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DETERMINATION RESULTS ON POTENTIAL PRODUCTION OF OPEN PIT MINES AT CEMENT RAW MATERIAL DEPOSITS IN RUSSIAN REGIONS BY SATELLITE REMOTE SENSING DATA

The information obtained using the satellite technologies of remote sensing provides new massive knowledge about open pit mining operations at deposits of carbonate rocks for manufacture of cement in 26 regions of Russia. The number of mining and haulage machines operating in each individual open pit mine and within the whole cement industry sector is determined. The obtained information was used in the analytical estimation of each open pit mine capacity and the overall potential production in this sector. By the authors' estimates, the annual technologically feasible volume of rock mass treated in 47 open pit mines of the cement industry is 190 Mt, including 135 Mt of useful minerals.

Keywords: *remote sensing, open pit mining, cement raw material deposit, open pit mine capacity, overall potential production, mining and haulage machines, remote monitoring*

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Introduction

The cement industry constitutes the industrialization basement in any country. The money matter of the industry performance directly depends on the suppliers of cement produced at calcium mineral quarries, on the one hand, and on the demand for cement by the market participant at the scale of a nation or the world. Recently the cement industry is to ensure success in implementation of two national projects entitled as The Safe and High Quality Highways and The Residence and Urban Environment, intended to improve the quality of life in Russia. To this effect, it is critical to have an integrated picture of the current mineral resources and mineral reserves, as well as about the potential production of open pit mines within the structure of the cement industry.

The regular satellite data are used by climatologists and researchers in the area of reparative ecology, appraisal of forest resources of the Earth, assessment of rotation areas, etc. [1–14]. The literature review reveals a deficiency in applied engineering using the remote sensing data, and this deficiency is concerned with the technology and production studies in the mining industry. The present paper authors believe it is urgent and highly promising to investigate production aspects in open pit mining of solid minerals using the satellite technologies of the remote sensing. This approach to nonmetallic mineral mining is described in [15]. This research trend will remain relevant in the near future as in the territory of more than 17 million square kilometers in Russia, it is indeed impossible to get an integral insight into production performance of various mining practices in the current conditions of the subsoil management using traditional methods of statistics gathering. The free information resources of satellite surveys provided an integral representation of the current situation concerned with the mineral reserves in the cement industry in Russia and enabled determining the total potential production of all open pit mines involved [16].

Studies in open pit mining and total potential production of quarries within the cement industry

Cement production uses raw materials composed of rocks containing calcium lime (CaO) or calcium carbonate ($CaCO_3$). The common carbonate rocks in Russia are limestone, chalk, shell limestone and tufaceous limestone. Out of carbonate-and-clay rock types, the cement industry uses marly limestone and marl. Quaternary rocks introduced in the cement composition in amount of 8–10% are mostly clay and include shale, loam, loess and loess soil.

The integrated studies into open pit mining in the cement industry included: identification of regions of operating cement plants and open pits producing raw materials for cement manufacture using the satellite images (using some information from [17]); review of basic characteristics of open pit mining; determination of operating or long-standing mining and haulage machines in open pits; description of natural geography of the deposits (surface terrain, water content of deposits, etc.); evaluation of annual capacity of each shovel engaged either in overburden removal or actual excavation in each open pit; estimate of haulage distance for cement raw material from receiving bunkers at open pit to cement plants and for overburden to dumping sites; calculation of overall volume of rocks sent to cement plant in Russia within the limits of a calendar year.

Based on the satellite survey data, it is found that 26 regions hold large operating cement plants which possess one (or two) open pits of raw materials for cement manufacture. Furthermore, there are 34 deposits of rocks suitable for cement manufacture are developed using the open pit method in Russia (see the **table**). More than a half of the deposits (19) are developed in the form of 16 open pits in European Russia due to the historically mature capacity of the industry and high concentration of population. Inside a smaller sector in the Urals and in the Orenburg Region, 10 open pit mines extract cement raw material from 6 deposits. In the most extended geographical sector of Russia, between Novosibirsk and southern Primorye in the east, 11 open pit mines at 9 deposits produce raw material for the cement industry.

The tabulated data for the regions in European Russia and in the Ural were obtained by readout of information from satellite images of the territory from the north to the south and from the west to the east, while the territory of Siberia and Russian Far East was analyzed west–eastward. For the open pit mines in the cement industry, the authors assumed Academician Rzhevsky's classification of open pit solid mineral mining. Open pit mining with cutback of one or two working flanks is carried out in 39 pits. These deposits mostly occur in an even land or on a gently dipping terrain with the level difference of 10–20 m per 1 km of ground surface. These pits often have the depth in a range of 30–60 m. At three deposits (3101, 6401, 3401) the bottom level exceeds –60 m and reaches even –100 m (deposit 3401).

This group also includes two pits (central and southern) at deposit No. 2303 and a pit at deposit No. 3801. These pit are located on the mountainous terrain and are upland mining projects therefore, but mining is advanced without deepening and with one working flank.

As seen in the satellite images, mining with deepening (when pit bottom is deepened vertically), with cutback of one or two working flanks (horizontally) is carried out in 8 open pits. In pits at deposits No. 2303 (in the north) and No. 2401, deepening and cutback are executed concurrently. At the same time, the upland flanks of these pits remains long-standing (more than 20 years). In carbonate rock pits at deposits Nos. 0901, 2301, 2302, 7401, 5901 and 0301, deepening and cutback of a single working flank along its whole height are carried out simultaneously.

At deposit No. 1301 the cement raw material is produced by three open pit mines. Geological explorations at Pikalevskoe and Tarakan deposit identified two isolated productive sites. Each site is being developed by an individual surface mine. Each of deposits Nos. 6401, 0901, 5901, 6601, 6602, 7402 and 5401 has two open pits within one cement plant. One of the pits produces 90–92% of cement raw materials (carbonate rocks), and the other pit gives 8–10% of shale.

The remote monitoring data show that alongside with the deposits of cement raw materials described in the table, European Russia holds three deposits (Afanasevskoe in the Moscow Region, Savinskoe in the Arkhangelsk Region and Zhigulevskoe in the Samara Region) suspended between 2017 and 2018. These open pit mines deliver no raw material to any cement plant. However, shovels and drill rigs, the open pits are equipped with, are yet there and standing ready for use, thus, the operations can be readily resumed at these deposits when necessary.

From the satellite survey data, it is found that open pit mining of cement raw materials is carried out using crawler-mounted excavators with rope drive (EKG-8i, EKG-10) or rope-rack-and-gear drive (EKG-5A), as well as hydraulic excavators with bucket capacity no higher than 10 m^3. In European Russia, in open pits at excessively watered deposits Nos. 3201, 4701, 1301, 7301, 7302, 3101 and 3401, overburden removal and actual mineral extraction are performed using draglines with bucket capacity from 4 to 20 m^3 and with a boom 40 to 90 m long.

Let us discuss a few pits on free satellite images. An operating open pit limestone mine in the Sverdlovsk Region (No. 6602) is shown in **Fig. 1**. The pit has two working flanks. Mining is advanced in the north and in the south (yellow-color arrows). A flank has five 12 m-high benches. Overburden, except for the loose quaternary rocks at the top, is subjected to ripping by blasting. The open pit is 1230×1550 m in plan. In the northeast of the pit, there is a shoulder 250×500 m. The depth of the pit is constantly 60 m. All benches are operating. The length of the mining front along the upper bench is 3600 m.

The access to the operating benches in the north of the pit is made via a permanent road embedded in the structure of

Geography of cement raw material deposits and open pit mining description in Russia

Region	Cement raw material deposit, identification number	Mining system, open pit depth m (pit wall height, m)
European Russia		
Leningrad Region	Pikalevskoe, 4701	SALOF, 45–60
Komi Republic	Pravoberezhnoe, 1101 Levoberezhnoe, 1102	SALOF, 20–22 SALOF, 22–25
Moscow Region	Shchurovskoe, 5001	SALOF, 26–30
Tula Region	Gurovskoe, 7101	SALOF, 35–40
Bryansk Region	Fokinskoe, 3201	SALOF, 30–40
Ryazan Region	Serebryanskoe-I, 6201 Kumovogorskoe, 6202	SALOF, 45–50 SALTF, 35–40
Mordovia	Alekseevskoe, 1301	SALOF, SALTF, 30–35
Lipetsk Region	Sokol-Sitovskoe, 4801	SALOF, 50–55
Ulyanovsk Region	Shirokovskoe, 7301 Shirokovskoe II, 7302	SALOF, 42–45 SALOF, 42–45
Belgorod Region	Belgorodskoe, 3101	SALOF, 75–80
Saratov Region	Bolshevik, 6401	SALOF, 45–90
Volgograd Region	Sebryakovskoe, 3401	SALOF, 45–100
Karachay-Cherkessia	Dzhegutinskoe, 0901	SALOF, DACOF 30 (120)
Krasnodar Krai	Novorossiyskoe IV, 2301 Verkhnebakanskoe, 2302 Novorossiyskoe I+III, 2303	CRDM, 20 (40) CRDM, 15 (50) SALOF, CRDM, 30 (240)
Ural and Orenburg Region		
Perm Krai	Novo-Pashiyskoe, 5901	SALOF, DACOF, 25 (60)
Sverdlovsk Region	Nevyanskoe-I, 6601 Kunar, 6602	SALTF, 35–40 SALTF, 60
Chelyabinsk Region	Gora Gruzdovnik, 7401 Sheinskoe, 7402	DACOF, 20 (75) SALTF, 40–45
Orenburg Region	Akkerman, 5601	SALTF, 45–50
Siberia and Russian Far East		
Novosibirsk Region	Chernorechenskoe, 5401	SALTF, 55–60
Kemerovo Region	Solominskoe, 4201	SALTF, 55–60
Krasnoyarsk Krai	Torgashinskoe, 2401 Kuznetsovskoe, 2402	DACOF, 40–45 SALOF, 15–20
Irkutsk Region	Pereval, 3801	SALOF, 150–160
Buryatia	Tarakan, 0301	SALOF, DACOF 30 (60)
Republic of Sakha (Yakutia)	Sasaabyt, 1401	SALTF, 45–50
Jewish Autonomous Oblast	Teploozerskoe, 7901	SALOF, 45–50
Primorsky Krai	Dlinnogorskoe, 2501	SALTF, 40–50

Comments: SALOF—surface mining along the strike with one working flank; SACOF—surface mining across the strike with one working flank; SALTF—surface mining along the strike with two working flanks; DACOF—deepening mining across the strike with one working flank; CRDM—centered ring-wise deepening mining.

Fig. 1. Operating open pit mine at deposit No. 6602 in the Sverdlovsk Region, satellite image

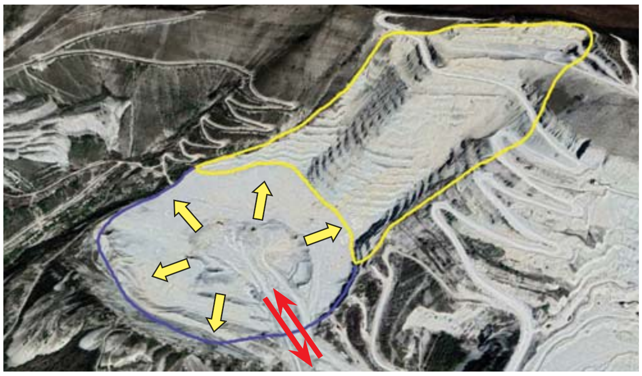

Fig. 2. Northern deep-and-upland type pit at deposit No. 2303 in the Krasnodar Region

the non-mining western flank. In the south, dump trucks come to the excavation benches along driveways with double-shift directions of traffic and with traffic outlet in the south of the non-mining western flank.

The roads have a gradient of 60‰ toward the pit. The exit direction for dump trucks is marked by red-color arrows.

A northern pit (one of three pits) of the mixed deep-and-upland type at marl deposit No. 2303 is shown in **Fig. 2**. The upland portion of the pit is delineated by the yellow line, and the deep portion—by the blue line. Mining in the upland area is suspended, which is clear in the image. On the right, there is a permanent access road to the top benches on the other side of the hill. Dump trucks 6 times alternate the traffic direction. The upland part of the pit has 20 non-mining benches 12 m high each. The total non-mining flank height is 240 m. The depth of the pit in the deep part is 48 m. At the time of the image, mining operations were carried out on the third and fourth benches. The advance direction of the deep mining is shown by yellow-colored arrows.

Access to working benches is provided by straight driveways with the exit for dump trucks in the southeast of the pit. The traffic direction of dump trucks is marked by red-colored arrows.

All deposits of cement raw materials in Russia are conditionally divided into two groups: horizontal (or gently dipping at 2–3°) bedding of productive carbonate rocks overlaid with loose quaternary sedimentation; large stockworks of carbonate rocks, to a few tens of kilometers long along three axes (x, y, z). The geology of the first-group deposits allows surface mining with one or two working flanks. Such deposits usually occur on the even land.

The second-group deposits occur on the dissected or mountainous terrain. Mining involves deepening with concurrent cutback of the pit walls. At all deposits, overburden rocks mean the top quaternary layer to 30 m thick and barren rocks, and are placed in dumps.

The satellite image identification allowed fixing models of drill rigs and excavators, as well as capacities of dump trucks and dumpcars, and the number of the latter in trains to be loaded. The analytical calculations using common procedures of open pit mine planning and design estimated annual capacities of excavators in each pit included in the testing program. The annual capacity is estimated with regard to bucket capacity and maintenance/repair times, and is then adjusted by the face cutting complexity (type of a face, specific weight of oversizes in disintegration of broken rocks) and by the height of disintegration of broken rocks. The numbers and size of oversizes are credibly determined on the satellite images. Later on, the execution condition of annual capacities of excavators was checked with respect two technological constraints.

The first constraint is feasibility of rock ripping by blasting. It was checked whether the volume of rocks prepared by drilling (using available drill rigs determined from the satellite survey data) is equal to the volume of loosened rocks for the complete loading of excavators. Capacities of drill rigs is determined based on the design variables and with regard to rock drillability and blasthole length. The comparison reveals that in each open pit under analysis, available drill rigs ensure 100% loading of available excavators. This technological constraint exists when enclosing rock mass requires drilling-and-blasting before actual mining.

The second constraint of the annual capacity condition for an excavator is sufficiency of dump trucks. The number of dump trucks (or trains) required for continuous operation of excavators is compared with the actual number of machines available for haulage of rocks out of the pit. The annual capacity of a dump truck (or a train) is calculated using common procedures of transport structure design in open pit mining. The calculations take into account tonnage of dump trucks, time of loading by excavator, longitudinal gradient of a motor (or rail) road along its whole length, terrain, haulage distance, elevation different between the exit from the pit and the unloading point of a dump truck. For the railway transport, the travel time to an excavator is determined with regard to the interchange point location relative to the excavator installation site. All characteristics, except for the loading time of transport, are determined from satellite images.

At the next stage, the design capacities of the pits were summed up. The overburden volumes were found from their thickness and from the annual advance of mining operations, which was reliably definable from the highly detailed satellite images.

After interpretation of satellite images, equipment of 26 mining regions of Russia with mining and haulage machines is as follows. Drilling and blasting operations are performed in the pits at nearly all deposits, except for deposits Nos. 3201, 1301, 7301, 7302, 3101 and 6401. Drilling involves 49 drill rigs SBSH-250, including their import analogs. Drill rigs are placed in the pits in accordance with produced volumes of cement raw material. All 31 draglines with bucket capacity from 4 to 20 m^3 operate in European Russia in overburden removal and in productive cutting at deposits Nos. 4701, 3201, 1301, 7301, 7302, 3101 and 3401. Only dragline ESH-20/90 is engaged in overburden rehandling at Pikalevskoe deposit.

In the Volgograd Region, in the pit at deposit No. 3401, the top overburden layer is stripped using the only rotor excavator in this industry sector, ERG-1600, in combination with spreader OSH-1600/110 used for internal dumping. Excavators operated in open pit mines producing raw material for manufacture of cement are equipped with rope drives mostly and with hydraulic drives to a lesser extent. There are 92 excavators EKG-5A. Crawler-mounted excavators EKG-8i and EKG-10 in amount of 29 machines operate in combination with railway transport or with dump trucks with bucket capacity of 40–55 t in the open pits in European Russia, and two machines EKG-8i are used in a pit at deposit No. 4201. Excavation is also carried out by 47 hydraulic excavators with bucket capacity from 2 to 8 m^3. Three open pit mines at deposits Nos. № 4801, 6401 and 0901 use surface miners.

Rock haulage operations use 344 dump trucks with bucket capacity to 55 t. Open pits with enclosing rock mass having low load-bearing capacity are equipped with 32 articulated-frame dump trucks of foreign manufacture, with chassis type 6×6 and capacity up to 25 t. The railway transport is used in the surface mines in European Russia, when it is required to ensure production out at the level of 6 Mt and more per year. In this case, dump trucks become inefficient. The railway transport includes 30 locomotives TEM-7, 8 electrics EL-21 and 364 dumpcars 5VS-60 and 2VS-105. Haulage distance of dump trucks in all open pits ranges widely from 1 to 10 km, the haulage distance of railway transport varies from 4.5 to 14.5 km.

In this manner, owners of cement plants and associated open pit in Russia use 1036 mining and haulage machines, including 49 drill rigs, 31 draglines, 170 crawler-mounted excavators, 376 dump trucks with capacity of 20–55 t and 402 units of railway transport. Furthermore, stripping and mining operations use 1 rotor excavator in combination with a spreader, and 6 surface miners.

Based on the data of remote sensing, four large industrial associations producing cement in European Russia operate open pit mines equipped with 363 mining machines. In the Bryansk Region, two plants supplied with raw materials from Fokinskoe deposit annually produce 4.5 Mt of cement. In Mordovia, at Alekseevskoe deposit, four operating cement plants ensure annual production of 10 Mt of cement. In the Volgograd Region, three cement plants using raw material from Sebryakovskoe deposit produce 6 Mt of cement per year. In the Krasnodar Krai, on the right-hand bank of the Tsimlyansk reservoir, four plants annually produce 9 Mt of high-quality cement. In the other regions of Russia, the annual production of cement amounts 1.2 to 1.3 Mt.

From the evidence of the satellite survey data and analytical calculations, the total technologically feasible volume of rock mass in 47 open pit mines producing raw material for the cement industry in 26 test regions in Russia is 190 Mt yearly. This figure includes the overburden volume of 55 Mt. The remote sensing also allowed identifying the main process equipment at the cement plants in Russia. All in all, the cement industry employs pipe rotating furnaces with diameter from 3 to 7 m and 90 to 180 m long, and 15 large systems for cement manufacture using dry process. This process equipment is capable to ensure cement production at the level of 90 Mt per year.

Conclusions

Thus, the use of the remote sensing technology and high-resolution satellite images has made it possible to accomplish the large-scale studies into open pit mining operations in the cement industry, with identification of mining systems, as well as characteristics of technology, equipment and logistics. The studies into arrangement of mining and haulage machinery in open pit mines enabled analytical calculations of each pit capacity in stripping and in actual mining. The critical numerical result is the overall potential production of open pit mines of cement raw materials.

According to the analytical estimation, the mining and haulage machinery available in the cement industry can provide the annular production round 135–136 Mt of minerals. In the test territories of Russia—European Russia, Ural and Orenburg Region, and Siberia and Russian Far East, the technologically feasible mineral production to supply cement plants is 95, 18 and 22 Mt per year, respectively. These volumes of cement raw materials are advised to take into account in the annual cement production estimation with a view to strategic planning of mineral resources to ensure efficient implementation of the national projects on The Safe and High Quality Highways and The Residence and Urban Environment in every specific region of Russia.

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SCIENTIFIC AND TECHNOLOGICAL FOUNDATIONS FOR GROUNDWATER EXTRACTION BY THE INJECTION-FORCED SELF-DISCHARGE METHOD

The problem of developing underground water deposits is particularly relevant at the moment. The existing method of opening aquifers by drilling vertical wells is ineffective in terms of water yield in relation to the amount of drilling activity, material and labor costs.

A system for opening and extracting underground water by the injection-forced self-discharge method is proposed, based on the use of internal energy of aquifers and the physical principles of water withdrawal (injection) and lifting to a height (hyd-ram).

Structurally, the system consists of an injection and a water-lifting well connected by a smooth bend at depth and oriented towards the attitude of aquifers.

The system is equipped with a cascade of a hydrojet device designed to implement the effect of injection and a hyd-ram, as well as a water return tank.

The initial hydrogeological prerequisites for extracting underground water by the injection-forced self-discharge method were established, and the conditions and means of creating a system of communicating wells were determined.

The design parameters of the hydro-jet device cascade and their purpose were specified.

The system technical capabilities test was carried out on a test-setup designed in accordance with the research objectives and the physical principles of modeling hydraulic phenomena.

A series of experiments recorded the dependence of the injection coefficient on the gravitational water yield coefficient at different working water flow rates.

Information is given about the advantages of the proposed system for extracting underground water by the injection-forced self-discharge method in comparison with the traditional method of exploration and development of underground water deposits.

Keywords: *underground water, drilling, wells, aquifers, injection, hyd-ram, hydrojet, self-discharge*
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Introduction

Traditional for all types of groundwater deposits, the method of opening aquifers by drilling vertical wells is obsolete. The disadvantages are a significant amount of well drilling in waste rocks, a limited area of opening aquifers in relation to the value of their thickness, low water yield, the need to use energy-consuming deep pumps and airlifts, laborious to maintain and repair, to extract water.

There was a need for a radical restructuring of the system for the development of groundwater deposits on a new ideological basis, where the efficiency indicator is the ratio of the volume of extracted water to the physical volume of well drilling.

The main idea is to achieve a forced groundwater self-discharge by using the internal energy of aquifers in combination with the physical principles of water withdrawal (injection) and lifting to a height (hyd-ram).

The idea of the injection-forced groundwater self-discharge method was taken