

# “HISTORICAL BUILDING CODES ISSUED AFTER THE STRONG ITALIAN EARTHQUAKES OF NORCIA (1859) AND ISCHIA (1883)”

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## ABSTRACT

Building codes are a fundamental part of the overall strategy for the reduction of seismic risk but their origin is not recent, indeed, several historical examples are available. After the 1859 Norcia (Central Italy) and 1883 Ischia (Southern Italy) earthquakes two standards were issued, which can be considered a remarkable attempt to improve the performance of ordinary unreinforced masonry structures by regulating architectural configuration and structural details. Both documents contain interesting observations about ground stratigraphy and topography, masonry units and mortar, vaults and horizontal floors, connections and tie-rods, new and existing construction. All these aspects represent a codification of earthquake-resistant techniques used in seismic zones in accordance with best practice, still extraordinarily relevant when compared with both recent standard recommendations about structural details and with the performance observed during the 2016 and 2017 earthquakes.

## 1. INTRODUCTION

The urban development of several municipalities located in seismic areas is closely linked to the occurrence of strong earthquakes [Penta, 1964; Reitherman, 2006a; Tobriner, 1984]. Historical seismic-resistant techniques arise from the necessity to reduce earthquake damage with locally available materials and details [Clemente, 2017; Ortega et al., 2017; Reitherman, 2006b]. In Italy, the history of the city of Norcia and of the island of Ischia (Figure 1) is particularly relevant, because *ad hoc* standards were enacted on the basis of post-earthquake observations, as discussed below. Previous examples include the technical recommendations of L. Gaudin after the 1746 Lima earthquake [Cancino, 2019], the constructive practice developed by General De Maia at the request of the Minister S.J.C.M. Pombal in 1755 [Fonseca, 2005;



FIGURE 1. Location of Norcia and Ischia in Italy.

França, 1965; Mascarenhas, 2004; Rossa, 1998; Ruggieri, 2017), and finally the “Instructions for Engineers commissioned in South Calabria” by the *Borbone* government in 1784 [Grimaldi, 1863; Ruggieri, 2017; Vivencio, 1788]. All these regulations are unquestionably a first fundamental, qualitative, step towards the more complete quantitative standards of the twentieth century, such as those issued after the 1906 San Francisco earthquake [Reitherman, 2012] and the 1908 Messina and Southern Calabria earthquake [Sorrentino, 2007].

Despite the presence of extensive literature on a coeval earthquake-resistant system involving the use of half-timbered constructions, named “Pombalino system” in Portugal and “casa baraccata” in Italy [Favaro, 1883; Galassi et al., 2014; Marcovigi, 1916; Masciari-Genoese, 1915; Riccò, 1907; Ruffolo, 1912; Sacco, 1908; Stellacci et al., 2016; Vivencio, 1788], seismic-resistant techniques for unreinforced masonry buildings seem to arouse less interest, resulting in a lack of literature. Therefore, emphasis will be placed in this paper on the recommendations for unreinforced masonry constructions present in the codes issued after the 1859 and 1883 earthquakes.

The cases of Norcia and Ischia are outstanding ex-

amples of accurate analysis of observed buildings performance during seismic events, then used as the basis for detailed recommendations for new constructions and for an accurate selection of repair measures for existing buildings. It is worth noting that Norcia and Ischia were both recently hit by earthquakes, respectively in 2016 ( $M_w$  6.5) [Sorrentino et al., 2018] and 2017 ( $M_w$  4.0) [Briseghella et al., 2018]. The provisions in the two standards, when implemented, helped reduce seismic damage (Figure 2). In particular, in the case of Norcia, the design requirements introduced by the 1860 building code were observed in many buildings that withstood the seismic sequence, resulting in light damage [Mazzoni et al., 2018], despite the severity of the shaking [Mollaioli et al., 2018]. Sisti et al., [2018] have explained the good performance of Norcia with the measures taken after the 1979 Valnerina earthquake according to technical guidelines issued thereafter [Regione Umbria, 1981]. However, the same guidelines were used in Sellano, which offered a less satisfactory performance after the 1997-1998 Umbria-Marche earthquake [Borri and De Maria, 2004]. Indeed, the original features of the buildings in Sellano and Norcia were different, with the latter being of higher quality thanks to the 1860 code.



a)



b)

**FIGURE 2.** Example of damage occurring in: a) Norcia, after the 2016 earthquake (Snapshots from videos released by the Firefighters Corps, [www.vigilfuoco.tv](http://www.vigilfuoco.tv)) and b) Ischia, after the 2017 earthquake (photo courtesy of Antonio Formisano).

## 2. SEISMIC EVENTS PRECEDING AND FOLLOWING THE NORCIA AND ISCHIA BUILDING CODES

The earthquake that struck Norcia and surrounding areas on August 22<sup>nd</sup>, 1859 ( $M_w$  5.7) [Rovida et al., 2016] caused extreme damage and casualties. On an estimated population of 4000-5000 people, 101 died and two entire neighbourhoods were heavily hit, with great losses in terms of church and public heritage. No study about site effects in Norcia in 1859 is available, but a detailed description of damage distribution is reported by [Boschi et al., 1998] after a systematic analysis of archive data. The impact on churches and palatial buildings was dramatic. Moreover, 29% of ordinary buildings completely collapsed, 60% partially collapsed, and 11% were severely damaged. Co-seismic ground cracks and landslides occurred; water wells temporarily run dry. The severity of the earthquake effects was compounded by the characteristics of the constructions. In the aftermath of the seismic shock, a specific “Safety Committee” was established [Secchi, 1860], which included, among others, the pontifical architect Luigi Poletti, previously responsible for post-earthquake restorations [Sorrentino et al., 2008], and the scientist Angelo Secchi, a prominent name in seismology in those years.

On the basis of the observations made by the Committee, it was noticed that the most affected buildings had at least three storeys, thin unreinforced masonry walls made with undressed river pebbles, heavy and irregular vaults often poorly interlocked with the piers and without tie rods, and pavilion roofs without trusses. The first earthquake of comparable intensity, after the one in 1859, occurred on September 19<sup>th</sup>, 1979 ( $M_w$  5.8) [Rovida et al., 2016], damaging several buildings of the city: many sections of the city walls, a tower, six churches and five palatial buildings were extensively damaged. The number of damaged buildings was estimated at 773 (5% involving partial collapse, 32% severe damage, 25% moderate damage, 38% slight damage) and 44 buildings were judged to require demolition [Boschi et al., 1998]. It is worth noting that the areas of the city most damaged by the 1979 earthquake were not the same as in the 1859 shock [Reale, 2001; Scheibel, 2001; Vignoli, 2001]. The greatest concentration of damage took place along a street, Corso Sertorio, which was created by gutting of part of the historic urban fabric, without adequate connection between the new façades and the existing orthogonal walls: clearly a detrimental practice which, as shown below, was in violation of the building code. Con-

versely, when strengthening interventions and reconstructions were made following the code, the damage that occurred was much smaller [Reale, 2001; Scheibel, 2001; Vignoli, 2001].

The municipality of Casamicciola on the island of Ischia was hit by a severe earthquake on July 28<sup>th</sup>, 1883 ( $M_w$  4.3) [Rovida et al., 2016], whose seismological aspects are addressed in several research studies [Baldacci, 1883; Castenetto et al., 1999, 1998]. The earthquake caused 1784 victims in Casamicciola (41.5% of the population) out of about 2300 fatalities [Castenetto et al., 1998; Polverino, 1998], including 650 tourists. The high number of fatalities, both in absolute and relative terms, helps explain the reason for the great notoriety of this earthquake [Caiafa, 2012]. This high human toll was the result of significant damage to the building stock, already weakened by the event of March 4<sup>th</sup>, 1881 [Castenetto et al., 1998]: in Casamicciola alone, out of 672 buildings, 537 collapsed and 134 were damaged. Despite the moderate magnitude (in a range between 4.3 and 5.2), the 1883 earthquake determined such substantial damage, and a maximum macroseismic intensity as large as XI Mercalli-Cancani-Sieberg scale due to the shallow depth of its source. Local amplification of damage was detected on soft soils, and stiff or soft soils influenced the attenuation of intensities [Carlino et al., 2010]. Similarly to Norcia, a special Committee was instituted for the inspection of the damaged areas and the subsequent proposal of an “earthquake-resistant building standard”, drafted by engineers Felice Giordano, from the Royal Corp of Mining Engineers, and Paolo Comotto, from the Corp of Civil Engineers. A careful examination of the topography and geology of the island, of the construction details and of the damage distribution was the basis for the outline of the building regulations [Giordano and Comotto, 1883a], later officially released with minor modifications [RD, 1884].

The impact of the two building codes during the following decades is demonstrated by their dissemination among scholars and their use as guidelines for other standards. The 1860 Norcia building code was issued by the Holy See just before Italian unification, therefore limiting its circulation. Nonetheless, it was studied in depth after the Casamicciola earthquake, which was the first important earthquake following Italian unification, with Giordano and Comotto, reproducing the whole 1860 code in an annex to their 1883 report. For the same reason, being the first Italian standard for earthquake-resistant constructions, the 1884 Ischia building code be-

came a reference point for the following events. In fact, it was analysed by Uzielli [1887], investigating the 1887 Liguria earthquake. Moreover, it was studied in depth after the 1894 Calabria and Sicily earthquake by Camerana [1907], who praised the adoption of the half-timbered technique and discussed at length the permission to use unreinforced masonry, considered acceptable in Ischia where tuff was easily reduced to regular blocks and pozzuolan was easily available. Both the 1860 and 1884 building codes were closely examined by the committee [Maganzini, 1909] which prepared the building code after the 1908 Messina and Southern Calabria earthquake. The main recommendations about wall geometry and structural details of the Norcia standards were explicitly reported. Even more detailed was the analysis made of the Ischia code, discussing both the interpretation of observed damage, the suggestions about unreinforced masonry constructions and the provisions concerning half-timbered constructions. Again, both codes were briefly mentioned in the thousand-page-long treatise written by Masciari-Genoese [1915], but mainly with reference to half-timbered constructions, although the Ischia code was also mentioned with regard to balconies. The translation of the [1884] Giordano and Comotto report in French testifies the international impact of the event. Freeman [1932] was also aware of both codes through the report edited by Maganzini [1909], and contributed to their dissemination in the Anglosphere.

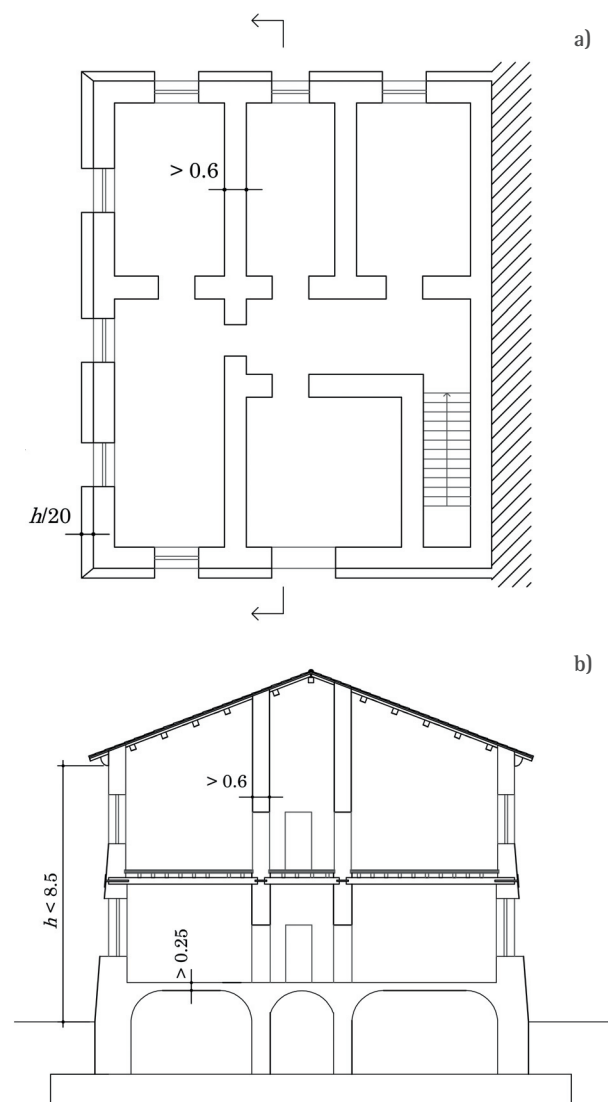
### 3. THE 1860 NORCIA BUILDING CODE

The building code was issued on April 24<sup>th</sup>, 1860 [Archivio Storico Comunale di Norcia, 1859; Boschi et al., 1998] following the aforementioned scientific reconnaissance. The first draft was revised several times and subjected to numerous city council debates. The most disputed topics were the criteria of funds allocation and the period needed for the application of the transitional tax regime, as well as technical aspects such as building height, building materials, and construction system (e.g. vaults). The final version was in three parts, totalling thirty-three articles, and including an additional standard on ornamental design.

Since the committee detected minor damage in buildings on bedrock and, conversely, a concentration of collapses on slopes, it was forbidden to build on surface cohesionless soil, unless an underlying compact layer was reached (Article 18). It was further prescribed that foundation excavations needed to have a rectangular

cross-section, instead of the poor tapered section common at that time (Article 20).

Geometrical indications were given in Article 19, with foundation depth and wall thickness to be determined by a municipal committee on a case-by-case basis. Nonetheless, in unreinforced masonry, the thickness had to be no less than 600 mm and the external walls had to have a tapered section with an additional thickness at the foot which was to be at least one twentieth of the height (Figure 3 and Figure 4a). Hence, Norcia's building code endorsed the use of buttresses and tapered section walls suggested in previous technical literature [Milizia 1785, tome 3, book 3, chapter 2, pp. 156-157] and post-earthquake appraisals [Archivio di Stato di Catania, 1825].



**FIGURE 3.** Exemplification of the Norcia building code provisions: a) plan with external walls having a tapered thickness; b) section of a two-storey building. All measures in m.

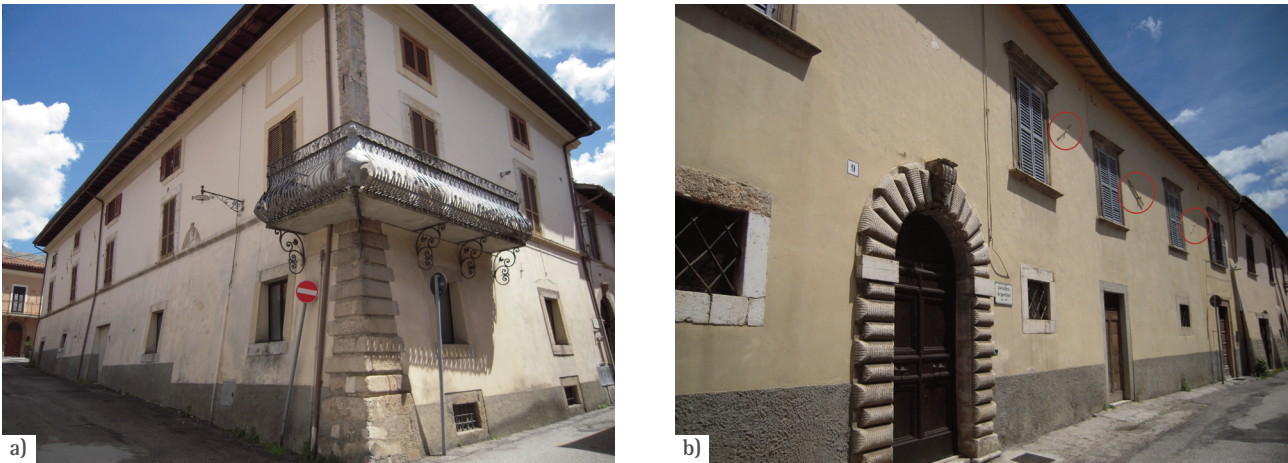


FIGURE 4. a) Example of a two-storey building constructed after the 1860 building code with basement and external walls with tapered thickness; b) Example of the extensive use of metal tie-rods in Norcia.

The post-earthquake survey also led to the drafting of Article 16, which restricted new buildings to two storeys, i.e. a ground floor and an upper one (Figure 3b), although a basement was possible. This limitation was clearly enforced, because in the historical centre of Norcia buildings with one or two storeys currently account for more than 80% of all buildings, whereas this percentage is less than 60% in Amatrice [Sorrentino et al., 2018]. Article 17, similarly to current regulations, differentiates the provisions for new and existing buildings, allowing a third floor for the latter, if only lightly damaged.

According to Article 16, eaves height should not exceed 8.5 m. Articles 16 and 19 set a maximum height/thickness ratio slightly higher than 14 and consequently, in a simplified overturning verification neglecting all connections, a horizontal collapse load multiplier of about 0.07. This value is then raised to 0.16 by the introduction of the additional tapered section. Probably to reduce the height/thickness ratio of tympanum walls, roof slope should be kept to a minimum. This provision was supposed to contain the sliding of the roof cover during seismic shaking [Ceradini and Pugliano, 1987; Mauri-Mori, 1909].

Adequate interlocking between façades and orthogonal walls was recommended in Article 19 while, recognizing the role of openings in this regard, Article 22 stated that doors and windows should be located at a convenient distance from building corners and from intersections between walls. They should be vertically aligned and have carefully executed jambs.

Damage observations guided the provisions, as specified in Articles 26 and 27, concerning the construction

of unreinforced masonry. The former regarded the quality of the units: a natural-stone unit had to be dressed, laid according to its grain, resistant and not excessively small; rounded pebbles were prohibited for above-ground walls and allowed in the foundations only. Vaults had to be made with fired-clay bricks or squared natural-stone units. Article 27 focused on the mortar, whose lime had to be produced from stones without impurities, grinded and not left drying in the air, but regularly dampened with water and kept in a putty-like condition. Soil and large gravel needed to be removed from the sand. The recommendations on mortar are of the greatest significance [Liberatore et al., 2016], given the dramatic occurrence of masonry disintegration observed in and around Amatrice, the most affected municipality of the 2016-2017 sequence, where lime was seldom present in the mortar [Roselli et al., 2018], and considering the much better performance of Norcia [Sorrentino et al., 2018].

As for horizontal structures, Article 21 allowed vaults only in the basement of new buildings, and in the ground floor of existing ones, provided that tie rods were present. Thus, it was clear that the vaults increased building seismic vulnerability due to their horizontal thrust and higher mass compared to timber floors, especially if located at higher storeys [Sorrentino and Tocci, 2008]. The assumption that vaults were earthquake resistant was already rebutted by the 1784 *Borbone* regulations, which allowed their construction only in the basement, differing from the 1755 *Pombalino* system where vaults were permitted above ground [Ruggieri, 2017]. Barrel, segmental sphere or coquet vaults with panels were mentioned. Solid masonry was mandatory above the vault up to one third of the rise and unnecessary overburden had to be avoided.

The minimum thickness at the crown of the vaults was 250 mm or an eighteenth of the diameter. This recommendation is very interesting because it is known that a semi-circular barrel vault, made of a material with zero tensile and infinite compressive and frictional strengths, loaded by its own weight, needs a minimum thickness of about one twentieth of the diameter [Heyman, 1969]. The occurrence of vertical and horizontal live loads justifies the larger thickness recommended in the building code. On the other hand, modelling the seismic action as static and horizontal, the code thickness/diameter ratio involves a collapse multiplier of 0.04 if the vault has an angular span of 180°, which rises to 0.24 if this angle is reduced to 157.5° [Oppenheim, 1992].

Article 23 was devoted to roofs, which had to be supported by horizontal battens resting on the whole thickness of the wall, or resting on a spreader beam. All girders had to be connected to supporting walls by means of iron anchors, and there was a similar provision for horizontal floors in Article 24. Similar indications can be dated back to at least the 1<sup>st</sup> century b.C. (Ecclesiasticus 22,16) or, closer in time, were suggested in the aftermath of the 1783 Messina earthquake [Biblioteca Regionale di Messina, 1784], or in the Milizia treatise [Milizia 1785, tome 3, book 3, chapter 9, p. 190]. Therein, it was additionally recommended that all floors be at the same level, as suggested also by Camillo Morigia after the 1786 Rimini earthquake in northern Italy [Archivio di Stato di Forlì, 1787]. Drawings of metal wall-floor connections can be found in the handbooks by Valadier [1832] (Figure 5) and by Colonnetti [1953].

Nonetheless, this provision was only partially enforced in the façades of Corso Sertorio. Surprisingly, the code did not mention metal tie rods, extensively used in Norcia (Figure 4b) and elsewhere [AlShawa et al., 2018].

Half-timbered constructions were used effectively after historical earthquakes [Tobriner 1983; Dipasquale et al. 2015; Tiberti et al. 2019]. Articles 16 and 19 of the 1860 code mention them, but no additional detail is given, and recent studies have not documented their implementation in Norcia [Sisti et al., 2018].

#### 4. THE 1884 ISCHIA BUILDING CODE

The Ischia building code [RD, 1884] was based on a scientific report by Giordano and Comotto, which was initially published as a journal paper [Giordano and Comotto, 1883a], and the same year as a stand-alone book [Giordano and Comotto, 1883b]. An overview of the latter is given below, together with page references. The appendix of the report contained proposals for two separate standards, one for public buildings and one for private constructions, but the approved code did not differentiate between these two typologies. Their suggestions are of great interest and demonstrate the existence of broader knowledge than that contained in legislation alone.

First of all, the two engineers recognize that the most severe damage was observed in constructions on slopes, as already reported after the 1851 Vulture earthquake [Palmieri and Scacchi, 1852]. Consequently, in their proposal, Giordano and Comotto recommended that new

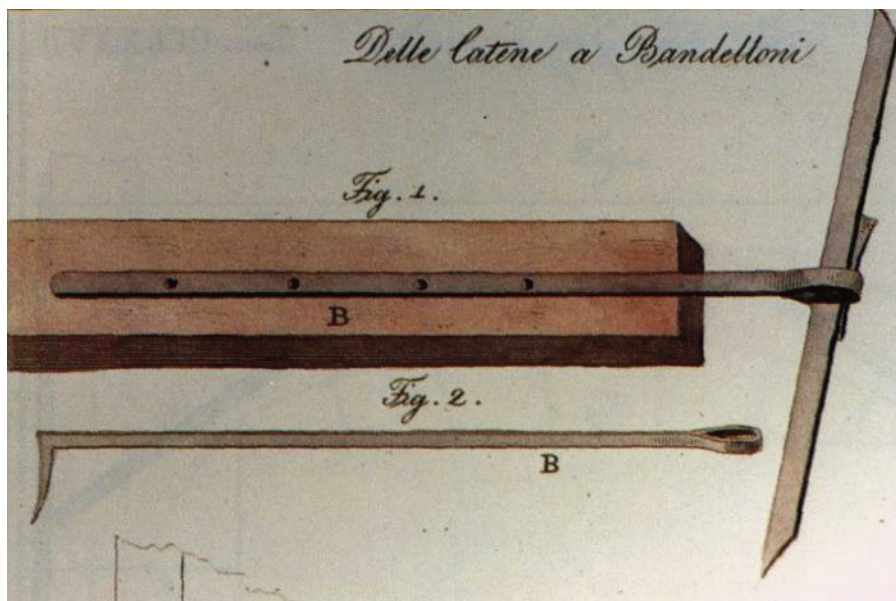
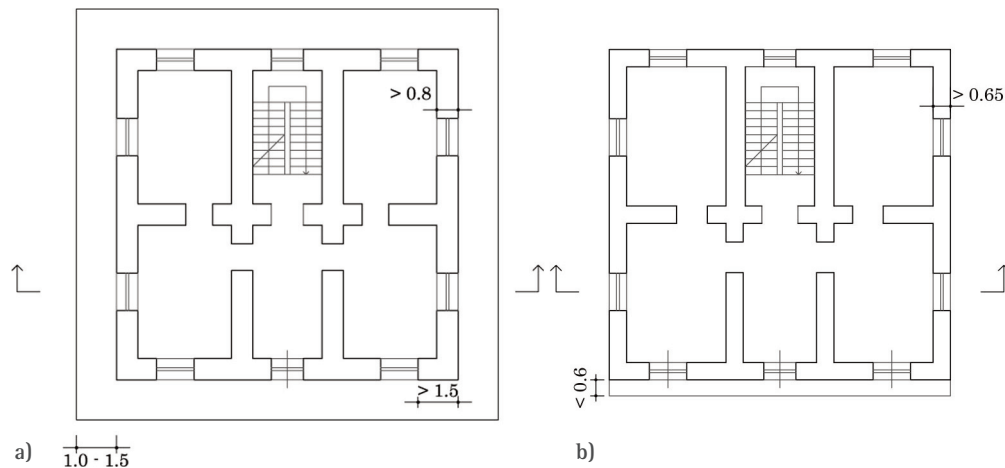


FIGURE 5. Drawings of metal wall-floor connections (Valadier [1832], tome IV, plate CCLXXVI).



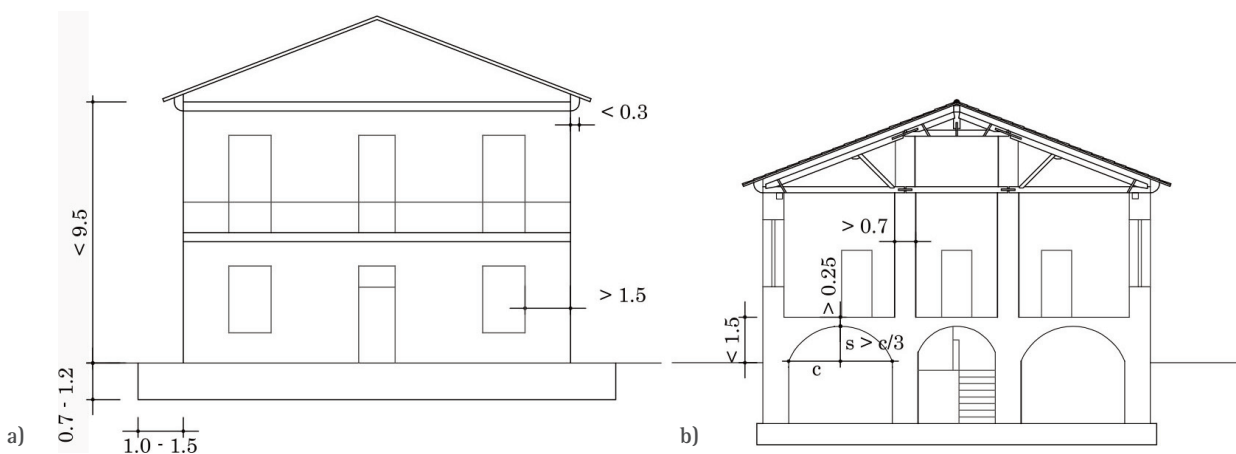
**FIGURE 6.** Exemplification of a two-storey house on stiff soil according to Giordano and Comotto's proposal for the Ischia building code: a) ground-floor; b) first-floor. All measures in m. Approved code allowed only one storey.

buildings be laid preferably on flat sites, or at least on gentle slopes, avoiding hills, ravines, and landslide-prone areas. Additionally, they observed that buildings resting on volcanic lava were less damaged (ps. 13, 28 and 35). However, such soils were not suitable for agriculture and, consequently, the dwellings were located preferentially in more fertile sites, which unfortunately were softer and induced greater damage (p. 14). Therefore, they recommended the removal of surface cohesionless soil as a minimum requirement, to reach a solid layer and build thereon the foundations. If possible, volcanic lavas or well-cemented tuffs were to be preferred to fractured tuff, clay and other soft soils (p. 67). Based on site-effect observations, they set zones of different hazard. Among the most dangerous, they included coastal areas up to 10 m above sea level, because they were prone to tsunamis. It is worth noting that they recommended that code prescriptions be graduated according to seismic hazard, a

suggestion that would enter Italian legislation more than four decades later [RDL, 1927].

Furthermore, it was suggested that a single-storey (two-storey) building should rest on a 0.7 (1.2) m thick foundation mat. A basement up to 1.5 m above ground was allowed, but if absent, the foundation mat should exceed the perimeter of the building by 1.0 to 1.5 m, according to the specific site conditions (Figure 6a).

In addition to the severity of shaking and site influence, building vulnerability was properly recognized, especially in the excessive number of storeys. The two engineers, consequently, recommended restrictions, looser for timber and steel structures and stricter for masonry (p. 47). Only one floor of limited height was suggested for masonry buildings located in the high-hazard zone. According to the proposal, a second floor was permitted on lava or well-cemented tuff soils (ps. 69 and 77, Figure 6b and Figure 7a), but the approved code allowed



**FIGURE 7.** a) Exemplification of the elevation of the two-storey house on stiff soil according to Giordano and Comotto's proposal for the Ischia building code (approved code allowed only one storey); b) Cross section of the one-storey building allowed by the Ischia building code. All measures in m.

only one (Figure 7b). As in Norcia, in the case of existing buildings, Giordano and Comotto permitted the preservation of a lightly damaged third floor (p. 79).

It is interesting to emphasize the attention Giordano and Comotto paid to limiting building size, in order to reduce exposure. Consequently, for churches, two medium buildings were recommended instead of a large one. In the latter case, a basilica cross-section was suggested, with lateral naves being much lower than the central one (p. 72), in order to counteract a lateral mechanism of the central nave [Marotta et al., 2017a, 2015]. Similarly, the accesses and internal distribution of hotels, baths, theatres, and public buildings in general had to be studied to facilitate evacuation in the event of an alarm being raised.

In addition, Giordano and Comotto recommended a square, or approximately square, plan layout for any building of more than one storey (p. 68). The recommendation was accepted and included in Article 6 of the code. They seem to be influenced by the widespread opinion of that time [Masciari-Genoese, 1915; Sguario, 1756] that seismic shaking had a prevailing direction, according to which it was advisable to orientate the building diagonal, possibly to reduce out-of-plane actions on façades [Abrams et al., 2017; Sorrentino et al., 2017].

As for geometric prescriptions, the two engineers stated that, in buildings with just a ground floor, the internal height cannot exceed 4.0 m and the perimeter wall thickness, if units were made with the tuff present on the island, would have to be at least 700 mm. In the foregoing suggestion, incorporated in Article 6 of the code, Giordano and Comotto stated that the thickness had to be a third or a half greater than for buildings not exposed to earthquakes. Increasing the height/thickness ratio  $4.0 / 0.70$  between 33% and 50%, a geometric slenderness of about 8 is obtained. This figure is already prudent according to Rondelet [1832], who wrote that an isolated wall will have good stability if its thickness is one eighth of its height; medium stability if its thickness is a tenth of its height, and low stability if the height/thickness ratio is twelve to one. Interestingly, the two engineers suggested that the thickness of clay brick could be reduced (p. 70). In this regard, Breymann [1885] noted that if the thickness of a brickwork wall is 8, the same wall made with sedimentary stones requires a thickness of 10.

In the case of two-storey buildings the thickness at the ground floor was increased to 800 mm, and reduced to 650 mm at the first floor (p. 78). Therefore, a different strategy from the one used in Norcia was deliberately

adopted, in order to avoid rain penetration, typical of tapered section walls.

All buildings must have properly interlocked walls and connections to the roof by means of external and internal anchors (p. 76), as observed also in other seismic-prone countries such as Nepal [Brando et al., 2017]. Similarly to Norcia, openings had to be vertically aligned but the distance from corners was here specified as greater than 1.5 m. Above the opening, a lintel or an arch with a span/rise ratio of less than 3 had to be present. Any overhanging or cantilever element, including embossed ornaments (p. 73), was prohibited, with the exception of iron or timber balconies protruding less than 600 mm and firmly connected to the wall (ps. 70-71, 77).

Regarding masonry, in the aftermath of the earthquake, the two engineers noticed that walls were built mostly with local tuff, frequently using irregular-shape units. The lack of bond stones repeatedly produced wall delamination (p. 40). The depletion of clay quarries made the production of bricks rather expensive. Additionally, due to the total absence of limestone in the island, mud mortars were prevalent. Despite the poor performances observed, Giordano and Comotto accepted the use of masonry because compatible with local practice and available materials. Nonetheless, they recommended brickwork, but allowed the use of local tuff units as long as they were dressed (p. 45). Units needed to be long enough to guarantee interlocking across sections, in order to avoid a loose nucleus, at wall intersections and at opening jambs. The mortar had to be made of lime and pure sand, or sand with pozzolan, excluding any mixture of earth (p. 77). The use of cement pressed within formworks, *pisè*, and of *adobe* was not encouraged, because either not local, and thus expensive, or not durable.

With respect to vaults, the two engineers observed they performed poorly, especially when located at upper floors, having a limited rise and suffering from the movement of the lateral supporting walls (p. 29). Masonry consisted of irregular units, inadequate transversal interlocking and poor mortar. Use of tie-rods to counteract thrust was not common (p. 40), and in those buildings where they were installed after the 1881 earthquake, they did not improve response, probably because their wall anchors were too small (p. 41), or their spacing was too wide, as observed in Marotta et al. [2018] in New Zealand churches. The two engineers considered tie-rods effective only in relation to the horizontal but not the vertical component. Moreover, they recommended tie-rods only for damaged buildings, but not as a general solu-



tion (p. 53). In fact, in light of the inspections performed after the 2017 seismic event, the use of tie-rods was found not to be widespread on the island. In this regard, Giordano and Comotto seemed to be influenced by Milizia's [1785, tome 3, book 1, chapter 8, p. 88] opinion, that well-constructed buildings do not need these type of connections, which are just remedies for old and collapsing constructions. As in Norcia, vaults already present on the ground floor of existing buildings might be preserved, if only lightly damaged, reinforced by tie-rods and after removal of the backfill (p. 79). Otherwise, their proposal allowed basement vaults, provided they were made with good quality masonry, had span/rise ratio smaller than 3, and thickness at crown greater than 250 mm (Figure 7b, p. 70).

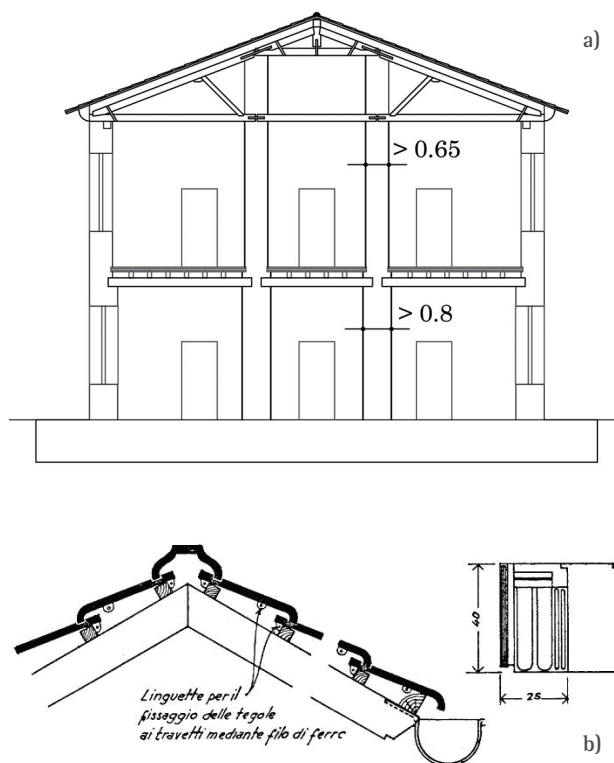
With regard to floor structures, Giordano and Comotto observed poor performance when the beams were not supported on the whole wall thickness. Therefore, they recommended that the joists should rest on the whole wall section and be complemented by two or more orthogonal girders. As in Norcia, a proper metal connection between walls and floors at all storeys was advised (p. 79).

At roof level, they forbade structures made of inclined rafters resting on pillars or walls, suggesting, on the contrary, a complete roof truss with a horizontal tie beam extended up to the external face of the wall and placed on a longitudinal spreader beam (Figure 8a). Each structural element needed to be properly connected to the one adjacent, in order to form a system resistant to shocks in all directions (p. 73). Timber boards needed to be nailed on the roof joists (p.78), as recommended also in Article 6 of the code.

Interesting observations were made on non-structural elements. Roof tiles not fixed to supporting structures underwent dislocation, and therefore their use was tolerated (especially in single-storey buildings, ps. 71 and 78) as long as the tiles were light and fixed to the supporting floorboards, as found also in handbooks (Figure 8b). Nonetheless, lighter roof covers, such as metal sheets, were endorsed.

Roof vulnerability derived also from the habit of having terraces with a 300-mm-thick layer of volcanic lapilli (p. 39). Therefore, chestnut-timber terraces were allowed, but without such heavy overburden (p. 70). In the case of existing terraces, clearly undersized structures had to be demolished and rebuilt according to the code, while adequate structures could be preserved provided that the lapilli layer was removed (p. 79).

Finally, Giordano and Comotto shared the belief that



**FIGURE 8.** Exemplification of a two-storey house on stiff soil according to Giordano and Comotto's proposal for the Ischia building code: a) section (approved code allowed only one storey); b) connection of the roof cover to the timber structure, namely "Holed lugs for the connection of the tiles to the battens by means of iron wire" [Colonnetti, 1953].

half-timbered or iron-reinforced constructions were safer than unreinforced masonry buildings, as recommended by other practitioners of that time [Petra di Caccuri and Mensinger, 1883]. Therefore, they gave ample space (ps. 48-52, 56-58, 70-72) to the presentation of the "casa baraccata" system. The system was mentioned in articles 1 and 6 of the code and, contrary to Norcia, was implemented in several instances [Caiafa, 2012; Polverino, 1998].

## 5. CONCLUSIONS

This paper examines two early regulations for earthquake-resistant constructions, both issued after a careful scientific damage survey. The building codes issued after the 1859 Norcia and 1883 Ischia earthquakes can be considered ahead of their time and many aspects are still relevant today. Beyond the isolated detail suggestions, of great importance is the philosophy of the two standards, especially calibrating requirements according

to building condition (new or existing) and hazard zone (in the case of Ischia). A qualitative understanding of the role of site response was already present, identifying the benefits of being on stiff soil and on level ground. The codes provide quantitative geometrical limitations, such as the maximum number of storeys and their maximum height, the minimum thickness for both walls and vaults, the minimum distance of openings from corners and wall intersections. Moreover, they provide comprehensive detailed indications about masonry construction, connections between vertical and horizontal structures, robustness of structural and non-structural elements belonging to floors and roofs.

These standards represent an extraordinary relevant codification of the correct way to build in seismic-prone areas, contributing to the historical development of earthquake engineering. This local construction culture deserves to be recognized and preserved, as far as suggested solutions proved adequate. Finally, at least in the case of Norcia, they can help explain the good performance observed in a recent seismic sequence, especially if compared to that of other affected historic centres.

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## REFERENCES

- Abrams, D.P., AlShawa, O., Lourenço, P.B., Sorrentino, L., 2017. Out-of-Plane Seismic Response of Unreinforced Masonry Walls: Conceptual Discussion, Research Needs, and Modeling Issues. *Int. J. Archit. Herit.* 11, 22–30.
- AlShawa, O., Liberatore, D., Sorrentino, L., 2018. Dynamic one-sided out-of-plane behaviour of unreinforced-masonry wall restrained by elasto-plastic tie-rods. *Int. J. Archit. Herit.* <https://doi.org/10.1080/15583058.2018.1563226>
- Archivio di Stato di Catania, 1825. Relazione degli Ingegneri comunali Michele Sciacca e Paolo Musumeci relativa al Convento dei Padri riformati di San Francesco di Aci Catena colpito dal terremoto del febbraio 1818. *Intendenza* 4210, 1818–26.
- Archivio di Stato di Forlì, 1787. Relazione de danni sofferti dalla Città di Rimini, da suoi Borghi, Bargellato e Contado pel Tremuoto della notte del SS.Natale dell'Anno 1786 presentata all'E.mo e Rev.mo Principe il Sig.r Cardinale Nicola Colonna di Stigliano Legato di Romagna da Camillo. *Arch. Stor. Comunale, Sez. di Rimini AP*, 815–817.
- Archivio Storico Comunale di Norcia, 1859. Perizia relativa ai danni dovuti al terremoto del 1859, particelle catastali proprietà private, particelle catastali proprietà pubblica redatta dalla "Commissione d'incolumità per la riparazione dei Fabbricati danneggiati in Norcia dal tremuoto del 22 ago". *Cart. Amministrativo*.
- Baldacci, L., 1883. Alcune osservazioni sul terremoto avvenuto all'isola d'Ischia il 28 luglio 1883. *Boll. del R. Com. Geol. d'Italia* 4, 157–166.
- Biblioteca Regionale di Messina, 1784. Relazione data all'Illustrissimo Senato di questa città da Andrea Gallo Publico Professore di Filosofia, e Matematica in questo Real Collegio Carolino [...] pella rifabrica della città di Messina distrutta dai tremoti del 1783. *Sala Rari, Misc. di Scr. vari F.N.* 283, 88–110.
- Borri, A., De Maria, A., 2004. Comportamento sismico di edifici consolidati. Il caso Sellano., in: XI Congresso Nazionale "L'ingegneria Sismica in Italia", Genova 25-29 Gennaio 2004. ps. C1—03.
- Boschi, E., Guidoboni, E., Ferrari, G., Valensise, G., 1998. I terremoti dell'Appennino Umbro – Marchigiano. *Compositori, Bologna*.
- Brando, G., Rapone, D., Spacone, E., O'Banion, M.S., Olsen, M.J., Barbosa, A.R., Faggella, M., Gigliotti, R., Liberatore, D., Russo, S., Sorrentino, L., Bose, S., Stravidis, A., 2017. Damage Reconnaissance of Unreinforced Masonry Bearing Wall Buildings After the 2015 Gorkha, Nepal, Earthquake. *Earthq. Spectra* 33, S243–S273.
- Breymann, G.A., 1885. Trattato generale di costruzioni civili con cenni speciali intorno alle costruzioni grandiose, *Costruzioni in pietra e strutture murali*. Vallardi, Milano.
- Briseghella, B., Demartino, C., Fiore, A., Nuti, C., Sulpizio, C., Vanzi, I., Lavorato, D., Fiorentino, G., 2018. Preliminary data and field observations of the 21st August 2017 Ischia earthquake. *Bull. Earthq. Eng.* <https://doi.org/10.1007/s10518-018-0490-x>
- Caiafa, F., 2012. Le prescrizioni edilizie dell'isola d'Ischia emanate dopo il terremoto di Casamicciola del 1883: il caso del complesso termale Pio Monte della

- Misericordia. Università di Roma Sapienza.
- Camerana, E., 1907. Il terremoto del 16 novembre 1894 in Calabria e Sicilia: relazione tecnica. Tip. Naz. di Giovanni Bertero e C., Roma.
- Cancino, C., 2019. *It Always Takes a Village: Preserving Earthen Sites*. Springer International Publishing, Cusco, Perù. <https://doi.org/10.1007/978-3-319-99441-3>
- Carlino, S., Cubellis, E., Marturano, A., 2010. The catastrophic 1883 earthquake at the island of Ischia (southern Italy): macroseismic data and the role of geological conditions. *Nat. Hazards* 52, 231–247. <https://doi.org/10.1007/s11069-009-9367-2>
- Castenetto, S., Cubellis, E., Delizia, I., Luongo, G., Rebuffat, M., 1999. Il terremoto del 28 luglio 1883 a Casamicciola nell'isola d'Ischia, Catalogo della mostra. Istituto Poligrafico e Zecca dello Stato, Roma.
- Castenetto, S., Cubellis, E., Rebuffat, M., 1998. Il terremoto del 28 luglio 1883 a Casamicciola nell'isola d'Ischia. Istituto Poligrafico e Zecca dello Stato, Roma.
- Ceradini, V., Pugliano, A., 1987. Indagini conoscitive sulle tecniche premoderne di prevenzione sismica. Università di Roma Sapienza.
- Clemente, P., 2017. Seismic isolation: past, present and the importance of SHM for the future. *J. Civ. Struct. Heal. Monit.* 7, 217–231. <https://doi.org/10.1007/s13349-017-0219-6>
- Colonnetti, G., 1953. *Manuale dell'architetto*. CNR, Roma.
- Dipasquale, L., Omar Sidik, D., Mecca, S., 2015. Local seismic culture and earthquake-resistant devices: Case study of Casa Baraccata, in: *Proceedings of the International Conference on Vernacular Heritage, Sustainability and Earthen Architecture*. ps. 255–260.
- Favaro, A., 1883. Norme di costruzione per aumentare la resistenza degli edifici contro il terremoto, in: *Atti Del R. Istituto Veneto Di Scienze, Lett. Ed Arti*, (1883/84) 6.s., t. 2, n. 1. Venezia, ps. 21–90.
- Fonseca, J.D., 2005. 1755: O terramoto de Lisboa. *Argumentum*, Lisboa.
- França, J., 1965. *Une ville des Lumières*. La Lisbonne de Pombal. S.E.V.P.E.N., Paris.
- Freeman, J.R., 1932. *Earthquake damage and earthquake insurance*. New York et al: McGraw-Hill.
- Galassi, S., Ruggieri, N., Tempesta, G., Zinno, R., 2014. Stability and stiffness contribution of the masonry in the Borbone anti-seismic system, in: *Proceeding of 9th International Masonry Conference*.
- Giordano, F., Comotto, P., 1884. *Rapport sur les prescriptions administratives concernant l'île d'Ischia: presente par la Commission instituee par le Ministre des travaux publics (Genala) a la suite du trem-blement de terre de juillet 1883*. Traduit par V. Bouhy. Liege.
- Giordano, F., Comotto, P., 1883a. *Relazione della Commissione per le prescrizioni edilizie dell'isola d'Ischia istituita dal Ministero dei Lavori Pubblici (Genala) dopo il terremoto del luglio 1883*. G. del Genio Civ. 4, 541–624.
- Giordano, F., Comotto, P., 1883b. *Relazione della Commissione per le prescrizioni edilizie dell'isola d'Ischia istituita dal Ministero dei Lavori Pubblici (Genala) dopo il terremoto del luglio 1883*. Tip. Lit. del Genio Civile, Roma.
- Grimaldi, A., 1863. *La cassa sacra ovvero la soppressione delle manimorte in Calabria nel secolo XVIII*. Stamperia dell'Iride, Napoli.
- Heyman, J., 1969. The safety of masonry arches. *Int. J. Mech. Sci.* 11, 363–385.
- Liberatore, D., Masini, N., Sorrentino, L., Racina, V., Sileo, M., AlShawa, O., Frezza, L., 2016. Static penetration test for historical masonry mortar. *Constr. Build. Mater.* 122, 810–822. <https://doi.org/10.1016/j.conbuildmat.2016.07.097>
- Maganzini, I., 1909. *Relazione della commissione incaricata di studiare e proporre norme edilizie obbligatorie per i comuni colpiti dal terremoto del 28 dicembre 1908 e da altri anteriori*. Stabilimento Tipo-litografico del Genio Civile, Roma.
- Marcovigi, G., 1916. *Un moderno Padiglione-Ospedale a sistema baraccato*. *Riv. di Ing. Sanit. e di Edil. Mod.* 12, 133–135.
- Marotta, A., Goded, T., Giovinazzi, S., Lagomarsino, S., Liberatore, D., Sorrentino, L., Ingham, J.M., 2015. An inventory of unreinforced masonry churches in New Zealand. *Bull. New Zeal. Soc. Earthq. Eng.* 48, 171–190.
- Marotta, A., Sorrentino, L., Liberatore, D., Ingham, J.M., 2017a. *Vulnerability Assessment of Unreinforced Masonry Churches Following the 2010–2011 Canterbury Earthquake Sequence*. *J. Earthq. Eng.* 21, 912–934. <https://doi.org/10.1080/13632469.2016.1206761>
- Marotta, A., Sorrentino, L., Liberatore, D., Ingham, J.M., 2018. *Seismic Risk Assessment of New Zealand Unreinforced Masonry Churches using Statistical*

- Procedures. *Int. J. Archit. Herit.* 12, 448–464. <https://doi.org/10.1080/15583058.2017.1323242>
- Mascarenhas, J., 2004. *Sistemas de Construção, V. O Edifício de Rendimento da Baixa Pombalina de Lisboa, Processo evolutivo dos edifícios; inovações técnicas; sistema construtivo. Materias Básicos (3.ª parte): O vidro.* Livros Horizonte, Lisboa.
- Masciari-Genoese, F., 1915. *Trattato di costruzioni antisismiche preceduto da un corso di sismologia.* Hoepli, Milano.
- Mauri-Mori, G., 1909. Riedificazione di Reggio Calabria dopo i terremoti del 1783. *Nuova Antologia* 44, 88–99.
- Mazzoni, S., Castori, G., Galasso, C., Calvi, P., Dreyer, R., Fischer, E., Fulco, A., Sorrentino, L., Wilson, J., Penna, A., Magenes, G., 2018. 2016–17 Central Italy Earthquake Sequence: Seismic Retrofit Policy and Effectiveness. *Earthq. Spectra*. <https://doi.org/10.1193/100717EQS197M>
- Milizia, F., 1785. *Principi di architettura civile.* Remondini, Bassano.
- Mollaioli, F., AlShawa, O., Liberatore, L., Liberatore, D., Sorrentino, L., 2018. Seismic demand of the 2016–2017 Central Italy Earthquakes. *Bull. Earthq. Eng.* <https://doi.org/10.1007/s10518-018-0449-y>
- Oppenheim, I.J., 1992. The masonry arch as a four-link mechanism under base motion. *Earthq. Eng. Struct. Dyn.* 21, 1005–1017.
- Ortega, J., Vasconcelos, G., Rodrigues, H., Correia, M., Lourenço, P.B., 2017. Traditional earthquake resistant techniques for vernacular architecture and local seismic cultures: A literature review. *J. Cult. Herit.* 27, 181–196. <https://doi.org/10.1016/j.culher.2017.02.015>
- Palmieri, L., Scacchi, A., 1852. Della regione vulcanica del monte Vulture e del tremuo-to ivi avvenuto nel dì 14 agosto 1851. Nobile, Napoli.
- Penta, F., 1964. Alcuni provvedimenti presi dopo i grandi terremoti italiani dei secoli XVIII, XIX e XX. *Assoc. Geotec. Ital.* 5, 247–254.
- Petra di Caccuri, F., Mensinger, G., 1883. Progetto tipo per la costruzione di edifizii sopra suoli di natura vulcanica proposto per le riedificazione di Casamicciola. Tipografia dell'Accademia Reale delle Scienze, Napoli.
- Polverino, F., 1998. *Ischia: architettura e terremoto.* CLEAN, Napoli.
- RD, 1884. Regio Decreto n. 2600. Regolamento edilizio per i comuni dell'Isola d'Ischia danneggiati dal terremoto del 28 luglio 1883. Casamicciola, Lacco Ameno, Forio, Serrara Fontana e Barano. *Gazzetta Ufficiale del Regno*, 1 settembre 1884.
- RDL, 1927. Regio Decreto Legge n. 431. Norme tecniche ed igieniche di edilizia per le località colpite dai terremoti.
- Reale, C., 2001. *Aspetti urbanistici, architettonici e meccanici della città di Norcia (PG) derivanti dai terremoti storici e dalle normative anti-sismiche.* La Castellina. Università di Roma Sapienza.
- Regione Umbria, 1981. *Direttive tecniche ed esemplificazioni delle metodologie di interventi per la riparazione ed il consolidamento degli edifici danneggiati da eventi sismici.* Dipartimento per l'assetto del territorio, Perugia.
- Reitherman, R., 2012. *Earthquakes and Engineers: An International History.* ASCE.
- Reitherman, R., 2006a. The effects of the 1906 earthquake in California on research and education. *Earthq. Spectra* 22, 207–236. <https://doi.org/10.1193/1.2187053>
- Reitherman, R., 2006b. Earthquakes that have initiated the development of earthquake engineering. *Bull. New Zeal. Soc. Earthq. Eng.* 39, 145–157.
- Riccò, A., 1907. Il terremoto del 16 novembre 1894 in Calabria e Sicilia: relazione scientifica della Commissione incaricata degli studi dal R. Governo, in: C., G.B. e (Ed.), *Annali Dell'Ufficio Centrale Meteorologico e Geodinamico Italiano.* Roma.
- Rondelet, G., 1832. *Trattato teorico e pratico dell'arte di edificare, prima traduzione italiana sulla sesta edizione originale con note e giunte importantissime per cura di Basilio Soresina.* Negretti, Mantova.
- Roselli, G., AlShawa, O., Liberatore, D., Sorrentino, L., Di Girolami, G., Cinaglia, P., Scognamiglio, F., Mirabile Gattia, D., Persia, F., Petrucci, E., Piloni, R., Zamponi, S., Francola, C., 2018. Mortar analysis of historic buildings damaged by recent earthquakes in Italy. *Eur. Phys. J. Plus* Submitted.
- Rossa, W., 1998. *Beyond Baixa: Signs of urban planning in eighteenth century Lisbon/ Além da Baixa: Indícios de planeamento urbano na Lisboa Setecentista.* IPPAR, Lisboa.
- Rovida, A., Locati, M., Camassi, R., Lolli, B., Gasperini, P., 2016. CPT15, the 2015 Version of the Parametric Catalogue of Italian Earthquakes. *Ist. Naz. di Geofis. e Vulcanol.*
- Ruffolo, F., 1912. *Stabilità sismica dei fabbricati.* L'elettricista, Roma.

- Ruggieri, N., 2017. The Borbone “Istruzioni per Gli Ingegneri”: A Historical Code for Earthquake-Resistant Constructions. *Int. J. Archit. Herit.* 11, 292–304. <https://doi.org/10.1080/15583058.2016.1212128>
- Sacco, F., 1908. Edilizia sismologica. *G. di Geol. Prat.* 6, 65–94.
- Scheibel, B., 2001. Aspetti urbanistici, architettonici e meccanici della città di Norcia (PG) derivanti dai terremoti storici e dalle normative anti-sismiche. San Benedetto. Università di Roma Sapienza.
- Secchi, A., 1860. Escursione scientifica fatta a Norcia ad occasione dei terremoti del 22 agosto 1859, in: *Atti Dell’Accademia Pontificia de’ Nuovi Lincei*. ps. 63–104.
- Sguario, E., 1756. *Specimen physico geometricum de terraemotu ad architecturae utilitatem concinnatum*. Recurti, Venezia.
- Sisti, R., Di Ludovico, M., Borri, A., Prota, A., 2018. Damage assessment and the effectiveness of prevention: the response of ordinary unreinforced masonry buildings in Norcia during the Central Italy 2016–2017 seismic sequence. *Bull. Earthq. Eng.* <https://doi.org/10.1007/s10518-018-0448-z>
- Sorrentino, L., 2007. The early entrance of dynamics in earthquake engineering: Arturo Danusso’s contribution. *ISIT J. Earthq. Technol.* 44, 1–24.
- Sorrentino, L., Bruccoleri, D., Antonini, M., 2008. Structural interpretation of post-earthquake (19th century) retrofitting on the Santa Maria degli Angeli Basilica, Assisi, Italy. *Struct. Anal. Hist. Constr. Preserv. Saf. Significance* 217–225. <https://doi.org/10.1201/9781439828229.ch23>
- Sorrentino, L., Cattari, S., da Porto, F., Magenes, G., Penna, A., 2018. Seismic Behavior of Ordinary Masonry Buildings During the 2016 Central Italy Earthquakes. *Bull. Earthq. Eng.* <https://doi.org/10.1007/s10518-018-0370-4>
- Sorrentino, L., D’Ayala, D., de Felice, G., Griffith, M.C., Lagomarsino, S., Magenes, G., 2017. Review of Out-of-Plane Seismic Assessment Techniques Applied To Existing Masonry Buildings. *Int. J. Archit. Herit.* 11, 2–21. <https://doi.org/10.1080/15583058.2016.1237586>
- Sorrentino, L., Tocci, C., 2008. The structural strengthening of early and mid 20th century reinforced concrete diaphragms, in: *Proceedings of the 6th International Conference on Structural Analysis of Historic Construction*. Bath, ps. 1431–1439.
- Stellacci, S., Ruggieri, N., Rato, V., 2016. Gaiola vs. Borbone System: A Comparison between 18th Century Anti-Seismic Case Studies. *Int. J. Archit. Herit.* 10, 817–828. <https://doi.org/10.1080/15583058.2015.1086840>
- Tiberti, S., Scuro, C., Codispoti, R., Olivito, R.S., Milani, G., 2019. Experimental and Numerical Analysis of Historical Aseismic Construction System, in: *RILEM Bookseries*, Vol. 18. ps. 910–918.
- Tobriner, S., 1984. A history of reinforced masonry construction designed to resist earthquakes: 1755–1907. *Earthq. Spectra* 1, 125–149.
- Tobriner, S., 1983. La Casa Baraccata: Earthquake-Resistant Construction in 18th-Century Calabria. *J. Soc. Archit. Hist.* 42, 131–138.
- Uzielli, G., 1887. Le commozioni telluriche e il terremoto del 23 febbraio 1887: tre conferenze fatte nella R. Università di Torino il 26 e 28 febbraio e il 2 marzo 1887: con note sul terremoto del 23 febbraio 1887. Tip. L. Roux e C., Torino.
- Valadier, G., 1832. *L’architettura pratica dettata nella Scuola e Cattedra dell’insigne Accademia di S. Luca*. Com permesso de’ Superiori, Roma.
- Vignoli, F., 2001. Aspetti urbanistici, architettonici e meccanici della città di Norcia (PG) derivanti dai terremoti storici e dalle normative anti-sismiche. Palazzo Comunale. Università di Roma Sapienza.
- Vivencio, G., 1788. *Istoria de’ tremuoti avvenuti nella provincia della Calabria ulteriore, e nella città di Messina nell’anno 1783, e di quanto nelle Calabrie fu fatto per lo suo risorgimento fino al 1787, preceduta da una teoria ed istoria generale di tremuoti*. Stamperia Reale, Napoli.

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