



# Conservation of the Cathedral of Acerenza by means of a multidisciplinary approach

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## Abstract

The study concerning the historical-constructive evolution of a monument becomes very difficult when the monument looks as a palimpsest of traces, forms and materials which are placed one upon another as a result of different construction phases. The Cathedral of Acerenza, an important example of religious architecture of XI-XII century, characterised by a presbytery built by an ambulatory with radial chapels, represents one of these cases. On this church, the research has been developed by means of a cross-disciplinary approach. The first one regards the morphological and metrological analysis of the architecture. It has allowed, after a topographical survey, to trace the elements of the architectonic body to regular geometrical forms. Besides useful information has been drawn about the structural homogeneous elements. The outcomes are confirmed by the petrographic and mineralogic study of constructive materials and techniques, which stimulated a second phase of the research. The study of the masonry has been particularly interesting to know the constructive phases. It has been realised on the basis of a photogrammetric relief of the facades. Another analysis concerns the seismic hazard. In particular, in the town of Acerenza at least three seismic events, with macroseismic intensity greater than VII MCS, have been recorded

## 1 Introduction

Methods about advanced technologies employed for the study of a monument have become inevitable to analyse its constituents, executive routine and the relative chronology of fabrication phases.<sup>1</sup>

These methods are necessary to complete and to integrate the work of the historians about historical, artistic and documentary values, cultural models, that *toutcourt* define in the work of art a reliable evidence of civilization, which renders it a cultural heritage.

Acerenza<sup>2</sup> Cathedral study has been the occasion to set an analytical methodology of research up, which has aimed to enlarge the knowledge background of the monument and to give answers to questions already put down from different disciplinary slants and nowadays solved not yet.<sup>3</sup>



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Acerenza Cathedral distinguishes itself from the ample and variegated architectonic medieval panorama of the South of Italy thanks to its plan, very original in the South of Italy, but very similar to coeval French cathedrals. It is characterised by a *deambulatorio* with radial chapels. There are other two similar examples, bound fast to Acerenza, for typological and historical matters and for geographic nearness: *Cathedral of Aversa* and *SS Trinita' church in Venosa*<sup>4</sup>.

A lot of researchers have studied the origin, the evolution and the diffusion of this iconographic model in the South of Italy. The main discussion was between who supported a direct importation of this model from France through the Benedictines, during the first phase of the Norman domination in Southern Italy, in the second half of XI century, and who, even if they recognised a French cultural derivation, emphasised also autochthonal characters, typical of Southern Italy Romanesque style<sup>5</sup>. In this essay we go forward this *querelle* that concerns a large number of monuments and questions, such as the spiritual re-birth of the Benedictine movement after the *Cluny* reformation and the diffusion of cultural and artistic models in Southern-Central Europe, and about the ways of integration between such imported models and the pre-existing cultural *substrata*.

This work presents, in a problematic way, the results of a research tended to solve some questions about the evolution of the Cathedral such as:

- a) the unitariness of the transept-apse body;
- b) the chronological and spatial relation between naves and the transept-apse body;
- c) the relative chronology of main building phases.

Besides the research has allowed drawing information about building techniques and materials (manners of employment and quarries), the organisation of the yard and the characterisation of seismic parameters.

The aims of this research have been obtained by means of the following methodologies and techniques:

- the morphological analysis of the architectonic plan, on the basis of an accurate topographic survey;
- the metrological investigation executed with an innovative method that enables to draw original measurement units;
- the study of constructive techniques by means of photographic images and photogrammetric surveys<sup>6</sup> (see fig.3);
- the characterisation and individuation of the provenance of stony materials through XRD and other analyses;
- the assessment of the earthquake *hazard* by means of historical and mathematical analyses, on the basis of data supplied by the Italian seismic catalogue.

## 2 Morphological and metrological analyses of the plan

The morphological analysis enables, after a precise survey, to translate the architectonic elements and structures into regular geometric shapes.

- The superposition of the plan survey on the geometric elaboration, puts usually constructive "anomalies" or imperfections into relief. These anomalies are often due to particular vicissitudes of the life of the monument, to the discontinuity of constructive phases and to morphological factors that have forbidden a regular shape.<sup>7</sup> The Cathedral plan is formed by a 73.30 m. long three naved latin cross, which is interrupted by a 40.50 m. long transept from whom a *deambulatorio* develops itself to East of the altar.

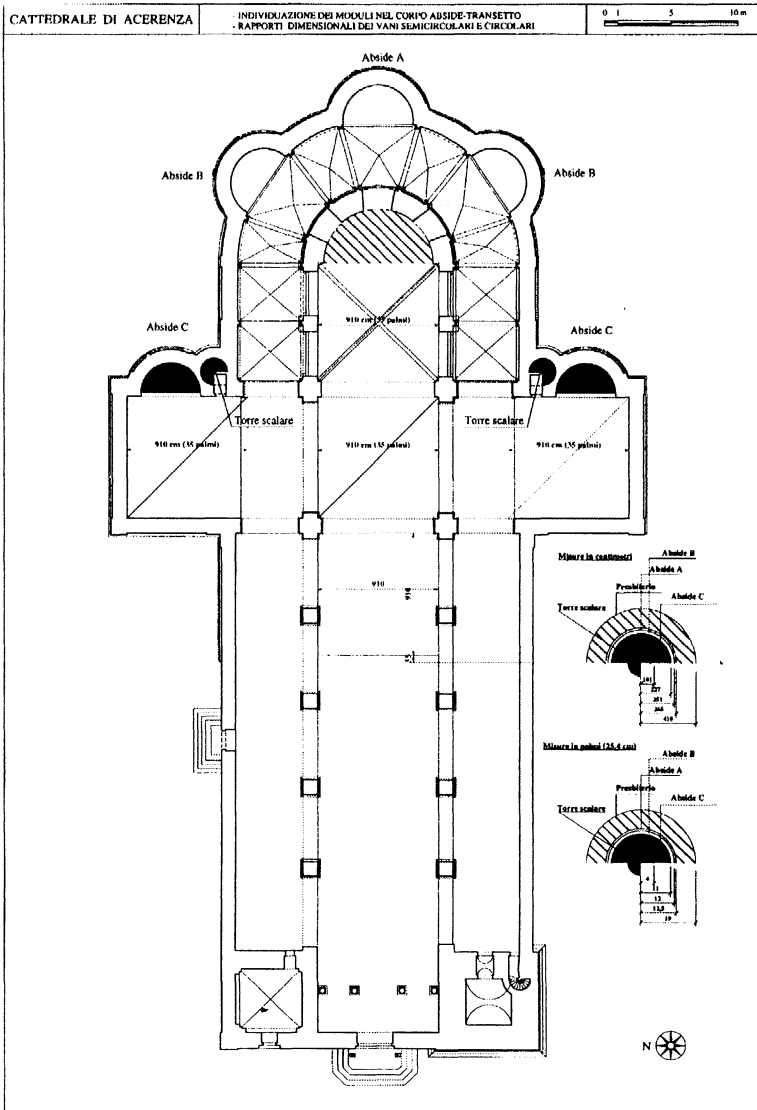


Figure 1: Individuation of modules and dimensional relations in the apsidal complex.

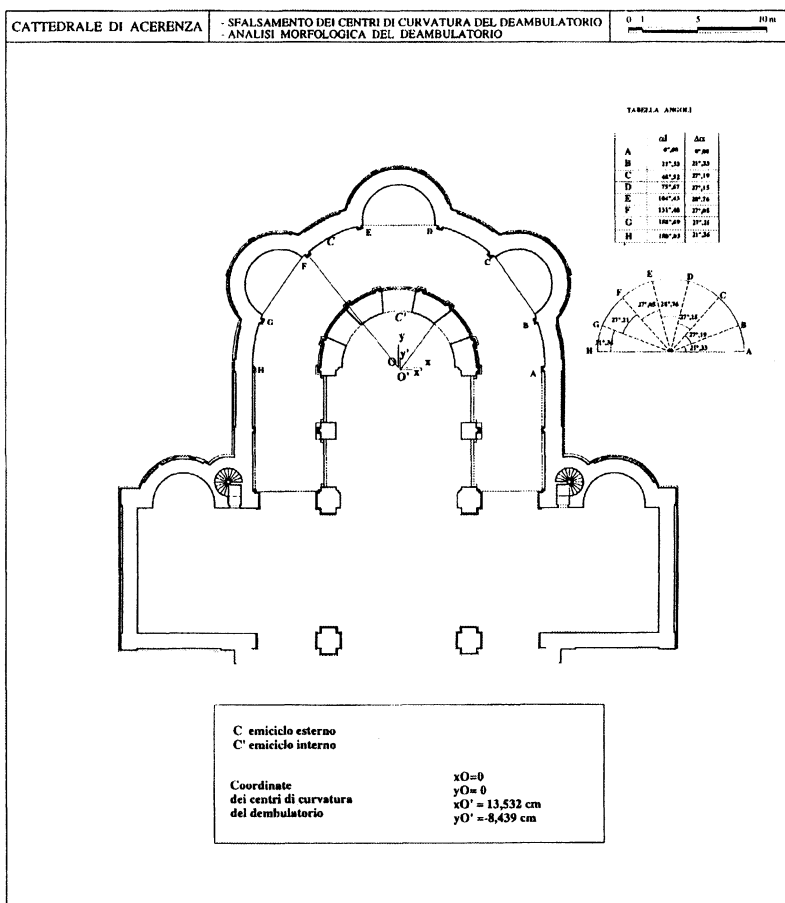


Figure 2: Morphological analysis of deambulatorio and stagger of bending centres.

This last one is covered by small cross vaults, one by one inscribed in a trapezium. The semicircular outside wall is interrupted by three radial chapels. To East-sides of the South and North transept arms there are two semicircular apsidioles and two scalar cilindric towers.

Before the morphological analysis, a metrological study has been done, through a translation of numeric data of the survey in the original measurement units, which have been drawn not *a priori*, as it has been usually done, but *a posteriori* on the basis of statistical analyses.

Because of the variety of measurement units, according to the Age and to the geo-cultural areas, they have been obtained by means of an empirical method.

In the case of the medieval architecture, it has been usually used the *palmo* and the *canna*, of whom we know the approximative values.

Therefore, we start with an arbitrary value of *palmo*,  $p_1$ . Then we select some measurements of significant architectural elements  $m_j$  and we compute the ratio  $r_j = m_j / p_1$ .

To each value of  $r_j$  corresponds the ratio between this last one and the relative integer number (for example if  $r_j = 2,314$  m,  $|r_j|$  will be equal to 2 m, while if  $r_j = 2,746$  m,  $|r_j| = 3$  m)

Consequently to  $n$  measurements will correspond  $n$ -values of  $r_j$  and  $n$  values of the ratios  $u_j = r_j / |r_j|$ , next to one.

Then, first we compute the mean  $\mu_u = \sum_i u_i / n$ , after mean square deviation  $\sigma_u = 1/n \times \sqrt{(\sum_i (u_i - \mu_u)^2)}$ .

Lastly the final result will be equal to  $\mu_u \pm \sigma_u$ .

Then we obtain another value of *palmo*:  $p_2 = p_1 \times \mu_u$

If  $p_2$  will be very different of  $p_1$  we should reiterate with a second value equal to just  $p_2$ . The iterative computing will finish when we will get  $p_n \approx p_{n-1}$

We applied this method in Acerenza cathedral\* and we have obtained  $\mu_u = 25.43$  cm and  $\sigma_u = 0.037$  cm.

Considering valid the value of 25.4 cm. for the Acerenza *palmo*, the metrological survey has put a module into relief, equal to 8 *palmi* (this last is just equal to the *canna* = 2.03 m.).

The metrological study of the architectonic set-up has made possible to obtain some other modules like that one of 35 *palmi*, we find in the transept and in the choir (fig.1). This measure characterises also the sides of the squared rooms inscribed in the crossing between the transept and the nave, the inside rooms, in the South and North arms of the transept and the span, that is surmounted by a cross vault, to East of the transept.

The metrological analysis has already shown that the diameters of the semicircular existing rooms are multiple of the *palmo* (fig.1). The uniform measure system adopted is a valid proof to demonstrate that the mentioned structures are coeval.

In particular, regarding the deambulatorio there was the doubt that the two walls of the semicircular deambulatorio would be realised in two different moments.

Therefore it has been necessary to study the morphology of the two semicircular walls, and in particular the compute of the two relative bending centres. The topographic survey shows a distance between these last ones about equal to 10 cm, that is insignificant if it is compared with the two semicircles bending radius (respectively of 4.14 m. and 10.61 m.)<sup>9</sup> (fig.2). Therefore the two semicircular walls were traced and built together.

By some measurements it has been possible to determine an elevate construction appraisalment of workers. An example of it is the perfect symmetric position of the radial chapels, respect to the longitudinal axis of the Cathedral (see fig.2)

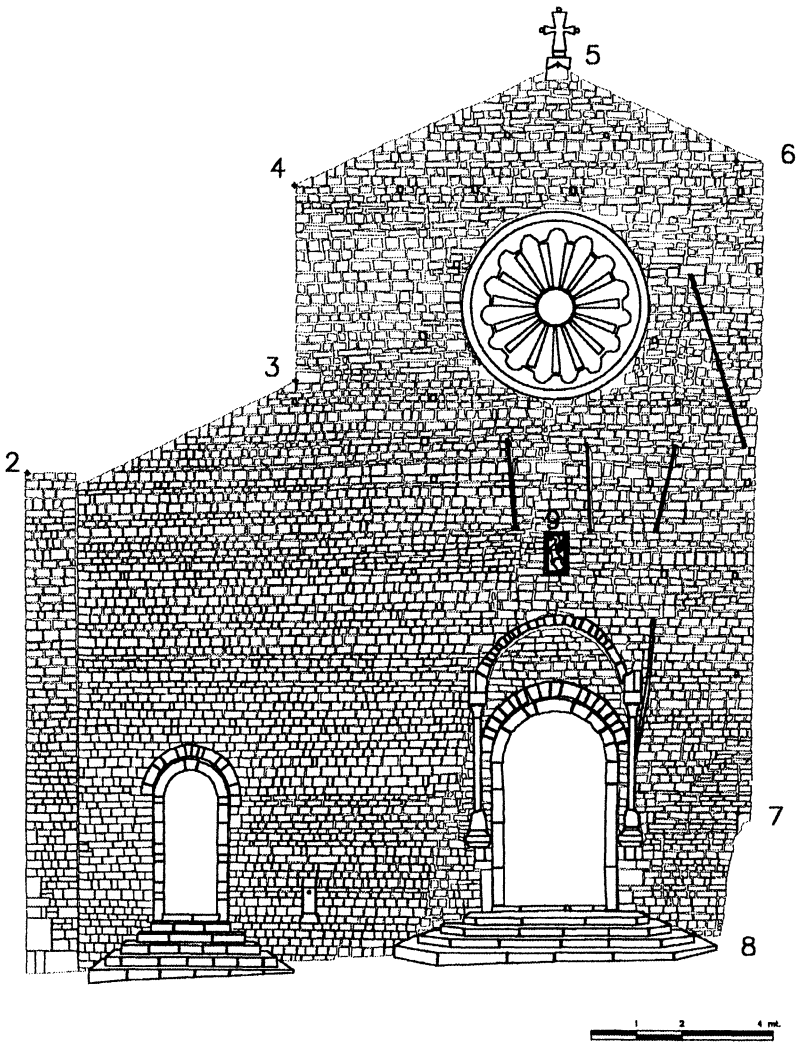


Figure 3: Photogrammetric survey of the main facade of the Cathedral of Acerenza.

### 3 Building techniques

The constructive techniques study has supplied information about the employment of materials and yard technologies.

Data and results of this research, are the followings:

- I) walling map;
- II) scaffoldings holes survey;
- III) singular constructive devices analysis;
- IV) building materials characterization and individuation of quarrying sites.

I) The individuation of the masonry has been executed on the basis of morphological characteristics and constructive elements (stones, mortar, etc.).

II) The photogrammetric survey of scaffoldings holes<sup>10</sup>, focalised two different technological levels of the yards of the transept-apse and nave fabrics. For this last, it has been analysed only the Northern wall.

In the first body, we notice a vertical and horizontal alignment of the holes and also a regular horizontal disposition of the same.

In the latter body yard, the distance between the scaffoldings holes is smaller. The distribution of the holes is very irregular, rather in the vertical than in the horizontal direction, and there are many differences between their relative distances.

The first *datum* supplies us an indication about an excessive prudence for the position of scaffoldings. This yard could be related to restorations, as a consequence of a collapse of a large side of the northern wall caused maybe by dynamic stresses of an earthquake.

The second *datum* indicates a mediocre level in the organisation of the yard, that is confirmed in the not much refined wall techniques, here employed.

III) Singular constructive devices analysis.

The constructive techniques analytical study has allowed to draw precious informations on the structural functions of constructive elements, with particular referring to some technical devices which get the resistance to seismic movements better.

Among them, it can be emphasised a particular way of assembling the ashlar in the apsidal angular pilaster strips. The employment of very well-squared stone blocks, arranged in a vertical way, warrants a perfect and continuous vertical course. It's possible to observe the alternation of a vertical block, supported by two, three, and sometime four ashlar, and one ashlar placed in a horizontal way, for a length that covers the overall width of the pilaster strip and more over, for a line, as a sort of tooth of 15-20 cm. that warrants the anchorage to the adjacent walling. The insertion of "stony chains" interests the semicolons too, that, two by two, adorn the plastic semicircular apsidal surfaces. In a methodical way, it is possible to observe, some semicircular ashlar with the same radius, to the inferior and superior extremities of column elements, with two lateral prismatic "ears", that are anchored to the walling.

Such constraint has forbidden, during the centuries, that the most of the semicolons should come out from its seat, because of seismic stresses.

It is only a representative example of many "antiseismic precautions", we find in the mediaeval walling structures of the Cathedral.

IV) Building materials characterisation and individuation of quarrying sites.

We are working in progress about this last research. However the lithostratigraphic analysis of the truncated-cone Acerenza mount<sup>11</sup> and a remarkable number of samples drawn by the Cathedral walling, allows already us to affirm that:

- the main face and the pillars of the nave have been built with stones coming from Apulian caves;
- the bell tower and the apse-transept body walling are composed by blocks quarried *in situ* both, from two different rocky layers.<sup>12</sup>

At the end of these last analyses, it will be our purpose to elaborate a thematic map for the classification and the distribution of the materials employed. This map and the informations obtained by the morphological and the metrological study will allow us to take a step forward in the knowledge of the Cathedral construction history.



## 4 Seismic hazard

Among geological hazards, seismic events are certainly the ones that cause the heaviest losses in terms of human lives and, at the same time, set serious constraints on the conservation of private, public and artistic-architectonic heritage; it is an historical evidence that, due to intense telluric activity, some urban settlements have been moved to areas characterised by a lower seismotectonic activity. Nowadays, the protection against seismic events is only possible via the probabilistic *definition* of event occurrence, i.e. the *seismic hazard*.

Starting from the assumption of the recurrence of seismic source, a first step, for the appraisal of seismic hazard, is the compilation of site earthquakes list by analysis of earthquakes recorded in the chosen national catalogue (GNDT-Camassi e Stucchi, 1997).

Tab.1 shows the highest ( $I_0 \geq IX$  MCS) seismic events that have occurred in the Southern Apennine with felts ( $I_5 \geq V$  MCS) in the Acerenza town.

One of the most devastating ( $I_0 = X$  MCS) earthquakes of Southern Italy took place in 1456. Indeed, due to the vastness of the area affected by the seismic event, *Magri and Molin (1985)* first proposed to consider the macroseismic effects like the superposition of more shakes. This seismic event caused the complete destruction of Acerenza (Claps V., 1982) which "*fu rasa al suolo e pianse 1200 morti (the house of town were completely pull down and 1,200 peoples died)*".

Another very strong earthquake was recorded in the *XVII century*. In fact, the 1694 *Calitri* earthquake ( $M_S = 7.0$ ) was perceived on immense area of Southern Italy (9.500 square kilometres) comprising beyond 120 locations of Campania, Basilicata and Puglia that suffered considerable damages. Thirty villages, of the provinces of Avellino and Potenza ( $I_5 = VIII-IX$ ), were nearly completely destroyed (Boschi).

Another earthquake, localized in the region of the Mount Vulture Volcano region, hit the Southern Italy in 1851. Little damages (V-VI MCS) were recorded in the town of Acerenza; indeed the effect of the main shake was limited to the area around the Volcano.

The 1857 earthquake ( $I_0 = X-XI$  MCS) caused the death of 9,000 peoples. An area wide about 3,000 square kilometres was completely destroyed. Acerenza suffered heavy damages, the macroseismic local intensity being VII MCS. The cathedral dome was seriously damaged owing to the 1930 Irpinia earthquakes ( $I_0 = X$  MCS), while the town suffered heavy losses ( $I_5 = VII-VII$  MCS). (Mallet). Finally, we recall the 1980 *irpino-lucania* seismic event ( $I_0 = IX-X$  MCS). This event caused destruction and death in an area wide about 3,500 square kilometres, while the area affected was of 250,000 square kilometres. The macroseismic site intensity at Acerenza was evaluated to be VI MCS.

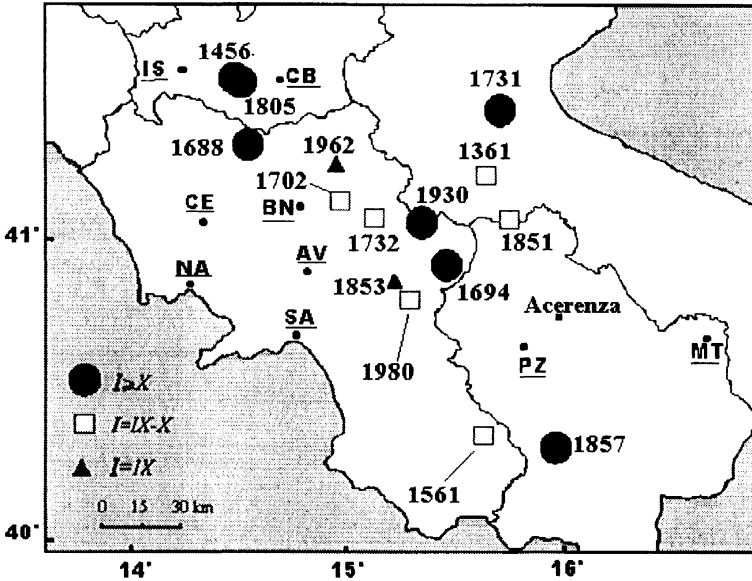


Figure 4: Main earthquake in GNDT catalogue and location of Acerenza site.

#### 4.1 PGA and intensity hazard assessment

The second step for hazard assessment is the analysis of the parameters that represent it. They are mainly two: the macroseismic intensity and the horizontal peak ground acceleration (PGA). The first, which is predominantly used internationally, represents the main seismic hazard indicator and can be expressed in terms of maximum observed intensity or intensity at a given probability level. It is also helpful for an initial approach to the assessment of seismic risk. The second one used for representation of earthquake hazard is the horizontal peak ground acceleration (given in  $g$ , the gravity acceleration) that is a very important indicator commonly used in urban planning, definition of new building specifications and also for retrofitting old constructions.

Tab.1 shows these values calculated (in absence of historical source), for Acerenza town, starting from the site subcatalogue and by means of the following formulas (Leggeri, 1997):

$$MCS_{site} = -1.338 + 1.489 \cdot I_0 - 1.606 \cdot \text{Log}_e(\text{Distance}) \quad (1)$$

$$PGA = 10^{(0.1805 \cdot MCS - 2.222)} \quad (2)$$



Table 1-Main earthquakes occurred in Southern Apennine (from 1000 to 1992), PGA (g) and macroseismic intensity (MCS) for Acerenza site. The values with asterisk are relative to *Monachesi G. & Stucchi M., 1997.*

YEAR	M	D	EPICENTRE	I <sub>o</sub>	I <sub>site</sub>	PGA	D (km)
1273	0	0	POTENZA	VIII-IX	6.4	0.085	21.62
1361	7	7	ASCOLI SATTRIANO	IX-X	6.4	0.086	53.20
1456	12	5	MOLISE	X	10	0.383	98.27
1561	8	19	VALLO DI DIANO	IX-X	6.6	0.093	47.42
1627	7	30	CAPITANATA	X-XI	6.6	0.093	118.36
1646	5	31	GARGANO	IX-X	5.2	0.051	115.37
1688	6	5	MATESE	XI	7.2	0.121	128.83
1694	9	8	CALITRI	X-XI	7.0*	0.110	44.17
1702	3	14	BARONIA	IX-X	5.6	0.060	90.44
1731	3	20	FOGGIA	IX	5.6	0.059	59.09
1732	11	29	IRPINIA	IX-X	5.8	0.068	76.11
1805	7	26	MATESE	X	5.6	0.061	141.39
1851	8	14	VULTURE	IX-X	5.5*	0.127	29.78
1853	4	9	VALLE DEL SELE	IX	5.5	0.059	58.35
1857	12	16	BASILICATA	X-XI	7.0*	0.110	50.39
1930	7	23	IRPINIA	X	7.5*	0.135	60.71
1963	2	13	TITO	VII	7.0*	0.110	35.74
1980	11	23	IRPINIA-LUCANIA	IX-X	6.0*	0.073	56.63

In addition to these determinations it is important also to consider the occurrence probability of the two hazard parameters relatively to the chosen time interval, that usually is 475 years, according to the seismic Eurocode EC8.

In fact, the trend of the European seismic code is the planning of buildings fit of completely released the ductility features (even assuming damages, but without the collapse of the buildings) for earthquakes with return time of 475 years.

Therefore, the above mentioned hazard indicators frequently are referred to this temporal interval. The data can be explained also like the value of shaking that will be exceeded in 50 years with a probability of the 10%.

The appraisal of these parameters has been recently carried out by Slejko et al. (1998). From this analysis results that the highest values of horizontal PGA occur in North-eastern Italy, in the Central Apennine and in the area near Potenza. The expected value for Acerenza site is from 0.16 to 0.20 g.

Regarding the map of macroseismic intensity, it is comparable with the PGA values. In fact, the maximum expected intensity are in Southern Italy and in particular for the Potenza site I=IX MCS and for Acerenza I=VIII MCS.

## Conclusions

Morphological analysis and the study of masonries put into relief two building moments. The first one is the apsidal complex, characterised by good constructive techniques, with antiseismical devices.

The second one is represented by the naves, which have approximative construction techniques, partially rebuilt after an earthquake.

Besides, the study of historical seismicity has put in evidence the particular vulnerability to seismic shakes of another architectural element: the dome.

The knowledge of the construction history, architectural and building characteristics and the historical seismicity of the site, contributed to the



definition of strategies aimed to a careful evaluation of the seismic risk for suitable actions of conservation.

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<sup>1</sup> The informations obtained about the constructive phases refer only to the relative chronology.

<sup>2</sup> Acerenza is a little town in Basilicata to 36 km NE from Potenza.

<sup>3</sup> Many renowned learned men have studied Acerenza Cathedral, among them : Schulz, Lenormant, Croce, Bertaux (1897), Bertaux(1903), Bordenache, Brandi and Kronig.

<sup>4</sup> There are in Italy five churches with a deambulatorio provided with radiale chapels. Three of them are in the South of Italy (Venosa and Acerenza in Basilicata, Aversa in Campania), the last two are in the central Italy and they are Sant'Antimo in Monte Amiata and Santa Maria a pié di Chienti in Marche region. According to Bordenache, all of them are similar for what concerns the plan and the architectonic structures (Bordenache).

<sup>5</sup> In agreement with the French derivation, about the ichnographic model, are many learned men who studied Acerenza and Venosa churches. Among them, we remember Schulz, Croce, Enlart, G. Dehio-G. von Bezold, Bordenache, Lenormant, Bertaux. These last two uphold a theory according to which Norman hands worked in Venosa and Acerenza yards. On the contrary, Toesca has no doubts about autochthonal hands and Rivoira remarks the cultural relationship with Italian mediaeval architecture.

<sup>6</sup> The photogrammetrical restitution of the Cathedral faces has been realized by a monoscopic system, that elaborates photographs taken by a semimetric camera (Rollei 6006), provided with a calibrated reticle. The surveys of the plan and of the points of topographic support for the photogrammetrical restitution have been made with a topographic total station (Topcon GTS-6). All the surveys have been realized by our photogrammetry and topography laboratory.

<sup>7</sup> Common "anomalies" consist of: disalignment of pilars and walls, variation of walls thicknesses and presence of not orthogonal angles;

<sup>8</sup>For more details of this method see Masini.

<sup>9</sup> We underline that the two semicircles C and C' are theoretical. Infact they are simple curves that interpolate a broken line determined by topographic methods.

<sup>10</sup> They are perforations realized in the wall to accomodate the beams that bore the scaffoldings.

<sup>11</sup> It is characterized by well-cemented lapideous strata, of micro-conglomerate, such as a pudding stones with a sandstone matrix and calcite cement, in alternatio with grey-yellow clays levels, classified like feldspar lithoarenite.

<sup>12</sup> XRD and other analyses put in relief the presence of :

a) micro-crystalline limestone, hazel coloured in the main face and in the nave pillars of the Cathedral;

b) quartzose-carbonatic materials in the bell tower stones and in its foundation ground.

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