Directivity effects of the May 11, 2011 Lorca (Spain) Mw=5.1 earthquake

Juan Rueda [(a,b)]*, *Julio Mezcua* [(a)] and *Rosa M. García Blanco* [(b)]
[(a)] Instituto Geográfico Nacional, [(b)] Universidad Politécnica de Madrid, Spain

* **Corresponding Author:** Instituto Geográfico Nacional. Calle General Ibáñez de Ibero 3, 28003 Madrid, SPAIN jjrueda@fomento.es

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Abstract

The great damage produced by this earthquake with 10 persons killed and more than 600 Million Dollars of direct costs in the city of Lorca (95000 inhabitants) in the southwest of Spain may be considered the most important event occurred in Spain since the Andalusian 1884 Earthquake in Granada. Focal parameters are 37.690 N latitude and 1.674 W longitude with a focal depth of 3 km and a Mw=5.1, and a PGA=0.39 g recorded at Lorca.

The great damage observed in this moderate earthquake is mainly due to the directivity effect of a unilateral rupture.

1.- The May 11, 2011 Lorca Mw=5.1 earthquake

This earthquake took place in the Alhama de Murcia active fault (AMF) which forms part of a NE-SW trending system of faults present in the SE part of Spain. This fault shows a left lateral movement caused by the NNW-SSE shortening direction of the Eurasia and African plates boundary. Besides the historical and instrumental seismicity related to this fault there is evidence of paleoseismicity in the last 30000 years, Martínez Díaz (1998).

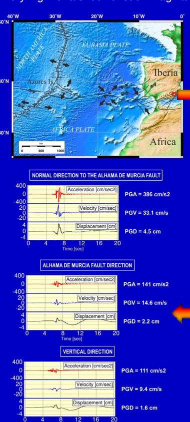
Historical seismicity associated to the AMF is moderate being VIII (EMS) the maximum intensity at the city of Lorca.

Total collapse in the Santiago Chapel in Lorca caused by the May 11, 2011 5.1 Mw Lorca Earthquake.

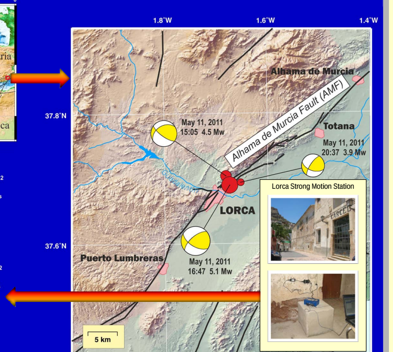
Total collapse of a reinforce building in Infante Juan Manuel Street in Lorca.

On May 11, 2011 at 15:05 (GMT) a 4.5 Mw earthquake was located on the AMF very close (≈3 km) to the city of Lorca and it was felt with intensity VI (EMS). At 16:47 (GMT) another shock 5.1 Mw hit Lorca with an intensity VIII (EMS), resulting the total collapse of some buildings, specially ancient churches and towers and very severe structural damage to new reinforce concrete buildings. At 20:37 (GMT) a 3.9 Mw aftershock occurred and it was followed in the next days for near 50 aftershocks of minor magnitude.

The PGA recorded at Lorca was 386 cm/s^2 in the normal component to the AMF trace, which is very high for a shock of such magnitude.



Three components of acceleration, velocity and displacement of the 5.1 Mw strong motion record at Lorca.

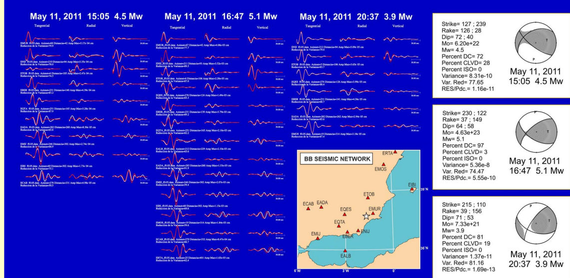


Main active faults in the area showing the corridor to the north of Lorca of the two branches for the AMF. Focal mechanisms of precursor, main shock and main aftershock.

2.- Finite-Source inversion

2.1.- Seismic Moment Tensor

The focal mechanism of main shock obtained by inversion of the waveforms recorded in the Spanish National Broadband Network, using the Dreger (2003) technique shows plane A (230, 64, 37) and B (122, 58, 149) with a variance reduction of 74% and a high double couple component of 97%. The seismic moment obtained is 4.63×10^{23} dyn·cm, with a Mw of 5.1. Plane A is in the same direction than the AMF. The precursor and main aftershock focal mechanisms are also shown.

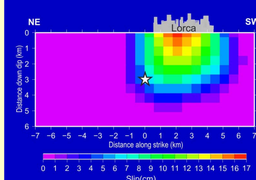


Results of the seismic moment tensor inversion of precursor, main event and principal aftershock.

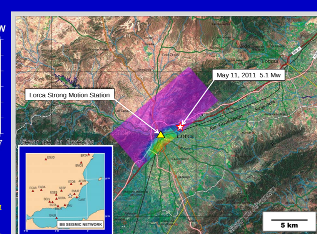
2.2.- Seismic Slip Distribution

An inversion for planar slip of the displacement regional records is carried out over the two possible planes using different rupture velocities by the Dreger and Kaverina (2000) technique. For a fault length of 5 km the highest variance reduction corresponds to the NE-SW plane, which corresponds with the AMF trace, with a Rupture Velocity V_R = 3.1 km s^{-1}. The slip distribution shows only one patch and there is no evidence of bilateral rupture, focusing the maximum slip at the city of Lorca.

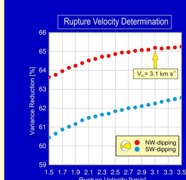
The slip at surface at the location of the strong ground instrument is of same order than the observed displacement in the Lorca strong motion record.



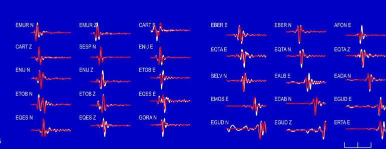
Finite Fault Inversion solution for a 3.1 km s^{-1} rupture velocity, constant rise time over the dipping NW plane determined by the Seismic Moment Tensor inversion.



Horizontal projection of the slip distribution over the fault plane. Stations used for the slip distribution inversion.



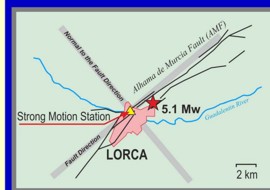
Rupture velocity determination for both planes, obtaining the maximum value for the NW dipping plane.



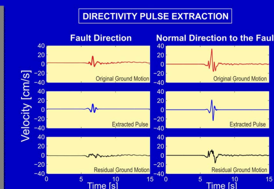
Displacement data (white) filtered (0.02-0.10 Hz) compared with synthetics waveforms (red) produced by finite source model.

3.- Directivity analysis

The damage pattern of this earthquake shows a linear concentration along the fault direction over the city of Lorca independently of the soil effect which is similar all over the city. The closet strong motion instrument in Lorca shows a pulse in the three components, being grater in the normal direction to the Alhama de Murcia fault trace. This velocity pulse is identified following the wavelet transform from Baker (2007) as a directivity pulse. The corresponding pulse period obtained is of T_p = 0.67s



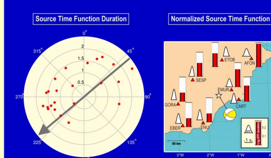
Distance between main shock epicenter and the Lorca strong ground motion instrument.



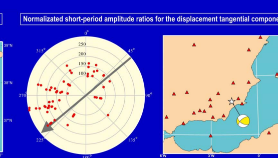
Velocity records for the directivity pulse extraction using the Baker (2007) technique, at Lorca strong motion instrument.

An empirical Green Function (eGF) analysis was done using the main event and the aftershock of Mw=3.9 with same focal mechanism. A deconvolution is performed to the three components displacement (0.05-1.0 Hz) records for both main event and the selected aftershock and stacking the results for each station. The resulting normalized Source Time Function (STF), Roumelioti *et al.* (2003), shows a shortening in those stations in the forward directivity direction as compared with those in the opposite direction.

The normalized short-period Wood Anderson amplitude ratio between main shock and the 3.9 Mw aftershock and three smaller aftershocks in their tangential component of displacement, shows a tendency in the NE-SW direction that ensures that the amplitude ratio is bigger than in any other direction. This is interpreted as an excess of amplitude of main event in that direction produced by a forward directivity.



Source Time Function duration in seconds for different stations around the epicenter showing a shortening in the forward directivity direction.



Short-period Wood-Anderson amplitude ratios for the tangential component of displacement between main shock and the 3.9 Mw aftershock and three smaller aftershocks.

Conclusions

- ➢The great acceleration recorded and the damage pattern observed for this 5.1 Mw earthquake indicates we are dealing with a special event.
- ➢A Seismic Moment Tensor inversion from the BB Spanish network data has been performed for precursor, main event and one aftershock obtaining a reverse and left lateral strike-slip movement for the AMF, compatible with the neotectonics studies.
- ➢Seismic Slip Distribution over the NW dipping plane show no evidence of bilateral rupture for a high velocity rupture of 3.1 km/s which may be interpreted as a requirement for directivity phenomena.
- ➢From the analysis of the strong ground motion record in the city of Lorca an extraction of a directivity pulse in the velocity record of 0.67 s period has been performed using the wavelet transform.
- ➢The empirical Green Function analysis and the normalized short period amplitude ratios observations for stations around mainshock confirm the directivity effect in the NE-SW direction.
- ➢The presence of the directivity phenomena in the AMF implies that in future hazard studies for the area a different treatment for this fault should be considered to take into account the directivity pulse influence. The most important difference would be not in the PGA but in the 0.3-0.6 s response spectra.

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