International Journal of Recent Advances in Multidisciplinary Topics
Volume 6, Issue 10, October 2025
https://www.ijramt.com | ISSN (Online): 2582-7839


# Selection of the Curve Trajectory Type of Dump Scroll Tracks of the Inclined Skip and Energy Analysis During Unloading

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***Abstract*: In open pit mines, the unloading process of the inclined skip is a process of the variation in the tension of the hoisting rope, i.e. the energy of the skip-rope system, which depends on the structure of the skip and the track type of the dump scroll tracks. This study analyzes the energy consumption of a skip-rope system according to the track type of the dump scroll tracks when the inclined skips are unloaded in the dump scroll tracks. To this end, the dump scroll tracks equations are formulated and the cam design theory is applied to derive novelty equations (cosine and linear accretion track) for two types of dump scroll tracks. Next, the Discrete Element Method (DEM) software is used to analyze the skip unloading process in both tracks and the dynamic simulation is performed using Visual Nastran software. From the dynamic simulation, the tension of the hoist rope is obtained and based on it, the energy consumed during unloading is obtained. From the results of the final study, it can be seen that the cosine track is superior to the linear accretion track, regardless of the change in the characteristics of the load on the skip (egg group distribution, viscosity) in terms of the energy consumed in the skip-rope system during the unloading process. The results of the proposed study are of great significance in studying the structure and the dump scroll tracks type of large inclined skips in engineering practice.**

***Keywords*: open pit mine, inclined skip, buprenorphine, dump scroll tracks, energy consumption.**

## 1. Introduction

During the unloading of the skip bucket, a large force is applied to the unloading track, especially between the unloading roller and the unloading track of the skip [1].

Figure 1 shows the process of skip with overburden in a double drum hoist installed in an open pit along a curved unloading guide track.

However, the author did not mention the design method of the unloading guide track and the analysis of the unloading process of the skip.

So far, many researchers have discussed the construction of the unloading guide track of a shaft skip winch and the unloading operation of a skip.

[2] Note that skip hoists are the main haulage units transporting minerals on the surface.

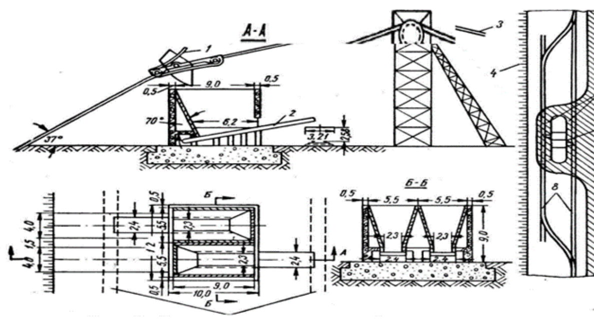

Fig. 1. Skip hoisting facility installed in open pit
1- unloading track, 2-feeding device, 3-hoisting rope, 4-lateral wall, 5-motor road, 6-car yard,7-unloading miner, 8-railway track

These dumps scroll tracks are mounted to the headframe structure and the skip travels into them by interfacing with rollers on the skip [3]. The author reported that during loading in a skip bucket to a bunker in a hoist tower, a large force was applied on the skip, and a severe impact force was applied on the unloading roller and the dump scroll tracks during the unloading period due to inaccurate contact between the guide and the skip slider, and this load was also affected by the jumping of the central position between the dump scroll tracks and the skip unloading roller from its theoretical position. [4] describes a modern computational model that is currently used for sheave calculation of a mine skip winch and presents accurate strength calculation results. According to [5], a detailed study on the mathematical modeling of lateral vibrations induced by a large-capacity skip due to the displacement of the guide track during the movement of the skip in a shaft was carried out. So far, there has been much research on skip dynamics in track trajectories due to the large dynamic force exerted by skips in unloading trajectories of hoisting equipment. Several researchers have studied the structure of skips and their kinematics and dynamics during unloading. [6] have used ANSYS structural analysis software to perform structural analysis of a large volume skip and found the relationship between the strength and cross-section of skip, body thickness, rib cross-section and rib spacing, after which the main factors affecting the skip strength coefficient and the optimum structural parameters were identified. [7] proposed the

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optimization of skip unloading process smoothness as an objective to improve the balance of impact force between skip and dump scroll tracks curve during unloading in an overturning skip, and found the optimal solution using the ideal point method based on the construction of a multi-objective optimization design model of the dump scroll tracks curve. The optimization resulted in a reduction in the impact force experienced by the skip unloading wheel, acceleration of the unloading wheel motion, and an improvement in the smoothness of the skip unloading process. [8] performed a dynamic analysis of the impact force variation between the unloading wheel and the loading track curve using LabView, based on the kinematic analysis of the tipping skip with a sector door moving in a loading track composed of straight, curved and straight tracks during unloading. The authors proved that the friction coefficient between the coal and the sector and the initial velocity of the skip are higher, the impact force experienced by the dump scroll tracks is higher. [9] used Adams software to construct a 3D real model of four loading trajectories applicable to overturning skips in a shaft, namely, the “arc + straight + arc”, the “3D curve + straight + 3D curve”, “cosine curve” and the “polynomial curve” trajectories, based on this, the dynamic simulations were carried out using ADAMS/View to analyze the loading rate and acceleration of the loading wheels with ADAMS/PostProcessor. It was also proved that the velocity and acceleration curves in the cosine trajectory are smoother, the maximum and mean values of the acceleration are smaller, and thus are superior to the “polynomial curve” trajectory. Thus, the comparison of the impact force, velocity and acceleration curves of the four loading track curves from the requirement of the ideal dump scroll tracks curve revealed that the "cosine curve" track is the best. [10] analyzed the unloading process of an overturning large skip dynamically and proposed a design method for a loading track trajectory that minimizes the impact force between the unloading wheel, the fan door and the dump scroll tracks curve, and applied it to a 32-ton large shaft skip to obtain a trajectory of a new dump scroll tracks curve of the "curve + curve + curve" type with radius r1=2000 mm, r2=1000 mm and r3=600 mm, respectively. [11] introduced the advantages and disadvantages of a dump scroll tracks with a moving straight structure and a fixed curved track with a vertical overturning skip. Through theoretical analysis and mathematical derivation, the lateral force under the skip guide was determined and a method for calculating the radius of the dump scroll tracks curve was proposed. This study also presented a design method for the unloading curve trajectory of the shaft skip, but not for the inclined skip. The effect of various kinematic parameters of mine hoist on fretting parameters of the hoisting rope was investigated and a new fretting fatigue test apparatus was designed [12]. By [13], safety for axial fluctuations of head sheaves in mine hoist based on coupled dynamic model is estimated.

Many researchers have simulated the flow characteristics of particles in equipment using EDEM.

The effects of variables such as feed rate, deck inclination, vibration frequency, amplitude, direction, and aperture size on screening efficiency were investigated by DEM simulation [14]. Numerical simulations of the motion of non-spherical particles in a banana screen using DEM were carried out to determine the optimum amplitude, vibration frequency, and vibration direction angle [15]. Through DEM simulations, the behavior of the screened particles needs was simulated to improve screening performance [16]. The mechanism of multiple abrasive particles in the complete complex internal cavity using DEM is presented [17]. Using EDEM, the behavior of coal particle material for optimized technological dimensions selection in screw conveyor was simulated [18].

In the current energy problem, the energy consumption of the operating process in the design field is reflected as a key design parameter and the research to reduce energy consumption is increasing. Previous studies have been conducted on the design of the curve trajectory type of dump scroll tracks for shaft skips. However, all the studies were carried out for the purpose to reduce the impact force between the unloading roller and the dump scroll tracks. Therefore, the tension of the hoist wire rope was not taken into account during this process, especially in the inclined skip. In practice, during unloading, the tension of the wire rope changes according to the type of the dump scroll tracks, which results in the energy change consumed in the skip-rope system. Therefore, when designing a curve trajectory type of dump scroll tracks, the tension variation of the wire rope during the unloading of the skip moving above it and the corresponding energy consumption relationship must be taken into account. In this paper, the authors propose a new method to analyze the effect of the curve trajectory type of dump scroll tracks on energy consumption during skip unloading. This study is of practical help in designing a rational curve trajectory type of dump scroll tracks according to the structure of the inclined skip.

## 2. Selecting the Curve Trajectory Type of Dump Scroll Tracks of a Large Inclined Skip

### *A. Structure and Working Principle of the Inclined Skip*

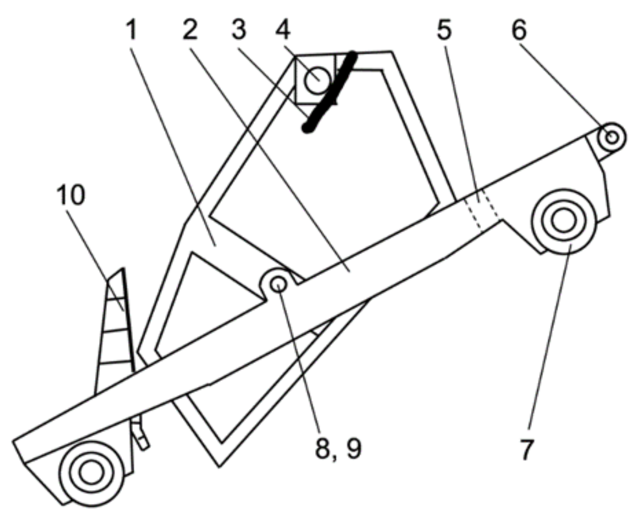



Fig. 2. Structure of the inclined skip

Figure 2 shows the structure of a new type of inclined skip for open pit mine. As shown in Fig. 2, the skip was composed of bucket (1) and bogie (2). The bucket has a rotating bearing shaft (8) to provide the rotational motion of the bucket during unloading. Also, an unloading roller (4) is installed on both sides of the bucket, which moves along the dump scroll tracks (3), and overturning the bucket. The bogie has a fixed plate (10) which is mounted to prevent load from flowing out when loading the bucket and when the skip moves on the roadbed. At the center of the bogie there is a rotating bearing (9) of the bucket, and a wire link (6), a wheel (7), and a supporting jaw (5) that holds the bucket. The working principle of this skip is as follows.

When the skip is loaded and is moving on the roadbed, the bucket is supported by two points: a rotary bearing and a supporting jaw, and the gap between the bucket and the fixed plate is very small so that the load does not flow out. In the unloading zone, the bucket rotates around the rotating bearing axis, with the unloading roller moving along the dump scroll tracks. At that time, the load is unloaded by opening the gap between bucket and a fixed plate.

### *B. Selecting the Curve Trajectory Type of the Dump Scroll Tracks*

To select the curve trajectory type of the dump scroll tracks, the first stage of the bucket movement in the unloading zone, i.e. the first stage when the unloading roller enters the dump scroll tracks, and the last stage of unloading after a certain time of motion are shown in Fig.3.

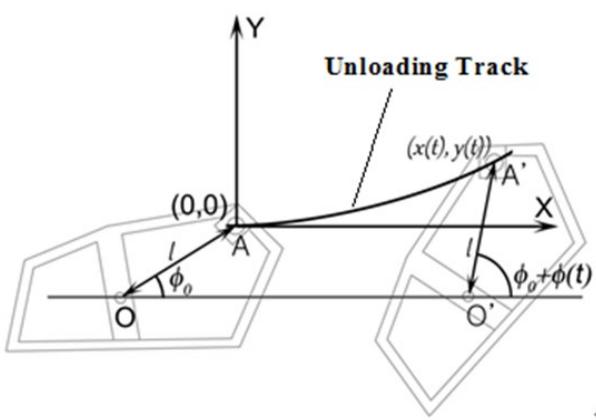



Fig. 3. Behavior of buckets in the unloading zone

As shown in Fig. 3, the Cartesian coordinate system is set by setting the origin of the unloading roller position at the moment when the skip enters the dump scroll tracks. The trajectory equation of the dump scroll tracks is expressed as following [19].

$$\begin{cases} x(t) = v_0 t - \dfrac{1}{2}at^2 + l[\cos(\phi_0 + \phi(t)) - \cos\phi_0] \\ y(t) = l[\sin(\phi_0 + \phi(t)) - \sin\phi_0] \end{cases} \quad (1)$$

In this equation, the angle of rotation of the skip bucket with time is given by $\phi(t)$.

$x(t)$ - x-coordinate of the dump scroll tracks at time *t*, m

$y(t)$ - y-coordinate of the dump scroll tracks at time *t*, m

$v_0$ - initial velocity at the moment when the skip enters the dump scroll tracks, m/s

$a$ - skip deceleration during unloading, m/s$^2$

$l$ - distance between the unloading roller and the rotating bearing shaft, m

$\phi_0$ - angle of the horizontal plane of the line connecting the center of the unloading roller and the rotary support shaft, degree

$\phi(t)$ - function representing the angle of rotation of a skip bucket with time, s

In Equation (1), the coordinates of the unloading trajectory curve are varied according to the function $\phi(t)$ which describes the variation of the angle of rotation of the bucket. When designing the dump scroll tracks of a large inclined skip, the following conditions must be satisfied. In general, the moment skip enters the dump scroll the tracks, impact occurs if the unloading roller is not smooth. Hence, according to the cam design theory, two change laws of $\phi(t)$ are chosen to analyze and select the curve trajectory of the dump scroll tracks from the energy consumption point of view while ensuring the absence of impact at the inlet.

$$\phi(t) = \frac{1}{2}\left(1 - \cos\pi\frac{t}{t_a}\right)\phi_m \quad (2)$$

$$\begin{cases} \phi(t) = 4\left(\dfrac{t}{t_a}\right)^3 \phi_m, \quad t < \dfrac{t_a}{2} \\ \phi(t) = \left[4\left(\dfrac{t}{t_a}\right)^3 - 12\left(\dfrac{t}{t_a}\right)^2 + 12\left(\dfrac{t}{t_a}\right) - 3\right]\phi_m, \quad t \geq \dfrac{t_a}{2} \end{cases} \quad (3)$$

In the expression;

$t_a$ - skip unloading time, (s)

$\phi_m$ - maximum angle of rotation of skip bucket, (deg)

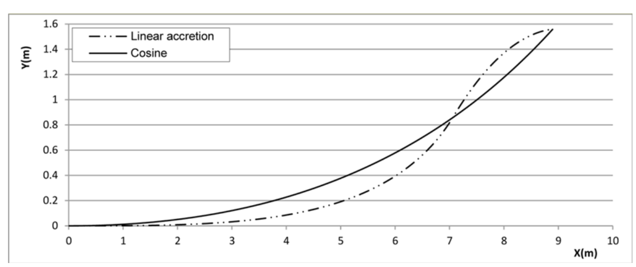



Fig. 4. Two-way dump scroll tracks

Equation (2) is derived from a simple harmonic motion curve (Simple Harmonic motion Curve), and Equation (3) is derived from a polynomial cam curve (The 2-3 Polynomial Cam Curve). Substituting Equation. (2) and Equation. (3) into

Equation. (1), we shall call the cosine track and the linear accretion track respectively (Figure 4).

## 3. Simulation and Analysis

### *A. Simulation and Analysis of Unloading Process by DEM Program*

To perform dynamic simulations of the skip unloading process, one must clarify the unloading characteristics of skips during the skip movement and unloading in the unloading section, i.e., the mass-change characteristics of the skip load over time. Various factors affect the unloading characteristics, which differ each time a skip is loaded. In this study, the authors simulate the unloading process of a skip, considering that the siliceous limestone is loaded in a uniform distribution on the skip, and on this basis, the change in the unloading characteristics is considered when the size distribution characteristics of the load on the skip are changed. The simulation material is chosen as siliceous limestone, which is the main component of the upper rock of the open pit, and the parameters used in the simulation are listed in Table 1-3 [20].

Table 1
Properties of cherty limestone and Steel

| | Silica Grass | Steel |
|---|---|---|
| Poisson's ratio | 0.29 | 0.28 |
| Modulus of elasticity in shear, Pa | 1.1e9 | 8.2e10 |
| Density of material, kg/m^3 | 2090 | 7800 |

Table 2
Interaction properties of silica grass and steel

| | Silica Grass-Silica Grass | Silica Grass-Steel |
|---|---|---|
| Elastic ratio | 0.5 | 0.35 |
| Static friction coefficient | 0.7 | 0.5 |
| Coefficient of rolling Friction | 0.025 | 0.015 |

Table 3
Grain size distribution of the siliceous limestone in skip

| Diameter of particle (mm) | Mass of material (kg) | % |
|---|---|---|
| -50 | 4 518.5 | 22.76357 |
| -75+50 | 4 173.5 | 21.02551 |
| -100+75 | 5 229.8 | 26.347 |
| -125+100 | 3 952 | 19.90962 |
| -150+125 | 1 975.9 | 9.954307 |
| **Total mass** | **19 849.7** | |

With respect to the operational load, the type of the load particles in the skip was chosen to be spherical, and the load particles less than 50 mm in size were excluded from the simulations, which simulated the skip unloading process in the two tracks chosen above. The data of the distribution of the grains of the siliceous limestone, given in Table 3 and Figure 5, are averaged over the size measurements of the siliceous limestone in the skip over several occasions in the field. The schematic diagram of the skip bucket is shown in Figure 6, and the structural parameters and the characteristics of the skip motion in the dump scroll tracks are given in Table no 4 and Table no 5.

In the simulation, the unloading interval was divided into 100 equal parts and the rotation of the bucket was considered at those points, of which the time-dependent rotation angle of the bucket at 20 points is given in Table 6 and Fig. 7.

Figure 8 shows the simulation results of the skip unloading process in the linear accretion track and Figure 9 in the cosine track.

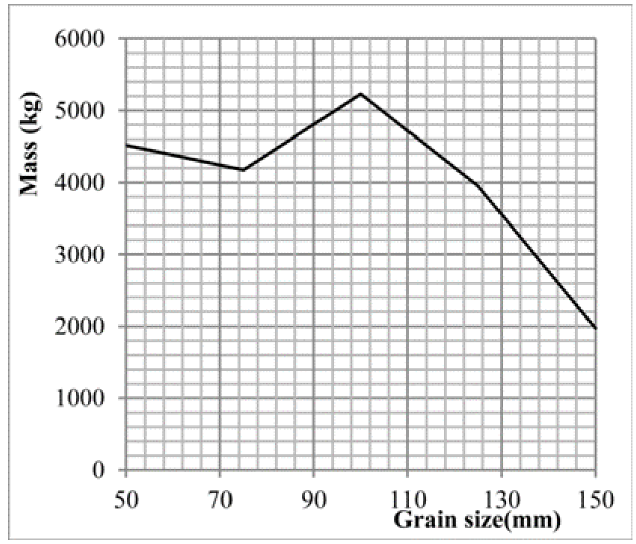



Fig. 5. Grain size distribution graph

The rotational behavior of the bucket at 2.5 s, 7.5 s, 12.5 s, and 17.5 s from the first moment of unloading in the bucket is shown in a), b), c), and d), respectively. As can be seen, at the moment of 12.5 s, more load is applied in the cosine track and at 17.5 s more load is applied in the linear accretion track. Fig.10 shows the mass variation of the load on the bucket during the skip unloading.

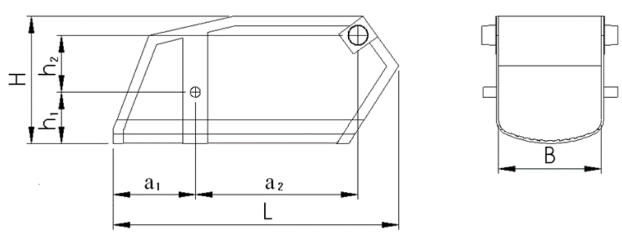



Fig. 6. Schematic of skip bucket

Table 4
Structural parameters and mass of bucket

| | | | |
|---|---|---|---|
| H, m | 2.514 | L, m | 5.685 |
| $h_1$, m | 1.013 | $a_1$, m | 1.638 |
| $h_2$, m | 1.122 | $a_2$, m | 3.235 |
| B, m | 2.130 | mass, kg | 10 887 |

Table 5
Skip's motion characteristics

| | |
|---|---|
| initial velocity, $m/s$ | 1 |
| deceleration rate, $m/s^2$ | 0.05 |
| angle of inclination of subgrade, deg | 28 |

During the simulation, the graphs were obtained with a reference point of 2.5 s, since 0~2.5 s was the time to generate the load in the bucket. As can be seen in Figure 10, the amount of load in the bucket when unloading in both tracks is different with time.

Table 6
The time-dependent rotation angle of the skip bucket in both track trajectories, deg

| times | linear accretion track | cosine track | times | linear accretion track | cosine track |
|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 11 | 17.16 | 15.61 |
| 1 | 0.01 | 0.17 | 12 | 20.09 | 17.67 |
| 2 | 0.11 | 0.66 | 13 | 22.37 | 19.63 |
| 3 | 0.36 | 1.47 | 14 | 24.08 | 21.44 |
| 4 | 0.86 | 2.58 | 15 | 25.31 | 23.05 |
| 5 | 1.69 | 3.95 | 16 | 26.14 | 24.42 |
| 6 | 2.92 | 5.56 | 17 | 26.64 | 25.53 |
| 7 | 4.63 | 7.37 | 18 | 26.89 | 26.34 |
| 8 | 6.91 | 9.33 | 19 | 26.99 | 26.83 |
| 9 | 9.84 | 11.39 | 20 | 27.00 | 27.00 |
| 10 | 13.50 | 13.50 | | | |

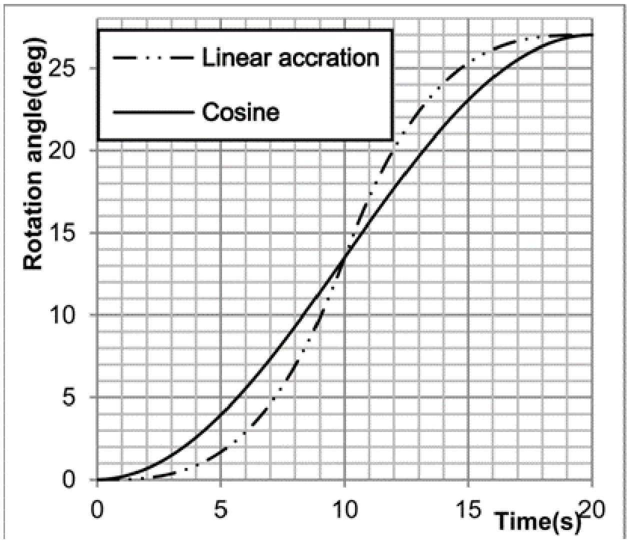


Fig. 7. Rotational angle of skip bucket with time

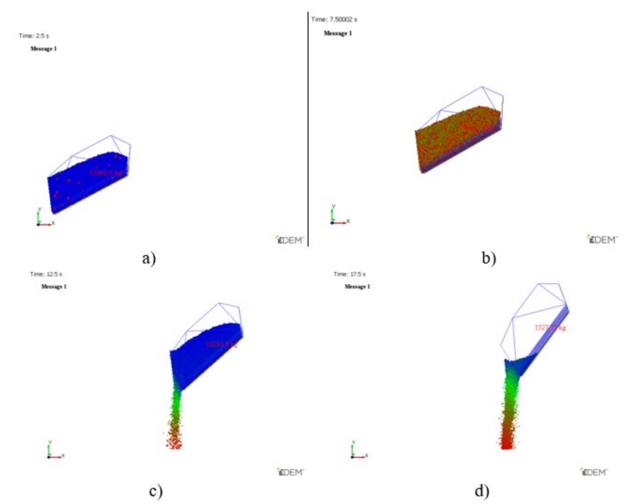


Fig. 8. Simulation of unloading process in linear accretion track (a) t=2.5s, b) t =7.5s, c) t=12.5s, d) t =17.5s)

The unloading rate at any moment is expressed as,

$$v_a = \frac{m_{n-1} - m_n}{\Delta t} \tag{4}$$

Here

$v_a$ -Unloading velocity, kg/s

$m_{n-1}, m_n$ -The mass of the load in the bucket at any computational step $n-1,\ n$, kg

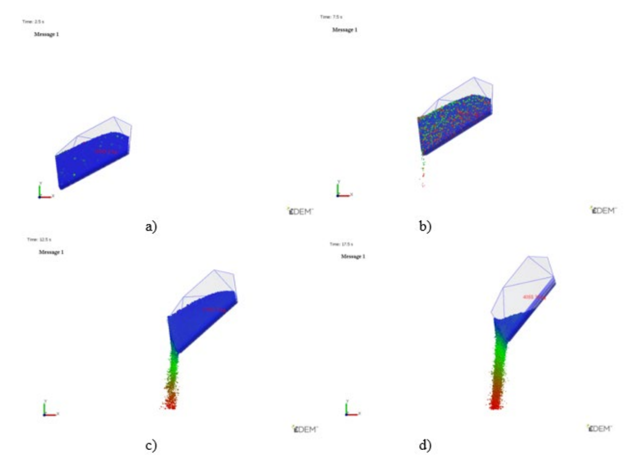


Fig. 9. Simulation of unloading process in a cosine track (a) t=2.5s, b) t =7.5s, c) t=12.5s, d) t =17.5s)

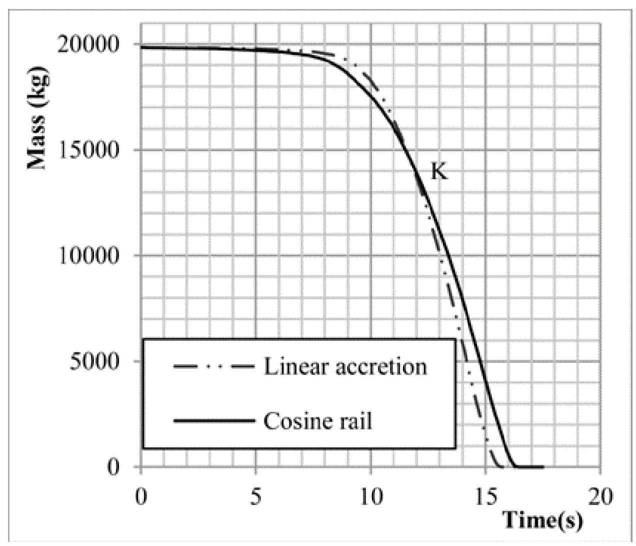


Fig. 10. Mass variation of load on the skip over time

$\Delta t$ -Simulation calculation step, s

Figure 11 shows the unloading rate variation with the width of the discharge port in both dump scroll tracks.

From Fig. 11, it can be seen that the unloading rate in both tracks is almost identical when the distance between the bucket nose and the fixed plate during unloading, i.e., the discharge interval is 750 mm, but higher unloading rate in the linear accretion track.

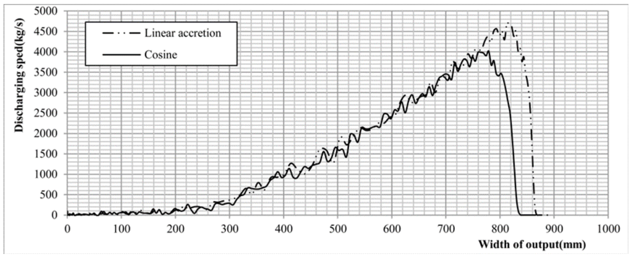



Fig. 11. Unloading rate variation with the width of the discharge port

### B. Dynamic Simulation and Energy Analysis of Unloading Process

Dynamic simulations were carried out in MSC. Visual Nastran software to analyse the energy relationships consumed in the skip-rope system when the skip is unloaded while moving along the dump scroll tracks. Figure 12 presents a model for dynamic simulation of the unloading process of a skip bucket moving along a dump scroll tracks.

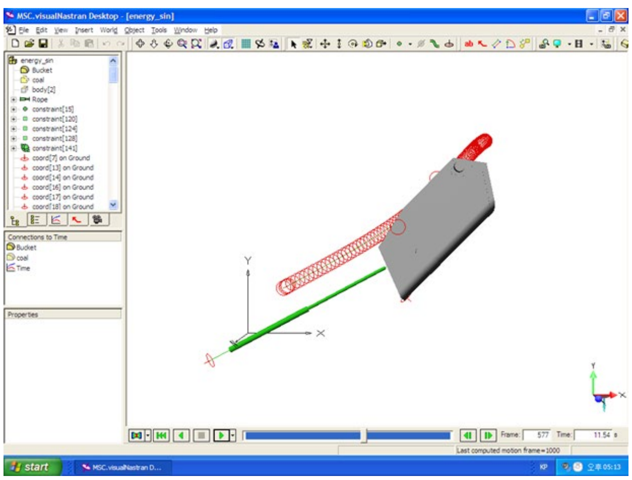


Fig. 12. Dynamic simulation of the unloading process

Table 7
x and y coordinate values of two dump scroll tracks

| | linear accretion track | | | | Cosine track | | | |
|---|---|---|---|---|---|---|---|---|
| | x | y | x(28°) | y(28°) | x | y | x(28°) | y(28°) |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.10 | 1.90 | 0.01 | 1.67 | 0.90 | 1.88 | 0.04 | 1.64 | 0.92 |
| 0.20 | 3.58 | 0.06 | 3.13 | 1.73 | 3.53 | 0.17 | 3.04 | 1.81 |
| 0.30 | 5.03 | 0.20 | 4.35 | 2.53 | 4.95 | 0.37 | 4.20 | 2.65 |
| 0.40 | 6.20 | 0.45 | 5.26 | 3.31 | 6.12 | 0.61 | 5.12 | 3.41 |
| 0.50 | 7.06 | 0.86 | 5.83 | 4.07 | 7.06 | 0.86 | 5.83 | 4.07 |
| 0.60 | 7.66 | 1.22 | 6.19 | 4.68 | 7.78 | 1.09 | 6.35 | 4.62 |
| 0.70 | 8.15 | 1.42 | 6.53 | 5.08 | 8.29 | 1.29 | 6.72 | 5.03 |
| 0.80 | 8.54 | 1.52 | 6.83 | 5.35 | 8.64 | 1.44 | 6.95 | 5.33 |
| 0.90 | 8.80 | 1.55 | 7.04 | 5.50 | 8.83 | 1.53 | 7.08 | 5.50 |
| 1.00 | 8.90 | 1.56 | 7.12 | 5.55 | 8.90 | 1.56 | 7.12 | 5.55 |

The model consists of skip buckets; dump scroll tracks and hoist wire ropes. Bogies that do not affect the energy variation were excluded from the simulations. The revolving point of the skip bucket was given the Revolute on Slot constraint so that the skip bucket could perform translational and rotational motions. Gravity was applied in the y direction -9.81 m/s^2, and the effect of friction was not considered. Table 7 gives the x and y coordinate values of 10 points of the two dump scroll tracks.

In Table no 7, x and y are x and y coordinates when the track is horizontal, and x (28°) and y (28°) are coordinates rotated by 28° considering the skip moving on a 28° inclined subgrade.

Figure 13 shows the tension variation of the hoist rope when the skip is loaded in two tracks respectively.

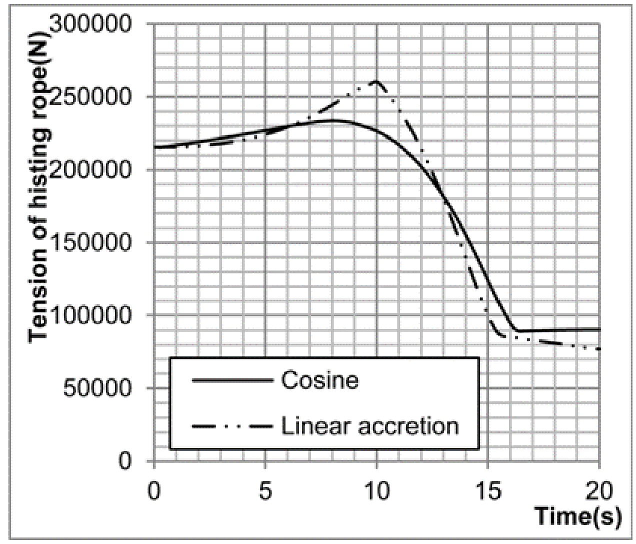



Fig. 13. Variation in tension of hoist wire rope during unloading

From the tension variation of the hoist rope obtained in the simulation, the energy consumed in the skip-rope system during unloading is:

$$A = \sum_{t=0}^{\tau} F_t S_t \quad (5)$$

Where,

$A$ -The energy consumed in the system, (J)

$F_t$ -Tension of the hoist rope at moment *t*, (N)

$S_t$ -The distance travelled by a skip bucket along the dump scroll tracks at moment *t*, (m)

$\tau$ -The time of skip movement in the dump scroll tracks, (s)

When the skip is unloaded while moving along two dump scroll tracks, the energy consumed by the system is shown in Figure 14 and the energy difference consumed is shown in Figure 15.

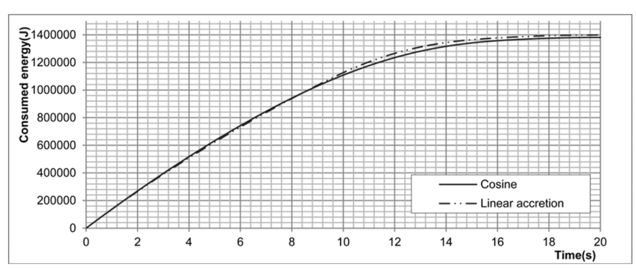



Fig. 14. Energy consumed in two tracks during unloading

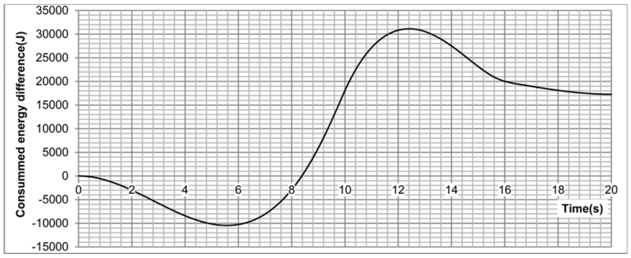



Fig. 15. Energy difference consumed in two tracks (when referring to cosine tracks)

Considering the entire unloading zone, 1,399MJ is consumed in the linear accretion track and 1,381MJ in the cosine track. This indicates that 17,290 J of energy is more consumed in the linear accretion track.

### 4. Discussion

To verify the accuracy of the theory, which analyzes the two dump scroll tracks from the energy consumption point of view, we compared the output variation of the skip-rope system.

Expressing Equation. (5) as the output of the system,

$$A = \sum_{t=0}^{\tau} F_t v_t \Delta t = \sum_{t=0}^{\tau} N_t \Delta t \tag{6}$$

Where,

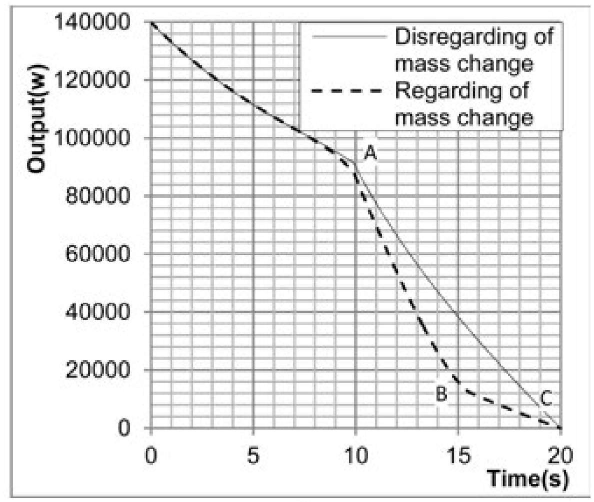
$v_t$ -skip translational rate at instant *t*, (m/s)

$N_t$ -output at instant *t*, (w)

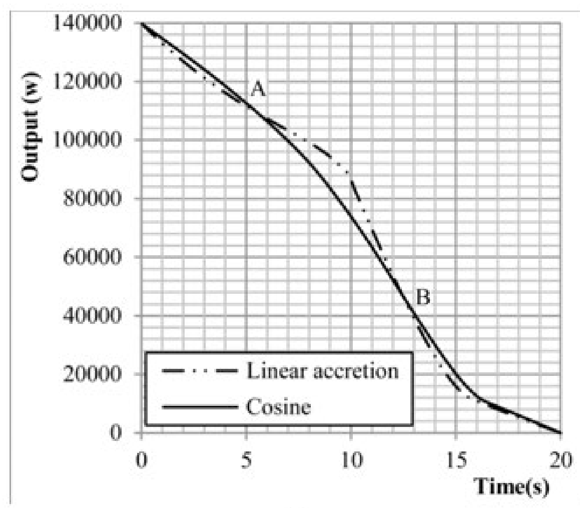
The output variation graph of the system is shown in Fig. 16.

Fig. 16 a) shows the output variation in the case of no unloading in a linear accretion track, i.e., without mass variation of the useful load in the bucket and with respect to unloading, and the area of the closed zone can be said to be the energy consumed during unloading. Fig. 16 b) shows the output variation in both dump scroll tracks, indicating that the closed region below the cosine track has a high power in the cosine track, whereas the closed region above it has a low power in the cosine track. Therefore, it can be concluded that the value of the lower area minus the upper area is the difference in energy consumed in the unloading zone of the two dump scroll tracks. Based on this, the authors analyse the variation of energy difference with the variation of the load characteristics. If the size and viscosity of the load on the bucket are high and the moisture content is high, the area of the influence zone of mass variation is reduced and point B is shifted towards point B', as the unloading process moves to the right. Therefore, the energy consumption in the linear accretion track cannot be lower than that in the cosine track. In the opposite case, when the load particle size is smaller than the simulated value, the area of the influence zone of mass variation is larger, and point A in Fig. 17 moves to the left. And the above-mentioned point K of Fig. 10 moves to the right rather than the point obtained in the present simulation, which means that, in terms of energy consumption, the load is unloaded with lower energy consumption in the cosine track than in the linear accretion track.

Thus, the shift of point K to the right will result in a shift of point B to the right, and the characteristic of unloading, it is evident that the area of the cosine dominated zone is larger with decreasing the load size and the area of the cosine-series region is smaller, which increases the energy difference.




a)




b)

Fig. 16. The output variation graph of the system

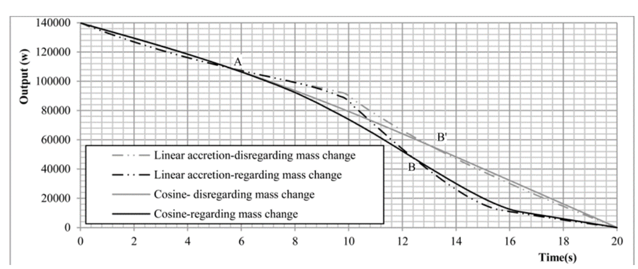



Fig. 17. Output comparison for two dump scroll tracks

### 5. Operational Status Analysis

At the time of preparing this manuscript, the incline shaft hoisting system was in the final stages of installation and commissioning. That is 1,600 kW rock winder with 42-ton skip capacity operating at a speed of 4 m/s. It is clear that once the system is operational, it will bring significant improvements to open pit mining operations.

Fig. 18 shows the inclined skip hoist tower, cosine track and 42-ton skip installed in the open pit.

a)

b)

Fig. 18. Site operation of inclined skip and cosine track
a) 42-ton skip, b) unloading yard

As shown in Figure 17, skip discharges payload on the asymmetry truss girder where cosine track consists of upper chord. Compared with the simulation results, the bucket full discharges by rotating as 27 degree and then the angle of inclination between the bucket and the surface is 55 degree.

## 6. Conclusion

This paper analyses the energy consumption relationship of the curve trajectory type of the dump scroll tracks during unloading of the inclined skip. The energy consumption during skip unloading is significantly related to the type of the dump scroll tracks. In other words, when skips move along the dump scroll tracks, the unloading roller does not move smoothly and the acceleration variations are large, resulting in a shock load, which results in the tension variation of the rope and energy consumption of the skip-rope system. Hence, the authors chose the curve of linear accretion track and cosine track with small acceleration variation from the cam design theory as the curve trajectory of the dump scroll tracks, and simulated the skip-loading process on it using DEM and Visual Nastran software. In this process, the energy consumed in the skip-rope system was compared based on the analysis of the tension variation of the hoist rope. As a conclusion of this paper, it can be said that there is less energy in the cosine track than in the linear accretion track, regardless of the variation in the load characteristics during the unloading of inclined skip. In the future research, the influence of the design parameters of skip dump scroll tracks on energy consumption will be investigated with the running conditions of the skip.

## Acknowledgement

The authors would like to thank the National Institute of Science and Technology of the Democratic People's Republic of Korea for giving selfless assistance to our research work. The authors would also like to thank the referees for their comments improving the presentation of this paper.

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