15-35°) ore deposits. The idea of this technology is that a powerful water stream is directed at bulk broken ore lying on the inclined soil of the chamber. The interaction of the water stream with the bulk ore results in a underground landslide water-rock stream which moves down by gravity to a ore accepting working. After outflow of water to a water collector, the dewatered ore mass is loaded into haul trucks and delivered to the main ore chute or shaft.

KEY WORDS: Mining method, inclined deposit, shaft landslide water-rock stream, landslide delivery, efficiency.

I.INTRODUCTION

Some ore deposits, for example, the Khondiza deposit in the Republic of Uzbekistan are represented by a variety of separate sheetlike inclined deposits located at different depths.

The main problem which does not allow to efficiently develop such inclined ore deposits is that in order to ensure access of drill rigs and loaders to sub-levels, and relocate broken ore from sub-levels to the haulage level using large-size haul trucks it is required to develop cascades of spiral entries (ramps) with big (≥ 25 m^2) section and big length (600 – 1,000 m) at flanks of blocks (panels).

In order to reduce the volume of pre-production mining works it is suggested to deliver broken ore using artificial landslide water-rock streams.

II.METHODS OF DEVELOPMENT OF INCLINED ORE DEPOSITS USING LANDSLIDE DELIVERY OF ORE

A. Method of development of inclined deposits with moderate thickness.

The method of development with arrangement of chambers upwards and landslide delivery of ore with free-flowing water-rock streams was suggested to develop inclined ore deposits with moderate thickness (Fig.1).

The essence of this method is as follows. The developed panel (block) upwards the ore deposit is divided into extraction chambers, and pillars are left between chambers. A haulage gate (1) is made in the lower part of the panel. An air gate (2) is made in the upper part of the panel. Inclined drilling rooms (3) are made between the haulage gate (1) and the air gate (2) along the axis of extraction chambers upwards the ore deposit. Ore collection workings (4) are made from the haulage gate (1) in the gate with extraction chambers. A dismountable water collection tank (5) is erected in the air gate (2) by sealing the area of this gate between inclined drilling workings (3), where folding doors which are opened outside are installed. A water collector (6) is erected in the flank of the panel from the haulage gate

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(1) by making a blind inclined working. A special inclined ventilation and manway working (7) is made in the same flank near the water collector (6) in order to ensure the closed water supply circuit.

A distinctive feature of the proposed method is that development of chambers must be performed in parallel one by one with simultaneous preparation of pillars of hexagonal shape with elongated sides upwards the ore deposit. The ore is broken in a chamber by blasting a fan-shaped drilling pattern drilled from inclined drilling workings (3) at an angle of 45° relative to the axis of these workings. At that, in order to make inter-chamber pillars in places of cutting of a chain pillar, fans of drill holes are drilled to the middle of this chain pillar at an angle of 45° relative to its axis which allows to break ore in slots and discard to the developed chamber area.
Dismountable water-guiing partitions (8) are installed after formation of bulk ore in the chamber soil. Water is fed to the developed chamber area onto the bulk broken ore through the sealed area of the air gate (2) and the inclined drilling working (3). An unbound water-rock stream is formed as a result of interaction of the water stream with bulk ore which under the action of gravitational force along the inclined chamber soil is moved downwards to the ore collection working (4) where the ore mass brought with the water-rock stream stops. Further, the "used" water arrives in the water collector (6) after passing drainage units (9) already clear of ore fines. As the water outflows from the ore mass brought with the stream it is delivered through the haulage gate (1) to the main ore chute. Then, the ore and wash-out of the ore bulk in the chamber is repeated using the above-described scheme. At that, water is fed to the collection tank (5) from the water collector (6) after ore breaking in the chamber using a pump installed in the pump chamber (10) along pipelines laid in the ventilation and manway working (7) and the air gate (2).

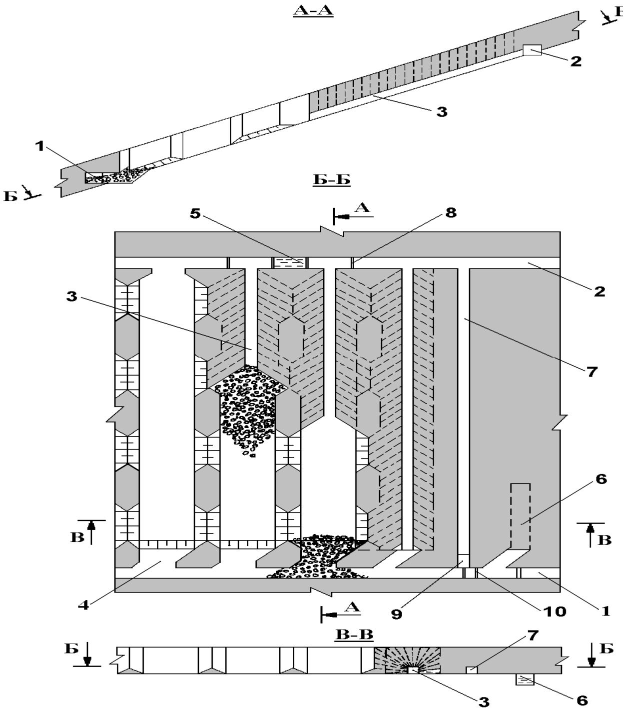

Fig. 1- Method of development with arrangement of chambers upwards and landslide delivery of broken ore
Trimming of pillars directed with their long side at the rise will allow to ensure big stability of the pillar-roof system in inclined deposits, as elongated inter-chamber pillars resist the shear more reliably in the area of contact with the soil and the roof, aspecially when these inclined contancts are represented by surfaces with insignificant adhesion with the body of pillars. Besides, delivery of ore by shaft landslide streams excludes the presence of people in the open developed area of chambers.
Taking into account safe conditions of mining operations and high efficiency of the method with arrangement of chambers upwards and delivery of the broken ore through shaft water-rock streamts it may become a decent alternative to methods of development using large-size self-propelled drilling and LHD equipment used for extraction of chamber reserves.

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B. The method of development of thin inclined deposits.

We suggest to use the method of landslide delivery of ore in combination with scraper delivery and water jet wash-out of ore to develop low-grade and ROM ore in thin inclined ore deposits.
This method is as follows (Fig.2).

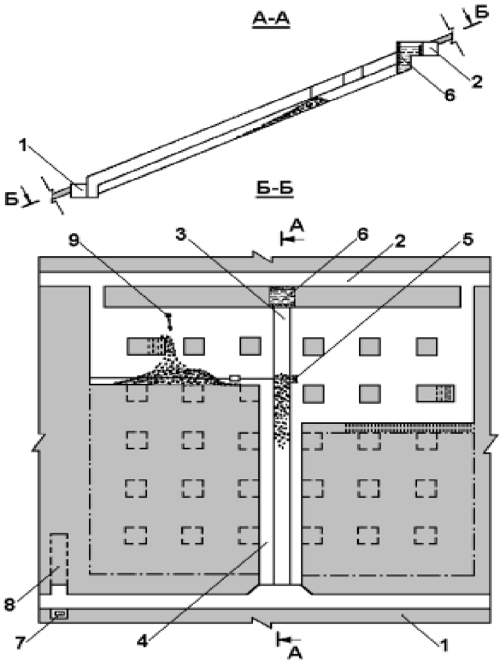

Fig. 2 - Method of development of thin inclined deposits using the landslide delivery in combination with scraper delivery and water jet wash-out of ore

The developed thin inclined deposit is divided into blocks consisting of two adjacent panels (areas) which in their turn are divided into extraction chambers along strike of the ore body along the whole width of adjacent panels. The haulage gate (1) goes in the lower part of the block. The air gate (2) is found in the upper part of the block. The haulage raise working(3) is made between the air gate (2) and the haulage gate (1) on the boundary of adjacent panels with a deepening in the underlying rock of half of the height of its section, and then it is expanded to 5-6 m. At that, passages (4) at the level of soil of the deposit in the form of rectangular rock benches are made in side walls of the haulage raise working (3). Scraper hoists (5) are installed in the passages (4) on sledges with a horizontal platform relative to the incline of the passages (4), and the movement is performed using a special mounting hoist. The main water collector (6) is arranged at the entry to the haulage raise working (3) by means of heading from the air gate at the level of its soil, the chamber towards the haulage inclined working which are met on the boundary of the panel pillar and adjacent pillars, at that a concrete partition is made in the side wall of the air gate which divides it from the chamber, and a shutter door is installed in the place where the chamber meets with the inclined haulage working at the level of its soil.

A pump chamber (7) and a water collector (8) are installed in the lower part of adjacent panels in the flank of the block in side walls of the haulage gate (1).

Cleanup works are commenced after completion of the indicated preparatory works.

Cleanup works are performed simultaneously in both adjacent panels whereas one panel is cleaned up a little bit in advance.
Ore is broken by descending layers with a thickness of 1.5-2.0 m. Drilling of drill holes with small diameter is performed with lgith truck-or sledge-mounted mobile equipment. Scraping of ore to the haulage raise working (3) is

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performed after breaking a layer of ore in the chamber. At that, scraper hoists (5) are installed at the entry to the faceine, and scraping of the broken ore is performed after breaking a layer of ore. Further, as the sufficient volume of bulk broken ore is accumulated in the soil of the haulage raise working (3), the collection tank (6) is filled with water and it is released to this haulage raise working. A shaft landslide water-rock stream is formed as a result of interaction of water streams with bulk ore, and it moves by gravity along the inclined soil of the haulage raise working (3) downwards to the haulage gate (1) where after outflow of the "used" water the broken ore is transported to the main ore chute with the help of self-propelled LHD equipment.
Interchamber pillars (ICP) are formed to support the roof as ore reserves are extracted from adjacent panels. The remaining broken ore is washed out between ICP using low-pressure water jets (9) connected with the pump using a flexible water pipeline. Water jets (9) are installed in the upper-lying chamber. Scraping of the broken ore to the haulage raise working (3) is performed after wash-out of the ore to the lower chamber and outflow of the "used" water, and from there the ore is delivered to the haulage gate (1) using the above-mentioned scheme and the shaft landslide water-rock stream, and then using small-size self-propelled LHD equipment to the main ore chute.
Thus, all reserves are mined by alternating the extraction of the main champer reserves using the scraper equipment and landslide delivery of ore with water jet cleaning of the chamber soil.
Due to the commencement of development and establishment of a new highly efficient technology of development of inclined ore deposits with the help of landslide delivery of ore there are not so many works on calculation of the optimal water consumption for preparation and movement of shaft landslide water-rock streams possessing the maximum haulage capacity under different conditions of application.
The work [4] contains a semi-empirical formula for determination of the specific water consumption depending on the working incline angle (landslide stream bed) and the swell factor of the broken rock mass.

$$\frac{m_d}{m_n} = \frac{\mu\cos\alpha - \sin\alpha}{\sin\alpha + \frac{\mu\cos\alpha}{K_{p-1}}} \cdot (0{,}02\alpha + 0{,}72) \quad (1)$$

where, α – elevation angle (of the stream bed),
μ – dynamic friction factor,
Кр – Swell factor for broken ore,
Кз = (0,02α + 0,72) – water consumption reserve factor depending on the shaft landslide stream bed incline angle.

But to increase the reliability of calculations it is required to perform a research to determine the dependence of specific water consumptions on the length of landslide delivery of the rock mass, as this parameter, as well as the stream bed incline angle, significantly affect the efficiency of haulage of the rock mass using the artificial shaft landslide water-rock stream.

Modelling method. Depending on the consumption of water participating in formation of a landslide stream, the amount of solid material and its grain size distribution, it is possible to form different types and kinds of landslide streams.

In our case, the solid part of the landslide stream formed in underground conditions is represented by broken rock. On the basis of experimental studies for determination of the grain size distribution of the broken ore [5], the formed landslide stream can be classified as unbound type of landslide streams in terms of the character of dispersed medium, and water-rock - in terms of its type. As for its physical nature, such stream represents a complicated model of a suspended matter-carrying water stream. Consequently, the main regularities connected with haulage of heavy inclusions by water streams are principally appicable to the description of unbound water-rock streams close to them in terms of the character of turbulence of movement [6]. As there is no general theory describing the movement of two-phase streams of different structural types yet, the modelling is performed at this stage of study of landslide streams on the basis of general criteria of similarity adopted in the hydraulics with some restrains and adjustments determined both by the modelled medium and modelling conditions.

The geometric similarity of the natural and model streams is ensured with the equality of lower Froude numbers for them [5], i.e. at $Fr_M = Fr_H$ or

$$v^2/L_M g = v^2/L_H g$$

where g – gravity acceleration, m/s2;
v – stream velocity, m/s;
L – linear size in meters.

It is noted in the work [5], that the transition zone between the laminar and turbulent circumfluence of particles with a water stream is a zone with particle sizes from 0.05÷1.0 to 2÷2.5 mm. The particles which are finer than the

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lower size are circumflown in a laminar way, and particles whcih are bigger than the upper size are circmuflown in a turbulent way, being in the automodel area allowing direct geometric similarity in accordance with the adopted scale.

In our case we deal with the broken ore mass with a small amount of fine particles. But the amount of sand particles with a size of 1 to 3 mm of crushed stone particles from 3 to 20 mm equals to 11 % [4]. At the modelling scale of 1:50, based on the geometric similarity of linear sizes of the stream, we need to replace all sand particles with dusty particles with a size of 0.06-0.4 mm. This way we will distort the physical medium of the stream, as water and dusty particles represent a suspension of the semi-colloidal type, the viscosity of which will be several times higher than the water viscosity. That is why, without having an opportunity to take into account the corresponding criteria of similarity, transfer of the solid part from the zone of turbulent circumfluence to the zone of laminar circumfluence with geometric reduction of particles in accordance with the linear scale of the modelling, a part of sandy and crushed stone particles is replaced with coarser crushed stone particles with a size of 20 to 50 mm.

Table 1 below contains the grain size distribution of the modelled dose of ore, where sandy and crushed stone particles with natural sizes of 1 to 20 mm are replace with coarser crushed stone particles with sizes exceeding 20 mm. These particles in the modelled dose of ore are included in the fine particles with a size of 1 mm.

Table 1 - Grain size distribution of the actual broken ore and the dose of ore in the model

Pos. No.	Actual linear size of lumps, mm	Linear size of lumps in the model, mm	Lumpiness in the total mass			
			Actual size		Model 1:50	
			kg	%	kg	%
1	up to 3	up to 0.06	17,572			
2	upto 3	upto 0.06	17,572	2.19		
3	from 3 to 5	from 0.06 to 0.1	16,400	2.05		
4	from 5 to 10	from 0.1 to 0.2	32,880	4.11		
5	from 10 to 25	from 0.2 to 0.4	38,800	4.85		
6	from 25 to 50	from 0.4 to 1.0	54,720	6.84	1.282	20.04
7	from 50 to 100	from 1.0 to 2.0	92,640	11.58	0.741	11.58
8	from 100 to 200	from 2.0 to 4.0	108,480	13.56	0.868	13.56
9	from 200 to 350	from 4.0 to 7.0	131,200	16.40	1.050	16.40
10	from 300 to 500	from 7.0 to 10.0	128,560	16.07	1.028	16.07
			800,000	100	6.400	100

Artificial shaft landslides used in the mining industry for haulage of solid material (ore) have certain inherent characteristics different from natural landslide streams. They include:

1. Formation of a landslide stream takes place by flowing of water to the bulk solid material (ore), as a rule, having a certain shape, volume and grain size distribution.
2. The flowing water stream has certain (set) hydrodynamic characteristics.
3. Movement of the formed landslide stream takes place withi a small (very limited) period of time.

Movement of the landslide takes place along the hard stream bed, at that the landslide itself is accumulated on a relatively small area of the hard steam bed.

The main difference of the experimental unit is that it gives an opportunity to fully identify the conditions of the stoppage of the modelled landslide streams. The identity of conditions of stoppage of landslides allows to obtain a number of characteristics of formation and movement of shaft landslides studied on these models. Observance of the identity of conditions of stoppage of the studied landslide streams is implemented in the additional section of the landslide stream bed. Such opportunity to study the landslide stream using the additional stream is connected with the fact that the additional stream bed does not differ, as a rule, from the main stream where a landslide is formed and moved, by shape and quality.

The difference is that the additional stream is established at an angle which is smaller than the incline angle of the main stream bed connected with it, ensuring this way full stoppage of the landslide stream within the additional stream bed. Its length and incline angle depend on technical conditions of the experiment. The presence of an additional stream bed established at a selected incline angle allows to create identical conditions for stoppage of the landslide stream with different characteristics.

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C. Establishment of the dependence of specific water consumption on the length of landslide haulage of the rock mass.

Tests were performed in the landslide flume with a big length. At that, the maximum length of the main flume was 12 m, and the additional flume - 2 m.

Measurement of the haulage capacity of the modelled landslide water-rock stream was performed at different sections of the main flume. Lengths of these sections were 2, 4, 8 and 12 m.

After stacking a certain dose of ore into the upper part of the main flume, a minimum amount of water was fed to the bulk ore in the flume. The water quantity fed to the bulk ore was gradually increased in each subsequent test to ensure full wash-out of the ore from the surface of the flume and relocation to the additional section of the stream bed. After relocation of the landslide mass to the additional flume, they recorded the time of stoppage (discharge) of the landslide stream and determined the way made by the landslide in the additional section of the stream bed (flume) characterising its haulage capacity.

It was done the following way. Location of the center of the stopped mass was determined approximately by eye. Then, starting from the tail of the stopped landslide mass, the rock was removed in small quantities into a tank to weigh the removed rock each time and until the tank has the half of the initially stacked dose of the modelled rock less the mass left in the armouring near the walls of the main flume. The way made by the landslide in the additional section of the stream bed (flume) at a set average incline angle of the main flume was the baseline. During further tests, the main flume had different lengths of the landslide delivery, and other specific consumptions were recorede at which the haulage capacity of modelled landslide streams was approximately the same as the baseline at the average incline angle of the main flume.
The modelling results are given in Table 2.
Recalculation of the specific water consumption for actual (commercial production conditions) were performed taking into account the modelling scale by means of the following ration:

$$E_x = E_i - E_i^0\left(\frac{N-1}{N}\right)$$

where, N - modelling scale, N = 50;
$\hat{E}_x$ - actual relative water consumption factor (under commercial production conditions);
$\hat{E}_i$- relative water consumption factor for the model;
$\hat{E}^0$ - factor characterizing the moisture conent of the ore used in the models.
The factor value was determined experimentally. The moisture content of the ore for the described modelling conditions at N = 50 was $\hat{E}^0$ = 0.082-0.084.

Table 2 - Results of the laboratory experiment for determination of the haulage capacity of the modelled landslide stream depending on the stream bed length (incline angle of the main flume - 24º, length of the additional flume – 2 m, flume width – 17 cm (1 caliber), bulk solid mass – 6.4 kg, incline angle of the additional flume – 9.5º).

Pos. No.	Main flume length, lmain, (m)	Water mass fed to the bulk ore in the model, (l)	Rock mass in the armouring, (kg)	The way made by the landslide in the additional flume (in calibers)	Specific water consumption in the model, Q_M, (l/kg)	Actual length of the landslide delivery of ore mass, L, (m)	Actual specific water consumption, QH, (m^3/t)
1	2	1.54	0.21	-0.71			
2	2	1.75	0.15	0.9			
3	2	2.0	-	2.14			
4	2	2.62	-	**5.95**	0.49	100	0.41
5	4	2.0	0.34	-0.47			
6	4	2.5	0.27	2.77			

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7	4	2.75	0.23	4.02			
8	4	3.0	0.2	**6.05**	0.55	200	0.47
9	8	3.0	0.75	-0.52			
10	8	3.5	0.56	0.64			
11	8	4.0	0.52	2.73			
12	8	4.5	0.51	**5.33**	0.78	400	0.70
13	12	3.5	1.24	-0.36			
14	12	4.5	1.17	0.88			
15	12	5.0	1.09	1.76			
16	12	5.5	0.98	**5.41**	0.93	600	0.85

Fig. 3 shows a dependency graph of specific water consumptions and the length of landslide delivery of rock mass.

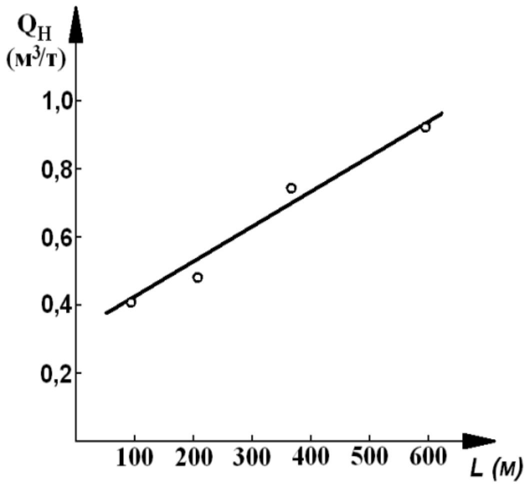

Fig. 3 - Dependency graph of specific water consumptions and the length of landslide delivery of rock mass.

The graph (Fig. 3) shows that the specific water consumption Q_H is 0.85 m^3/t at the length of landslide delivery of the rock mass of 600 m under natural (commercial production) conditions. Atthe same time, the specific water consumption is 0.41 m^3/t at the minimum length of the landslide delivery of rock mass to a distance of 100 m. I.e. if the delivery length is increased by 6 times, the specific water consumption must be increasedbyb 2.07 times. As the dependence of specific water consumptions, Q_H on the landslide delivery length L is expressed by the linear function, then, the water consumption reserve factor depending on the landslide delivery length will be K_L = 0.00178L + 0.998

Thus, to specify the calculations for determination of specific water consumptions depending on the length of landslide delivery under certain production conditions it is required to use the indicated reserve factor in order to ensure the optimal haulage capacity of the shaft landslide stream.

The final calculation formula for determination of the optimal specific water consumption will be as follows:

$$\frac{m_a}{m_{oa}} = \frac{\mu\cos\alpha - \sin\alpha}{\sin\alpha + \frac{\mu\cos\alpha - \sin\alpha}{K_p - 1}} \cdot (K_a + K_L)(2)$$

where,m_a - mass of water supplied to the bulk ore, òâ

m_{oa}-bulk ore mass,

α - stream bed (chamber) incline angle, μ = 0.82÷0.84 – dynamic friction factor for ranites, diorites, sandstones and other hard rocks,

K_p- swell factor of the ore (rock)

K_α = (0,02 α + 0,72) – water consumption reserve factor depending on the shaft landslide stream bed incline angle.

For example, if the chamber (stream bed) incline is α = 30°, the landslide delivery length is L=120 m, the specific water consumption will be 0.268 m^3/t.

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III. CONCLUSION

1. To develop inclined ore deposits with the medium thickness (5-15 m) it is suggested to use the method of development with arrangement of chambers upwards, creation of inter-chamber pillars and landslide delivery of broken ore allowing to avoid many sub-level workings along strike of the deposit and cascades of spiral ramps with a big section (22-25 m) to have access to sub-levels for big-sized self-propelled LHD equipment which cannot compete with landslide delivery in terms of haulage of broken ore within one block. Thus, for example, only 40-50 seconds will be required to relocate 100 t of broken ore using a shaft landslide along the inclined soil of the chamber with a length of 100 m.

2. To develop thin (1-5 m) inclined ore deposits it is suggested to use the method of combined delivery of broken ore and descending extraction layer by layer, including separation of the block into two wings with arrangement of chambers along strike, arrangement of an inclined main roadway in the middle of the block with closing of the face line in it which equals to the block width, scraping of ore from flanks of the block to the inclined main roadway and delivery of broken ore through it using an artificial landslide stream. Application of this method will allow to improve the intensity of cleanup works by 2 times and more, at that only one raise working must be made between levels for the whole block with a width of 80-100 m.

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AUTHOR'S BIOGRAPHY

Bakirov G.X., lecturer of the Almalyk branch of the Tashkent State Technical University named after Islam Karimov.	
KoraboevKh.A.,engineer surveyor State unitary enterprise “State design research institute of engineering survey and construction, geoinformatics of the urban planning cadastre”