Safe Management of Stone Balconies: an Overview

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Stone balconies are structural elements and architectural features mainly used in European and Mediterranean countries. The knowledge and the continuous creation of new materials do not constitute a limit to the use of natural stone in structural works such as balconies: this use is often justified by a mere aesthetic reason in the restoration of historic buildings. As a natural material, the stone is difficult to control in terms of homogeneity and isotropy, it has poor tensile strength and it is difficult to consolidate to ensure adequate structural safety. Thus, first, a research of the main balconies' collapse events was carried out to understand how much extended and critical the situation is. Then, to understand the phenomena of the falling balconies, the problem was approached from different points of view: besides the structural aspect, the overall process was analyzed with the "What-if" technique, to identify the Hazard Factors. The research confirmed that, in Italy, high numbers of balconies collapsed in recent years and a good percentage includes balconies in stone. The paper discusses several proposals and a solution (pre-compressed corbel) is analyzed and proposed to save both the structural conditions and the aesthetic aspects of the building, ensuring a safe construction and use of stone balconies.

Keywords: Balconies, stone, restoration, tensile strength, occupational safety, users' safety.

1. Introduction

Stone balconies are structural elements used in the past mainly in European and Mediterranean countries, especially in Italy, where there is a considerable historical heritage (Acocella 2004; Brebbia and Hernández 2015). The knowledge and continuous development of new building materials are not a limit even today, when it comes to the use of natural stone to build structural works such as balconies; this use is often justified by a mere aesthetic reason in the restoration of the historical heritage (Lombardo and Luparello 1997). However, as a natural material, the stone is difficult to control due to its unpredictable chemical, mechanical and physical characteristics. This has recently led to several events of collapse of stone balconies, such as the one shown in Figure 1, involving both end-users and workers (Manzone and Patrucco 2007). Because of the lack of detailed statistics, an estimate of the collapses that occurred in the decade 2009-2018 in Italy has been done. This research pointed out how extensive the phenomenon is in Italy. It is therefore important to provide a set of tools to analyze the suitability of the stone as a structural material. Indications for the safe restoration and management of the existing artifacts are finally discussed.

Figure 1. Sudden subsidence of a corbel of a balcony located on the third floor, with the fall of the slabs. The worker standing on its suffered fatal injuries.

2. Materials and methods

Initially, a research was carried out in the major media on collapses in 2009-2018, and the incidence of stone balconies was estimated. Then, in order to fully understand the phenomenon, the problem was analyzed from different points of view: besides the structural aspect, the Safety aspect was also studied from

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the quarry phase to the final use. The whole process was analyzed with the "What-if" technique (Center for Chemical Process Safety 2008; Card et al. 2012) to identify deviation dynamics and consequently to define some preventive technical, organizational and procedural measures, as well as other supplementary measures to ensure Safety for workers and users.

2.1 *Static scheme assumption and bending moment calculation*

It is important to investigate on strength characteristics of the material, in particular for structural uses: while compressive strength is a necessary requirement for vertical structures, the flexural strength is a necessary requirement for cantilevered elements or horizontal slabs leaning or wedged at the far ends such as stone balconies (Boeri 1996). Preliminary survey was therefore carried out in literature on the tolerable traction and flexural values of the stone material. The following assumptions were subsequently formulated:

- The corbels do not provide continuous support to the slab, since they cannot be perfectly horizontal: in favor of Safety, it is assumed that the slab is leaning in only two points against the corbels. The load that the slab transmits to the corbel is therefore treated as a load concentrated at the far end and not distributed over the entire length (Figure 2)
- The presence of the parapet is taken into account through a concentrated force at the far end of the slab due to the weight of the parapet portion relative to the cantilever
- The presence of horizontal variable overloads, in accordance with the decree "Aggiornamento delle Norme tecniche per le costruzioni" (2018) (which confirms the recommendations of Bollettino Ufficale del Consiglio Nazionale delle Ricerche 1967), is taken into account for sample checks; Hk linear horizontal loads are applied to walls - at 1.20 m height from the walking surface- and to parapets or handrails- at the height of the top edge
- The weight of the corbel is assumed evenly distributed on the actual span of the corbel

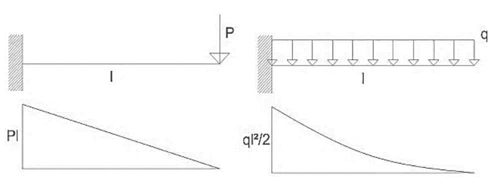

Figure 2 Bending moment for wedged corbel.

The reactions of the slab at the far end of the corbel must therefore be cautiously calculated using the classic methods of construction science, assuming the support planes of the two corbels not perfectly coplanar. In the case of corbel's length equal to the slab's width, the load concentrated at the far end of the corbel involves double bending moment, differently from the assumption of continuous support (Figure 2).
Finally, taking into account the assumptions, it can be supposed that the static scheme is as in figure 3, similar to what suggested by Lombardo and Luparello (1997).

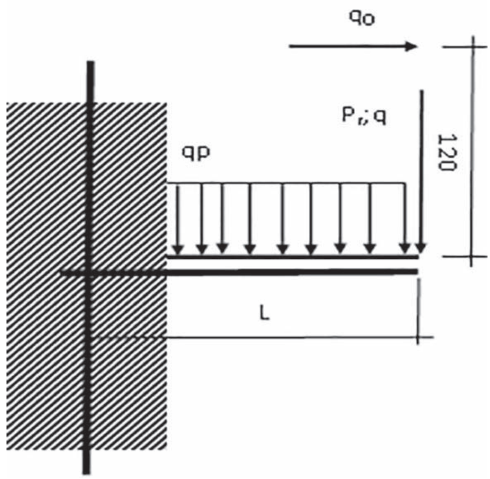

Figure 3. Static scheme and loads on the corbel. Pr= load of the railing; q=permanent load (weight of the slab); qo= horizontal load on the railing; qp=permanent load (weight of the corbel); L=length of the corbel and width of the slab.

Finally, theoretical calculations led to the assessment of the maximum bending moment, the resistance moment and the maximum tensile strength based on three examples of collapsed balconies. In the analysis, only the weights of the slab and the corbel were taken into account, in the hypothesis of not perfect parallelism of the corbels, which are therefore stressed by the entire weight of the slab positioned at their far end, to demonstrate the criticality of the situation itself.
The specific weight of the stone was assumed as 27 kN/m3 (Vallario, 1992).

2.2 *Applying the "What-if" technique*

The What If analysis takes into account all the phases of construction and life of the structures:

- Extraction and processing of stone material

- Balcony construction
- Use of the balcony

To obtain suitable questions, the parameters outlined in Table 1 for each phase were taken into account.

Table 1. Parameters taken into account in What-If analysis

Phase	Parameters
In the extraction (quarry) and processing (laboratory) of material	correct material correct winning, handling and dimensioning procedures
In the construction of the balcony	correct procedures information formation and training of workers
In the use of existing balconies	limitation of every kind of loads consider impulses of force consider critical environmental conditions necessity to consolidate both corbel and slab.

Finally, for each question, direct consequences, level II consequences, and preventive and supplementary technical, organizational and procedural measures were identified.

2.3 *Developing a qualitative scheme for choosing the best technique to consolidate existing stone balconies*

A team of experts consisting of three engineers, an architect and a risk prevention technician was formed. The experts met in a conference room and participated in a one-day discussion. Participants were informed of the purpose of the study and the first Author, expert in consolidation techniques, moderated the discussion.

3. Results and discussion

Sources have shown that from 2009 to 2018 the balcony collapses' trend is irregular, with an average of 5 balconies per year of which more than a half are made of stone. It should be taken into account that the numbers reported are certainly less than the real total, since the sources consulted typically include only the events deemed of interest in the news, i.e. striking or with victims.

The literature analysis showed that the best stones (granites) have an average flexural strength of 14 MPa, much lower than the reported mean value for compressive strength (approx. 183 MPa). Breymann (1877) observed that the traction in these stones cannot exceed 0,1 MPa, confirming that the stone material shows poor traction performance. It should be noticed that this statement is not in contrast with the results of technical tests (EN 12372:2006; EN 13161:2008; ASTM C880/C880M-09) on rock specimens. In fact, the specimens are small (ratio 1/10 – 1/100 and above) compared to the elements used in the construction of the balconies, and are selected "healthy" by discarding the portions of rock from which would result incomplete specimens due to breakages during the preparation. In this sense, random sampling of several rock specimens (at least 10 specimens according to EN 12372:2006 and EN 13161:2008) would be of pivotal help to achieve representativeness. Another important aspect is to corroborate the hypothesis of normality (for the calculation of the mean value, the standard deviation and the coefficient of variation) and lognormality (for the calculation of the lower expected value) assumed by the Standards. This can be done through the Shapiro-Wilk test (Shapiro and Wilk 1965) or plotting the measured values of flexural strength in ascending order on log-probability paper (Barbato et al. 2019) for small sized data sets.

Considering stone elements at a larger scale, such as balcony components, it should be taken into account that, unlike in the past, the handling techniques used at present for stone elements reduce the impacts. As a consequence, the elements (corbels and slabs) used at present for the construction of balconies may not be "healthy" and can conceal internal cracks and components of different mineral nature, even on a small scale or not discernible in a cursory surface analysis.

As a numerical example, Table 2 shows the possible results of the verification (assuming the static scheme of Figure 3) of 3 balconies, where corbels broke at the point of maximum stress, that is in correspondence with the vertical wall, in the absence of accidental overloads (events that occurred in Italy on which some of the Authors had access to detailed information as entrusted with the role of consultants in a Prosecutor's investigations).

Table 2. Balconies' check example.

	Balcony #1	Balcony #2	Balcony #3
Balcony length (m)	1,70	2,70	2,50
Balcony width (m)	1,10	0,80	0,90
slab thickness (m)	0,09	0,08	0,08
n. slabs	2	2	2
corbel length (m)	1,10	0,80	0,90
corbel thickness (m)	0,18	0,16	0,20
average corbel height (m)	0,30	0,40	0,30
maximum corbel height (m)	0,38	0,50	0,40
maximum bending moment (kNm)	5,87	4,32	4,59
resistance moment W (cm^3)	4332,00	6666,67	5333,33
tension σ+max (daN/cm^2)	13,55	6,48	8,61
stone typology	felsic intrusive igneous	felsic intrusive igneous	felsic intrusive igneous

Table 2 brings into evidence that the resulting stress values, maximum values calculated considering imperfect supports (corbel loaded at the tip and not in distributed load) must be halved if the corbel-slab support is continuous. The tensile stress values at the breaking time (in absence of overloads) are extremely modest.
Considering a safety coefficient of at least 7÷8, the tensile strength's value results of approx. 1 kg/cm^2, i.e. very close to zero.
Thus, the low tensile strength of the stone material and the bending moment evaluated in these examples suggests that the stone is unsuitable for structural elements, subject to flexion such as balconies.

The What If analysis (composed of 32 questions) showed that:

(i) the major events, in the extraction and processing phase of stone material, that could lead to the collapse of the balcony during the use are:
- (a) not adequate determination of the site of extraction
- (b) incorrect identification of the direction of the natural layers
- (c) inadequate preparation of the mining site
- (d) incorrect "primary cut" operation
- (e) incorrect "secondary cut" operation (cutting of the mass block)
- (f) not suitable material sorting and elimination of lumps with obvious defects
- (g) impacts in the handling of the material at the mining site
- (h) impacts in the handling of the material during the transport action from the quarry yard to the laboratory
- (i) impacts in handling the material at the laboratory
- (j) not adequate lumps sawing
- (k) inadequate cutting and trimming
- (m) not adequate inspection of the material (with reference to the finished product)

(ii) the major events, in the construction phase of the balcony, that could lead to the collapse of the balcony during the use are:
- (a) abnormal impacts or stresses in handling the material during the transport action from the laboratory to the site or in on-site storage
- (b) material not suitable for structural function (not in accordance with what is commissioned)
- (c) impacts in handling material at the site
- (d) impulse of force on the corbel during the installation
- (e) inappropriate adjusting of the material or operated with inadequate tools or procedures

(iii) the exceptional events, in the utilization phase of the balcony, that could lead to the collapse of the balcony during the use are:

(a) excessive loads (overload, crowding, snow, ...)
(b) inappropriate use of the balcony
(c) impulse of force on the slab
(d) earthquakes and exceptional vibration

(iv) several technical, organizational and procedural preventive and supplementary measures were developed, for the extraction, processing phase and for the construction phase, including:

(a) surveys
(b) dedicated geological inspections
(c) geophysical, geochemical surveys
provide adequate impact mitigation through piles of debris
(e) check the compactness and general uniformity of the extracted material
(f) eliminate material that is overstressed during the handling
(g) information, formation and training of workers
(h) use of layers of cement mortar between corbel and variable thickness slab to horizontalize the slab (Perino 2008)

(v) For the use phase (regarding excessive loads) the main measures identified are:

(a) balcony consolidation
(b) maximum load limitation

Summarizing, from a strict Safety point of view, it can be pointed out that the general situation can lead to a non-exhaustive quantification of the risk, both for workers (in the construction phase) and for users. In fact, the criticalities pointed out by the What if analysis are often not quantifiable, the rock characteristics are determined on a small-scale and rock specimen may be not representative. Therefore, the worst credible case coincides, in this situation, with the risk cause. This is also confirmed by the tensile strength values suggested by many authors. Obliviously, in this situation, also a high safety coefficient may not be enough. Thus, during the design of the restoration of historic balconies, strict quality checks of the stone material should be carried out during the laboratory phase. Procedures and instruments for quality checks should be continuously improved to ensure the safety of the existing balconies.
The consolidation of the balcony, as identified by the committee of experts, can be carried out with different techniques. Table 3 summarizes the main techniques of consolidation of stone balconies with their advantages and disadvantages.

Table 3. List of the main techniques for the consolidation of stone balconies.

Solution	Description	Advantages	Disadvantages	Notes
Inclusion of a steel section in the corbel	Drilling of the corbel throughout its length, in order to ensure the housing of a section, that absorbs the tensile stress of the corbel during the use	Good aesthetic impact; Medium shear strength;	Limited tensile strength (section does not work); Risk of stone disintegration around the metal beam;	Appropriate drilling of the corbel (for the total length) Appropriate selection of mortar to be used;
Inclusion of steel bars in the corbel	Inserting of metal bars into the corbel, drilling a hole along all its length.	Medium tensile strength; Good aesthetic impact; Medium shear strength;	Risk of stone disintegration around metal bars;	Appropriate drilling of the corbel (for the total length) Appropriate selection of mortar to be used;
Top milling of the corbel and insertion a steel section	milling the top of the corbel in such a way as to ensure the housing of a laminated T-profile	Good tensile strength;	Small shear strength; Limited step between the slabs;	Appropriate selection of mortar to be used;
Pre-compressed corbel	inducing a state of precompression in the corbel: this solution would reduce the tensile stress near the interlock. One way to apply this solution is to drill the corbel through waterjet thorough its length.	Entirely compressed section, under operating loads;		Appropriate selection of mortar to be used;
Steel corbel	replacing the stone corbel, with a steel section, that plays the structural function and resists the tensile stress	Improved tensile strength; ductility;	No aesthetic result; Large number of corbels;	If the steel corbel is covered by stone material, ensure the stability and durability of the latter;
Carbon fibers	Attachment of the carbon fiber to the corbel or the slab to ensure adequate structural reinforcement. The consolidation of the balcony can be achieved with unidirectional carbon fabrics placed at the top surface of the slab. The consolidation of the slab can be achieved with placement of a bidirectional carbon-fiber mesh at the top surface.	Good tensile strength; Used to improve and repair	No aesthetic result;	Appropriate installation to ensure adherence with stone and overlapping longitudinal and cross-section;

In addition to the techniques discussed in Table 3, in some cases injection of mortar and resins into the stone are used only to repair (not to improve) the balcony. Table 3 shows how the pre-compressed corbel can be considered at a qualitative level as the most suitable solution for the problem of the restoration of the existing stone balconies.

4. Conclusion

The research highlights that the problem of balcony collapse and instability at national level is current and relevant, and the impact of balconies supported by stone corbels or stone slabs compared to the total number of collapses recorded is important. Given the low tensile strength of the stone material and the bending moment obtained considering the concentrated load at the end of the corbel, the conclusion is that stone is unsuitable for structural elements subject to flexion such as balconies. In addition, since traction tests are generally carried out on "healthy" small specimens, there is no representativeness of the sample tested, because it could not represent the real situation of the future balcony. However, the adoption of stone balconies is justified where the aesthetic aspect is a priority (especially in the historical centers). In this case, as pointed out by the What If analysis, it is strictly necessary to set the appropriate safety measures in the collection of the material and in the construction of the balcony and consider the possibility of consolidation of the structure through one of the techniques proposed in the paper.

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References

Acocella, A. (2004). *L'architettura di pietra. Antichi e nuovi magisteri costruttivi.* Lucense- Alinea.

ASTM C880/C880M-09. *Standard Test Method for Flexural Strength of Dimension Stone.* ASTM International.

Barbato, G. a. Germak, and Genta G. (2019). *MISURARE PER DECIDERE Misure e Statistica di Base.* Esculapio.

Boeri, A. (1996). *Pietre Naturali nelle costruzioni, Requisiti- Criteri progettuali- Applicazione- Prestazioni*. Hoepli.

Consiglio Nazionale delle Ricerche (1967). *Ipotesi di carico sulle costruzioni.* Bollettino Ufficiale del Consiglio Nazionale delle Ricerche.

Brebbia, C.A. and S. Hernández (2015). *Structural Studies, Repairs and Maintenance of Heritage Architecture XIV.* WITPRESS.

Breymann, GA (1877). *Trattato generale di costruzioni civili.* Vallardi.

Card, AJ, Ward JR, and PJ. Clarkson (2012). Beyond FMEA: the structured what-if technique (SWIFT). *J Healthcare Risk Manage 31, 23–29.*

Center for Chemical Process Safety (2008). *Guidelines for Hazard Evaluation Procedures 3rd Edition.* Wiley.

EN 12372:2006. *Natural stone test methods - Determination of flexural strength under concentrated load.* CEN.

EN 13161:2008. *Natural stone test methods - Determination of flexural strength under constant moment*. CEN.

Lombardo, L. and S. Luparello (1997). *Restauro strutturale 1.* Dario Flaccovio Editore s.r.l.

Manzone, G. and M. Patrucco (2007). *Consulenza tecnica su incarico Pubblico Ministero in materia di infortunio mortale connesso con cedimento di mensola di balcone in corso di attività di manutenzione straordinaria di un edificio. Sondrio.*

DECRETO 17 gennaio 2018, Ministero delle Infrastrutture e dei Trasporti (2018). *Aggiornamento delle «Norme tecniche per le costruzioni».* Gazzetta Ufficiale della Repubblica Italiana.

Perino, L. "Balconi in pietra: casi studio e prove di durabilità". Tesi di laurea, Politecnico di Torino, 2008.

Shapiro, S.S. and M.B. Wilk (1965). An Analysis of Variance Test for Normality (Complete Samples). *Biometrika 52, 591-61.*

Vallario, A. (1992). *Frane e territorio: le frane nella morfogenesi dei versanti e nell' uso del territorio.* Liguori.