1. SPATIAL TSUNAMI WAVE MODELLING FOR THE SOUTH JAVA COASTAL AREA, INDONESIA

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SPATIAL TSUNAMI WAVE MODELLING FOR THE SOUTH JAVA COASTAL AREA, INDONESIA

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ABSTRACT: Geoposition of Indonesia that the country was surrounded by Eurasian – Australian and Pacific tectonic plate with its subduction zone (ring of fire) had experiencing very high frequency tectonic earth quake and risk of tsunami wave. The need of reliable tectonic plate earth quake and risk of tsunami spatial data base model was inevitable. The paper built numeric and spatial data base, analysis and develop tsunami modeling for three sites of south Java (Serang – west of south Java, Bantul - central and Banyuwangi - east of south Java) which were regarded as the most dense populated island. Phase one steps were built spatial database of the tectonic plate subduction zone with variable of depth, distance and ocean floor topography using ETOPO-2 USGS bathymetric data. Phase two steps including the development of tectonic plate earth quake history data base with above 6 Richter scale for the past five years. Development of numeric tsunami spatial model using MIKE-21 software (Evaluation License) with variable of tectonic plate earth quake coordinate, magnitude of 8 Richter scale and depth. Followed with detail analysis of the tsunami waves characters such as the height and travel time and direction towards coastal area, tsunami wave oscillation, time and run-up height and distance in reaching the coastal area. Phase three steps including development of spatial data base of contour Digital Elevation Model (SRTM-data), run-up model and wave height in reaching the dense population area and detail village and sub-district boundary, population, number of house and buildings, infrastructure and land use of the affected area and finally followed by escape route scenario and site-selection for possible community escape site.

Keywords: *Earth quake, Tsunami, South-Java, Indonesia*

1. INTRODUCTION

Indonesia as the most vulnerable country for tectonic erathquake surounded with 'ring of fire' of the Eurasian, Indo-Australian and Pacific plate, especially at the west coas of Sumatra, south coast of Java, along the south coast of West and East Nusa Tenggara, north Papua, Sulawesi/ Celebes and Molucas. The discrepancies in the past view year in spatial modelling for marine risk and hazards including risk of tsunami waves is especially due to the limitation of spatial data-base [1], analysis method and lack of a holistic point of view that an ecological spatial distribution state and analysis should be based on the whole ecosystem parameters itself as a unity, and should not be analyzed partially [2]. After three earthquakes with 8.4, 7.9 and 7.0 magnitude occurred along the coast of Mentawai islands West Sumatra since the last quake with 8.9 magnitude in 1833 the region might still hold enough energy to release 9.0 magnitude tremor that could produce deadly tsunami echoing the Aceh 2004 tsunami that klled more than 230,000 people in southeast Asia [3]
Great extensional faulting events in the shallow outer trench-slope region seaward of subduction zones are relatively rare, with the three largest-known events being the 1933 Sanriku, Japan, earthquake (moment magnitude Mw58.4), the 1977 Sumbawa, Indonesia,earthquake (Mw58.3). These huge intraplate earthquakes all had relatively high stress drop and strong tsunami genesis, with ruptures extending through the oceanic crust and at least 15–20 km into the uppermost mantle. These extensive fractures of the oceanic lithosphere are a result of plate bending and slab-pull forces. The deep faulting probably facilitates hydration of the lithosphere before subduction, enabling intermediate-depth and deep earthquakes once the plate subducts. The Sanriku and Sumbawa events occurred seaward of subduction zones for which the largest interplate thrust events are small, suggesting weak frictional coupling of the megathrusts. The 2009 Samoa event, with a seismic moment that places it among the four largest known trench-slope events, thus appears similar to the 1933 Sanriku and 1977 Sumbawa earthquakes, with the Tonga subduction zone megathrust apparently having weak frictional coupling [4]. The paper aimed to built spatial database, tsunami wave numeric modelling at along the south coast of Java. As well as to plann of escape zone for the worst tetonic earthquake scenario above 8 magnitude, for dense populated area of south Java coast at Serang (sout of west

Java) , Bantul (south of central Java) and Banyuwangi regency (south of east Java).

2. METHOD

Ocean floor morphology analysis using ETOPO2. v2 2006, USGS USA with 2-minute Gridded Sea Floor Topography to generate 2D-ocean floor morphology. Data base of tectonic earthquake history was compilled for ten years periode, consisting of coordinates, magnitude and tectonic earthquake depth (Km). Spatial tsunami wave modelling was built using MIKE-21 software (evaluaton license, Waindo SpecTerra Company) with variable of tectonic earthquake such as Initial rupture time [hh:mm:ss - UTC], Dip-angle (δ) : 35, Slip-angle (α) : 90, Strike angle (θ) : 315, , Fault mechanism : subduction dip-slip, Mw [-] : 8.4, Shear Modulus [Gpa] : 29.4 , Lambda [Gpa] : 25.9, with vertical deformation of tsunami wave generations. Three area of south Java coast tsunami model were made for Serang (south west Java), Bantul (south central Java) and Banyuwangi (south east Java). Scenario of earthquake magnitude of 8.4 Richter scale, depth (Km) was 23 Km for Serang coast latitude : 06° 32'09.60" S, longitude : 103° 34'19.20" E (south of west Java), with 315 degree of earthquake slope angle. Magnitude of 7.9 Richter scale, depth of 20 km for Bantul coast (south of central Java) with 300 degree of earthquake slope angle and magnitude of 7.0 Richter scale, depth of 15 km for Banyuwangi (south of east Java) with 270 degree earthquake slope angle. All the three model with geodetic datum of WGS1984. Magnitude of earthquake was made based on range of ten years data 6.1 – 8.7 Richter scale) based on ten years earthquake recorded data along the west Sumatra and south of Java. Analysis on predicted impact to coastal region using DEM-SRTM and Geo-Eye satellite data, tsunami run-up model, demographic or district population density data, coastal infrastructure such as roads and buildings.

3. RESULT and DISCUSSION

The spatial affection of the possible tsunami waves generation after plate tectonic earthquake on the coastal for coastal area zonation and risk and hazards aspects antisipation in order to minimise human lost, coastal infrstuctural damages and coastal management purposes were the main focus of the paper. Analysis of ocean floor morphology was cansidered as one of important point, where as also in the case of Aceh Tsunami 2004 that there is actually present a deep bottom channel structure infront of Banda Aceh region [2] and in this case is the presence of steep slope of bottom morphology reach to Sunda strait and approaching near to Lampung Bay (Fig. 1). That both we can use to anticipate and take into account the strength of tsunami wave striking energy since there was no ocean floor barrier structure in reducing the tsunami wave energy striking to the coastal area. Based on bathymetric and ocean morphology analysis we can identify the depth at subduction zone at Sunda strait is 6,453 m with distance to the most dense population district of Serang regency is 291.7 Km (Fig. 1). Scenario for tsunami wave model for Serang was set with 8.4 Richter scale at coordinate for tectonic earthquake at latitude : 06° 32'09.60" S, longitude : 103° 34'19.20" E located at the outer part of Sunda strait, inline with subduction zone (Fig. 2). Lesson learned based on the west Sumatra earthquake that the region might still hold enough energy to release a magnitude-9.0 tremor that could produce a deadly tsunami, echoing the 2004 tsunami that killed more than 230,000 people in southeast Asia. The earthquakes released pressure from a 700-kilometre-long region, known as the Mentawai section, which had been building since the last quake, an event of magnitude 8.6–8.9 in 1833 [5].

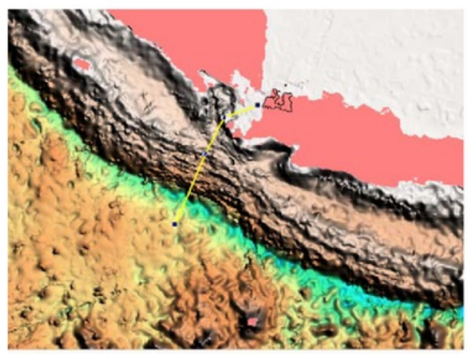

Fig.1. Ocean morphology and the subduction zone of Serang south West Java.

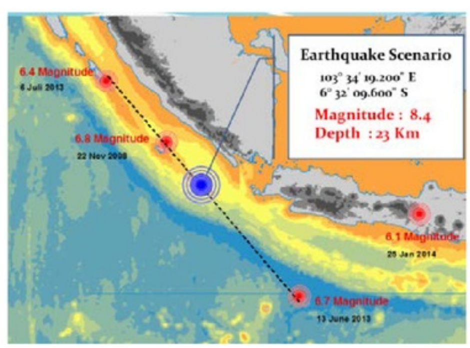

Fig.2. Tectonic database and tectonic earthquake scenario of 8.4 Richter scale and depth 23 km

After running the numerical spatial tsunami wave model, the tsunami waves reach the most dense populated coastal district coastal area of Serang and regarded as the most vulnerable coastal zone. Travel time of two tsunami wave was 66 minute, with elevation of 8 m height, 30 minute lag-time and followed with a 3 m low-seawater between the two big tsunami waves (Fig.3).

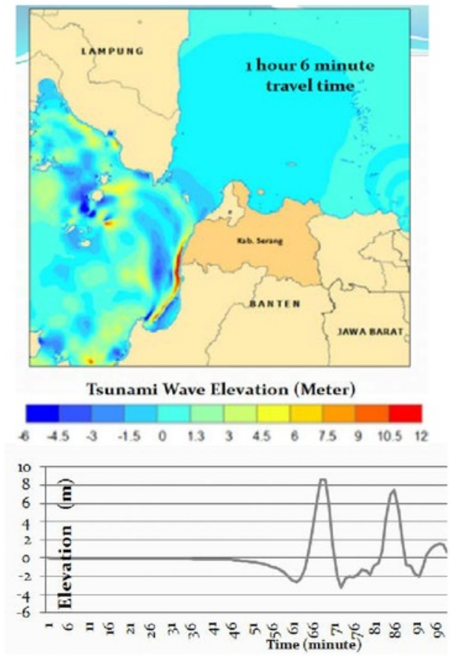

Fig.3. Tsunami wave height (m) and travel time (minute) reach the dense coastal populated zone of Serang coastal zone

Based on the tsunami wave model that reach to the Serang west Java, about 231.63 Km long of coastal area was affected by tsunami waves (Fig 3). Two most dense populated district at Serang were detected at the most vulnerable coastal zone with population density between 6,413 - 8,437 per hectare (Fig.4).

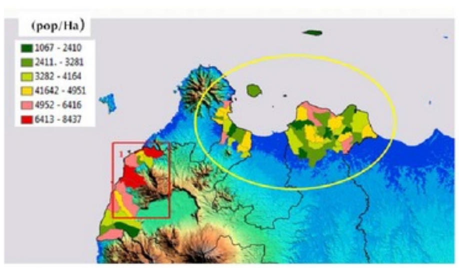

Fig.4. High population density at most vulnerable coastal districts of Serang regency south of west Java

The area was highly packed with the existance of many important and large scale industrial zones, industrial and passenger harbour, power plants, luxurius resetlements, resorts and hotels. Tsunami escape point scenario was made with radius from 200 up to 800 meter radius zone (Fig.5) characterised with hill and flat coastal area and alluvial soil type. Spatial model of run-up height and zone was used to set based on maximum tsunami wave elevation plus 30% and plus 3m height for safe escape building height plann.

Fig.5. Distance model and analysis for the escape zone and building at Serang coastal zone

Bathymetry analysis made at south Bantul coast (south central Java) indicates the presence of relatively more gentle slope of ocean floor comparred to Banyuwangi (south east Java) with a more steep ocean floor (Fig.6) as assumed relatively will have a beter bottom resistance for tsunamy wave energy. Distance from subduction zone to the coast of Bantul is 247.2 Km, while distance at Banyuwangi is 257.8 Km. After running in the tsunami wave model for these two coast, about 79.42 Km long at Bantul coast and about 111.16 Km long coastal area at Banyuwangi which mainly would be affected by high tsunami run-up model (Fig 7 and Fig 9) up to 8m high with 2m low-water cycle (Fig 8 and Fig 10). Time lag in between high and low water run-up model at Bantul coast was about 30 minutes, while at Banyuwangi coast was only 10 minutes delay. The difference of high-low water time lag at Bantul and Banyuwangi was considered due to the difference of ocean floor morphology, where more gentle slope identified at Banyuwangi. The two coastal area were mostly flat with sandy soil type (Fig 11). Population density at these coastal districts were less than 100 people per hectare and much less coastal infrastructure such as harbour, electricity plant, highway and big roads, comparred to Serang coast.

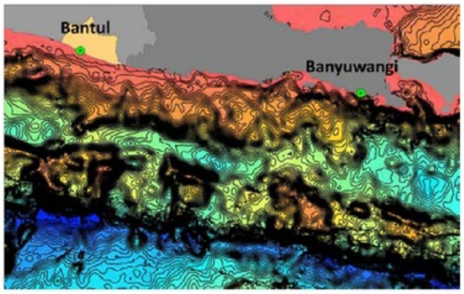

Fig.6. Bathymetry at south Bantul (south central Java) and Banyuwangi (south east Java)

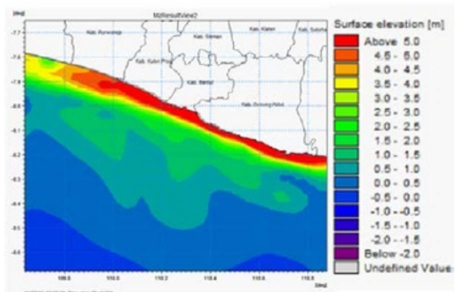

Fig.7. Tsunami wave model and height at Bantul south of central Java coastal zone

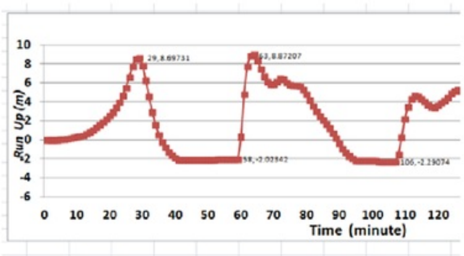

Fig.8: Run-up numerical model at Bantul south of central Java coastal zone

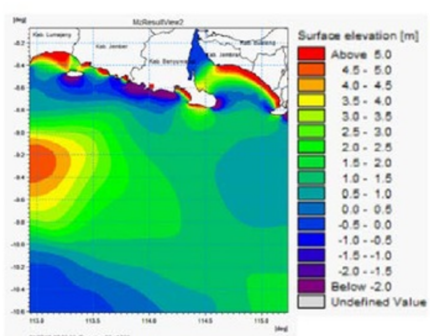

Fig.9. Tsunami wave model and height at Banyuwangi south of east Java coastal zone

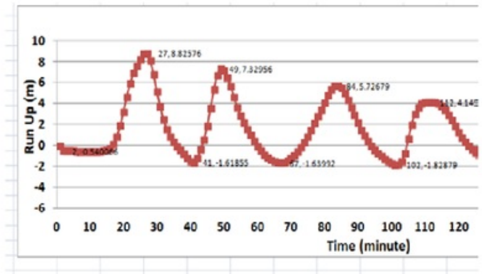

Fig.10. Tsunami wave height at Banyuwangi south of east Java coastal zone

Fig.11. Escape zone at the south of Banyuwangi coastal zone

Refer to the world's largest earthquakes occur along the contact between subducting and overriding tectonic plates in subduction zones. Rock and sediment properties near this plate interface exert important controls on the frictional behaviour of faults and earthquake rupture dynamics. An important material property to define along the plate interface is the rigidity (the resistance to shear deformation). Rigidity affects the degree of earthquake shaking generated by a given fault displacement through its influences on seismic wave speed and earthquake rupture velocity. Hundreds of subduction zone events had been analysed from northern Japan, the Alaska and Aleutian islands region, Mexico, Central America, Peru and Chile satisfying the following criteria: (1) close proximity to the interplate contact, (2) faulting geometry consistent with interplate thrusting, (3) moment magnitude (Mw) between 5.0 and 7.5, and (4) availability of at least four high-quality teleseismic digital P-wave recordings with good azimuthal coverage and high signal to noise ratio. If stress drop is assumed constant, rigidity appears to increase with depth in each seismogenic zone by a factor of 5 between depths of 5 and 20 km. This fact is consistent with the hypothesis that `tsunami' earthquakes (characterized by large slip for a given seismic moment and slow rupture velocity) occur in regions of low rigidity at shallow depths 3 - 5m. The rigidity trends should provide an important constraint for future fault-zone and earthquake-modelling efforts [4]-[5].

The Indian Ocean has experienced, along with three main phases of seafloor spreading, two major plate reorganizations from the late Jurassic to the present. With the first phase of spreading started in northwest (NW)–southeast (SE) direction and resulted in India's movement away from Antarctic-Australia during the early Cretaceous. During the middle Cretaceous, it appears that the Indian plate rotated from its early NW–SE to north (N)–south (S) direction and moved at a slow spreading rate. The second phase of spreading started in the N–S direction and during this period, India drifted in N–S direction from Antarctica with a rapid speed of 11 to 7 cma21. The Indian and Australian plates merged and formed as a single Indo-Australian plate during the middle Eocene. The third phase of spreading initiated in northeast (NE)–southeast (SE) direction and appears to continue since then where Java island characterised with mainly North-South plate tectonic movement and fault zones [6]-[9].

Rigidity, extent of rupture of any mega tectonic fault, coastal deformation [10] combined with stretch of tsunami such as Tohoku Kashima tsunami run-up had reached to 3,200m and tsunami deposist range from 300 – 2700 m from shoreline [11], together with spatial analysis in the future would be next important for coastal area risk and hazard zonation and planning.

4. CONCLUSION

Based on the running of tsunami wave model gererated, the three coastal area at the south of Java (Serang, Bantul and Banyuwangi coastal area) would be characterised with two up to 8 m high of two high tsunami waves with average of 30 minutes time-lag in between, coupling with a 2m of low-water will striking to the coastal area after 60 minutes travel time.

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