

1 The INGV macroseismic photographic database (DFM): a 2 structured photographic collection of earthquake effects 3 in Italy

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11 **Abstract**

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

29 **1. Introduction**

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

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

49 To address this gap, INGV developed the Macroscopic Photographic Database (in Italian "Database
50 Fotografico Macrosismico", DFM; Quick Earthquake Survey Team, QUEST, 2023). The recent formalisation of
51 QUEST's operational structure, which supervises its contents, and the public launch of the DFM web portal
52 after a period of development and testing, mark the maturation of this long-term effort. The DFM transforms
53 this heterogeneous collection into a structured, curated, and openly accessible scientific dataset. Its primary
54 objectives are to preserve a unique visual heritage of Italy's recent seismic history, to provide a standardised
55 framework for damage classification based on the European Macroscopic Scale 1998 (EMS-98; Grünthal,
56 1998), and to create an interoperable resource integrated with Italy's national seismic databases.

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

66 **2. Data Collection and Quality Control**

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

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

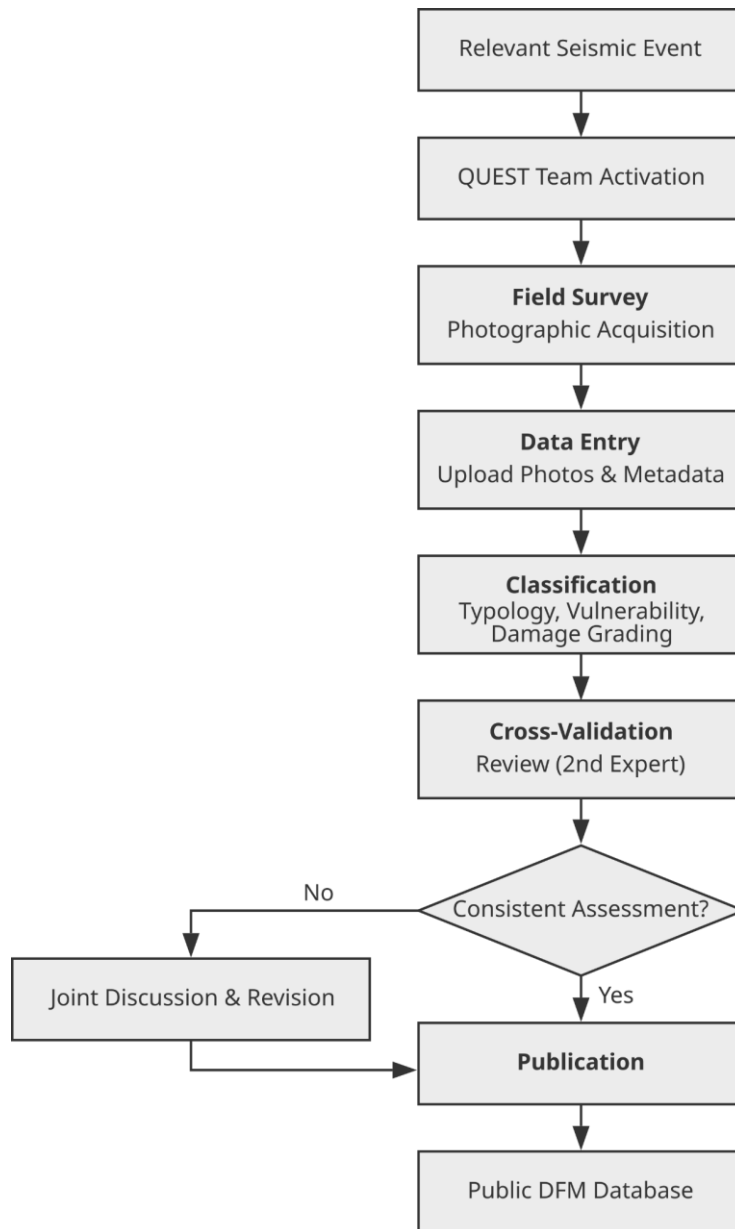
78 It is important to highlight the challenging conditions under which these surveys are conducted. For safety
79 reasons, physical entry into damaged buildings is rarely possible, as they may be unsafe or officially
80 interdicted. In the most heavily affected areas (the so-called "red zones"), access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

82 photographic documentation is predominantly of building exteriors.

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

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

101



102

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

105 **3. Database Architecture, Content, and Overview**

106 **3.1. Technical Architecture**

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

116 to specific earthquakes or notable damage typologies and offering a thematic approach to data consultation.

117 **3.2. Data Structure and Metadata**

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

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

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

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

150 **3.3. Dataset Overview**

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

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

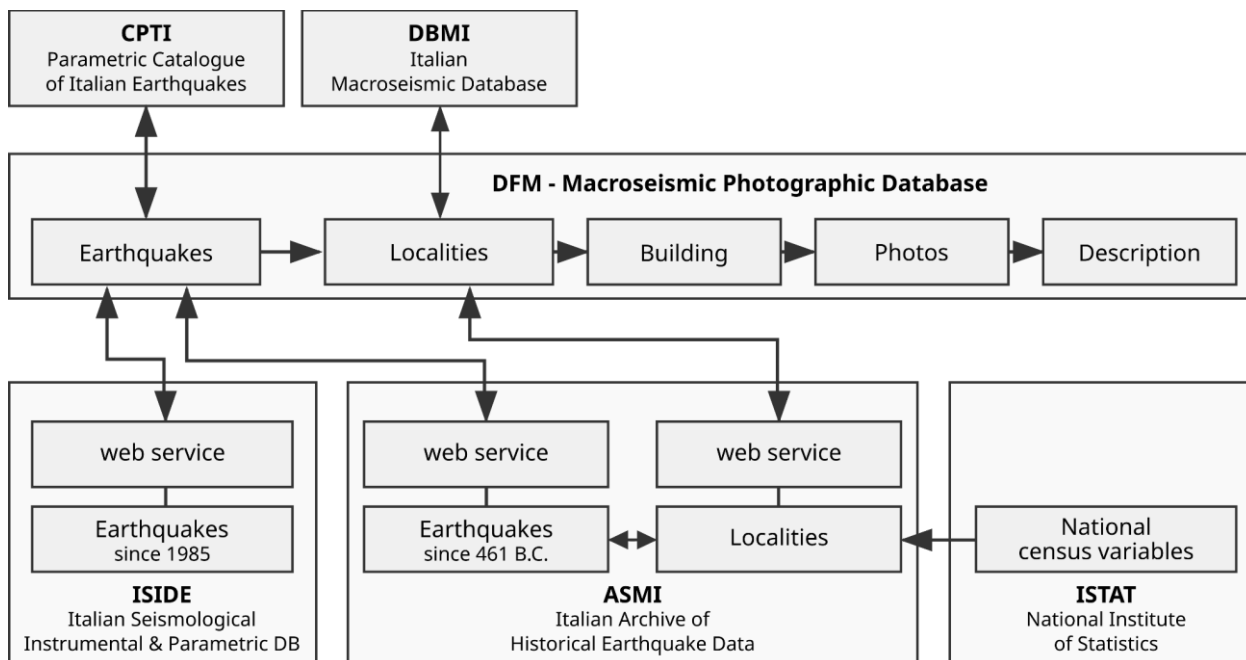


162
163 *Figure 2. Geographic coverage of DFM. The red stars represent the epicentres of earthquakes for which the*
164 *QUEST group has taken action, and the blue dots represent inhabited locations for which photographs are*
165 *available on the DFM.*

166 **4. Interoperability and programmatic access**

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

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



181
 182 *Figure 3. Diagram showing the interoperability of the DFM with other INGV seismological databases.*

183 4.1. Data Access via Web Services

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

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

195 5. Use cases and future developments

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

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

205 The large corpus of images labelled with building structural typology and damage grade makes the DFM an
206 ideal machine learning resource, providing a high-quality training set for developing algorithms for
207 automated damage classification, such as the rapid damage mapping approaches described by Pittore et al.
208 (2018). Finally, the database supports Civil Protection agencies in emergency planning and post-earthquake
209 response by offering a visual record of damage patterns from past events in a given area.

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

221 **6. Data availability**

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

229 **7. Conclusions**

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

241 **Author contributions**

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

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255 who supervise the insertion and cataloguing of photos and metadata in the DFM. The activities of the QUEST
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260 based on the authors' input and guidance. The authors retained full responsibility for the final content,
261 scientific accuracy, and all conclusions presented in the paper.

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