VIRTUAL MODELING FOR ENVIRONMENTAL DECISION SUPPORT

by

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Abstract. The paper describes mining activities at the Velika Pirešica quarry in Slovenia and the introduction of a new environmentally-friendly mining method. In the last few years computer applications have become an almost indispensable tool in mine planning. Based on the introduction of the new mining method and reclamation problems in the Velika Pirešica region, the authors will present a 3D virtual model which was developed and used in environmental impact studies. For 3D visualization, the authors decided to use the Surpac2000 software package. In addition to 3D design the software package supports various database formats. Databases connected to the geometrical database contain useful geological, physical and chemical data, etc. The application of the virtual model and its role in reclamation, practical planning and decision-making at the Velika Pirešica Quarry are discussed. The advantages of virtual quarry modeling will also be illustrated and detailed in this paper.

Additional Key Words: environmentally-friendly mining method, virtual quarry model

Introduction

Computer-aided systems are almost indispensable for engineering and planning. In addition to fast planning and large time savings, they enable the preparation of realistic photograph-quality images of planned structures prior to their construction. Traditional modeling methods are nowadays being replaced by three-dimensional virtual models produced from plans with the use of CAD tools. Computer-aided systems also enable the entry of corrections and changes later in the planning process, and the cooperation and coordination of engineers from various fields. The study of virtual models allows engineers to have direct contact with the structure they are planning, in virtual space, before any actual work is done on it.

The chief product of the Velika Pirešica quarry is limestone, as well as dolomitized limestone and dolomite. The quarry's annual production is estimated at 500,000 m^3, i.e. 750,000 t of rock. The reserves of the entire exploitation field amount to 22 million tons (until 2063), while reserves within the boudaries of the presently approved exploitation area amount to 6.3 million m^3 (until 2013). The quarry provides aggregates of different fractions for the needs of civil engineering and road construction and aggregates for the production of different types of asphalt and concrete.

The first part of the paper presents the basic parameters of the quarry and its further development. This is followed by a description of the procedures which have enabled the production of a three-dimensional virtual model of the Velika Pirešica quarry. The nse of the virtual model of the Velika Pirešica quarry is also presented.

Location of the bed of mineral raw materials

The area of the Velika Pirešica quarry is defined as an exploitation area for the production and processing of limestone and dolomite aggregates. The quarry's regular production provides aggregates of different fractions for the needs of civil engineering and road construction and aggregates for the production of different types of asphalt and concrete.

The quarry is named after Velika Pirešica, a village located in the central part of northeastern Slovenia, between Celje and Velenje, in the Pirešica stream valley. The valley cuts into the hills on the northern outskirts of the lower Savinja river valley (the Celje basin). West of the valley lies the Ponikovska (or

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Ponikvanska) plain, which is characterized by Karst relief covered in vegetation, partially forests and partially grass. East of the valley lies a slightly more textured relief of Pernovo, Galicija and Hramše, where the steeper slopes are generally covered by forests and the gentler ones more by grass. At the southern end of the valley, the slopes of Pernovo are first less steep and then increasingly steeper, and rise up into the Lasje hill. Due to the exploitation of mineral raw materials, this slope has been completely transformed and will experience further morphological changes until the end of its exploitation. The Lasje hill, on which the excavation area of the quarry is located, is covered in deciduous forest on its western and southern sides. East of the quarry there are meadows on which lie the hamlets of Gorica in Železno.

Figure 1. Top view on the Velika Pirešica quarry.

The surface layer of the ground is composed of brown-red soil, which is characteristic of Carboniferous soil. The thickness of the surface layer does not exceed 30 cm.

The exploitation area of the quarry and the entire area of the Velika Pirešica site are not populated, with the exception of two farms at the extreme southeastern end of the quarry (see Figure 1.). Residential buildings are located outside the exploitation and research area towards northeast, at a distance of about 300 m. When the exploitation of mineral raw materials reaches the boundaries of the exploitation field, the work area will come close to the residential buildings, within a distance 50 - 100 m. The area of land which lies within the exploitation boundaries is 20.15 ha.

The quarry has been operating for several decades. It was opened before the Second World War and was then privately owned. After the war, the quarry was nationalized and production was resumed due to the large need for construction materials. The quarry was managed by the Celje Section of the Republic Administration for Roads until 1962, when the Celje Road Building Company took over the administrative duties. Its production increased with the construction of a new sorting (separation) facility in 1966. In parallel with the increase in capacity, an asphalt plant was constructed for road network maintenance in the Celje area. In 1970 and 1971, another new separation facility was constructed and mass mining was introduced due to a further increase in the quarry's capacity. The asphalt plant is located at a distance of approx. 300 m from the quarry's separation facility and it operates almost exclusively with the use of mineral raw materials from the quarry.

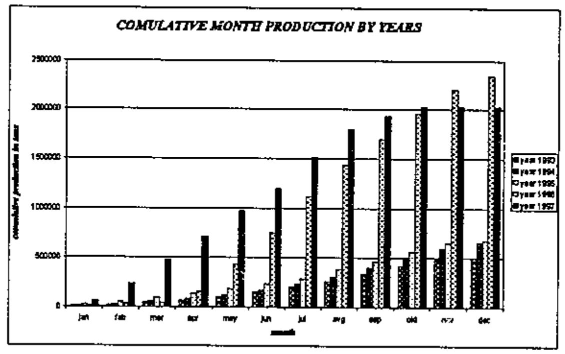

Figure 2. Production of mineral raw materials per month for the period 1993-1997.

Due to the increasingly greater demand for construction materials for the construction of highways and rebuilding of old roads, production has increased even further in the past two years (see Figure 2.), with relatively low additional costs and minor renovations of buildings and equipment. The present normal capacity of the quarry and the separation facility is estimated at 500,000 m^3 of ineral raw materials per year, i.e. 750,000 t of rock.

<u>Reserves of mineral raw materials</u>

The reserves of the entire exploitation field at the present normal rate of production will last for about 66 years (until 2063), while reserves of the presently used exploitation field will last for about 16 years (until 2013).

The continuation of exploitation in the excavation field, limited by the current approval, will depend on the purchase of additional private land parcels. However, the present proposal for the arrangement plan does not anticipate any purchase of additional land, because the entire currently excavated area is owned by the quarry. The question arises of the economic consequences of a possible reduction of the exploitation area for the development of exploitation of mineral raw materials at the Velika Pirešica site, since the production dynamics in the plan were determined on the basis of the average expected demand and the possibility of increasing production during the construction of a highway in the area of the quarry.

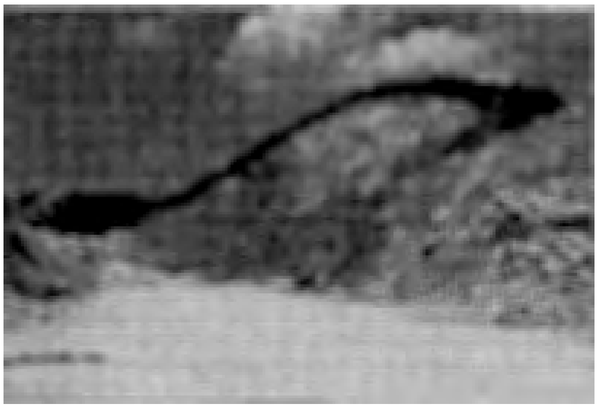

Figure 3. View on the exploatation area of the Velika Pirešica quarry.

<u>Construction of the excavation area</u>

The following factors were taken into account during the construction of the excavation area:

- Boundaries according to the proposed site plan
- Conditions for efficient recultivation of the excavation area
- Final purpose of the area on which mining work is performed

With regard to site structure, excavation needs to be performed from above downwards (see Figure 3.) using two systems of terraces in order to provide high-quality fractions and enable immediate recultivation of excavated levels:

- System of temporary terraces (limestone)
- System of final terraces (dolomite and limestone).

For the purpose of excavation, the excavation area is divided by height into work levels with heights of 20 m (higher levels) and 15 m (lower levels) and final terraces with a height of 30 m. The following work levels will be formed within the excavation area: elevation 275 m (E275), E280, E295, E310, E325, E340, E355, E370, E385, E400, E420, E440 and E460. In the system of final terraces, the following final levels will be formed: E275, E280, E310, E340, E370, E400, E420 and E460.

The basic level is E295. It contains the collection bin of the existing sorting facility. Two more levels, E280 and E275, are planned beneath the basic level. It is planned that water accumulation in the excavation area will reach the height of level E 280, therefore the anticipated width of this stage is 50 m. The height above sea level of the lowest level will be determined with respect to the level of ground water and other hydrogeological conditions for the excavation of mineral raw materials.

<u>Technological procedure for the excavation</u>

The technological procedure for the excavation of mineral raw materials at the Velika Pirešica quarry includes the following processes:

- Blasting of mineral raw materials
- Breaking of large rocks with a hydraulic hammer
- Loading of excavated mineral raw materials into a mobile crusher
- First crushing of mineral raw materials
- Transport of mineral raw materials by dump truck (conveyor belts)

Blasting of mineral raw materials is performed by drilling deep oblique boreholes 76-89 mm and horizontal bottom boreholes with the same diameter, and by large-scale blasting. Single-row and double-row arrangements of boreholes are used, with a distance of about 3.5 m between boreholes. A combination of Amonal V and Nitrol I powder explosives is used, and also Komex C in special conditions. Specific consumption of explosives amounts to from 0.25 kg/m^3 to 0.35 kg/m^3. Drilling and blasting are performed by a contractor at a price of 1.6 DM/t.

The quarry has rented a KRUPP-90 hydraulic hammer on cat tracks for the breaking of large rocks at an average price of 0.22 DM/t.

The loading of excavated mineral raw materials is performed by another contractor using a CATERPILLAR loader with a shovel of 2-7 m^3 volume. The average hourly production capacity of the loader is 300 t per machine hour.

Preliminary crushing is performed using two NORDBERG LOKOTRAC 1313 mobile crushers with capacities of 400 t/h (fractions 0/150) or 180 t/h (fractions 0/32), ownership of the quarry. The average productivity of the mobile crusher in crushing limestone is 240 t per machine hour. The annnal number of operating hours depends on the anticipated average annual demand and amounts to from 3330 to 5000 operating hours.

The transport of excavated raw materials will be performed by trucks in the transitional period until transport by conveyor belts is introduced (by the year 2000). The quarry owns several ASTRO BM 501 dump trucks with bed capacities of 17 and 28 m^3. Transport by conveyor belts is economically justified for excavation at levels E310, E295, E280 and E275.

Environmental degradation caused by quarry operation

With regard to the duration of the negative influence of the excavation of mineral raw materials, the following effects are distinguished:

- Permanent changes in the area
- Temporary changes in the area
- Momentary disturbances in the area

Permanent negative effects of the excavation of mineral raw materials include destruction of and damage to the ground and biotopes within the excavation area, changes of relief within the excavation area and changes of the visible environment in the wider surroundings of the quarry (the positions of working and final terraces in the quarry).

Temporary negative spatial disturbances include dustiness in the immediate vicinity of the quarry.

Momentary disturbances include noise due to machine operation, gas emissions from internal combustion engines and the effects of blasting.

Permanent changes in the area

Up to 1997, 17 ha of land have been completely degraded by mining work at the Velika Pirešica quarry. Turf has been selectively removed and deposited on the southern border of the excavated area. If the present excavation method continues to be used, the final size of the degraded area will amount to about 41 ha.

Temporary changes in the area

The following sources of dust emissions due to surface mining of mineral raw materials in the Velika Pirešica quarry can be identified:

- Crushing and sorting of mineral raw materials
- Road transport of mineral raw materials
- Reloading of mineral raw materials following the system of work terraces
- Drilling and blasting

Dustiness of the surroundings is present in dry seasons. The dust does not contain flint particles and is not harmful to health, but it causes some disturbance of the living environment.

Momentary disturbances in the area

Noise from machine operation is caused above all by diesel internal combustion engines and compressors. During normal operation of the Velika Pirešica quarry, currently 10 to 15 machines with a total power of about 1000 kW operate simultaneously.

Mass blasting in the quarry is performed by drilling boreholes and using millisecond delay detonators. The amount of explosive for simultaneous activation and the millisecond interval are determined such that vibrations never exceed 2 mm/s, which is in conformance with the categorization of buildings located in the vicinity of the quarry and their distance from the blasting field. Safety from the dispersion of blasted materials is ensured by a safety distance of R=250 m. During blasting, air pressure at a distance of 200 m from the quarry does not exceed 3 mbar.

In addition to gas emissions from machines, gas emissions created by blasting also need to be taken into account. With the annual production of 800,000 t and the existing technology, the estimated average consumption of diesel fuel is 90 kg/h of quarry operation. The annual consumption of explosives is approx. 100 t or on averages 26 kg/h of quarry operation.

Measures to reduce environmental degradation

These measures can be divided into long-term and operative ones.

Long-term measures to reduce environmental degradation

Include:

- Changes in the excavation system
- Spatial arrangement measures
- Technical measures

A change in the excavation system, i.e. progression of work from the highest levels downwards instead of the former horizontal, parallel progression of the excavation front at all levels has enabled simultaneous recultivation of the final terraces. This has reduced the extent of environmental degradation in real time.

In planning the rehabilitation of the excavation area at the Velika Pirešica quarry, the long-term purpose of use of this area and its recultivation after the cessation of mining work need to be determined, and the execution of current mining work needs to be adapted to that. A preliminary proposal for the final use of the excavated area in the quarry includes the use of recultivated areas for recreation purposes. Level E275 could serve as a water surface (15 ha), level E280 for various sports grounds (football, tennis, volleyball, basketball, etc.) and infrastructure buildings (8.3 ha). All levels above level E280 will be covered by forests and will have access roads for individual levels.

A reduction in dustiness of the surroundings can be achieved through the following measures:

- Replacement of road transport with conveyor belts
- Pouring of excavated materials between levels will be replaced by controlled pouring through closed channels and pipes

The introduction of conveyor belts for the transport of excavated raw materials will cause an increase in costs, but will at the same time enable central interlevel pouring of materials using closed channels.

A reduction of noise caused by machine operation can be achieved through the following measures:

- Replacement of road transport with conveyor belts
- Reduction of work site exposure
- Installation of an antinoise barrier by recultivating temporary terraces

Reduction of work site exposure can be achieved by using mobile crushers or surface cutters in the cuts, such that a work terrace of an excavation site is always located between the populated surroundings and the work site.

Reduction of the influence of blasting can be achieved only partially by introducing a surface cutter. With respect to the position of mineral raw materials in the excavation area, especially dolomite, the reduction will be noticeable only in the northern part of the excavation area, at higher exposed work levels. A preliminary assessment of the physical and mechanical properties of the dolomite indicates that the introduction of a surface cutter would not cause an increase in the costs of excavation.

A reduction of the influence of gas emissions from internal combustion engines can be achieved by introducing conveyor belts in the surface mining of mineral raw materials. The use of a surface cutter for dolomite reduces gas emissions by approx. 35 % and the use of an electrically powered mobile crusher reduces gas emissions by approx. 30 %.

<u>Operative measures for a reduction of environmental degradation</u>

Operative measures include the use and conscientious maintenance of dust removal devices on machines for crushing and sorting and on machines for drilling boreholes for blasting.

<u>Recultivation of the excavation and excavated area</u>

The decision on the final use of the excavated area will enable the beginning of the performance of rehabilitation measures with respect to the adaptation of relief shape, recultivation of the ground with appropriate plants, arrangement of surface water drainage and arrangement of the water regime in the collection pool. The adaptation of the excavation area to relief shapes for final use is presented in Figure 4.

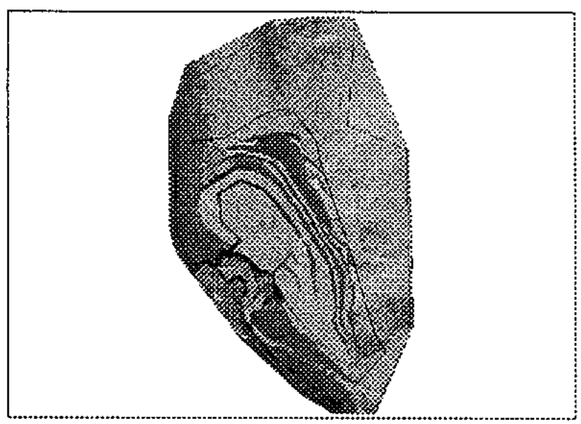

Figure 4. Top view on virtual model of the Velika Pirešica quarry.

Two types of recultivation of the system of terraces are planned:

- Digging of two longitudinal planting rows on each level
- Digging of two planting holes in steep final terrace slopes

Longitudinal planting rows will be dug simultaneously with the progression of the excavation front when the final or temporary terraces are still part of work level terraces. In this manner, the production of the rows will be part of the excavation process and will not entail any additional costs. Each level will have an outer and an inner row with a driving lane for access to the level. Oblique surfaces which connect levels will have planting rows as well. Where there are road connections in the temporary terrace system, only an inner planting row is planned. Taller tree varieties will be planted immediately next to the terrace slopes in order to cover the slopes as much as possible. Bushes will be planted as undergrowth. At the edge of each level the band of vegetation will consist mainly of bushes and groups of smaller trees. Fast-growing plants will be planted above all on the temporary terraces.

Plant holes will be made by blasting. The longitudinal distance between holes will vary in order to avoid the feeling of symmetry. The planting row and holes will be subsequently filled with turf, which will be acquired in the preparation of lower levels for excavation. The holes will be planted with different types of climbing plants.

The area of Velika Pirešica has the pronounced characteristics of a continental climate with a lower amount of precipitation, lower average annual temperature and greater temperature variation, a higher number of frost days and a shorter growing season. Fog appears here less often, but in spring and autumn it often reduces the effect of frost. The northern slope of the excavation area is not exposed to cold northern winds and receives a great deal of sun.

Virtual study of the visual appearance of the quarry

Surface mining of mineral raw materials causes changes in the terrain in the excavation area. Instead of a uniformly inclined slope of the Lasje hill, a system of working and final terraces will be created in time, which will consist of horizontal levels and very steep slopes. In order to determine the visual impact of work on this area, a study of phase opening of the quarry was made using a virtual model. The table below presents the calculated surface area of the system of final terraces in the horizontal and vertical projection. The vertical projection is very important for the assessment of environmental degradation because it due to direct visual exposure.

	Horizontal projection		Horizontal and vertical surfaces	
Levels and roads	35.5 ha	86 %	35.5 ha	69 %
Steep terrace slopes	5.6 ha	14 %	16.2 ha	31 %
Total	41.1 ha	100 %	51.7 ha	100 %

The study of the visual appearance of the quarry shows a large exposure of the steep slopes of the excavation area from large distances, especially for slopes above level E325 in a total area of approx. 6 ha. The southern slope of the Lasje hill is visible from the Šempeter-Žalec road and from the planned highway.

Virtual comparison of two different excavation concepts

The Velika Pirešica quarry used to employ two different concepts of excavation of the slope in accordance with the site plan. The two concepts were visualized using Surpac2000 and virtual models of the final state were made. The selected concepts were then compared and the concept presented in Figure 4. was selected.

Virtual model

The virtual model is a computer-aided 3D graphical simulation which provides the user to have visual contact with the model. The virtual model can be made by digitalization of the existing documentation (plans, cave maps, etc.) using data obtained by terrain surveying, aerial photogrammetry and photogrammetric processing of satellite imagery. A database is produced from the existing data and it serves as the basis for the production of the virtual model. In addition to data on mining structures, the database can also contain geological and hydrogeological data and the results of chemical research, as well as data on drilling and mechanical data, etc.

The spatial position of mining structures on ordinary cave maps and plans both on the surface and below it are hard to understand for people who are not mining specialists. Virtual modeling allows spatial 3D presentation of mining structures from different perspectives. This type of presentation can be used for business presentations, for public presentation of planned work, for the presentation of mining structures to visitors, in advertising, etc.

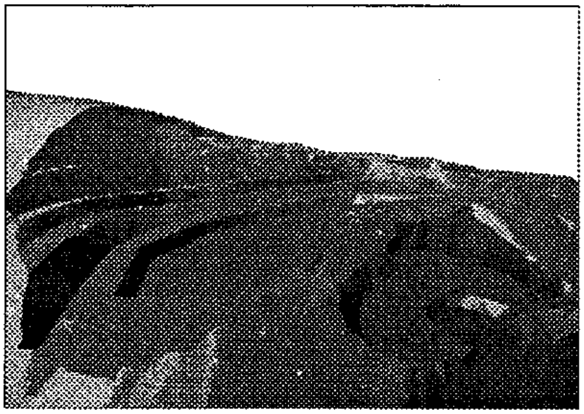

Figure 5. Perspective view on virtual model of the Velika Pirešica quarry.

Virtual model the Velika Pirešica quarry

A virtual model of the Velika Pirešica quarry is one of the first attempts at virtual modeling of surface mining in Slovenia.

For the production and visualization of the virtual model, a 150 MHz PC 486 DX with 64MB DRAM and a Surpac2000 program package ver. 3.0-A were used.

Data on the quarry was acquired by digitalization of the existing documentation and by processing DXF format files using surveying data on the quarry and its surroundings. The database is updated along with the progression of work in the quarry.

The database was used for the production of a series of string files with 3D data on the terrain in the quarry surroundings, development of individual levels in the quarry, access roads to levels, etc. This later enabled the production of optional data combinations. String files are the basis for the digital terrain model (DTM) and subsequently the virtual model. DTM files contain a digital description of the upper surface of the terrain. They consist of two parts:

- The data part contains data on known points with surface point altitudes
- The program part enables the calculation of altitudes at unknown point using known point by spatial interpolation

Calculation of the volume of mineral raw materials

The volume of mineral raw materials in the excavation area was determined using the transverse parallel profiles method at a distance of 50 m and verified with a DTM with the aid of the virtual model. Profiles were updated as of September 1996. The volume mass of mineral raw materials of 2,6 t/m^3 and an excavation efficiency of 0.99 were considered in the calculation. The comparison of results for the volume of mineral raw materials acquired by different methods showed no deviations.

Two different DTMs are needed in order to calculate the volume of mineral raw materials. The first DTM represents the relief of the previous situation in the quarry and the second one the new, updated situation. The total volume between the two DTMs is calculated using Surpac2000.

It was calculated that up to the year 2013, 17.8 million tons of limestone and 0.5 million tons of dolomite (a total of 18.3 million tons) can be excavated.

Conclusion

The Velika Pirešica quarry pays particular attention to the elimination or reduction of environmental degradation due to intense excavation of mineral raw materials. With this aim the quarry began to introduce corresponding measures and began using a new, environmentally more friendly excavation method. A change of the excavation method to progession from the highest levels downwards (in comparison with horizontal progression of the excavation front at all levels) enables immediate recultivation of the final terraces after the completion of excavation on each level.

The introduction of virtual modeling into everyday mining practice may mean a large step forward in preserving the competitiveness of the mining industry. Virtual modeling may completely change the methodology of planning and construction of structures, reduce unnecessary costs, reduce the costs of production and maintenance of mining structures, etc. It also enables engineers from different fields to visualize complex mining structures, plan new ones and test or compare new concepts with the old ones. Mining structures whose construction would take months or years can be produced quickly in the form of virtual models. Virtual models enable a reduction of costs and large time-savings at the early phase of planning of mining structures. With respect to efficiency, this places them even ahead of rapidly developing prototyping technologies.

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