Reconnaissance of scree as potential aggregate resources

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Abstract: Aggregates are used in nearly all building construction and in most technical works including highway and airport pavements, dams, tunnel linings, bridges, railroad ballasts, riprap facings etc.

As urbanization and development rapidly increase, the demand for aggregates is increasingly high. As existing sources become insufficient, assessment must be focused on the systematic evaluation of "lower quality" aggregate material deposits encountered in the region.

That problem has recently arisen in the city of Patras, the third largest city of Greece. Aggregate demand has increased in the wider area because of rapid urbanization and the continuing development of infrastructure for the city and its region (highways, railways, port, Rio-Antirio long cable bridge etc). The aggregate quarries are located about 50 km from the city of Patras, however their operation will shortly be interrupted because of environmental requirements.

So, aggregate assessment is focused on unconsolidated scree that covers a large part of the wider area close to the city. It consists of fragments, pebbles and gravels of limestones (but also cherts and sandstones) with sandy - clayey matrix. Engineering geological maps were prepared including land allocation and classification of aggregate sources using geographical information systems (GIS). Some of the properties of scree were determined by laboratory tests on samples, including abrasion, water absorption, soundness and impurities such as material finer than the No 200 sieve, clay lumps and friable particles etc.

Aggregate resources reconnaissance showed that these scree deposits are potentially suitable as aggregate sources for the construction industry. Their quality can be improved by the usual processing operations (washing, sieving etc).

Résumé: Les granulats sont employés dans presque toutes les constructions d'immeubles ainsi que dans la plupart des travaux les plus techniques comme les revêtements de routes et trottoirs d'aéroports, barrages (hydrauliques), tunnels, ponts, ballasts de chemins de fer etc.

L'augmentation rapide de l'urbanisation et le développement entraîne une hausse considérable de la demande de granulats. Etant donné que les sources existantes deviennent insuffisantes, l'appréciation doit être concentrée sur l'évaluation systématique des dépôts de granulats de moindre qualité produits dans la région.

Ce problème est récemment apparu dans la ville de Patras, la troisième plus grande ville de Grèce. La demande de granulats a augmenté dans une grande partie de la region en raison de l'urbanisation rapide et du développement continu d'infrastructures pour la ville et sa région (routes, chemins de fer, port, le pont Rio-Antirio, etc). Les carrières de granulats sont situées à environ 50 km de la ville de Patras, cependant leur exploitation sera sous peu interrompue pour des raisons d'ordre environnemental.

L'appréciation de granulats se base donc sur des éboulis non consolidés, qui couvrent une grande partie de la zone étendue près de la ville. Ils se composent de fragments, cailloux et graviers de calcaire (mais aussi de cherts et de grès) avec une matrice sableuse – argileuse. Les cartes de géologie civile ont été réalisées, à l'aide du système d'information géographique (SIG), en incluant l'affectation des terres et la classification des sources de granulats. Certaines des propriétés d'éboulis ont été déterminées par des essais en laboratoire sur des échantillons, tels que l'abrasion, l'absorption d'eau, l'altération et les impuretés tels que les matériaux plus fins que le tamis No 200, les morceaux d'argiles et particules friables, etc.

La reconnaissance des ressources en granulats a prouvé que ces dépôts d'éboulis sont potentiellement appropriés comme sources de granulats pour l'industrie du bâtiment. Leur qualité peut être améliorée par des opérations usuelles (lavage, tamisage, etc).

Keywords: Aggregate, geomaterial, natural resources, engineering geology maps.

INTRODUCTION

Comprehensive planning and resources management strategies are required to make the best use of aggregate resources. Such strategies must be based on an appropriate planning framework and a sound knowledge of the total mineral aggregate resources. Worldwide, the research on aggregates focused either on the assessment and management of natural aggregate resources (Langer 2002, Bliss, Moyle & Bolm 2003, Langer & Turker 2003) or on usefulness of specific deposits for concrete and in road construction (Paige-Green & Sampson 1990, Poitevin 1999, Zarif & Tu rul 2003).

Aggregate demand has increased in the surroundings of Patras, the major city of western Greece, where major engineering projects (railways, motorways, port and dams) are under construction. The annual demand for aggregates was about 2 million tonnes excluding the quantities for infrastructures. Thus the use of lower quality unconsolidated sediments as aggregates comprised of sand and gravel deposits is becoming important to replace the river supply sources and the expensive far transported limestone (crush stone) products.

Unconsolidated scree covers about 45 km^2 of the wider area of the city of Patras and they constitute formations initially suitable for aggregate uses.

ENGINEERING GEOLOGICAL MAPPING

Geology generally controls the location and quality of aggregate resources. The engineering geological conditions of the wider area were considered using available information (Rozos 1989, Koukis & Rozos 1990, Tsiambaos, Sabatakakis & Koukis 1997, Koukis et al. 2005) in combination with aerial photo interpretation and field mapping. So, a multipurpose large scale engineering geological map was compiled at an original scale 1:100000 (Sabatakakis, Koukis & Spyropoulos 2005). In this map (Fig.1) the geological formations were grouped into four lithological types based on their origin and relevant age.

- Quaternary deposits consisting of: a) fine grained sediments such as clays, silts, siltstones, sands of a fluvial – lacustrine, lagoon and/or aeolian origin and weathering products of older formations, b) coarse grained deposits of coarse clastic formations from pebbles and gravels of varying sizes with a minimum proportion of fine grained materials, scree and fans, c) loose deposits of mixed phases consisting of clayey silts, sands of a varying grain size distribution, grits and gravels as well cemented coarse grained sediments (polygenic conglomerates, usually of a poor gradation and/or slope breccias) and cemented formations of mixed phases (loose to semi-cohesive conglomerates, clayey-marly materials, sand with a low degree of diagenesis and rocky fragments with red clay as a cementing material).
- Plio – Pleistocene coarse – grained sediments consisting of conglomerates loose to well cemented, with pebbles of various origin (mainly limestone and chert) and clayey – sandy cementing material
- Plio – Pleistocene fine – grained sediments as clays, marls, siltstones, marlstones with alternating sands of a varying degree of diagenesis
- Mesozoic basement (flysch, limestones, schists, cherts and semi-metamorphic formations).

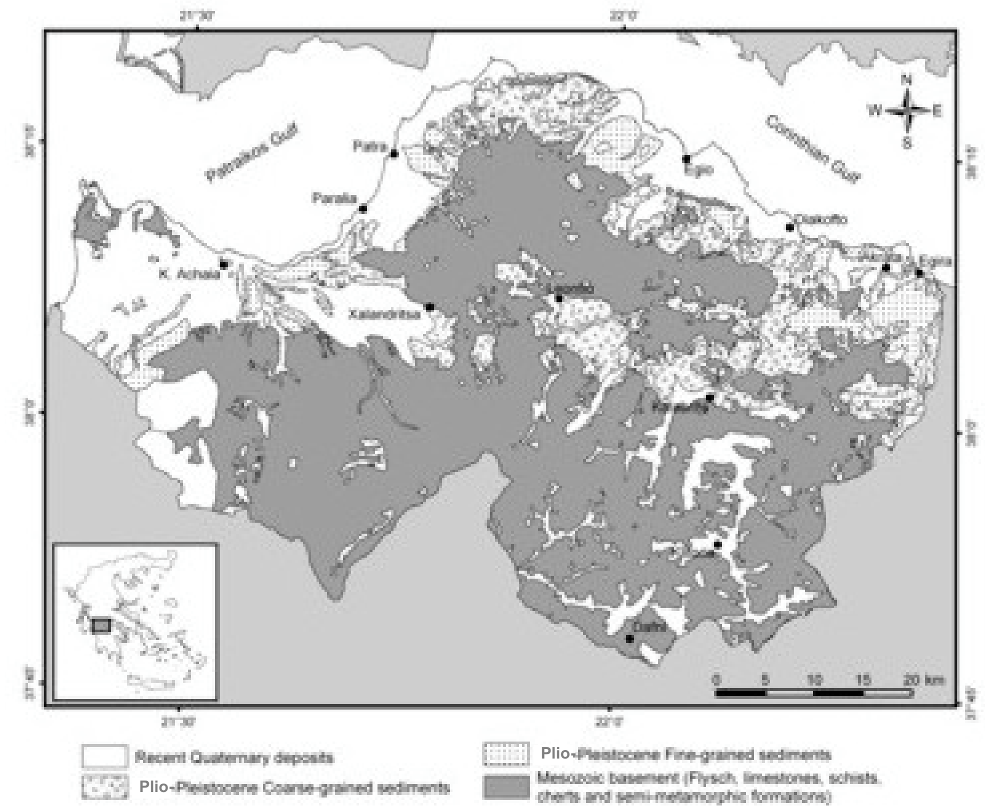


Figure 1. Simplified engineering geological map of the studied area (Sabatakakis et al. 2005)

The evaluation of the multipurpose engineering geological map combined with detailed field mapping led to the compilation of specific purpose large scale maps providing the distribution of the formations possibly suitable for aggregate uses. In Figure 2, the distribution of scree as potential aggregate resources in the examined area is shown.

The map preparation was compiled using Geographical Information Systems (GIS). Issues such as location, quality and general characteristics of aggregate can be addressed using this technique, while because statutory regulations, technological capabilities and available funding can change with time, the maps are designed to provide a resource data base that will be useful over the years.

SAMPLING AND TESTING METHODS

Unconsolidated scree covers a total surface of about 45 km^2 of the wider area of the city. A number of samples of the material were collected and tested. The locations of the samples are shown in Figure 2. They consist of pebbles, gravels and rock fragments mainly derived from the Cretaceous thin bedded limestones including up to 10% chert (Fig. 3). After the washing of sand and gravel samples, the main geometrical, physical and mechanical properties were determined according to ASTM and BS standards. The particle shape tests were performed according to BS 812-105.1:1985 and BS 812-105.2:1990, while the grain size analysis carried out following the procedure described in ASTM C 136 – 95 and C 117 – 95 for the determination of materials finer than 75μm (No 200). Tests to determine bulk specific gravity and water absorption were performed in accordance with ASTM C127-93. The LA abrasion loss was determined using ASTM procedure C131 - 89. In this study, “A” gradation, which is the largest size gradation according to ASTM specifications, was used because of its frequent use in highway construction. The Aggregate Impact Value tests carried out following the procedure described in BS 812: Part 112:90. Sodium sulfate soundness tests, sand equivalent tests and the determination of clay lumps and friable particles in aggregates were made according ASTM C88-90, D2419-01 and C142-90, respectively.

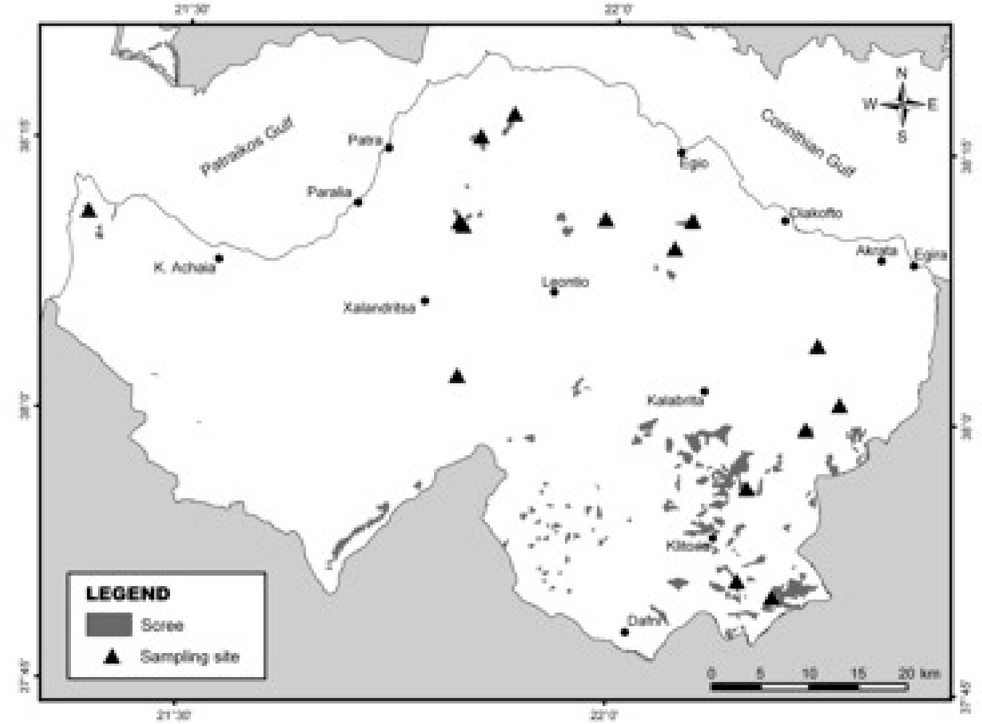


Figure 2. Simplified, specific purpose engineering geological map showing the distribution of the scree suitable for aggregate uses

Figure 3. Areas of scree deposits derived from Cretaceous limestones

RESULTS AND DISCUSSION

The maximum, minimum and average values of geometrical, physical and mechanical characteristics for the tested material are listed in Table 1.

The examined scree deposits mainly consist of limestone pebbles, gravels and fragments (88% - 100%) with chert (< 10%) and locally sandstone. Based on USCS they are mainly classified as well – graded gravels (GW) and locally poor – graded (GP) to clayey (GC) gravels.

The pebbles and fragments of the studied deposits are subround to subangular with flakiness index (I_F) between 10% and 21% while the elongation index (I_E) varies from 10% to 16%.

The bulk specific gravity values are over 2.60 and the percentage of water absorption is less than 1.1%. The results obtained from Los Angeles abrasion tests and aggregate impact value tests characterize relatively high material strengths. Los Angeles abrasion value (LAAV) varies from 25% to 29% while Aggregate Impact Value (AIV) ranges between 21% and 25%.

Table 1. Maximum, minimum and average values of geometrical, physical and mechanical characteristics of scree deposits

Properties	**Measured values**		
	Max	**Min**	**Average**
Flakiness index (%)	21	10	16
Elongation index (%)	16	10	13
Filler (%)	14.61	4	7.95
Sand equivalent (%)	30	16	24
Bulk specific gravity	2.65	2.60	2.62
Water absorption (%)	1.09	0.53	0.79
Los Angeles abrasion value (%)	29.19	25.32	27.11
Aggregate impact value (%)	25	21	23
Soundness (%)	8.21	1.43	4.46
Clay lumps and friable particles (%)	0.61	0.39	0.51

The wide distribution of percentage of filler values (4% - 15%) as well as the low sand equivalent results (15% - 30%) indicate that scree deposits need improvement by the usual processing operations (washing, sieving) to be acceptable as aggregates for construction purposes.

The sodium sulfate soundness values are less than 9%. The percentage of clay lumps and friable particles is low and varies from 0.4% to 0.6%.

Regression analysis was applied among testing results (Fig. 4, 5, 6, 7). The procedure is to fit a line through the points, which is computed so that the squared deviations of the measured points from that line are minimized. The line in a two – variable space is defined by the relevant equation, whereas the value of coefficient of determination or R-square value is determined. The estimated relationships including the equations and R-square values are summarized in Table 2.

Figures 4a,b and 5a,b show the relationships between aggregate resistance and geometrical properties of the tested material. The testing results are plotted in form of Los Angeles abrasion value (LAAV) and aggregate impact value (AIV), against the flakiness (I_F) and elongation (I_E) indexes respectively (Fig. 4a, 4b and Fig. 5a, 5b). The figures demonstrate that the related quantities exhibit very good linear relationships while a clear increase of resistance with increasing values of geometrical indexes is shown. Similar relationships have also been defined by Collis and Fox (1985).

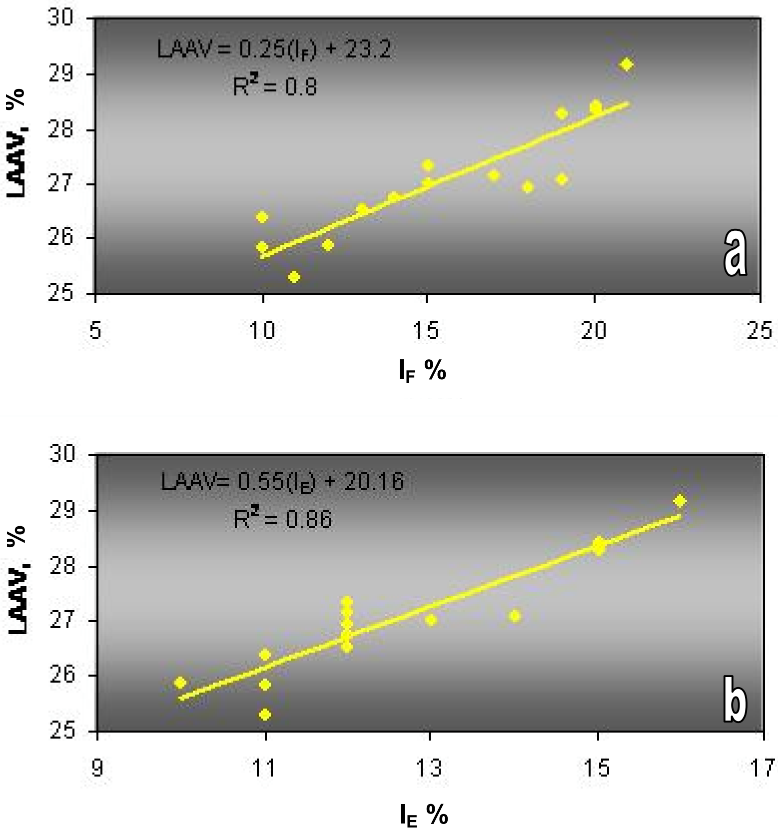


Figure 4. Correlations between (a) LAAV and Flakiness index (I_F), (b) LAAV and Elongation index (I_E).

Figure 6a shows the estimated LAAV – AIV relationship for the testing results obtained from the present study. Both LAAV and AIV give a relative measure of the resistance of an aggregate to impact (wear and impact and to sudden shock respectively) using different test procedures. The correlation is linear (Table 2) with strong correlation coefficient. Similar correlations have been formulated by Irfan (1994) and Al-Harthi (2001).

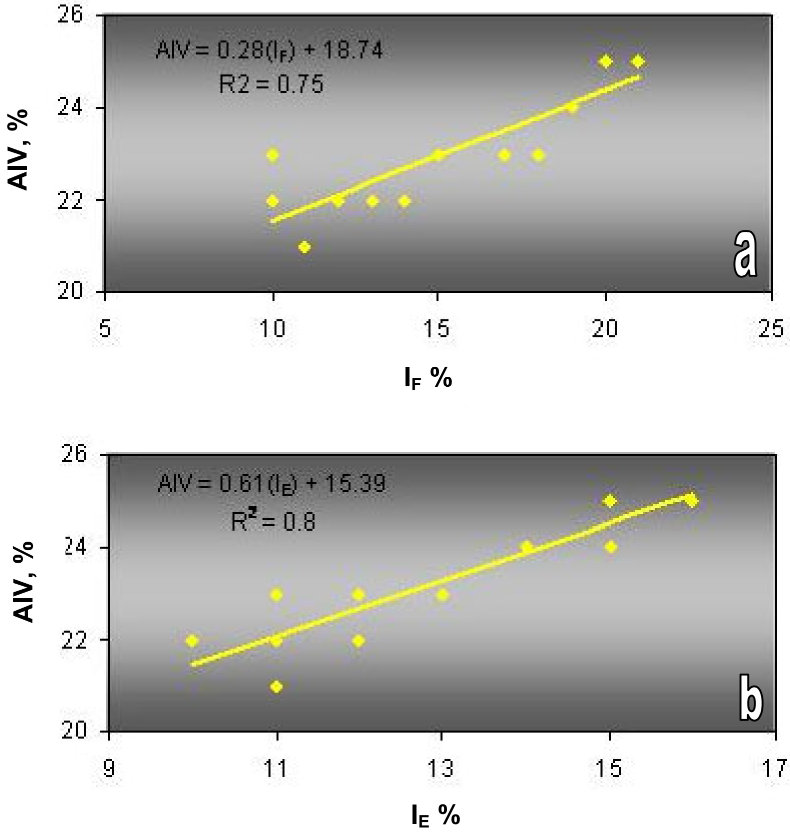


Figure 5. Correlations between (a) AIV and Flakiness index (I_F), (b) AIV and Elongation index (I_E)

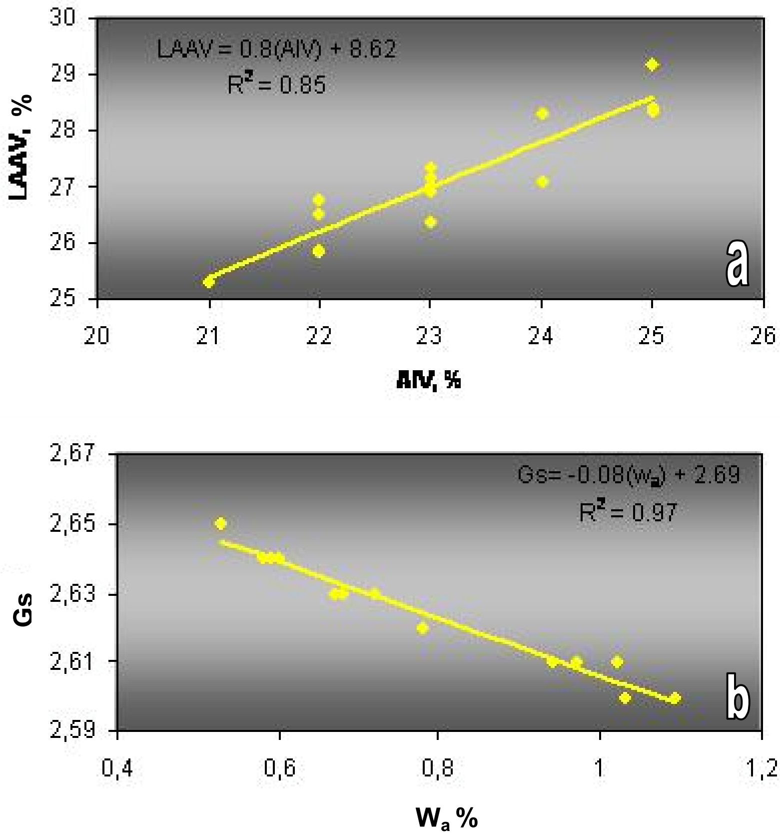
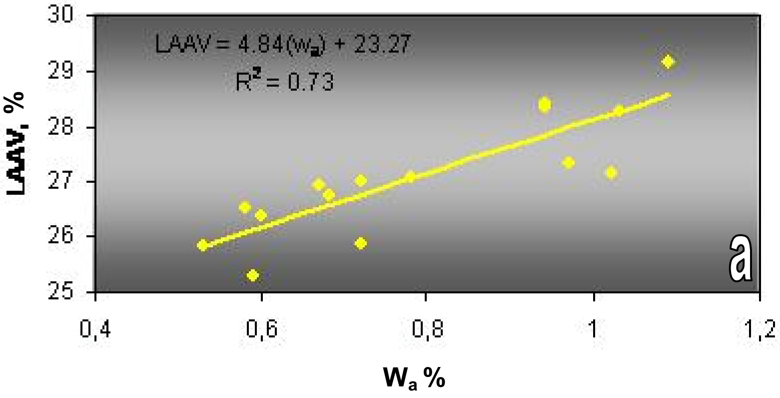


Figure 6. Correlations between (a) LAAV and AIV, (b) Bulk specific gravity (Gs) and Water absorption (w_a)

Figure 6b shows that bulk specific gravity (Gs) tends to decrease as water absorption increases. The increase of water absorption cause an increase in the LAAV as the volume of pore spaces, expressed by water absorption, decrease the durability of these deposits (Fig. 7a).

In Figure 7b, the relationship between soundness and water absorption is shown. Higher values of water absorption indicate a weathered unsound aggregate that is prone to degradation. The correlation is linear with strong correlation coefficient.



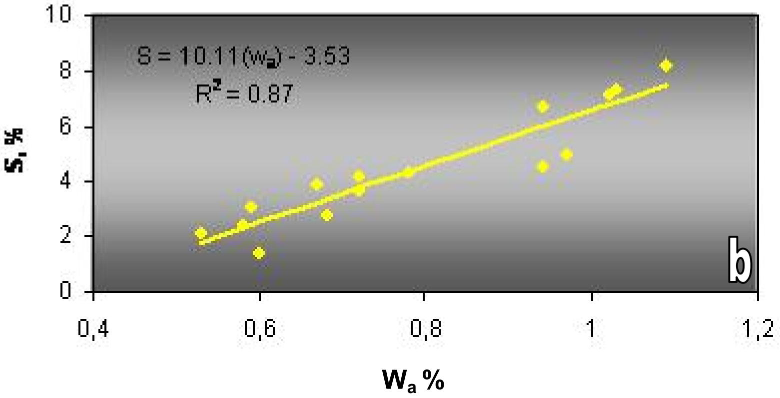


Figure 7. Correlations between (a) LAAV and Water absorption (w_a), (b) Soundness (S) and Water absorption (w_a)

Table 2. Relationships and correlation coefficients between the main examined variables

Variables	Equation	Correlation Coefficient (R^2)
LAAV vs I_F	LAAV=0.25 (I_F) + 23.2	0.8
LAAV vs I_E	LAAV=0.55 (I_E) + 20.16	0.86
AIV vs I_F	AIV=0.28 (I_F) + 18.74	0.75
AIV vs I_E	AIV=0.61 (I_E) + 15.39	0.8
Gs vs w_a	Gs=-0.08 (w_a) + 2.69	0.97
LAAV vs AIV	LAAV=0.8 (AIV) + 8.62	0.85
LAAV vs w_a	LAAV=4.84 (w_a) + 23.27	0.73
S vs w_a	S=10.11 (w_a) – 3.53	0.87

CONCLUSIONS

Unconsolidated scree covers a large part of the wider area of the city of Patras in western Greece. The tested materials constitute low quality aggregates mainly consisting of clastic pebbly and gravely deposits including potentially deleterious constituents such as chert.

The examination of geometrical, physical and chemical properties of scree shows that the material might be usable as aggregates of good quality. Washing and size processing operations are essential to improve the quality of the scree materials, as otherwise the locally high percentage of filler diminishes the results of the sand equivalent and make them unsuitable for concrete and road construction.

The resultant best fit curves among the estimated aggregate parameters are generally similar in appearance with those determined by other authors for other material but differ in quantitative terms. This may due to the presence of cherty constituents.

Considering that high quality aggregates are missing in the wider area, potentially scree could be used locally for construction purposes (road construction, concrete, gabions, filters etc.), subject to further investigation for particular uses.

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REFERENCES

AL-HARTHI, A.A. 2001. A field index to determine the strength characteristics of crushed aggregate. *Bulletin of Engineering Geology and the Environment,* **60**, 193-200.

ASTM 1996a. *Standard Test Method for resistance to degradation of small-size coarse aggregate by Abrasion and Impact in the Los Angeles machine, C131-89, Annual Book of Standards, 4.02.* American Society for Testing and Materials, West Conshocken, PA.

ASTM 1996b. *Standard Test Method for Soundness of aggregates by use of sodium sulfate or magnesium sulfate, C 88-90, Annual Book of Standards, 4.02.* American Society for Testing and Materials, West Conshocken, PA.

ASTM 1996c. *Standard Test Method for Clay Lumps and Friable Particles in aggregates, C 142-90, Annual Book of Standards, 4.02.* American Society for Testing and Materials, West Conshocken, PA.

ASTM 1996d. *Standard Test Method for Specific Gravity and Absorption of coarse aggregate, C 127-93, Annual Book of Standards, 4.02.* American Society for Testing and Materials, West Conshocken, PA.

ASTM 1996e. *Standard Test Method for Materials Finer than 75-μm (No. 200) sieve in mineral aggregates by washing, C 117-95, Annual Book of Standards, 4.02.* American Society for Testing and Materials, West Conshocken, PA.

ASTM 1996f. *Standard Test Method for Sieve Analysis of fines and coarse aggregates, C 136-95, Annual Book of Standards, 4.02.* American Society for Testing and Materials, West Conshocken, PA.

ASTM 2002. Standard Test Method for Sand Equivalent value of soils and fine aggregate, D 2419-01, Annual Book of Standards, 4.03. American Society for Testing and Materials, West Conshocken, PA.

BLISS, J.D., MOYLE, P.R., BOLM, K.S. 2003. Statistical, economic and other tools for assessing natural aggregate. *Bulletin of Engineering Geology and the Environment*, **62**, 71-75.

BSI 1985. *Methods for determination of Flakiness index, BS 812.105.1.* British Standards Institute, London.

BSI 1990a. *Methods for determination of Elongation index, BS 812.105.2.* British Standards Institute, London.

BSI 1990b. *Methods for determination of Aggregate Impact Value, BS 812.112.* British Standards Institute, London.

COLLIS, L., FOX, R.A. 1985. Aggregates: Sand, Gravel and Crushed rock aggregates for construction purposes. Geological Society of Engineering Geology, Special Publication 1.1, London.

IRFAN, T.Y. 1994. Aggregate properties and resources of granitic rocks for use in concrete in Hong Kong. *Quarterly Journal of Engineering Geology,* **27**, 25-28.

KOUKIS, G., ROZOS, D., 1990. Geotechnical properties of the Neogene sediments in the NW Peloponnesus, Greece. *In: Proceedings of the 6th International IAEG Congress,* Rotterdam, 405 – 412.

KOUKIS, G., SABATAKAKIS, N., TSIAMBAOS, G., KATRIVESIS, N. 2005. Engineering geological approach to the evaluation of seismic risk in metropolitan regions: the case of the city of Patras, western Greece. *Bulletin of Engineering Geology and the Environment,* **64**, 219-235.

LANGER, W.H. 2002. *Managing and protecting aggregates resources*. USGS OF Report 02-415.

LANGER, W.H., TUCKER, M.L. 2003. *Specification aggregate quarry expansion – A case study demonstrating sustainable management of natural aggregate resources*. USGS OF Report 03-121.

PAIGE-GREEN, P., SAMPSON, L.R. 1990. The selection of construction materials for basic access streets in developing areas. *In: Proceedings of the 6th International IAEG Congress,* Rotterdam, 3095-3102.

POITEVIN, P. 1999. Limestone aggregate concrete, usefulness and durability. *Cement & Concrete Composites*, **21**, 89-97.

Rozos, D. 1989. *Engineering – geological conditions in the Achaia County. Geomechanical characteristics of the Pleio-pleistocene sediments*. Ph.D. Thesis, Patras University (In Greek).

SABATAKAKIS, N., KOUKIS, G., SPYROPOULOS, A. 2005. Quality assessment of Pleio-Pleistocene and recent Quaternary coarse grained sediments as aggregates for road construction. *In: Proceedings of the International Symposium GEOLINE 2005:Geology and linear infrastructures,* Lyon.

TSIAMBAOS, G., SABATAKAKIS, N., KOUKIS G. 1997. Engineering geological environment and urban planning of the city of Patras, Greece. *In: Proceedings of the International Symposium on Engineering Geology and the Environment, IAEG,* Athens, 2, 1527 – 1534.

ZARIF, I.H., TU RUL, A. 2003. Aggregate properties of Devonian limestones for use in concrete in Istanbul, Turkey. *Bulletin of Engineering Geology and the Environment,* **62,** 379-388.