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The legacy of the 1976 Friuli earthquake

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ABSTRACT A brief *excursus* is presented on the projects funded by the Civil Protection of the Friuli Venezia Giulia Region aimed at reducing seismic risk. The projects have tackled different aspects of seismic risk reduction: the regional seismometric network can give information on earthquakes in real time, the seismic hazard and risk maps represent the guidelines on how to construct new buildings and where to retrofit existing ones with high priority, the survey on the school buildings in Friuli-Venezia Giulia provides indications on what to do to make them safe.

Key words: 1976 earthquake, Friuli, seismometric network, seismic risk, seismic hazard, vulnerability, school buildings.

1. Introduction

Forty years have passed since the dramatic occurrence of the 1976 Friuli earthquake, which destroyed several villages and killed about 1,000 people (Carulli and Slejko, 2005; Slejko, 2018). Some say that out of every evil comes something good, but has anything good been left by the Friuli earthquake in terms of greater safety for the population? In other words, are things that went badly at that time any better today?

It is not our intention to speak about the reconstruction of the destroyed settlements because the Friuli model has been widely analysed in the literature (see e.g. Fabbro, 2017; Carpenedo, 2018). Here, we wish to describe the virtuous cooperation between the regional Civil Protection and the regional scientific institutions [National Institute of Oceanography and Experimental Geophysics (OGS) and Trieste and Udine universities] aiming at reducing the seismic risk.

2. Buildings and emergency at the time of the 1976 earthquake

Two aspects play a major role when an earthquake strikes: the state of the buildings and the emergency system. As concerns the emergency system here, we will analyse the seismological support needed to rapidly activate the rescue teams.

2.1. Buildings and building code in Friuli before the 1976 earthquake

To explain the high number of victims and the widespread destruction in Friuli, it is necessary to briefly describe the building heritage: age, type of construction, and antiseismic measures applied.

2.1.1. The building heritage of Friuli in 1976

Most of the buildings in the area seriously affected by the earthquake were typical of a centuries-old rural-agricultural economy and only a very few were built following the modest post-war industrial development. From a construction point of view, these were poor quality buildings, very often made of irregular stones or round pebbles with weak and aged mortar. The village and town centres had developed by an unplanned aggregation of dwellings and service structures such as stables, barns, etc. Over time, the changes mainly involved covered extensions and decorative elements and, rarely, structural interventions. The settlement structure was highly vulnerable both in the individual buildings and in the built up areas as a whole. Tragically, this appeared all too evident to the first rescuers who, on the morning of 7 May, saw that the few modern buildings were almost always intact in a landscape of rubble.

2.1.2. The Italian building code and its application in Friuli

The earliest seismic regulations were issued in Portugal probably due to the Great Lisbon earthquake in 1755. They consisted largely of preventive rules: for example, to forbid construction types that were weak and had collapsed, while requiring the use of certain building and technical measures that had proved very effective.

In Italy, anti-seismic design rules have always made progress as a result of devastating earthquakes, creating a clear cause-effect relationship between a seismic event and the corresponding law. The regulations prior to 1960 can be considered purely prescriptive; those issued from 1960 to 1980 can be defined as referring to a first level of building performance [i.e. focusing on violent earthquakes, they request that building performance should safeguard human lives (i.e. avoiding collapse)].

Summarizing the development of the Italian seismic code (see also Slejko, 1993), the first seismic prevention measures were those of 28 March 1784, issued by the Bourbon Government after the earthquakes that devastated the Calabria region in 1783 and caused more than 30,000 deaths. Those measures, established by law, and all those that followed, up to the beginning of the 20th century, were based on prescriptive limitations alone (e.g. choice of the sites for rebuilding) and on the construction standards (e.g. height of buildings). In the following years, some regulations were issued for the Papal States after the 1859 earthquake in Norcia. After the unification of Italy, numerous regulations lapsed and the Italian state was unprepared to manage the situation after the 1883 earthquake that ruined all the villages on the island of Ischia.

A decisive improvement took place as a result of the magnitude 7.5 earthquake that destroyed Messina and Reggio Calabria, on 28 December 1908, causing the death of about 80,000 people. The rule that followed, the Royal Decree (RD) no. 193 of 18 April 1909, may be considered the first genuine Italian seismic legislation. It consisted in listing the municipalities of Sicily and Calabria where technical regulations for building must be applied. These rules obligated structures to resist the Equivalent Lateral Forces (ELFs), representing the dynamic effects applied to the masses of the building because of the seismic motion. This method is still used, albeit with suitable adjustments, by the main codes as a simplified method of seismic design.

The commission responsible for preparing the 1909 regulations defined, as design values for the new edifices, the maximum sustainable forces that were experienced by certain types of buildings, which did not collapse during the earthquake. These actions were officially defined later with the Decreto Legislativo Luogotenenziale (DLL) 1526 of 1916. These standards were followed by further refinements, including the Royal Decree (RD) no. 431 of 1927 that introduced the concept of seismic zonation (Fig. 1a), dividing the national territory into two zones, associated with two selected categories of seismic forces to be considered for designing new buildings, according to the grade of seismicity and the geological context of the zone itself. This grade of seismicity was defined only with the Ministerial Decree of 3 March 1975, where the grades S=12 and S=9 were associated with the first and the second category, respectively, and were used to compute the horizontal forces to be applied to the building in the static analysis.

The seismic classification was updated after every destructive (intensity larger than, or equal to, VIII Mercalli Cancani Sieberg) earthquake simply by adding municipalities to the official list: it was therefore based only on the fact that a municipality had experienced damage because of earthquakes after 1908, without any scientific consideration on the Italian seismicity and principally meant public funding [for more details see Petrini (1991)].

A new rule was established in Italy with the national law no. 64/1974: it presents a kind of inner dynamics because it only states the criteria for constructing in a seismic area and the classification, intended as list of regulated municipalities, is established by decree, and, therefore, it can be easily updated, either after a damaging earthquake (following the old philosophy) or when the increased knowledge of the Italian seismicity requests a revision of the classification. Law 64/1974 focused on violent earthquakes and required the safeguarding of human lives (i.e.

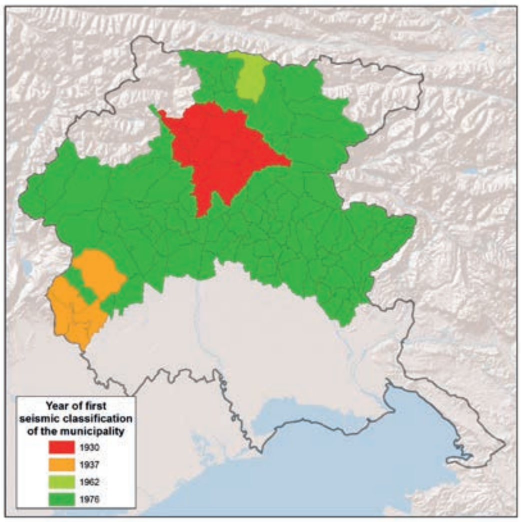

Fig. 1 - Seismic classification according to the RD no. 431 of 1927: a) Italy in 1927, the seismic zones are classified as first category (highly seismic, red) and second category (moderately seismic, orange), the black spots indicate declassified municipalities; b) Friuli-Venezia Giulia in 1977; the different colours indicate the different year of first seismic classification of the municipalities.

avoiding the collapse of buildings). It was based on research developed in the U.S.A. that began to formalize the concept of elastic spectrum, already introduced in the provisions of the Uniform Building Code of 1958 (International Conference of Building Officials, 1958) and in the blue book of the Structural Engineers Association of California (SEAOC Seismology Committee, 1959). Law no. 64/1974, still in force, represents the framework law of the Italian seismic legislation, setting out the planning guidelines and requiring the Ministry of Public Works to issue specific technical regulations containing design guidelines. This norm, with subsequent decrees, has brought important innovations: 1) the seismic classification of the territory must be established on the basis of well-founded technical-scientific reasons; 2) the morphological features of the site where a building is located must be accurately investigated together with the physical-mechanical characteristics of the soil; 3) the multi-modal analysis can be considered instead of the equivalent static analysis; and 4) the design spectrum has to be defined in terms of acceleration.

Regarding the Friuli Venezia Giulia region, Fig. 1b shows the municipalities classified seismic before 1976, with their first year of classification, and those classified after the 1976 earthquake (dark green area). A first group of municipalities refers to the 1928 Tolmezzo earthquake (red area); a second group, at the western border of the region, is related to the 1936 Cansiglio earthquake (orange area); after the 1958 Carnia earthquake, the Paularo municipality was also classified seismic (pale green area).

After the 1976 Gemona earthquake, the regional Public Administration requested two public institutions (Osservatorio Geofisico Sperimentale of Trieste and Politecnico of Milano) to provide scientific support in planning the reconstruction of the destroyed villages. This can be considered the first urban intervention based on seismic hazard studies (Faccioli, 1979; Giorgetti *et al.*, 1980). It was only on the basis of probabilistic studies performed for Friuli, that an actual separation of the two seismic categories was possible.

Many different studies devoted to the knowledge of Italian seismicity started after the 1976 Gemona earthquake. These studies were developed by the cooperation among geologists, geophysicists, and engineers in the frame of the Progetto Finalizzato Geodinamica of the Consiglio Nazionale delle Ricerche. One of the products was the maps of shakeability of Italy (Gruppo di Lavoro Scuotibilità, 1979; Petrini *et al.*, 1981) on the basis of which the CNR's proposal of seismic classification was based (see Petrini, 1980; Servizio Sismico del Consiglio Superiore dei Lavori Pubblici, 1986; Petrini *et al.*, 1987). That proposal was accepted by the Italian government, also motivated by the disaster caused by the 1980 Irpinia earthquake, and translated into a series of decrees by the Ministry of Public Works between 1980 and 1984 (Fig. 2a). Based on probabilistic studies, the municipalities with a calculated hazard larger than, or equal to, that of the already classified municipalities, were inserted into the second category, leaving the already classified municipalities in their old position and defining a third category for some municipalities of Campania, Apulia, and Basilicata, in southern Italy (see yellow spots in Fig. 2a), where even low shakings could produce severe damage. The new classification of Friuli-Venezia Giulia is reported in Fig. 2b. A limit of this classification is that it considers only new buildings without planning reinforcement interventions on the existing buildings. In any case, the concept of risk is present, although not explicitly, in the Italian seismic code, for instance with the presence of the third category.

2.2. The seismological situation in Friuli before the earthquake

As stated by Slejko (2018), the Friuli earthquake shifted the Italian seismology from the macroseismic (Giorgetti, 1976; Tertulliani *et al.*, 2018) to the instrumental approach. Although

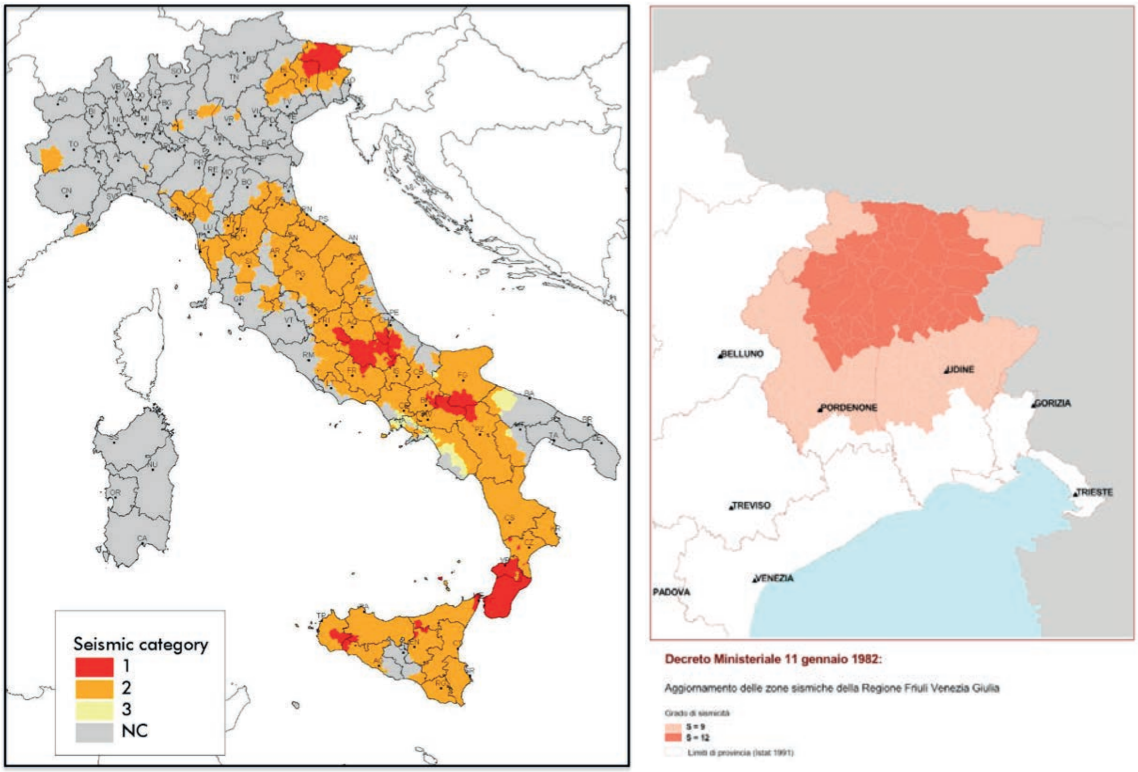

Fig. 2 - Seismic zonation according to DMLLPP of 1984: a) Italy; b) Friuli-Venezia Giulia, where the third category is not present.

there was a national seismological network, the number of its stations was in fact very few and no fast communication was established among the other seismological stations operating in Italy. The Trieste station was about 70 km away from the epicentre of the 6 May 1976 earthquake and only three other stations operated in north-eastern Italy at that time (Fig. 3): Padua, Bolzano, and Salò. Outside Italy, the stations that were operational and relatively close to central Friuli (within 250 km) were those of Ljubljana and Cerknica, in former Yugoslavia, Kremsmunster, Mariazell, Molln, and Innsbruck in Austria (Slejko, 2018). The standard epicentre location at the seismological observatories was manual since no software for earthquake location was generally available and because no data were available in real time. In fact, the recording system was analogic and data had to be read by a seismologist. Concerning the situation of the Trieste station, belonging to the U.S.G.S. World Wide Standardized Seismometric Network, there were 8 seismometers operating, 3 Benioff (E-W, N-S, and Z) for local earthquakes, 3 Ewing-Press (E-W, N-S, and Z) for teleseisms, and 2 Wood-Anderson (N-S and E-W) for computing the magnitude of the local events. For all these instruments, the recording system was photographic and it took about half an hour to collect the seismograms and perform the photographic treatment, before the recordings were ready for reading. The data elaborations entailed computing the distance, from the time arrival of the different seismic waves, and the azimuth, from the first onset on the 3 directions (E-W, N-S, and Z). With distance and azimuth, it was possible to locate the epicentre on a map of suitable dimensions. It is clear that even any small mistake in distance and azimuth could have generated large errors in the location. Moreover, in the case of strong events, as was the case of the 6 May earthquake, the

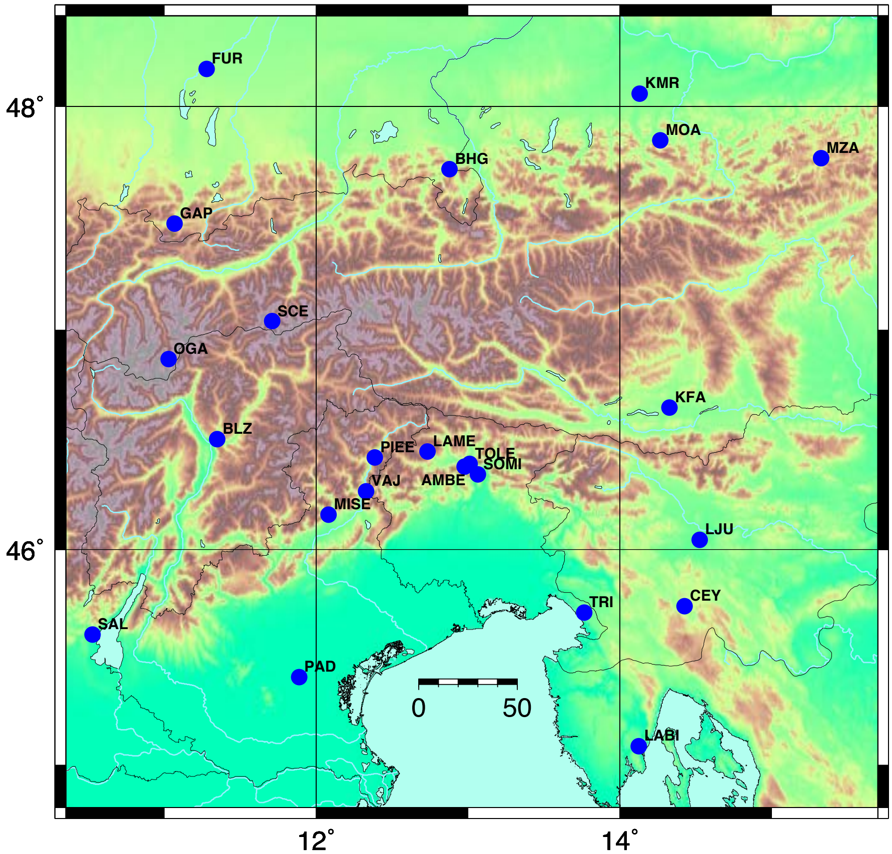

Fig. 3 - Seismic stations operating in early 1976.

recorded trace was often too faint to be seen, leaving a white space instead of a seismogram. The data of one station could have been compared with the data of other stations to control if the related distances matched the occurrence of an event and, in a positive case, a distance triangulation could have been done to identify the epicentre without using the azimuth value, whose estimate was always problematic. In the case of the 6 May earthquake, the telephone connections in the Friuli-Venezia Giulia region were interrupted because of damage to the communication systems and, consequently, there was no way to check the Trieste location, done with distance and azimuth. In short, this was the genesis of the association of the Mt. San Simeone to the 6 May epicentre. Years later, better locations have been provided (see Rebez *et al.*, 2018).

The situation described here explains the reason why it was not possible, at that time, to give an accurate epicentre location rapidly: this would have helped addressing the first emergency response and informing the population properly.

3. Projects financed by the regional Civil Protection

The regional law n. 64/1986 on activities of civil protection offered the opportunity to the regional administration of Friuli-Venezia Giulia to fund research projects aimed at reducing the seismic risk [for a detailed analysis of the law and its application see Riuscetti (2010)]. In this frame, the regional seismometric network was deployed and managed during all these years.

In addition, three main projects were proposed commonly by OGS and the Trieste and Udine universities and were funded by the Civil Protection of Friuli-Venezia Giulia.

3.1. From 1977 to today: the Friuli-Venezia Giulia Seismometric Network

Instrumental seismological observations in north-eastern Italy started at the end of the 19th century with a few observatories in Italy and the former Hapsburg Empire. The reference station for the area was located in Trieste (Finetti and Morelli, 1972). In 1931, it was taken over by an institute that is now OGS, and in 1963 it became part of the World Wide Standardized Seismographic Network (WWSSN, station code TRI-117). Since 1996, the station has been equipped with a Streckeisen STS 1 broadband seismometer and it is included in the Mediterranean Very Broadband Seismographic Network (MEDNET) as station TRI (Sandron *et al.*, 2015).

In 1977, OGS activated the first five short-period vertical seismometers of the Seismometric Network of Friuli-Venezia Giulia in the area of the M_L 6.4 Friuli earthquake of 1976. Since that time, OGS has installed new stations in Friuli-Venezia Giulia and in the nearby Italian regions and has improved the digital acquisition system. Today, OGS manages the North-East Italy Seismic Network (OX, doi: 10.7914/SN/OX) that spans from Lake Garda to the Italian-Slovenian border and from the River Po to the Italian-Austrian border, including 42 seismological stations (Priolo *et al.*, 2005; Bragato *et al.*, 2011). The OX network (Fig. 4) acquires data in real time from approximately 100 stations, integrating those belonging to neighbouring seismic networks,

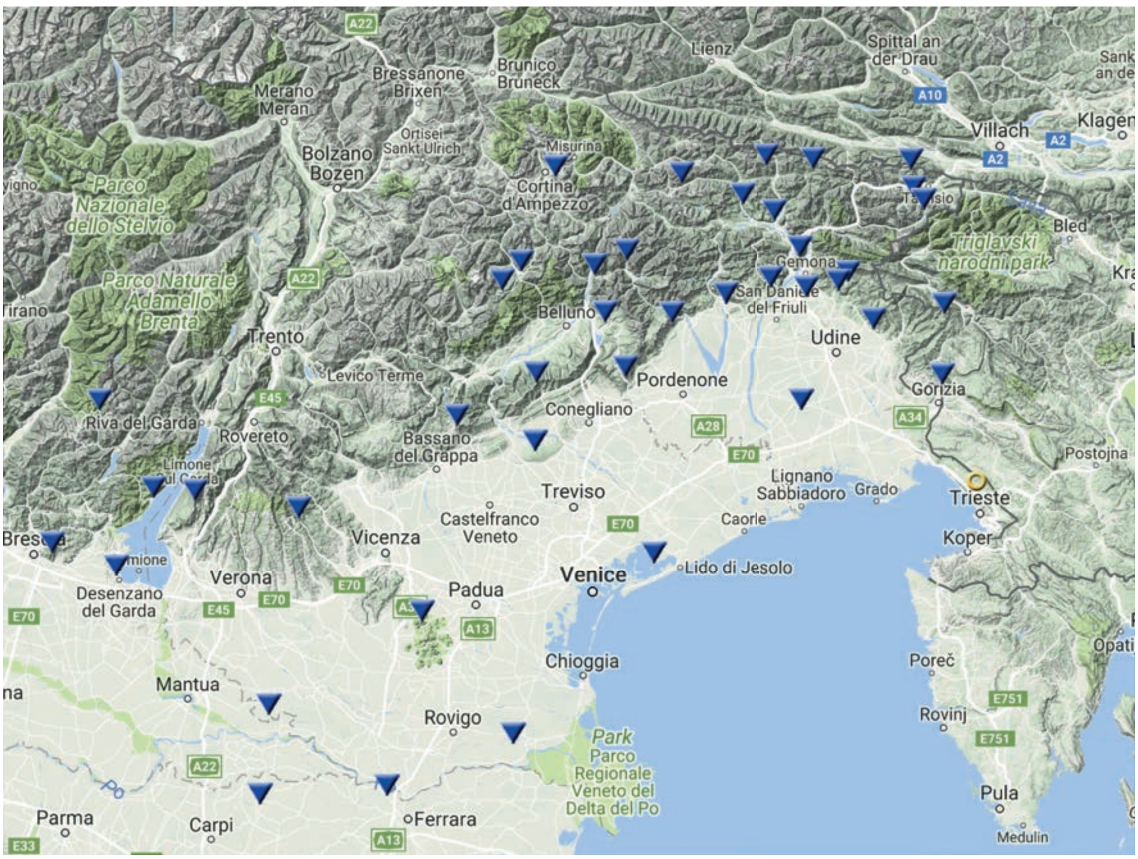

Fig. 4 - The OX network operating in north-eastern Italy.

specifically those maintained by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), the University of Trieste, the Regione Veneto, the Provincia Autonoma di Trento, the Provincia Autonoma di Bolzano, the Zentralanstalt fur Meteorologie und Geodynamik (ZAMG) in Vienna, the Agencija Republike Slovenije za Okolje (ARSO) in Ljubljana, the University of Zagreb, and the Schweizerischer Erdbebendienst (SED) of Zurich. This data integration greatly improves the overall geometry of the network, and increases its earthquake detection performance (Moratto *et al.*, 2017).

Recent developments include the installation of broadband instruments, the creation of a GPS network to monitor crustal deformation, the real-time moment-tensor computation by waveform inversion and the rapid estimate of ground-motion shaking. For an appropriate ground-motion prediction, specific empirical models have been developed for the monitored area, taking into account the large Moho reflection effects observed. The system has provided the opportunity to implement new tools for automatic and manual data processing to support research activities and emergency response by civil protection authorities. As of now, alert messages reporting the magnitude and the location of an earthquake are sent within 5 minutes via fax, e-mail, and SMS. The ultimate goal is to decrease the earthquake response time to less than one minute and increase the quality of the automatic hypocentral determinations.

3.2. From 1998 to 2001: the regional seismic risk map

Friuli lies among the highest risky areas in central-northern Italy. The experience of the 1976 earthquake (but also of the previous ones) shows that, at that time, the vulnerability of the buildings and of the socio-economic system was very high, causing unacceptable risk in comparison to that of countries with far greater seismicity, which had tackled the problem of prevention better than in Italy. It is well known that the 1976 earthquake struck municipalities that for the most part were not considered seismic by law, although their seismic hazard was well known to seismologists. The classification in the following years has rectified this situation and the laws for reconstruction have obliged the architects and designers to stick to the seismic code. It is, therefore, reasonable to think that vulnerability has been notably reduced in most of the municipalities destroyed in 1976 to an acceptable level of risk, at least for new buildings.

In the frame of its institutional activities, the Autonomous Region Friuli Venezia Giulia funded three regional scientific institutions (OGS, Trieste and Udine universities) to compile the regional seismic risk map, whose structure has few precedents in Italy or elsewhere. It is worthwhile mentioning that seismic risk is defined as the likelihood of observing damage as a result of earthquakes and it derives from the interaction of three elements: 1) seismic hazard (i.e. the estimate of ground shaking expected on a certain site during a given period of time due to earthquakes), 2) vulnerability (weakness of a building, or system, to resist ground shakings), 3) exposed value (economic value of a building, or system, exposed to earthquake. The map of regional seismic risk (Fig. 5) was realized in the period 1998 to 2001 and was calculated for the private masonry buildings on the basis of the census information related to the cadastral sections (administrative subdivisions of the territory implemented with all data pertaining to size and value of land and real estates). Vulnerability was estimated taking into account the outcomes of *a posteriori* studies on the damage provoked by the 1976 Friuli earthquake on different building typologies (Carniel *et al.*, 2006) collected and organized in the Friuli Earthquake Damage - FrED database (Di Cecca and Grimaz, 2009). The expected damage was estimated as the total amount

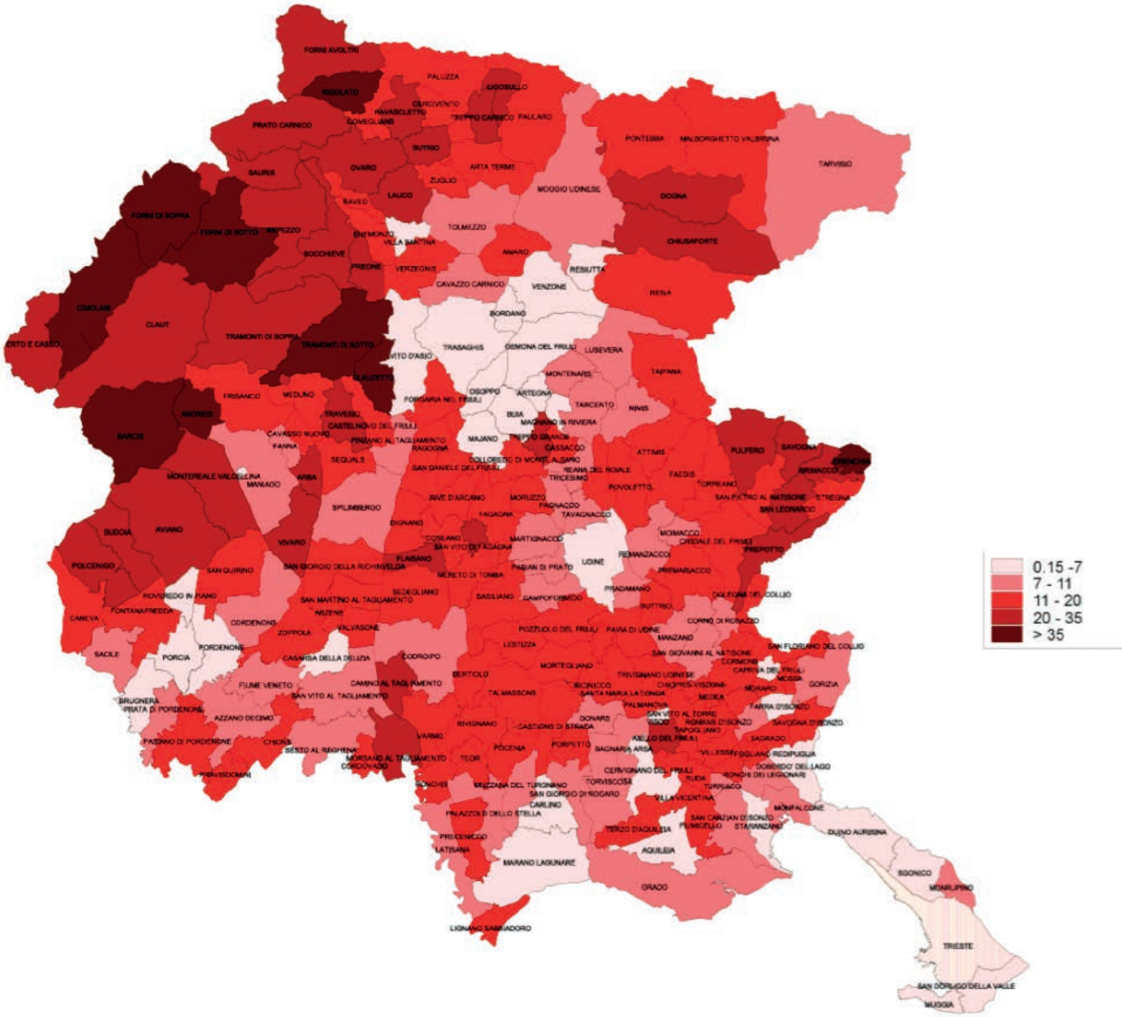

Fig. 5 - Seismic risk map of Friuli-Venezia Giulia (from Carulli *et al.*, 2003).

for each municipality, as well as the specific amount for each inhabitant in the municipality (Carulli *et al.*, 2003). More precisely, the final map provides a detailed spatial distribution of the expected damage on the regional territory due to a ground motion (peak acceleration) with a 475-year return period. The damage is related to the masonry buildings that make up the prevalent and most vulnerable part of the regional building stock. The regional administration, thus, has an instrument for reducing the expected monetary damage owing to earthquakes by defining priorities of financing for retrofitting existing private buildings that were not reinforced or reconstructed after the 1976 earthquake.

One of the peculiarities of this seismic risk map is the estimation of seismic hazard in terms of soil hazard. In fact, the specific soil conditions (rock, stiff soil, soft soil) of the regional territory were taken into account to compute the expected ground motion at the different sites.

The layered structure of the digital map was designed to be easily modified and adapted for future changes in knowledge about seismic hazard, vulnerability, and exposed value of the regional building stock.

3.3. 2003-2006: the seismic classification of the Friuli-Venezia Giulia region

The seismic reclassification for Friuli-Venezia Giulia (Fig. 6) was promulgated in 2010 by the regional authority on the basis of the official national seismic hazard map (Stucchi *et al.*, 2011) and also considering a seismic hazard study (Slejko *et al.*, 2011) carried out in 2003-2006 by OGS and the Trieste and Udine universities.

Given that seismic hazard maps that account for site amplification (due to both lithological and morphological local characteristics) are very useful since they represent the expected ground motion at the Earth's surface, albeit needing much more information and elaboration than the usual rock hazard maps, a specific project was funded by the Civil Protection of Friuli-Venezia Giulia. This aimed at calculating the expected shaking at the free surface, taking into account the specific local characteristics, acquired by geotechnical surveys at selected test sites in the region.

The regional soil hazard map (Slejko *et al.*, 2011) has been developed for the Friuli-Venezia Giulia region using the most updated approach. In fact, the structure of the seismic hazard analysis was based on the logic tree approach to achieve a robust statistical computation including, in addition to the aleatory variability, also the epistemic uncertainties. The logic tree adopted for rock and soft soil conditions consisted of 54 branches: three seismogenic zonations, representing various levels of our seismotectonic knowledge, three methods for the seismicity rate computation, three statistical approaches for the maximum magnitude estimation, and two attenuation models of different spatial relevance (European and Italian) for peak ground acceleration (PGA).

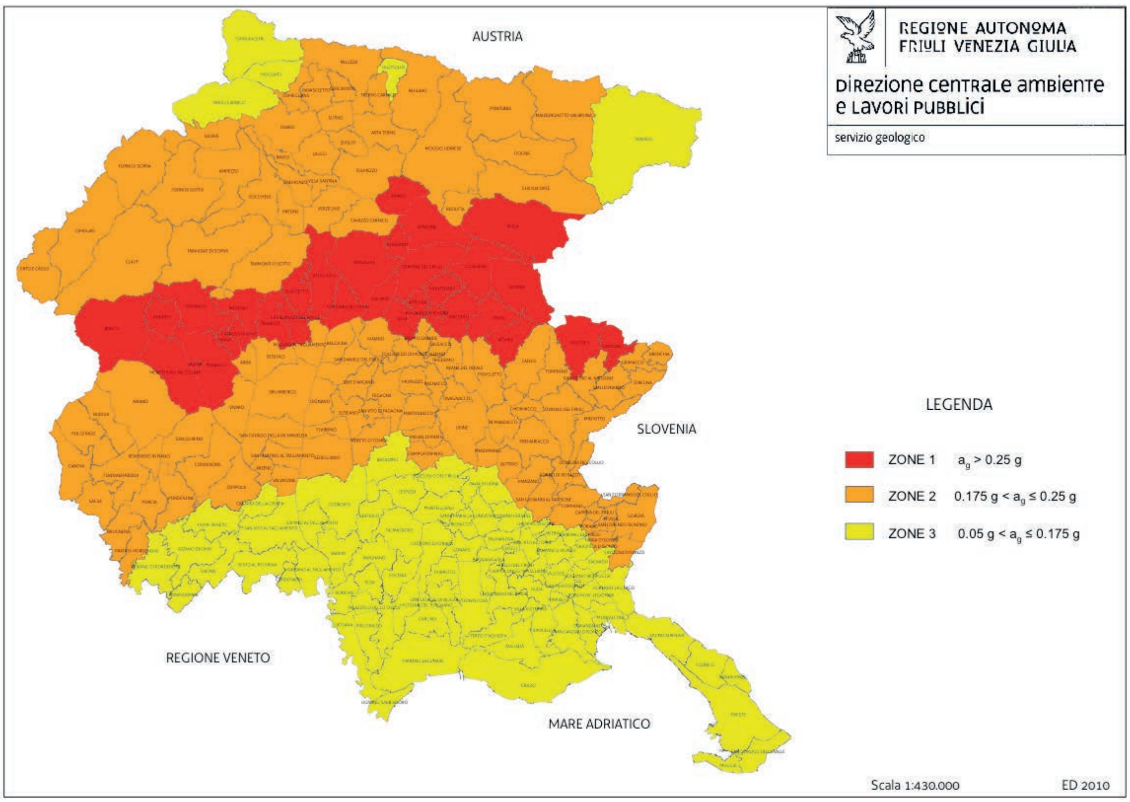

Fig. 6 - The 2010 seismic classification of Friuli Venezia Giulia: red = zone 1 (the most dangerous), orange = zone 2, yellow = zone 3; zone 4, the least dangerous is not present in Friuli Venezia Giulia.

An additional regional attenuation model was applied only for stiff soil conditions, increasing the number of branches of the logic tree to 81. A consolidated 1D modelling, widely adopted in the U.S.A., was used to compute the soil ground motion, properly modified on the basis of the results of the geotechnical soundings. The morphological effects were estimated taking in consideration the outcomes of an *a posteriori* study that analysed the different levels of damage in different morpho-scenarios observed following the 1976 Friuli earthquake (Grimaz, 2009). The result of that study was represented by the map of the expected ground motion in the Friuli-Venezia Giulia region, computed taking into account the different litho-stratigraphic and morphological conditions existing in the area. That map (Fig. 7) clearly showed the contribution given by the soft sediments along the Alpine valleys and by the steep formation of the moraine amphitheatre in central Friuli. Comparing the results of that study, where both the lithological and morphological local amplifications were calculated on the basis of *ad hoc* collected data, with those obtained by directly applying the amplification factors suggested by the most popular seismic codes, highlighted that the actual ground shaking could be notably larger than that forecasted by the application of the seismic codes.

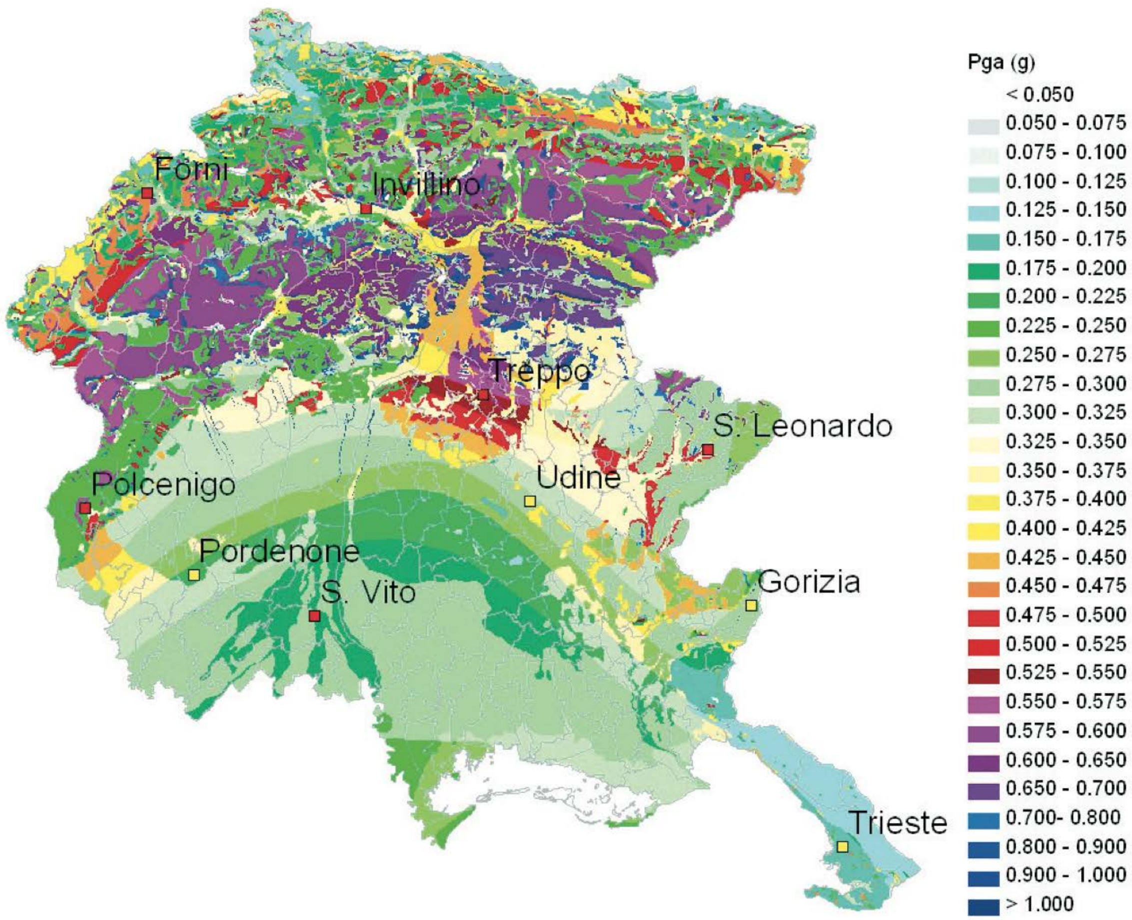

Fig. 7 - Soil seismic hazard map for Friuli Venezia Giulia. The PGA with a 475-year return period is represented (from Slejko *et al.*, 2011). The names identify the test sites considered in the study.

3.4. From 2008 to 2010: the ASSESS project

The seismic risk reduction of strategic and important facilities is one of the most delicate problems that administrators are being asked to deal with. In a seismic area, a major concern of public administrators is to ensure the safety of people in the case of earthquakes, especially in public buildings and, in particular, in school buildings. This problem was addressed in the ASSESS project [AnalySis of SEismic Scenarios of School buildings for a definition of intervention priorities for the seismic risk reduction; see Grimaz *et al*. (2012, 2016) and Slejko *et al*. (2012)], aimed at knowing, as a preventive measure, the level of seismic risk of school buildings in the Friuli-Venezia Giulia region. The ASSESS project was a prototypal study, developed on sound technical and scientific bases, useful to define decision-making tools for preventive purposes. In particular, the ASSESS methodology identified the possible actions for improving the seismic safety; it made an economic evaluation of these actions and, moreover, defined, through specific indicators, the intervention priorities to reduce seismic risk of school buildings throughout the studied area. The project led to specific and innovative decision supports aimed at helping public administrators develop and manage strategies for seismic risk mitigation of schools.

The estimation of seismic risk of the regional school heritage (Grimaz *et al.*, 2016) was performed in the 2008-2011 period and was funded by the Civil Protection of Friuli-Venezia Giulia. The study followed an interdisciplinary and holistic approach organized on three levels of analysis (Fig. 8): the basic level (desk approach), where the seismic hazard of the site and the building were studied using data from the literature (census data); the first level (screening approach), where the seismic hazard was calculated on the basis of all the latest regional information, also

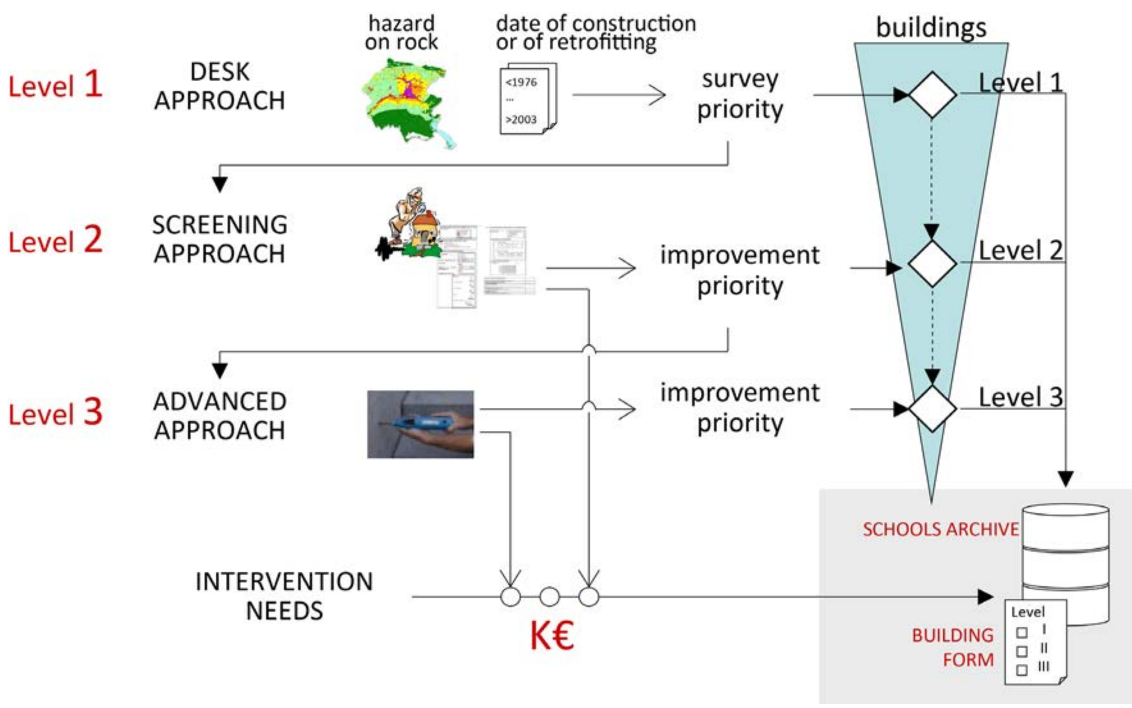

Fig. 8 - The three approaches applied in the ASSESS project (from Grimaz *et al.*, 2017).

School ID	School typology	Structural performance class	Intervention requirement rose	ASSESS safety stars	Costs (K€)
GO 000 XXX	Preschool	A		★★★★★	0
GO 000 XXX	Preschool	A		★★★☆☆	Technical verification
GO 000 XXX	Primary school	B		★★☆☆☆	47÷63
GO 000 XXX	Secondary school	D		★★☆☆☆	1.380÷1.870
GO 000 XXX	High school	E		★☆☆☆☆	2.300÷3.150
PN 000 XXX	Primary school	D		★★☆☆☆	920÷1.250

Fig. 9 - Extract from the collective report: indices used in the ASSESS project to characterize the seismic behaviour of an analysed school building: SPC, IRR, SSs. A rough estimate of costs for the required interventions is also reported (from Grimaz *et al.*, 2017).

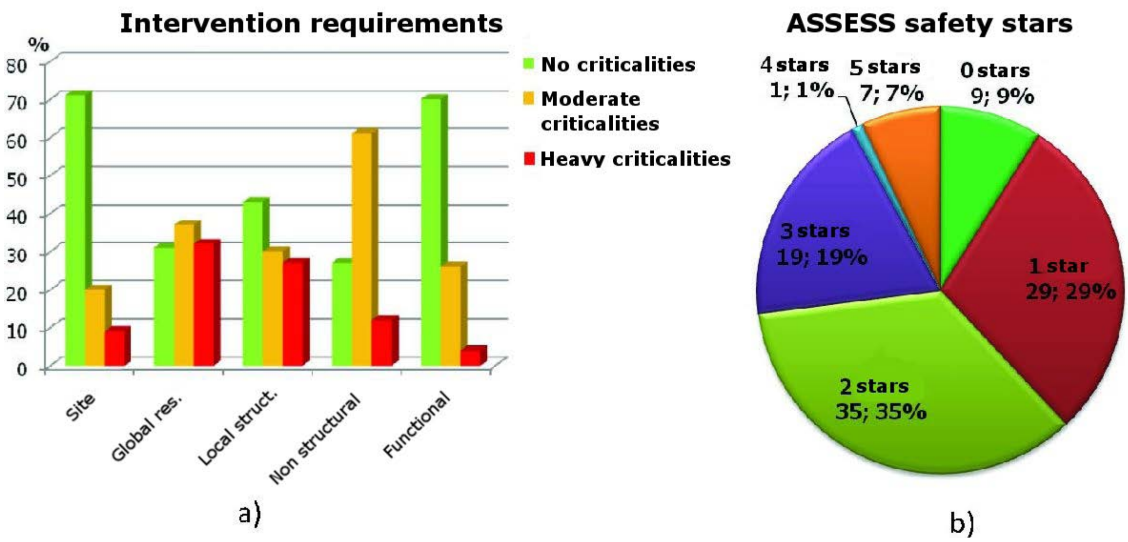

Fig. 10 - Summary of the results obtained by the ASSESS project: a) types of interventions required by the school buildings investigated; b) percentage of the quality of safety currently shown by the school buildings investigated (from Grimaz *et al.*, 2017).

supported by in situ measurements, while the building vulnerability was rated by visual surveys; and the second level (advanced approach), in which material testing and detailed modelling described the building behaviour under the seismic action. The basic level was applied to all 1022 regional school buildings, the first level to 10% and the second level to 1% of the buildings. The comparison among the results from the three levels of analysis showed that the results obtained in the first level, summarized by 3 risk indicators [structural performance class (SPC), intervention requirement rose (IRR) diagram, safety stars (SS); see Fig. 9] can be considered satisfactory to characterize the actions necessary to secure school buildings (Fig. 10) on the basis of current seismic standards (Ministro delle Infrastrutture, 2008).

Moreover, to facilitate communication with administrators, it was decided to use simple and known symbols (SPC, IRR, SS) making the recognition of the situations and the identification of intervention priorities simple and similar to other sectors.

4. Conclusions

Forty years after the Friuli earthquake, we can say that the awareness of the earthquake threat has increased greatly among the population (see also Peruzza *et al.*, 2018) as well as among the administrative bodies. This is largely due to the meritorious action of the regional Civil Protection that has been funding scientific projects over the years aimed at reducing the seismic risk. Earthquakes cannot be forecasted so far but the expected ground motion has been estimated, taking into account the specific peculiarities of the territory (Slejko *et al.*, 2011), and a warning system, able to react in real time, has been established.

Looking at the Italian scenario, it is possible to state that *ex ante* and *ex post* earthquake research and studies in the Friuli-Venezia Giulia region have opened the way to actions and applications aimed at reducing seismic risk in several other regions. Indeed, seismometric networks have been deployed in various regions (e.g. north-western Italy, Campania, Calabria), and regional studies on seismic hazard and risk have been developed (e.g. Petrini, 1995). Moreover, it is worth citing that, from 1996 to 2001, the Department of Civil Protection promoted and implemented, through the National Group for the Defence against Earthquakes (GNDT), some extensive survey campaigns seeking to classify the seismic vulnerability of the building heritage of southern Italy (Abruzzo, Basilicata, Calabria, Campania, Molise, province of Foggia in Apulia, and Sicily). The projects, involving public, private and monumental buildings, were carried out in the context of the activity "Socially Useful Works" (MLPS-DPC-GNDT, 1999, 2000, 2001).

In these last few years, we are witnessing the beginning of a policy of financing retrofitting work on public buildings (mainly schools). We believe, notwithstanding the modest amount of dedicated resources, that this is an encouraging sign of a new and positive attitude towards a problem that has generally been neglected.

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REFERENCES

Bragato P.L., Di Bartolomeo P., Pesaresi D., Plasencia Linares M. and Saraò A.; 2011: *Acquiring, archiving, analyzing and exchanging seismic data in real time at the Seismological Research Center of the OGS in Italy*. Annals of Geophysics, **54**, 67-75, doi: 10.4401/ag-4958.

Carniel R., Cecotti C., Chiarandini A., Grimaz S., Picco E. and Riuscetti M.; 2001: *A definition of seismic vulnerability on a regional scale: the structural typology as a significant parameter*. Boll. Geof. Teor. Appl., **42**, 67-83.

Carpenedo D.; 2018: *The role of local government in the reconstruction after the 1976 Friuli earthquake*. Boll. Geof. Teor. Appl., **59**, 381-384, doi: 10.4430/bgta0214.

Carulli G.B. and Slejko D.; 2005: *The 1976 Friuli (NE Italy) earthquake*. Giornale di Geologia Applicata, **1**, 147-156.

Carulli G.B., Riuscetti M. and Slejko D.; 2003: *La carta del rischio sismico*. Rassegna Tecnica del Friuli Venezia Giulia, **54 (2)**, 17-22.

Di Cecca M. and Grimaz S.; 2009: *The new Friuli Earthquake Damage (Fr.E.D.) database*. Boll. Geof. Teor. Appl., **50,** 277-287.

Fabbro S.; 2017: *Il "Modello Friuli" di ricostruzione*. Forum, Udine, 144 pp.

Finetti I. and Morelli C.; 1972; *Earthquake magnitude determination for Trieste WWSS station*. Boll. Geof. Teor. Appl., **14**, 67-83.

Faccioli E.; 1979: *Engineering seismic risk analysis of the Friuli region*. Boll. Geof. Teor. Appl., **21**, 173-190.

Giorgetti F.; 1976: *Isoseismal map of the May 6, 1976 Friuli earthquake*. Boll. Geof. Teor. Appl., **18**, 707-714.

Giorgetti F., Nieto D. and Slejko D.; 1980: *Seismic risk of the Friuli - Venezia Giulia region*. Publ. Inst. Geoph. Pol. Acad. Sc., **A-9** (135), 149-169.

Grimaz S.; 2009: *Seismic site effects estimation from Probit analysis of the data of the 1976 Friuli earthquake (NE Italy)*. Boll. Geof. Teor. Appl., **50**, 319-337

Grimaz S., Slejko D., Cucchi F. and Gruppo di Lavoro ASSESS; 2012: *Il progetto ASSESS (Analisi degli scenari sismici degli edifici scolastici per la definizione delle priorità di intervento per la riduzione del rischio sismico): un esempio di stima del rischio sismico esportabile ad altre realtà nazionali*. Geoitalia, **39**, 27-35.

Grimaz S., Slejko D., Cucchi F. and Working Group ASSESS (Barazza F., Biolchi S., Delpin E., Franceschinis R., Garcia J., Gattesco N., Malisan P., Moretti A., Pipan M., Prizzon S., Rebez A., Santulin M., Zini L., Zorzini F.); 2016: *The ASSESS project: assessment for seismic risk reduction of school buildings in the Friuli Venezia Giulia region (NE Italy)*. Boll. Geof. Teor. Appl., **57**, 111-128.

Gruppo di Lavoro Scuotibilità; 1979: *Carte preliminari di scuotibilità del territorio nazionale*. C.N.R. P.F. Geodinamica, pubbl. 227, ESA, Roma, 25 pp.

International Conference of Building Officials; 1958: *Uniform Building Code 1958 edition*. International Conference of Building Officials, Los Angeles, U.S.A., 404 pp.

Ministro delle Infrastrutture; 2008: *Decreto 14/01/2008 - Norme Tecniche per le Costruzioni.* Ministero delle Infrastrutture, Roma, 438 pp.

MLPS-DPC-GNDT (Ministero del Lavoro e della Previdenza Sociale, Dipartimento della Protezione Civile, Gruppo Nazionale per la Difesa dai Terremoti); 1999: *Censimento di vulnerabilità degli edifici pubblici, strategici e speciali nelle regioni Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia*. Dipartimento della Protezione Civile, Roma, 3 vols. + CD-Rom.

MLPS-DPC-GNDT (Ministero del Lavoro e della Previdenza Sociale, Dipartimento della Protezione Civile, Gruppo Nazionale per la Difesa dai Terremoti); 2000: *Censimento di vulnerabilità a campione dell'edilizia corrente dei Centri abitati, nelle regioni Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia*. Dipartimento della Protezione Civile, Roma, 508 pp.

MLPS-DPC-GNDT (Ministero del Lavoro e della Previdenza Sociale, Dipartimento della Protezione Civile, Gruppo Nazionale per la Difesa dai Terremoti); 2001: *Censimento relativo alle emergenze a carattere monumentale ed ambientale nei comuni ricadenti in tutto o in parte all'interno dei Parchi naturali, nazionali e regionali*. Dipartimento della Protezione Civile, Roma, 29 posters + CD-Rom.

Moratto L., Saraò A. and Priolo E.; 2017: *Moment magnitude (Mw) estimation of weak seismicity in north-eastern Italy*. Seismol. Res. Lett., 88, 1455-1464, doi: 10.1785/0220170063.

Peruzza L., Saraò A., Barnaba C. and G. Massolino G.; 2018: *Elapsed time: 40 years. What young people of Friuli Venezia Giulia know about the 1976 earthquakes, natural hazard and seismic safety*. Boll. Geof. Teor. Appl., **59**, 575-588, doi: 10.4430/bgta0227.

Petrini V. (ed.); 1980: *Proposta di riclassificazione sismica del territorio nazionale*. C.N.R. P.F.Geodinamica pubbl. 361, ESA, Roma, 83 pp.

Petrini V.; 1991: *Il rischio sismico in Italia*. In: Boschi E. (a cura di), Il rischio sismico, Le Scienze quaderni 59, Le Scienze S.p.A., Milano, pp. 3-5.

Petrini V. (a cura di); 1995: *Pericolosità sismica e prime valutazioni di rischio in Toscana*. C.N.R. Ist. Ric. Rischio Sismico e Regione Toscana Dip. Ambiente, Firenze, 120 pp. + 28 tav.

Petrini V., Bosi C., Bigi G., Eva C., Grandori G., Iaccarino E., Luongo G., Postpischl D., Praturlon A., Riuscetti M., Scandone P., Scarpa R., Stucchi M. and Vezzani L.; 1981: *Carta della pericolosità sismica d'Italia*. C.N.R. P.F. Geodinamica, Pubbl. 442.

Petrini V., Stucchi M. and Tento A.; 1987: *Classificazione sismica e revisione del catalogo sismico: analisi dell'influenza del catalogo sulla carta di pericolosità sismica ed alcune ipotesi per la revisione di quest'ultimo*. In: Boschi E. and Dragoni M. (a cura di), Aree sismogenetiche e rischio sismico in Italia. I. Galilei Ed., Lausanne, pp. 147-165.

Priolo E., Barnaba C., Bernardi P., Bernardis G., Bragato P.L., Bressan G., Candido M., Cazzador E., Di Bartolomeo P., Durì G., Gentili S., Govoni A., Klinc P., Kravanja S., Laurenzano G., Lovisa L., Marotta P., Michelini A., Ponton F., Restivo A., Romanelli M., Snidarcig A., Urban S., Vuan A. and Zuliani D.; 2005: *Seismic monitoring in north-eastern Italy: a ten-year experience*. Seismol. Res. Lett., **76**, 451-460.

Rebez A., Cecić I., Renner G., Sandron D. and Slejko D.; *2018: Misunderstood "forecasts", two case histories from former Yugoslavia and Italy.* Boll. Geof. Teor. Appl., **59**, 481-504, doi: 10.4430/bgta0244.

Riuscetti M.; 2010: *Research and Civil Protection in Friuli-Venezia Giuli a regarding seismic risk.* Boll. Geof. Teor. Appl., 51, n. 2-3, 203-209.

Sandron D., Gentile G.F., Gentili S., Saraò A., Rebez A., Santulin M. and Slejko D.; 2015: *The Wood Anderson of Trieste (NE Italy): one of the last operating torsion seismometers*. Seismol. Res. Lett., **86**, 1645-1654, doi: 10.1785/0220150047.

SEAOC Seismology Committee; 1959: *Recommended lateral force requirements, first edition*. Structural Engineers Association of California, Sacramento, U.S.A.

Servizio Sismico del Consiglio Superiore dei Lavori Pubblici; 1986: *Atlante della classificazione sismica nazionale*. Ist. Poligrafico e Zecca dello Stato, Roma, 209 pp.

Slejko D.; 1993: *Considerations on the seismic risk*. Annali di Geofisica, **36**, 169-175.

Slejko D.; 2018: *What science remains of the 1976 Friuli earthquake?* Boll. Geof. Teor. Appl., **59**, 327-350, doi: 10.4430/bgta0224.

Slejko D., Carulli G.B., Riuscetti M., Cucchi F., Grimaz S., Rebez A., Accaino F., Affatato A., Biolchi S., Nieto D., Puntel E., Sanò T., Santulin M., Tinivella U. and Zini L.; 2011: *Soil characterization and seismic hazard maps for the Friuli Venezia Giulia region (NE Italy)*. Boll. Geof. Teor. Appl., **52**, 59-104.

Slejko D., Grimaz S., Cucchi F. and the ASSES Working Group; 2012: *Seismic risk of schools at a regional scale: the ASSESS project*. In: SISMOS 2012, por una gestión stratégica de riesgos de desasters, Ediciones UO, Santiago de Cuba, ISBN 978-959-207-449-1, CD-Rom, paper C1.Slejko.It.pdf.

Stucchi M., Meletti C., Montaldo V., Crowley H., Calvi G.M. and Boschi E.; 2011: *Seismic hazard assessment (2003–2009) for the Italian building code*. Bull. Seismol. Soc. Am., **101**, 1885–1911, doi: 10.1785/0120100130.

Tertulliani A., Cecić I., Meurers R., Sović I., Kaiser D., Grünthal G., Pazdírková J., Sira C., Guterch B., Kysel R., Camelbeeck T., Lecocq T. and Szanyi G.; 2018: *The 6 May 1976 Friuli earthquake: re-evaluation and unification of transnational macroseismic data*. Boll. Geof. Teor. Appl., **59**, 417-444, doi: 10.4430/bgta0234.

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