Seismic safety of places of worship in Italy's Gran Sasso and Monti della Laga National Park

Aurelio Petracca[1], Carmela Morisi[2], Giandomenico Cifani[3], Giovanni Cialone[4]

Abstract title

The abundance of historic architectural heritage within Italy and its vulnerability to earthquake heighten the need for a risk analysis aimed at preserving buildings and their contents. In particular, churches are often more vulnerable than other buildings, even in the case of brief tremors. The reasons for this increased vulnerability are due to structure and peculiar geometrical proportions: presence of large open areas without internal walls to provide bracing, absence of intermediate ceilings, thinness of walls and certain vaulted structures, presence of thrust-exerting elements (arches, vaults). These features of churches, along with the use of architectural and structural criteria that are recognisable and comparable, albeit within the unique nature of each object, has led to a quest for specific procedures to assess seismic vulnerability, these being different to those utilised for ordinary buildings. The method involves dividing the building into macroelements, i.e. architectural sections of recognisable construction technique and showing similar seismic response (facade, apse, bell tower, etc.). The way in which damage can occur and the collapse mechanisms that the earthquake can provoke are therefore identified for each macroelement.

A specific risk analysis of places of worship has been carried out as part of the European project RECES modiquss "The network of small old town centres as a model of urban quality and sustainable development" - INTERREG IIIA Adriatic cross-border programme. Research has been concentrated on places of worship located in an area comprising six communes of the L'Aquila province in central Italy. Many of the churches involved underwent a vulnerability analysis. The earthquake that struck central Italy on 6th April 2009 seriously damaged many of the churches surveyed prior to this event. It is now possible to compare the damage suffered and the mechanisms unleashed with the mechanisms predicted during survey and analysis.

Keywords: seismic vulnerability, churches, collapse mechanisms, damage, macroelements.

---

[1] Italian National Research Council
[2] Architectural firm Proteo Associati
[3] Italian National Research Council
[4] Italian National Research Council

1. Introduction

The abundance of historic architectural heritage within Italy and its seismic vulnerability, i.e. its susceptibility to damage or alteration following an earthquake, heighten the need for a risk analysis of certain areas aimed at preserving buildings and their contents. A specific risk analysis of places of worship was carried out by the L'Aquila branch of the National Research Council Construction Technology Institute (NRC CTI) as part of a European project whose objectives included knowledge, protection and enhancement of cultural heritage, including in support of socioeconomic development linked to sustainable tourism. Research concerned places of worship located in an area comprising six communes of the L'Aquila province: Barisciano, Calascio, Castelvecchio Calvisio, Castel del Monte, Carapelle Calvisio, S. Stefano di Sessanio. This area forms one of the Cultural Tourism Districts of the Gran Sasso and Monti della Laga National Park called Terre della Baronia. This survey of places of worship has led to the identification and registration of 64 elements, some in a state of ruin, comprising churches, convents and chapels (figure 1).

Figure 1. San Cipriano Church in Castelvecchio Calvisio

Some of the churches involved, representing the largest part of the sample, underwent a vulnerability analysis. The sample consists of 33 mainly aisleless churches of various size and complexity. The method used is about the study of building and the analysis of seismic risk with a quickly form and an analytical method, according to the indications of the Italian rule for cultural heritage.

The earthquake that struck central Italy on 6^{th} April 2009, in particular the city of L'Aquila and the above-mentioned communes, has enabled a check to be carried out on the effectiveness of the forecasts made and methodology used.

2. SAMPLE TYPE ANALYSIS

The different types of construction were identified, these ranging from a simple chapel to very large churches (see table 1 and figure 2). The higher the surface area, the greater the building's structural complexity. The sample surveyed comprises 73% aisleless churches and 24% with two naves or three aisles. 70% are buildings with vaulted structures. Domes are present in only 24% of the sample. Projections and gables are found in 64% of the sample and mainly feature bell gables and gable façades, whilst 21% have a bell tower. 36% of the sample have an apse and 12% a transept. Only 6% of the churches have a prothyron.

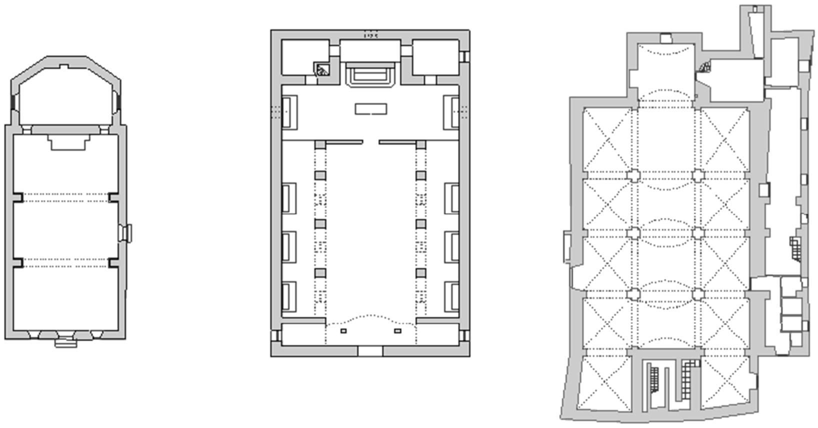


Figure 2. Plan of the Santa Maria della Pietà di Collerotondo church, Santa Maria ab Extra church, both in Barisciano, and the San Marco Evangelista church in Castel del Monte

Various types of façade are to be found (figure 3), the most characteristic and at the same time most vulnerable feature, but all meet standard architectural criteria. The rectangular façade typical of L'Aquila (45% of sample) is the most common, whilst 24% of the churches surveyed have a gabled façade and in 21% of cases it follows the outline of the roof. This last-mentioned type is a feature of aisled churches or those having side chapels. It is worth noting that 39% of the sample have a façade with gables and other projections that can be particularly vulnerable in the event of an earthquake.

Figure 3. Façade of the churches of Santa Maria di Valleverde in Barisciano, Madonna del Lago in S. Stefano di Sessanio and Santa Maria and San Vittorino in Carapelle Calvisio

3. SEISMIC VULNERABILITY ANALYSIS

An in-depth study was conducted into the construction of each of the churches, this considering the following aspects:

- its history, using available bibliography and archive material from the L'Aquila Heritage Commission;
- comprehensive geometric, technological and material characteristics survey based on direct observation and the survey and archive material available from the L'Aquila Heritage Commission (figure 4);
- survey of cracks and deformation**.**

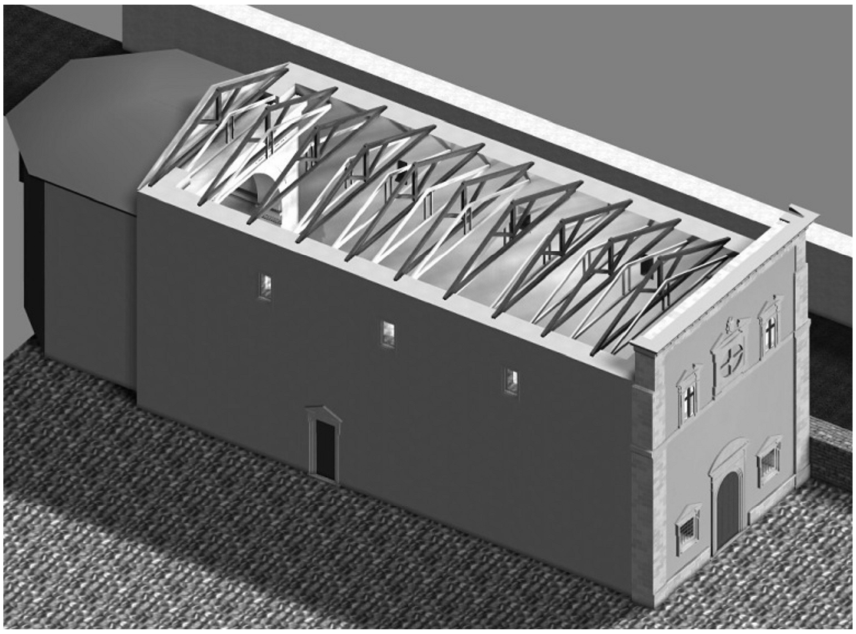


Figure 4. Santa Maria di Valleverde church in Barisciano, axonometric projection

In addition, these churches also underwent a data sheet survey using the "Level II churches damage and vulnerability survey sheet". The survey method is based on identifying 28 possible damage mechanisms affecting a series of the church's macroelements and analysing the factors that can facilitate or prevent the activation of such mechanisms. The procedure leads to the creation of a vulnerability index i_v ranging from 0 to 1, using a suitable combination of points awarded to the various seismic vulnerability and protection elements. This index offers comparison of the degree of vulnerability of churches of different shapes and sizes, allowing a sort of hierarchy to be established (see fig. 5).

For each damage mechanism considered, its frequency of activation was calculated along with the damage level as a percentage of all the churches surveyed. The information provided by the data sheets highlights the absence of seismic damage. When present, damage is limited and does not exceed level 3. Indeed, the main problem was caused by lack of maintenance, as noted during surveying.

N	COMUNE	DENOMINAZIONE CHIESA	navata unica	due navate	tre navate	pianta centrale	facciata	protiro	campanile	vela	cappelle	abside	transetto	corpi annessi	volte	cupola	lanterna	posizione
1	Barisciano	S. Maria della pietà	X				X			X				X				isolata
2	Barisciano	S. Maria di Capo di Serra		X			X			X					X			estremità
3	Barisciano	S. Maria del Carmine	X				X			X	6	X		X	X		X	nel contesto
4	Barisciano	S. Maria di Valleverde	X				X		X			X		X				corpi annessi
5	Barisciano	Immacolata Concezione	X				X			X	1			X	X	X		nel contesto
6	Barisciano	S. Flaviano			X		X		X		12	X	X	X	X	X	X	corpi annessi
7	Barisciano	Oratorio del SS.Rosario	X							X		X		X	X			estremità
8	Barisciano	S. Colombo	X				X			X	4	X		X	X			corpi annessi
9	Barisciano	S. Martino	X				X				4			X				estremità
10	Barisciano	Madonna del Rosario	X				X							X				corpi annessi
11	Barisciano	S. Maria ab Extra			X		X		X			X	X	X	X	X	X	isolata
12	Carapelle Calvisio	S. Pancrazio	X				X			X	10			X	X			isolata
13	Carapelle Calvisio	S. Francesco	X				X			X	1			X				nel contesto
14	Carapelle Calvisio	S. Vittorino	X				X								X			isolata
15	Carapelle Calvisio	S. Maria e S. Vittorino		X			X			X	3	X			X	X		nel contesto
16	Castelvecchio Calvisio	S. Cipriano	X				X			X		X		X				isolata
17	Castelvecchio Calvisio	S. Giovanni Battista		X			X			X	1			X	X			estremità
18	S.Stefano di Sessanio	S. Stefano Protomartire	X				X		X					X	X			isolata
19	S.Stefano di Sessanio	Madonna del Lago	X				X	X		X	2			X	X			isolata
20	S.Stefano di Sessanio	S. Maria in Ruvo		X			X			X		X		X				nel contesto
21	S.Stefano di Sessanio	Anime S. del Suffragio	X								1			X				nel contesto
22	Castel del Monte	S. Marco Evangelista			X				X				X	X	X	X		nel contesto
23	Castel del Monte	S. Maria del Suffragio	X				X			X				X	X			corpi annessi
24	Castel del Monte	S. Donato	X				X				6	X			X			isolata
25	Castel del Monte	S. Maria delle Grazie	X				X			X					X			isolata
26	Castel del Monte	S. Rocco				X	X			X						X		estremita
27	Castel del Monte	S. Caterina		X			X								X			nel contesto
28	Calascio	S. Maria delle Grazie	X				X	X	X			X		X	X			corpi annessi
29	Calascio	S. Antonio Abate	X				X			X				X				corpi annessi
30	Calascio	S. Nicola di Bari	X				X		X		4	X	X	X	X	X		nel contesto
31	Calascio	S. Leonardo	X				X			X				X	X			corpi annessi
32	Calascio	Madonna delle Grazie	X				X			X				X	X			isolata
33	Calascio	S. Francesco	X				X								X			isolata

Table 1. Types of church forming the sample

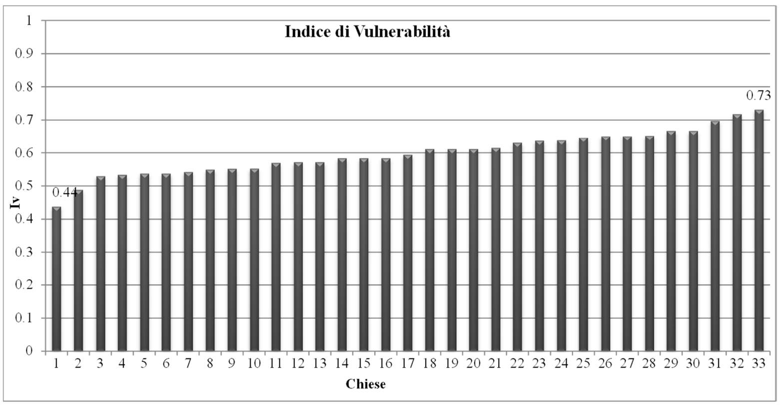


Figure 5. Vulnerability indices

By assessing the damage mechanisms that can be activated in the presence of a certain macroelement, it can be noted that façade mechanisms are likely in almost all the churches (97%). This shows that the sample is composed of buildings that are either isolated or form part of complexes in which such macroelement can be identified. The highest damage level, and thus mechanism activation, is also found: 24% overturning of façade, 15% top, 27% in-plane mechanisms. The cases noted of overturning are characterised by the presence of vertical cracks on the side walls close to the façade, mainly due to poor bonding between masonry walls. Cracks relating to a mechanism at the top of the façade is almost always due to either the fact that façades project above the top of the roof and are pounded or the thrust of nave vaults. On the other hand, in-plane mechanisms are helped by the presence of various openings in the façade, some of notable size. The greater possibility of activating a transverse response (100%) as opposed to mechanisms connected to nave vaults (70%) underlines the absence of vaulted structures in some churches that instead have timber trusses or beams resting on stone cross arches. In this case, the damage is to be found above all in the vaults (mechanism activated in 21% of cases) with cracks in the keystone or on the lunettes, mainly due to the absence of suitable protection to dampen thrust. The mechanism in the roofing is also likely to be activated in almost all the buildings analysed (97%). Some of the roofing structures are constructed using timber trusses, but most are made using reinforced concrete. In 88% of the sample, interaction is possible between the individual structures forming the building as a whole.

4. MASONRY QUALITY ANALYSIS

Masonry quality was assessed by referring to the “Level I data sheet for assessing masonry type and quality”. Using the data contained in the survey sheets for the sample considered it has been possible to carry out a statistical survey with regard to the presence of the different construction parameters that can be found in the various types of masonry. A total of 67 masonry structures have been identified and these can be broken down into four types specified by current technical standards (figure 6). The data sheets serve the dual purpose of facilitating the collection and filing of information and allowing immediate identification of the masonry’s specific characteristics and determination of the main types. By analysing the data concerning their constituents, it can be seen that the masonry structures are all composed of elements of a calcareous nature with lime mortar.

Tipologia muraria	Numero casi	Percentuale
A. Muratura in pietrame disordinata	53	79%
B. Muratura a conci sbozzati	5	7%
C. Muratura in pietra a spacco con buona tessitura	3	4%
E. Muratura a blocchi lapidei squadrati	6	9%
Totale	67	100%

Table 2. Masonry types

The breakdown of the different types (table 2) shows that most of the sample belongs to type A, whilst there are no examples of type D. Type E often regards the façade, this being built with large blocks of limestone that are carefully squared in order to produce a building of striking architectural impact.

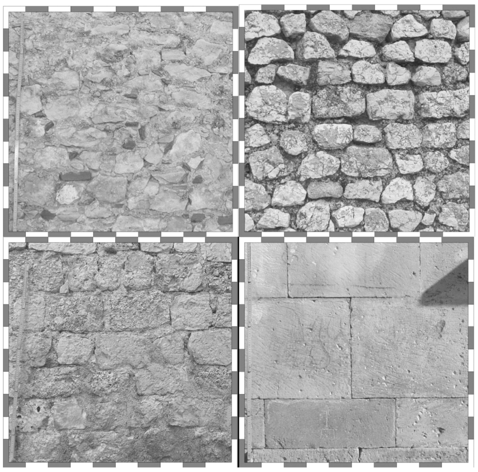


Figure 6. Sample of masonry types: starting from top left A, B, C, E

Thermal imaging was carried out on some of the buildings in order to assess, without touching plastered surfaces, the elements required for characterization of structural members such as: the vertical arrangement of the masonry structure, presence of gaps/irregularities and substructures, vault type, degree of instability and details of the cracks. Thermal imaging was carried out by a workgroup led by Prof. Ermanno Grinzato. The thermal images produced enabled direct verification of the quality of the information that can be obtained (figures 7, 8).

Figure 7. Santa Maria di Valleverde church in Barisciano, thermograph and photo

Figure 8. Madonna del Lago church in Santo Stefano di Sessanio, thermograph and photo

5. ANALYTICAL VULNERABILITY ASSESSMENT

5.1 LV1 assessment level

The analytical vulnerability assessment of the churches in question was carried out in accordance with the procedure specified in the "G*uidelines for the assessment and reduction of the seismic risk to cultural heritage*". Initially, the simplified LV1 model proposed by the above-mentioned guidelines was applied. This model, based on statistical data collected from previous Italian earthquakes, enables an estimate to be made of the peak ground acceleration corresponding to the Ultimate Limit State (ULS) and Damage Limitation State (DLS) as a function of the vulnerability index i_v calculated with the damage and vulnerability survey sheet using the following expressions:

$$a_{SLD} = 0{,}025 \times 1{,}8^{2{,}75-3{,}44 i_v}$$

$$a_{SLD} = 0{,}025 \times 1{,}8^{5{,}1-3{,}44 i_v}$$

The structure's safety index at the Ultimate Limit State represents the ratio of structural capacity to seismic demand and can be calculated as:

$$I_s = \frac{a_{SLU}}{\gamma_I S a_g}$$

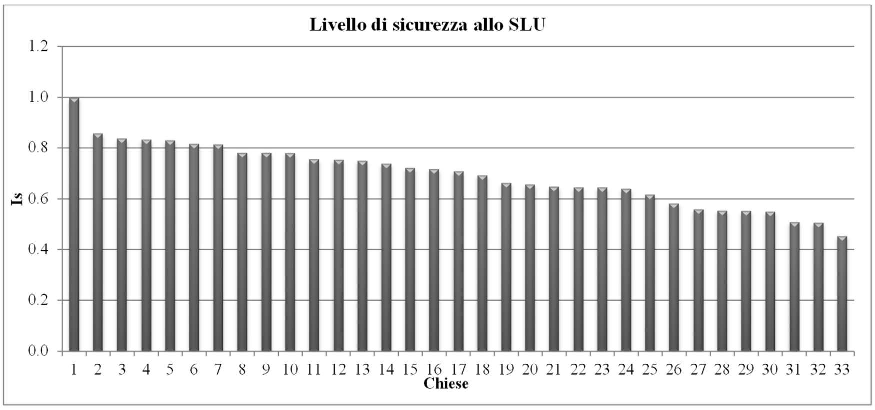
where: a_{ULS} is the ground acceleration that will lead to the ultimate limit state being reached; S is a parameter that takes account of the stratigraphic profile of the underlying subsoil and morphological effects; γ_I is the importance coefficient that takes account of the building's position and its cultural importance. a_g is the reference acceleration for the site. This is the same for the Damage Limitation State. This purely statistical approach may be considered correct since it refers to the analysis of a specific area. It allows drawing up of lists of priority and programming of more detailed assessments in the best possible manner with a view to implementing preventive measures. Indeed, the use of a single model for assessments of this type allows more objective comparison as far as seismic risk is concerned. Reference accelerations for the communes in which the places of worship are located were taken from current technical standards. Safety indices at ULS and DLS for the churches in question are given in the following table and graphs (table 3, figure 9).

As confirmation of that previously noted in the case of minor earthquakes, it is worth pointing out that these structures are more susceptible to DLS than ULS. It may be noted that ground acceleration values corresponding to the ultimate limit state (ULS) are fairly high. Indeed, mechanisms will generally be activated at lower values, although higher acceleration levels are needed before causing the structure to collapse.

In order to make a more accurate forecast as to the seismic risk for these buildings, more in-depth studies and processing are required, applying the LV2 second level procedure based on the analysis of individual mechanisms.

N	Chiesa	Comune	S	γ_I	Fc	a_{SLD}		a_{SLU}		Is_{SLD}	Is_{SLU}
1	S. Cipriano	Castelvecchio Calvisio	1.25	0.65	1.12	0.05	g	0.21	g	0.63	1.00
2	S. Rocco	Castel del Monte	1.25	0.65	1.12	0.04	g	0.17	g	0.54	0.86
3	S. Maria delle Grazie	Calascio	1.25	0.65	1.12	0.04	g	0.17	g	0.53	0.84
4	S. Caterina-Cong. della SS Annunziata	Castel del Monte	1.25	0.65	1.12	0.04	g	0.16	g	0.52	0.83
5	S. Antonio Abate	Calascio	1.25	0.65	1.12	0.04	g	0.17	g	0.52	0.83
6	S. Francesco d'Assisi	Calascio	1.25	0.65	1.12	0.04	g	0.17	g	0.51	0.82
7	S. Stefano Protomartire	S. Stefano di Sessanio	1.25	0.65	1.12	0.04	g	0.17	g	0.51	0.81
8	S. Donato	Castel del Monte	1.25	0.65	1.12	0.04	g	0.15	g	0.49	0.78
9	S. Maria delle Grazie	Castel del Monte	1.25	0.65	1.12	0.04	g	0.15	g	0.49	0.78
10	Immacolata Concezione e Cappella	Barisciano	1.25	0.65	1.12	0.04	g	0.16	g	0.49	0.78
11	S. Pancrazio	Carapelle Calvisio	1.25	0.65	1.12	0.04	g	0.16	g	0.47	0.76
12	S. Maria di Capo di Serra	Barisciano	1.25	0.65	1.12	0.04	g	0.16	g	0.47	0.75
13	Madonna delle Grazie	Calascio	1.25	0.65	1.12	0.04	g	0.15	g	0.47	0.75
14	S. Maria del Suffragio	Castel del Monte	1.25	0.65	1.12	0.04	g	0.15	g	0.46	0.74
15	S. Maria di Valleverde	Barisciano	1.25	0.80	1.12	0.05	g	0.19	g	0.45	0.72
16	S. Colombo	Barisciano	1.25	0.65	1.12	0.04	g	0.15	g	0.45	0.72
17	S. Leonardo	Calascio	1.25	0.65	1.12	0.04	g	0.15	g	0.44	0.71
18	S. Maria Ab Extra	Barisciano	1.25	0.65	1.12	0.04	g	0.15	g	0.43	0.69
19	S. Francesco	Carapelle Calvisio	1.25	0.65	1.12	0.03	g	0.14	g	0.42	0.66
20	S. Maria del Carmine	Barisciano	1.25	0.65	1.12	0.03	g	0.14	g	0.41	0.66
21	S. Giovanni Battista	Castelvecchio Calvisio	1.25	0.80	1.12	0.04	g	0.17	g	0.41	0.65
22	Madonna del Rosario	Barisciano	1.25	0.65	1.12	0.03	g	0.14	g	0.41	0.65
23	S. Vittorino	Carapelle Calvisio	1.25	0.65	1.12	0.03	g	0.13	g	0.40	0.64
24	S. Maria della Pietà	Barisciano	1.25	0.65	1.12	0.03	g	0.13	g	0.40	0.64
25	Anime Sante o del Suffragio	S. Stefano di Sessanio	1.25	0.80	1.12	0.04	g	0.16	g	0.39	0.62
26	Oratorio Confraternita del SS. Rosario	Barisciano	1.25	0.65	1.12	0.03	g	0.12	g	0.37	0.58
27	S. Martino	Barisciano	1.25	0.80	1.12	0.04	g	0.14	g	0.35	0.56
28	S Nicola di Bari	Calascio	1.25	0.80	1.12	0.04	g	0.14	g	0.35	0.55
29	S. Marco Evangelista	Castel del Monte	1.25	0.80	1.12	0.03	g	0.13	g	0.35	0.55
30	S. Maria in Ruvo	S. Stefano di Sessanio	1.25	0.65	1.12	0.03	g	0.11	g	0.35	0.55
31	Madonna del Lago	S. Stefano di Sessanio	1.25	0.80	1.12	0.03	g	0.13	g	0.32	0.51
32	S. Maria e S. Vittorino	Carapelle Calvisio	1.25	0.80	1.12	0.03	g	0.13	g	0.32	0.51
33	S. Flaviano	Barisciano	1.25	0.80	1.12	0.03	g	0.12	g	0.28	0.45

Table 3. Safety indices



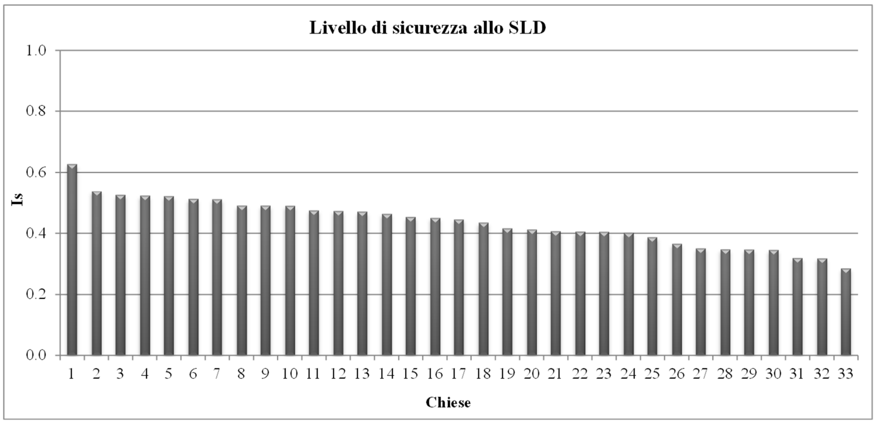


Figure 9. Safety indices at ULS and DLS

5.2 Linear kinematic analysis

As regards places of worship, the guidelines prefer kinematic analysis methods (linear and non linear) applied to the various macroelements that thus become the reference structural units. This highlights the need to utilise local models and assessments rather than complex models.

As previously stated, during the course of the research project, besides collecting historical records regarding the churches in order to have a better idea of past events, comprehensive surveying was also carried out along with observation and cataloguing of the types of vulnerability present.

Observing a church's alteration, disrepair and damage processes reveals the essential characteristics that condition its seismic vulnerability. The weakest parts of the structure are identified, those that could collapse when the earthquake strikes, thus indicating the ways in which the earthquake will be able to cause damage. This involves a preliminary qualitative analysis that is swiftly followed by a quantitative assessment of stability.

The aim of the qualitative analysis is to highlight the mechanisms whose presence and activity are revealed by some degree of damage for which they are directly responsible and identify the mechanisms most likely (figure 10) to be activated in the future based on observation of the churches' structural features, type and vulnerability attributable to specific characteristics or else statistically common. Having ascertained the mechanisms already activated or likely to be so, linear kinematic analysis was carried out in accordance with technical standards.

***Figure 10. On the left the San Francesco church in Carapelle Calvisio (AQ), façade overturning mechanism; on the right the Madonna del Lago church in S. Stefano di Sessanio, tympanum overturning mechanism with formation of oblique hinges*.**

6. CONCLUSION

As previously stated, the seismic vulnerability study of the sample described was carried out over the two-year period 2007-2008.

The earthquake on 6th April 2009 struck all communes in the Baronia di Carapelle area to a lesser or greater degree. With the exception of Calascio, all communes fall within the "*seismic footprint*".

The churches studied have suffered varying amounts of damage, in some cases severe (figure 11).

Figure 11. Example of damage suffered by the churches: starting from top left the churches of Santa Maria e San Vittorino (Carapelle Calvisio), San Marco Evangelista (Castel del Monte), Madonna del Rosario and Santa Maria del Carmine (Barisciano)

Damage assessment was carried out using the church seismic damage survey sheet that considers the same macroelements and damage mechanisms as the vulnerability survey sheet. The method associated with the survey sheet provides for the calculation of a damage index i_d (ranging from 0 to 1) representing the church's average damage level (fig. 12).

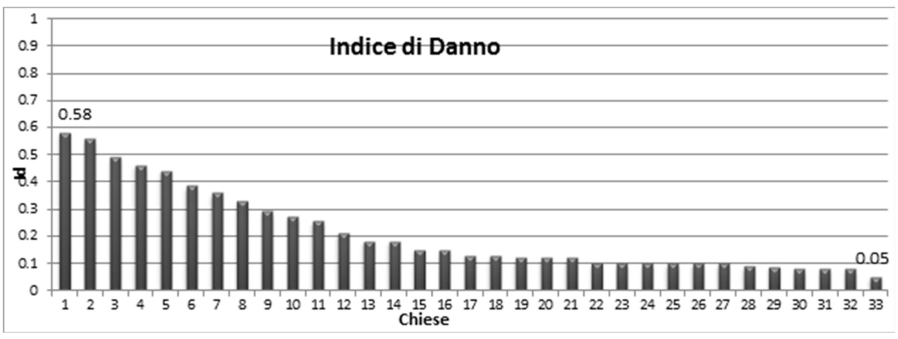


Figure 12. Damage indices for the sample of churches

It can indeed be noted that there is good correspondence between mechanisms deemed more hazardous (see table 8) and those in which the highest damage level was found.

DAMAGE MECHANISMS	Possible activation (%)	D0(%)	D1(%)	D2(%)	D3(%)	D4(%)	D5(%)
1. Overturning of façade	97%	79%	12%	6%	6%	0%	0%
2. Mechanisms at the top of the façade	97%	88%	9%	3%	3%	0%	0%
3. Façade in-plane mechanisms	97%	79%	15%	6%	6%	0%	0%
4. Prothyron or narthex	6%	94%	0%	6%	6%	0%	0%
5. Nave area transverse response	100%	79%	3%	12%	12%	0%	0%
6. Shear mechanisms in the walls	100%	88%	9%	3%	3%	0%	0%
7. Colonnade longitudinal response in aisled churches	21%	97%	0%	3%	3%	0%	0%
8. Nave vaults	70%	82%	9%	6%	6%	0%	0%
9. Aisle vaults	18%	24%	0%	3%	3%	0%	0%
10. Overturning of transept end walls	12%	24%	3%	0%	0%	0%	0%
11. Shear mechanisms in transept walls	12%	27%	0%	0%	0%	0%	0%
12. Transept vaults	12%	24%	3%	0%	0%	0%	0%
13. Triumphal arches	36%	79%	3%	3%	3%	0%	0%
14. Dome-drum	21%	85%	0%	0%	0%	0%	0%
15. Roof lantern	9%	85%	0%	0%	0%	0%	0%
16. Overturning of apse	36%	79%	3%	0%	0%	0%	0%
17. Shear mechanisms in presbytery or apse	73%	91%	0%	6%	6%	0%	0%
18. Presbytery or apse vaults	64%	85%	6%	3%	3%	0%	0%
19. Mechanisms in roofing (side walls)	97%	88%	3%	6%	6%	0%	0%
20. Mechanisms in roofing (transept)	9%	97%	0%	0%	0%	0%	0%
21. Mechanisms in roofing (apse and presbytery)	73%	85%	0%	3%	3%	0%	0%
22. Overturning of chapels	36%	85%	0%	3%	3%	0%	0%
23. Shear mechanisms in chapel walls	42%	88%	0%	0%	0%	0%	0%
24. Chapel vaults	42%	85%	0%	3%	3%	0%	0%
25. Interaction at plan and elevation irregularities	88%	91%	3%	0%	0%	0%	0%
26. Projections (bell gable, spires, pinnacles, statues)	64%	94%	0%	0%	0%	0%	0%
27. Bell tower	24%	94%	0%	0%	0%	0%	0%
28. Bell gable	30%	94%	0%	0%	0%	0%	0%

Table 4. Damage mechanisms and damage percentage

The earthquake of 6 April 2009 has allowed us to verify the validity of scientific method used for the risk analysis of the churches in the "restricted area". The next phase of research will be directed toward a consolidation of the procedures in order to allow vulnerability assessments of the churches on a large site. The processed data can be used to study risk analysis. More over they can be useful to the building owners as a guide to restore the cultural heritage.

References

Beolchini G.C., Martinelli A., Petracca A. ed altri (2007): “Repertorio dei meccanismi di danno, delle tecniche di intervento e dei costi negli edifici in muratura, Sisma Marche 1997”. Ancona.

AA.VV. (2008): “Sisma Molise 2002: Dall’emergenza alla ricostruzione. Edifici in muratura”. Roma.

Romeo, R., Pugliese, A. (2000) “Seismicity, seismotectonics and seismic hazard of Italy” Geol., 55, 241-266.

Cifani G., Lemme A. Podestà S. (2005) “ Beni monumentali e terremoto: dall’emergenza alla ricostruzione” L’Aquila