Selection of the optimum in-pit crusher location for an aggregate producer

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T r a n s a c t i o n   P a p e r

Synopsis

In-pit crusher location selection has had an important role recently, since increasing diesel prices. One way of reducing the haulage costs is to shorten the truck haulage distance by bringing the truck dump point into the pit. This study covers the work done on the optimum crusher location definition for a company that produces aggregate near Izmir, a city of Turkey located in the west. This paper will discuss the effects of pit geometry and mine access requirements on optimum crusher location selection that are mainly based on the establishment of minimum haulage distance. The method will be introduced first and then the computer algorithm developed for this study will be discussed later in the paper.

Keywords: in-pit crushing, optimum location selection, optimizing haulage, computer aided design.

Introduction

Rising operating costs have forced aggregate producers to look at various alternatives to cut costs to stay competitive. Haulage costs have risen significantly with the increase of diesel price. Recently, it was announced in a Turkish newspapers that the most expensive fuel in the world is being used in Turkey. This makes fuel consumption important when designing open-pit mining or limestone quarries to shorten haulage distances.

Several approaches have been developed over the years. Althoff and Clark[1] gave the detailed comparison between a stationary crushing plant with haulage by heavy trucks and a mobile crushing with a belt conveyor system. In this study capital expenditure and operational expenses are compared and the individual cost factors explained. In-pit crushing and conveying is a well proven concept for pit automatization but higher interest rates, limited available capital and low fuel prices limited the introduction of in-pit systems in 1990s[5]. Singhal[8] mentioned optimization truck usage by applying a truck dispatching system, but the optimization of a crusher location, as far as haulage distances are concerned, is first introduced by Roberstson[6,7]. Generally works on the subject have concentrated mostly on the comparison of truck haulage and the conveyor system in order to eliminate the cost of diesel[2,4].

The company fleet is made up of four 3.5 m^3 back-hoe hydraulic excavators and eighteen 35-ton capacity rear dump quarry trucks together with a rotary drilling machine. Three-inch diameter blasting holes have been used for blasting operations with the pattern of 3 m of burden and 3.5 m of spacing. The blasted material is fed to the primary jaw crusher that has one of the biggest capacities in Turkey with 600 tons/hour, and then the material goes through the secondary hammer crusher to the screening unit for commercial final products. The final classified product sizes are 0–5 mm, 5–15 mm, 15–25 mm, and 25–70 mm. All classified materials are stored in different silos to allow asy loading to customer's trucks.

The company, for which this study is done, with an annual aggregate capacity of 3 000 000 tons/year provides nearly a quarter of Izmir's demand in the building industry. There are several other aggregate producers situated around Izmir. The company has been operating a crusher with screening plant, which is visible from the city centre, for nearly 8 years at a place located approximately 10 km from Izmir. The company authorities have recently decided to move all the plant to a new suitable position to keep it out of sight of the city, because of increasing pressure coming from Izmir municipality. The existing crusher plant is located near a quite busy Izmir-Ankara (capital of Turkey) motorway, so sight of the quarry and dust coming off both crusher and the quarry trucks has always been problem to the people of the province.

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 Paper received Jul. 2006; revised paper received Mar. 2007.

As a result of the circumstances mentioned above, in 2005 authorities of the company obtained a mine permit for a new area that is 4 km away from its existing position behind a hill. They started limestone production from the new mine site and planned to move the existing crusher plant to the new quarry site. The authorities were not sure on which bench it would be better to install the crusher plant to keep haulage distance to a minimum, so they applied for a project to the University of Dokuz Eylul in Izmir.

Evaluation of the new quarry

In order to determine the new in-pit crusher position, topographic mapping had to be completed and all permit boundaries drawn on this map. The topographic map and existing position of the new workable area are given in Figure 1.

The body of limestone that will be used for aggregate production is surrounded by two river beds passing from the east to the north part of the mine permitted area. Limestone bearing formations lie on the uphill between +240 to +340 m above sea level. Flat regions situated on the eastern part of the river bed are schist formations where limestone forms a boundary. Geological prospecting and drill holes showed that limestone reached to level +240 without any interruption, hence this level is taken as the pit bottom.

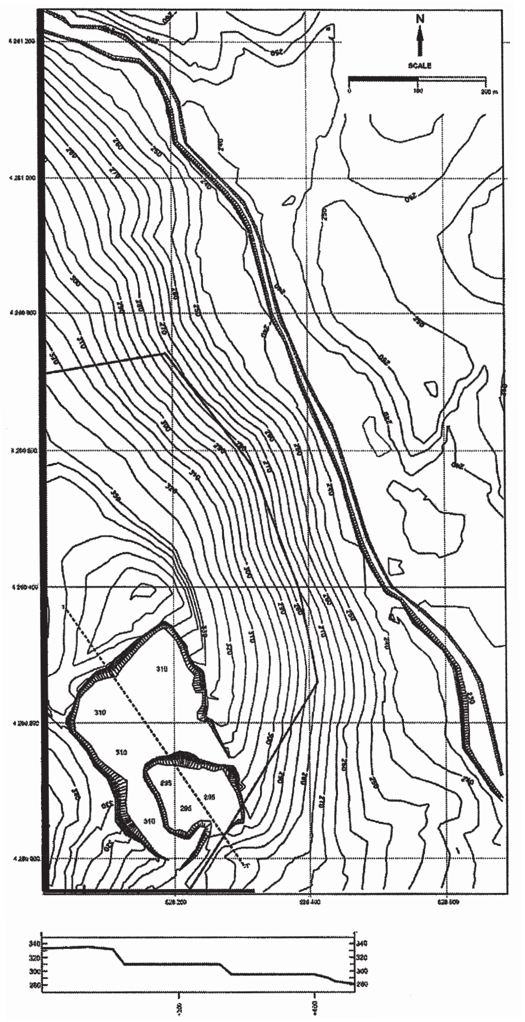

Figure 1—Existing status of the mine site

Bench heights are planned to be 15 m when considering the size of the equipment used in the main operation and a 50° final slope angle is organized for the quarry. Figure 2 gives the bench geometry planned for the new quarry.

The first step when evaluating the potential installation of crusher and screening plant is to establish the geometric settlement requirements of whole plant. Several alternatives were taken into consideration, and the final decision was an online installation. The flow of material utilizing an in-pit crusher-screening system starts with the trucked material being dump into the feeder pocket located at a certain bench level. A decision was taken to establish the main crusher-screening system on a platform that is located 10 m below the feeder. The size of the platform was chosen as 30 m wide and 80 m long. The material to be crushed and screened will move on a direct line on this platform, then the final products will be stored on a floor established 10 m below the platform that houses the crusher-screening units. The existing plant that the company holds requires 20 m of total height. Beside the space allocated for crusher-screen installation, a specific requirement came from the company authorities for a large storage area for different classes of aggregate. An illustration of the dimension and the system planned for installation is given in Figure 3.

The method of selecting the optimum in-pit crusher location

The main idea behind the optimization technique that was utilized to solve the current problem was to develop all potential alternatives and then select the best one i.e. It was a trial and error process. So it becomes important to show all possible alternatives that satisfy the criteria. For this purpose, the limestone deposit were first divided into regular vertical slices of 5 m thickness. The problem was to find the best slice level which minimizes the overall travelling distance to the plant. The crushing plant could be located at any position on one of these vertical layers, but creating the area necessary for the crushing plant and stocking area would limit the utility of the reserve of a specific slice level, so it was decided to assemble the crushing plant on the edge of each 5 m thick slice. That gave the planner a chance to define a permanent average lateral transporting distance that each truck should travel for a specific vertical slice. This means that if all the material of a certain vertical slice supposed to be carried to the crusher plant on the edge of the slice, the average travelling distance would be this length.

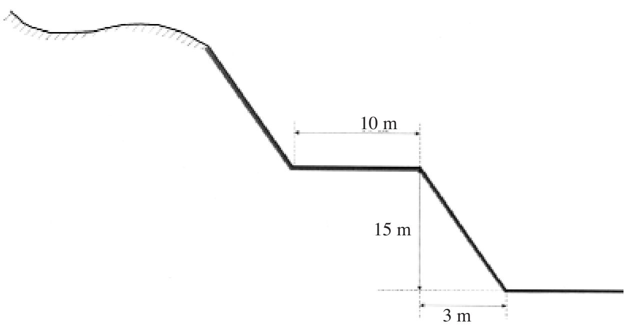

Figure 2—Planned bench geometry

The usable limestone reserve between the permit boundary and schist contact zone has been divided into 5 m thick vertical slices in order to define bench reserves. The amount of limestone existing within the layers and horizontal haulage distances for each slice have been calculated by using computer software developed for mapping purposes. Results from these calculations are given in Table I.

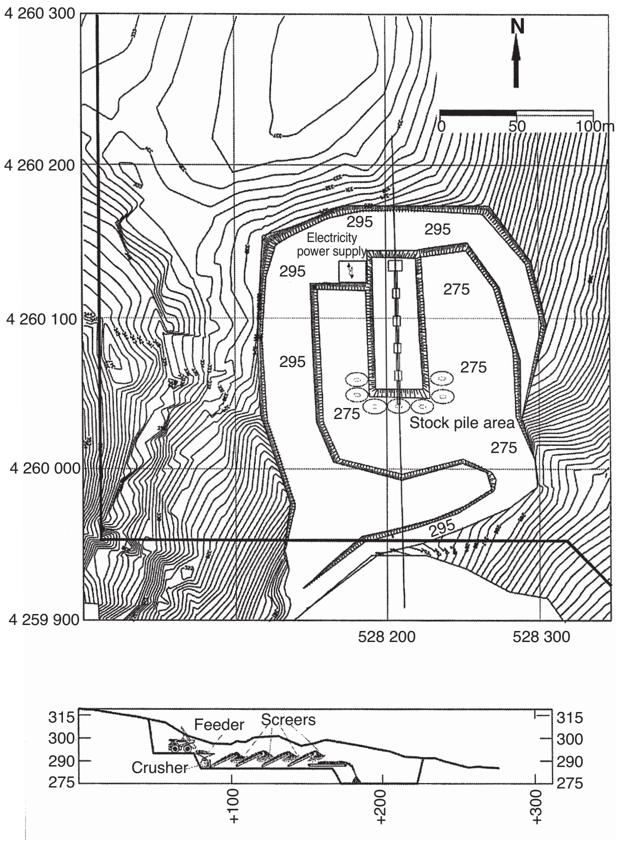

Figure 3—Plan view and cross-section of the rooms for the plant location

Table I gives both the reserves containing 5 m slices and the average horizontal haulage distances necessary to travel on this level. The shape of the limestone body brings about longer haulage distances from higher altitudes to lower altitudes.

The most important concept in selecting the optimum crusher location is to exhaust the limestone reserve with minimum overall haulage distances so as to minimize haulage cost. To achieve this objective, several crusher movements have been considered during the life of mine. Using an in-pit mobile crusher can reduce the haulage costs, but due to high initial investment cost, this option has not been considered. Instead, changing the location of the crusher-screening plant during the operational period by uninstalling and installing the plant has been studied. Utilizing the crusher at a stationary position without moving to another level until the end of mine is the first alternative. Similarly changing the crusher installation levels once, twice and three time has also been analysed. Moving the crusher-screening plant from one level to another has a direct assembly cost and time cost resulting from stoppage, hence the final decision should be taken by comparing both alternatives.

The main considerations to determine the optimum haulage route can be summarized as follows:

- Feeding limestone to the crusher from levels below to the crusher position will have an additional cost, since additional energy is required for trucks hauling material in an upward direction. The cost of raising material from the lower benches to the upper crusher position will increase the cost of haulage. To utilize the effect of upward haulage, total distances were increased 20% and 30%
- Diesel consumption of a truck is taken as 1 ℓ/km from the company's fuel consumption records, and the price of diesel in Turkey is 1.5 US$/ℓ
- The company is equipped with 35-ton capacity trucks, so that the total limestone reserve of 55 198 996 tons

Table I

Reserves of 5 m thick slices and average horizontal haulage distances[3]

Bench level (m)	Bench reserve (tons)	Cumulative reserve (tons)	Horizontal bench haulage distance (km)
335	376 337	376 337	0.120
330	921 175	1 297 512	0.180
325	1 191 143	2 488 655	0.186
320	1 514 635	4 003 290	0.198
315	1 961 154	5 964 444	0.210
310	1 797 627	7 762 071	0.213
305	2 092 311	9 854 382	0.216
300	2 385 167	12 239 549	0.222
295	2 570 726	14 810 275	0.240
290	2 667 096	17 477 371	0.252
285	2 923 588	20 400 959	0.264
280	3 131 263	23 532 222	0.276
275	3 280 716	26 812 938	0.282
270	3 463 746	30 276 684	0.288
265	3 674 541	33 951 225	0.294
260	3 806 634	37 757 859	0.300
255	3 651 006	41 408 865	0.306
250	4 629 373	46 038 238	0.312
245	4 400 170	50 438 408	0.324
240	3 400 420	53 838 828	0.330
238	1 360 168	55 198 996	0.336

will be removed with total a of 1 577 114 truck cycles. The main purpose of this study is to chose a crusher position that minimizes the haulage distance of these cycles, in another words, minimize the diesel consumption

- The main access road of the pit is located on the south part of the mine site at level +305. A crusher located on lower benches has an advantage as far as downward transportation is concerned, but when it comes to raising all crushed material to the main access road, lower crusher positions have become inappropriate
- Apart from haulage distances, locating the crusher plant in the middle of the limestone reserve will limit the bench reserve utilization due to the necessity of allocating of large areas for stock pile installation. This limits the alternatives of the crusher position on a certain bench.

The method of finding the optimum crusher position is one of trial and error. The number of alternative crusher positions to be considered is so high that a computer program has been written for calculating all possible alternatives. To explain the method, the first alternative of not changing the crusher position will be examined. What are the possible alternatives for locating the in-pit crusher? The answer to this question is easy for the alternative of not changing the crusher position until the end of the life of the mine; so, for the first alternative, the crusher is supposed to be located at the highest level in the quarry, 335 m level, and all other level reserves will be transported to this level. By doing so, the decision variable of reserve transfer value (ton × km) can be calculated with the following formula by using material the rising coefficient of 1.2 for level 335:

(Bench 335 reserve*HBHD[1] 335 + bench 330 reserve*(HBHD 330 + ((335–330)/100)[2]*1.2) + bench 325 reserve*(HBHD 325 + ((335–325)/100)*1.2) +………………………)/total quarry reserve

[1] Horizontal bench haulage distance (km) from Table I

[2] Total uphill haulage distance with maximum 10% road grade (km)

376 337*0.120 + 921 175*(0.180 + 0.05*1.2) + 1 191 143*(0.186 + 0.10*1.2) + 1 514 635*(0.198 + 0.15*1.2) + 1 961 154*(0.210 + 0.20*1.2) + ……………..+ 1 360 168*(0.336 + 0.97*1.2) = 46 490 460 tons*km

46490460 tons*km / 55 198 996 tons = 0.84223 km average haulage distance

The study area has been divided into 21 units of 5 m thick levels, so the number of possible alternatives is the same as the level numbers as far as the stationary crusher position is concerned. When any level below the highest one is considered to obtain the average haulage distance, the material from upper levels haas been treated with the formula above without the material rising coefficient.

When it comes to study one crusher position change during the life of the quarry, the algorithm becomes more complex than the stationary one. The first possible way to employ the crusher is on the highest level 335, and the second crusher position would be on level 320 as far as bench height is concerned. In this case, the level reserves of 335 will have only horizontal bench haulage, all the material from level 330 and 325 will be carried to the crusher positioned on level 335 with the rising coefficient. Then the crusher is supposed to move to level 320 so all reserves of this level and lower levels will be crushed with this crusher. The second possible alternative is to move the crusher from level 320 to 305. The algorithm calculates all alternatives by moving the second crusher position down to the lowest level possible, then continues calculating, taking the first position of the crusher on level 330. Table II gives an idea about the possible alternatives.

If the crusher has been located on the highest level of the pit then it is supposed to move to lower benches, calculating the value of the reserve multiplied by bench horizontal haulage distance (ton × km). Figure 4 is the flow chart of the algorithm developed for optimizing the crusher position if changed once during mine life.

The computer program considers all possible alternatives, so the solution obtained from the algorithm can be said to be the optimum. As seen in Figure 4, the first position of the crusher stays stable, then the second position of the crusher changes from 15 m below the first position down to the minimum level of the pit, storing all alternative ton × km values in the memory. The next step is to move the first crusher position 5 m below and do the necessary calculations by moving the second position 15 m below the first position, and so on. When the crusher changes its position twice, the algorithm does the same calculations by adding a C3 position to the algorithm.

There are a total of 21 alternatives to chose from for the stationary crusher position, whereas this number rises to 458 when it comes to changing the crusher position once during the life of quarry; 1 682 and 6 012 different possibilities are created by the algorithm for changing the crusher position twice and three times respectively.

Evaluation of the obtained results

Average haulage distances (km), minimum travelling distances (km) and cost of diesel consumptions ($) have been calculated by the computer program for four different crusher movement alternatives and results are given in Table III.

Table II
Possible alternatives

The first position	The second position	The first position	The second position	The first position	The second position	
Level 335	Level 320	Level 330	Level 315	Level 325	Level 310	….
Alt2	Level 305	Alt8	Level 300	Alt14	Level 295	….
Alt3	Level 290	Alt9	Level 285	Alt15	Level 280	….
Alt4	Level 275	Alt10	Level 270	Alt16	Level 265	….
Alt5	Level 260	Alt11	Level 255	Alt17	Level 250	….
Alt6	Level 245	Alt12	Level 240	Alt18	Level 238	….

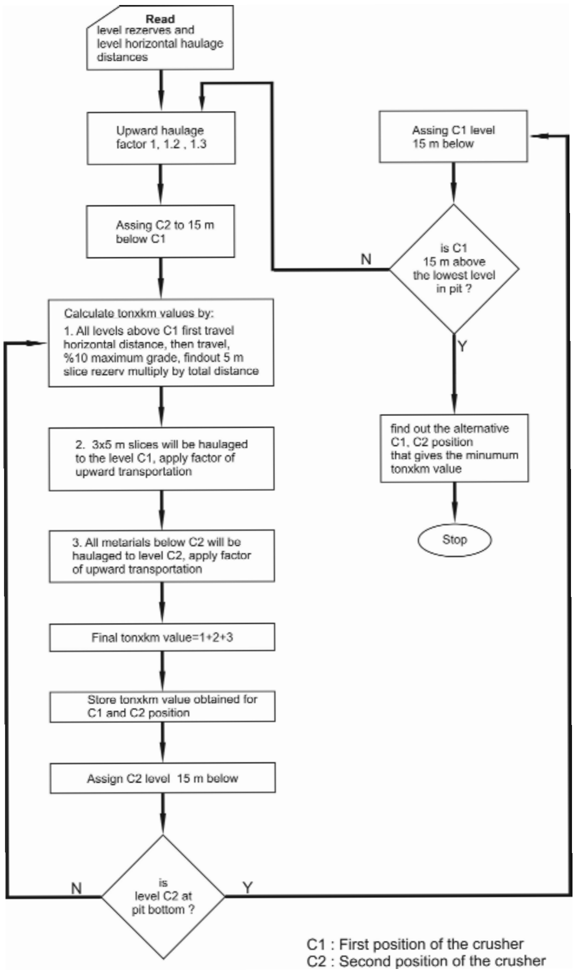

Figure 4—Flow chart of the computer program

Table III
Optimum travel distance and diesel consumptions for different crusher installations[3]

Upward haulage %	Bench levels giving optimum solution	Average distance (km)	Minimum distance (km)	Total diesel cost (US$)
Stationary crusher position*				
0	270	0.461	709 134	1 063 701
20	265	0.475	730 670	1 096 005
30	265	0.480	738 361	1 107 542
Crusher level swap number = 1				
0	295–250	0.357	549 156	823 734
20	295–250	0.363	558 386	837 579
30	295–250	0.366	563 000	844 500
Crusher level swap number = 2				
0	305–275–250	0.320	492 241	738 362
20	300–275–250	0.326	501 470	752 205
30	300–275–250	0.329	506 085	759 128
Crusher level swap number = 3				
0	310–285–265–245	0.296	455 323	682 985
20	310–285–265–245	0.299	459 937	689 906
30	305–285–265–245	0.300	461 476	692 214

*Crusher level swap number = 0

In Figure 5, the results obtained from the computer algorithm are given for all possible alternatives covering crusher level swaps with 0% upward haulage factor. Table III gives the optimum solutions obtained from Figure 5 for three crusher level swaps by considering 3 different upward haulage factors. As it can be seen from Table III, if the crusher position does not change during the life of mine, 0.475 km average haulage distance is obtained with 20% upward haulage factor. The optimum crusher position is located at level +270 m. When the crusher position is changed once during the life of mine, a 0.363 km average haulage distance is obtained as the minimum possible alternative by locating the crusher at level 290 and 270. Since the computer program searches all possible alternatives for locating the crusher at different positions, this figure gives the optimum crusher feeder position. The difference in

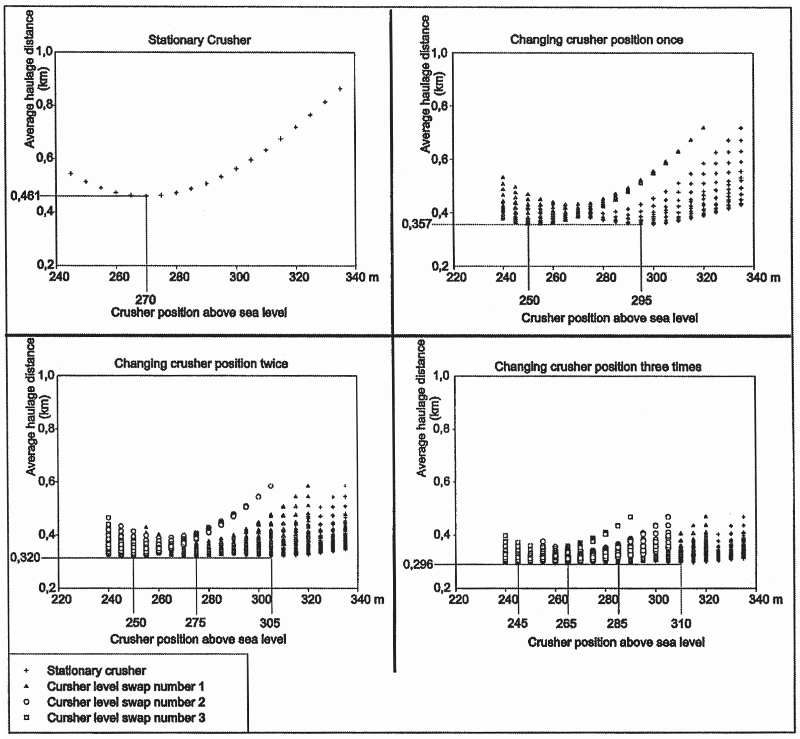

Figure 5—Optimum crusher locations for all different crusher installation levels

diesel consumption between the stationary crusher position and changing the crusher position once during mine life is 172 284 litres, equivalent to 258 426 US$. Three crusher position changes result in 0.299 km average haulage distance and have a cash advantage of US$ 406 099 over a stationary crusher position.

At the decision-taking stage, selecting the optimum location not only depends on the fuel consumption, but also depends on the money to be spent on assembling and reinstalling works for the crusher. There is also an indirect cost for reinstallation, namely time cost that can be caused by stopping aggregate production during the assembling period.

Results

In this study, a simple decision-taking process has been introduced for selecting a crusher location for a company working in the aggregate sector near Izmir, Turkey. Due to public pressure, owners had started operating of a limestone quarry that is 4 km away from the existing location and they decided to move the crusher and screening plants to the new pit area. Then a question arose about where that crusher would be installed to minimize the haulage cost of the limestone reserve. To answer this question, some assumptions have been made by considering the company's previous working strategies. The main assumption is that installing the crusher inside the quarry will minimize haulage distances, but it will obstruct the utilization of the limestone reserve. So moving the crusher plant to different locations on a certain bench level is not considered. As the results show a US$25 8426 difference overcomes the cost of reinstallating the plant, so changing the plant location once over the life of mine has been chosen. Operations are still being carried out to prepare the first crusher base at level +295 and stock piling space at level +275. The estimated life of mine is about 18 years if the reserve utilization is kept at the same level as at present; hence it is planned to move the new crusher position in 8 years to bench level +250. In this study different upward haulage increasing factors have been utilized to take equipment depreciation in to account for future years. There are also detailed annual plans done to show the main access, bench access to crusher feeder pocket and the geometry of the limestone quarry over years. Access to the crusher and transfers has been assured for maintenance as well as for removal of the drive stations when the system is moved.

Acknowledgement

This project was funded by BEMAS, an aggregate producer company under contract to Dokuz Eylul University, Mining Engineering Department.

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