The INGV macroseismic photographic database (DFM): a structured photographic collection of earthquake effects in Italy

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Abstract

The Macroseismic Photographic Database (DFM) is a FAIR (Findable, Accessible, Interoperable, and Reusable) dataset developed and maintained by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). It provides a structured archive of photographic evidence documenting the effects of moderate to strong earthquakes in Italy since the 1980s. The data collection is primarily carried out by the INGV's QUEST (QUick Earthquake Survey Team) during post-event macroseismic field campaigns. The database was initially conceived to preserve at-risk analogue photographic material but has evolved into a comprehensive digital resource where each image is catalogued with detailed metadata. The classification of building typologies and damage grades is standardised according to the principles of the European Macroseismic Scale 1998 (EMS-98). The DFM is designed for full interoperability within the INGV data ecosystem, linking each photograph to earthquakes, localities, and macroseismic observations contained in primary databases such as the Italian Seismological Instrumental and Parametric Database (ISIDe), the Parametric Catalogue of Italian Earthquakes (CPTI15), and the Italian Macroseismic Database (DBMI15). This paper describes the database structure, the data collection protocol, the metadata schema, and the technical solutions adopted to ensure data quality and accessibility. The DFM represents a valuable resource for scientific research in engineering seismology, historical seismology, and for training operators involved in damage assessment, providing crucial ground-truth data for seismic hazard studies and civil protection purposes. The dataset is publicly accessible at https://doi.org/10.13127/dfm (Quick Earthquake Survey Team, QUEST, 2023).

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1. Introduction

Systematic documentation of earthquake-induced damage is fundamental to seismology and earthquake engineering. Macroseismic surveys assess seismic intensity based on the observed effects on buildings, people and the environment, and provide fundamental data for understanding seismic hazards (Tertulliani et al., 2011; Galli et al., 2009). The concept of macroseismic intensity and the scales used to measure it have evolved over two centuries of observations (Tertulliani, 2019; Musson et al., 2010). While written reports and intensity assignments are important, they are, by nature, the results of interpretations and therefore inherently abstract. In contrast, photographic documentation offers an unfiltered, objective record of damage, capturing nuances that are often lost in textual descriptions. This visual data is vital for calibrating macroseismic scales, studying the seismic performance of different building types, and validating damage scenarios (Rossi et al., 2019).

In Italy, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) is mandated with the seismic surveillance of the national territory. This responsibility is carried out, in part, by the QUEST (QUick Earthquake Survey Team), an operational group active for over two decades (Tertulliani and QUEST Team, 2003). QUEST conducts rapid-response macroseismic surveys following significant earthquakes as an institutional task within the framework of the National Civil Protection System. Over several decades of activity, QUEST has amassed a vast collection of photographs, initially in analogue format and later in digital format. However, this collection was fragmented and at risk of degradation, lacking a standardised structure that limited its scientific usability. Further details on the group's activities are available on the official website (https://quest.ingv.it/).

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To address this gap, INGV developed the Macroseismic Photographic Database (in Italian "Database Fotografico Macrosismico", DFM; Quick Earthquake Survey Team, QUEST, 2023). The recent formalisation of QUEST's operational structure, which supervises its contents, and the public launch of the DFM web portal after a period of development and testing, mark the maturation of this long-term effort. The DFM transforms this heterogeneous collection into a structured, curated, and openly accessible scientific dataset. Its primary objectives are to preserve a unique visual heritage of Italy's recent seismic history, to provide a standardised framework for damage classification based on the European Macroseismic Scale 1998 (EMS-98; Grünthal, 1998), and to create an interoperable resource integrated with Italy's national seismic databases.

While other valuable image datasets of earthquake damage exist, such as the EUCENTRE's IDEA database (Senaldi et al., 2025; Casarotti et al., 2025) and engineering-focused collections like EERI's Concrete Coalition Damaged Concrete Buildings Database (Wallace et al., 2012), their primary purpose is typically to provide labelled data for training machine learning algorithms or to support detailed structural performance analysis. In contrast, the DFM is uniquely designed as a macroseismic tool. Each image is not just a depiction of damage, but a piece of evidence contextualised within the framework of the EMS-98 scale, intended to support expert-driven intensity assessment at the locality scale and to preserve a standardised visual record of earthquake effects on the built environment. This paper presents the DFM, detailing its design, architecture, contents, and potential applications for the earth science community.

2. Data Collection and Quality Control

The scientific value of the DFM lies in its rigorous and consistent process of acquiring and validating data. This process is managed by the QUEST Operational Group. As INGV is a geographically distributed institution, QUEST involves personnel from various INGV sites. To ensure efficient and scientifically robust operations, QUEST is therefore structured with an overarching Coordination Committee and a Territorial Support Group.

Following a significant earthquake, QUEST is officially activated according to its operational protocol. The standard activation thresholds are for earthquakes with magnitude ≥ 5.0 in tectonic areas, although interventions can also be planned for lower magnitude events of particular scientific or training interest. Once activated, QUEST teams are deployed to the epicentral area to perform a systematic macroseismic survey, aiming to achieve a comprehensive overview of the earthquake's impact in the affected area by estimating macroseismic intensity and collecting data on building seismic vulnerability and damage severity. This is achieved by targeting a representative sample of buildings within each locality.

It is important to highlight the challenging conditions under which these surveys are conducted. For safety reasons, physical entry into damaged buildings is rarely possible, as they may be unsafe or officially interdicted. In the most heavily affected areas (the so-called "red zones"), access is often restricted, and QUEST personnel must be escorted by the fire brigade, with movements severely limited. Consequently, the photographic documentation is predominantly of building exteriors.

The data acquisition workflow starts in the field, where expert surveyors photograph significant damage patterns, building typologies and environmental effects. According to the standard protocol, a general overview of the building must be taken before capturing detailed photos of the damage, although this may not always be possible due to challenging field conditions or limitations of older analogue archives. Once collected, the photographic material enters a quality control pipeline. Building typology and damage grade are attributed by trained personnel and subsequently reviewed by at least one other expert to ensure consistency and minimise subjectivity. This cross-validation process, illustrated in the workflow diagram in Fig. 1, is fundamental to guarantee the reliability of the labels associated with each image. During this internal assessment phase at the office, experts routinely use online tools (e.g., Google Street View), when applicable and available, to evaluate the pre-existing conditions of buildings and resolve any uncertainties, keeping in mind the limitations of historical archives. This makes the DFM a high-quality dataset suitable for scientific analysis.

Finally, although QUEST has been officially operational since 2004, the DFM archive has also collected images from older macroseismic surveys, dating back to the 1980s. Regarding future field surveys, QUEST has recently updated its operational protocol to include the use of a dedicated mobile application (QUEST-DATA; Arcoraci et al., 2020). Among its features, it can feed photos and preliminary classifications directly into a centralised repository, significantly reducing the delay between field surveys and data becoming available in DFM.

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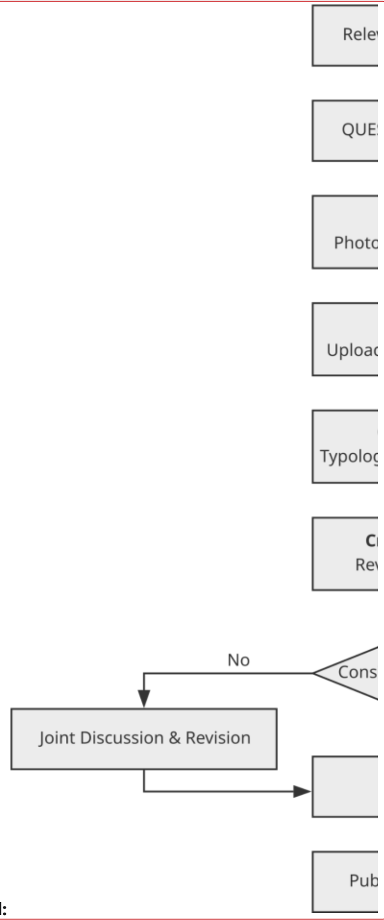

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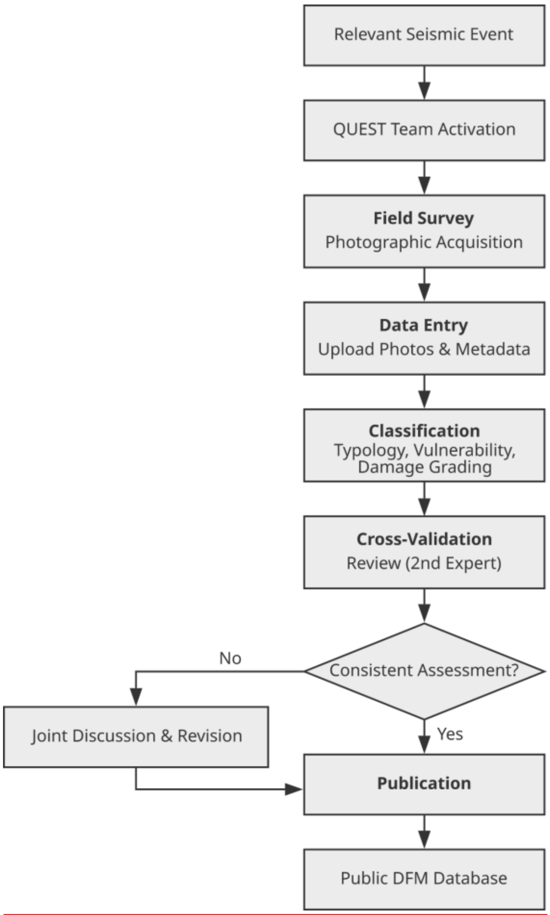

Figure 1. Flow chart of the process of collecting, entering and validating data in the DFM. The "Classification" step involves Typology, Vulnerability, and Damage Grading.

3. Database Architecture, Content, and Overview

3.1. Technical Architecture

The DFM is built on a relational database managed with MySQL, with a web interface developed using PHP and JavaScript. The system is designed to handle a large volume of high-resolution images and their metadata. The web portal is divided into two main sections: a public-facing area for data consultation and a restricted-access administration backend. This backend allows accredited contributors to upload and catalogue new photographic data, and enables coordinators to validate the content and metadata before final publication. The public architecture allows for multiple query modalities. Users can perform simple or advanced searches, filtering by earthquake or by subject type. A key feature of the web portal is the interactive, map-based search function, which enables users to explore the available data geographically. Furthermore, the DFM provides curated 'thematic paths', guiding users through collections of images related to specific earthquakes or notable damage typologies and offering a thematic approach to data consultation.

3.2. Data Structure and Metadata

The core of the DFM is the link between a photographic image and the subject it portrays. A key aspect of the database design is that each subject can be linked to multiple photographs, allowing for a comprehensive documentation from different angles. Behind the scenes, multiple pictures of the same building from different angles are linked together by a unique "Subject ID". This approach is crucial for a reliable macroseismic assessment, as observing a single façade can often be misleading. Each photograph is enriched with a comprehensive set of metadata, which includes image-specific information such as the author, date of capture, original resolution, and a Creative Commons (CC BY 4.0) license. Crucially, full georeferencing is ensured by associating precise geospatial information with the photographed subject.

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It is important to note that the DFM database currently does not record the precise geolocation of individual buildings, even for recent events. Given the available resources, grouping photos at the locality level was the most feasible approach. Therefore, the public portal only shows the locality to which the building belongs. To comply with GDPR (General Data Protection Regulation) and protect individual privacy, sensitive elements such as vehicle license plates, house numbers, and the faces of any individuals not belonging to the QUEST team are systematically blurred before publication. A detailed subject description further clarifies what is depicted in the image.

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To ensure consistency, photographed subjects are classified into predefined categories such as building, special building (e.g., schools, hospitals, factories), monumental building (e.g., churches, towers), other structure (e.g., bridges, walls), domestic object, external object, overview, environmental effects, and miscellaneous.

For subjects classified as Building, the DFM implements a detailed cataloguing system based on the EMS-98 scale (Grünthal, 1998). This involves assigning a building types based on the primary structural material, such as masonry (with sub-categories like rubble stone, adobe, unreinforced, with manufactured stone units, or massive stone), reinforced concrete, steel, and wood, which directly corresponds to the EMS-98 vulnerability classes (A to F). The vulnerability assessment in DFM strictly adheres to the EMS-98 guidelines. For reinforced concrete structures, for instance, the scale implicitly considers the level of earthquake resistance in the design. During field surveys and subsequent photo cataloguing, expert surveyors assess vulnerability classes, considering building typologies and inferring likely earthquake-resistant design levels based on the construction period, field experience, and the municipality's seismic classification history. In parallel, a damage grade is assessed and classified into one of five grades, ranging from Grade 1 (negligible to slight damage) to Grade 5 (destruction), as defined by the EMS-98 guidelines. This structured approach allows users to perform granular queries, such as retrieving all images of unreinforced, with manufactured stone units, masonry buildings (vulnerability class B) that suffered Grade 4 damage during a specific earthquake.

3.3. Dataset Overview

As of the current version, the DFM contains 1685 photographs. The dataset documents the effects of 11 significant seismic events that have occurred in Italy, with a temporal coverage extending from the 1980 Irpinia earthquake to the present day. The surveys have been conducted in 150 distinct localities across the national territory, providing a geographically diverse and extensive collection of macroseismic evidence, as shown in Fig. 2. It is important to note that these figures represent only the initial fraction of a much larger photographic archive collected over decades. The population of the DFM is a recent and ongoing long-term

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effort, carried out primarily on a best-effort basis by researchers alongside their other institutional duties. Our prioritisation scheme for adding new data generally follows three steps: 1) new events, to make data available quickly; 2) major past events, digitising analogue archives such as the 1980 Irpinia earthquake; and 3) progressively filling gaps for other recent events. The dataset is expected to grow substantially in the coming years.

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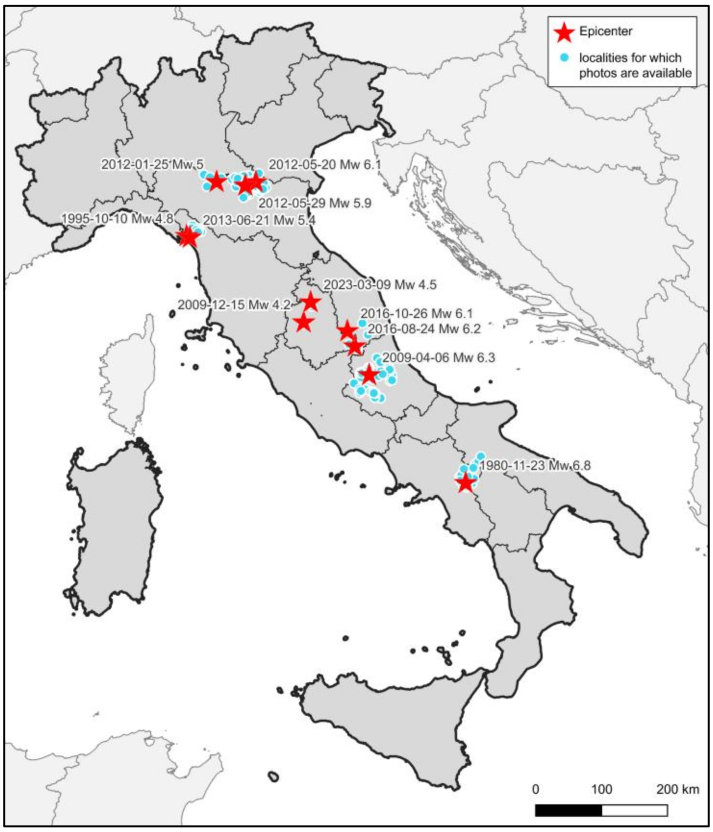

Figure 2. Geographic coverage of DFM. The red stars represent the epicentres of earthquakes for which the QUEST group has taken action, and the blue dots represent inhabited locations for which photographs are available on the DFM.

4. Interoperability and programmatic access

A key feature of the DFM is its seamless integration into the INGV data infrastructure, achieved through web services and the use of unique, persistent identifiers that make it a fully interoperable component of a larger data ecosystem, as schematised in Fig. 3. Each earthquake is linked via a unique event ID to the Italian Seismological Instrumental and Parametric Database (ISIDe Working Group, 2007) for events since 1985, or to the Parametric Catalogue of Italian Earthquakes (CPTI15; Rovida et al., 2020; 2022) for historical events. Similarly, the localities where photographs are taken are linked to the Italian Macroseismic Database (DBMI15; Locati et al., 2022), allowing users to retrieve the complete seismic history and all macroseismic observations for a specific site. This connection is further enriched by links to the Italian Archive of Historical

Earthquake Data (ASMI) (Rovida et al., 2025) and the Catalogue of Strong Italian Earthquakes (CFTI). Consistency across these resources is guaranteed by the adoption of the official INGV Gazetteer, a unified geographical reference system that facilitates robust cross-database queries and geospatial analysis. This deep integration allows researchers to move fluidly from a single photograph of a damaged building to the instrumental parameters of the causative earthquake, its complete macroseismic intensity map, and the full seismic history of the locality.

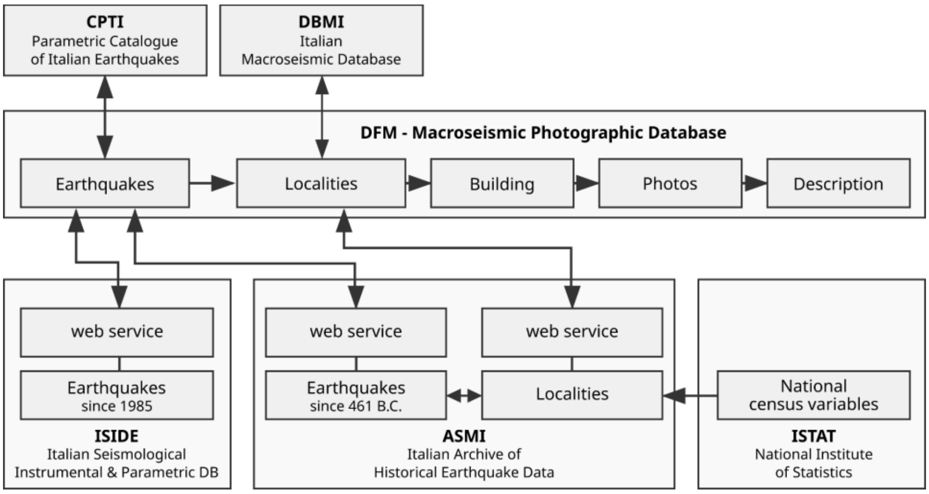

Figure 3. Diagram showing the interoperability of the DFM with other INGV seismological databases.

4.1. Data Access via Web Services

To further enhance data accessibility and interoperability, the DFM provides a RESTful web service that allows for programmatic querying and downloading of the information associated with the archived photographs. This service is designed for researchers, developers, and specialists who need to integrate DFM data into their own systems, GIS applications, or analysis workflows. Access is provided via an HTTP GET request to the main endpoint (https://dfm.ingv.it/services/query), which can be customised with a range of parameters to filter results based on geographic, temporal, or seismological criteria.

The service returns data in GeoJSON format, an open standard based on JSON for representing geographic features. Each feature in the response corresponds to a single photograph and includes a Point geometry with the coordinates of the photographed location, along with a set of properties detailing the earthquake parameters, the locality, and the photograph's metadata, including the URL to the original image and the damage description according to the EMS-98 scale.

5. Use cases and future developments

The DFM is a versatile resource with multiple applications for research and operational activities. For scientific research, the georeferenced nature of each photograph, combined with the structured damage classification, enables detailed spatial analyses to correlate observed damage with local geological conditions, ground shaking parameters, or to study damage progression during seismic sequences (Graziani et al., 2019).

A crucial application is in the realm of training and education. As stated in the official QUEST operational protocol, the DFM is the reference tool for the online training of the group's surveyors. This creates a positive feedback loop: the high-quality data produced by experts are used to train new personnel, ensuring that the standards of data collection and classification remain consistent and robust over time.

The large corpus of images labelled with building structural typology and damage grade makes the DFM an ideal machine learning resource, providing a high-quality training set for developing algorithms for automated damage classification, such as the rapid damage mapping approaches described by Pittore et al. (2018). Finally, the database supports Civil Protection agencies in emergency planning and post-earthquake response by offering a visual record of damage patterns from past events in a given area.

Future developments will focus on continuously expanding the database with data from future seismic events and digitised historical archives. Furthermore, we plan to enhance the user interface with more advanced data visualisation tools, including making the date and time information of the captured photos prominently visible, although this level of detail is often unavailable for historical older data. Additionally, future releases of the web portal will make the grouping of multiple photographs depicting the same building via the unique "Subject ID" more evident to users. We will also explore future interoperability with engineering databases such as Da.D.O. (Dolce et al. 2019) and IDEA. While highly desirable for combining seismological and structural engineering data, direct cross-referencing on a building-by-building basis is currently limited by the lack of precise building coordinates in DFM and access-related constraints of external platforms. Finally, we aim to establish a formal link between the INGV Gazetteer and the official identifiers published by ISTAT (the Italian National Institute of Statistics) to facilitate socio-economic impact analysis.

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6. Data availability

The DFM is an open-access resource, accessible via its public web portal at https://dfm.ingv.it/. The entire dataset, including images and metadata, is freely available for scientific and non-commercial use. The data are published under the Creative Commons Attribution 4.0 International (CC BY 4.0) license. The dataset is identified by the persistent Digital Object Identifier (DOI): https://doi.org/10.13127/dfm. Detailed metadata are available through the INGV data portal at https://data.ingv.it/dataset/774. When using data or images from the DFM, users are required to cite this paper and the dataset itself (Quick Earthquake Survey Team, QUEST, 2023).

7. Conclusions

The DFM provides a unique, structured, and open-access collection of photographic evidence of earthquake effects in Italy. By standardising damage and building types descriptions according to the EMS-98 scale and ensuring full interoperability with national seismic databases, the DFM represents more than a simple image archive: it is a scientific tool that connects direct field observations with parametric and historical data. The transparent data collection and quality control protocol, rooted in the institutional mandate of the INGV QUEST Operational Group, ensures the reliability of the dataset. It is a living dataset, continuously updated and improved, that serves as a fundamental resource for the seismological community, civil engineers, and Civil Protection authorities. Crucially, in a context where the Italian macroseismic community faces the risk of knowledge loss due to generational turnover, the DFM also acts as a vital tool for preserving and transferring decades of field experience to new generations of surveyors. We believe the DFM will foster new research on seismic vulnerability and contribute to a better understanding of seismic risk in Italy.

Author contributions

The DFM was conceived and developed by all the authors. A.T. and L.G. provided the main scientific supervision. M.S. and M.L. were responsible for the technological development of the database and the web portal, including both its public and private sections. M.B. coordinated the population of the database. C.C. provided overall support to all aspects of the project. M.L. wrote the main draft of this manuscript. All authors contributed to the final version with reviews and edits.

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