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Initial Tsunami Levels in the Philippine Trench (Philippines) from 1 in 100 Year and 1 in 1000 Year Return Period Earthquakes

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ABSTRACT

A major earthquake in the Philippine Trench in Philippines cannot be ruled out. In this paper initial tsunami levels from the earthquake parameters by Salcedo [1] have been generated. The initial tsunami levels from an 1 in 100 year return period earthquake have been generated to support design of marine structures and facilities. Initial tsunami levels from an 1 in 1000 year return period earthquake have also been generated to support emergency and rescue planning and operation. The initial tsunami levels have been generated using the MIKE21 Toolbox developed by DHI [2]. These initial tsunami levels can be used to drive a tsunami propagation model to derive tsunami levels, arrival time and forward velocity at anywhere around the Philippine Trench. The methodology described in this paper for generating initial tsunami levels in the Philippine Trench could also be applied to this type of events at other sites around the world.

Key words: Tsunami, Natural Hazards, Philippine Trench, Philippine Sea, Numerical Modelling, Port Development, Royal HaskoningDHV

1. INTRODUCTION

1.1 The Trenches in Philippines

Philippines is located in an active seismic zone. Both inland and offshore earthquakes are generated in the Philippines seismic regions generating tsunamis.

Known trenches in the Philippines [3] are:

1) Manila Trench
2) East Luzon Trough
3) Philippine Trench
4) Negros Trench
5) Sulu Trench
6) Cotabato Trench

These trenches are shown in Figure 1 from Tongkul et al. [4].

1.2 The Philippine Trench

As reported in Hou et al. [5], the Philippine Trench is located on the eastern side of the Philippines Islands. It is about 1320 km long, reaching a depth of 10497 m. The Philippine Trench extends from the north-eastern part of Luzon of Philippine to the Maluku Islands of Indonesia [6]. This trench was formed by a collision of two plates, the Philippine plate sub-ducting under the Eurasian Plate. The intersection of two plates is the Philippine Trench.

1.3 Tsunamigenic Earthquakes in the Philippine Trench

Besana et al. [7] reported two large earthquakes (Q1 and Q2 separated by 26 minutes) that occurred off the eastern coast of Mindanao along the Philippine Trench on 17 May 1992. These two events are only 20 km apart along Philippine Trench where the Philippine Sea plate subducts beneath the Philippine archipelago. During these events, the south-eastern coasts of the island experienced one strong ground shaking and suffered from one set of tsunami waves. The 17 May 1992 earthquake parameters are provided in Table 1 from Besana et al. [7].

Table 1 – 17 May 1992 earthquake parameters (Besana et al. [7])

Earthquakes	Date and time	Magnitude (Ms)	Location	Depth (km)
Q1	09:49:19.11 GMT	7.1	7.239°N, 126.645°E	25
Q2	10:15:31.31 GMT	7.5	7.191°N, 126.762°E	33

As reported in (Besana et al. [7]), a number of significant earthquakes occurred beneath the Mindanao Island along the Philippine trench [8-9]. High seismic activity confirms an active Benioff zone of mantle earthquakes along this zone that extends down to 150 km at 14° latitude and at around 100 km in the southern portion (5° latitude) with under-thrusting focal mechanism solutions along a NNW fault plane that dips 24° to the west [8].

1.4 Previous Studies on the Philippine Trench

Salcedo [1] provided a set of earthquake source parameters for events which can occur in subduction zones surrounding the Philippines and cause large tsunamis and damages. Salcedo [1] identified six source regions (Manila Trench, Negros Trench, Sulu Trench, Cotabato Trench, East Luzon Trough, and the Philippine Trench) surrounding the Philippines. The Philippine Trench was divided into six segments (PT1, Mw 8.3; PT2, Mw 8.1; PT3, Mw 7.9; PT4, Mw 8.2; PT5, Mw 8.1 and PT6, Mw 8.5). The earthquake source parameters such as fault location (longitude, latitude, depth), fault length, fault width, strike angle, dip angle, rake angle and slip amount as well as the maximum plausible earthquake magnitude for each fault segmentation were provided.

Besana et al. [7] carried out numerical modelling of the 17 May 1992 tsunami.

1.5 The Present Study

In this paper initial tsunami levels from the earthquake parameters by Salcedo [1] have been generated. The initial tsunami levels from an 1 in 100 year return period earthquake have been generated to support design of marine structures and facilities. Initial tsunami levels from an 1 in 1000 year return period earthquake have also been generated to support emergency and rescue planning and operation.

The general definition of tsunami level and tsunami wave height is illustrated in Figure 2. The flowchart in Figure 3 illustrates the steps and the software involved in a typical tsunami modelling study. The MIKE21 Toolbox developed by DHI [2] was used to generate the initial tsunami levels.

2. SELECTION OF EARTHQUAKE PARAMETERS

2.1 Fault Parameters of the Philippine Trench

The Philippine Trench was divided into six segments, namely PT1, PT2, PT3, PT4, PT5 and PT6 (as in Figure 4) by Salcedo [1] following the segmentation given by Bautista and PHIVOLCS-DOST [10]. The fault parameters from Salcedo [1] are provided in Table 2. The coordinates of the corner location of the fault are shown in the table.

Table 2 – Fault parameters of the Philippine Trench from Salcedo [1]

Sub-faults	Mw	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
PT1	8.3	15.00	125.10	230	86.20	60	3.29	150	33	90
PT2	8.1	13.00	126.00	190	77.40	60	2.63	150	34	95
PT3	7.9	11.60	126.60	143	65.95	60	1.89	165	45	90
PT4	8.2	10.40	127.00	206	81.01	60	2.89	165	36	90
PT5	8.1	8.20	127.50	190	77.40	60	2.63	180	35	90
PT6	8.5	6.44	127.40	325	95.00	60	4.00	135	39	90

2.2 1 in 100 Year Fault Parameters of the Philippine Trench [Mw 8.5]

Tsunami levels and forward velocity for an 1 in 100 year return period earthquake are required for designing marine structures and facilities. Therefore, initial tsunami levels were generated for an 1 in 100 year earthquake.

The earthquake magnitude (Mw) for various return periods for Philippines were obtained from Rong et al. [11] and are provided in Table 3 and shown in Figure 5.

Table 3 – Earthquake magnitudes for Philippines for various return periods [11]

Return periods	Earthquake magnitudes (Mw)
1 in 50 year	8.26
1 in 100 year	8.50
1 in 250 year	8.76
1 in 500 year	8.92
1 in 1000 year	9.00

All parameters (except depth and slip) were obtained from Table 2 [1]. Slip was estimated to obtain an earthquake Mw 8.5. The MIKE21 Toolbox does not accept a depth greater than 50km and, therefore, a depth of 50km was used in the study. The MIKE21 Toolbox requires the coordinates of a fault at its centroid and, therefore, the latitudes and longitudes from Salcedo [1] were modified. The final parameters for an 1 in 100 year earthquake are shown in Table 4. The resulting earthquake magnitude (as calculated by the author of this paper) is about Mw 8.5.

Table 4 – Fault parameters of an 1 in 100 year earthquake (Mw 8.5) in the Philippine Trench

Sub-faults	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
PT1	14.1111	125.0000	230	86.20	50	2.3	150	33	90
PT2	12.4444	125.7778	190	77.40	50	1.8	150	34	95
PT3	11.0889	126.4444	143	65.95	50	1.3	165	45	90
PT4	9.4444	126.9222	206	81.01	50	2.1	165	36	90
PT5	7.6111	127.2000	190	77.40	50	1.8	180	35	90
PT6	5.4444	127.8556	325	95.00	50	2.8	135	39	90

2.3 1 in 1000 Year Fault Parameters of the Philippine Trench [Mw 9.0]

Tsunami levels for an 1 in 1000 year earthquake are required to support emergency and rescue planning and operation. Therefore, initial tsunami levels were also generated for an 1 in 1000 year earthquake.

All parameters (except depth and slip) were obtained from Table 2 [1]. Slip was estimated to obtain an earthquake Mw 9.0. The MIKE21 Toolbox does not accept a depth greater than 50km and, therefore, a depth of 50km was used in the study. The MIKE21 Toolbox requires the coordinates of a fault at its centroid and, therefore, the latitudes and longitudes from Salcedo [1] were modified. The final parameters for an 1 in 1000 year earthquake are shown in Table 5. The resulting earthquake magnitude (as calculated by the author of this paper) is about Mw 9.0.

Table 5 – Fault parameters of an 1 in 1000 year earthquake (Mw 9.0) in the Philippine Trench

Sub-faults	Latitude (°N)	Longitude (°E)	Length (km)	Width (km)	Depth (km)	Slip (m)	Strike (°N)	Dip (°)	Rake (°)
PT1	14.1111	125.0000	230	86.20	50	13.3	150	33	90
PT2	12.4444	125.7778	190	77.40	50	10.5	150	34	95
PT3	11.0889	126.4444	143	65.95	50	7.7	165	45	90
PT4	9.4444	126.9222	206	81.01	50	11.9	165	36	90
PT5	7.6111	127.2000	190	77.40	50	10.5	180	35	90
PT6	5.4444	127.8556	325	95.00	50	16.1	135	39	90

3. GENERATION OF INITIAL TSUNAMI LEVELS

It is assumed that the initial sea surface rise is the same as the final seafloor deformation after the earthquake. This is a reasonable assumption because the duration of an earthquake is generally short and the size of the rupture area is much larger than the water depth. Consequently there is not enough time for the water above the deformed seafloor to drain out. The seismic rupture is much faster than water wave propagation.

Initial tsunami levels were generated for the earthquakes parameters in Tables 2, 4 and 5 using the MIKE21 Toolbox. Square grid size of 10 km x 10 km was used for the domain to generate the initial tsunami levels. Initial tsunami levels for each sub-fault were generated separately and were then summed up to obtain the combined initial tsunami levels. Figure 6 shows the initial tsunami levels generated using earthquake parameters proposed by Salcedo [1] as in Table 2. Figures 7 and 8 show the initial tsunami levels for Mw = 8.5 (1 in 100 year) and 9.0 (1 in 1000 year) respectively. The maximum initial tsunami level for each of the conditions are provided in Table 6. It should be noted that the maximum initial tsunami level and its location for a given Mw will vary due to the distribution of the length, width and dislocation (slip) of the sub-faults.

Table 6 – Maximum initial tsunami levels in the Philippine Trench

Earthquake magnitude (Mw)	Maximum initial tsunami levels (m)
8.6 (Salcedo, [1])	1.4
8.5 (1 in 100 year)	1.0
9.0 (1 in 1000 year)	5.6

4. SUMMARY AND FINDINGS

Literature search suggests that a major earthquake in the Philippine Trench cannot be ruled out. Initial tsunami levels for Mw 8.5 (1 in 100 year) and 9.0 (1 in 1000 year) were generated in the present study using the MIKE21 Toolbox.

Maximum initial tsunami levels of 1.0 m and 5.6 m were found from the present study for Mw 8.5 and 9.0 respectively. The initial tsunami levels generated in the present study can be used to drive a tsunami propagation model to derive tsunami levels, arrival time and forward velocity at anywhere around the Philippine Trench.

The maximum initial tsunami level and its location for a given Mw will vary due to the distribution of the length, width and dislocation (slip) of the sub-faults.

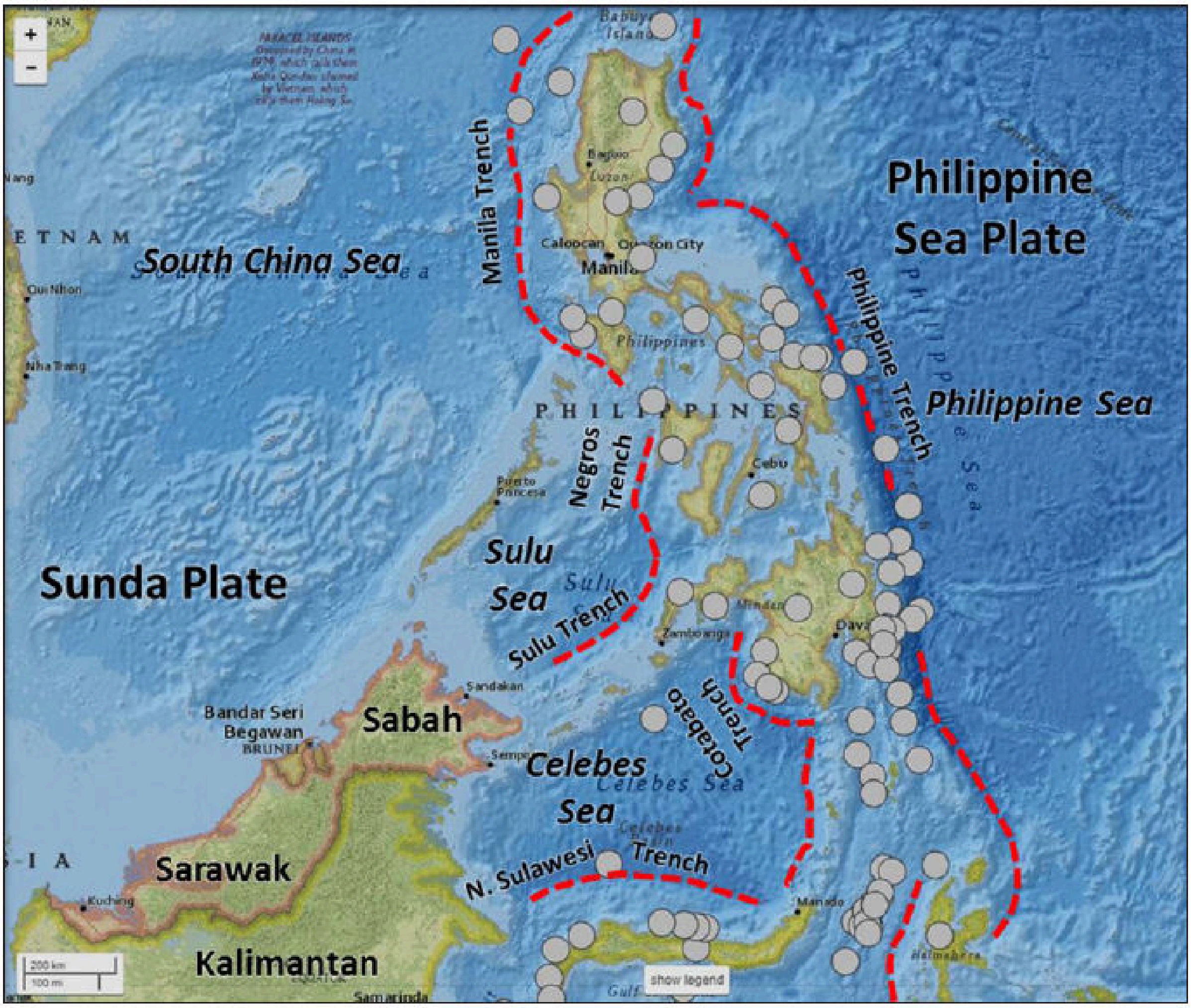

Fig. 1 Location of trenches around the Philippines [4]

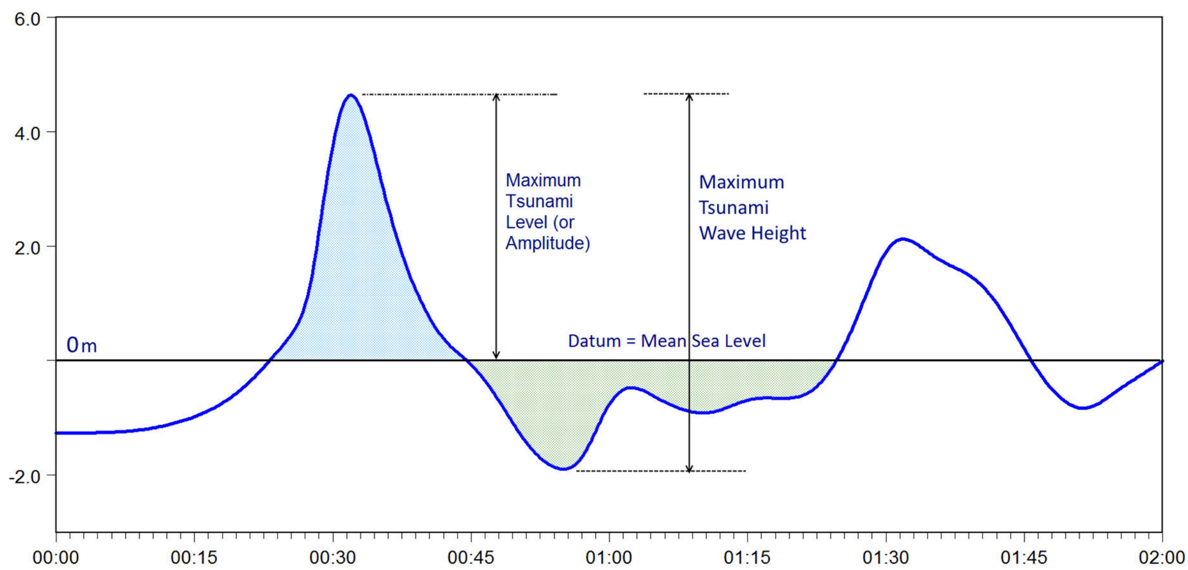

Fig. 2 General definition of tsunami level and tsunami wave height

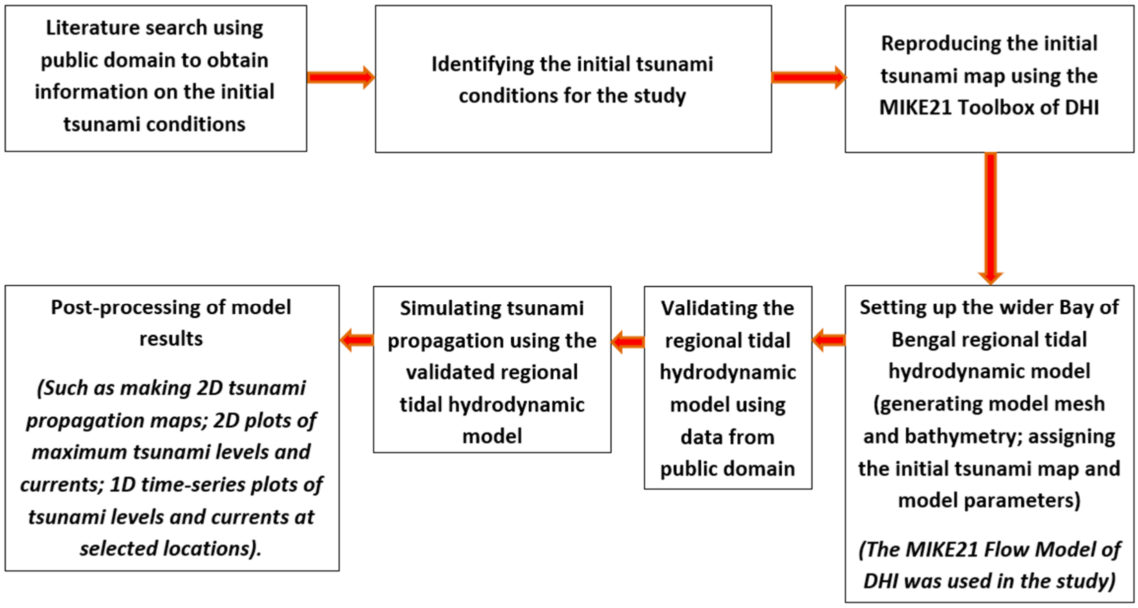

Fig. 3 Steps and software used in a typical tsunami modelling study

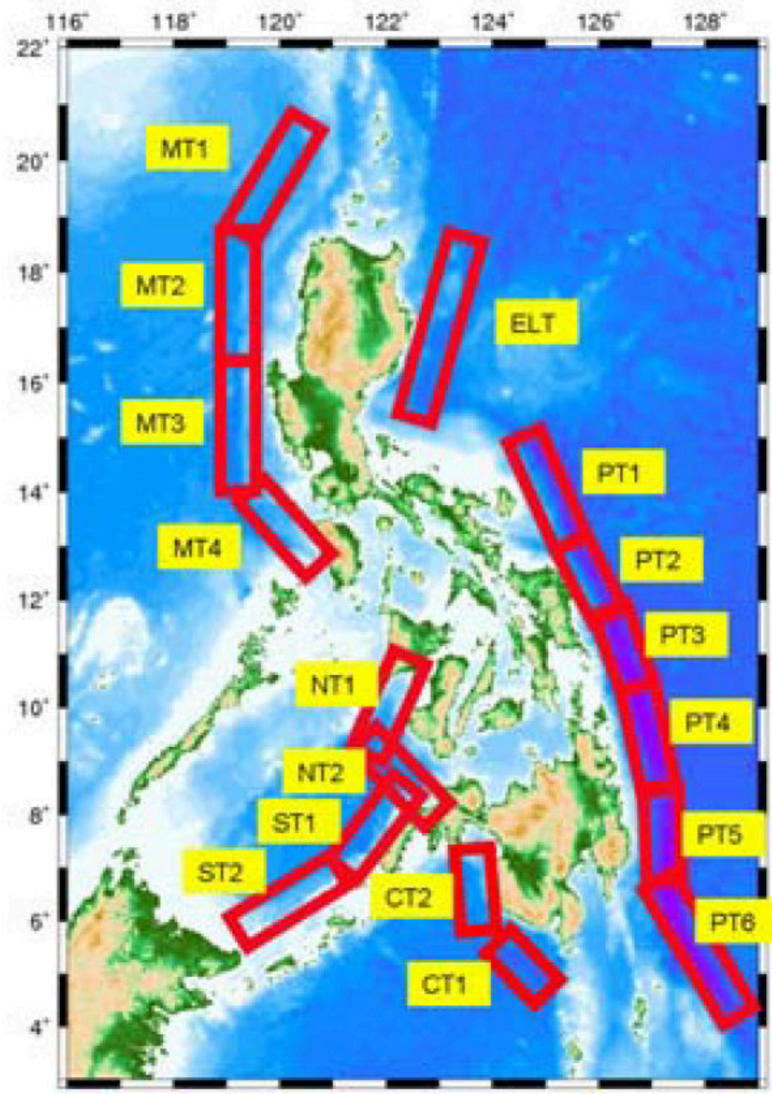

Fig. 4 Sub-fault distribution of the trenches around the Philippines from Salcedo [1]

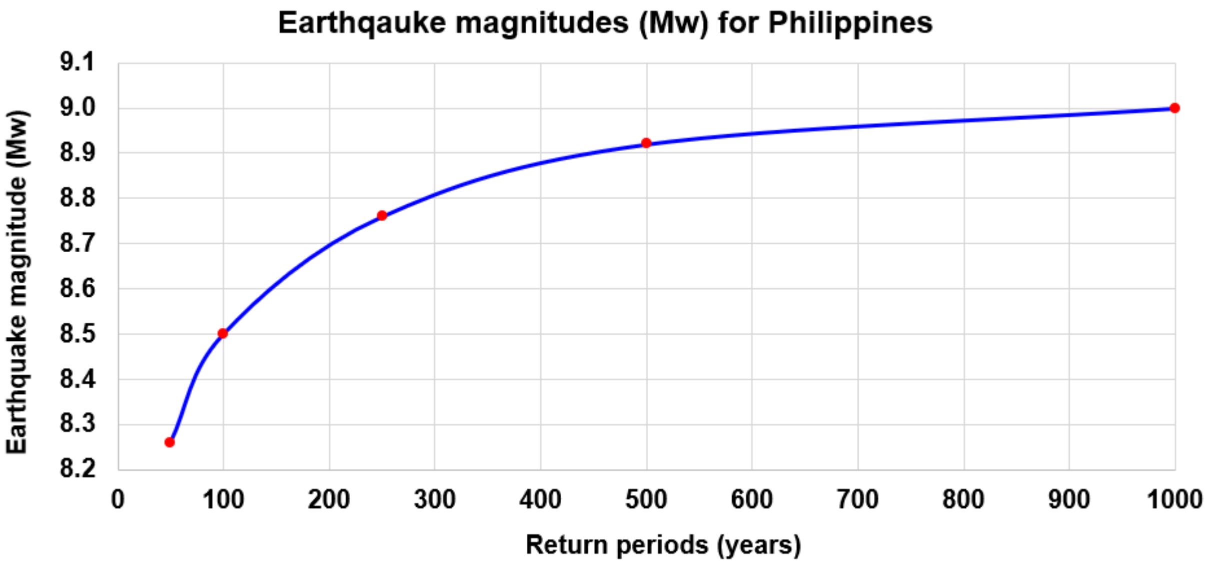

Fig. 5 Earthquake magnitudes (Mw) in Philippines for various return periods [11]

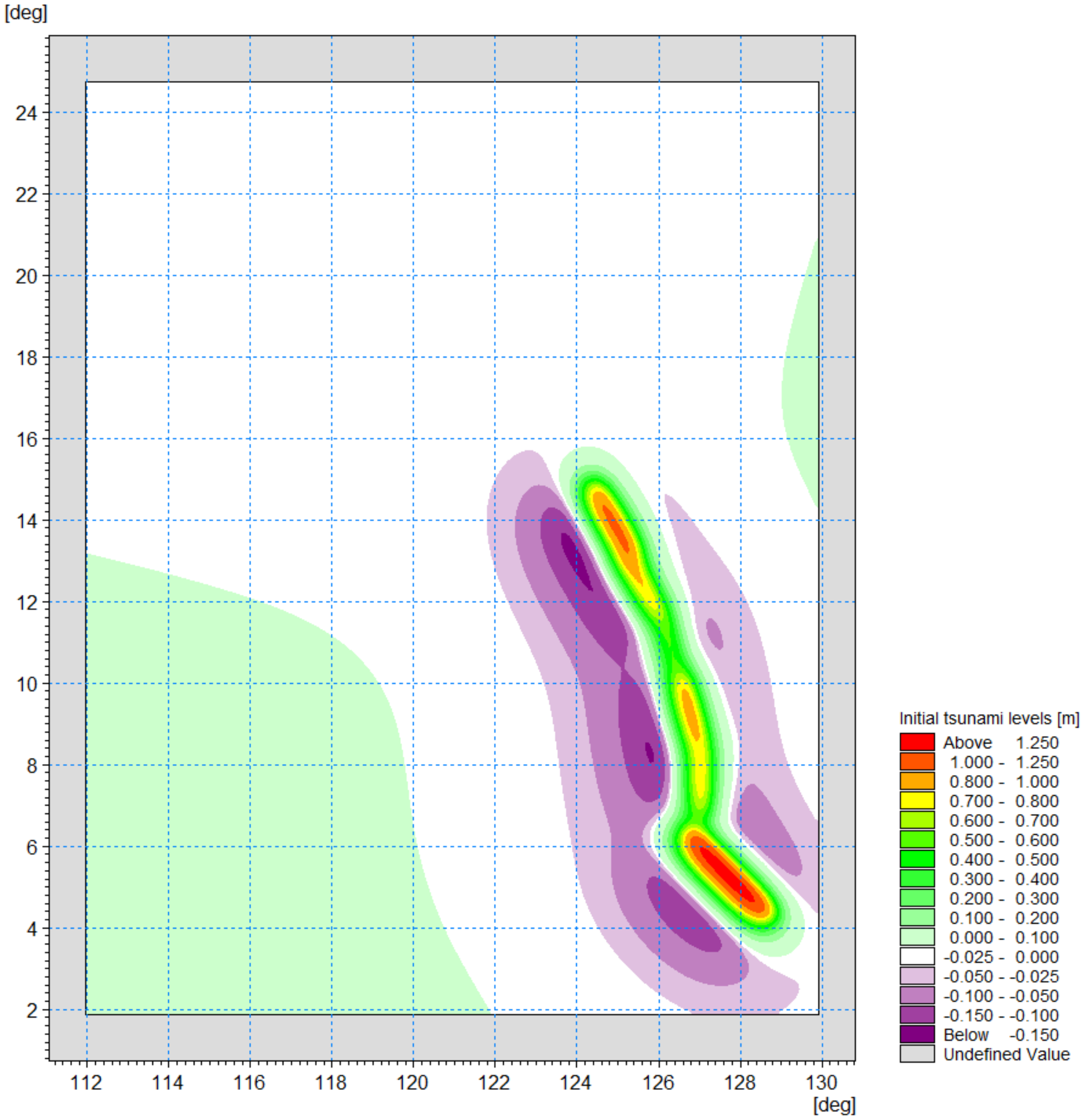

Fig. 6 Initial tsunami levels for the earthquake parameters (Mw 8.6) proposed by Salcedo [1]

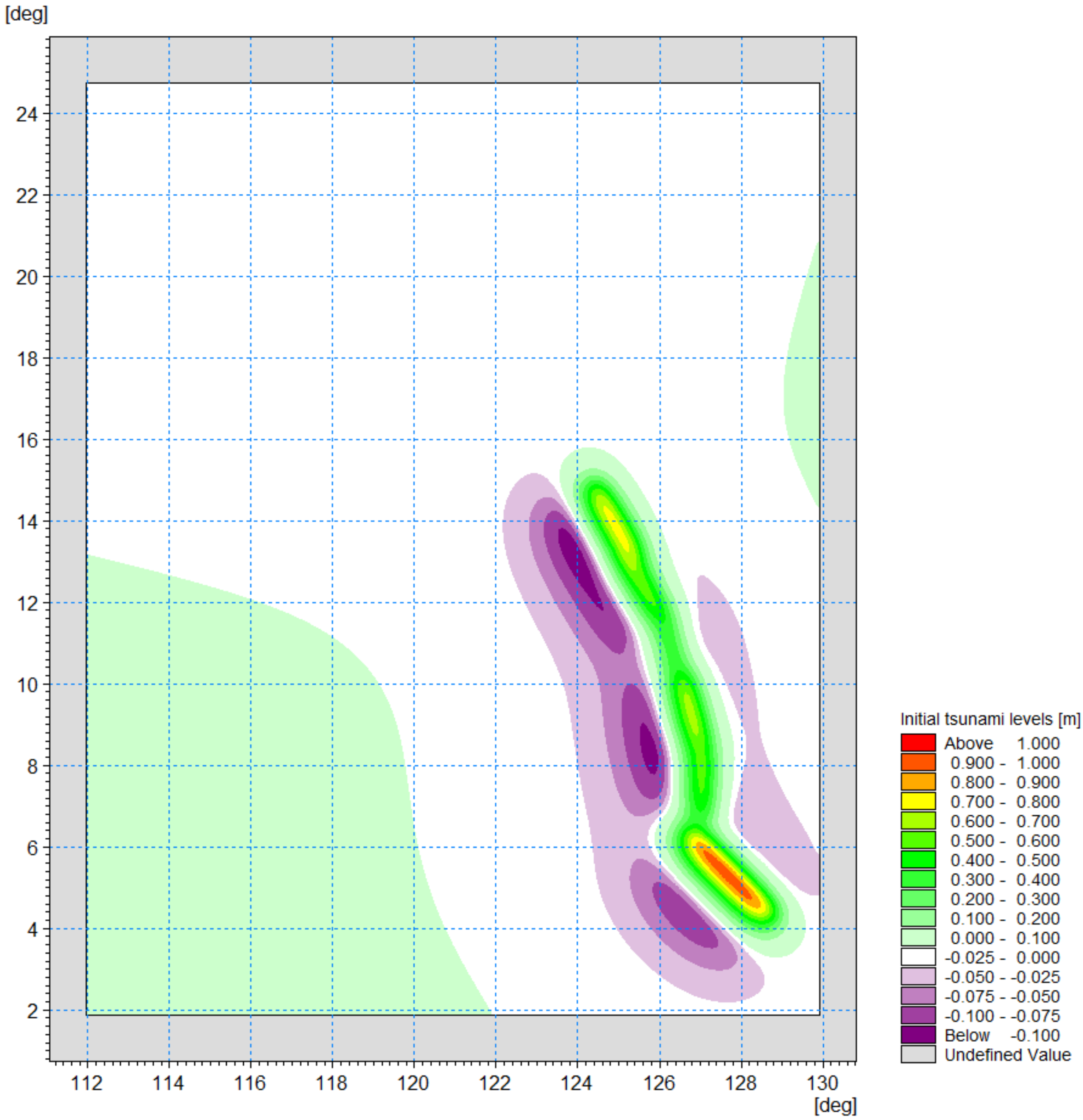

Fig. 7 Initial tsunami levels for an 1 in 100 year earthquake (Mw 8.5) in the Philippine Trench generated by Royal HaskoningDHV

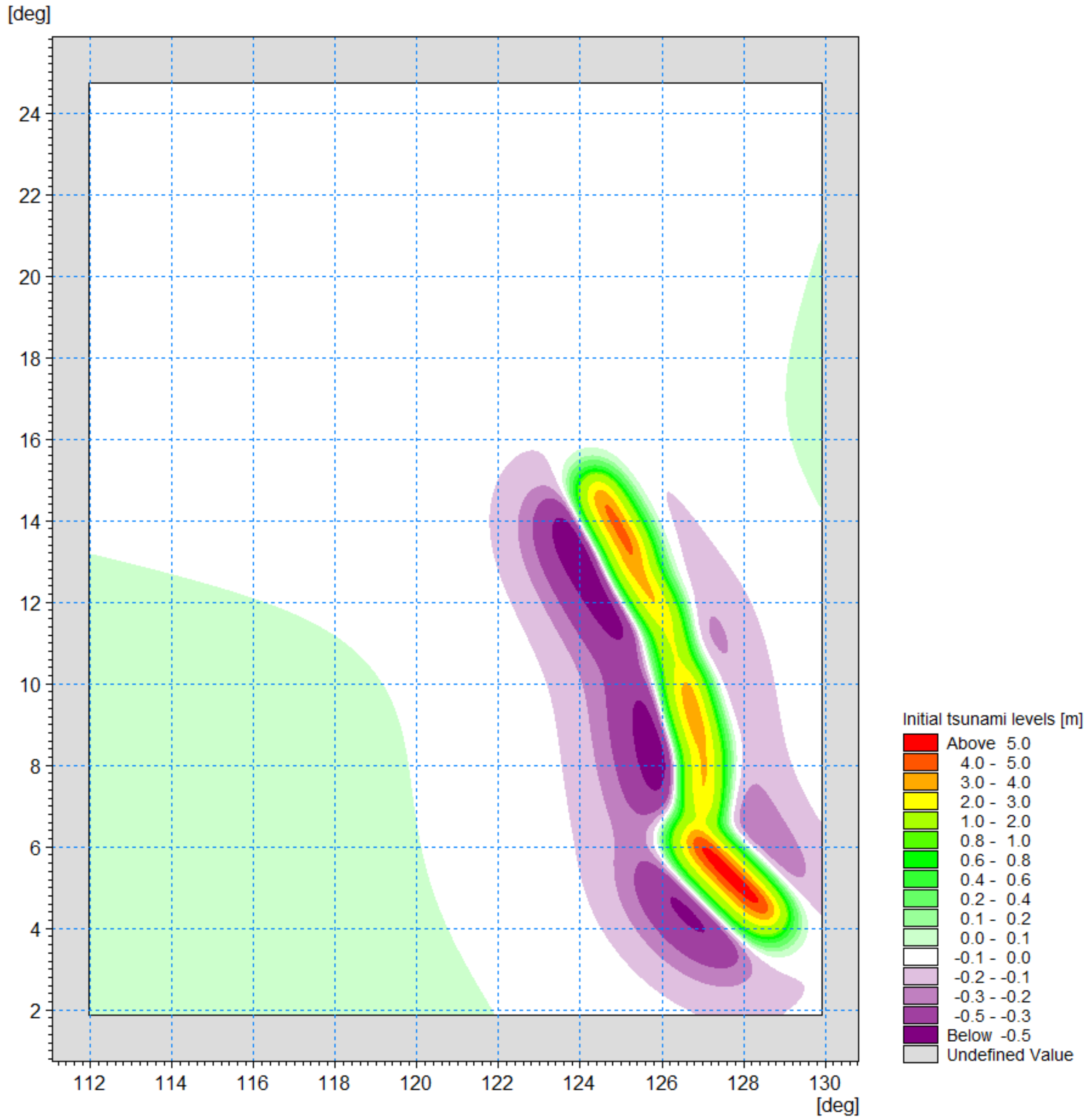

Fig. 8 Initial tsunami levels for an 1 in 1000 year earthquake (Mw 9.0) in the Philippine Trench generated by Royal HaskoningDHV

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REFERENCES

[1]. Salcedo, J. C. (2010). Earthquake source parameters for subduction zone events causing tsunamis in and around the Philippines. Bulletin of International Institute of Seismology and Earthquake Engineering (IISEE), Japan, 45:49-54.

[2]. DHI (2021). MIKE21 Toolbox User Guide, Agern Alle 5, DK-2970 Hosholm, Denmark.

[3]. Wikipedia (2021). Philippine Trench, https://en.wikipedia.org/wiki/Philippine_Trench.

[4]. Tongkul, F., Roslee, R. and Mohd Daud, A., K., T. (2020). Assessment of tsunami hazard in Sabah – Level of threat, constraints and future work. Bulletin of the Geological Society of Malaysia, Volume 70, November 2020, pp. 1 – 15, DOI: https://doi.org/10.7186/bgsm70202001.

[5]. Hou, J., Yuan, Y., Li, T. and Ren, Z. (2020). Tsunami hazard analysis for Chinese coast from potential earthquakes in the western North Pacific. GEOMATICS, NATURAL HAZARDS AND RISK 2020, VOL. 11, NO. 1, 967–983, https://doi.org/10.1080/19475705.2020.1766579.
[6]. Thio, HK., Somerville, P. and Ichinose G. (2007). Probabilistic analysis of strong ground motion and tsunami hazards in Southeast Asia. J Earthquake Tsunami. 01(02):119–137.
[7]. Besana, G. M., Y. Tanioka, M. Ando, M. H. Mirabueno, J. Manahan, J. De Ocampo, J. Perez, and B. Bautista (2004). The May 17, 1992 earthquakes in south-eastern Philippines, Geophysical Research Letter, vol 31, L24618, doi:10.1029/2004GL020917.
[8]. Cardwell, R. K., B. L. Isaacks, and D. E. King (1980). The spatial distribution of earthquakes, focal mechanism solutions, and subducted lithosphere in the Philippines and northern Indonesian islands, in The Tectonics and Geologic Evolution of Southeast Asia Seas and Islands, Geophy. Monogr. Ser., vol. 23, edited by D. E. Hayes, pp. 1 – 36, AGU, Washington, D. C.
[9]. Taylor, B., and D. E. Hayes (1983). Origin and history of the south China Basin, in The Tectonics and Geologic Evolution of Southeast Asia Seas and Islands: Part 2, Geophys. Monogr. Ser., vol. 27, edited by D. E. Hayes, pp. 23 – 56, AGU, Washington, D. C.
[10]. Bautista, B.C. and PHIVOLCS-DOST (2007). Tsunami Hazard Mapping and Risk Assessment Project, DOST-GIA.
[11]. Rong, Y., Jackson, D. D., Magistrale, H. and Goldfinger, C. (2014). Magnitude Limits of Subduction Zone Earthquakes. Bulletin of the Seismological Society of America, Vol. 104, No. 5, pp. 2359-2377, 16 September 2014, https://doi.org/10.1785/0120130287.