The reuse of mining and construction waste for backfill as one of the sustainable activities

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Abstract. Human civilization brings the need for energy sources and construction materials. A large amount of materials are extracted from deep and open pit mines. Mining activities are inevitably related to the large direct impact on the local environment (dewatering, landscape). A lot of spoil material is produced in the course of mining production and further processing of extracted products. Various issues of the use of waste material from empty rocks, enrichment tailings and demolition works in civil engineering as a backfilling material should be analyzed. All factors must be considered depending on the amount of the material to be used for the construction of embankments or fillings, the cost of its processing before reuse and environmental cost of the transport. The implementation of sustainable technologies may reduce the costs for the mining waste disposal in dumps, as well as minimize the negative impact of mining enterprises on the region ecology and comfort of inhabitants. The same benefits can be observed on a smaller scale when construction waste material (debris) is considered. The work presents overall conditions for abandoned working in the deposits underground development in selected regions of Russia and some experiences gathered at numerous construction sites in Poland where the working of machines (rollers, impulse compactors) imposed vibrations on neighboring areas. In order to take into account the totality of all forms of the impact of geotechnology on the natural environment and neighboring human activities in the course of extraction of the minerals and to improve measures for the rational use of natural resources, a complete change in the concept of environmental protection is necessary. It is necessary to move from purely protective measures to the planned management of natural resources and to develop a mathematical model of the impact of geotechnology on the environment. It is also crucial to increase the role of environmental issues in mining and civil engineering education at universities and specialized institutions to form a new generation of mining engineers and civil engineers who will take into account all the aspects of sustainable and responsible work.

1. Introduction – social aspects of waste production
Industrial society cannot do without the consumption of natural resources. Currently, the volume of mined mineral resources in the world is estimated at billions of tons. The constant increase in the volume of extraction and production of minerals often occurs at the expense of compliance with...
environmental norms. The mining industry has a significant impact on the environment: millions of tons of harmful substances are emitted into the atmosphere, millions of cubic meters of contaminated wastewater are discharged into the water bodies, and a huge amount of solid waste is stored on the surface of the earth. As a rule, the area of adjacent territories affected by the activities of mining enterprises is incomparable with the development territory itself, and often exceeds the area of adjacent cities (Figure 1). The analysis presented below focuses mainly on the last factor e.g. production and storing of a large amount of solid waste in the course of mining activities.

Recently, during the extraction of minerals, various indirectly man-made disasters occur. By the form of environmental impact, they go beyond the previously known. In developing deposits in the Urals, Kuzbass and Gornaya Shoria, the Kola Peninsula in Russia, and also in the foreign deposits, mountain-tectonic shocks occur. They cause fractures on the surface, the formation of dips (Figure 2), the appearance of cracks, the disappearance of watercourses, etc. Technogenic seismicity is noted in the development of oil and gas fields, construction of ultra-high buildings in cities. Technogenic seismicity has become a social factor in some mining regions of Russia. This situation led to an increased risk of exploitation of other industrial production and began to have a direct effect on the biological optimum for humans.

Figure 1. Zone of the technogenic impact of the mining enterprise (1) and the territory of the city (2)  

Figure 2. Failure in the territory of BKPRU-1 of OJSC Uralkali

In addition, it is necessary to take into account that the development of deposits goes to great depths. This leads to a change in the vertical amplitude of the natural environment. Taking into account the depth of development and the heights (heaps) in the mining regions of Russia, the amplitude reaches 2.000-2.500 m. Technical and economic indicators of mining are taken into account initially when choosing the method and development systems. The influence of human activity on the environment has reached a size commensurate with the impact of natural processes on the Earth. Therefore, the economic consequences of the impact of mining on the environment must be taken into account. It is necessary to apply technological solutions to rational extraction of minerals from the depths, taking into account all forms of geotechnology impact on the environment. It is also necessary to develop concepts that will ensure the environmental safety of subsoil development. The problem of storing wastes of enrichment and waste rock is one of the most important. Significant areas of agricultural land are seized. The nearby water bodies are polluted. The level of groundwater is changing. In addition, rock dumps and beaches of tailings are sources of dust formation. Similar risk is related to storing large amounts of unprocessed debris from demolition works. Some attempts to deal with the possible reuse of such materials were discussed in the work of Khairutdinov [1-6] and in the work [7]. At the same time, mining waste, as well as recycled concrete, may be suitable for use for large earthworks, under the condition of its neutral environmental impact concerning spreading of chemical contamination or other sources of pollution. Examples of land planning with regard to the
potential use of hard coal tailing dumps were developed at VŠB–Technical University of Ostrava [8,9].

Effective use of technological waste products of mining directly at the mine solves many issues associated with storing them on the surface. Placement of mining and processing industries waste in underground mines (chambers) and voids creates favorable conditions for the introduction of non-waste technologies in the development of ore deposits. Such an approach makes it possible to exclude almost completely the costs of construction and operation of tailing dumps. The use of the development system with the backfill of the abandoned working allows improving the technical and economic parameters of extraction, controlling the mining pressure, and conducting the development of the deposit in a combined way. This technology increases the safety of mining operations and almost completely eliminates the loss of a useful component. However, the use of the backfill significantly influences the increase in production costs. The use of mining waste in the preparation of filling mixes can reduce the negative impact of mining on the environment. The use of tailings for preparation of filling mixes will minimize the area of tailing dumps and lead to a significant reduction in the area of mining outlets. This is especially important in areas with fertile lands. The use of industrial waste to prepare a back-filling mixture has both an ecological and economic effect. The economic effect is achieved by saving money on:

• construction and maintenance of waste storage facilities (tailing dumps, waste rock dumps);
• construction of special quarries for extraction of aggregate;
• fare.

Since tails of enrichment (rocks from dumps) are, as a rule, local material. And the cost of their delivery to the place of consumption is relatively not high. Reducing the harmful impact of geotechnology on the environment, conservation, restoration, enhancement and rational use of natural resources, perhaps due to targeted changes in the technologies used; at the same time, different biological communities react differently to the same effect. Therefore, the limit of the magnitude of each man-caused impact, which is followed by irreversible changes in the ecosystem, should exist for each individual ecosystem. The search for such limits is a fundamental multi-disciplinary problem. The solution of many problems requires an integrated approach and is carried out at the junction of several sciences: geotechnology; economy; ecology and nature management; biology, etc. Underestimation of the mining industry's impact on the environment and environmental damage leads to the selection of an inefficient technological solution. It is necessary to take into account that in the problem of integrated development of mineral resources, taking into account the harmful impact of mining on the environment, there are a number of not fully resolved issues. This is due to a number of reasons for an objective and subjective nature.

• inadequate justification for environmental constraints in the technology of mining and processing of minerals;
• a qualitative difference in the circulation of matter and energy in artificial (economic) systems in comparison with natural (ecological) systems;
• contradictions between technical and economic indicators of mining production and reduction of harmful impact on the environment;
• lack of precise methods of the economic evaluation of natural resources and damage caused by mining to elements of the biosphere;
• often not fully developed concept of planned management of natural resources;
• lack of precise models for calculating the positive or negative impact of the technology applied on the environment.

Similar problems, but with a smaller range of impact can be observed in the case of civil engineering production. Reuse of spoil material from demolition works may be a good training for further large projects related to the reuse of large amounts of mining production spoil material.
Practical aspects of those applications (replacement columns, large embankments formed of debris) were described in works of Kawalec [10,11]. Some novel attempts of numerical analysis of phenomena occurring during the reuse of spoil material can be found in works of Kanty [12-13].

2. The need for practical education of the new generations of students

The above mentioned aspects bring the need of the new way of formation of young engineers profile [14-16], simultaneously focused on both, the efficiency of mining or civil engineering production and reducing of the environmental footprint of the works. The first step that does not require large changes in university curricula could be a system of training periods or students’ exchange programs [17] and/or summer schools [18]. The presented below results of vibration monitoring were gathered in the course of such a training period of Cheynesh Kongar-Syuryun at Wrocław University of Science and Technology (figure 3). The access to the building site was granted by the construction company. Practical education based on visits on the construction site and gathering information and experiences from real production processes helps to understand all the dependencies between natural and technical conditions of performed activities. It is especially important in the case of geotechnical and geo-environmental works, where personal experience must compensate the uncertainties of computational models and scheduling of works.

3. Experiences of training periods with dynamic monitoring of geotechnical works

Special attention should always be paid to the current impact of works (mining, civil engineering) on the neighborhood. It is not determined by long term planning but it just requires fast decisions, like in the so-called observational method of the structural design. Instrumentation of the control procedures and the possibility of fast data acquiring and analysis makes it possible for almost “online” modification of technology when unacceptable interference of impacts is observed and recorded (figure 4.).
Figure 4. Simultaneous work of many vibratory rollers increasing their total impact

Figure 4 and the exemplary graph in figure 5 given below present the situation where vibration control was implemented to measure the joined impact of compacting rollers and other equipment working simultaneously on the test field. Figure 5 gives an image of the randomness of machine positions and time of exposure. The background vibration does not exceed 0.30 mm/s but the peak values reach the limit of 12 mm/s (when the roller approaches at 2.00m from the position of the receiving unit. It may be noticed that most of the severe impacts have a transient nature, however possible interference of impacts may increase both: the intensity of vibrations (measured by means of peak particle velocities) and their duration. Another example of the trial field with vibration control is given in figure 6.

Figure 5. Values of the observed velocities in the time domain in course of trial soil compaction
It is crucial to notice that large scale phenomena described in the introductory section are significant but does not appear every day and, due to their unique manner, cannot form the basis for strict recommendations. The ability of testing and setting of strict limits is always limited everywhere, where the natural phenomena are considered and where natural ground conditions meet the dynamic impact of human activities. Some attempts to summarize the author’s experiences were presented in works [19-21]. Description of vibration control procedures and criteria of acceptance were given for numerous technologies like: machine induced vibrations [22], blasting works [23], piling [24] and Rapid Impulse Compaction [25,26]. That range of anthropogenic (non-seismic) vibrations may be to some extent reduced by means of active generators. A brief summary of such techniques and examples of numerical modeling of active generators’ efficiency are presented in works of Herbut [27,28]. All the dynamic impacts may bring some threats not only to existing structures but also to the new build ones [29]. A Comprehensive research on the impact of vibrations on steel-concrete adherence was published by Wojtowicz et al. [30,31].

4. Practical application of sustainable technology of spoil material reuse
Large amounts of spoil crushed brick and concrete are produced in course of demolition works. Various ways of its reuse in geotechnical engineering were described in reference [10]. Field training and understanding of the variety of problems that can appear in course of its application help in proper decision making in the mining industry where the amount of spoil material is much bigger. Large infrastructural projects may be the solution. Figure 7 shows the deposit of unsorted concrete with some steel reinforcement before its final extraction. Placing of this debris over a landfill and further compaction is presented in figure 8. The machinery used for the soil replacement column formation makes it possible for forming well compacted ground slab on partially replaced subsoil by means of stone columns. The only disadvantage of this technology is the large dynamic impact that may limit its application in close vicinity of some objects (building structures and objects under other environmental restrictions). But that problem may be to some extent solved by the monitoring.
Figure 7. Deposit of unsorted crushed concrete before reuse

Figure 8. Machinery involved in forming of earthworks out of the debris

All the activities related to the reuse of spoil materials should be surely proceeded by laboratory and preferably field testing of their durability. Crushed rocks, concrete and especially crushed ceramic materials may change their parameters in time and depend on external conditions (humidity). Implementation of easily degradable material (crushed bricks) may cause weak slip planes like in the case of soft clayey material underlying rock masses [32].

5. Conclusions
Raising demands of contemporary modern societies for energy, infrastructure and goods supply raise the problem of the spoil material from production plants and its possible reuse. Both mining and civil engineering sectors of industry have a potential for “producing” and reuse of spoil material. In both cases, sustainable activities are inevitably related to the environmental impact (transport, crushing and sorting, providing the desired state of compaction). It is, however, the only price that has to be paid for getting rid of debris. Modern monitoring systems allow for keeping whose impacts within acceptable limits. There is a big need for a proper engineering education and supporting active and practical teaching activities for specialists from both mining and civil engineering sector. The international cooperation, like activities described in the current study, is a perfect and relatively cheap way of widening the horizons of new generations of engineers.
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References
[1] М.М. Хайрутдинов, “Пути совершенствования систем разработки с закладкой выработанного пространства”, Ways to improve development systems with laying the developed space, Gornyi Zhurnal, no. 11. pp. 40-43, 2007 (In Russian).
[2] М.М. Хайрутдинов, М.В. Вотяков, "Гидравлическая закладка на калийных рудниках", Hydraulic Bookmark in Potash Mines, Mining Information and Analytical Bulletin, no. 6, pp. 214-218, 2007 (In Russian).
[3] М.М. Хайрутдинов, "Технология закладки высокоплотными смесями (на основе хвостов обогащения) при подземной разработке руд", Technology of laying high-density mixtures (based on tailings) in underground mining of ores, Mining Information and Analytical Bulletin, no. 11. pp. 276-278, 2008 (In Russian).
[4] М.М. Хайрутдинов, М.В. Вотяков, "Возможность применения систем с твердеющей закладкой при отработке калийных месторождений", The possibility of using systems with hardening bookmark during mining of potash deposits, Mining Information and Analytical Bulletin, no. 9, pp. 265-286, 2007 (In Russian).
[5] М.М. Хайрутдинов, “Применение отходов горного производства в качестве закладочного материала для снижения вредного воздействия на окружающую среду”, The use of mining waste as a filling material to reduce the harmful effects on the environment, Gornyi Zhurnal, no. 2. pp. 64-66, 2009 (In Russian).
[6] М.М. Хайрутдинов and И.К. Шаймярдянов, "Подземная геотехнология с закладкой выработанного пространства: недостатки, возможности совершенствования”, Underground geotechnology with the laying of the worked-out space: disadvantages, opportunities for improvement, Mining Information and Analytical Bulletin, no. 1. pp. 240-250, 2009 (In Russian).
[7] Р.О. Качаев, Э.Ц. Айрапетян, А.Л. Иванников, "О соблюдении условий охраны окружающей среды при строительстве подземных хранилищ газа”, On compliance with environmental conditions during the construction of underground gas storage facilities, Mining industry, no. 2, p. 98, 2007 (In Russian).
[8] P. Zástĕrová, D. Niemiec, M. Marschalko, J. Durďák, M. Duraj, I. Yilmaz, M. Drusa, “Analysis the Purposes of Land Use Planning on the Hard Coal Tailing Dumps”, IOP Conf. Ser.: Earth Environ. Sci., vol. 44 (2), 022034, 2016.
[9] D. Niemiec, M. Duraj, X. Cheng, M.Marschalko, J. Kubáč, „Selected Black-Coal Mine Waste Dumps in the Ostrava Karviná Region: An Analysis of Their Potential Use”, IOP Conf. Ser.: Earth Environ. Sci., vol. 95, 042061, 2017.
[10] J. Kawalec, S. Kwiecień, A. Pilipenko, J. Rybak, “Application of crushed concrete in geotechnical engineering - selected issues”, IOP Conf. Ser.-: Earth Environ. Sci., 95, 022057, 2017.
[11] J. Kawalec, T. Warchal, “Dynamic Replacement Columns with Aggregate Transition Zone Stabilized by Geosynthetics for Embankment Foundation over Weak Deposits”, XVI European Conf. on Soil Mech. and Geotech. Eng., Edinburgh, pp. 1511-1516, 2015.
[12] P. Kanty, K. Sternik, S. Kwiecień, “Numerical analysis of consolidation of embankment subsoil reinforced with dynamic replacement stone columns”, Technical Trans., 2-S (24), pp. 79-100, 2015.
[13] W.T. Solowski, S.W. Sloan, P.T. Kanty, S. Kwiecień, “Numerical simulation of a small scale dynamic replacement stone column creation experiment”, 3rd Int. Conf. on Particle-based Methods Fundamentals and Applications, PARTICLES, pp. 522-533, 2013.
[14] Д.А. Палехов, М. Шmidt, Б. Хансманин, Л.Л. Палехова, А.Б. Копылов, А.Л. Иванников, "Проблема организации высшего образования в интересах устойчивого развития", The problem of organizing higher education for sustainable development, 10th Int. Conf. on Mining, Constr. and Energy, Tula, November 6-7 2014, vol. 1, pp. 34-51, 2014 (In Russian).

[15] Drusa M., Sitáňiová D., "Experiences from advanced teaching in Geotechnics under Erasmus programme", Proc. of the 1st Int. Conf. on Education and Training in Geo-Engineering Sciences: Soil Mechanics, Geotechnical Engineering, Engineering Geology and Rock Mechanics, pp. 421-425, 2008.

[16] J. Kozubal, “Technical universities for civil engineering career in Republic of Poland”, Procedia Engineering, vol. 117, pp. 516-524, 2015.

[17] J. Rybak, A. Egorova, K. Ohotnikova, I. Fernandes, A. Ivannikov, „Some remarks on experience based geotechnical education”, 17th Int. Multidisciplinary Scientific GeoConf. SGEM 2017, 29 June – 5 July, Albena, Bulgaria, vol. 17, Issue 12. pp. 1003-1011, 2017.

[18] Д.А. Палехов, М.В. Рогоза, А.Л. Иванников, "Роль летних школ в стимулировании "зеленого" образования в ВУЗах". The role of summer schools in promoting "green" education in universities, I International Scientific and Practical Internet Conference, December 25-26, 2014 - Dnepropetrovsk-Cottbus: NSU-BTU / under total ed. V. Ya. Shvets, L. L. Palekhova. - Dnepropetrovsk: PP emphasis, p. 195, 2015 (In Russian).

[19] J. Rybak, K. Schabowicz, “Survey of vibrations generated in course of geotechnical works”. NDE for Safety: 40th int. conf. and NDT exhibition: proceedings, Brno University of Technology, pp. 237-246, 2010.

[20] F. Oliveira, I. Fernandes, “Influence of geotechnical works on neighboring structures”, 17th Int. Multidisciplinary Scientific GeoConference, SGEM 2017. Science and technologies in geology, exploration and mining, vol. 12, pp. 993-1001, 2017.

[21] M. Wyjadłowski, “Methodology of dynamic monitoring of structures in the vicinity of hydrotechnical works - selected case studies”, Stud. Geotech. Mech., 39 (4), 121-129, 2017.

[22] J. Grosel, W.M. Pakos, W. Sawicki, “Experimental Measurements as the Basis for Determination of the Source of Pumps’ Excessive Vibration”, Procedia Eng., vol. 111, 269-276, 2015.

[23] D. Papan, V. Valaskova, M. Drusa, “Numerical and experimental case study of blasting works effect”, IOP Conf. Ser.: Earth Environ. Sci., vol. 44 (5), 052052, 2016.

[24] W. Brząkała, M. Baca, “The measurement and control of building vibrations in course of sheet pile wall and Franki pile driving”, 17th Int. Multidisciplinary Sci. GeoConf., SGEM 2017 Science and technologies in geology, exploration and mining, vol. 12, pp. 929-936, 2017.

[25] A. Herbut, J. Rybak, “Numerical Modelling of Rayleigh Wave Propagation in Course of Rapid Impulse Compaction”, IOP Conf. Ser.: Mater. Sci. Eng., vol. 245, 032001, 2017.

[26] P. Dobrzycki, P. Rychlewski, „Site control procedures for applicability and quality of Rapid Impulse Compaction”, MATEC Web. Conf., vol. 251, 02018, 2018.

[27] A. Herbut, "The efficiency of an active generator in the case of a deep foundation location", Stud. Geotech. Mech., vol. 39(1), pp. 3-12, 2017.

[28] A. Herbut, “A proposal for vibration isolation of structures by using a wave generator”, Soil Dyn. Earthq. Eng., vol. 100, pp. 573–585, 2017.

[29] O. Lohunova, M. Wyjadłowski, “Modification of vibratory driving technology for sustainable construction works”, MATEC Web of Conf., 151, 03063, 2018.

[30] A. Wojtowicz, J. Michalek, A Ubysz, “How vibrations affect steel-to-concrete adherence”, MATEC Web Conf., vol. 251, 02045, 2018.

[31] A. Wojtowicz, J. Michalek, A Ubysz, “Range of dynamic impact of geotechnical works on reinforced concrete structures”, E3S Web Conf., vol. 97, 03026, 2019.

[32] E. Sanz-Pérez, I. Menéndez-Pidal, A. Lomoschitz, R. Galindo-Aires, “The pico de navas slump (Burgos, Spain): A large rocky landslide caused by underlying clayey sand”, Journal of Iberian Geology, vol. 42 (1), pp. 55-68, 2016.