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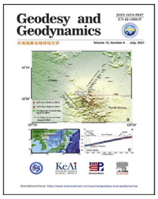

GIS-based study of the evolution of the IGN's strong motion network of mainland Spain and the balearics

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ABSTRACT

In some countries with seismicity, an adequate detection network is essential to assess seismic hazards. The Instituto Geográfico Nacional (National Geographic Institute/IGN) of Spain manages a strong motion network distributed throughout the whole country and an earthquake detection network composed of velocity stations. This paper aims at studying the development of the strong motion network of the Spanish National Seismic Network (focusing on mainland Spain and the Balearics) in the last three decades. A Geographic Information System (GIS) has been implemented to integrate the attributes from the IGN's database concerning the earthquake catalogue, seismograph and accelerometer networks, which enabled to analyse the data and map the distribution of detection equipments in the region. The irregularly distributed Spanish strong motion network was greatly expanded from 1990 to 2010. In the past decade, it developed at a slower rate, but more modern technology was implemented.

1. Introduction

The importance of seismic detection networks is irrefutable, especially in those areas with frequent earthquakes. Having a database with seismic events, recorded seismograms and accelerograms is essential to evaluate the seismic hazard. The ability to detect and parameterise events evolves over time, which may be due to the geographic configuration of the network and the use of new calculating methods/instruments [1]. In Southern European countries, the current network is the result of (at least) 20–30 years of evolution, and it is still under development [2,3].

In Spain, beyond the detection networks, the distribution of the strong motion network primarily depends on the location of the earthquake epicentres (spatial seismic pattern). This distribution is irregular since the epicentres are mainly in the Pyrenees, Galicia, Canary Islands, and the south of the Iberian Peninsula, as shown in Fig. 1.

The seismicity of the Iberian Peninsula can be rated as moderate or low-to-moderate. However, it has also been affected by large earthquakes, such as the offshore earthquakes of Lisbon (1755) and Cape Saint Vincent (1969), and the mainland earthquakes of Arenas del Rey (the so-called Andalusian Earthquake in 1884), Torrevieja (1829), Malaga (1680), and Queralbs (the Pyrenees in 1428) [4].

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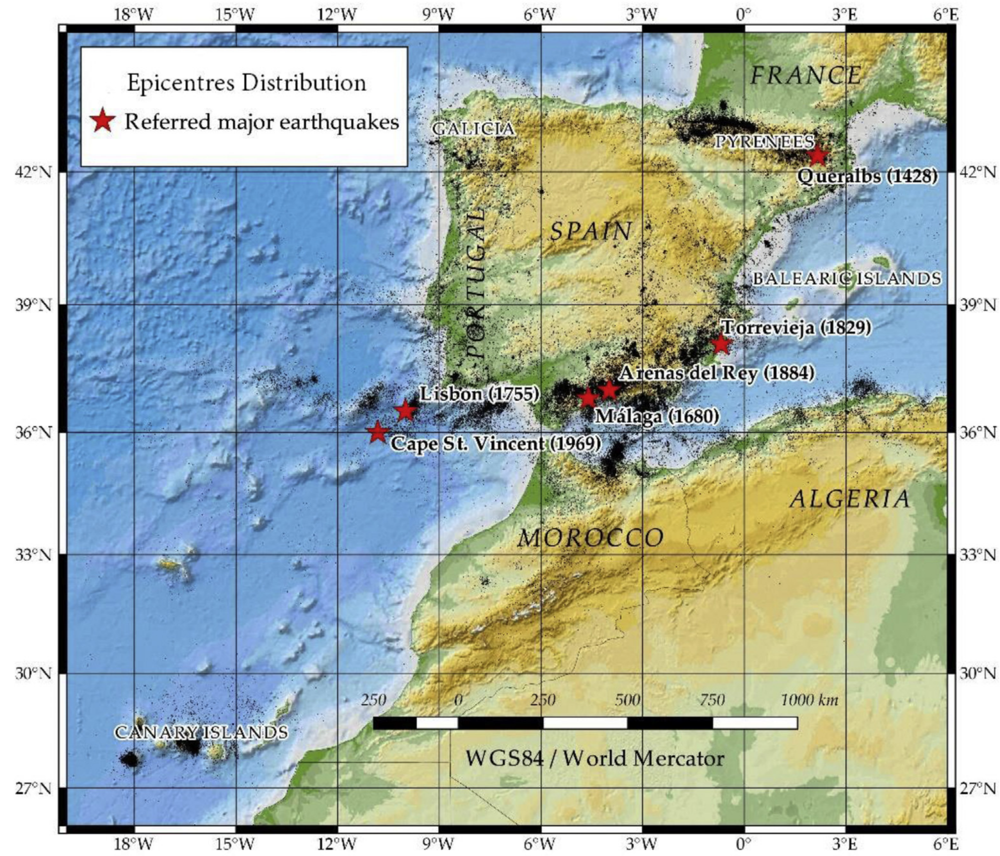

Fig. 1. Overall view of the epicentre distribution from IGN's earthquake catalogue (1373—July 2020).

In order to carry out probabilistic seismic hazards analyses (PSHA), it is helpful to know the expected ground motion. Therefore, the recordings of ground accelerations closely related to the macroseismic intensities are essential [5].

In addition to the earthquake detection network composed of velocity stations, the IGN manages a strong motion network distributed throughout Spain. The distribution of strong motion stations (accelerometers), the quality of the instruments, and the recording and transmission mode of information have improved over time [6]. The new accelerometer devices of IGN allow for real-time data reception, which contribute to achieving better hypocentral calculations since they are generally closer to sources than seismometers [6]. The instrumentation evolution towards real-time operation and the emergence of low-cost accelerometers make shakemaps more reliable. These maps are nearly real-time representations of ground motion generated by earthquakes [7], and help to predict hotspots where emergency services and troops need to be allocated.

In the seismic risk framework, simultaneously dealing with the attribute and geospatial information is crucial. Thus, the use of geographic information systems (GIS) is becoming increasingly common. Karimzadeh et al. [8] employed a GIS to conduct a topographic characterisation of seismic station in Iran; Phuong et al. [9] developed a Web-GIS support system to improve the earthquake warning service in Vietnam; Zaalishhvill et al. [10] evaluated the soil condition of strong motion stations through GIS simulation; Lam et al. [11] established a GIS approach to generate a risk map to arise infrastructure vulnerability to seismic hazards in Japan; Chatzopoulos et al. [12] used a GIS to analyse the spatial patterns of the strong motion parameters in Greece.

The evolution of the main seismic detection network in Spain has not been comprehensively studied. Consequently, with a GIS implementing geographical data, this paper is intended to study the growth of the strong motion network of the Spanish National Seismic Network (focusing on mainland Spain and the Balearics) for the last three decades. The paper is organised as follows: in Section 2, the methodological approach is presented, and the earthquake catalogue and the seismic detection network of the IGN are described; In Section 3, the evolution of the strong motion network is shown and analysed.

2. Materials and methods

2.1. Methodological approach

Based on data from the IGN and related scientific publications, a GIS was implemented to integrate the attributes from the earthquake catalogue, seismograph and accelerometer networks. Next, this tool was used to analyse the data and map the distribution of detection equipments in mainland Spain and the Balearic Islands.

2.2. IGN's earthquake catalogue

The official and more comprehensive seismic database of Spain is held by the IGN, as it is responsible for seismic activity monitoring throughout Spain. In fact, all the seismic data recorded by this institution are available on its website [6].

The geographical range of the IGN's earthquake catalogue expands from 20°W to 6°E and 26°N to 45°N. It primarily focuses on these areas: the Iberian Peninsula, the Balearics, and the Canary

Islands. The space between them is mainly Morocco with few records, because they hardly affect the seismic risk of Spain, and the distribution of the stations is consistent with this circumstance. The catalogue currently contains 139,187 events from 1373 to July 2020, which can be downloaded free of charge from IGN's website [13]. The catalogue comprises the magnitude and seismic intensity. The IGN updates the earthquake catalogue on a daily basis as new accelerations are recorded. Fig. 1 illustrates the distribution of the seismicity recorded in the catalogue. This study focuses on events appearing in the IGN catalogue with magnitude records in Mainland Spain and the Balearics. The distribution of the epicentres is provided in Fig. 2, which consists of 97,339 events. The oldest event with a recorded magnitude dates from 1910.

Besides, the earthquake magnitude distribution of Mainland Spain and the Balearics is displayed in Fig. 3. Based on the comprehensive analysis of Figs. 2 and 3, it can be stated that the magnitude of most events (more than 50,000) is less than 2.0, mainly concentrated in the south and southeast of the peninsula and the Pyrenees; more than 25,000 earthquakes with M_W2.0–3.0 occurred mainly in the Pyrenees and the southern peninsula; a significant part of nearly 10,000 earthquakes with M_W3.0–4.0 and more than 2000 earthquakes with M_W4.0–5.0 occurred outside the peninsula: on the Algerian coast and the south of Cape Stint Vincent. Low magnitude earthquakes in this area are not detected by the Spanish seismic network as expected. According to the catalogue, less than 200 earthquakes of magnitude greater than 5.0 (some were damaging as already mentioned), are mainly in the south of the peninsula, but there are also earthquakes in the southwest of Cape Saint Vincent, and the magnitude of earthquakes along the Algerian coast is relatively small.

2.3. Seismic detection networks

In mainland Spain and the Balearics, two main seismic detection networks of IGN coexist [6] and complement each other: whereas one network uses accelerometers to record ground motions, the other uses seismographs to determine the location and magnitude of earthquakes. Apart from the comprehensive national (IGN) network, there are others of different contexts and purposes, such as the Real Observatorio de la Armada (along the Spanish coast), the Instituto Andaluz de Geofísica (Andalusia and surroundings), and the Institut Cartogràfic i Geològic de Catalunya (mainly in Catalonia and nearby regions such as the Pyrenees mountain range). The characteristics and uses of seismographs and accelerographs of the main network are gathered in Table 1.

If close to the epicentre, the new accelerometers devices can calculate the hypocentral location more accurately —the depth of the seismic event is usually the coordinate with higher uncertainty. The accelerogram database presents acceleration records of earthquakes between 0.3 km and 653 km from the epicentre, with magnitudes ranging from 1.3 to 6.2.

The current accelerograph configuration can be seen in Fig. 4, including the mode of data extraction: real-time transmission, query upon remote request and in situ extraction. On the other hand, Fig. 5 depicts the current distribution of the seismograph (velocity) network.

As per Fig. 4 (132 devices) and Fig. 5 (93 devices), the ground motion network is more comprehensive, and the velocity network is more homogeneous over the territory. The closer the former is to the source, the more accurate the local parameter (acceleration) is; the smaller the azimuth gap, the more effective the latter is.

Fig. 6 shows the graphical output of the signal data recorded by one of the network accelerometer during a sample earthquake event. It occurred in Granada in January 2021 (Fig. 7), which was one of the largest earthquakes in the last 60 years in the mainland.

The ID of the earthquake event in the IGN's database is es2021bpbpa, its macroseismic intensity is V–VI, and the moment magnitude (M_W) is 4.4. This accelerogram shows the ground gravity acceleration (g) from 20 s before the event to 20 s after it. The highest peak ground motion (0.1538 g) is displayed in the vertical component (purple colour, third graph).

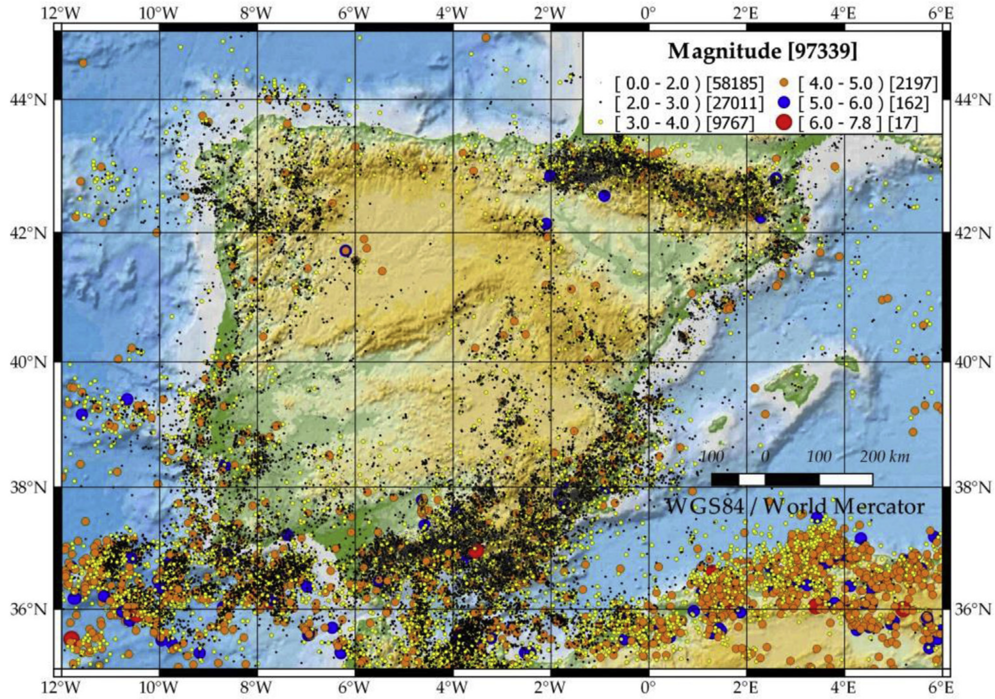

Fig. 2. Epicentre distribution of Mainland Spain and the Balearics only taking into account the magnitude records in the IGN catalogue.

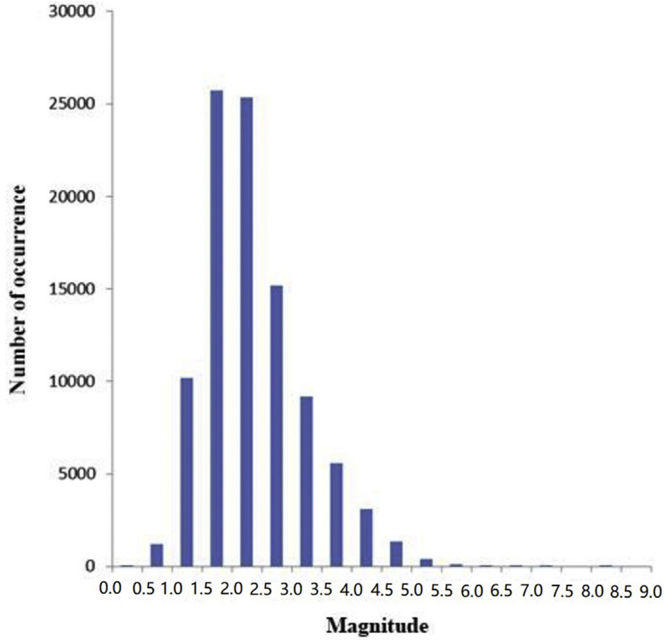

Fig. 3. The magnitude histogram of the IGN catalogue in Mainland Spain and the Balearics.

From the joint analysis of Figs. 6 and 7, the importance of the distribution of the strong motion stations can be highlighted. Due to their density, it has been possible to obtain the ground acceleration at a station approximately 2 km away from the epicentre, making the data more accurate and reliable, even allowing the integration of accelerogram data into the hypocentral calculations. Therefore, knowledge of the network evolution can help to accurately understand the seismic risk in a region.

Table 1
Seismograph and accelerograph characteristics.

Seismograph	Accelerograph
Measures wave velocity	Measures ground acceleration
Weak motions	Strong motions
Continuous measurement	Trigger threshold: 0.002 g
High signal amplification	Low signal amplification
Highly affected by cultural noise	Little affected by cultural noise
Isolated location	Urban settlement
Used for earthquake hypocentre location and magnitude determination	Used in seismic engineering

3. The evolution of IGN's strong motion network

Since 1977, when the IGN installed a network of analogue accelerographs distributed in areas with high seismic risk [14], the infrastructure has been evolving in terms of digital technologies implementation, the number of devices, resolution and data transmission mode. This paper aims to study the evolution of the strong motion network of the National Seismic Network in mainland Spain and the Balearics during the last three decades. As explained in subsection 2.2, a GIS is used to enquire attributes from the IGN's database regarding the detection equipment in 1990, 2000, 2010, and 2020 in the region (Fig. 8).

The different resolutions of the accelerometers are specified, in which the blue, yellow and red circles represent 12, 22 and 24 bits, respectively. The analogue network disappeared from the national territory after 2000 in favour of more modern devices. Thus, there has been a transition from 12-bit to 22 or 24-bit equipment; a larger number of the latter devices have been installed in comparison with past decades. In addition, high-resolution (24-bit) accelerometers have been set up in each predominant seismic area of the Iberian Peninsula (northwest, the Pyrenees, south-southeast) in 2020. Fig. 8 shows that the number of devices in 1990, 2000, 2010 and 2020 are 17, 58, 110 and 132, respectively. In view of the above, the evolution of the

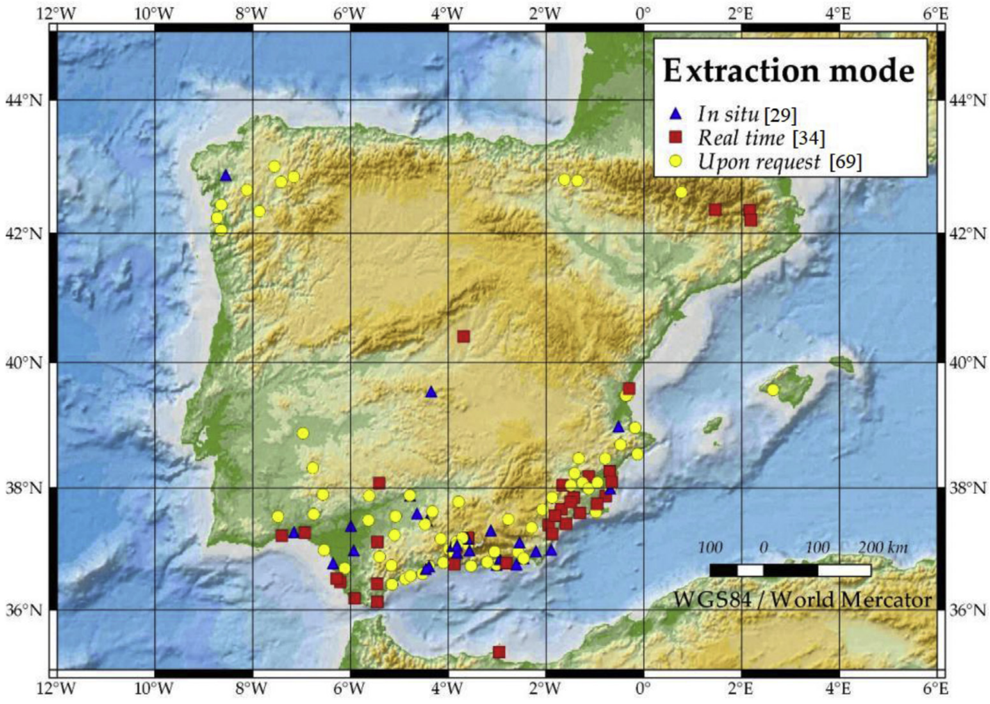

Fig. 4. Current accelerometer configuration network of IGN with the extraction mode.

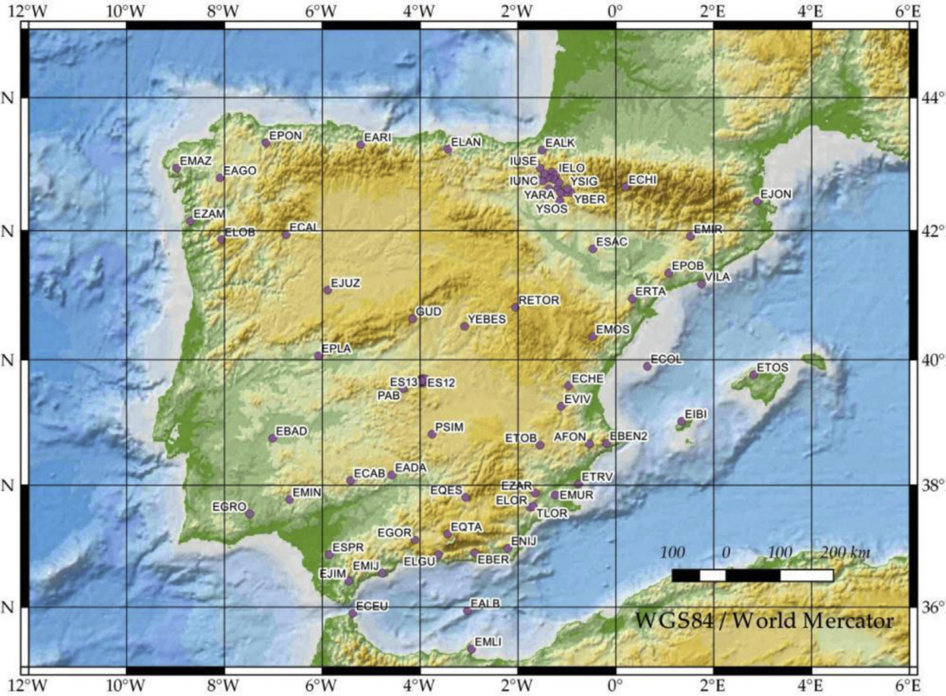

Fig. 5. Current seismograph configuration network of IGN.

number of accelerometers can be summarised as follows: the increase during 1990–2000, 2000–2010 and 2010–2020 are 241.18%, 89.66% and 20.00%, respectively. It should be noted that, during 2010–2020, although the increase in the number of devices is not prominent, the resolution of accelerometers has improved significantly. Fig. 9 shows the evolution of the number of devices in detail.

During the first two periods, the accelerometer network has been expanded with more equipment installed throughout the south and the southeast of the country. In addition, during the last decade, some units have been set up in other key areas of the Iberian Peninsula (Galicia and the Pyrenees) due to the seismicity (as seen in Fig. 2).

The accelerometer network is closely related to the location of the expected strong ground motion (following the spatial seismic pattern), and the geometrical configuration of the seismograph network is essential for successfully calculating the seismic parameters. Thereby, the geometry is of paramount importance to

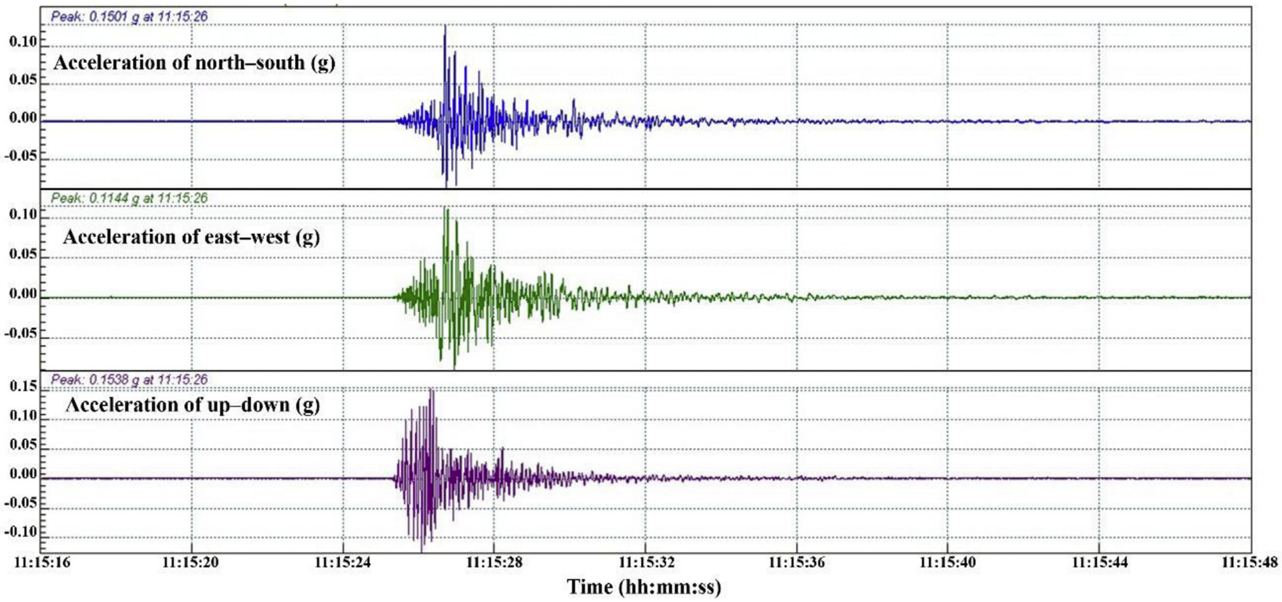

Fig. 6. Accelerogram of a seismic event, where the ordinate axis illustrates the acceleration of north–south (blue), east–west (green) and up–down (purple) components, respectively, and the abscissa axis represents the time.

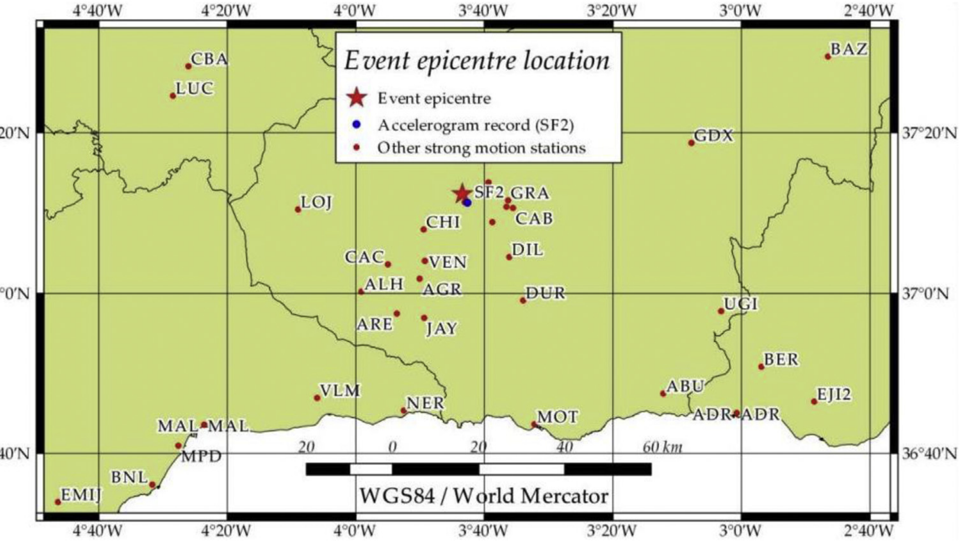

Fig. 7. Location of the epicentres of the seismic event in Granada (2021).

obtain an appropriate azimuthal gap. Furthermore, where the seismic hazard is greater, the density is higher.

González [1] conducted an in-depth study on the magnitude and a number of other seismic parameters in Spain. At present, the work of densifying these two networks is underway to improve the location calculation and ground motion recording. Nevertheless, this is carried out at a slower pace since any action on the networks is subject to budgetary constraints.

More details of the strong earthquake data collected in the study area [14], which can be used as background information of this study (30 years), are presented in Table 2. This includes peak ground acceleration (PGA), earthquake magnitude (Mag), epicentral distance (Dist) and macroseismic intensities (Int).

In Table 2, PGA_{Min} and PGA_{Max} denote the minimum and maximum acceleration triggering the accelerometer in the reference year; Mag_{min} and Mag_{max} represent the minimum and

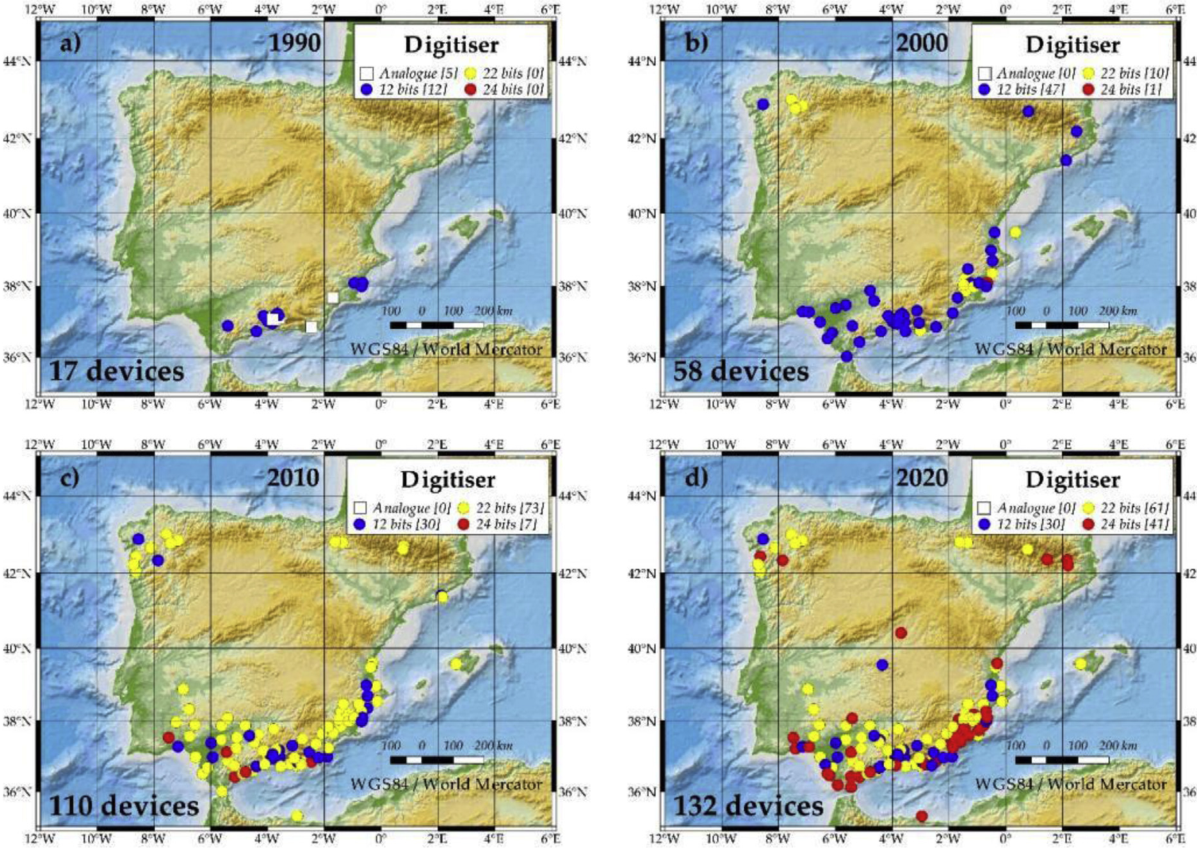

Fig. 8. IGN's strong motion network evolution (1990–2020).

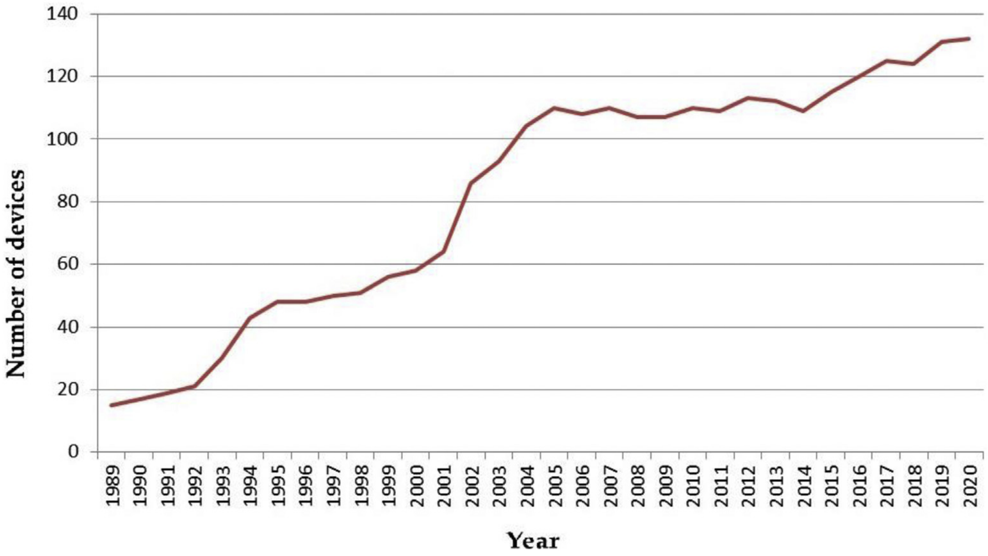

Fig. 9. Evolution graph of the strong motion network detection devices of the Spanish National Seismic Network.

maximum magnitude (not all are recorded as M_W) of the event with an acceleration recorded; $\mathrm{Dist}_{\min}$ and $\mathrm{Dist}_{\max}$ denote the minimum and maximum distance from the epicentre to a strong motion station; $\mathrm{Int}_{\max}$ represents the maximum epicentral intensity recorded for the reference year. From the above, the maximum recorded acceleration was in 2011 in Lorca, Murcia, and the maximum magnitude was 6.3 in 2016 (offshore). In addition, the macroseismic intensity generally did not exceed V, and it is uncommon to reach intensity VII. Finally, Fig. 10 illustrates the strong motion stations whose ground type has been characterised by Eurocode 8 classification. To do this, the IGN implemented the following surface wave analysis techniques such as Multichannel Analisys Surface Waves (MASW, active technique), Microtremor Array Measurements (MAW, passive technique), and Nakamura Technique (HVSR) to obtain V_s30 and f_o (ground natural frequency), where V_s30 is the average shear wave velocity for the shallowest 30 m [15].

Upon Eurocode 8, there are mainly five ground types (depending on V_s30), which have a major influence on earthquake vibration at the Earth's surface. The higher $Vs30$ is, the better (less hazardously) the ground behaves in an earthquake. The strata can be divided into: A (rock); B (very dense gravel/sand or very stiff clay);

Table 2
Main seismic parameters from 1993 to 2020.

Year	$\mathrm{PGA}_{\mathrm{Min}}$ (mg)	$\mathrm{PGA}_{\mathrm{Max}}$ (mg)	$\mathrm{Mag}_{\mathrm{Min}}$	$\mathrm{Mag}_{\mathrm{Max}}$	$\mathrm{Dist}_{\mathrm{Min}}$ (km)	$\mathrm{Dist}_{\mathrm{Max}}$ (km)	$\mathrm{Int}_{\mathrm{Max}}$
1993[a]	0.62	103.58	2.7	5.0	2.8	251.2	VI-VII
1994	0.57	119.96	2.8	5.7	1.1	269.5	VII
1995	0.65	29.90	2.6	4.1	3.9	71.4	V-VI
1996	0.56	58.64	2.2	5.0	0.7	352.9	V
1997	0.49	197.99	2.5	4.4	1.4	103.0	V
1998	0.39	35.06	1.9	3.8	1.4	76.4	IV
1999	0.54	55.06	2.1	4.7	0.4	228.3	VII
2000	0.51	38.03	1.9	3.8	0.7	377.1	V
2001	0.54	17.49	2.0	3.7	2.0	56.7	IV
2002	0.38	33.47	1.3	5.0	0.5	205.7	V
2003	0.62	33.06	1.8	5.3	0.5	367.1	V
2004	0.76	29.44	1.7	6.2	3.6	653.3	VIII[b]
2005	0.55	40.80	1.6	4.8	0.6	210.2	VII
2006	1.74	15.14	1.2	4.5	0.2	107.3	V
2007	0.88	100.60	1.8	6.1	0.5	629.2	V
2008	0.77	56.45	2.1	5.5	2.1	201.2	V
2009	0.80	86.16	2.1	5.5	0.9	379.7	IV
2010	1.06	43.32	1.6	4.3	1.4	57.8	V
2011	2.08	360.40	1.6	5.1	1.0	182.8	VII
2012	1.34	40.93	1.7	4.2	1.1	78.4	IV
2013	2.26	197.00	1.8	5.5	1.7	80.1	V
2014	2.05	22.34	1.4	4.2	2.3	70.1	V
2015	0.36	62.14	1.2	4.7	2.4	424.9	V
2016	1.80	96.97	2.3	6.3	2.3	268.0	VI
2017	2.22	161.33	1.9	4.7	1.1	131.5	V
2018	2.26	75.07	1.3	4.3	0.7	158.4	IV-V
2019	1.64	43.60	2.0	4.5	1.3	53.6	V
2020	1.14	80.13	1.5	4.5	1.3	78.2	V

[a] First recorded accelerogram in the IGN's database with reliable information.

[b] Both epicentre and macroseismic intensity were recorded in Morocco (Event ID in IGN catalogue: 458391).

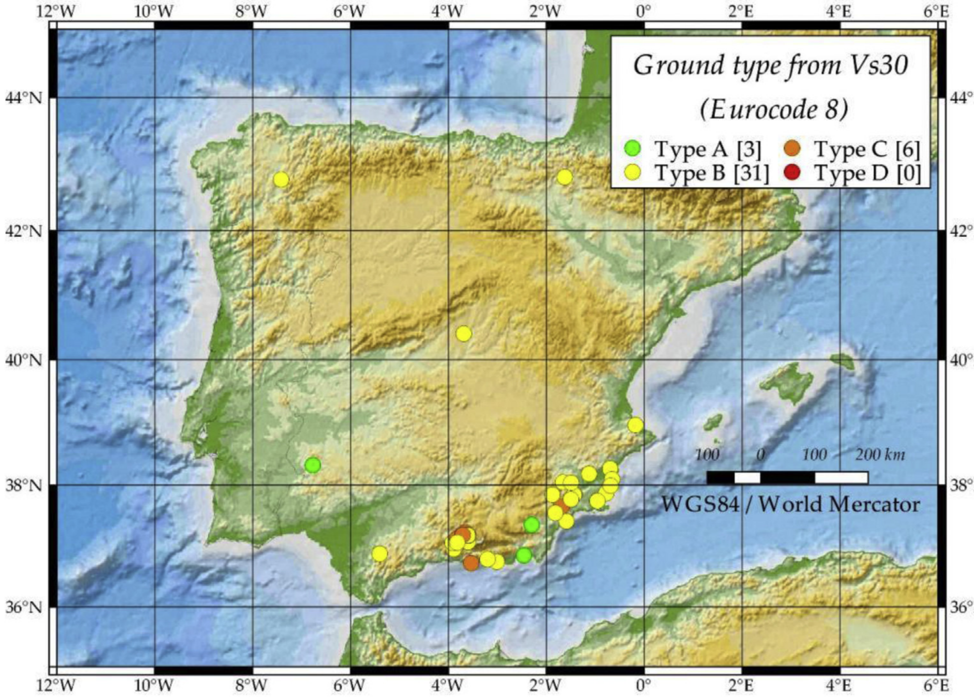

Fig. 10. Ground classification (Eurocode 8) at each strong motion station with V_S30 in-situ measurements.

C (dense gravel/sand or stiff clay); D (loose to medium cohesionless soil or soft to firm cohesive soil; and E (5–20 m thick surface alluvium layer over C/D or a much stiffer material). Thus, as Fig. 10 exhibits, there are six stations in a terrain that withstands the worst earthquake shaking (type C).

When the V_S30 of the station sites is not determined through exploration, the ground type should be estimated. According to the IGN, over 30% of the acceleration stations (40) already have V_S30 calculations from in-situ measurements. In this sense, the IGN is currently increasing the number of stations with field measurements to determine the ground type.

4. Conclusions

This paper addresses the study of the main strong motion network in Spain with moderate (or low-to-moderate) seismic activity. The scientific community frequently consults more than 2000 records in the IGN acceleration database for seismic engineering and seismology studies. This research analyses the evolution of the IGN network from the number, location and resolution of accelerograph and data transmission mode.

Technical development has enabled a more accurate accelerometer system to detect, record and monitor seismic events in the country. Both the increase in the number of acceleration stations with more extensive coverage over the territory and the use of new instrumentation contribute to improving the location of hypocenters and detecting strong motions more accurately. These are some of the input data for developing, revising and maintaining seismic-resistant standards for buildings and constructions, so as to prevent or minimise such natural disasters. The location of the IGN strong motion network devices is closely related to the areas with the greatest seismic hazard such as the south and southeast of Spain, the Pyrenees, and Galicia. However, certain seismic activity has taken place in regions such as the center and center-east of the Iberian Peninsula, with magnitudes ranging from 4 to 5. It should also be highlighted that the IGN is currently making efforts to provide the strong motion stations with the V_S30 parameter to determine the ground type for a better assessment of the seismic response.

Finally, this research reveals that the improvement of the IGN network includes low-cost strong motion accelerographs to enable a better knowledge of ground motions. This low-cost equipment also helps to create seismograms in real-time, which is very important for managing resources in case of a seismic emergency.

Author contributions

José-Lázaro Amaro-Mellado: Conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – review & editing, visualisation, supervision, and project administration.

Daniel Antón: Conceptualisation, methodology, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – review & editing, visualisation, supervision, and project administration.

Juan-Manuel Alcalde: Methodology, software, validation, formal analysis, investigation, resources, data curation, writing – review & editing, visualisation, and supervision.

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Conflicts of interest

The authors declare no conflicts of interest.

References

[1] Á. González, The Spanish national earthquake catalogue: evolution, precision and completeness, J. Seismol. 21 (2017) 435–471, https://doi.org/10.1007/s10950-016-9610-8.

[2] M. Siino, S. Scudero, L. Greco, A. D'Alessandro, Spatial analysis for an evaluation of monitoring networks: examples from the Italian seismic and accelerometric networks, J. Seismol. (2020), https://doi.org/10.1007/s10950-020-09937-0.

[3] E. Carreño, J. Rueda, C. López-Casado, J. Galán, J.A. Peláez, Spanish national strong motion network. Recording of the Huelva earthquake of 20 December, 1989, Pure Appl. Geophys. PAGEOPH. 136 (1991) 395–404, https://doi.org/10.1007/BF00878577.

[4] J.L. Amaro-Mellado, A. Morales-Esteban, F. Martínez-Álvarez, Mapping of seismic parameters of the Iberian Peninsula by means of a geographic information system, Cent. Eur. J. Oper. Res. 26 (2018) 739–758, https://doi.org/10.1007/s10100-017-0506-7.

[5] A.A. Gomez-Capera, M. D'Amico, G. Lanzano, M. Locati, M. Santulin, Relationships between ground motion parameters and macroseismic intensity for Italy, Bull. Earthq. Eng. 18 (2020) 5143–5164, https://doi.org/10.1007/s10518-020-00905-0.

[6] Insitituto Geográfico Nacional, Información Sísmica, Inst. Geográfico Nac, 2020. http://www.ign.es/web/ign/portal/sis-area-sismicidad. (Accessed 4 September 2020).

[7] State of California – United States of America, California ShakeMaps, 2019. https://www.conservation.ca.gov/cgs/shakemaps. (Accessed 26 October 2020).

[8] S. Karimzadeh, M. Miyajima, B. Kamel, V. Pessina, A fast topographic characterization of seismic station locations in Iran through integrated use of digital elevation models and GIS, J. Seismol. 19 (2015) 949–967, https://doi.org/10.1007/s10950-015-9505-0.

[9] N.H. Phuong, N.T. Nam, P.T. Truyen, Development of a web-GIS based decision support system for earthquake warning service in Vietnam, VIETNAM J, Earth Sci. 40 (2018) 193–206, https://doi.org/10.15625/0866-7187/40/3/12638.

[10] V. Zaalishvili, A. Kanukov, D. Melkov, K. Kharebov, M. Fidarova, GIS simulation of the geological objects' soil conditions: strong motion banks and databases, in: V. Murgul, V. Pukhkal (Eds.), EMMFT 2019, Springer, Cham, 2021, pp. 492–501, https://doi.org/10.1007/978-3-030-57453-6_47.

[11] C.Y. Lam, K. Tai, A.M. Cruz, Topological network and GIS approach to modeling earthquake risk of infrastructure systems: a case study in Japan, Appl. Geogr. 127 (2021) 102392, https://doi.org/10.1016/j.apgeog.2021.102392.

[12] G. Chatzopoulos, I. Papadopoulos, F. Vallianatos, J.P. Makris, M. Kouli, Strong ground motion sensor network for civil protection rapid decision support systems, Sensors 21 (2021) 2833, https://doi.org/10.3390/s21082833.

[13] Insitituto Geográfico Nacional, Catálogo de terremotos, Inst. Geográfico Nac, 2020. http://www.ign.es/web/ign/portal/sis-catalogo-terremotos. (Accessed 29 April 2020).

[14] J.M. Alcalde, L. Cabañas, E. Carreño, Red de Acelerógrafos del Instituto Geográfico Nacional, Topogr. y Cartogr. 34 (2016) 93–97. https://dialnet.unirioja.es/servlet/articulo?codigo=7446507.

[15] N.V. Silacheva, U.K. Kulbayeva, N.A. Kravchenko, On the realization of seismic microzonation of Almaty (Kazakhstan) in ground accelerations based on the "continual" approach, Geod. Geodyn. 11 (2020) 56–63, https://doi.org/10.1016/j.geog.2019.07.006.

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