NUMERICAL SIMULATION OF THE 1940 LIMA-PERU EARTHQUAKE AND TSUNAMI (8.0 MW)

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ABSTRACT

In this research, we have conducted a numerical simulation to obtain the seismic source, coseismic deformation field and the tsunami propagation of the great 1940 Lima-Peru earthquake and tsunami, based on macroseismic information and focal mechanism from the literature. The seismic dimensions of our preferred model were set at 162 km×71 km according to VIII isoseismal intensity. The slip distribution is homogeneous with a mean value of 2.7 m. The fault plane orientation was set at strike=330°, dip=20° and rake=90°. The maximum simulated uplift was 1.27 m and the maximum subsidence was 0.36 m. Due to the proximity of the seismic source to the coast, the city of Huacho was uplifted around 11 cm. The fault plane of the 1940 earthquake was located in the updip near the coast. The maximum tsunami height simulated in Huacho was 1.80 m. We suggest that there is a high tsunamigenic potential near the trench to generate a shallow earthquake.

Keywords: Numerical simulation, Seismic source, Tsunami.

1. INTRODUCTION

On May 24, 1940, at 11:35 local time (16:35 UTC), the city of Lima and nearby towns were shaken by an earthquake, the maximum intensity of which was felt with VIII MM in Huacho. The shaking was felt from Guayaquil Ecuador to the north to Arica Chile to the south. It generated the destruction of many facilities in Lima, Callao, Chorrillos, Barranco, Chancay and Lurín. This earthquake left a balance of 179 dead and 3500 injured. The port of Callao suffered considerable damage due to the earthquake. In Chancay, 60 km north of Lima, damage to buildings was comparable to those observed in Lima. In Huacho, 130 km north of Lima, and in Lurin, 20 km south of Lima, the damages were minor and comparable to each other (Silgado, 1978).

Silgado (1978) has compiled a catalogue or database of earthquakes for Peru from 1500 (16th century) based on a recopilation of historical documents and observation field. According to Silgado (1978): “after the earthquake there was a small tsunami, in Ancon the sea retreated about 150 m, left the dock dry and filled slowly flooded land and passed over the defense wall of the pier, flooding the hangars of the Air Base, the phenomenon of the retreat of the sea was observed in La Punta, Callao and Pisco”.

1.1 Background of previous studies

Silgado (1978) reported the effects, damages on facilities and intensities in Lima and other cities; the isoseismal map is important, where the isoline of VIII bounds from Paramonga (to the north) until Lurín-Lima (to the south). Beck and Ruff (1989) recognize that there is very little information about the 1940 earthquake and the instruments constant and magnification factors of old seismographs are not always reliably known. They have calculated the focal mechanism of the 1940 earthquake (Table 1), which is an inverse fault type on the megathrust from teleseismic recordings of 8 stations. They obtained a simple source time function with one main pulse of moment release, the total duration of the rupture process was 30 s. The location of the asperity for the 1940 earthquake (to the south and near the epicenter) is estimated from the duration of the pulse of seismic moment release. They demonstrated that this was an interplate earthquake and finished the debate in those years about the nature of the seismic rupture of this event.

Beck and Nishenko (1990) stated that the 1940 earthquake was smaller than the 1966 (Mw 8.1) and the 1974 (Mw 8.1) events. A comparison of the P wave seismic recordings of 1940 and 1942 earthquakes indicates that the 1942 (Mw 8.2) event was approximately twice the size of the 1940 earthquake. We must take into account that twice the

Table 1. Hypocentral parameters and focal mechanism of 1940 Peru earthquake.

Date	24 May 1940
Origin time	16:35 UTC
Latitude	-11.22°
Longitude	-77.79°
Depth	10-30 km
Magnitude	8.0 Mw
Strike	340°
Dip	20°
Rake	90°

seismic moment corresponds to a difference of 0.2 in magnitude, therefore we can assign a moment magnitude of the Mw 8.0 to 1940 earthquake. Dorbath et al. (1990) obtained an empirical relation between the rupture length and the seismic moment of great historical earthquakes in Peru. They suggested that rupture zones are adjacent to regions of substantial destruction; in terms of isoseismal curves, the latter coincide roughly with the areas inside the isoseismal curve of intensity VIII. So, they assigned a fault geometry dimension of 220 km length for the 1940 Peruvian earthquake.

In this research, the seismic source of the 1940 Lima earthquake has been modeled (as a homogeneous slip distribution) for a seismic scenario based on Beck & Ruff (1989). The rupture geometry is based on the isoseismal of VIII according to Dorbath et al. (1990). Then, the coseismic deformation pattern is calculated to obtain the coseismic displacements vectors and to simúlate the tsunami propagation on a real bathymetry

1.2 Seismotectonic setting of Central Peru

The ocurrence of great earthquakes (Mw>7.0) in Peru is a consequence of the subduction of the Nazca Plate under the South American Plate, with a convergence velocity of 6-7 cm/y. The Central region of Peru is bounded by two tectonic elements: the Mendaña Fracture Zone to the north and the Nazca Ridge to the south, separated by a distance around 600 km. These tectonic elements act as a barrier for propagation of the seismic rupture (Figure 1). The seismic profile in the central region of Peru indicates a flat or normal subduction, with absence of Quaternary volcanic activity (Barazangi, 1976).

The great tsunamigenic earthquakes (of shallow focal depth) are distributed, in general, between the coastline and the trench. In the history of Peru, there were several of these megathrust earthquakes and tsunamis generated in Peru and reported from the 16th century by the spanish conquerors: 1586, 1687 and 1746 (Dorbath et al., 1990; Silgado, 1978). The accumulation of the seismic moment released by the 1940 (Mw 8.0), 1966 (Mw 8.1), 1974 (Mw 8.1) and 2007 (Mw 8.1) seismic sequence represents only around 20% of the accumulated moment deficit since 1746 (Mw 9.0), suggesting that a significant amount of seismic momento would still be released in this segment of more than 550 km from the Nazca ridge to the Mendaña fracture zone.

2. METHODOLOGY

2.1 Fault plane scenario

According to the methodology of Jimenez et al., (2013), we have constrained a homogeneous seismic source from macroseismic information reported in the literature (Silgado, 1978; Dorbath et al., 1990). For the seismic scenario of magnitude of Mw 8.0, the dimensions and slip of the fault geometry have been calculated using the scaling relations of Papazachos et al. (2004). Hence, the length is 162 km, the width is 71 km and slip is 2.7 m. The upperside depth of the fault is set at 8 km. The location of the fault geometry fits the isoseismal intensity of VIII. The focal mechanism parameters were taken from Beck and Ruff (1989). The azimuthal or strike angle was changed to 330°,

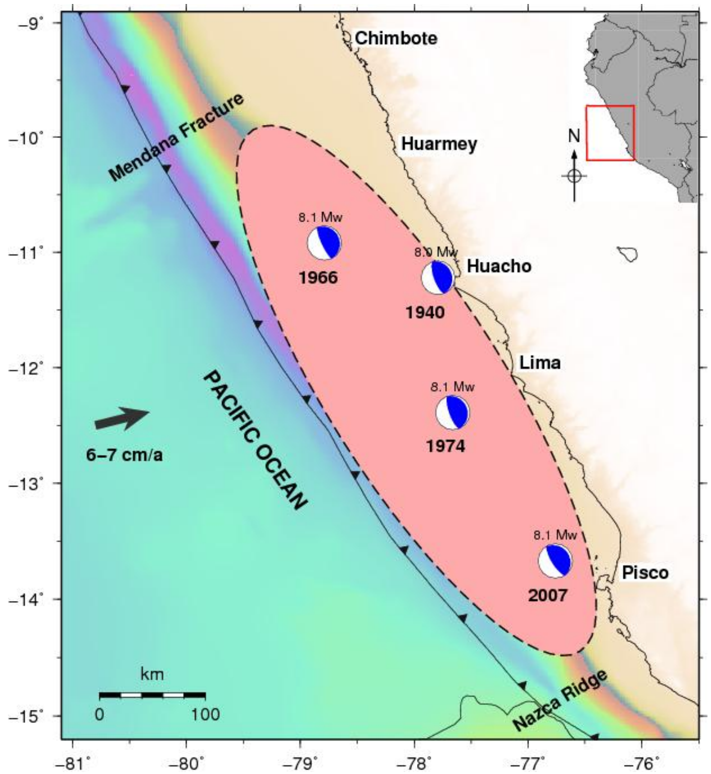

Figure 1. Seismotectonic setting of the Central Peru region. The pink ellipse represents the fault geometry of 1746 Callao earthquake (_Mw8.8-9.0). The focal diagrams represent the locations of events of the seismic sequence of 20th and 21st centuries

similar to the strike angle of the trench axis, to take into account the mean value of this parameter according to Global CMT catalog (www.globalcmt.org) for the central Peru region.

2.2 Tsunami numerical modeling

To obtain the initial condition for tsunami propagation, we have calculated the coseismic deformation field (vertical, north and east components) using the formulation of Okada (1992) considering an elastic, homogeneous, linear and semi-infinite medium. We take into account that the sea surface deformation is similar to sea bottom deformation and the deformation process is instantaneous. In this research, we use the linear shallow equations to simulate the tsunami propagation; however, the non-linear effects can not be ignored as the tsunami approached the coasts, because the tidal stations are located at very shallow region. Therefore, we have used also the non linear equations to simulate the propagation and inundation processes near the tidal stations (Jiménez and Moggiano, 2019).

3. RESULTS ANS DISCUSSION

The parameters and dimensions of the preferred seismic source geometry are: mean slip = 2.7 m, location of one corner of the fault plane (-77.66°, -12.02°, 8 km) and focal mechanism (strike = 330°, dip = 20°, rake = 90°). The seismic moment and magnitude equivalent was estimated in Mw 8.0. The synthetic tsunami waveforms were calculated in the locations of the tidal stations of Chimbote, Huarmey, Huacho, Callao and Paracas for two tsunami modeling: the linear and non linear models (Figure 2). We can noticed that the tsunami waveforms for thefirst period of linear and non linear models have a very good correlation. This fact allows the use of linear equations in tsunami waveform inversion, where only the first waveform period is used. Another observation is that the maximum height of the linear waveform is slightly greater than the non linear waveform; furhtermore, the linear waveform is contaminated by short period noise due to reflections on the coast.

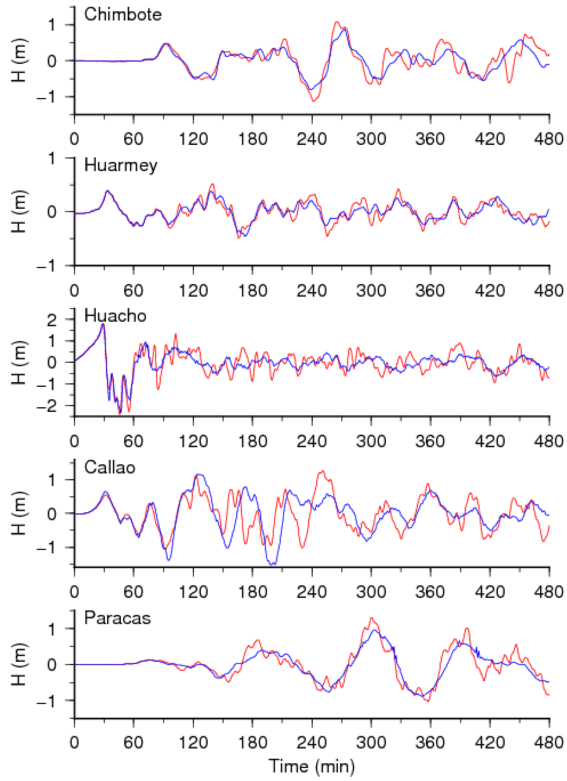

Figure 2. The synthetic tsunami waveforms recorded on the virtual tidal stations from the preferred model (Mw 8.0). The blue signals represent the non linear model and the red ones represent the linear model. For the _rst period, the linear and non-linear waveforms agree very well. H represents the tsunami height.

4. CONCLUSIONS

We have modeled a homogeneous seismic source of magnitude Mw 8.0 (corresponding to the preferred model) with dimensions 162 km by 71 km, with a mean slip of 2.7 m. Due to the lack of geophysical data, it is difficult to obtain a heterogeneous slip distribution and therefore to identify the main asperity. The first period of tsunami waveforms from linear and non linear models fits with a very good correlation. This fact allows the use of linear equations in tsunami waveform inversion, where only the first period is used. The maximum height of the linear waveform is slightly greater than the non linear waveform; furhtermore, the linear waveform is contaminated by short period noise due to reflections on the coast.

The maximum simulated tsunami height obtained for Huacho was 1.80 m and for Callao was 1.17 m, compatible with the historical reports of no significant damages in these ports. The tsunami travel time for Huacho would be immediate. For Callao, it would be 13 min and for Chimbote would be 68 min. Considering that the seismic sequence of earthquakes (Mw8) in 20th and 21st centuries has released only around 20% of the seismic moment accumulated from the megathrust earthquake of 1746 (Mw 9), and considering the interseismic coupling distribution for the Central Peru region, we suggest that there is a high potential for the generation of a shallow tsunamigenic earthquake offshore Huacho and near the trench.

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