THE COMPARISON BETWEEN THE STRONG EARTHQUAKES NEAR SUMATRA (26th DECEMBRE 2004 AND 28th MARCH 2005) AND THEIR TSUNAMIGENIC POTENTIAL

Dessilava Milusheva[1], Boyko Ranguelov[2]

[1]University of Mining and Geology "St. Ivan Rilski", Sofia 1700; dessie_milusheva@abv.bg
[2]Geophysical Institute, BAS, Sofia 1113

ABSTRACT. The comparative analysis about the two strong earthquakes near Sumatra Island (Indonesia) is made concerning their tsunamigenic potential. In the frame of the recent geotectonics, epicenter and hypocenter positions, depths of the seismic events, rupture process and the as well as other parameters considered the explanation about the tsunami generation process is outlined. The first giant earthquake (Mw9.3) generated a huge transatlantic tsunami, which kills more than 200 000 people in many countries around the Indian Ocean, thus appeared one of the greatest catastrophes during the mankind history. The second one (Mw8.7), located to the south produced a very small tsunami (which is absolutely unusual for such size of magnitude), but brought large destructions and more than 1000 deaths on the Nias Island. To know why two similar in power events generated (or did not generate) huge tsunamis, appears of essential importance in view of the people protection and economic safety of the threaten nations.

СРАВНЕНИТЕЛЕН АНАЛИЗ НА ДВЕТЕ СИЛНИ ЗЕМЕТРЕСЕНИЯ КРАЙ СУМАТРА (26ТИ ДЕКЕМВРИ 2004 И 28МИ МАРТ 2005) И ТЕХНИЯ ЦУНАМИГЕНЕН ПОТЕНЦИАЛ

Десислава Милушева[1], Бойко Рангелов[2]
[1]Минно-геоложки университет "Св. Иван Рилски", София 1700; dessie_milusheva@abv.bg
[2]Геофизичен институт, БАН, София 1113

РЕЗЮМЕ. Направен е сравнителен анализ относно цунамигенния потенциал на двете силни земетресения край Суматра (Индонезия) през 2004 и 2005 г. Разгледани са техните тектонски позиции, силата, разположението на епицентрите и хипоцентрите им, дълбочините, процесите на разломяване и други параметри имащи отношение към процеса свързан с генерирането на цунами. Първото земетресение с магнитуд 9,3 предизвика огромни трансокеански цунами, които взеха повече от 200 000 жертви, явявайки се по този начин една от най-грандиозните катастрофи, сполетели човечеството. Второто – с магнитуд 8,7, разположено по на юг, предизвика относително малка вълна цунами (което е абсолютно необичайно за земетресения с подобна сила), но генерира тежки разрушения на остров Нияс. Установяването на причините, защо близки по сила земетресения генерират (или не), опасни цунами е от изключителна важност за защитата на населението и икономическата инфраструктура на застрашените страни.

Introduction

This study is focused on one of the main problems generated by the two strong earthquakes – the Sumatra one (on 26th December 2004, M~9.3) and the Nias one (March 28th 2005, M~8.7) and their tsunamigenic potential. To answer the question – why similar in their magnitudes and other dynamic parameters very strong seismic events, generated so different tsunamis? - is a complicated task. The first dangerous event (a couple of earthquake and tsunami) had heavy consequences of more than 200 000 fatalities. The second one – with relatively small tsunamis with no victims, produced about 1 500 deaths as a consequence mainly due to the earthquake effects to the buildings. These very strong and destructive disasters lead to this investigation. Many data and information have been collected and different models of explanations suggested. The special attention has been paid to the historical seismicity and tsunamis. The preliminary assessment of the observed differences of the both seismic events and occurred tsunamis suggests that probably several factors influenced the tsunami generation process. The main result of this study shows that the most probable explanation about so different tsunami consequences are the volume of the displaced water due to the large bottom deformations of the both shocks and the average water depth of the areas where both shocks occurred.

Tectonic setting

The region where the great earthquake occurred on 26 December 2004, marks the seismic boundary formed by the movement of the Indo-Australian plate as it collides with the Burma subplate, which is part of the Eurasian plate. However, the Indo-Australian tectonic plate may not be as coherent as previously believed. According to recent studies reported in the Earth and Planetary Science Letters (vol. 133), it appears that the two plates have separated many million years ago and that the Australian plate is rotating in a counterclockwise direction, putting stress in the southern segment of the India plate. For millions of years the India tectonic plate has drifted and moved in a north/northeast direction, colliding with the Eurasian tectonic plate and forming the Himalayan Mountains. As a result of such migration and collision with both the Eurasian and the Australian tectonic plates, the Indian plate's eastern boundary is a diffuse zone of active seismicity and deformation, characterized by extensive faulting and numerous large earthquakes. The epicenter of the 26 December 2004 earthquake was near the triple point junction of three tectonic plates where major earthquakes and tsunamis have occurred in the past. Previous major earthquakes have occurred further north, in the Andaman Sea and further South along the Sumatra, Java and Sunda sections of one of the earth's greatest fault zones, a subduction zone known as the Sunda Trench. The great Sunda trench extends for about 3,400 miles (5,500 km) from Myanmar (Burma) south past Sumatra and Java and east toward Australia and the Lesser Sunda Islands, ending up near Timor. Slippage and plate subduction make this region highly seismic. The volcanoes of Krakatau, Tambora and Toba, well known for their violent eruptions, are byproducts of such tectonic interactions. In addition to the Sunda Trench, the Sumatra fault is responsible for seismic activity on the Island of Sumatra. This is a strike-slip type of fault which extends along the entire length of the island. The Burma plate encompasses the northwest portion of the island of Sumatra as well as the Andaman and the Nicobar Islands, which separate the Andaman Sea from the Indian Ocean. Further to the east, a divergent boundary separates the Burma plate from the Sunda plate. More specifically, in the region off the west coast of northern Sumatra, the India plate is moving in a northeastward direction at about 5 to 5.5 cm per year relative to the Burma plate.

Data about the earthquakes

The 26th Boxing Day 2004 earthquake occurred with a starting point of the hypocenter located at 3,316°N; 95,854°E. The reported mechanism by the Harvard tensor moment solution was thrust type (Fig. 1a).

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a) the 26th December 2004 seismic event

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b) the 28th March 2005 seismic event

Fig.1 a and b. The Harvard moment tensor solutions of both shocks, showing the same thrust type dislocations. [http://earthquake.usgs.gov/]

Then the ruptured process has extended to the North for about 10 minutes and according different models (Wahyu Triyoso, 2005; José Fernando Borges, 2005) the area of the surface dislocations covered more than 337 500 sq. kilometers. The depth reached 33 km. The initial aftershock's behavior confirmed this direction of dislocation. Almost two-three months after the main event, all aftershocks covered the north part of affected area, thus suggesting the highest probability to expect the next strong event located to the south. The thrust type mechanism, the great magnitude, large area of surface deformations, the activation of the underwater deposits slides and the displaced water volume are the main factors leaded to the giant tsunami spread across the Indian Ocean and brought so much victims and destructions. The earthquake of March 28, 2005 (M~8.7, depth down to 33 km., coordinates 2,074°N; 97,013°E) was probably triggered by the dynamic stress loading caused by the 26 December 2004 (M9.3) earthquake. The March 28 earthquake occurred – as a result of thrust faulting – on the boundary of the Australian and Sunda plates (Fig. 1b). It was caused by the release of stresses when the Australian plate subducted (and perhaps rotated) beneath the overriding Sunda plate. This interaction results in convergence at the Sunda Trench and involves local movement, with a total area of displacement of about 63 750 km^2. The shock was located to the south of the ruptured area of the first strong seismic event, and thus could be considered as a giant aftershock – Fig. 2.

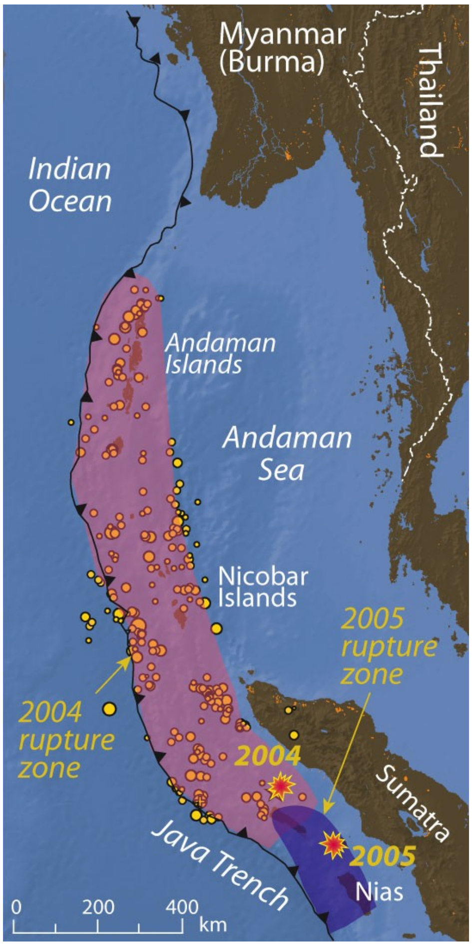

Fig. 2. The location of the both (26th Dec.2004 and 28th March, 2005) epicenters, ruptured zones (red and blue) and some aftershocks distribution, according their tectonic positions.

The data about the maximum heights of tsunamis and observed strong earthquakes in the region have been compiled and presented on Fig. 3 and Fig. 4. They show that this area is strongly seismic active and frequently produced tsunamis (Murty, 1977; Tinti, 1993). The maximum observed heights are connected with the 1883 Krakatau eruption and affected Batavia (at present Djakarta city).

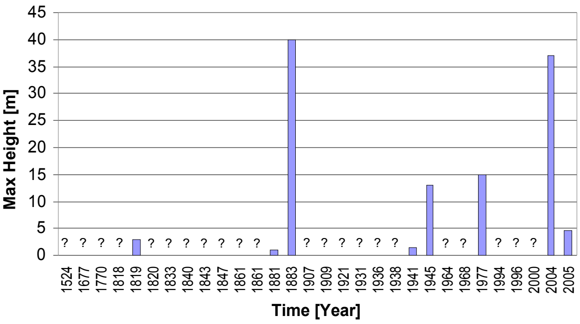

Fig. 3. The tsunami maximum heights data distribution versus time about the area 15° S 15° N latitude and 90-120° E longitude. The question marks show the indicated tsunamis, without heights data

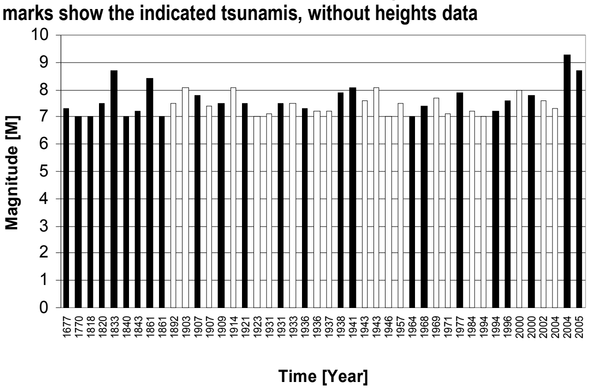

Fig. 4. Data about the known earthquakes in the region 15° S 15° N latitude and 90-120° E longitude with magnitude greater than 7.0. The tsunamigenic earthquakes are indicated by solid bars

A comparative analysis

Such great earthquakes (magnitude greater then 8.0) do not occur with great frequency on earth. Great earthquakes occur on the average every ten years. In the 20th century there have been about a dozen earthquakes with magnitude greater than 8 that can be characterized as great.

For two great earthquakes to occur so close to each other in time and space – as the 26 December 2004 and the 28 March 2005 events – is very unusual. However, the northern segment of the great Sunda Trench is a seismically unusual region of the world, characterized by very active interaction between the Indian and Australian tectonic plates and the Burma and Sunda subplates of the Eurasian tectonic block. Both of the recent earthquakes had their epicenters near the triple junction point where the Indian, Australian and Burma tectonic plates meet. Triple junction points of tectonic plates, particularly in areas of active subduction, are some of the most seismic areas of the world – capable of causing great earthquakes and tsunamis. The 1960 Great Chilean Earthquake and Tsunami originated near such a triple point tectonic junction. Usually, when a great earthquake occurs, most of the stress is relieved and another great earthquake may not occur for many years in the same region. However, this is not always the case, as dynamic stress loading can accelerate the occurrence of another earthquake along an adjacent seismic zone. Sometimes the opposite occurs and the release of energy on one segment, may also release stress on an adjacent seismic fault. In this case it appears that the process was accelerated rather than delayed. The summary of all investigated parameters have been presented at Table 1. Both seismic events have very similar characteristics (magnitude, depth, mechanism type). The differences are connected mainly to the ruptured areas (length, width, vertical displacements), average water depth, the supposed underwater slides and the tsunami parameters – maximum observed run ups and the displaced water volumes. It is visible that the maximum run ups Hmax are of one order difference and the displaced water volumes have the same differences. So, the reasonable explanation is connected with the presented model and due probably to the displaced water volumes. These numbers depends mainly on the average water depth in the areas of bottom displacements and their sizes. The energies released are 1/3 to 1/4 and depend on the magnitudes.

Table 1

Main characteristics of both earthquakes and tsunamis occurred on 26th December and 28th March

Date	M	H [km]	H_{water} [m]	Earthquake mechanism	H_{max} [m]	Location	Rupture length [km]	Rupture width [km]	Volume displaced water [km^3]	Underwater landslides	Energy released [J]
26.XII.2004	9,3	30 (10-33)	500-750	Thrust type	37	3,316°N; 95,854°E	1200-1300	270	210938	yes	$3.35x10^{18}$
28.III.2005	8,7	33	250-500	Thrust type	4.7	2,074°N; 97,013°E	350-400	170	20719	?	$1.11x10^{18}$

Conclusions

When the 26 December 2004 earthquake occurred, the Indian plate subducted the Burma plate and moved in a northeast direction. This movement caused dynamic transfer and loading of stress to both the Australian and Burma plates, immediately to the south, on the other side of the triple junction point. As a result of this load transfer, the Australian plate moved in relation to the Burma plate and probably rotated somewhat in a counterclockwise direction, causing the great earthquake of 28 March 2005. The block that moved was relatively small in comparison. However, another great earthquake similar to that of 1833 (magnitude 8.7) along the south coast of the western Sumatra, is possible. That particular earthquake generated a great tsunami. The waves may have been as much as 10 t0 15 meters on the western coast of Sumatra. Luckily, most of the energy from that tsunami was directed towards the unpopulated regions of the southwest Indian Ocean. According to Carayannis the smaller tsunami generated by the second shock is due to the different tectonic position, the lower energy (1/2 to 1/4 smaller) than to the first shock and the thicker sediments to the north (http://www.drgeorgepc.com/). According to our research and models the main reasons for the first generated giant tsunami are the earthquake ruptured mechanism, the great water volume displacements, the large magnitude and area affected (probably the underwater deposits slides activated) and the velocity of the rupturing process. The smaller second earthquake generated tsunamis are due to the shallower water (the earthquake epicenter located just near the Nias Island) and smaller area of displacements covered by the smaller volume of ocean water.

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