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EMPIRICAL CONSEQUENCE CURVES FOR LONG-SPAN-BEAM BUILDINGS USING 2012 EMILIA-ROMAGNA EARTHQUAKE LOSS DATABASE

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Abstract: *In May 2012, a series of medium-high intensity seismic events struck the central-northern part of Italy, provoking 28 casualties and vast damage to structures and infrastructures, mostly within the region Emilia-Romagna. After the seismic events, the local administrative authority started collecting information about seismic damage and consequences, so to be able to fairly distribute financial compensations to citizens and business owners – as of October 2018, the total amount of public money granted was up to EUR 1.9 billion. Information regarding buildings geometry and location, damage level, experienced direct economic losses and reconstruction costs was stored in an electronic database. The so-called SFINGE database was assembled with a bottom-up approach, with the help of both private technicians and public report-evaluation teams; as a result, the now available dataset is vast, reliable and consistent. The authors of this paper accessed SFINGE so to study a specific buildings subset: long-span-beam structures belonging to business activities. In this work, the main research results in terms of direct economic losses and reconstruction costs are reported. Innovative empirical consequence curves are provided in order to contribute to the on-going scientific discussion about seismic consequences on long-span-beam buildings. Furthermore, reported data can be included within the existing theoretical PBEE framework, significantly enhancing the state of the art of seismic performance assessment tools.*

Keywords: *2012 Emilia earthquake, consequence curves, business facilities, SFINGE database, loss assessment, long-span-beam buildings.*

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INTRODUCTION

In May 2012, a widely industrialized area of Northern Italy was struck by a series of seismic shocks whose maximum magnitude was M_w 5.86 (Scognamiglio, 2012); in Figure 1 the shakemaps of the two most relevant events of the series are depicted (INGV, 2015). Due to lack of proper preparedness – this territory was for long considered not prone to significant seismic risk (INGV, 2009) – many public and private structures and infrastructures suffered relevant damage (Galli, 2012; Parisi, 2012; Rossetto, 2012; Savoia, 2012; Liberatore, 2013; Magliulo, 2014; ARR, 2018). Consequences were reported in 69 towns within the region (among which Modena, Ferrara, Bologna and Reggio-Emilia) and few more in Veneto and Lombardy. During the sequence, 28 people lost their life, and circa 300 were in some way injured (R E-R, 2018); many business activities had to face downtime: 40752 workers, in 3748 different enterprises, experienced temporary lay-off (R E-R, 2012a). The total economic loss in Emilia-Romagna was assessed to be in the order of EUR 13.2 billion (R E-R, 2018); the business sector alone suffered

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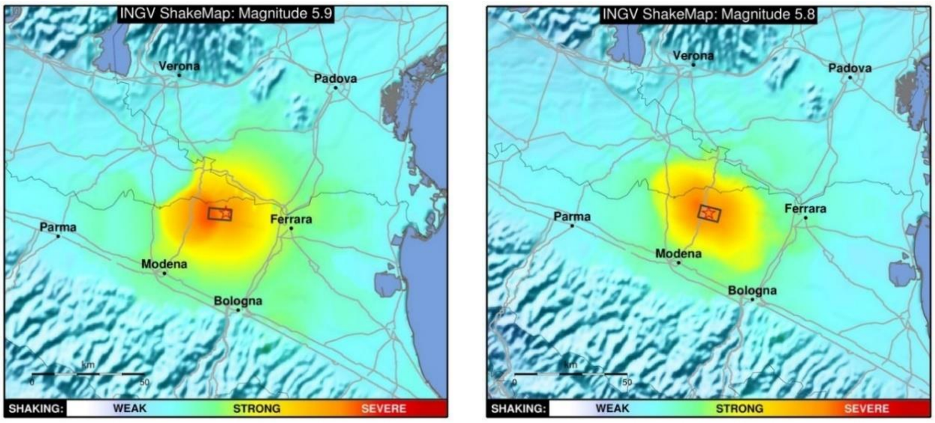
a total direct economic loss of more than EUR 2.41 billion, i.e. 18.3% of grand total (Rossi, 2019a), of which EUR 1.9 billion was then granted by the Italian State (R E-R, 2017; R E-R, 2018). In order to recover from the disaster, three public funding schemes were launched: one for the private housing, “MUDE” (R E-R, 2012d); one for the cultural heritage and the infrastructures, “FENICE” (R E-R, 2012c); and one for the business activities, “SFINGE” (R E-R, 2012e). Regarding the latter, attention was paid not only to the structural elements of the buildings, but also to non-structural components; assets as machineries, production systems, in-stock products and goods, were taken into consideration. Directly accessing the database SFINGE – see also (Rossi, 2019a) – we were able to collect empirical evidences regarding seismic economic consequences on business activities. In the following, results of our investigation are reported, so to provide the reader with useful quantitative tools, to be used in the field of both Performance Based Earthquake Engineering (PBEE) and disaster management.



(a) (b)

Figure 1. INGV’s maps for the 2012 Emilia-Romagna earthquake main shocks – Events’ magnitude (ML) and qualitative shakemaps (a) May 20th (b) May 29th (Michelini 2008; INGV 2015).

LONG-SPAN-BEAM BUILDINGS

In the SFINGE database there are more than 3800 application files, for a total of 4423 well-documented non-residential structures (i.e. used for business activities). Available records can be furtherly classified as “housing type” (2319 items) and “long-span-beam type” (2104 items, referred to as LSB). The first subset refers to RC and masonry structures, with beam span and columns height in the order of 3-6 m, resembling house structures. For what concerns the second subset, it is (mostly) about single-storey buildings, with a simple rectangular plan, and prefabricated RC beams between 10 and 20 m long; columns are also prefabricated or normal RC, or made of masonry too. Heavy, concrete-made, simply-supported panels, as well as infill masonry walls, usually define the buildings’ perimeter. In this set, steel structures also exist, but they account for a small minority (i.e. tens of units). Such building typology is definitely common in Italian industrial areas (Bonfanti, 2008) – it is commonly called “capannone”. Most frequent vulnerabilities of this structural typology were already described in many scientific papers (Toniolo 2012, Liberatore 2013, Magliulo 2014, Bellotti 2014). In any case, these structures were originally designed taking into consideration horizontal forces of quite a small amount, with little over-resistance and limited global ductility. In particular, brittle failure modes (e.g. precast beam unseating because of large horizontal relative displacement) prevented the actual structural ductility to manifest itself. In Figure 2, the reader can see an example of an LSB building damaged during the 2012 Emilia-Romagna sequence.

Figure 2. Example of damaged LSB building (source: Agenzia Regionale per la Ricostruzione - Sisma 2012).

CONSEQUENCES CLASSIFICATION

In SFINGE, applications are classified within three business macrosectors: industry, trade, and agriculture (in the following referred to as INDU, TRAD, and AGRI respectively). Furthermore, the wide spectrum of seismic consequences suffered by enterprises is organized under five main categories: real-estate, business relocation, capital goods, in-stock products, and special food products. Definitions are given in the following – for more details see (Rossi, 2019a).

- **Real estate, or closely related to it (REA)**: Primary or secondary structural components of buildings (e.g. RC frames and cladding panels), including finishes (e.g. windows or doors) and non-productive systems (e.g. electrical systems).
- **Business relocation (REL)**: Temporary relocation of the enterprise's activities to another site within the affected area. The purchase and rental of temporary structures (e.g. tents), the connection of utilities, and the moving of production facilities are also included in this category.
- **Capital goods, except real estate (CAP)**: Machinery (e.g. metal lathes), tools (e.g. compressors), equipment (e.g. cabinets) and systems for production (e.g. air purification systems); hardware in general.
- **In stock goods (STO)**: Raw material (e.g. glass jars), finished and semi-finished products in storage (e.g. canned food), who lost at least 20% of their initial value.
- **Products (PRO)**: Special food and agriculture products: this is the case of aged cheese and balsamic vinegar. This category – that represents quite an important term on the regional budget – is only related to enterprises in agriculture.

REA and REL can be considered structure-related, while the remaining ones (CAP, STO, and PRO) refer to contents (non-structural elements). Examples of the five different categories, taken from SFINGE database, are given in Figure 3 and in Figure 4. In Figure 3a, the reader can see a precast RC building whose external panels overturned; the hosted content (STO) is also partially damaged. In Figure 3b, an example of production site relocation (REL) is given: a small metal workshop is reinstalled in a temporary tent structure. In Figure 4a, the main precast RC structure (REA) collapsed on top of itself, destroying (among other things) a technical air conditioning system serving production and a car parked close by (CAP items); in Figure 4b, a light metal structure hosting aged cheese (PRO) overturned, losing its content.

(a) (b)

Figure 3. Examples of consequences after the 2012 Emilia earthquake (a) REA and STO (b) REL (source: Agenzia regionale per la ricostruzione – Sisma 2012).

(a) (b)

Figure 4. Examples of consequences after the 2012 Emilia earthquake (a) REA and CAP (b) PRO (source: Agenzia regionale per la ricostruzione – Sisma 2012).

For each macro sector-accounting category pair (e.g. INDU-REA), consequences were defined in terms of two report variables: experienced loss (**L**) and induced cost (**C**) (Rossi, 2019a). On one hand, **L** represents the economic amount that has been annihilated by the earthquake; it was assessed by the applicant, *ex-ante* (i.e. before reconstruction works start), using official price lists (R E-R, 2013; R E-R, 2012b), market price levels and expert judgement. On the other hand, **C** was obtained – *ex-post* – by collecting receipts about the money actually spent during the reconstruction phase; enterprises were entitled to use money for reconstruction works, machineries repair actions, goods repurchase, and business relocation. In order to avoid overcompensation from the state, every applicant had to submit documents regarding received insurance refunding – **I** (this aspect is beyond the scope of this paper). The three variables are used during the evaluation process carried out by the public authority (Regione Emilia-Romagna), to define the actual amount of money to be granted (**G**) – see (Rossi, 2019a). Quantitative information about losses and costs is given in the next section.

CONSEQUENCE DATA

In the SFINGE database, documented experienced losses and induced costs were organized by application files. The dataset we accessed is composed by 3869 application files, to every one of which corresponds one or more damaged items: looking at the data in the aggregated form, we get what is reported in Table 1 and 2.

L	(u.m.)	REA	REL	CAP	STO	PRO	Total
Number of files	(-)	2 847	453	372	180	17	3 869
% of total	(-)	73.6%	11.7%	9.6%	4.7%	0.4%	100%
Money amount	(10^3 €)	1 967 911	89 466	258 870	48 794	47 557	2 412 598
% of total	(-)	81.6%	3.7%	10.7%	2.0%	2.0%	100%

Table 1. Loss data summary.

First of all, from Table 1 emerges how losses – **L** –are mostly linked to real-estate (REA) items (73.6% of applications and 81.6% of total amount). Business relocation (REL) can also be considered structure-related; for this reason, of the documented EUR 2.41 billion, only EUR 355.2 million (i.e. 14.7%) depends on non-structural elements (CAP, STO, and PRO): Among them, capital goods (CAP) is the most relevant one. If we look at induced costs, **C**, reported in Table 2, we see that their distribution is in-line with the values parametrically assessed ex-ante; again, most of the money (85.8%) went for the buildings themselves (local strengthening, reparation, retrofitting and relocation), and only a minor amount (14.2%) for contents.

C	(u.m.)	REA	REL	CAP	STO	PRO	Total
Total amount	(10^3 €)	2 032 460	85 422	251 785	50 785	47 643	2 468 094
% of total	(-)	82.3%	3.5%	10.2%	2.1%	1.9%	100%

Table 2. Cost data summary.

Data disaggregation

Data reported in Tables 1 and 2 are partially disaggregated by accounting category – i.e. REA, REL, CAP, STO, and PRO; nonetheless, for every one of the 3869 items, information is still aggregated by refunding application. In other words, each of the 2847 REA loss and cost items reported in the tables may refer to one or more buildings at a time – indeed, the total number of listed structures is 4423. At the current state, higher data granularity can be achieved for the sole REA category, and just for the LSB subset. So, here we will consider experienced cost regarding real estate – the so-called *DREC*, or *Direct Real estate-related Economic Cost* – as the variable of interest. Interestingly, once the single-unit scale is reached, two further information fields – structure's total area and geographical location – become available. As a further step, in order to make provided results more portable, for every item of SFINGE database we will also take the term DREC as divided by the corresponding building's area – obtaining the so-defined *relative DREC*. Such variable is a measure of the reconstruction cost by structure's square meter; it can be adopted by the interested reader while assessing the seismic direct economic consequence, for a building with typological features resembling the LSB-type's. Additional assessment tools, as coefficients that put in relation real estate-related consequences to the other terms (CAP, STO and PRO) can be found in (Rossi, 2019a).

EMPIRICAL CONSEQUENCE CURVES

The available building's area-relative DREC pairs are scattered in Figure 5 (axes are on Log10 scale); in it, despite a considerable relative dispersion (root mean square error – RMSE – being 0.467), a fundamentally linear relationship emerges: The Log10 of the two variables have a correlation coefficient of 0.647. From the practical point of view, such linear dependency is completely fine: the larger the building, the bigger (on average) the resulting real estate reconstruction cost, plus some variability. In the chart, data points are represented with 3 different markers and colours, so to highlight the three business macrosectors. The reader can notice how businesses in agriculture tend to occupy, mostly, the left-bottom part of the scatter plot, while industrial and trade enterprises are largely widespread.

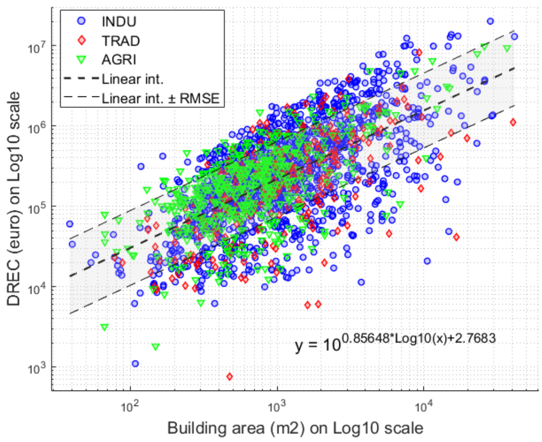
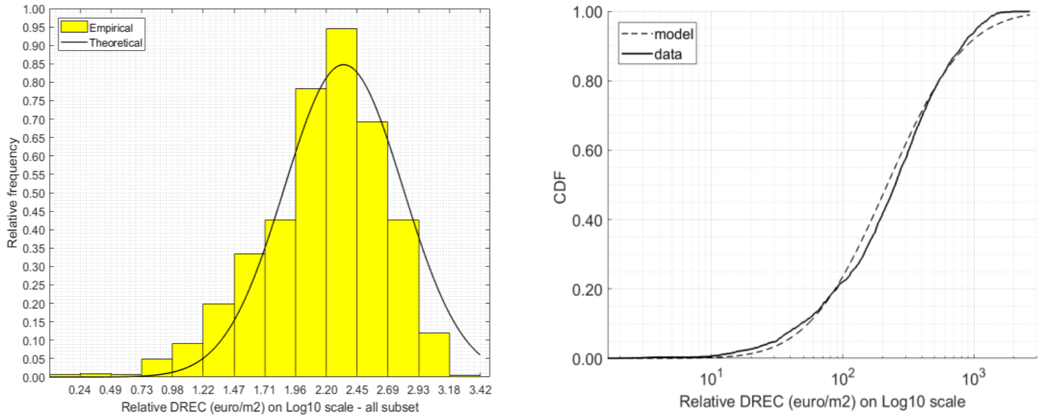


Figure 5. Scatterplot of direct real-estate-related economic costs (DREC) by building area (on Log10 plane).

Figure 6a shows the probability density function (PDF) of relative DREC, with reference to the whole dataset; in Figure 6b instead, we report the corresponding cumulative distribution function (CDF). Despite the analysed sample doesn't succeed in the Kolmogorov-Smirnov Test (Massey, 1951), we notice a clear proximity of the empirical evidences to lognormality (the μ and σ parameters of the theoretical curve are reported in Table 3). As a further step, the dataset can be disaggregated by macrosector, as shown in Figure 7: from it, it clearly emerges that the subset regarding business in agriculture is the least close to the lognormal distribution, while good results in this sense are obtained for the industry-related data points (see again Table 3). For what concerns information portability, it has to be noticed that, in this part of Italy, typical industrial productions are in the fields of metal works, mechanics, biomedical, food processing, ceramics and textile manufacturing; this makes the provided results portable to other industrialised areas of Europe.



(a) (b)

Figure 6. Relative DREC's empirical and theoretical (a) probability density function, PDF and (b) cumulative distribution function, CDF.

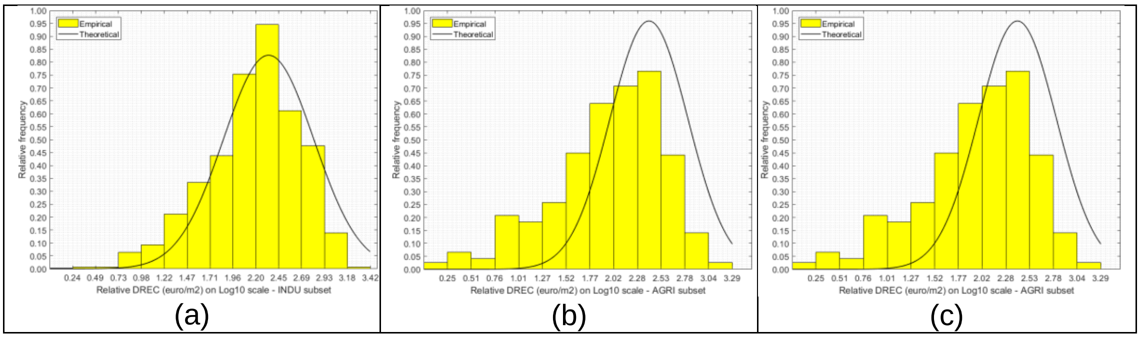


Figure 7. Relative DREC's empirical and theoretical probability density functions (PDF) for (a) Industry (b) Trade (c) Agriculture.

Log10 (rel. DREC)	All	INDU	TRAD	AGRI
μ	2.338	2.337	2.233	2.401
σ	0.471	0.483	0.482	0.416

Table 3. Parameters of the theoretical curves for Log10 of relative DREC (in EUR/m²).

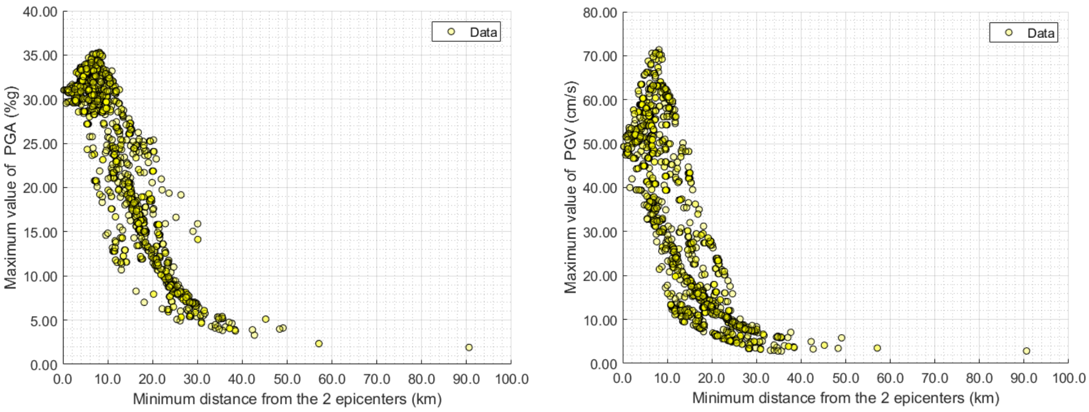
In practical terms, the reader can access both the charts of Figure 6 and Figure 7, or the parameters in Table 3, so to determine, with reference to the studied building stock (Rossi, 2019b) and the occurred seismic scenario (Scognamiglio, 2012; Mucciarelli, 2014), the probability of experiencing a relative DREC between two specific values. In computing both the PDF and the CDF, we tacitly assumed that: relative DREC > 0; in other words, in this section we reported the relative DREC conditional probability, i.e

$$P(a \leq \text{relative DREC} \leq b \mid \text{relative DREC} > 0) \quad (1)$$

with *a* and *b* values of interest in the X-axis. In this sense, the probability values here presented have to be considered as first attempts – a possible way of adopting such values in the framework of PBEE is described in (Rossi, 2019b); indeed, neither occurred damage patterns, nor ground motion parameters were taken into account so far. The first one are beyond the scope of this paper – see instead (Rossi, 2019b) – while the latter are introduced in the next section.

Consequence curves by PGA and PGV

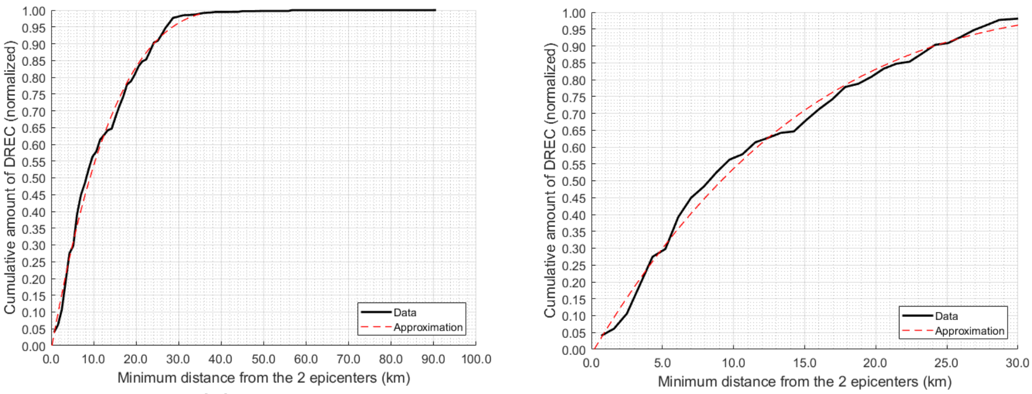
Using the building's location record of the studied LSB dataset, and the envelope of the seismic sequence's shakemaps in terms of PGA and PGV, it is possible to obtain innovative empirical consequence functions. First of all, for every known site, we computed the corresponding minimum distance (in the following, referred to as Dmin) from the two most relevant seismic events (i.e. May 20th and 29th). A Dmin-IM scatterplot – on Log10 plane – is reported in Figure 8. As expected, the value of experienced ground shaking intensity rapidly decreases with distance from the epicentre.



(a) (b)

Figure 8. Dmin – IM scatterplot with ordinate in terms of (a) PGA and (b) PGV.

As a second step, for the available data points, it is possible to plot a Dmin-cumulative DREC curve (see Figure 9); a detail is given in Figure 9b. Provided charts can be used to have, at a glance, a distance-to-epicentre versus cumulative DREC relationship. In particular, as the reader can see, 50% of the economic consequence value grand total occurred within circa 7.5 km from the closest epicentre. At the same time, we notice that the external areas (Dmin > 30 km) contributed for less than 5% to total DREC. Such results mean that – at least for LSB buildings, and relatively to real estate – most of the consequences of the 2012 Emilia earthquake were provoked on near fault range.

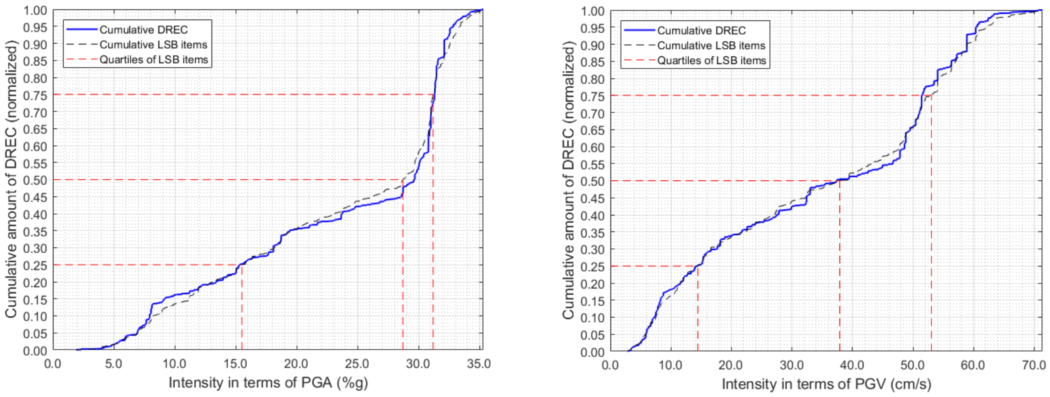


(a) (b)

Figure 9. Dmin – cumulative DREC (a) whole chart (b) closest 30 km detail.

As a final step, in order to make the provided results more portable, in Figure 10 we report the plot of intensity measure-cumulative DREC pairs, using respectively PGA (as % of g) and PGV (values in cm/s) as an abscissa. In the charts, red dashed lines highlight the LSB sample quartiles.

First of all, from both the two charts we notice that cumulative DREC and cumulative number of LSB items have similar trends. For what concerns the PGA-plot, we see a steep increase at around 28% of g, so that 50% of the items of the building stock belong to the narrow range between that point and 35% of g. On the contrary, when it comes to PGV, the cumulative distributions are closer to linearity – the medians being at circa 38 cm/s. Provided charts can be used in seismic consequence assessment, when evaluating the expected amount of DREC – or of an equivalent variable – by ground shaking intensity range. To this regard, one limitation arises: results depend on the specific seismic scenario of 2012 Emilia-Romagna earthquake, i.e. not only on the characteristics of the occurred shocks, but also on the geographical distribution of LSB buildings (and their structural capacity), and on the socio-economic context of the region. Nonetheless, the reported information represents a first reference for possible similar events in Italy.



(a) (b)

Figure 10. Intensity measure-cumulative DREC with abscissa in terms of (a) PGA and (b) PGV.

CONCLUSIONS

In this paper we used empirical evidences of the 2012 Emilia-Romagna earthquake to define innovative, data-based, seismic economic consequence curves for long-span-beam structures. In the first part of the document, we provided the reader with essential information regarding the 2012 seismic sequence; then, details are given about the so-called SFINGE database, that was created by the public authority Regione Emilia-Romagna to fairly manage economic compensations to enterprises who suffered damage and loss. To this regard, we described the adopted consequence classification system. As a second work step, we introduced the loss and cost variables, and the corresponding economic amounts, with reference to the Emilia-Romagna's classification categories. In a further section, available consequence data were disaggregated at the scale of the single structure. Such disaggregation allowed us to define empirical consequence curves in terms of a variable called *relative DREC*, i.e. "Direct Real-estate-related Economic Costs" divided by buildings' area. Probability density functions (PDF) and a cumulative density function (CDF) for such variable are presented in the text. Then, by referring to the buildings' minimum distance from the closest epicentre (Dmin) and the publicly available events' shakemaps (both in terms of PGA and PGV), we created three informative charts regarding the studied building stock: 1) A D_{min}-ground motion intensity; 2) A D_{min}-cumulative amount of DREC; 3) An intensity measure-cumulative amount of DREC. All the provided charts can be used by the PBEE user in assessing seismic economic consequence on LSB buildings. For what concerns the study results, the following limitations arise: first of all, in this paper only damaged – LSB – structures are taken into consideration. We haven't included data about the number of non-damaged buildings. A further study on the database will allow the authors to properly address such shortcoming. Secondly, results are meaningful within the specific seismic scenario of the Emilia-Romagna earthquake. This means that, in order to adopt the results in a different context, the user will have to check for similarities with the Emilia-Romagna case; in this sense, provided tools may be adopted in consequence assessment studies regarding other seismic prone Italian regions (e.g. Umbria, Marche and Veneto).

REFERENCES

ARR – Agenzia regionale per la ricostruzione - Sisma 2012 (2018), *Analisi tecnico-economica della ricostruzione post sisma degli edifici produttivi*, Centro Stampa Regione Emilia-Romagna, Bologna, Italy – ISBN 9788890737091 (in Italian)

Bellotti C, Casotto C, Crowley H, Deyanova MG, Germagnoli F, Fianchisti G, et al. (2014), Single-storey precast buildings: probabilistic distribution of structural systems and subsystems from the sixties, *Progettazione Sismica*, 5:41–70

Bonfanti C, Carabellese A, Toniolo G (2008). Strutture prefabbricate: catalogo delle tipologie esistenti. Available at: http://www.reluis. it (Accessed 28/03/2019)

Galli P, Castenetto S, Peronace E (2012), The MCS macroseismic survey of the 2012 Emilia earthquakes, *Annals of Geophysics*, 55, 663-672. DOI: https://doi.org/10.4401/ag-6163

INGV – Istituto Nazionale di Geofisica e Vulcanologia (2009). Italian seismic hazard maps. Available at: http://zonesismiche.mi.ingv.it (Accessed 28/03/2019)

INGV – Istituto Nazionale di Geofisica e Vulcanologia (2015). Shakemaps. Available at: http://shakemap.rm.ingv.it/shake/index.html (Accessed 28/03/2019)

Liberatore L, Sorrentino L, Liberatore D, Decanini L (2013), Failure of industrial structures induced by the Emilia (Italy) 2012 earthquakes, *Engineering Failure Analysis*, 34:629–47

Magliulo G, Ercolino M, Petrone C, Coppola O, Manfredi G (2014), The Emilia earthquake: seismic performance of precast reinforced concrete buildings, *Earthquake Spectra*, 30:891–912

Massey FJ (1951), The Kolmogorov-Smirnov Test for Goodness of Fit, *Journal of the American Statistical Association,* Vol. 46, No. 253, pp. 68–78

Michelini A, Faenza L, Lauciani V, Malagnini L (2008), ShakeMap Implementation in Italy, *Seismological Research Letters*, 79, 5, 688-697, DOI: https://doi.org/10.1785/gssrl.79.5.688

Mucciarelli M, Liberatore D (2014), Guest editorial: The Emilia-Romagna 2012 earthquakes, Italy, *Bulletin of Earthquake Engineering*, 12:2111-2116, Springer
DOI: https://doi.org/10.1007/s10518-014-9629-6

Parisi F, De Luca F, Petruzzelli F, De Risi R, Chioccarelli E, Iervolino I (2012). Field inspection after the May 20th and 29th 2012 Emilia-Romagna earthquakes. Available at: http://wpage.unina.it/iuniervo/papers/Report_reluis_damages.pdf (Accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2012a). A sei mesi dagli eventi del 20 e 29 maggio 2012: I danni del terremoto e le politiche messe in campo per affrontare l'emergenza e la ricostruzione. Available at: http://www.regione.emilia-romagna.it (Accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2012b). Elenco Regionale dei Prezzi delle Opere Pubbliche della Regione Emilia-Romagna - Art. 8 Legge Regionale N.11/2010 - Art. 133 Decreto Legislativo 163/2006. Available at: www.regione.emilia-romagna.it (Accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2012c). FENICE. Available at:
https://www.regione.emilia-romagna.it/terremoto/fenice (in Italian, accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2012d). MUDE. Available at:
https://www.regione.emilia-romagna.it/terremoto/mude-modello-unico-digitale-per-ledilizia

(in Italian, accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2012e). SFINGE. Available at: https://www.regione.emilia-romagna.it/terremoto/sfinge (in Italian, accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2013). Prezzario Regionale per Opere e Interventi in Agricoltura Adeguamento 2007. Available at: www.regione.emilia-romagna.it (in Italian, accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2017). 2012-2017 L'Emilia dopo il sisma - Report sui cinque anni di ricostruzione, Report, Agenzia regionale per la ricostruzione, Bologna. Available at: https://www.regione.emilia-romagna.it/terremoto/archivio/cinque-anni-di-ricostruzione/report-a-5-anni-dal-sisma (in Italian, accessed 28/03/2019)

R E-R – Regione Emilia-Romagna (2018). 2012-2018 L'Emilia dopo il sisma – Report su sei anni di ricostruzione, Report, Agenzia regionale per la ricostruzione, Bologna. Available at: https://www.regione.emilia-romagna.it (in Italian, accessed 28/03/2019)

Rossi L, Holtschoppen B, Butenweg C (2019a), Official Data on the Economic Consequence of the 2012 Emilia-Romagna Earthquake – A First Analysis of Database SFINGE, *submitted for publication*

Rossi L, Parisi D, Casari C, Montanari L, Ruggieri G, Holtschoppen B, Butenweg C (2019b), Empirical Data about Direct Economic Consequences of Emilia-Romagna 2012 Earthquake on Long-span-beam Buildings, *submitted for publication*

Rossetto T, et al. (2012). The 20th May 2012 Emilia Romagna Earthquake - EPICentre Field Observation Report, UCL EPICentre. Available at: http://www.ucl.ac.uk (Accessed 28/03/2019)

Savoia M, Mazzotti C, Buratti N, Ferracuti B, Bovo M, Ligabue V et al. (2012), Damages and collapses in industrial precast buildings after the Emilia earthquake, *Ingegneria Sismica*, 29:120–31

Scognamiglio L, Margheriti L, Mele F, Tinti E, Bono A, De Gori P, Lauciani V, Lucente FP Mandiello AG, Marcocci C, Mazza S, Pintore S, Quintiliani M (2012), The 2012 Pianura Padana Emiliana seimic sequence: location and magnitudes, *Annals of Geophysics*, 55(4):549–55

Toniolo G, Colombo A (2012), Precast concrete structures: the lessons learned from the L'Aquila earthquake, *Structural Concrete*, 13:73–83