17th World Conference on Earthquake Engineering, 17WCEE

Sendai, Japan - September 13th to 18th 2020

SEISMIC RISK OF NON-STRUCTURAL ELEMENTS: IT TOOL FOR RAISING AWARENESS AND MITIGATE CONSEQUENCES

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Abstract

In many part of the world, including Italy, seismic design approaches for non-structural elements (NSEs) are incomplete or missing from standards and codes. This is often due to the lack of information on the seismic behavior of non-structural building components, as also expressed by the research community. Nevertheless, in several cases, international standards exist but national regulations do not enforce their use, leading to some impediments to incorporate seismic design of non-structural elements into practice by designers and manufacturers. The inadequate performance of NSEs often observed during past seismic events, even if not extreme ones, underlines the deficiency in terms of proper design strategies of NSEs. In order to reduce the economic losses, it appears essential to raise awareness from many points of view and to involve different stakeholders. For examples, designers need to be informed about available design methods and risk mitigation strategies, building control officers need to understand how to perform quality checks and final clients, or owners, needs to switch to a logic of generalized costs.

In the past, few attempts were made to collect data (mainly from field observations) on the behavior of NSEs. This paper presents a new trial to gather information, starting from the experience of the past. The database developed by the EUCENTRE Foundation, in collaboration with the Italian Civil Protection Department, the International SPONSE (Seismic Performances Of Non-Structural Elements) Association and IUSS (University School for Advanced Study in Pavia, Italy), provides a contribution to this endeavor. Besides collecting data on NSE performances, the database includes references to state of the art guidelines and standards, design approaches and qualification methods, creating a direct link to each considered NSE typology. Because the scope of the database is not only to collect information but also to raise awareness on the importance of the seismic design of NSEs, besides normal data accessing tools, a BIM module has been also developed. The BIM module allows to link part of content of the NSE database with Building Information Models in order to expose information to a broader community and to help in the implementation into practice of the seismic design/assessment of NSEs. International standards specifically aimed at the classification and organization of information on construction work were used to develop the database and to facilitate its integration in BIM software and localization. This strategy allows for and facilitates the adaptation to multiple languages and national contexts.

Keywords: non-structural elements; BIM; database

1. Introduction

Literature on non-structural elements (NSEs) underlines that they represent the majority of the economic value of a building, especially in the case of critical buildings (e.g. hospitals). Economic losses caused by damages to NSEs can be significant, even in case of moderate earthquakes. For most NSEs, experimental data as well as methods for NSE design and characterization are scarce and incomplete. In several countries, the spread of information about NSEs in the engineering community is limited, jeopardizing effective improvements of both the state of art and the reduction of the seismic risk induced by these elements. Aiming to improve the current situation, for example by trying to adopt design methods such as performance-based design, the availability of data regarding the performance of NSEs is the basis of the process. In fact, the development of design methods cannot but remain an exercise in style without knowing the level of stress corresponding to the achievement of the various limit states or the relationship between the external actions and the response of the NSEs in terms of deformations, damping, deterioration of the cyclic behavior and so on. Fortunately, today the number of laboratories and scientific publications dealing with the seismic response of NSEs is increasing fast. Considering such rapid evolution and the scientific community's needs, appropriate ways to store and share continuously increasing amounts of data is essential. To this end, the best option, if not the only one, seems to be the use of a specific database (DB).

This document describes the development and the characteristics of a NSEs database developed by the authors and implemented at the EUCENTRE Foundation. As described in the following, the database design aimed to host data from multiple sources (e.g. static and dynamic experimental tests, field observation of the seismic behavior of NSEs) and metadata relating to each entry (e.g. photographs and videos, drawings of assembly, installation instructions). In addition to that, unlike the databases developed in the past ([14] and [17]), this DB will also allow listing of design and verification methods, qualification and certification standards currently available for the various NSE typologies. Another important objective pursued while developing the DB is the dissemination of the DB and its contents. Fundamental aspects of each DB, which decree their usefulness and duration over time, are (*i*) the usability of the data and (*ii*) the spread of the DB itself to the targeted users, in this case represented by the engineering and the scientific communities. To achieve the first objective, the DB was implemented with an easy-to-use interface aligned with the standards of the other software and web tools developed as part of the collaborative project between the Italian Department of Civil Protection and the EUCENTRE Foundation. The design of the DB interface allows authorized users, not only part of the EUCENTRE staff, data entry and extraction in the simplest and most flexible way, aiming at the same time to guarantee the uniformity of the entered data. Extending the use of the DB to external user, both for entering data and querying database, was seen as one of the means used to pursue the spread of the database.

The second dissemination strategy is aimed at the world of professional engineers and it is related, in particular, to the side of the DB related to standards. The developed tool aims to spread knowledge by indicating to professionals which national or international standards is a reference for a particular NSE. To this end, instead of simply allowing professional users to use the DB, a simple software able to process BIM (Building Information Model) files was implemented. The software analyzes BIM files created by third-party users, automatically identifies the NSEs and adds to the corresponding virtual elements some attributes indicating possible design or qualification standards. The content of the NSEs database is made available to potential users through IT tools that they normally use, without the need to directly interact with the DB.

2. Past NSEs database

Literature about past implementation of NSEs database (DB) is limited. The two most important examples are the MCEER [14] and the PEER [17] database. A database of damage to NSEs was developed and published in 1999 by the MCEER (Multidisciplinary Center for Earthquake Engineering Research), based at the University of Buffalo. The database contains information on the damage to NSEs recorded since the 1964 Alaska earthquake, up to the date of publication of the DB. In total, the DB includes about 3000 NSEs entries from more than 50 earthquakes. The data was mainly collected from publications, books and reports. The classification of NSEs adopted in the DB following the "NEHRP Guidelines for the seismic rehabilitation of buildings" includes architectural, mechanical, electrical/communications, furnishing/interior and medical equipment.

The database created by the PEER (Pacific Earthquake Engineering Research Center) was developed starting from the MCEER one, expanding it with a series of additional information and research tools to improve data accessibility. Important changes concerned the classification of the NSE and the structure of the DB itself. The adopted classification has a tree-like structure using different levels to subdivide the NSEs with increasing level of detail moving from one level to another (e.g. internal construction – ceilings – suspended ceilings). A further classification subdivides the NSEs according to their sensitivity to a particular response parameter: displacement, acceleration or both. Another difference, which is even more important, concerns the implementation of the DB, which was performed using a relational scheme: data are organized in mutually related tables allowing minimizing the storage space and improving its flexibility. The database contains about 4000 entries, about around 1000 images of seismically damaged NSEs and includes information about repair cost for NSEs.

Another type of DB is the SQUG (Seismic Qualification Utility Group) DB [5], which contains data related to the seismic behavior of the NSEs present in US nuclear power plants. The DB was implemented aiming to seismic qualification of NSEs using the experience-based method developed by SQUG. The method, documented in the GIP (Generic Implementation Procedure), provides a cheaper alternative to shake table tests or dynamic analyses normally required to qualify equipment or machinery. This procedure includes protocols and check lists to compare NSEs capacity and seismic demand. For example, it allows to check anchor capacity of some NSEs and/or possible interaction with nearby equipment.

3. Object classification

A review of the literature and seismic design standards (e.g. [9], [10], [13] and [15]) led to many possible options about the classification of NSEs, which range from general indications to detailed definitions. Considering the need for interaction between the DB and the BIM software, the organization of the objects stored in the former must comply with the classification adopted by the latter. This was the main reason to choose the classification defined in the IFC4 standard developed by buildingSmart [1] that is incorporated in the standard ISO 16739:2018 [12] and adopted by several BIM software. Clearly, the classification implemented in the DB is just a subset of the complete IFC4 classification that is much broader because it includes a variety of information beyond the NSE context. It is worthwhile to mention that compatibility with the classification used by the DBs developed in the past and described above was verified to allow future possible inclusion of their data.

The adopted IFC4 classification has a tree-like structure subdividing the NSEs into subclasses with increasing level of detail. For what concerns the NSEs, the structure envisages an initial subdivision into five main classes (red-boxed items in Fig.1), which are gradually divided into increasingly detailed subclasses. The following Fig.2 shows an example relative to the building element class.

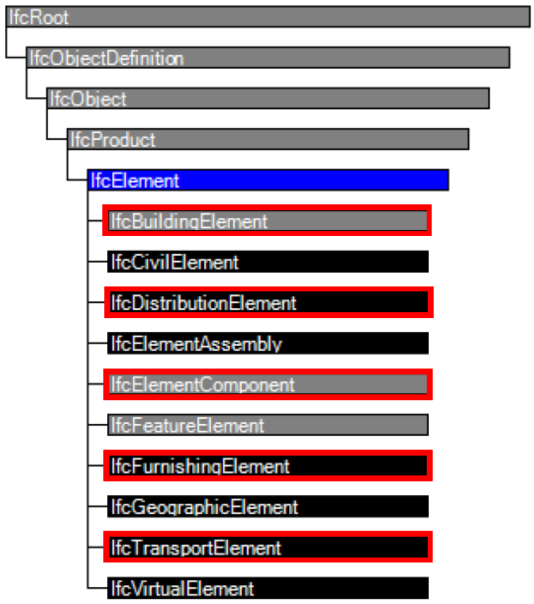

Fig. 1 – First classification level of IFC4 element (only red-boxed items include NSE subset) [1]

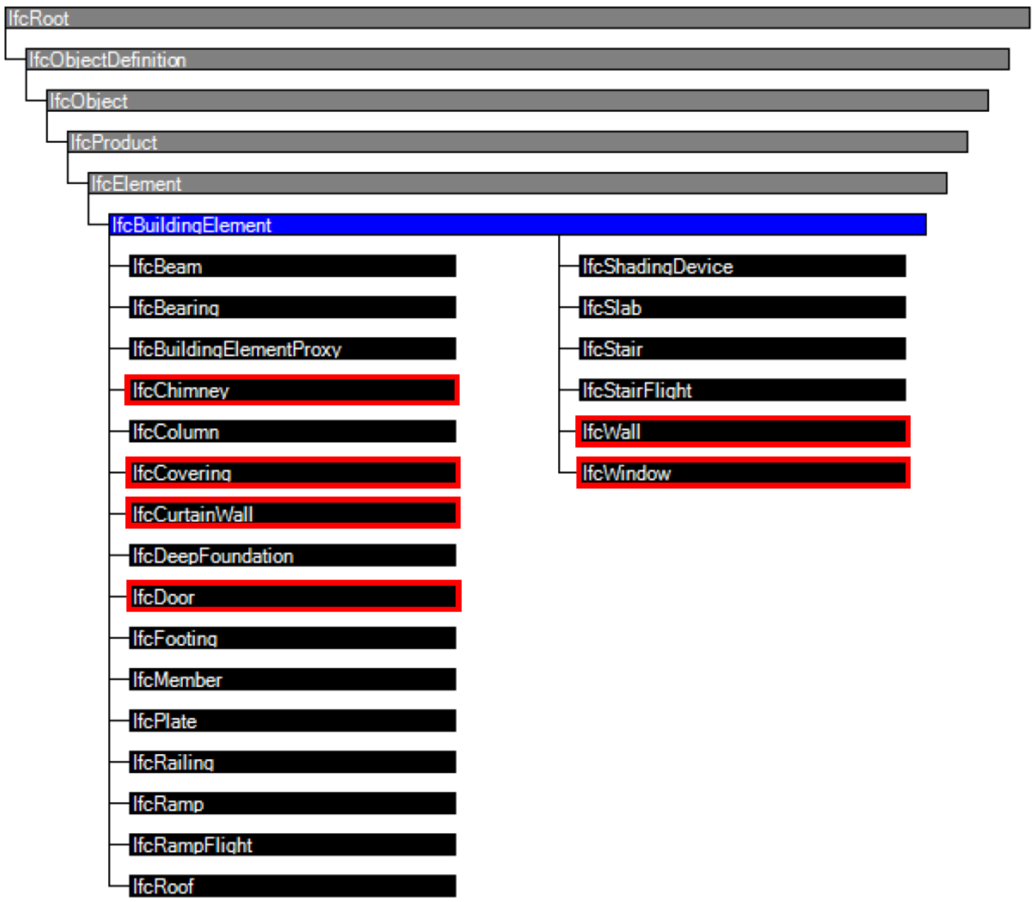

Fig. 2 – Second classification level IFC4 building elements (only red-boxed items include NSE subset) [1]

4. Structure and content of the database

The database was developed using a relational model that, as required, allows including varied sets of information characterized by low homogeneity between one another. Although in-depth descriptions of relational database would go beyond the scope of the document, it seems appropriate to clarify that the data are divided and organized into several tables, as schematically represented in Fig.3. A main table lists all the objects included in the database, each object (or record) is then linked to one or more further tables that store uniform subsets of data relative to the specific object. A careful initial analysis of the type of data and the desired functions is required to define uniform data subsets, each one implemented in a specific table. This subdivision allows creating a data collection system optimized for the specific needs, ensuring considerable flexibility. In fact, the developed database may contain data from different sources (e.g. post-event reconnaissance reports or papers, literature and technical reports about experimental campaigns) and characterized by different level of knowledge (from field observation to laboratory testing). Relational databases optimize the storage volume and facilitate possible modification interventions, for updates about the included information, correction of errors, as well as for inclusion of new dataset. In accordance with the set objectives of the present NSE database, it is possible to distinguish two parallel sections composing the whole database structure (see Fig.3): the former section include the data about experimental and field observations; the latter (dashed-line box in Fig.3) manages the data about design and qualification standards used by the BIM module. Clearly, all the stored data respect the same object classification discussed above.

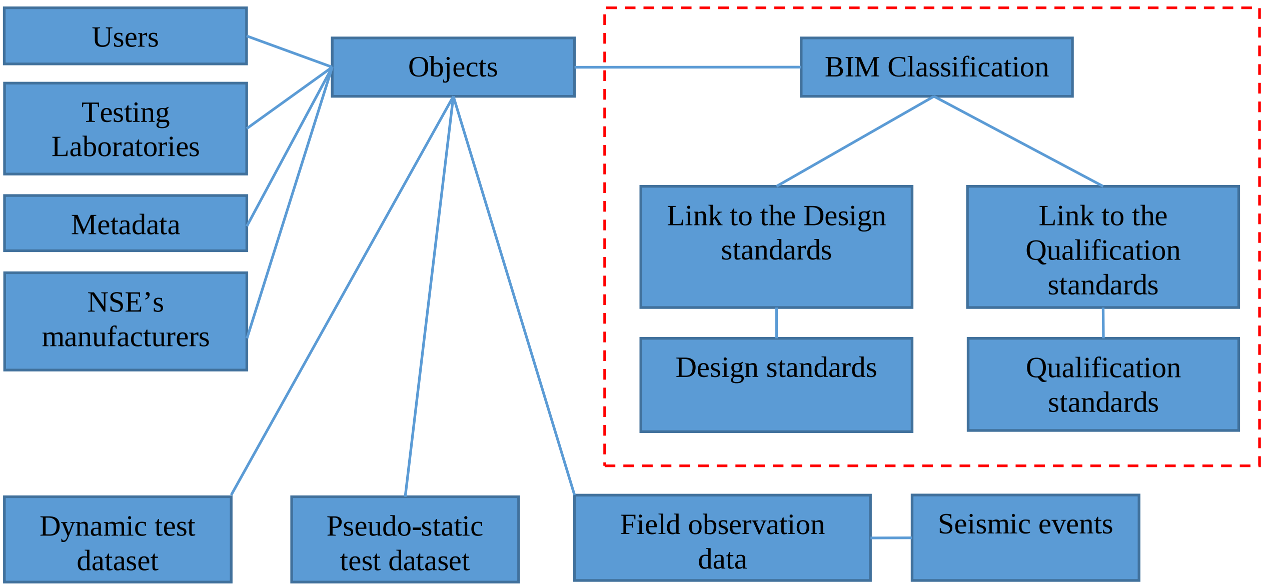

Fig. 3 – Structure of the tables composing the implemented relational database

The section of the database storing experimental and field observation is composed of many mutually related tables. For each object created inside the DB, it is possible to record: the corresponding BIM class; the user that input the data; the laboratory performing the tests (if any); a set of metadata about the object itself (if any) including pictures, technical datasheet, videos and so on; data about the manufacturer of the NSE (if known). Besides:

- for those entries relative to field observation, it is possible to store data about the observed damage (if any), the type of building in which the NSE was installed, as well as all the information required to evaluate a code-defined floor spectrum. A separate table is then hosting the data identifying the seismic event that led to field inspection: separating earthquake data avoids their multiplication and facilitates the use of the DB;

- for those records deriving from experimental investigations, data from dynamic shake table tests or pseudo-static tests can be stored. It is important to mention that the DB automatically evaluates some of the fields of these two tables. As an example, when inputting data from pseudo-static tests, the user is required to upload force and displacement history, while the software calculates equivalent bilinear backbone curve (i.e. elastic stiffness, yield and ultimate force and displacement). This choice followed from the decision to try to have data as uniform as possible. In the future, users will be able to choose between different strategies for the evaluation of the main response parameters (e.g. changing the method used to evaluate the bilinear approximation of the skeleton curve).

Concerning the standards, for each NSE class (i.e. NSE typology) the database stores one or more possible design and qualification norm or guideline. This section of the database is actually the input source for the software developed to manipulate BIM files. More in detail, since a single standard is often referenced for more than one NSE type, dedicated DB tables manage the link class to standard. This solution makes much easier to update the DB content in case of release of new or updated standards.

5. BIM module

As already mentioned, one of the objectives of the database is to spread knowledge about design and qualification of non-structural elements, hence helping practitioners and manufactures. To provide the information about available codes, guidelines, design methods and qualification procedures, a software has been developed that is able to automatically analyze the content of an IFC file created using the most common BIM software (see Fig.4). The application requires an IFC file as input, it automatically analyzes its content and, for each of the recognized NSEs, it creates additional attributes specifying design and qualification standards. The output of the software is then an enriched IFC file that can be opened with any BIM software, as shown in Fig.5. The standards analyzed and currently available in the database are classified either as seismic qualification standards or design standards. At the current stage of implementation, the DB includes the main standards and guidelines including some of those prepared by ISO [11], ICC [6], IEC [7], IEEE [8], FEMA [4], EERI [3], NIST [16] and DPC [2].

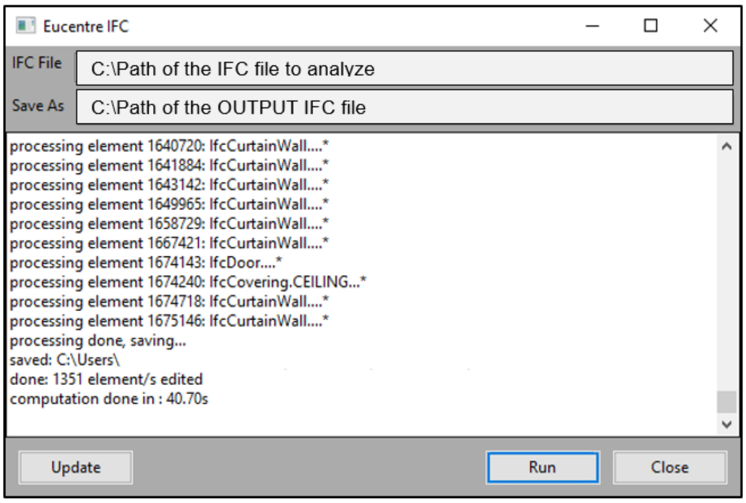

Fig. 4 – Screenshot of the running NSE software

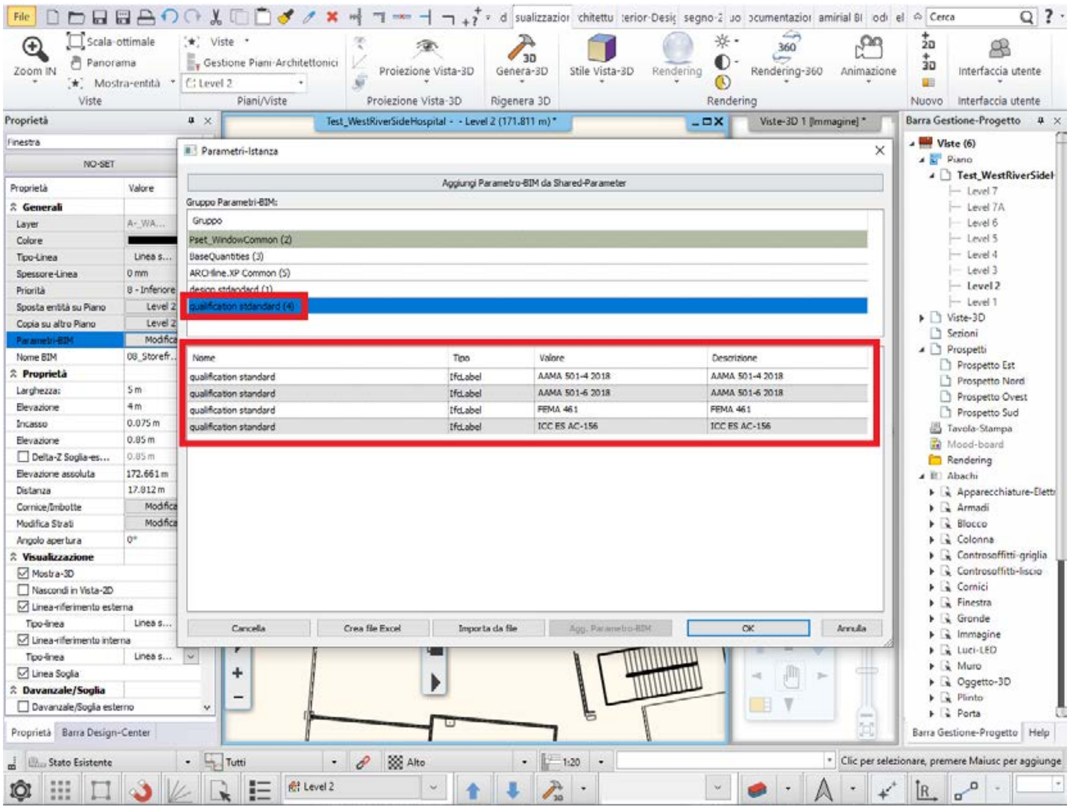

Fig. 5 – Example of visualization of the results through BIM software

The software has been implemented as a stand-alone desktop application in order to allow users not to share their projects. The software elaborates the files without any interaction with remote servers. The only required communication with the database is for the update of the list of the NSEs typologies and the corresponding standards. Expecting constant evolution of the standards, ability to keep the software up to date was assumed to be an essential requirement.

6. Conclusions

NSEs are essential for the functionality and usability of buildings. However, their importance has often been neglected in the building seismic design phase, as they are not part of its load-bearing system. Most of the design codes of the recent past do not consider nor mention NSEs. As a direct consequence, exceptional loads such as earthquakes are not part of the design of NSEs such as architectural components, electromechanical devices, piping systems and so on. In common practice, NSEs are usually designed mostly using experience, just considering dead-loads and restraining them only due to specific purposes or functionality. The seismic performance deficiencies of NSEs have been shown by numerous seismic events, even those of low intensity, highlighting that the collapse of these elements can induce an important risk to the safety of the occupants, can lead to important service interruptions of entire buildings and can cause significant economic losses.

Fortunately, this situation is changing with constantly increasing speed and research regarding NSEs is considerably growing. The scientific community is now eager to solve the problem of seismic design of NSEs and calls for data to work with. Experimental campaigns and field observations are the two main sources of data, which are currently still scarce. From here the necessity of spreading as much as possible the available data with a further attempt of creating a shared NSE database, the development of which is the objecte of the presented work. Starting from past experiences by MCEER [14] and PEER [17], the newly developed database has been implemented allowing the storage of information obtained by dynamic and pseudo-static tests as well as data from post-earthquake surveys.

However, the scientific community is not the only one working toward producing safer NSEs or wishing to reduce seismically induced damages to them. Stakeholders and owners of critical facilities, which are the building systems having the higher seismic risk connected to NSEs, are worldwide asking for certified seismic performances of every structural and non-structural component. Consequently, professional engineers and manufactures are looking for standards able to guide the design or the product qualification respectively. The global situation about NSE standards is all but uniform as certain nations (e.g. Japan, USA) started sooner than others to deal with the seismic performances of NSEs. Knowledge summarized within standards is worthy to be spread and to this end the database presented here founds its second aim. A section of the DB was specifically developed to store information about design codes, qualification standards and technical guidelines possibly helping practitioners. For them, the access to this information has been thought without the need of querying the database: an easy-to-use desktop application was implemented to transfer the details stored in the database to BIM files they commonly use. Exploiting the codified IFC4 object classification at the base of most BIM tools, the developed application is able to process large model in one-click adding attributes to each recognized virtual NSE. Valorization of these attributes is then used to identify one or more suggested standard.

Opening to advanced/scientific users both the phases of data input and query, as well as allowing designer and manufactures to take advantage from the information stored in the DB, the authors hope that it will possibly become a useful instrument able to sustain itself in time.

7. Acknowledgements

This paper describes an activity that is part of the work package WP11 "Characterization of the seismic response of non-structural elements" undertaken within the framework of a three-year project sponsored by the Italian Civil Protection Department. The authors would like to thank all the parties involved and acknowledge Claudio Moroni, Andre Filiatrault, Filippo Dacarro, Fracesco Lunghi and Alessio Cantoni for their support and feedback in the different phases of the database development.

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