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Geotechnics in the promotion of dimension stone

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ABSTRACT

Changes in the supply and use of dimension stone have extensively modified the approach of the engineering geologist to stone technology. Traditional expertise requirements have moved from exploration, extraction, and processing to quality control and application.

Reasons for this are the globalisation of dimension stone supplies from new and unknown sources; deterioration of environmental conditions; cost saving in using thin stone tiles or slabs as veneer, at times hazardous; incorrect cladding applications, and the assessment of weathering. All these require the knowledge and experience of the engineering geologist, whose skills are not commonly known. Promotion, assisted in the media by exposure of global hazards has drawn attention to the discipline and practices.

Research on the physical and mechanical stone properties has at last been taken up by major intergovernmental organisations. Large budgets are devoted to take stone testing out of century old routine. "High tech" facilities are now applied to make stone-related evaluations more objective and independent of the human factor. Acceptance criteria of testing results require rationalisation. Geotechnical knowledge is important to keep test results within economic restraints and timetables. This is of special importance when linking such factors to environmental planning and control of quarrying and subsequent rehabilitation of the workings. In this paper a bird's eye view of the problems related to dimension stones is provided. Some examples of research trends are also given to exhibit the state-of-the-art.

INTRODUCTION

The use of dimension stone is staggering. The world production exceeds a turnover of 55 million tons with consumption equivalent to 720 million square metres, worth US $ 25–30 billion. The geotechnical practices in the use of dimension stone are caused by several global escalation phenomena. These can be typified by the effect of proliferation of supply sources, and problems caused by increasing application of thin stone veneer on facades. All these require attention to quality.

Whereas in the past quality was taken for granted, today a great variety of stone-related practitioners show interest in the genesis, provenance, and properties of the stone used. These include masons, restorers, architects, designers, or engineering professionals who were formerly satisfied with explanations and assurances by the suppliers. Media exposure of global hazards plays an important part in the recent interest in geotechnical aspects affecting earthquake resistance, "durability" as related to environment, rehabilitation of quarries etc.

There is much emphasis on "durability", an important "property" of stone stressed from times immemorial with a controversial definition (Shadmon 1993). There exists no single test to measure it. Although the exposure effect of the stone can be observed in an existing construction, the behaviour of the stone depends on many factors.

In many parts of the developing world, the increase of the use of stone is a spin-off following activities of various development agencies. Dimension stone projects were started in the sixties by the United Nations Development Programme (UNDP), and more recently by the European Union (EU) and their Industrial Development Centre (IDC) in Brussels in their quest to develop the use of primary materials. The resulting demand for stone is the more appreciated in countries with no previous stone working or quality control traditions.

However the bounty, together with globalisation of stone quarrying, has increased the need to harmonise standards in the importing industrialised countries. Little experience or diagnostic data is available from the exporting third-world countries, which are the main beneficiaries.

To quantify the diagnosis and ensure reproducibility we resort to physical, mechanical, and chemical tests, promulgated mainly during the end of the 19th and beginning of the 20th centuries notably in the comprehensive work of Hirschwald (1912), still of basic value. In the last decades, a new approach was initiated to meet modern needs, leading to the revision of tests and specifications of stone with two major aims: harmonisation and technical upgrading.

Recently discovered dimension stone varieties, not used previously in sizeable projects, compete strongly with established stone products. They may lack geotechnical diagnosis or experience with the quality variations in the newly opened quarry beds or benches. Furthermore, appropriate and non-destructive extraction methods are not always available. The lack of this hands-on knowledge, even with reasonable care may not prevent rock bursts during quarrying; micro cracking, initially invisible to the naked eye, when processing; or still worse, delayed damage from blasting.

The appeal and value of dimension stone is firstly aesthetic and ornamental, with technical aspects subject to secondary attention. The architectural designer forms his concept and selects the stone at the early stage of the project for presentation to the rest of the team. More often than not the designer has received little education, training, or experience in stone application and still less in treating it as a material.

He seldom is aware that stone can be load-bearing and decorative at the same time, and not just a skin, that stone can be incorporated in the initial design; is not exclusively used in skyscrapers and institutional buildings, and that in urban and rural areas alike stone are used for all types of constructions and buildings.

In addition to the decorative aspect, modern management is concerned about the costing, maintenance, and 'durability' factors. Cost saving depends on the optimum use of the technical qualities of the stone in extraction, processing, and application. For this the stone technologist, draws attention to technical values, promotes quality control amongst the team's decision makers, and assures the continuity of the qualities shown in the stone sample, often a major source of misunderstandings and litigations.

STONE TESTING

The increase in world trade requires harmonisation of standard descriptions between countries. Optimum reliability, especially where safety factors (Shadmon 1994) are involved, is required for design of testing methods.

Stones extracted from quarries with beds or benches of different characteristics require multiple tests to see whether manufactured building materials are produced uniformly according to specifications. In designing a standard, the aim is to make the test as simple in the shortest possible time to ensure reproducibility of results. Some tests are time taking and costly as e.g. the freezing/thawing test where the many heat/cool cycles cannot be accelerated and testing time is empirical. This is a handicap for the client, usually in a hurry, who cannot use the stone before he knows the test results.

The tendency then is to order a minimum of tests, at times with disastrous consequences, leading to generalisations, e.g. hazardous in cladding where strict adherence to standards is mandatory. Falling stones are dangerous not only in earthquake-prone areas but also in other regions.

Changing or modifying standards is a slow process, initiated in principle by industrial and governmental interests and not by the technical community. Governmental action is limited to safeguarding public interest and is little influenced by commercial considerations, as is the case with industrial initiatives. An important activity of technical standardisation committees is to strike a balance, usually by consensus.

Specific to stone standards, in addition to their roots in concrete testing methods, is the longer life expectancy of stone than in other products. The use of stone results in a high cost product acquired once or twice in a lifetime, and standards have to respond to such anticipation. Yet a major part of the value or attraction of stone is its ornamental, and not always technical aspects. These stone elements are part of a structure containing mortar, adhesives, anchoring systems and other fixtures, backing, etc, all influencing the quality of the application and have to be considered as a system.

Leading in the advancements in stone and rock technologies are the various technical working groups of the Centre Europeen de Normalisation (CEN), the American Society for Testing of Materials (ASTM), International Union of Testing and Research Laboratories for Materials and Structures (RILEM) and the Commissions of the International Society of Rock Mechanics (ISRM), the International Association of Engineering Geology and the Environment (IAEG), the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE). The latter three are geotechnical sister societies, with ISSGME attending mainly to softer rocks, soil, and earth.

Stone standards are periodically being revised, but with little primary research. This is slowly being changed and a few research projects in the pipeline are now in the experimental stage. Unfortunately, the existence of these projects becomes knowledge at their final phases, and the application of the state-of-the-art is delayed.

After a slow start, the harmonisation of stone standards, notwithstanding widely diverging views amongst the CEN members, resulted finally in the acceptance of the 5 European Natural Stone Tests (denoted by EN- Norme Europeenne), after ratification by a public enquiry. These are:

EN1925: 1999 Determination of water absorption coefficient by capillarity, EN1936:1999 Determination of real density and apparent density and of total and open porosity,

EN1926: 1999 Determination of compressive strength,

EN12370:1999 Determination of resistance to salt crystallisation, and

EN12372: 1999 Determination of flexural strength under concentrated load.

The CEN members will have to comply with the regulations covering the EN conditions and consider them as a national standard. The countries concerned will eventually distributed the text in their national languages. Additional drafts of natural stone testing methods are now ready for further approval.

RECENT RESEARCH

Long-term projects in the pipeline include Image Analysis, Automated Visual Inspection, and Computerised X-Ray Tomography funded by the European Union (EU) rather than the International Standard Organisation (ISO). Advantage is taken of the array of high tech 'tools' presently available to create new testing methods, but not always at the disposal to the geotechnical organisations' commissions.

Quarrying techniques as e.g. in the Basic Research in Industrial Technologies for Europe (BRITE) Project BES2-5278 have entered the space age by probing "shape memory alloys" to create novel rock splitting systems with a geotechnical engineering firm as the Project Coordinator. Similarly, systems are under investigation for in situ evaluation of granite materials, requiring a profound knowledge of structural and textural rock features and of the rock massif.

Other ongoing medium-term EU sponsored projects with a co-/pre-normative objective include:

1. Characterisation of mechanical properties and damage of natural building stones in historical monuments. The research involves five types of destructive laboratory test related to tensile mode of damage and a non-destructive acoustic test.
2. Characterisation of ornamental stone standards by image analysis of slab surfaces, although the aim is to establish a definition of commercial standards based on objective measurements of appearance. Image analysis and pattern recognition techniques based on transformation of the findings in numerical information are used.
3. Development of six measuring portable drilling devices to determine the superficial hardness of exposed monumental rocks and provide data correlatable with compressive strength. The effectiveness of a stone-consolidating product is being assessed together with an application methodology for upgrading and restoration.
4. The Testing and Assessment of Marble (TEAM) Project is the most comprehensive of the above types although of a more extended duration. It aims to find out how to use marble (or other stone) without the risk of deterioration due to bowing or thermal expansion. Failure has increased in the recent climate changes causing large cladding to fall down in earthquake-prone areas.

GEOTECHNICAL PROMOTION

Besides tolerances and other geometrical quality aspects, technical management of construction projects is particularly concerned about the soundness of the dimension stone input. Confusion begins at the planning and design stages with improper terminology and non-representative samples. Many times, limestone has been sold as sandstone, requiring different specifications in applications. When it comes to igneous stone material, anything except a soft porous tuff may pass as "granite".

Then, there is the problem of provenance. To name the stone after a quarry may give the impression that it comes from a uniform bed suitable for building stone, amongst other lithological units unusable for dimension stone. Promotion, at present predominantly based on economics and aesthetics, is important. Stone, with its superior 'durability' and ornamental qualities, has technical advantages, not always familiar, to tilt the scale in the stone-use decision process.

Failures, counterproductive to promotion, more often than not due to workmanship rather than to the stone materials, are avoidable. They may result from ignorance about the mechanical and physical properties especially when stone is used as veneer. Thin stone slabs or tiles are sensitive to the direction of cutting. Disregard may result in failures when processing the quarry material and during cladding. The weaker stones may cause problems at the point of fixing of anchors or dowels.

The promotion of stone and its products requires an intimate knowledge of the stone properties: from genesis to application. The engineering geologist is fitted out par excellence for these tasks knowing the quarry, its depositional characteristics, and the environmental sensitivity of the material after cladding. No one is more convincing than the stone technologist familiar with the contents of the stone deposit, the extraction/supply history, and whether the quarry has been affected by blasting, uncontrolled or otherwise. Presentation of proper criteria leaves no doubt to the favourable properties of the stone.

All this covers a wide spectrum of the engineering geologist's knowledge and specialisation, turning him into a stone technologist. Working closely with colleagues who deal with bedrock structures and site responses, will influence stone cladding system designs in earthquake-prone areas. Site investigation could even lead to the use of the extracted rock as building stones for the construction with considerable savings in cost.

He knows the sampling procedure, the interpretation of the testing results, and the application potentials including the environmental behaviour of the stone. He will be able to clarify the origin of the product and the transformation, from ornamental carving as a generally accepted 'upgrading', to the routine technological processes like sawing. The meaning of aesthetic versus utilitarian upgrading has become controversial in the quest to harmonise the preferential rules in the General Agreement on Tariffs and Trade (GATT) of the World Trade Organisation.

Experience together with an impeccable track record is required. To convince demanding decision-makers to use dimension stone requires experience with specifications, building regulations, and the Bill of Works.

In Table 1 (based on ASTM 1996), there are different acceptance values for stone varieties of the same type. For example, in the limestones, the minimum compressive strength requirement for the low-density variety is 12 MPa. Yet for a high-density limestone, the minimum is 55 MPa. Similarly there is a large divergence in the physical values for what the ASTM terms the quartz-based stones.

In the sandstones, the nature of pores whether interconnected or separate influences the acceptance value. The apparent incongruency in the requirements stems from the fact that acceptance tests are based on long-time testing experience and not only on testing results. Conclusions depend on observation of stone in use, together with assessing the stone by its petrographical, physical and mechanical properties, qualities and performances. It is expected that the present spate of EU testing methods standards will eventually be followed by a new set of clearer acceptance values.

Table 1: ASTM requirements for dimension stones

Variety	Stone type	Abrasion resistance ASTM C241 minimum	Compressive strength (Mpa) ASTM C170 minimum	Modulus of rupture (Mpa) ASTM C99 minimum	Absorption ASTM C97 (mg/m^3) maximum	Density ASTM C97 (mg/m^3) minimum	ASTM standard
	Granite	25	13.1	10.34	0.40	2560	C615–85
Low density	**Limestone**	10	12	2.9	12	1760	C568–89
Medium density		10	28	3.4	7.5	2160	C568–89
High density		10	55	6.9	3	2560	C568–89
Calcite	**Marble**	10	52	7	0.20	2595	C503–89
Dolomite		10	52	7	0.20	2595	C503–89
Serpentine		10	52	7	0.20	2690	C503–89
Travertine		10	52	7	0.20	2305	C503–89
Sandstone*	**Sandstone**	2	27.6	2.4	8	2160	C619–95
Quartzitic**		8	68.9	6.9	3	2400	C616–95
Quartzite***		8	137.9	13.9	1	2560	C616–95

*contains minimum 60% of free silica, **contains minimum 90% of free silica, ***contains minimum 95% of free silica

A common problem encountered in practice is the quoting of previous and probably obsolete testing results. These may be repeated in several consecutive editions of textbooks, commercial literature, prospects, and brochures, and are then copied into the Specifications and Bill of Works of construction projects. Another problem is that those unfamiliar with stone technology do not always realise that stone can lose strength (Shadmon 1996) that regrinding or re-polishing can cause a slab to crack; that porosity can be benign, even advantageous and colour of stone can fade. Both the positive and the negative have to be stressed in promotion, as the properties of natural material cannot be engineered to specification. At best we are able to modify. The modification is controversial, typical examples being the use of coating material on stone surfaces, be it fronts or backs of tiles and slabs. This controversy is extended into restoration applied to stone buildings.

Failure in stone cladding or flooring is more likely due to workmanship than to what happens behind the slabs, whether by anchoring or other means of attachment. Materials used, the faulty mode of fixing, and poor design may result in the penetration of moisture and dampness, which are archenemies of stone cladding, especially with thin stone veneers (Gere 1998). Prevention of such pitfalls should be emphasised in the promotional information.

Complaints about changes in colour and shades are less numerous than mechanical or physical failures, and can be prevented by proper use and sealing of the more decorative stone varieties.

Kitchen countertops, the use of which has increased in recent years, are prone to etching and solution by acidic liquids. Red feldspars turning whitish, the yellowing of white marble, the fading of some varieties of black 'granite' materials, often observed in tombstones or black limestones on facades, all have their explanations (Kraeft et al. 1993).

ENVIRONMENTAL PROMOTION

This defensive aspect of stone promotion is bound to have not less impact in the long run than the quality aspects of the material. The rehabilitation of quarries has become of current importance (Shadmon 1997). The ecological changes caused by extraction activities have mushroomed a lobby strong enough to prevent the opening of quarries and to close quarries in many countries. Such challenges can typically be solved by well-prepared promotion.

Promotional slogans based and emphasised on actual rehabilitation projects by geotechnical practitioners include: quarrying is a temporary utilisation of land; reclamation, replication and rehabilitation are integral to the quarrying process – not a cosmetic treatment; maximum productivity with minimum damage; unproductive land is returned to productive use (Shadmon 1996).

Other environmental factors to be pointed out include: stone is user friendly, it resists weathering damage, it is rot and termite proof, has low fire hazard, and is completely recyclable. Proper maintenance, depending on technical stone properties besides environmental influences, is yet to be regulated, as is agreement on slipperiness.

CONCLUSIONS

Effective promotion of geotechnics is dependent on providing reliable parameters of dimension stone. For this, primary research of stone properties with consideration to the environment is essential. The pragmatic approach of the last century is to be replaced by up-to-date techniques. Appropriate approaches with various degrees of success are presently at an early stage. The harmonisation of standards has resulted in the issue of the first 5 approved CEN standards mainly based on pragmatic experiences. Account is taken in the standards of industrial requirements, especially where testing costs and speed are predominant considerations.

When launching a new variety of stone, the promotional presentation has to be well planned at an early stage. Thorough research of its extraction history and application, the efficiency and quality of the processes of the quarry and plant have to be diagnosed, and achievements stated. Stone qualities are to be compared with competitive varieties, the quality control spelt out and the comparative testing results ranked. Agreement on acceptance values for tests has to be justified. Promotion of controversial and not regulated procedures should be avoided.

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