# Abruzzo Earthquake 2009 : New Tools for damage relief to Archaeological Heritage

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**ABSTRACT**

The article deals with Archaeological Heritage damaged by the earthquake in Abruzzo (April 2009). ITC-CNR, L'Aquila, in view of the damaged areas recovery, activated a number of actions listed below:

- formulate earthquake damage detection and study procedure;
- formulate procedure to evaluate the vulnerability of the historical / archaeological sites;
- prepare guidelines about design and implementation securing Archaeological Heritage;

Starting from the form Models prepared by DPC (Department of Civil Protection) and MiBAC (Ministry of Heritage and Culture), ITC-CNR, L'Aquila, has developed a cataloguing system for damage detection based on the different typologies forming the archaeological heritage and their structural articulation.

In the following paragraphs datasheet for the relief of damage is shown, too.

## 1. Analisys of seismic damage Archaeological Heritage

Since pre Roman era, Aquila basin is divided into regional centers, basing on ethnic origins of its inhabitants: Vestini-Cismontani settled in the east territories and Sabini settled in the west area.

In Roman times, the administrative order traced these ancient geographical divisions that, almost completely intact and without interruption, have been transmitted over the centuries, originating the current configuration of settlements in Aquila territory.

Archaeological researches, such as surveys and topographic reliefs, and the correlation between the analysis of the results and the study of documents, archives, historical – artistic and toponymic sources, provided a thorough knowledge of the considerable Heritage existing in this part of Abruzzo.

In addition to monumental, architectural and art-historical relevancies, there are a lot of important archaeological sites in this territory.

These sites belong to different historical periods and are essential to the historical reconstruction of the territory.

For many years Institutions have been pursuing the achievement of the goals of their conservation, protection and preservation even in consideration of a sustainable territorial development.

Unfortunately archaeological heritage has been damaged by earthquake on April 2009.

ITC-CNR, L'Aquila, in view of the damaged areas recovery, activated a number of actions listed below:

- formulate earthquake damage detection and study procedure;
- formulate procedure to evaluate the vulnerability of the historical / archaeological sites;

- prepare guidelines about design and implementation securing Archaeological Heritage;

In order to evaluate earthquake damages on archaeological heritage, ITC-CNR completely mapped Aquila the archaeological heritage and researchers conducted seismic risk analysis.
The research activity showed that there are few data on damage assessment caused by natural risks and on archaeological heritage vulnerability.
The analysis suggested then defining survey forms.
These forms, used in the post-earthquake, can be defined as the methodology of damage detection.
The forms contain all necessary data for vulnerability assessment of the archaeological heritage and for the securing of the buildings.
Starting from the form Models prepared by DPC (Department of Civil Protection) and MiBAC (Ministry of Heritage and Culture), ITC-CNR, L'Aquila, has developed a cataloguing system for damage detection based on the different typologies forming the archaeological heritage and their structural articulation. In other words, single elements have been distinguished from a complex structure consisting of several elements. In addition, the following have been taken into consideration: building techniques, materials used, binders, the presence of artwork and the restorations that each heritage item may have suffered over time.
Regarding the identification of damage mechanisms activated by the quake, the analysis started by finding that the majority of archaeological remains is made up of ruins or partially intact buildings. However cases of buildings retained on all sides, even if rare, have been included in the analysis as well. 14 collapse mechanisms have been identified in addition to the damages detectable on the decorative apparatus and the pre-existing damages aggravated by the earthquake.
As already mentioned, the seismic damage detection form spends a substantial section on building types (masonry and binders) by virtue of the fact that in many cases the site is attended without interruption. This creates a masonry stratification composed of different building types that, stimulated by the earthquake, may have a different mechanical response. For this reason, even in conservative estimates of intervention, it has been considered essential to provide specific guidance on the nature and / or different typologies of the buildings, to determine the masonry mechanical properties.
The form can process both peculiarities related to a single archaeological object and those related to an archaeological complex. Therefore, in addition to the "mother" form, including all the basic information for typological data acquisition and damage mechanisms definition, some attachments have been developed in order to identify and highlight the seismic damage in a timely, topographical and typological manner for each component of the archaeological complex.

### 1.1 Datasheet for the relief of damage

The form is divided in three sections.
Only one form has to be filled in when analyzing a single archaeological value otherwise, if the object is complex and it is divisible in easily recognizable individual elements, the “mother” form must be filled in with using the attachments identified by an alphanumeric code (one for each elements).
The first section of the form is reserved to general details of the Heritage Object, its administrative and geographic location, the possible presence of obstacles that can be direct, indirect, landscape or environmental, morphological features of the site, disruptions presence, maintenance conditions, category and group type identification (ex: Civil-Amphitheatre) and the possible presence of wall or floor coverings.
The second section is for structural and dimensional data, specifications of the construction type (structures in elevation, horizon, original covers, cover Intervention, flooring, wall cladding) in mortar (function, texture, color, finish, grain size, including, binder, in type of plant.
Moreover it is possible the presence of work arts with information regarding the possible restoration.

When the intrinsic features of the object have been defined, the importance of the earthquake damage will be analyzed in the second section. In most cases, as already mentioned, we are in presence of masonry structures remains; for this reason we have better specified these in the first section so we can identify the damage mechanism.
Other types of buildings, like religious or civil district with complex structure or intact building, have been not excluded from analysis. For each type the mechanism damage activated or to be activated has been considered.
In the table below 14 possible damage mechanisms are listed. The detector has first to identify if the mechanism is present and, if the result is positive, if the mechanism is activated. In this case there are five damage levels for each mechanism.

**Table 1.**: List of damage mechanism identified.

| | | |
|---|---|---|
| **1 MECHANISMS OUTSIDE THE FAÇADE PLAN** | | ☐ **YES** ☐ **NO** |
| **Damage** | Wall detachment or visible misalignement, Hanging Separation and Global Mechanism of the hanging activation | □ □ □ □ □ |
| **2 MECHANISMS IN THE PLAN OF masonry walls** | | ☐ **YES** ☐ **NO** |
| **Damage** | Localized sloping damages function of the friction interior corner of the wall, Diffused sloping damages along the mortar joints, Hanging Separation, Material ejection, Sloping and Vertical Damages | □ □ □ □ □ |
| **3 THE CRUMPLING OF THE WALLS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Damages at the wall discontinuity, Wall Hanging Detachments | □ □ □ □ □ |
| **4 HORIZONTAL SLIDING** | | ☐ **YES** ☐ **NO** |
| **Damage** | Elements sliding at the base | □ □ □ □ □ |
| **5 ARCH STRUCTURES MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Arch Damages, Sliding blocks, Crushing Piers | □ □ □ □ □ |
| **6 COLONNADE MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Archs and Architraves Longitudinal Damages, Base Columns Crushing and or damages | □ □ □ □ □ |
| **7 ROOFING MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Diffused damages, Local Collapses, Traves Sliding or unthreading | □ □ □ □ □ |
| **8 VAULT STRUCTURES MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Diffused damages, Local Collapses, Damages at the foot of the key vaults or at the back | □ □ □ □ □ |
| **9 STAIRWAYS MECHANISMS** | | ☐ **YES** ☐ **NO** |

| | | |
|---|---|---|
| **Damage** | Diffused damages, Twisting, Local Collapses | □ □ □ □ □ |
| **10 FOUNDATIONS MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Yiealding of the Foundation level | □ □ □ □ □ |
| **11 MECHNAISMS DUE TO DIFFERENT HEIGHTS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Pounding damages due to contacts of corpus with different heights, Joint movement in the wall due to pounding, Vertical damages in the less rigid corpus, Rotation of the higher corpus | □ □ □ □ □ |
| **12 FLOORS MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Diffused damages, Subsidence or Detachment, Side Walla Detachment | □ □ □ □ □ |
| **13 OBJECTS (STATUES, PINNACOLS, FRAMES)** | | ☐ **YES** ☐ **NO** |
| **Damage** | Rotation, Sliding, Overturning | □ □ □ □ □ |
| **14 COVERING ELEMENTS MECHANISMS** | | ☐ **YES** ☐ **NO** |
| **Damage** | Diffused Damages, Localized Collapses | □ □ □ □ □ |

Damage mechanisms are completed with an additional table where it is required to explain decoration damage (if present).

The third section of the form is for:

- practicability information
- emergency measures suggested
- estimate of the costs of any necessary works

The free field has to be filled in with the OBJECT planimetry including sketch of the damages.

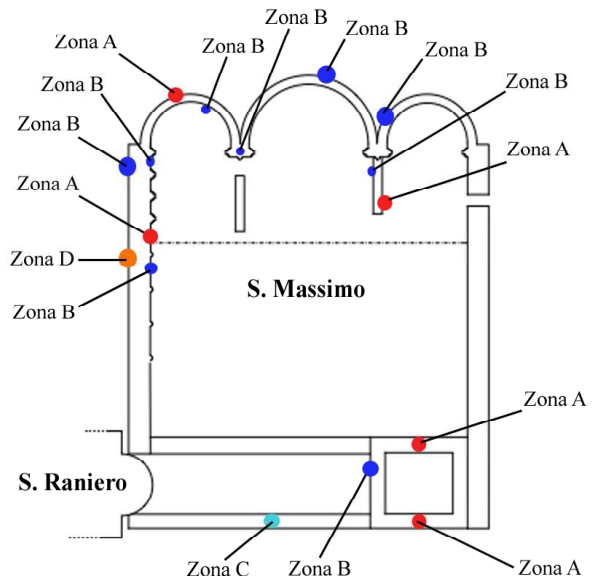
In order to obtain a comprehensive outline and a correct map of the damage after the seismic event, attachments indicating restoration data, mechanism types and suggested measures must be included in the form. Each attachment is a "zone" of the building, where was found a type of damage replicated in multiple locations of the building.

The damage highlighted as described, is shown on the sketch or on the available planimetry, allowing obtaining immediately both the level and the type of damage and, during the design and securing phase, an overview of the damage.

The sketch of the damages found in St Massimo of Forcona – Civita di Bagno is showed below:

**Table 2.** Sketch of the damages found in St Massimo of Forcona – Civita di Bagno

| | ATTACHMENTS | DAMAGE LEVELS |
|---|---|---|
| | ATTACHMENT 1 – ZONE A | □ □ □ □ □ |

| | | |
|---|---|---|
|  | MECHANISM OUTSIDE WALL PLANE<br><br>*Hanging Separation, Material Ejection* | |
| | ATTACHMENT 2 – ZONE B<br><br>MECHANISM IN THE PLANE OF THE WALLS- *Diffused sloping damages along the mortar joints, Sloping and Vertical Damages* | □ □ □ □ □ |
| | ATTACHMENT 3 – ZONE C<br><br>Crumping of the wall –<br><br>*Damages at the wall discontinuity, Wall Hanging Detachments* | □ □ □ □ □ |
| | ATTACHMENT 4 – ZONE D<br><br>Walls Overturning –<br><br>*Visible misalignments*<br><br>*Hanging Separation Global Mechanism of the hanging activation* | □ □ □ □ □ |

The form has been already tested on four different Archaeological types:

- The church of Saint Massimo of Forcona-Civita di Bagno
- The amphitheatre and the Amiternum Theatre
- The castle of Ocre- Fossa.

Currently we are testing the form on other Archaeological building like S. Michele, S.Arcangelo and its catacombs.

We are finally completing the study of the vulnerability identifying of the Archaeological buildings to be integrated in the damage detection form and masonry structures form.

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