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Damage and Retrofitting of the Castle in Melfi (Italy) after the 1694 Earthquake: Structural Interpretation of a Historical Accomplishment

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ABSTRACT: In 1694 a severe earthquake (EQ, epicentral macroseismic intensity I_O = X Mercalli-Cancani-Sieberg, MCS) hit the Irpinia-Basilicata region, in southern Italy, causing significant structural damage to the Castle of the city of Melfi. Francesco Canevaro retrofitted the monument, as shown by written and graphic evidence. He was quite successful since when in 1851 a double shock event occurred, this time much closer to Melfi with an I_O = X MCS, the Castle was one of the few surviving buildings. Moreover, in 1930 the Vulture region was shaken by a X MCS (IX in Melfi) intensity EQ. The restoration project, made thereafter, clearly shows that the Castle quarter strengthened by Canevaro passed the test better than other nearby constructions. The paper reconstructs the seismic catalogue of Melfi and the different construction stages of the Castle. Furthermore, historical solutions will be discussed both through a comparison to building practice recorded in historical treatises and Italian regulations issued before engineered codes, and from a structural point of view, by means of limit analysis.

1 INTRODUCTION

Unreinforced masonry buildings frequently behave poorly during severe EQs, as recent and historic events proved. However, in areas where seismic activity is frequent enough to be constantly reminded to inhabitants and builders, or were aspects (celebrations, inscriptions, etc) contribute to keep alive the memory of EQs, special solutions can be adopted during repair or, more seldom, even during construction in order to enhance the building performance. To recognise such cases is of some importance, both from a structural point of view, so that effective solutions can lead to minimum interventions, and from an historical one, in order to preserve them as a technical accomplishment worth to be passed on.

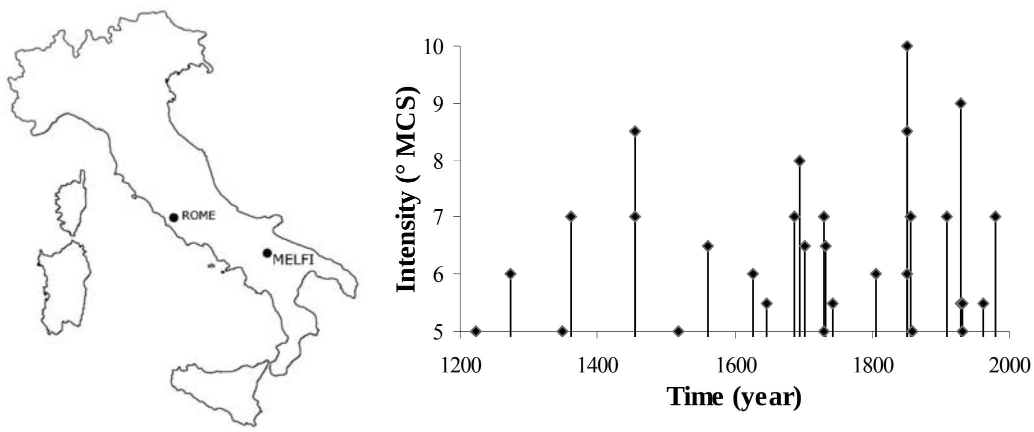
In this framework the Castle of Melfi represents an interesting example. Nearly a millennium old, it was subjected to many EQs and to some quite interesting retrofits.

2 SEISMIC HISTORY OF MELFI

Located in Southern Italy (Figure 1a), at the northern foot of the inactive Vulture volcano, in a plateau crossed by the Ofanto river, Melfi has a very long history, particularly rich under the Normans, Frederick II and the Angevins, as accounted for elsewhere (Acito 2003, and references therein).

However, it is important to stress that the seismic history is strictly entangled with Melfi's historical vicissitudes, and with those of the Castle. Therefore it is mandatory to reconstruct its seismic catalogue. This has been accomplished recurring both to macroseismic observations catalogues (DOM 1997, CSIE 2000) and, when these were missing, to attenuated intensities. The latter have been obtained applying the attenuation law in Decanini and Mollaioli (1997) to the epicentral intensities reported in CPTI (2004), and considering only felt intensities higher than IV/V MCS. A total list of 46 events (35 above the damage threshold) has been compiled, spanning between 99 and 1980 A.D., a selection of which is in Figure 1b.

By means of this catalogue it is possible to observe that Melfi lies in a rather seismic-prone area. Considering a time span between 1000 and 2002, the one within which continuity of historical data is more reliable, the law of occurrence of felt intensities can be established and the 500 years period of return EQ intensity can be estimated. This results higher than IX MCS, with an effective peak acceleration (EPA) in the order of 0.25g, evaluated according to Decanini et al. (1995). Following the CSIE (2000) the 1851 event, the most severe one, was characterised by two main shocks one hour and twenty minutes apart one from the other, with approximate 0.37g and 0.19g EPAs respectively. Information about damages can be found in CSIE (2000) for many events and in single sources for the earthquakes of 1456 (Araneo 1866, Claps 1982), 1694 (Lenzi 1935), 1851 (Arabia 1852, Palmieri and Scacchi 1852, Paci 1853, Araneo 1866), 1857 (Mallet 1862) and 1930 (Lenzi 1935, Castenetto and Sebastiano 2002).



(a) (b)

Figure 1 : (a) Location of Melfi in Italy; (b) Seismic catalogue of Melfi (only events starting from 1200 A.D. and with intensity ≥ V MCS shown).

3 THE CASTLE AND THE EARTHQUAKES

Located at the northwest and higher side of Melfi's historical nucleus, the Castle together with the Cathedral is its main landmark. Through the available literature (above all Lenzi 1935, and Dote 1991, Corrado 1997, Aurora 1998 and references therein), and an on-site survey (Acito 2003) it is possible to reconstruct its construction stages. According to reference in Lenzi (p.42), first written evidence dates back to 1128, when it was destroyed by Ruggero II. Following Lenzi, a Norman layout can be recognised still today (refer to Figure 2). This should have originally presented four square corner towers, the northern one having possibly being torn down by the Swabians to build the Jail tower (Lenzi 1935, pl.VII). On the contrary, Corrado and Aurora believe the Marcancione to be an isolated Norman tower connected to a chapel and a system of walls and square corner towers. The inner core had two storeys with vaulted rooms.

Frederick II used the Castle for occasional holiday stopovers, but inserted it in a net of fortresses and strongholds, maintaining a direct control. Although there is no written evidence, the main works at this time should have regarded the Squires hall, Jail, Northeast, Emperor towers (no.3-5, 7 in Figure 2), and related walls (Lenzi 1935, p.131-132).

Under the Angevin Carl I, following extensive written documents available in German literature (Lenzi 1935, p.103-129), in 1269-1274 repair works were carried out; in 1277-August 1278 a storey, the Throne hall, was added on top of the squires hall (3) and this was connected to the Emperor tower (7), which was probably raised, moreover the Collapsed tower (6) together to adjacent walls were constructed; in August 1278-1279 the Northeast tower was raised as well, the Lion, Secretary, Gallery, Entrance, Clock and Church (6, 8-13) towers and two scarp walls were built; the Throne hall was buttressed, the cistern (18) and the moat initiated; in 1280-1281 these were completed and the wall between the Lion and the Throne hall was erected.

During the Caracciolo rule the Castle suffered from the 1456 EQ (Araneo 1866 p.338, Claps 1982 p.22). The Doria, in 1549-1570, transformed the Castle in a Governor palace, doubled the walls, built new rooms in the first and second levels of the Baronial palace, erected the Chapel and the Guardhouse (24-25). Moreover, they oriented the Castle toward the city by laying down the Main courtyard, opening the Main entrance, and building the stone bridge (22-23, Lenzi 1935, p.55-56).

On September, 8th 1694 a X MCS epicentral intensity EQ hit the Irpinia-Basilicata area, and was felt with a VIII MCS intensity in Melfi. 56 houses suffered collapses, and many others were damaged. The same happened to churches and convents. The Cathedral was severely hit and the Castle suffered damages for many thousands scudi (CSIE 2000, s.v.). The Doria appointed Francesco Canevaro to carry out the retrofitting of both the Melfi and Leonessa Castles. To Canevaro we owe the first survey of the Castle, reproduced in Lenzi (1935, pls.I-V) from the Doria archive (although not quoting the call number). It is perhaps worth to translate part of the report sent by the practitioner to his customer:

"Excellent Prince, Following his orders and instructions about the works in the [Melfi] Castle, I started the works immediately after my arrival and I went on without losing any day in particular in the Governor quarter, which is already completed mainly due to the care and the surveillance by the Governor himself, living in the Castle for many days now, at the moment we are continuing with eight masons and we are building pillars and walls in the prison wing where I think we will be finished by the end of May, except for the Clock Tower, and some other minor works to be done in the Emperor wing following the attached report; explaining in detail to his Excellency all that was done would bore his Excellency. It is sufficient to stress that there was no dwelling more or less damaged where I considered appropriated the tie rods, that is on the two levels used by the Governor we laid eight iron tie rods as shown in the attached section [Figure 3], one in the Church, three in the wing that lead to the Gallery, two in the former Rasionale house and two in the wing next to the prison, his Excellency may stay clear that each dwelling in the Castle was properly enchained, which is unusual in this City and in the whole Kingdom where ruins follow each earthquake shake, God forbid […] Your devoted and humble servant Francesco Canevaro" (translated after DPA 1695; also, with minor mistakes, in Lenzi 1935, p.138-139).

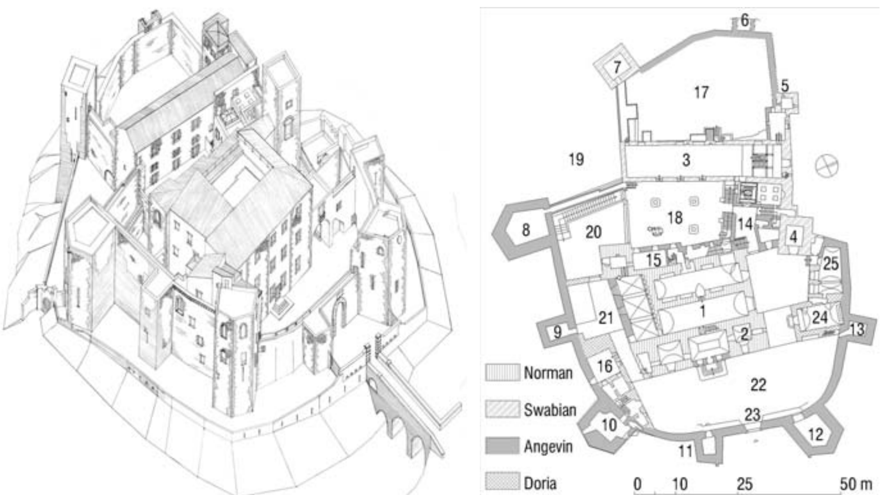


Figure 2 : Melfi Castle axonometric view (Acito 2003) and ground floor plan (reworked after Architectural Heritage Superintendance, Potenza survey). Main architectural elements and construction stages. 1 Baronial palace (upper floor: Governor quarter), 2 Prison, 3 Throne hall (Royal, Emperor quarter; lower. f.: Squires or Bad Council hall); towers: 4 Jail (*Marcancione*) t., 5 Northeast (*Turretta Parvula*) t., 6 Collapsed t., 7 Emperor (Four, Seven Winds) t., 8 Lion (West) t., 9 Secretary (Terrace) t., 10 Gallery (Banner, Cypresses) t., 11 Entrance t., 12 Clock, t., 13 Church t.; 14 hall, 15 rooms and warehouse (u.f.: Rasionale house), 16 stable and dwellings; courtyards: 17 Burial c., 18 Cistern (Emperor) c., 19 Squires c., 20 passage c., 21 Stabling c., 22 Main c.; 23 Main entrance, 24 Chapel, 25 Guardhouse.

The report and the drawing (refer e.g. to Figure 3) are useful both to have an idea of the damages and to reconstruct the retrofitting interventions. Canevaro basically increased the wall area density with respect to the building surface, through pillars and walls, and its connections., through tie-rods (*catene*). These were located mainly in the central core of the Castle (no.1, 2, 14, 24 in Figure 2), and in the so-called Emperor quarter (between 7 and 8). Furthermore from the section presented in Figure 3 it is possible to observe that the tie rods are specifically used with an aseismic intention, being present even in correspondence of timber floors or of thrusting structures but being laid perpendicular to the gravity-induced thrust. The intervention was certainly carried out since it is quoted many times in archive documents (e.g. DPA 1695-1696a). The mason responsible for the works, the Genoese master Agostino Drago, passed away at the end of summer (DPA 1695-1696b).

After 1695 many other EQs followed. In 1732 many cracks are reported in the Gallery and Jail towers. Much more interesting is however the double shock event of 1851. Sources are not unanimous. According to Arabia (1852, p.20-23) several portion of the Castle collapsed, and the remaining were widely cracked and displaced. Araneo (1866, p.377-390) is more specific, annotating the collapse of the Four Winds tower, and serious damage in the Jail one; cracks in the Bad Council hall and in the (so-called) upper Saint Francis apartment led to hasty and unnecessary demolition. Lenzi (p.51), however, criticised this report about the Jail tower. Contrary to these two descriptions, Palmieri and Scacchi (1852, p.128-135), physicist and geologist respectively, both professors in Neaples, highlight that the good constructions are not the first to collapse and allow their inhabitants to flee. The Diocese palace and the Castle due to their construction according to the rule of art survived the shake. Quite similar is the reasoning of Paci (1853, p.45-51, 86-87), professor of physics in Neaples, who describes the Castle and the Diocese palace as examples of buildings that, due to the regularity of their construction, the use of ashlar masonry, the quality of the mortar, although severely damaged and partially collapsed, still behaved better than other buildings and raise appreciation. To confirm the better behaviour of the Castle one can examine the contemporary painting by Nicola Palizzi (Ciliento 2002, 40-41), which represents a Castle towering upon a landscape of ruins. Moreover, not dated pencil field notes taken on three plans (variable size up to 57×42 cm, scale approximately 1:280, DPA 1854-1859) report damages in the Emperor tower, and the adjacent end of the theatre (throne hall), while the Baronial Palace was in far better shape with the main hall in perfect state. Also a report by some engineer Curcio, although sceptically quoted by Doria's Melfi manager (DPA 1851), referred limited harm to the central section of the Castle.

No specific damage has been reported for the subsequent events up to 1930. A very accurate survey, made during August-September 1930, of the Castle is available in this case.

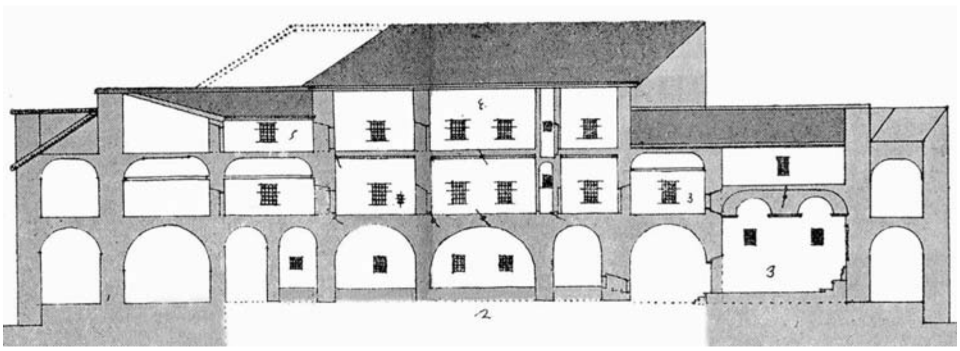


Figure 3 : Canevaro's intervention: S-N section across the Baronial palace and the chapel (detail, after Lenzi 1935, pl.IV; also, with minor differences, in DPA 1695). Inclined wall anchors can be noticed in the central zone (ε) and in the chapel (3).

The author observed greater damage in Emperor, Gallery, Clock and Church towers, in the façade on the cistern courtyard and on the east end of the main courtyard façade (Lenzi 1935 p.141 and pl.VI). Damages were present also in vaults, especially those with edgeset units. Engineer Lenzi was also the author of the repair project (Lenzi 1935, p.142-149), which however cannot be examined here.

4 STRUCTURAL INTREPRETATION OF HISTORICAL INTERVENTIONS

Comparing Canevaro's intervention to those damage descriptions (Palmieri and Scacchi, Paci) which indicated a comparatively better behaviour than that of other buildings, and to those accounts (Araneo and Lenzi) locating main damages mostly away from the section where tie rods were laid out, it is possible to assert that his retrofitting was quite successful. The improved connections in fact hampered separation of the façades and their overturning due to out-of-plane forces.

The 18th Century engineer was keen to stress how the solution was not common practice in the area. Indeed in historical treatises the use of tie rods was frequently criticised. E.g., Milizia (1785, p.87-88, 154), quoting also Vignola to corroborate his position, considered iron ties as a construction's sign of weakness. Even Alberti (1452, p.236) upheld that arches do not need ties. However, the use of such devices has been observed in seismic areas, although possibly not often enough as remarked by Canevaro and recognised as quite effective both in the past (Palmieri and Scacchi 1852 p.131, Paci 1853 p.87) and recently, experimentally (Tomaževič et al 1996) and on field (Tobriner et al. 1997). As a matter of fact, tie rods were recommended in the Instructions released after the Messina 1783 EQ (Grimaldi 1863, p.65) and the Calabria (Southern Italy) 1905 EQ (Regio Decreto 1906), while the provisions issued after the Norcia (Central Italy) 1859 EQ (Reale et al. 2004), the Casamicciola (Ischia island) 1883 EQ (Giordano and Comotto 1883, p. 67-80), and the Liguria (Northern Italy) 1887 EQ (Regio Decreto 1887) endorsed the connection between joists and masonry by means of iron wall anchors.

Provided that wall anchor and tie rod are appropriately designed, the failure of a restrained façade will be due to the masonry near the link. Following experimental campaigns, different models have been proposed for the mechanic behaviour of such anchorage. Antonucci and Giacchetti (1992), who performed both laboratory and *in situ* tests, estimated the strength of the connection through the flexural strength of the wall. Buccino and Vitiello (1995), compared their test results on high quality mortar specimens to the two models depending on cohesion and friction respectively proposed by Mastrodicasa (e.g. 1965, p.360-362). Giuffrè (1993, p.208-209, 239-241), based on tests on dry stacked ashlar and poor mortar rubble masonries, proposed a calculation procedure founded on friction only. The latter is probably more appropriate for historic buildings, where cohesion is generally weak, uncertain and scattered. Hence, this model will be applied to make some preliminary approximate estimation of the increase in strength that tying a façade can grant.

Considering a rigid uniformly dense wall of thickness a, and height H subjected to gravity and a uniform horizontal acceleration, the static collapse load multiplier c is equal to a/H. Assuming now a static friction coefficient f, a wall anchor of horizontal length d, height above the rotation hinge h, and influence length i, and a k ratio of the (stabilising only) top load to the wall self weight (Figure 4(a)), neglecting any lateral restraint, according to Giuffrè (1993) model of the link, the static collapse load multiplier c_t, of wall restrained by a tie with the masonry failing at the wall anchor, results equal to:

$$c_t = 4\frac{f}{i}\left[\left(1-\frac{h}{H}\right)(d+a)+k\right]\frac{h}{H}+\frac{a}{H}(1+k) \tag{1}$$

A plot of Eq. (1), with c_t made non-dimensional through c, is presented in Figure 4(b). The static collapse load multiplier increases with the coefficient of friction, the wall anchor length, the wall size and aspect ratio and overburden. It is interesting to note that very low or very high ties are almost ineffective. The first case seldom occurs, due to functionality issues, the second can be more frequent: possibly for this reason Regio Decreto (1906) recommended a distance from the top of the wall of at least 1 m. Moreover, from Figure 4(b) it is possible to recognise an optimal non-dimensional tie's height h_{opt}, that is equal to:

$$\frac{h_{opt}}{H} = \frac{1}{2}\frac{a+d+k}{a+d} \tag{2}$$

this is 0.5 for $k = 0$ and increases as k does. The overall increase in strength is quite remarkable. To that must be added the growth of displacement and energy dissipation capacity (Tomaževič et al 1996).

Although apparently not belonging to Canevaro's intervention, scarp walls were present in the Castle (infra § 3), as usual in military architecture, frequent in seismic-prone areas (Palmieri and Scacchi, p.132-133) and imposed by the Norcia 1860 Building Code (Reale et al. 2004). Fortresses often behaved satisfactorily during earthquakes, because towers and bastions as well as ramparts can effectively buttress the façades, thus contrasting out-of-plane inertia forces, although in a different way compared to wall anchors. That is what, e.g., Ruffolo (1912, p.227-234) observed in other regions of Southern Italy.

A simple mechanical interpretation of the role of scarp walls can be proposed. Assuming same height, depth, and density for the wall and the scarp, the collapse static load multiplier, c_i, for interlocked wall and scarp is equal to:

$$c_i = \frac{3a^2 + 6ab + 2b^2}{H(3a+b)} \tag{3}$$

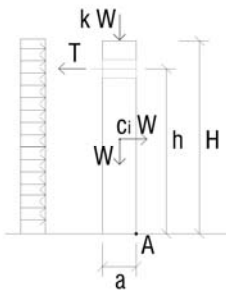
with b thickness of the scarp at the base, tapered up to zero on top (Figure 5(a)), while for simple adjacent wall and scarp there are two possible cases:

$$c_a = \begin{cases} 2\dfrac{b}{H} & \text{for} \quad b \le a/2 \\ \dfrac{3a^2 + 2b^2}{H(3a+b)} & \text{for} \quad b > a/2 \end{cases} \tag{4}$$

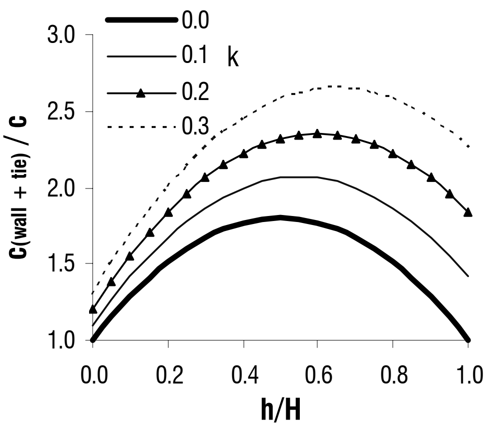
with c_a collapse static load multiplier. A plot of Eqs. (3) and (4), with c_i and c_a made non-dimensional again through $c = a/H$, is presented in Figure 5(b). Therein it is possible to note that if the thickness of the scarp is less than half that of the wall, the scarp will collapse earlier, thus proving useless.

On the contrary, a properly interlocked scarp is always effective, since it moves the mass of the wall away from the overturning hinge. The importance of interlock is often stressed in historical documents (RSA 1733, CSA 1818) as well as in treatises (Milizia 1785, p.156-157), although there are examples of ineffectively connected buttresses (Giuffrè 1988, p.96, 97, 106).

Moreover, a non-interlocked scarp can become ineffective even if $b > a/2$ due to pounding phenomena not considered in an equivalent static model. For this reason, despite the apparently marked increase in strength, observations after EQs were not as positive as those when tie rods where used.

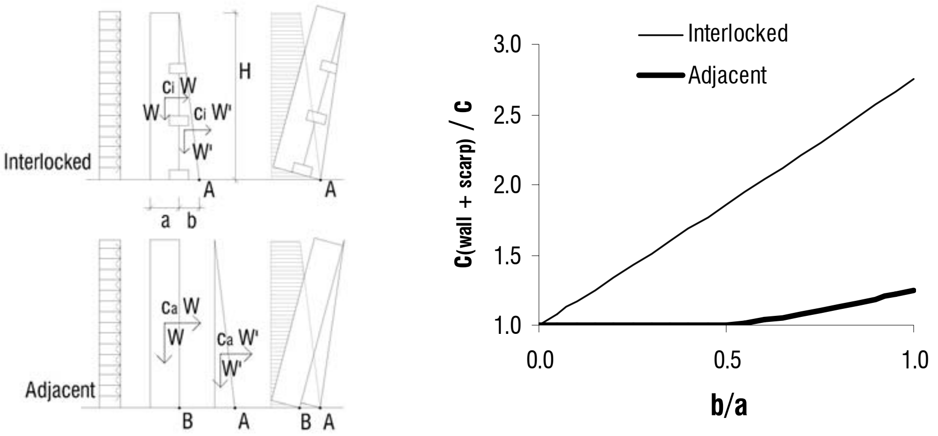


(a)



(b)

Figure 4 : Effectiveness of tie (a, f = 0.4, H/a = 10, d = 0.8 m, i = 5 m, a = 0.5 m) upon the static load multiplier.



(a) (b)

Figure 5 : Effectiveness of scarp wall, interlocked and adjacent, upon the static load multiplier.

5 CONCLUSIONS

The Castle of Melfi (Southern Italy), almost a millennium old, is located in a quite seismically active area. In fact, a local catalogue of 35 events above the damage threshold has been reconstructed. In this case such a list is an instrument not only to assess the seismic hazard but also to investigate the history and the building stages of the monument. This has been done recurring both to the literature and to an on-site survey, that allowed to present new drawings of the edifice and portrayal of different age elements. Of great interest is the written and graphic description of Canevaro's retrofit after the 1694 EQ. This consisted mainly of increased wall area density and, above all, enhanced connections by means of iron tie rods. The reports issued after subsequent seismic events showed that, although suffering damages, the section of the Castle rehabilitated by Canevaro performed much better than other buildings within the Castle perimeter and the city. This is a confirmation of both field and laboratory observation. Moreover, it corroborates the indications contained in treatises and non engineered (i.e. qualitative) code of practice issued in Italy since the end of the 18th to the beginning of the 20th centuries. Simplified quantitative investigations, by means of limit analysis, of historical interventions such as tie rods and scarp walls have been developed. These prove the marked increase in lateral load bearing capacity that they can add to an unrestrained, rectangular vertical section wall. They justify premodern provisions for the positioning of iron ties, which should be laid under a certain amount of masonry in order to develop an adequate friction reaction, and for the connection of the scarp to the main body of the wall. Such analyses can lead to minimise the intervention on historic and artistic heritage, and prove that builders of the past, although without carrying any calculation, were able to enhance the earthquake performance of their constructions.

REFERENCES

Acito, D. 2003. *Il ruolo dei terremoti nella concezione e nello sviluppo storico degli edifici antichi in muratura di Melfi (PZ): il Castello e il Palazzo Episcopale*. Laurea Thesis, "Ludovico Quaroni" First Architecture Faculty, "La Sapienza" University, Rome, Italy.

Alberti, L. B. 1452. *De Re Aedificatoria*. It. ed. Milano: Polifilo, 1989.

Antonucci R. and Giacchetti R. 1992. Experimental analysis of a discontinous wall-to-floor connection. *10th WCEE, Madrid, 7/19-24 1992*, 9: p.5355-5359. Rotterdam: Balkema.

Arabia, F.S. 1852. *Relazione storica del tremuoto di Basilicata nell'anno 1851*. Napoli: Del Vaglio.

Araneo, G. 1866. *Notizie storiche della città di Melfi nell'antico reame di Napoli*. Firenze: V. Sodi.

Aurora, I. 1998. Fonti storiche per la ricostruzione urbana della città di Melfi e del suo contado fra XII e XIV secolo. In C.D. Fonseca (ed), *Castra ipsa possunt et debent reparari*, p.59-75. Roma: De Luca.

Buccino, F. and Vitiello, E. 1995. Experimental behaviour and design criteria for anchorage between slabs and brick walls. *10th ECEE, Vienna, 10/28-9/2 1994*, 3: p.2255-2260. Rotterdam: Balkema.

Castenetto, S. and Sebastiano, M. (eds.) 2002. *Il "terremoto del Vulture". 23 luglio 1930 VIII dell'era fascista*. Roma: Istituto Poligrafico e Zecca dello Stato.

Catania State Archive (CSA) 1818. Intendenza, b.1159 (1818-24), Opere Pubbliche Comunali Acireale, *Perizia dell'Ingegnere Giovanni Maddem, Acireale 3 dicembre 1818*.

Ciliento, P. 2002. *Melfi: la città, il lavoro, le tradizioni*. Melfi: Libria.

Claps, V. 1982. *Cronistoria dei terremoti in Basilicata*. Galatina: Congedo.

Corrado, R. 1997. Il castello di Melfi: un cantiere militare angioino. *Arte medievale*, 11(1-2), p.133-144.

CPTI 2004. *Catalogo Parametrico dei terremoti italiani*. http://emidius.mi.ingv.it/CPTI

CSIE 2000. *Catalogue of strong Italian earthquakes from 461 B.C. to 1997*. http://storing.ingv.it/cft

Decanini, L.D. and Mollaioli, F. 1997. Sull'attenuazione dell'intensità macrosismica in alcune zone sismogenetiche italiane. *8° Conv. Naz.:ANIDIS, Taormina, 9/21-24 1997*, p. 895-902. Palermo: Priulla.

Decanini, L.D., Gavarini, C. and Mollaioli, F. 1995. Proposta di definizione delle relazioni fra intensità macrosimica e parametri del moto del suolo. 7° *Conv. Naz. ANIDIS, Siena, 9/25-28 1995*, p. 63-72. Firenze: Collegio degli Ingegneri della Toscana.

DOM 1997. *An intensity database of damaging EQs in the Italian area*. http://emidius.mi.ingv.it/DOM

Dote, M. 1991. Il Castello di Melfi. In R. Carafa (ed.). *Restauro dei castelli nell'Italia meridionale: atti, Caserta, 3/10-11 1989*, p.47-52. Caserta: Russo.

Doria-Pamphilj Archive in Rome (DPA) 1695-1696a. Corrispondenza diretta a Giovanni Andrea III Doria. Scaffale 19, Busta 5. Lettera del Governatore A.M. Maineri. Melfi 12 marzo 1695.

DPA 1695-1696b. Corrispondenza diretta a Giovanni Andrea III Doria. Scaffale 19, Busta 5. Lettera del Governatore A.M. Maineri. Melfi 3 settembre 1695.

DPA 1695. Piante di Fabbricati siti nella Basilicata: Melfi, Lagopesole, Leonessa, Forenza. Cartella 21, Interno 1. Relazione del Capo d'opera delle Fabriche e lavori da farsi alli Castelli di Melfi e della Leonessa. Melfi 12 marzo 1695.

DPA 1851. Corrispondenza diretta ad Andrea IV Doria Pamphilj e a Filippo Andrea V Doria. Scaffale 22, Busta 26, Lettera dell'Amministratore Generale V. Manassei, Melfi 6 settembre 1851.

DPA 1854-1859. Vari tipi di piante concernenti Melfi. Scaffale 24, Busta 5.

Giordano, F. and Comotto, P. 1883. *Relazione della Commissione per le prescrizioni edilizie dell'isola d'Ischia*. Roma: Genio Civile.

Giuffrè, A. 1988. Restauro e sicurezza sismica. La cattedrale di S. Angelo dei Lombardi. *Palladio* (2) 1(1), p.95-120.

Giuffrè, A. (ed.) 1993. *Sicurezza e conservazione dei centri storici: il caso Ortigia*. Roma-Bari: Laterza.

Grimaldi, A. 1863. *La cassa sacra*. Napoli: Iride.

Lenzi, G. 1935. *Il Castello di Melfi e la sua costruzione: note ed appunti*. Amatrice: Opera Nazionale per il Mezzogiorno d'Italia.

Mallet, R. 1862. *Great Neapolitan earthquake of 1857*. London: Chapman and Hall.

Mastrodicasa, S. 1965. *Dissesti statici delle strutture edilizie*. Milano: Hoepli, 4.ed.

Milizia, F. 1785. *Principî di architettura civile*. Bassano: Remondini.

Paci, G. M. 1853. *Relazione dei tremuoti di Basilicata del 1851*. Napoli: Stabilimento tipografico del R. Ministero dell'Interno.

Palmieri, L. and Scacchi, A. 1852. *Della regione vulcanica del monte Vulture e del tremuoto ivi avvenuto nel dì 14 agosto 1851*. Napoli: Nobile.

Reale, C., Scheibel, B., Vignoli, F., Decanini, L. and Sorrentino, L. 2004. Il Regolamento edilizio di Norcia del 1860: fra storia sismica e storia urbanistica. *9° Conv. Naz. ANIDIS, Genova, 1/25-29 2004*, p.88 and CD ref. C1-08. Padova: SGE.

Regio Decreto 13 novembre 1887. *Norme per la costruzione ed il restauro degli edifici nei comuni liguri danneggiati dal terremoto del 22 febbraio 1887*.

Regio Decreto 16 settembre 1906. *Norme per la costruzione ed il restauro degli edifici danneggiati dal terremoto nelle provincie calabresi ed in quella di Messina*.

Rome State Archive (RSA) 1733. Congregazione del Buon Governo, serie II (Atti per luoghi), Benevento V, b.476 (1731-1742), *Perizia di G.Angrisano, Benevento 20 settembre 1733*.

Ruffolo, F. 1912. *Stabilità sismica dei fabbricati*. Roma: L'elettricista.

Tobriner, S., Comerio, M. and Green, M. 1997. Reconnaissance Report on the Umbria-Marche Italy earthquake of 1997. *EERI Newsletter*, 31(12).

Tomaževič, M., Lutman, M. and Weiss, P. 1996. Seismic upgrading of old brick-masonry urban houses: tying of walls with steel ties. *Earthquake Spectra*, 12 (3): 599-622.