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The 1976 Friuli earthquake: lessons learned

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ABSTRACT A special session on the 1976 Friuli earthquake was organised during the 35th Assembly of the European Seismological Commission in Trieste, Italy, on the 40th anniversary of that event. Summarising the oral and poster contributions presented during the session, together with a few others related to the same subject, we present a general overview of the scientific findings as the final chapter of scientific research on that earthquake, which can be considered the first Italian seismic event studied with modern scientific tools.

Key words: 1976 earthquake, Friuli, NE Italy, 40th anniversary.

1. Introduction

The 6 May 1976 Friuli earthquake can be considered a watershed between *"amateur"* and "institutionalized" seismology for Italy. In fact, unlike this event, the earlier 1968 Belice earthquake in western Sicily did not stimulate any major scientific research (Slejko, 2018). What changed in the short span of just eight years to justify such a different interest shown by the international scientific community? Certainly, the emotional impact of the Friuli earthquake was greater, justified by a seismic sequence lasting more than 6 months and 977 deaths compared to 231 recorded for the Belice earthquake. But it is likely that the difference was motivated above all by the presence of a seismological centre, the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), at that time called Osservatorio Geofisico Sperimentale, located relatively close to the epicentral area. OGS was, then, able to follow the evolution of the phenomenon regularly, providing information to other scientific institutions and to the community (see e.g. Colautti *et al*., 1976; Finetti *et al*., 1979).

The earthquake of 1976 also coincided with a nationwide reorganization of the studies on earthquakes and their social impact, namely the Italian Geodynamics Project. This was the first institutionalized collaboration between geologists, seismologists, and engineers in order to mitigate seismic risk (see e.g. Gruppo Redazionale della Carta Sismotettonica del PFG, 1982; Carulli, 2018), which continued with the activities of the "Gruppo Nazionale per la Difesa dai Terremoti" (see e.g. Slejko *et al*., 1989).

But perhaps an even more important consequence that the Friuli earthquake had was the emergence of an institutionalized system of civil protection and the role of the Regions in the field of civil protection. The Italian Civil Defence was, in fact, established some years later (in 1982), but the appointment of a special commissioner by the government for the earthquake can be seen as the embryo of the Department of Civil Protection (Zamberletti, 2018). The recognition as an Autonomous Region in 1963 also meant the possibility for Friuli Venezia Giulia to intervene incisively both in the reconstruction of the earthquake-stricken areas, following the so called "Friuli model" (Carpenedo, 2018) which is still a milestone of reconstruction examples, as well as in funding special scientific projects aimed at seismic risk reduction (Santulin *et al*., 2018). The most important of these projects was the establishment of a regional seismic network, inaugurated with the first three stations on 6 May 1977, exactly one year after the main shock.

Concerning the reconstruction of the destroyed settlements, it is worth noting the beginning of studies in Italy aimed at defining the seismic hazard, which started in Friuli (Faccioli, 1979; Giorgetti *et al*., 1980) and were later extended to the whole peninsula (Petrini *et al*., 1981; Slejko *et al*., 1998). The place where the destroyed villages of Friuli should have been reconstructed raised an important debate. The mantra of the Friulians "where it was, how it was" was generally followed and Gemona (Fig. 1) and Venzone (Fig. 2) are paramount examples of the reconstruction. Conversely, in a few cases it was decided not to reconstruct small settlements characterised by a high risk (e.g. Portis Vecchio close to Venzone) or not to impose any building and urban planning restrictions (Osoppo). At the same time, isolated "California style" buildings began springing up here and there.

In short, as a consequence of the earthquake it can be said that the large amount of money that suddenly flowed into Friuli, accelerated an inevitable process of modernization of an area that passed from a predominantly agricultural economy to widespread industrialisation, in part betraying the "where it was, how it was" catchphrase. In Yugoslavia, there was a long and fierce discussion among experts and members of the public whether it would be better to reconstruct

Fig. 1 - The Cathedral of Gemona after the reconstruction (photograph by M. Riuscetti).

Fig. 2 - The Cathedral of Venzone reconstructed using the anastylosis technique (photograph by M. Riuscetti).

slowly but keeping the shapes, materials, and designs of the historical settlements, or instead, build new prefabricated homes that are inexpensive, safe, fast to erect, and in general offer better living standards for the inhabitants, but are not so picturesque as the old villages.

This paper presents and summarises the contents of the session organized during the 35th General Assembly of the European Seismological Commission (ESC) held in Trieste from 4 to 10 September 2016. The state of the art on the science developed during 40 years after the earthquake has been summarized in a series of presentations, collected in this volume together with some additional papers that complete the information about the event. A total of 17 papers are contained in the present volume, 9 of which were presented during the ESC conference as oral presentations or posters. But why a volume on the 1976 earthquake now, so many years after the event? Fig. 3 shows the number of papers published over time on the 1976 quake. The information is taken from the bibliography on geology and geophysics of Friuli published by Carulli (2012), which can be considered the most exhaustive documentation on the subject. In truth, it is not entirely complete but it is hard to find any similar documentation worldwide for a catastrophe. It can easily be seen that, after the 1980s, the interest in the event diminished notably and only a small number of papers have been published since then, although there were a few also after year 2000. The quality of the available data for the earthquake hardly supports new elaborations (see Rebez *et al*., 2018) and, consequently, the present volume is likely the last scientific summary on the subject.

The papers are organized in four chapters. The first is a summary of the main scientific characteristics of the seismic sequence initiated on 6 May 1976 and of the preceding and following seismotectonic studies. The second gathers some recollections of witnesses who took care, during those years, of different aspects of the seismic crisis. The third chapter illustrates some recent studies referring to the 1976 earthquake that contribute to a better comprehension of the seismic phenomenon. The fourth and last chapter introduces some topics that started with, or were motivated by, the 1976 earthquake and have contributed to reducing seismic risk at both a regional and national level over the following years.

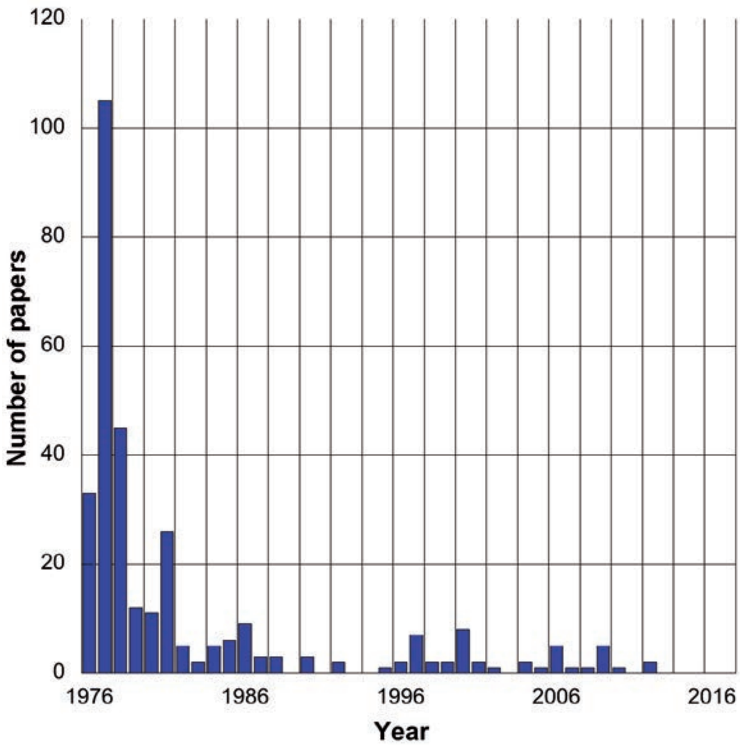

Fig. 3 – Number of papers dealing with the 1976 Friuli earthquake vs. time [data taken from Carulli (2012)].

2. A scientific summary of the Friuli 1976 event and related studies

The first paper by Slejko (2018) outlines the main aspects of the 1976 earthquake and of the long seismic sequence that followed and affected central Friuli for a year and a half. The earthquake stimulated a long series of studies (never before seen in Italy) regarding all aspects of the seismic phenomenon, from seismology, to geology, geodesy, seismic engineering, sociology, that led to identifying the tectonic sources involved in the phenomenon and the characteristics of its evolution in time. The focal parameters of the main events of the sequence are re-computed and compared with those found in the literature.

The second paper by Carulli (2018) gives an overview of the history of oil drilling, carried out to investigate the deep tectonic structure of the Friuli Venezia Giulia region, up until an interpretation of the deep structural style obtained from the data of the Bernadia well. The many studies following the earthquakes of 1976, leading to the formulation of a seismotectonic model and the identification of the seismogenic structures in the study region, are described in detail.

3. Witnesses of the 1976 Friuli earthquake

The third paper by Zamberletti (2018), the Government Commissioner for the earthquake, describes the coordination of emergency operations after the two strong earthquakes of May and September 1976, together with the specific problems faced and solved to help the local population return to normal life.

The guidelines for reconstructing the villages after the 1976 Friuli earthquake are summarized in the following paper by Carpenedo (2018). Special attention is given to the number of decrees issued by the Regional administration aimed at managing the emergency and initiating the reconstruction operation.

The role of newspapers during the Friuli earthquakes is described and commented in the fifth paper of this volume by Carbonetto (2018) with particular attention to the cooperation established with the regional scientific institutions. Thanks to this virtuous approach, people living in the epicentral area were informed correctly about the evolution of the earthquake and the actions undertaken to reconstruct the devastated settlements.

Moving on to the scientific research, the Friuli earthquake was not only the most devastating one in its epicentral region for centuries, but it was also felt in many parts of Europe, even in Berlin, where many people in high-rise buildings were frightened and ran outdoors. This contributed to the decision to establish seismology at the Potsdam Institute in particular with the macroseismic data collection. This aspect is described in the paper by Grünthal (2018), where the macroseismic data are also discussed according to contemporary cross-border isoseismal maps of the 1976 Friuli earthquake and compared with those of the 1690 Carinthia quake.

4. Scientific improvements

A simple question that could be raised may go like this: "Can modern studies give new information on the 1976 earthquake?" The following three papers answer positively to this question.

The paper by Tertulliani *et al.* (2018) proposes the whole macroseismic field of the 6 May 1976 Friuli earthquake in terms of the European Macroseismic Scale. Although a certain quantity of original data are missing and are probably lost forever, additional and yet unknown primary data have been discovered and used for the re-evaluation of the intensity map. The study presents the comprehensive macroseismic data set of 3423 intensity data points covering 14 European countries. In comparison to the previous studies, the largest intensities have changed from country to country, in some cases being lowered and in others increased, mainly due to the new data.

Pettenati *et al*. (2018) have used all the macroseismic data of the Friuli earthquake to retrieve geometric and kinematic information on the source, by doing automatic nonlinear geophysical inversions. In addition, they have analysed site effects on the Gemona fan in the epicentral area using intensities from 69 districts of the town. The general analysis confirms amplification on soft soils at great epicentral distances, while the analysis of Gemona showed a striking correlation between the trend of macroseismic data and the contour lines of the topography of the fan, with maximum intensity toward the apex of the fan and minimum intensity in the Friuli Plain beneath it.

By matching interpretation of seismic profiles of the Friuli pre-Alpine area with the superficial data collected during a detailed geological survey, Poli and Zanferrari (2018) have reconstructed the deep arrangement of the Susans-Tricesimo thrust (which is considered the seismogenic source of the 6 May 1976 earthquake). The structural framework of the upper crust in Friuli is updated in their study, suggesting a new seismotectonic model based on the slip partitioning between the Idrija-Ampezzo right lateral strike-slip system and the SSW-verging thrust system of central-eastern Friuli. This new seismotectonic model is of particular interest because it may have crucial consequences for the assessment of seismic hazard in Friuli.

Aiming at exploring the possibilities of forecasting the main shocks of the Friuli sequence, the paper by Rebez *et al*. (2018), after reporting a couple of examples on the subject, focuses on an accurate revision of the seismological data as well as on the analysis of the space distribution of the earthquakes. The final consideration is that, even with a good (or good enough) seismic monitoring, there is no clear evidence of epicentre migration towards the future location of the major events.

After the 6 May 1976 earthquake in Friuli Venezia Giulia, about 85,000 buildings in the affected area were investigated through damage-assessment forms. The Friuli Earthquake Damage database was created and more than 45,000 buildings with complete information were geo-localized. This enabled carrying out *a posteriori* studies to characterize both the vulnerability of different typologies of buildings and the effects of the geomorphology on the site seismic response. The paper by Grimaz and Malisan (2018) summarises the main results of these studies, in particular comparing the results of a statistical analysis of the information in the database at regional scale, with the results obtained, at local scale, through geophysical investigations.

The 1976 Friuli earthquake was the starting point for a new, observational-based approach to the vulnerability analysis of historical buildings, and in particular to churches and bell towers. This new approach enabled interpreting the mechanisms of damage and identifying the weakness points for a more effective and focused intervention of retrofitting. The paper by Doglioni *et al.* (2018) presents a brief overview of the contribution of the 1976 Friuli earthquake experience both to the knowledge of seismic behaviour of historical buildings and to the formulation of tailored safety upgrading projects.

5. Yesterday, today, and a possible tomorrow

Apart from the tragedy of victims and destruction, another question that may be raised concerns the issue of any eventual benefits that the earthquake has left, if any, in the epicentral area. The last three papers of the volume consider this aspect.

After the Friuli earthquake, a virtuous process of cooperation was established between the Civil Protection of the Friuli Venezia Giulia Region and the regional scientific institutions. Santulin *et al.* (2018) present a brief *excursus* on the projects funded by the Civil Protection aimed at reducing seismic risk. These projects have tackled different aspects of seismic risk reduction: seismic monitoring, regional seismic hazard and risk computation, and damage estimation for the school buildings.

In Italy, after the 1976 Friuli earthquake, progressive improvements were made concerning the approach and the techniques for securing and recovering historical buildings and monuments damaged by the earthquakes. The techniques to safeguard cultural heritage and strategic buildings are described in the paper by Grimaz *et al.* (2018) together with their application in safeguarding the cultural heritage during the seismic emergencies of L'Aquila (2009), Emilia (2012) and central Italy (2016).

The 40th anniversary of 1976 Friuli earthquakes has been an opportunity to revive the memory and awareness of living in a country affected by earthquakes. The results of a test on past and present natural hazards, compiled by 422 students and 35 teachers from middle-high schools of Friuli-Venezia Giulia in anonymous form and on a voluntary basis, are described in the paper by Peruzza *et al.* (2018). The sample includes both heavily damaged municipalities in 1976, and localities with light or no damage. The answers clearly show that the knowledge about the facts of the 1976 earthquakes is inadequate: better known is the social impact. Moreover, young people have a vague perception about the major natural hazard they are exposed to, and the answers are often influenced by misguided beliefs.

The paper by Petrini (2018) highlights the fact that the Friuli earthquake represented a turning point, still continuing, for the Italian way of viewing seismic risk mitigation. This is clear because of the important changes that have been introduced after the earthquake in terms of coordinated scientific research, importance of seismic zonation (also supported by studies of microzonation), and building code, as well as the need for vulnerability analysis for existing buildings and historical monuments.

In terms of victims and damage, the loss due to earthquakes in Italy appears to be too high when compared to the average level of seismic hazard. Riuscetti (2018) suggests that, while technical skills and norms in Italy are at a similar level to the most advanced countries in the field, a major effort is needed to diminish the vulnerability of the pre-code buildings and more attention should be paid to the epicentral effects that cannot easily be regulated by the seismic code.

The implicit conclusion is that, although science and regulations can satisfy the need for more protection against the seismic threat, the existing building stock generally shows a high vulnerability, with the exceptions of the few Italian regions hit by recent earthquakes, like Friuli. Moreover, the perception of seismic risk is strong soon after an earthquake but fades rapidly with the passing of time.

6. Conclusions

This volume considers only the scientific topics related to the 1976 Friuli earthquake. A more comprehensive overview should also take into account the sociological and economic aspects related to the occurrence of the event and the following evolution. Other conferences and literature have tackled these aspects (e.g. Geipel, 1982) that are beyond the scope of the conference where most of the material collected in this special volume were presented.

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