



## LITHUANIAN MINERAL RESOURCES, THEIR RESERVES AND POSSIBILITIES FOR THEIR USAGE IN ROAD BUILDING

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**Abstract.** This article has an aim to review the range and value of the underground resources of the Republic of Lithuania, to analyse the quality of local aggregates used for road building purposes and to recommend how local aggregates have to be used in order to give the max benefit for the state and public welfare. All the investigated in detail mineral resources of the Republic of Lithuania make almost one third of the value of the property the country. All the deposits of dolomite, gravel and sand explored in detail and used for road building, construction and other purposes occur under the less than 0.1% of the territory of the country. It was found that extraction and processing of local dolomite and gravel resources up to the max use of their potential properties for road building and other purposes saves over 700 mln LTL (over 200 mln EUR) per year in the cash flow of the Republic of Lithuania. It was determined that the physical and mechanical indices of asphalt concrete, containing crushed pebble and crushed dolomite, differ insignificantly. Based on the comparison to the normative requirements, local aggregate products consumption in asphalt concrete could be increased by extra 8–10% compared to the use of imported materials. It was recommended, that various subbase material mixtures from local, imported or mixed compositions were extra tested and analysed after at least of 350–700 freezing and thawing cycles corresponding to the average of 10–20 years subbase service under Lithuanian mild winter climate conditions with a high number of freezing and thawing cycles. The article gives a complex analysis of the research results versus the condition of the underground mineral resources and presents conclusions valuable for both geologists, road building scientists and engineers as well as decision makers finalising *The Strategy for the Optimum Use of Lithuanian Underground Mineral Resources* potential and implementing the *Communications of the European Commission the Raw Materials Initiative - Meeting our Critical Needs for Growth and Jobs in Europe* and *Improving Framework Conditions for Extracting Minerals for the EU*.

**Keywords:** geology, highway engineering, aggregates, raw materials, road building material properties, rational use of resources, strategy.

### 1. Introduction

Mineral resources are natural mineral materials occurring in the underground and used for production or other purposes. According to the amount and value of their extraction and utilization, the most important mineral materials in the world are those used for construction industry and road building, i.e. crushed stone, freestone and finishing stone, gravel and sand, raw materials of energy resources (oil, coal, peat), iron ore, limestone for cement industry and agriculture, clay, rock salt, etc. With the improving technologies in mining and processing industry and increasing number of population in the world, in order to maintain the already reached standard of life, the amount of world widely extracted resources has extremely increased – in the last century their extraction has been larger than in the whole lifetime of humanity.

The volume of extraction of all kinds of mineral resources shows that valuable resources are not only those glittering as gold. More than 29 billion t of mineral resources are extracted in the world per year, of which about 17 billion t (or up to 60%) consist of gravel, sand and crushed stone produced by crushing solid rocks or shingle. This means that according to the volume of extraction gravel, sand and crushed stone take the first place, and in monetary terms – the second place in the world and this makes the mining industry very important in various aspects. Lithuania is rich enough in what was settled from the seas and lagoons several hundred million years ago and what was left by the glaciers having occupied the territory of Lithuania for several times. Mineral resources, called as local and used in construction, road building and production of building materials, are familiar to many of us from the

childhood, they are surrounding and habitual to us and frequently nobody thinks that when used scientifically justified and rationally it is a significant part of the property of the state. Besides the widely spread mineral resources, Lithuania has valuable resources found in single areas – iron ore, anhydrite, rock salt, oil.

At present 17 kinds of mineral resources have been found and investigated in more or less detail (Table 1). Today, as well as earlier, 10 kinds of resources are extracted, such as dolomite, peat, limestone, clay, gravel, oil, marl, opoka (gaize), sapropel, however, extraction of the last three kinds is carried out discontinuously, and that of oil – was started only in 1990. Lithuanian mining companies create working places, promote regional development, cheapen the prices of new infrastructure projects by short-distance transportation of materials, adjust the recultivated excavation sites to the state and public demands, pay various taxes, of which the tax on the use of underground resources supplements the state budget with a several tens of a mln LTL every year. By new legislation decision the state tax on most of national resources has increased twice since 2010.

## 2. Reserves of mineral resources

In the *Classification of Solid Mineral Resources of the Republic of Lithuania* all the reserves of mineral resources are classified by three criteria: geological exploration, investigation of utilization possibilities and economic value. Since economical value and utilization possibilities of resources most frequently depend on the development of technologies, legal background, economic conditions of the state and market changes, and are variable values, thus, the

herein given information on mineral resources is based on the detail of geological exploration, i.e. are they explored in detail, in general or prognostic (detected or supposed).

The total area of mineral resources explored in detail, in general or prognostic takes only 0.283 mln ha or 4.3% of the territory of Lithuania. Of them more than half of the total area is taken by peat resources.

Reliability of resources explored in detail is the largest. Their value, based on data of the Statistics of Lithuania, in 2007 amounted to 58.3 billion LTL and made 29% of the total value of state property.

The deposits of dolomite, gravel and sand explored in detail and used for road building and other purposes occur under 6.8 thousand ha or 0.096% of the territory of Lithuania, their value amounts to 3.2 billion LTL and makes 1.6% of the state property value. According to the state property value per the area of Lithuanian territory, the value of explored in detail dolomite and gravel deposits is the most expensive in the country (30.9% of property value/1% of the territory) compared to the value of all resources (13.5% of property value/1% of the territory), roads of national significance (11.5% of property value/1% of the territory) and the value of forest land and the land of agricultural designation (2.8% of property value/1% of the territory). The value of explored in detail of resource lots being in use of dolomite and gravel deposits per the unit of the occupied area of the country is 16.6 times higher than the total value of state property divided by the area of the country.

This state property lies under the land rented for excavation by the state, under the state or private forests, private land, to be given back for private ownership, or to be

**Table 1.** Mineral resources of the Republic of Lithuania according Lithuanian Geological Survey in 2008

No	Mineral resources	Unit	Extraction of mineral resources in 2008	Amount of resources explored in detail	Amount of resources explored in general	Amount of detected prognostic resources	Amount of supposed prognostic resources
1	Rock salt	mln t	–	–	545.0	–	2450.0
2	Anhydrite	mln t	–	101.5	–	–	–
3	Dolomite	mln m <sup>3</sup>	2.359	106.71	140.59	306.0	–
4	Peat	mln t	0.448	206.96	370.5	1.867	–
5	Iron ore Fe > 20%, of which Fe > 45%	mln t	–	–	219.6 142.1	71.0 9.2	201.4 120.6
6	Fresh-water limestone	mln m <sup>3</sup>	–	0.6	1.0	0.219	–
7	Amber	thous t	–	–	0.112	0.227	–
8	Gypsum	mln t	–	23.3	2.2	9.3	–
9	Glauconite sandy loam	mln m <sup>3</sup>	–	–	7.4	21.681	–
10	Limestone	mln t	1.632	369.91	762.8	1780.0	50.0
11	Chalky marl	mln t	–	13.09	4.0	41.928	–
12	Clay	mln m <sup>3</sup>	0.301	141.20	102.70	113.212	–
13	Oil	mln t	0.12771	2.699	1.205	0.120	8.157
14	Gaize	mln t	–	33.7	–	–	–
15	Sapropel	mln m <sup>3</sup>	–	4.29	15.90	63.441	94.277
16	Gravel and sand	mln m <sup>3</sup>	12.047	745.36	982.61	3083.425	31.279

repurchased by state for public interest. For the state itself this facilitates or burdens the access to the use of its exclusive ownership – underground resources. This also strongly influences a continuous rationality of the use of resources especially in cases of separate land plots which are less than 100 ha and restricts the public and state interest in a rational and economically justified use of resources.

Reliability of the amount and quality of mineral resources explored in general, and especially prognostic ones, is lower than of those explored in detail, and conditions for their occurrence and mining are often more complicated, since first of all the resources of better quality and of more favourable mining conditions were initially investigated in more detail. A real potential of mineral resources is made of resources explored in detail and in general, while the prognostic resources is a reserve for future. The value of resources of various level of exploration differs not only according to the economic, public, national security, geopolitical, state cash flows, import-export balance or other criteria. Those criteria must be determined before setting priorities for the use of each kind of national resources.

Specific features of geological structure of the underground of our country determined conditions for the occurrence of mineral resources (depth, location) and their uneven distribution in respect of the territory. Almost all kinds of resources occur on the surface or under a small cover ranging from 1 m to 10 m, more seldom – to several meters. Only the resources of rock salt, anhydrite and iron ore were detected at a depth of 300–460 m, the depth of oil is usually higher than 1800 m from the surface.

Mineral resources of different kinds are distributed unevenly in respect of the territory of Lithuania, their distribution by kind, amount and detail of exploration within the territory of Lithuanian counties are given in Fig. 1.

The largest amount of resources, found in Lithuania, is of the most frequently used gravel and sand, limestone and dolomite. The largest part of explored gravel and sand resources is located in Vilnius, Kaunas, Utena, Alytus and Tauragė counties. All the detected deposits of dolomite and limestone are located in the northern part of the country in the territory of Šiauliai and Panevėžys (only dolomite) counties.

Any excavation of mineral resources, without doubt, affects the customary equilibrium of natural environment, however, the nature and extent of this impact is a function of interaction between the type of raw material to be excavated, natural conditions, excavation duration and technical-economical-environmental-social possibilities. Environmental impact caused by excavation of a larger part of the currently used deposits of mineral resources is not significant, since the cover sediment, spoil, the extracted raw materials and their processing waste according to the regulations of the *Directive 2006/21/EC on the Management of Waste from the Extractive Industries (the Mining Waste Directive)* meet the definition of inert materials having no negative impact on the environment. At present all the mineral resources of our country, with the exception of oil, are excavated only in open-pit mines (quarries). The depth of gravel, sand, clay, peat and dolomite quarries usually amounts to 6–12 m, of limestone and opoka (gaize) up to 15–30 m, and only the deepest quarry where Triassic clay is extracted is about 50 m deep. Only in several quarries (peat, limestone, dolomite, sand) the ground water or underground water level is being lowered due to self flowing or pumping up. After excavation of mineral resources there is usually a possibility to recultivate the excavated areas in a way not to only neutralize excavation consequences, not to decrease and even increase a functional-aesthetic value of the landscape.

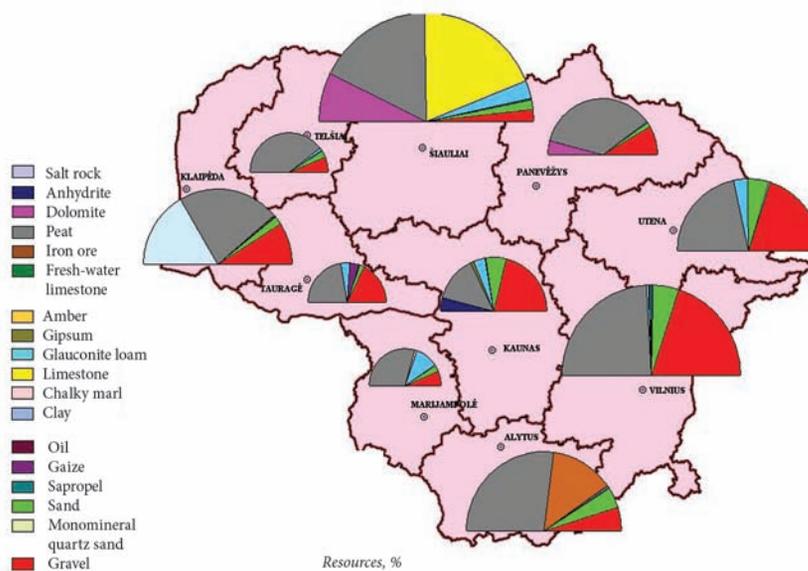


Fig. 1. Mineral resources explored in detail and in general in the counties of the Republic of Lithuania according Lithuanian Geological Survey in 2008

It is very important to harmonize the restored (created) geosystem with the surrounding landscape, land-tenure and regional demands. It often happens that the recultivated pits and quarries are adjusted to public demands: Kazokiškės dump in the former Kazokiškės gravel pit, Lampėdžiai and Kunigiškės water bodies in the former gravel pits, Ukmergė motor cross track “Versmė” in the recultivated part of Radiškės gravel pit, Pakruojis motor cross track in the recultivated Petrašiūnai dolomite quarry, etc.

### 3. Extraction of mineral resources in Lithuania

The legal base of Lithuania provides for that the underground and its mineral resources is an exclusive property of the state or the state has an exclusive right to the underground – this emphasizes that the objects important to national security must be owned by state. Assurance of the rational use of resources is of a public interest, without mineral resources Lithuania would have very limited as well as much more expensive possibilities to develop and improve transportation infrastructure sector which is one of the strategically important bases of national economy. The main axis of this sector – road building and maintenance – consumes the largest part of the locally excavated and properly processed raw materials. Mineral resources are necessary for construction, energy sector, agriculture, high technologies, food industry, health care and other systems (Jonynas *et al.* 2004; Staponkus 2010). The benefit for the public is created not by the existence of resources itself, but by the most optimum final material production and adjustment of their physical, mechanical and chemical properties for creating public welfare.

At the beginning of 2009, the permits for the extraction of solid mineral resources were issued to 244

enterprises. Most enterprises, even 185, are engaged in the extraction of gravel and sand resources, 35 – peat, 10 – clay, 7 – dolomite, and only several enterprises make business from the extraction of other mineral resources. The total about 65% of the resources explored in detail is designated and is under the usage – mainly gravel, limestone, dolomite and peat. The land areas assigned to the enterprises for the extraction of solid mineral resources make 21.2 thousand ha (of which for peat production – 14.4 thousand ha) or 0.32% of the territory of Lithuania.

In the world the amount of various kinds of extracted mineral resources per one inhabitant is approx 4–5 t, whereas, in the economically strong countries – 20 t per one inhabitant per year. In Lithuania twenty years ago this amount came to 10–12 t, in 1996–2001 – only up to 4 t of local mineral resources. From 2002 until the recent years, due to the influence of the developing industry, road and construction business, the amount of extracted mineral resources has been continuously increasing (Fig. 2) and in the year 2008 has reached 5–6 t per one inhabitant. Unfortunately, the recent financial crisis caused sharp changes in the mining industry. This industry was one of those which resulted in the most significant fall in the whole state economy. Stopped construction and sudden limitation of road building and maintenance financing, the volume of extraction in 2009 has in the whole country dropped by 44%. In addition to that, enterprisers producing the highest quality local mineral products (from Lithuanian Aggregate Producers Association – LAPA) had to limit their extraction even more – by extra 9% up to the drop of 53%. The turnover dropped even more. It is to be concluded that financial crisis makes a negative (9%) effect to the use of high quality products. The recent LAPA questionnaire informs that the accumulated January–September 2010 highest qual-

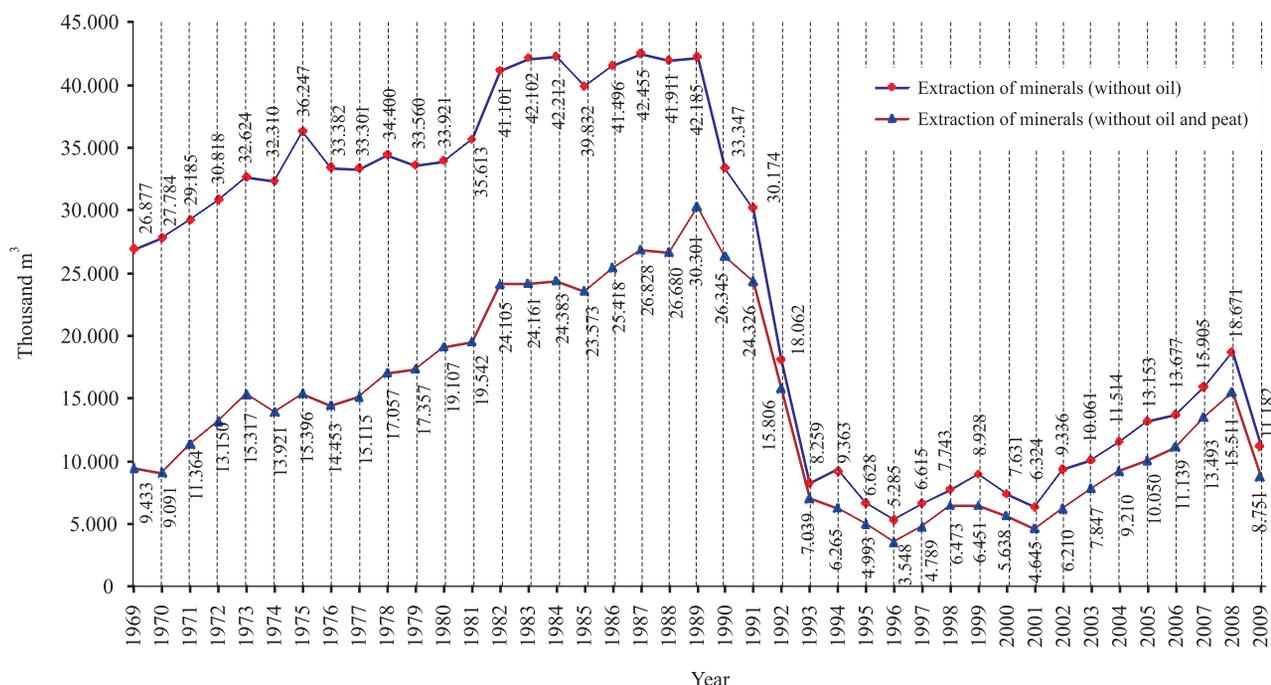


Fig. 2. Total extraction of mineral resources in Lithuania according Lithuanian Geological Survey

ity aggregate market in comparison to the corresponding period of 2009 still continues to drop. In order to survive, mining companies are sharply limiting personal, stopping extraction, selling equipment. The decrease in extraction volumes in 2009 brought the Lithuanian mining industry to the year 2004 and the predicted continuous drop in 2010 is throwing the excavation volumes and industry even further back. Preservation of advanced technologies and survival of enterprises becomes a challenge. Rational and continuous use of national resources faces destructive disturbances.

The largest amounts of resources excavated and consumed in the road building are those of gravel, sand and dolomite, for the production of binding materials – limestone.

Lithuania is provided with most of the being used solid mineral resources not for one century, though, without setting priorities between all resources, certain difficulties may arise in future when implementing Lithuanian Constitutional court explanation on the public interest of rational use of resources and using the max of their potential.

The fact that provision with local mineral resources is very important for the welfare of economy in each country is proved by the *Communications of the European Commission the Raw Materials Initiative – Meeting our Critical Needs for Growth and Jobs in Europe and Improving Framework Conditions for Extracting Minerals for the EU*.

#### 4. Mineral resources used for road building purposes

The largest amount of mineral resources extracted in Lithuania and used for road building purposes is that of gravel, sand and dolomite. For a filter bed the most widely used is local sieved sand, washed and sieved sand or sand-gravel mixtures of various fractions and compositions (Dvareckas, Skrinškas 1998); for road bases or subbases the mostly used are crushed dolomite, crushed gravel shingle and crushed rock of wider fractions and better coarseness imported from Belarus, Ukraine or Scandinavian countries, usually processed in Lithuania before using it according to standards. For asphalt concrete (AC) pavement layers, depending on the normative requirements, the local crushed dolomite or crushed shingle of narrow fractions is used, as well as imported mostly locally secondary or tertiary crushed and washed granite (Čygas et al. 2005).

Aggregates used for railway building consists of few components: laying elements of the top structure of railway track, railway bed and drainage layer. Mineral materials, produced in Lithuania, are also used for constructing, reconstructing or repairing railways. During railway construction, over the main site of railway bed a drainage layer of 15–20 cm sand is laid, when building tracks in the railway station a sand-gravel layer is applied. In both cases the Lithuanian mineral materials are fully suitable. However, for the bases of tracks – railway bed – the imported crushed granite of only E or F category of 31.5–63 mm fraction is used, which is as a rule finally processed in Lithuania.

To have a comparatively wider understanding on material properties short geologic information about gravel, sand and dolomite is presented below.

Gravel and sand are among most widely spread mineral resources in Lithuania. Gravel is a friable sedimentary rock. It consists of particles and fragments of variable diameter. The prevailing particles are those of sand (0.1–2 mm), pebbles (2–20 mm) and shingle (10–100 mm), most often it also contains boulders and particles of clay. Lithuanian gravel consists of crystalline rocks (20–40%) (mainly granite and gneiss), carbonated rocks (limestone, dolomite) and sandstone (50–70%) as well as grains of quartz or feldspar.

Sand is a sedimentary rock. It consists of 60–85% sand grains of 0.1–2 mm of various forms (angular and rounded fragments) consisting of quartz, feldspar, carbonates and some other minerals (mostly heavy) or admixture of rock fragments. Sand is usually of whitish colour, which mainly depends on the amount of quartz and feldspar in it; other colours are determined by the additives like glauconite, which gives green colour, ferrous oxides and hydroxide layer, which give yellow, brown and pinkish colours, organic carbon-rich materials add grey and blackish colour. Sand is friable and porous (its porosity reaches 26–49%). Its density is 1.6–1.8 g/cm<sup>3</sup>. In Lithuania sand is found from the Devonian, Jurassic, Neogene and Quaternary periods, however all known gravel and construction sand deposits are correlated only with Quaternary deposits: glacial and aquaglaciac (sand and gravel) as well as aeolian (sand). The largest deposits of gravel are associated with fluvioglacial deposits (sanders, fluvioglacial terraces and deltas) (Blazauskas et al. 2007).

In 79% of the territory of the Republic of Lithuania sand and gravel deposits are vast, but in 21% of the territory they are very miserable, since up to a 15–20 m depth Quaternary consists of moraine, clay, aleurite or very fine, clayey sand.

Dolomite beds in Lithuania are detected in many geological systems, but only dolomite deposits occurring near the land surface in the northern part of Lithuania in the Upper Devonian Pliaviniai, Įstras, Stipinai, Kruoja or Žagarė formations are considered to be of a practical significance. According to dolomite bed continuity, occurrence conditions, quantity and quality, dolomite of the Stipinai formation was found to be the best for extraction and production of aggregates (Gasiūnienė 1998).

#### 5. Research and analysis of laboratory testing data of local aggregate applicability for road building

Since the chemical composition and hence the mechanical properties of gravel has comparative variation from quarry to quarry and dolomite occurs in layers, with each layer as well as production site manifest differing characteristics, the investigation focused on few leading dolomite and gravel excavation and production sites in Pakruojis and Trakai regions.

Strength is one of the key requirements of the quality of chips. The strength is characterised by the crushability index, the flakiness index measured by pressing particles in a cylinder and resistance to wear measured by a drum test. The parameters simulate the resistance of rock to vehicle-caused loading and other mechanical factors when constructing the road (road grading, compacting) (Mačiulaitis *et al.* 2009; Skrinskas, Domatas 2006).

Majority of results given in Table 2 are based on laboratory testing data using crushed material from the leading Lithuanian high quality road building material production sites: Petrašiūnai and Klovainiai dolomite quarries and Trakai gravel pit.

After analysis of numerous laboratory tests (made by Road Research Laboratory of the Vilnius Gediminas Technical University, SE “Problematika” and JSC “Laboratorinių bandymų centras” laboratories) evaluating key material properties of dolomite and gravel chips, it was found that gravel chips gave better results in: Crushability Index SR8/12, the Polished Stone Value (PSV), amount of particles of P form, adhesion to bitumen (%), with the amount of “Wetfix”, adhesion to bituminous emulsion, frost resistance; dolomite chips presented better results in: Flakiness Index Msk, resistance to fragmentation by the LA test method, resistance to fragmentation by the impact test method (SZ), losses in the mass of particles after 10 freezing and thawing cycles (F50, F100).

The presented test results show that gravel chips have slight priority against dolomite chips, but these differences are not so significant to recommend priority of one or another local material. It should be mentioned that the inspected material properties depend not only on average

quarry or pit material, but also on the location, area or depth in the quarry, from which the material was given to production and further testing, as well as the production and crushing technology used. Therefore, further and wider key material testing with random and independent sampling is recommended.

The prices of delivered material together with material quality are both crucial aspects in the analysis of feasibility of application of local dolomite and gravel chips. The threshold value of the price preference in Lithuania fluctuates each year. Fig. 3 presents the average straight line showing where the prices of the delivered crushed dolomite and crushed gravel in 2009 were the same.

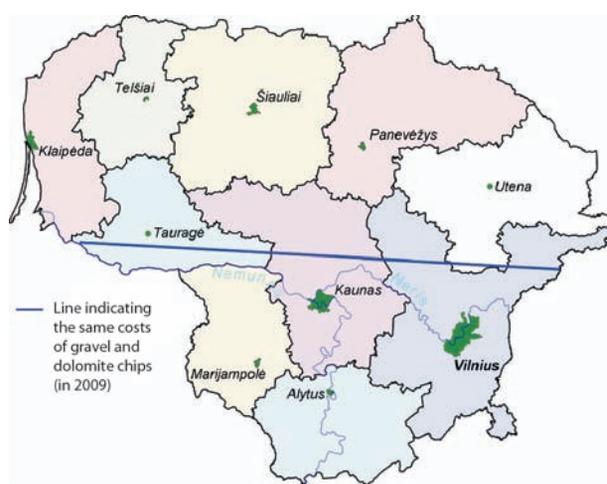


Fig. 3. Average theoretic straight line showing where the prices of the delivered crushed dolomite and crushed gravel in 2009 were the same

Table 2. Comparison of the properties of crushed gravel and crushed dolomite

Properties	Investigation data							
	Dolomite chips				Gravel chips			
	Mean value	Min	Max	Ranking	Mean value	Min	Max	Ranking
Crushability Index SR8/12	17.75	16.6	19.6	2	19.3	17	22.6	1
Flakiness Index Msk	8.45	5.9	16.7	1	11.58	7.5	13.61	2
Resistance to fragmentation by the LA test method	25	30	19	1	30	35	22.5	2
Resistance to fragmentation by the impact test method (SZ)	22.5	27	20	1	23.5	25	22	2
The Polished Stone Value (PSV)	44	41	47	2	47.5	38	52	1
Amount of particles of P form, %	9.8	1.9	19.4	2	6.4	1.1	14.5	1
Adhesion to bitumen (%), with the amount of “Wetfix” of 0.9%	85	85	88	2	87.5	80	95	1
Adhesion to bituminous emulsion, %	67.5	65	70	2	87.5	80	95	1
Frost resistance type		F50	F100	2		F100	F100	1
Losses in the mass of particles after 10 freezing and thawing cycles (F50, F100)	2.86	1.17	5.05	1	6.17	4.12	9.83	2
A sum of first priority positions				4				6
Rank				2				1

The total price of chips, delivered to asphalt plant, depends on both the production and transportation costs. Fig. 3 presents the somewhat of fluctuating threshold border of the sum of both production and transportation costs. Financial feasibility of dolomite delivery is better in the north of the country, versus gravel chips, which are more cost effective in the south of Lithuania. In practice the spread of delivered crushed dolomite or gravel chips (crushed shingle) exceeded the theoretic border line in both directions. The same tendencies are observed when comparing the prices of both dolomite and gravel products used for subbases.

Interesting results were obtained when analysing test results of the local and imported materials and their mixtures used in road bases. One of the characteristic indicators showing the predicted longer service life of the layer of road base under Lithuanian conditions is California Bearing Ratio determined by a percentage ratio between the stamp pressure on the soaked road base mixture and the stamp pressure on standard soil.

The longest service life expectancy is represented by the layers of road base which are built from crushed materials. The worst results are obtained when the road base mixture is produced from uncrushed sand with pebbles and shingle from local quarries. As well it is to be mentioned, that granite mixture fr. 0/56 mm low results were related to the emphasized by the laboratory standard requirements exceeding amount of flat and longitudinal particles.

Based on Fig. 4 it is interesting to conclude that in the layers of road base the best service life is represented by the optimum grading mixtures and not by the imported mixtures of crushed granite known for its better strength properties. The best results are obtained when both the

strength properties of used materials and the continuity properties of their grading curve are the best, water absorption is the least and frost resistance is the best.

The key climatic bottleneck for Lithuanian roads is mild winter conditions with an average of 70–80 freezing and thawing cycles per year (from min 50 cycles/y – to max 90 cycles/y) on the top of the wearing course of road pavement (Juknevičiūtė 2010). Measurements show that almost one half of the freezing and thawing cycles reach subbase. Interesting to note, that European standards do not obligatory require the material testing after more than 10 laboratory made freezing and thawing cycles. The authors of this article recommend that seeking for the economy of road maintenance and reconstruction costs the Lithuanian road maintenance authorities have to arrange the additionally required experiments. In order to find the best road base mixtures suitable for Lithuanian climatic conditions it is obligatory to arrange and finance the complex long-term laboratory research and to test the main properties of subbase layer after at least 350 to 700 freezing and thawing cycles, representing at least 10 to 20 years of road subbase service.

In road building a character of material service in the layers of road bases and in pavement courses differs. Correspondingly, the research methods were selected.

Experimental research into physical and mechanical parameters of the wearing and base course containing dolomite and gravel chips according to Marshall Test were made using both leading quality Petrašiūnai quarry dolomite and crushed gravel from Trakai pit. The tested parameters were:  $P$  (permanence),  $Pl$  (plasticity),  $LA$  (residual porosity),  $\rho_m$  (average density of AC mixture) and  $\rho$  (average density of AC). The test was carried out by vary-

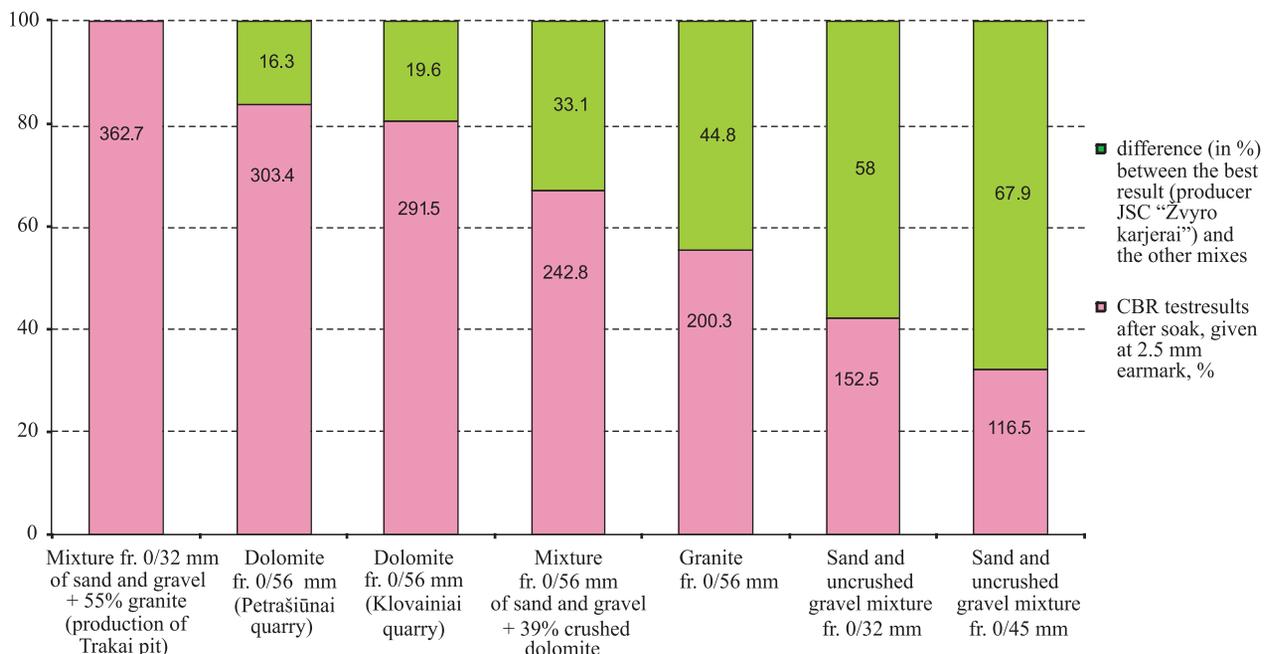


Fig. 4. Comparison of different producers and different road base mixtures according to CBR value after soaking

ing the amount of bitumen in AC from 5.0% to 7.0% (at an interval of 0.5%). It was identified that all of the above parameters largely depend on the percentage of bitumen in AC. Thus, physical and mechanical properties of AC according to Marshall Test are in conformity with the *Statybos Techninis Reglamentas STR 2.06.03:2001 Automobilių keliai* [National Standard R35–01 on Asphalt Concrete and Gravel Pavements of Roads and with the Construction Technical Regulation] (Čygas *et al.* 2005). The research results are presented in Table 3.

AC mixtures with local materials fully correspond to the normative requirements and exceed them. AC mixtures with crushed dolomite exceed the normative requirements by 42% on average (min 10%, max 95%). AC mixtures with crushed gravel shingle exceed the normative requirements by 33% on average (min 8%, max 80%).

It was determined that physical and mechanical indices of AC, containing crushed shingle and crushed dolomite, differ insignificantly, but Petrašiūnai crushed dolomite has slight priority over Trakai crushed gravel. Based on the data obtained the use of local materials according to the minimal exceeding of all normative requirements in road structures could be increased without breaking the normative requirements by 8 for crushed gravel and by 10% for crushed dolomite or more compared to the use of imported materials.

From the point of view of safe driving on a wet pavement, for the wearing course it is better to use gravel chips since their Polished Stone Value (PSV) is higher than that of dolomite chips, and during wet conditions pavement is safer and less slippery.

## 6. Economic and strategic milestones

Presented data on laboratory investigations of road building materials, shows the depth of scientific researches in Lithuania, and a complex entity of data obtained.

Best policy is based on the best science (Lubchenco 1995; 1998). Science, however, is a dynamic, ongoing process that is continually discovering new information. Thus the interaction between science and policy must also be ongoing and dynamic. This article based on thorough few years research data has an additional benefit – not just information, but as well synthesis of complex information, and also a frame of issues and communication to society and policy makers (Lubchenco 1995; Shields 1998). This year is a particular time when European Commission and Lithuanian Government sets priorities for the effective use of raw materials.

The fact that the provision with local mineral resources is very important for the welfare of society and state economy in each country is proved and supported by the *Communication of the European Commission The Raw Materials Initiative – Meeting our Critical Needs for Growth and Jobs in Europe and Improving Framework Conditions for Extracting Minerals for the EU*. Economic values of resources and optimum adjustment of their properties to public welfare gives crucial information for the creators of a strategy for the rational use of the underground resources.

Having made parallels between the presented data of experimental research, data on the specific features of national resources and the goal of Lithuania and European Union to rationalize the extraction and processing of resources seeking for public wealth and competitive economy, it was determined that:

- the most optimal final product of local gravel and dolomite resources is excavated and several times washed, sieved and crushed stone which can replace the expensive imported granite material;
- quality of produced building materials depends on their production technology, skill and management, the quality, the area, the homogeneity and

**Table 3.** Summary of the results of experimental research in AC mixtures

Experimental research	Normative requirements	AC with crushed shingle	AC with crushed dolomite
Base course of AC			
According to Marshall			
Permanence $P$ , kN	$\geq 8.0$	9.1	9.4
Plasticity $Pl$ , mm	2–4	2.5	2.4
Ratio of permanence and plasticity $P/Pl$ , kN/mm	$\geq 2.0$	3.6	3.9
Residual porosity $LA$ , %	3.0–7.0	5.9	5.4
Wearing course of AC			
According to Marshall			
Permanence $P$ , kN	$\geq 8.0$	8.6	8.8
Plasticity $Pl$ , mm	2.5–4.5	3.3	3.6
Ratio of permanence and plasticity $P/Pl$ , kN/mm	$\geq 2.0$	2.6	2.9
Residual porosity $LA$ , %	1.0–4.0	3.2	3.2

even the various layers location within the raw material of resources and other factors. Depending on the above parameters, not in all excavation sites it is feasible to produce the most optimal final products for road building. Only the adequate quality material sites with enough area for the production sites and available resources can be used for production of local dolomite and gravel chips;

- condition and value of different kind of resources, of their quality and level of exploration differ not only by economic, public, national security, geopolitical, import-export balance, national monetary cash flow or other criteria. They are subjects of additional analysis when preparing a strategy for the use of Lithuanian mineral resources which would ensure the optimum use of their economic potential and enrich and support implementation of Communications of the European Commission;
- accessibility of the explored in detail resources for rational and undisturbed use is the state and public interest;
- estimates of economic and public value of the production of the most optimal final product of local resources would be the first step to support the rational decision making.

Calculations based on 2007 and 2008 consumption of the most optimal final local products (several times washed, sieved and crushed stone and washed gravel) in road building and construction accumulates both economic (social) and financial savings of over 515–615 mln LTL/year of state cash outflow. Estimations are based on the economic (excluding VAT) border prices of the same volume of otherwise to be imported more expensive granite raw material. Additional estimate of economic border prices of imported sand in the mentioned period showed that due to the local resources the additional savings amounted to about 135–162 mln LTL per year. During 2007 and 2008 rational use of the finally processed local gravel and dolomite resources, versus the imported material border prices, has accumulated a total of 1.43 billion LTL (414 mln EUR) in a two-year period. These are both savings of the state cash outflow and the direct and indirect revenue to the budget of the Republic of Lithuania. Rational use of local resources gives the average yearly amount of over 700 mln LTL/year (200 mln EUR/year) and is equal to the savings of about 200 LTL (58 EUR) per capita per year (2007/2008). These figures could be increased – as was estimated earlier, up to 8–10% or more of granite used in AC layers could be replaced by cheaper and still enough strong locally properly produced chips. The value of lower production level of raw underground resource sites to the state and society is considerably lower, and they were not included into the estimation presented, but they have their value as well. It should be stated that the potential of final local aggregate products during the crisis has fallen nearly fourfold: one half because of less production and nearly half because of the lower border prices of imported raw material.

But taking into account budget restrictions the crisis emphasized the value of local resources and possible economy and benefit of feasible infrastructure investments.

According to the few average indicators for the gravel resources of Lithuania, an area exceeding 100 ha could be feasible for starting rational production of washed gravel and washed and crushed gravel shingle. In the less-size gravel pits investments into crushing of upper size of shingle are risky and unfeasible. Correspondingly, dividing of resource lots is irrational and unviable from the point of view of state and public interests.

For the rational extraction and production of crushed dolomite similar or slightly less minimal resource area could be feasible, but would much depend on the characteristics of upper soil layer and logistics. During the last decade aggregate production sites in Lithuania were upgraded considerably, productivity increased, but comparatively low available resource depths requires the estimated areas.

But recent decline has resulted in sharp increase and sell-out of unused capacity, equipment and skill. Since the world economic crisis forced the country and the banking sector to sharply decrease investments and loans into public infrastructure and housing, it resulted into force majeure situation in local aggregate production industry.

Rational, balanced, undisturbed, environmentally friendly and possible to forecast consumption and production of local resources is a goal for the state, public, decision makers, producers and scientists.

## 7. Conclusions

The national resources of gravel sand and dolomite explored in detail and in general (prognostic or supposed) amount to 4842.7 and 553.3 mln m<sup>3</sup>, respectively. Based on the amount of their extraction in 2008 they could be used for 400 and 235 years, respectively. However, according to the studied qualitative parameters, important to the road building, a current supply of local dolomite and especially gravel for crushing closer to large cities can decrease after 10–30 years, depending on the strategy for the use of state underground resources. Without sufficient state protection, part of the underground resources in future can become inaccessible for consumption.

The deposits of dolomite, gravel and sand explored in detail and used for road building and other purposes occur under 6.8 thousand ha or 0.096% of the territory of Lithuania, their value amounts to 3.2 billion LTL and makes 1.6% of the state property value. According to the state property value per the area of Lithuanian territory, the value of explored in detail dolomite and gravel deposits is the most expensive in the country (30.9% of property value/1% of the territory) compared to the value of all resources (13.5% of property value/1% of the territory), roads of national significance (11.5% of property value/1% of the territory) and the value of forest land and the land of agricultural designation (2.8% of property value/1% of the territory).

Local underground resources, if properly processed, could be perfectly used in road building:

- the most optimum final product of local gravel and dolomite resources is the crushed, washed and sieved stone and rock which replaces the imported granite material;
- having tested the two main Lithuanian road building aggregate materials it was found that the local gravel chips present better results in: Crushability Index SR8/12, the Polished Stone Value (PSV), amount of particles of P form, adhesion to bitumen, bitumen emulsion (%) and frost resistance. Dolomite chips presents better results in: Flakiness Index Msk, resistance to fragmentation by the LA test method, resistance to fragmentation by the impact test method (SZ), losses in the mass of particles after 10 freezing and thawing cycles (F50, F100);
- research showed that the longest service life is represented by the layers of road base which are built from crushed material. The best results are obtained when both the strength properties of used materials and the continuity properties of their grading curve are the best, water absorption is the least and frost resistance is the best;
- in order to find the best road base mixtures suitable for Lithuanian mild winter conditions (min 50 – max 90 freezing and thawing cycles/y on the top of pavement and on average up to 35–40 cycles/y in the subbase) it is obligatory to carry out the complex long-term research where the main properties of road subbase layer would be tested after at least 350–700 freezing and thawing cycles, representing 10–20 years of road subbase service;
- AC mixtures with crushed dolomite exceed the normative requirements by 42% (min 10%, max 95%). AC mixtures with crushed gravel shingle exceed the normative requirements by 33% on average (min 8%, max 80%). It was determined that physical and mechanical indices of AC, containing crushed shingle and crushed dolomite, differ insignificantly, but Petrašiūnai dolomite has slight priority. Based on the data obtained the use of local materials (according to the minimum exceeding level of all normative requirements) in road pavement wearing and base courses could be increased without breaking the normative requirements by 8% for crushed gravel and by 10% for crushed dolomite compared to the use of imported materials;
- from the point of view of safe driving on a wet pavement, it is better to use gravel chips for the wearing course since their Polished Stone Value (PSV) is higher than that of dolomite chips, and during wet conditions pavement is safer and less slippery.

Rational use of the optimal final products of local dolomite, gravel and sand resources gives the average yearly state budget and cash flow savings of over 700 mln LTL/year (over 200 mln EUR/year) and is equal to

the savings of about 200 LTL (58 EUR) per capita per year during the period of stable economic growth (2007/2008).

To achieve the most effective and the highest value of the extracted materials used in Lithuania for road building purposes (from the economic, public, state cash flow, strategic state competitiveness, tax collection and private investments feasibility point of view) only in those explored in detail gravel deposits which according to the average occurrence thickness of the national resources (7.8 m) and material quality, have the extraction site area of 100 ha or more. In the less-size gravel pits investments into crushing of upper size of shingle are risky and unfeasible. Correspondingly, dividing of resource lots is irrational and unviable from the point of view of state and public interests. For the rational extraction and production of crushed dolomite similar or slightly less minimal area could be feasible, but would much depend on the characteristics of upper soil layer and logistics.

World economic crisis and the falling demands for aggregate consumption in Lithuania made the additional negative (9%) effect on the use of high quality products. Preservation of advanced technologies and survival of enterprises becomes a challenge. Rational, balanced, undisturbed, environmentally friendly and possible to forecast consumption and production of local resources is a goal for the state, public, decision makers, producers and scientists.

Optimum and most effective way of usage of underground mineral resources of the country must be and is not only the base for state economy and public welfare but also the tool for optimizing national security, state budget and cash flow parameters. Mining developments (but not development restrictions) and new findings are the direct support to state geopolitics. Mining is a fundamental branch of the countries heavy industry through small and average enterprises creating thousands of working places within the branch itself and through its quality products improving the operating quality of other sectors of economy.

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