Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 161 (2016) 2222 – 2228

Procedia Engineering

www.elsevier.com/locate/procedia

World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium 2016, WMCAUS 2016

Buildings Under the Rocks: An Interdisciplinary Approach for A Safe Conservation

Eva Coïsson[a,]*, Andrea Segalini[a], Sabrina Maria Rita Bonetto[b]

[a] *DICATeA – University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, ITALY*
[b] *DST – University of Torino, via Valperga Caluso 35, 10125 Torino, Italy*

Abstract

Vernacular buildings have always been built by man in a strict relation with nature. This relation is particularly evident in the case of shelters built under rock protrusions, taking advantage of the natural element as a part of the building itself. Given their geological characteristics, the Western Alps are particularly rich of these type of vernacular buildings, which became a typical element of the local architecture and acquired a specific toponym ("barma"). Nevertheless, their conservation poses serious safety issues, that need a wide interdisciplinary approach to be solved. In this paper, the case of the Barma Mounastira hamlet (in northern Italy) is presented, with joint researches in architectural restoration and rock mechanics. First, the group of buildings was surveyed in its geometry, materials, decay phenomena, structural disorders. Then, the overhanging rock face was analysed starting with a geomechanical survey of the rock mass, in order to define potential instability phenomena and their implications on the safety of the Barma Mounastira site. This analysis enlighted that the three main problems for the conservation of the existing structures are strictly connected with the geological features of the site: water leaks from the rocks inside the buildings, the rock debris and soil where the structures are built are locally subjected to settlements and the rock cliff outcropping above the site can generate rock falls. The proposals for the solution of these problems could only come from an interdisciplinary approach, aimed at ensuring stability both for the buildings and for the rock face, as a first fundamental step for the preservation of an important typological witness of the past building traditions, respecting its equilibrium with nature.

Peer-review under responsibility of the organizing committee of WMCAUS 2016

*Keywords:*vernacular architecture; preservation; rock stability analysis; natural hazard

* Corresponding author. Tel.: +39-0521-905909; fax: +39-0521-905924.
E-mail address: eva.coisson@unipr.it

Peer-review under responsibility of the organizing committee of WMCAUS 2016
doi:10.1016/j.proeng.2016.08.819

1. Introduction

"The architectural heritage includes not only individual buildings of exceptional quality and their surroundings, but also all areas of towns or villages of historic or cultural interest" [1]: this statement from the Declaration of Amsterdam (1975) ratifies at an international level the feeling that some sensitive scholars (John Ruskin [2] among others) had already foreseen a century before, i.e. the necessity to enlarge the field of architectural restoration also to the "minor" architecture, as a witness of past techniques, traditions and way of life. The will to preserve these documents made of stones and timber and to pass them on to future generations is also widened to the surroundings, to the environment in which these objects were built: this is considered necessary because the perception we have of an object, especially at an architectural level, is deeply influenced by the light, by the perspective in which we look at it and by what we see around.

The relation with the surrounding natural elements is particularly significant in the case of vernacular buildings. But there are some cases in which the relation between a building and Nature all around is even deeper: the case of construction which take advantage of rock protrusions as a protection and a part of the building itself. In these cases, the boundary between the building and the natural elements vanishes and conservation cannot avoid to take into consideration buildings and rocks as a whole.

2. The case study: barma Mounastira

2.1. Description of the site

The object of this study is a hamlet in the Western Italian Alps named barma Mounastira (Figure 1). The small group of vernacular building is placed under a high stone face, on the steep left orographic side of the river Angrogna, tributary of the Pellice river. Its toponimy – barma – has a celtic origin (bal-men: high stone) and it is used in a wide area to refer to caves, protruding rocks and stone shelters [3].

Fig. 1. The barma Mounastira site, in complete harmony with the natural elements.

The hamlet, whose inhabitants were clearly dedicated to farming and lived in a strict relation with the surrounding woods, is composed by 11 small buildings, including:

- A main, three storeyed house, independent from the natural rock, with a stable, a kitchen and a room with a balcony;
- A two storeyed house with a stable, a kitchen and a room;

- A small independent stable;
- A hayloft with a particular floor made of interwoven branches, to improve air circulation;
- A laboratory for hand-craft works, particularly for winter months, when the field works were limited;
- A woodshed;
- An oven;
- Other small constructions

The dwellings are very simple, made of stone masonry, with little, poor mortar, and timber floor and roof structures. The roofs are covered with typical flat gneiss stone elements called "lose", which could be found by the builders in the same area. Most of the buildings take advantage of the natural rock mass as an external partition and some trusses are directly leaning on it. The connections between the different levels are made with external stairs, as the rooms inside are very small and low (to reduce the heat dispersion). Heating was ensured only by fire and some traces of smoke can still be found inside the kitchen rooms.

2.2. Survey of pathological phenomena

The first step to be taken towards a conscious conservation process regards the knowledge of the current preservation status. Therefore, an in depth survey and analysis of the decay phenomena and of the structural disorders were carried out.

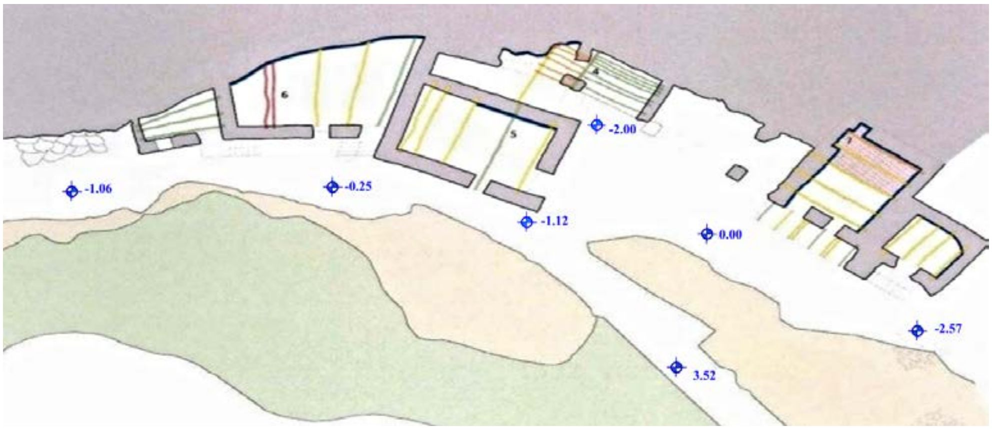

Fig. 2. The survey of the decay phenomena shows a strict connection with the water infiltrations from the rocks behind, [3].

The position chosen by the builders was supposed to protect the constructions from the elements and to supply water (two natural fountains are present near the buildings), but the strict relation between the buildings and the overhanging rocks also poses some problems to be solved in view of a possible restoration and reuse project. First of all, a safety issue: only two years ago, in 2014, a large stone element detached from a slope in the French Alps killed two children who were sleeping in their house below [4]: is it likely to happen also in this specific case?

An answer must be given before inserting a new function. Moreover, it was possible to observe that many of the decay phenomena in the dwellings (particularly on the timber elements) are connected to the water leaks coming from the rocks themselves (Figure 2): without an appropriate regimenting, water can change from resource to problem. At last, the most severe crack pattern was observed on a building which clearly suffered from a differential soil settlement (Figure 3), due to the different conditions of the foundations: on one side, nearest to the rocks, they rest directly over them, and on the other part, probably resting over debris and therefore more deformable. In conclusion, most of the identified problems are related to geological and geotechnical issues. Therefore, before addressing the specific restoration issues, analyses of these problems from a specialized point of view is needed.

Fig. 3. The main crack pattern is caused by a differential soil settlement.

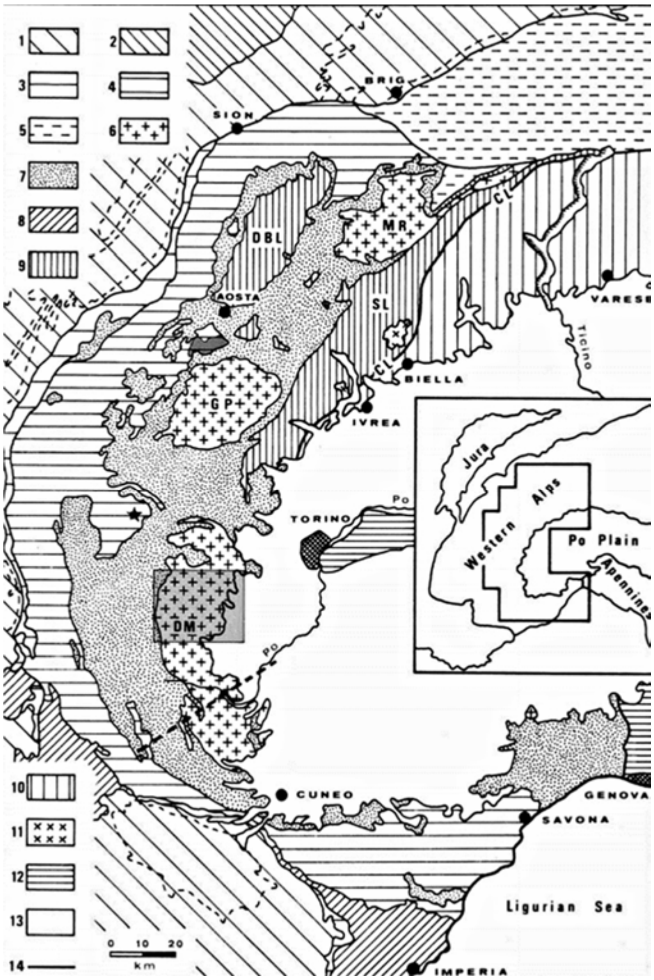

Fig 4. Sketch of the geological alpine domains.1) Basement (a) and Swiss (b) roofs; 2) Prealps; 3) Subbrianconais zone; 4) Brianconnais zone; 5) Sempione-Ticino Nappes and Camughera-Monucco Zone; 6) Internal crystalline massif; 7) Piedmonts Zone); 8) Alpine flysch of Ubaye-Embrunai and Liguria; 9) Sesia-Lanzo Zone (SL) and Dent Blanche Nappe (DB); 10) Southern Alps); 11) Tertiary, post-kinematic intrusive of Traversella and Valle del Cervo; 12) Apennines and Monferrato; 13) Quaternary and Tertiary sediments of Ligurian-Piedmontese basin and Po plain; 14) Canavese Line (CL) and boundary between Alps and Apennines.

3. The geological and geomechanical analyses

3.1. The geological framework

The Valle Angrogna is a left tributary of the Val Pellice, located in the Western sector of the Italian Alps and belongs to the Penninic Domain.which is characterized by two tectonics units: the Piedmontese Zone and the Dora Maira Massif. The studied area is included within the Dora Maira which is one of the Internal Crystalline Massif representing the ancient European continental crust (Figure 4). The Dora Maira is composed principally of a polimetamorphic basement of probable pre-Carboniferous age and by a mono-metamorphic cover unit of presumed Carboniferous-Permian age [8], [9] e [10].

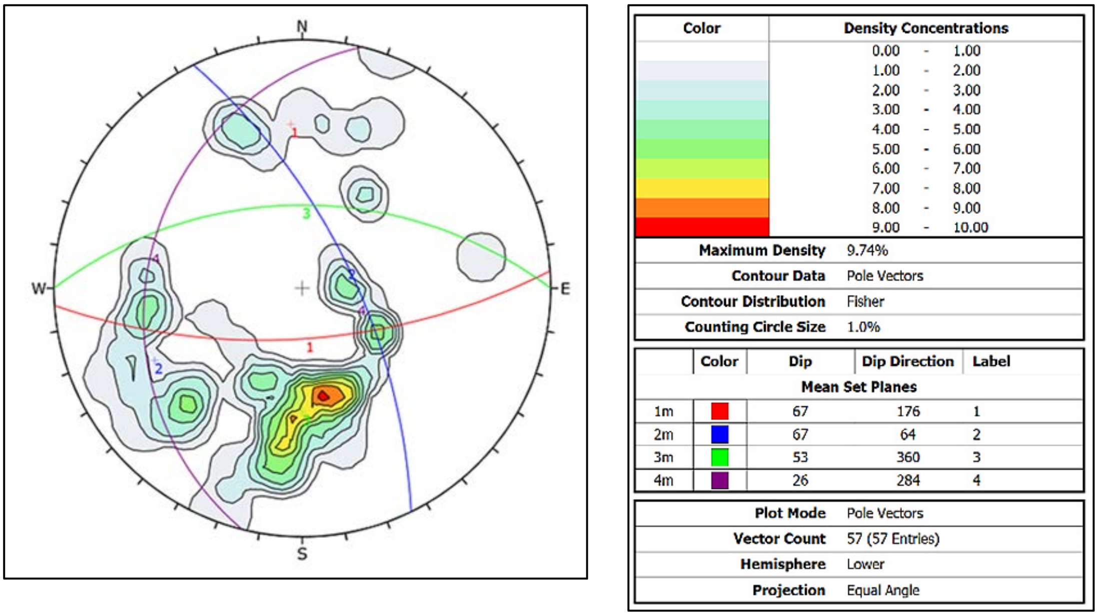

Fig. 5: Equiareal projections of the surveyed discontinuities [7]. Four main discontinuity systems were highlighted (Tab. 1).

Table 1. Summary of the systems orientation average values.

Sistem	Pole	Spacing	Mean Plane
	Dip/Dip Dir. [°]	[cm]	Dip/Dip Dir. [°]
K1	66/85	238	67/176
K2	58/112	95	67/64
K3	37/255	211	54/359
K4	56/271	122	26/284

Table 2: Hypothesized Bolt features and related Safety Factor.

Length	Anchor Length	Trend/Plunge	Capacity
[m]	[m]	[°]	[MN]
4	1.6	300/28	0.02
SAFETY FACTOR			
2.338			

In particular the Valle Angrogna is mainly composed by:

- a large variety of gneiss, that often exhibit textural and compositional multiple gradations, this lithology mainly characterize the rock mass overhanging the vernacular buildings;
- glandular gneiss complex comprising the several, with micro-gneiss and Micaschist intercalations belonging to “Ensembles Graphitique de Pinerolo”;
- complex graphite of Pinerolo, characterized by the presence of graphite in lenses, from sequences of conglomerate and quartzite, gneiss metapelites, metarenites of the coal age;
- complex of Dronero consisting of gneiss and Micaschist and gneiss minutedebris source several, smaller and micro-debris, Permian age volcano-source [9] [11].

3.2. Geomechanical Survey

The stability both for the buildings and for the rock face is strictly connected to the mechanical features of the rock mass. Traditional geomechanical survey were carried out in order to identify the main discontinuity systems that characterizes the rock face.

The adopted methodology consisted both in a subjective survey of the main discontinuities playing an important role on the face stability and an objective survey with scanlines nearly perpendicular to the main discontinuities on four different orientation of the rock face (50/140; 80/120; 70/88; 70/110) in order to define the values of the averages spacing for each set of fractures. A statistical analysis was performed and data were processed using a plotting patterns (Figure 5).

3.3. Kinematic analysis and preliminary investigations

In order to identify potential kinematic failure, the Markland Test [6] was performed. The test, made by imposing a friction angle value of 31° and a Dip/Dip Direction of the rock face orientation of about 80/120, highlighted some critical conditions for stability. Discontinuity systems 1 and 2 identify wedges (Figure 6), which fall within the plot area between the rock face, the friction angle circle and the ± 20° deviation of the dip direction. Movement can occur along the intersection line with inclination less than that of the rock face but greater than the friction angle. A second test also confirmed the possible triggering of planar sliding movement due to the presence of geometric conditions regarding the discontinuity orientation in respect to the rock face (similar dip direction and lower dip of the discontinuity).

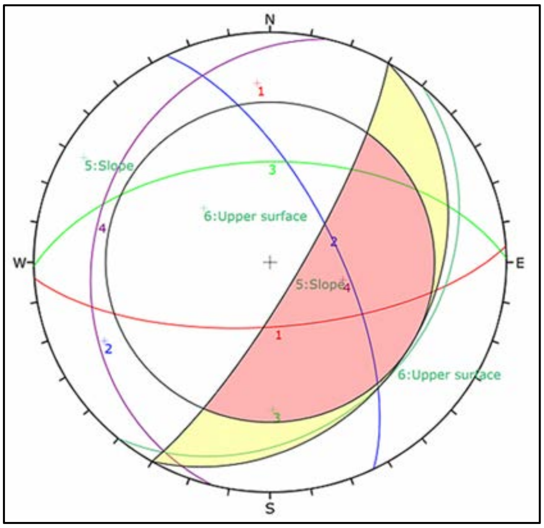

Fig. 6: Markland test carried out for three-dimensional sliding using the orientation of the rock face of 80/120.

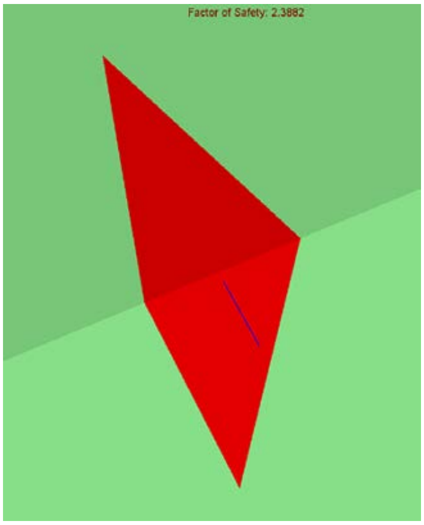

Fig. 7: Geometry of the potentially unstable rock wedge with indication of the protection measure (i.e. bolt, in blue).

The Markland Test allows to calculate the safety factor, which shows a value of 0.7 on potentially unstable blocks. Having determined that the average length of most discontinuities is between 1 and 3 m, the potential volume of unstable blocks is about 1-1.5 m^3. In this regard, using the program *Swedge* [12] nailings or boltings solutions can be applied, increasing the safety factor to appropriate values (Table 2, Figure 7). Water spills were locally observed particularly in correspondence of certain discontinuities.

4. Summary and Conclusion

The conservation and restoration of historical architecture, also in the humblest cases, is always a field in which different disciplines must meet and cooperate in order to reach the best solutions to pass on a testimony from the past to the future generations. In the case presented in this paper, an important role in the definition of the possibilities for a safe conservation is played by geomechanics, as the analyzed vernacular dwellings were built under a large rock face. The architectural and pathological survey clearly showed that the relation between buildings and natural elements had at the same time positive and negative effects. Indeed, the position guaranteed protection from the elements and water supply, but now, in view of a possible reuse, it poses serious safety issues and it induces water related decay phenomena and soil settlements. A first step in the geomechanical characterisation and definition of the stability conditions of the rock face have been accomplish. Traditional geomechanical surveys were carried out at the bottom of the rock face, where accessible. About 70 discontinuities were recorded and statistical analysis of these revealed four main families. The survey showed that the average length of most discontinuities is between 1 and 3 m, therefore, the volume of potentially unstable blocks varies between $0.01m^3$ and $1.6\ m^3$, with prevalence around $0.6\ m^3$. Planar and three-dimensional sliding are possible and the safety factor calculated for the potentially unstable blocks is 0.7. Numerical simulations allow to verify the effect of specific interventions (i.e. bolting) on the safety factor.

It was also observed the presence of water inside some discontinuity, assuming an active role in the instability processes. Sub-horizontal drilling could be suggested, draining the water further downstream; otherwise you could operate with the masonry or collector surface by known withdrawals. This would then solve the problem of humidity inside buildings combined with the rock. Finally, another aspect to be considered is the presence and the features of the debris on which some buildings seem to lean. The buildings were affected by subsidence phenomena of the debris on which they are based. Grain size distribution curves and compositional features of the debris should be accessed in order to define an appropriate localized intervention of stabilization.

Further investigations have to be carried out in order to integrate the geomechanical data with those coming from the upper portion of the rock face and to implement further safety measures.

The proposed interdisciplinary approach aims at preserving not only the buildings themselves in safe conditions, allowing their reuse and consequent maintenance, but also to respect the most meaningful characteristics of this hamlet: its perfect integration with the surrounding natural environment.

Acknowledgements

The authors would like to thank Laura Prati for the support in geomechanical survey and analysis and Annamaria Rodella and Giulia Zetti for the support in the architectural survey.

References

[1] Council of Europe. The Declaration of Amsterdam. 1975.
[2] Ruskin, John. The Seven Lamps of Architecture. London, 1849.
[3] Bertot R., Architettura rurale in Val d'Angrogna, Comune di Angrogna, 1985.
[4] Rodella A., Zetti G. Barma Mounastira: un'architettura da restaurare, riscoprire e vivere, Università di Parma, 2016.
[5] http://www.lastampa.it/2014/02/23/esteri/enorme-masso-frana-sullo-chalet-francia-muoiono-due-bambini-LBOGWDIm5enyQdJGLVQX0K/pagina.html
[6] Markland, J.T. 1972. A useful technique for estimating the stability of rock slopes when the rigid wedge slide type of failure is expected: Imperial College Rock Mechanics Research Reprints, n. 19
[7] Dips v. 6.0, Rocscience Inc., Toronto, Ontario. 2016
[8] Franchi S., Relazioni preliminari sulla campagna geologica dell'anno 1911. Boll. R. Comit.Geol. It., 43: 50-60.1912
[9] Vialon P., Etude gèologique du Massif cristallin Dora-Maira (Alpes cottinnes internes – Italie) Trav. Lab. Gèol. Grenoble, mèm. 4, 293 pp., 1966
[10] Borghi A., Cadoppi P., Porro A., Sacchi R., Sandrone R., Osservazioni geologiche nella Val Germanasca e nella media Val Chisone (Alpi Cozie). Boll. Mus. Reg. Sci. Nat. Torino, 2, pp. 503-530. 1984
[11]Mattirolo E., NovareseV., Franchi S., and Stella A., Carta Geologica d'Italia a scala 1:100.000, foglio Pinerolo, Litografia Artistica Cartografica, Roma, 1913
[12] Swedge v. 6.0 User Manual - Rocscience Inc. – Toronto, Ontario, 2016