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The Application of Multi-Criteria Analysis to Select Areas for Design and Construction of Tsunami Protective Systems along the Andaman Coast of Thailand

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***Abstract*:** *This paper introduces a study project proposed by the Department of Public Work and Country Planning in Thailand. This project started in 2013 after the great disaster of Indian Ocean earthquake and tsunami in 2004 in order to plan for the construction of Tsunami protection systems along Andaman coast of Thailand. The project was separated into two stages of study: the selection of areas (districts) and the design of tsunami protective systems. In the first stage, the multi-criteria analysis (MCA) was used to make the decision which areas are the first priority for further stage of study. This paper will present the application of MCA in the study project, involving three major criteria: tsunami severity, land occupancy, and affected population. These criteria were obtained from various statistical sources. Tsunami severity was simulated by scientific means; land occupancy used the database from some national agencies; and the affected population was obtained from the calculation. By using the MCA, all studied areas were classified into five grades based on their scores. The study results show that only 14% of all areas (1560 out of 11143) were qualified to be selected to further design of tsunami protective systems.*

Keywords: *multi-criteria analysis, tsunami, disaster management, Indian ocean earthquake, coastal protection*

1. Introduction

Thailand was one of the countries which were hardly hit by Indian Ocean Earthquake and Tsunami in December 2004. Due to proximity of the Andaman, the coast of Thailand situated just approximately 500 km east of the earthquake epicenter, northwest of Indonesian Sumatra Island, and the tsunami took about 2 hours to strike the western coastline of south Thailand. Due to the lack of experience, the country had had no protection systems and prevention policy. The official figures of damage in 2004 were reported as about 5000 killed people and the cost of billion dollars. In 2012, Thai government funded the ministry of interior through the Department of Public Work and Country Planning (DPWCP) to conduct a study project for planning the construction of protective structures along the coastline of southern Thailand. However, Due to a long distance of 954 kilometres and 11134 districts along the Andaman Coast of Thailand, the DPWCP anticipated the low possibility of establishing the construction projects for the entire areas because of high construction cost, thus the selection of construction areas would be the proper solution in order to minimize the government budget. The explanation in this paper concerns the details of processes that considered the concept of multi-criteria analysis to select areas for further design and construction stage. Figure 1 shows the diagram of the whole study processes in this project.

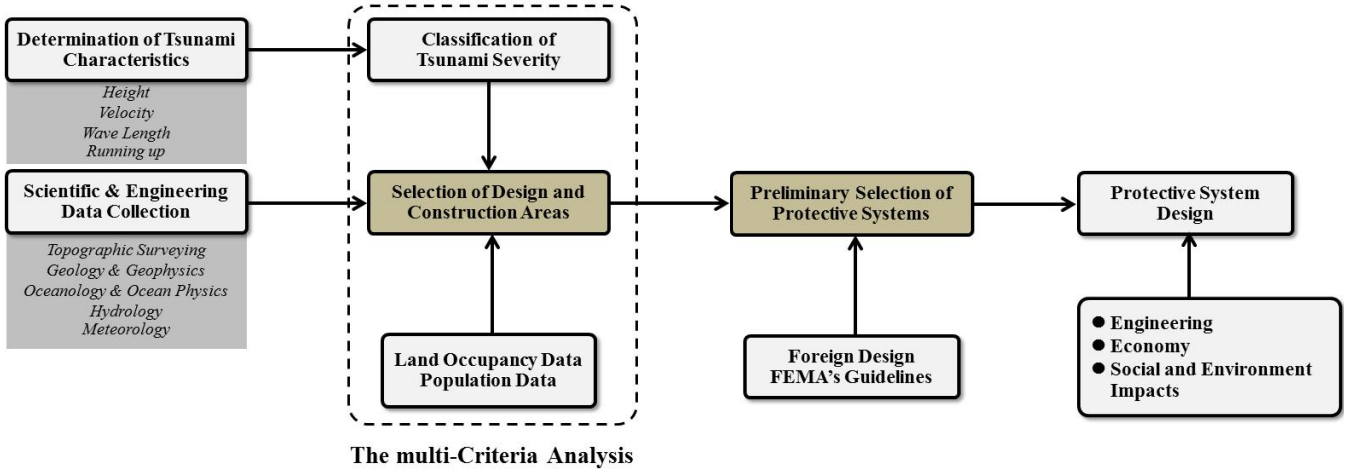

Fig. 1: The overall processes of the study project

2. The Simulation of Tsunami Characteristics

According to the reliable report [1], no data related to tsunami had been collected in Thailand before 2004. Thus the design the protection systems needs some mathematical models to simulate the possible characteristics of tsunami. To achieve this, the acquisition of statistical data was needed. The data were obtained from various fields of science and engineering, such as topographic surveying, geophysics and geology of the Indian Ocean, oceanology and ocean physics, hydrology, and meteorology. The sources were both domestic and foreign. The simulation was done by means of computerization in order to gain the important parameters in the design stage.

2.1. Acquisition of Statistical Data

The scientific data were obtained from various sources as shown in table 1.

TABLE I: Sources of Scientific data

Type of Statistical Data	Source
Tsunamis	NOAA (National Oceanic and Atmosphere Administration)
Earthquake	ISC (International Seismological Center)
	NEIC (National Earthquake Information)
	The Global Centroid-Moment-Tensor (CMT) catalog
	Thai Meteorology Office
Seafloor Topography	Earth Topography from NOAA
	MIKE C-MAP *
Land Geology & Geophysics	Department of Mineral Resources, Thailand
Oceanology	Department of Hydrography, Royal Thai navy
Meteorology	Department of Meteorology, Thailand

* Developed by Danish Hydraulic Institute

2.2. The Simulation of Tsunami Characteristics

In this study, MIKE 21, a set of mathematical models, was used as a tool to determine tsunami wave characteristics. The model set consists of five essential modules: hydrodynamics module, spectral wave module, shore sediment transport module, sand transport module, and mud transport module. In addition, the parameters related to the earthquake were generated from the movement of the Indian plate at Andaman subduction zone, the same location of the 2004 earthquake origin [2], and the magnitude of the earthquake was assumed to be 9.6 Richter scale and based on the return period of 475 years. The details and calculation in the simulation process are not described here. Figure 2 illustrates the bathymetry and the maximum surface elevation of tsunami wave obtained from the simulation process. The left figure is the bathymetry of the Andaman basin and the right figure is the wave profile showing the maximum surface elevation at various positions along the straight line lineated on the bathymetry map. The line begins at the origin of earthquake and heads to a desired location at the shoreline.

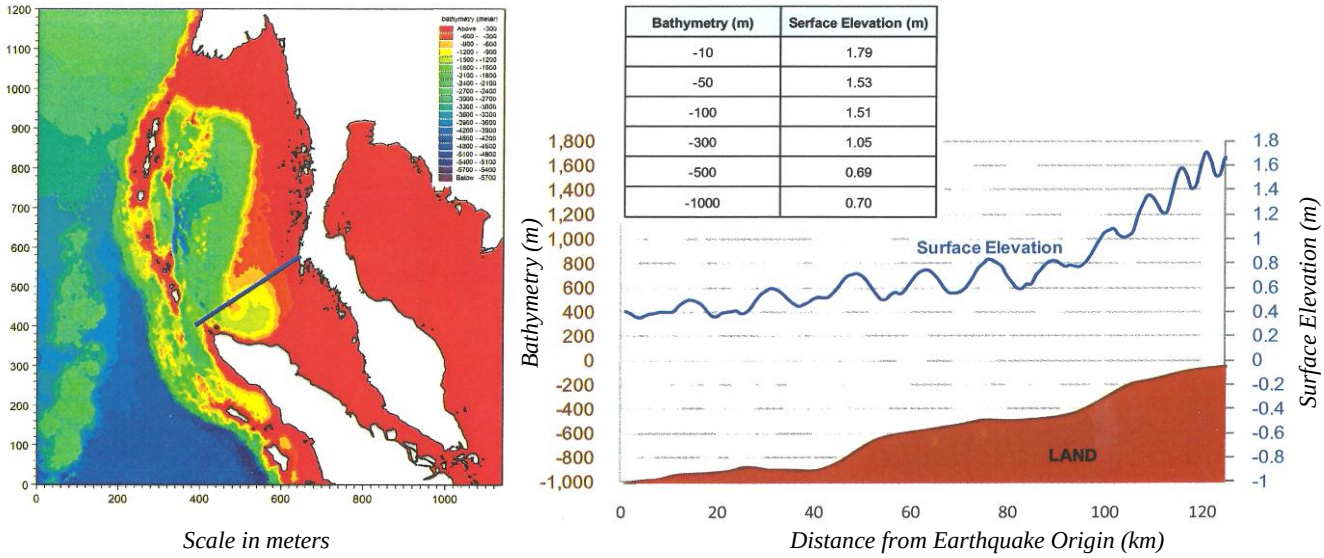

Fig. 2: The bathymetry of Andaman basin and the maximum surface elevations of tsunami wave

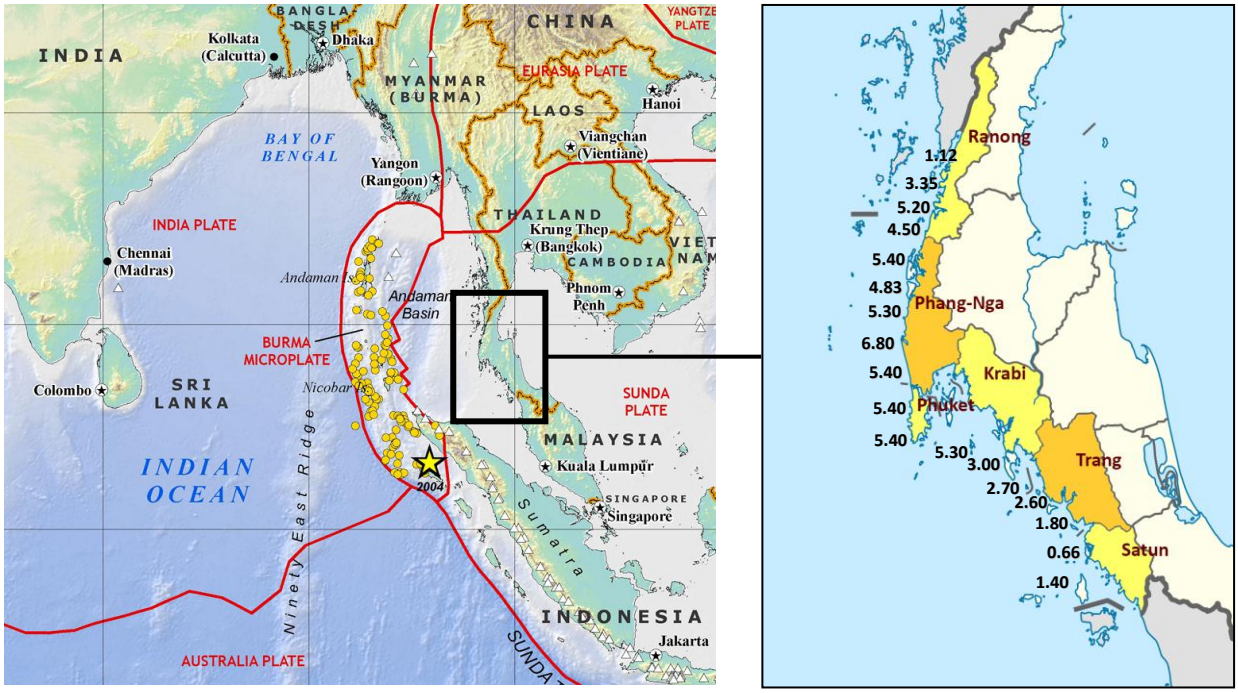

Fig. 3: The Surface Elevations at various locations in 6 prefectures near the Andaman coast

As shown in figure 2, the tsunami waves in the deep sea area (300 meters deep) have their heights less than one meter and the velocity is high; but when it approaches the land where the depth of the sea decreases, the wave height will rise to higher than one meter, and the velocity decreases. The travelling period of tsunami waves is variedly from 1.5 to 4 hours, which is near to that happened in 2004. The outputs taken from the simulation are shown in Figure 3. The maximum surface elevations of the tsunami waves are in the wide range at different locations along the coastline. The upper half of the coastline is subjected to the higher surface elevation than the lower half. The highest elevation is 6.80 m near Khaolak district, Phang-Nga prefecture, where was most destroyed by the tsunami in 2004. The wide range is because of the different geography of each half of the coastline [3]. The upper half lies against the straight direction of tsunami waves that travels from the subduction zone in the Andaman Sea, while tsunami is obstructed by Indonesian Sumatra Island in the lower

half of the coastline. These values of surface elevations were brought to evaluate the tsunami severity when it travels on the land. The areas with low attitudes will face the higher severity than the higher attitude.

3. Multi-Criteria Analysis (MCA)

The Multi-criteria analysis or multiple-criteria decision analysis is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. The reason to choose this method is that scores and weights, when used, are also explicit and are developed according to established techniques. They can also be cross-referenced to other sources of information on relative values, and amended if necessary [4]. In addition, performance measurement can be sub-contracted to experts, so need not necessarily be left in the hands of the decision making body itself. Since MCA has many models for achieve decision making, the Weigh Sum Model was used in this project which is the best known and simplest model among all others [5]. This model was applied to each of study areas which are also the township areas (districts). Three major criteria used in the study are the degree of tsunami severity, land occupancy and affected population, as detailed in table 2. Each of criteria was also divided into five sub-criteria with different definitions. The tsunami severity was defined by the wave height of tsunami wave on land; the land occupancy was defined by the apparent land use near the shoreline, and the affected population was defined by the factorized number of people who live in an area. A weighing score was assigned to each sub-criterion. The highest scores of these three criteria are 40 for tsunami severity, 40 for land occupancy, and 30 for affected population. The total score of a study area is obtained by summing scores from all criteria, thus the maximum score is definitely 100. Figure 4 shows the regions and boundaries of tsunami inundation on land with different severity levels. The region tagged as high severity means the highest wave surface elevation is higher than 3 meters above ground, whereas the inner zone tagged as moderate means the highest wave elevation is lower than 3 meters. To obtain the boundary line of each severity zone, the computer graphic processing was needed.

TABLE II: Criteria and Weighing Scoring

Criteria	Sub-criteria	Weighing Score
I. Tsunami severity	High A (> 3 m) covering larger than a half of area	40
	High B (> 3 m) covering smaller than a half of area	32 (80%)
	Moderate A (1.00 m-3.00 m) covering larger than a half of area	24 (60%)
	Moderate B (1.00 m -3.00 m) covering smaller than a half of area	18 (45%)
	Low (< 1 m) covering larger than a half of area	12 (30%)
II. Land Occupancy	Community/Municipal Area	40
	Beach	24 (60%)
	Agriculture	18 (45%)
	Forest	12 (30%)
	Mangrove Forest	6 (15%)
III. Affected Population	Over 2000	30 60%)
	1000-2000	24 (45%)
	500-1000	18 (30%)
	50 - 500	12 (30%)
	Less than 50	6 (15%)

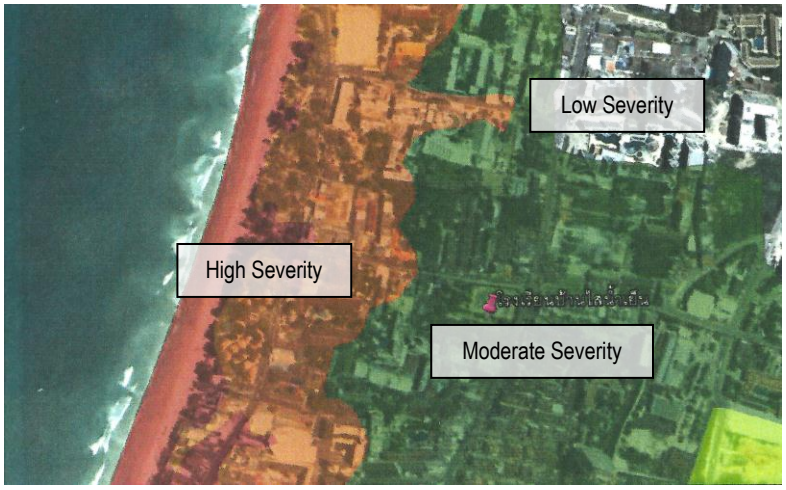

Fig. 4: Regions with different severity (Patong beach, Phuket prefecture)

The number of affected population is defined as people who are likely to evacuate and lose their properties after tsunami, To calculate it, two factors were used to adjust the number: the density factor and the affected population factor as shown in table 3. The density factor was used to adjust the number of population to the reasonable number for a specific type of land occupancy, and the affected population factors were evaluated from the data of lost and killed people in year 2004 compared to the normal population.

TABLE III: Population Density Factors for Adjustment of Affected Population

Type of Land Occupancy	Density Factor (F_1)	Affected Population Factor (F_2)
I. Community/Municipal Area	1.00	1.05
II. Beach/Seaside Area	0.50	1.07
III. Agricuture	0.15	1.10
IV. Forest	0	1.00
V. Mangrove Forest/ Abandoned Area	0	1.00

The number of affected people can be calculated by the following equation:

$$\textit{The number of affected population} = F_1F_2DA \quad (1)$$

Where F_1 and F_2 are the factors given in table 3, D is the actual population density in a township area (men/sq.km.), and A is the township area (sq.km.) For example, a district has an area of 0.820 sq.km. and its population density is 3560 men/sq.km. If most of the area is identified as beach, then the density factor is 0.5, and the affected population factor is 1.07. The affected population will be 0.5 × 1.07 × 3560 × 0.820 = 1562.

After summing scores for all study areas, grading is the next step to prioritize the necessity of tsunami protective system design. There are five grades set up: A, B, C, D and F. The definition and total score of each grade had been set forth in table 4. Table 5 shows some examples of the results extracted from the study report, showing the score and grade of each study area.

TABLE IV: Grading, Definitions and Further Processes

Total Score	Grade	Definition	Further Process
80 – 100	A	Extremely damages risk to both men and properties	To be further studied
70 – 79	B	Moderately damage risk to both men and properties	
60 – 69	C	Some damage with properties, but preventable man loss	
40 – 59	D	Low damage with properties but no economical affect	To be eliminated
0 - 39	F	Assumingly no damage	

TABLE V: No. of Districts with Various Criteria (from a total of 11134)

Severity		Land Occupancy		Affected Population	
High A	1378	Community	1495	Over 2000	247
High B	909	Beach	1201	1000-2000	985
Moderate A	2110	Agriculture	2045	500-1000	2450
Moderate B	1528	Forest	3544	50 – 500	3255
Low	5209	Mangrove Forest	2849	Less than 50	4206

TABLE VI: Example of Scoring and Grading

Land Occupancy	Score I	Tsunami severity	Score II	X1	District Area (sq.km.)	X2	X3	Score III	Total Score I + II + III	Grade
1. District Name: Naka Prefecture: Ranong										
Community	24	High A	40	5592	0.276	3086	1620	24	88	A
2. District Name: Kura Prefecture: Phang-Nga										
Beach	30	Moderate A	24	11572	0.343	2344	2125	30	84	A
3. District Name: Kho Phra Thong Prefecture: Phang-Nga										
Community	24	High B	32	998	0.510	509	560	18	74	B
4. District Name: Bang Muang Prefecture: Phang-Nga										
Beach	30	Moderate A	24	9836	0.185	1822	975	18	72	B
5. District Name: Lam Son Prefecture: Satool										
Community	24	Moderate A	24	346	0.816	7	8	6	60	C
6. District Name: Kampuan Prefecture: Ranong										
Beach	30	Moderate B	18	5454	0.047	254	136	12	60	C
7. District Name: Kapur Prefecture: Ranong										
Agriculture	18	Moderate B	18	330	0.110	363	6	6	42	D
8. District Name: Mai Fad Prefecture: Trang										
Forest	12	Low	12	184	0.353	65	0	0	24	F

Note: X1 = actual population density (men per sq.km.) X2 = affected population X3 = adjusted affected population

Table 5 is a set of fact numbers of districts enumerated from each criterion. Referred to table 6 and the study report, cases 1-6 are qualified to be selected for further study, but case 5 and 6 are to be eliminated. It is definitely seen that the A grade can be obtained from moderate severity and higher, also depending on the other criteria, e.g., land occupancy, affected population. The A, B and C grades are obtained from only areas of community and beach. Furthermore, even if the severity is moderate, an area is to be eliminated when affected population is less than 100 together and the land occupancy types are agriculture and forest.

4. The Results

The grading results are shown in figure 5. The percentages of area grades A, B, C, D and F are 3, 1, 10, 21, and 65, respectively.

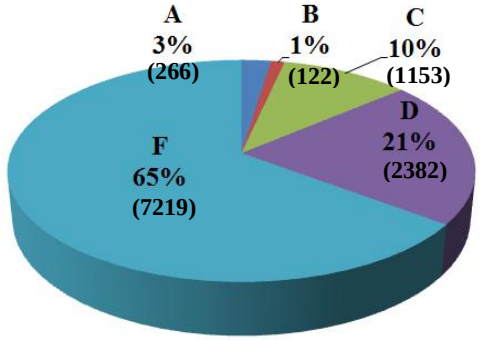

Fig. 5: Percentages of area grades

If we consider the qualifying grades mentioned in table 4, i.e., A, B, C, there are only 14% (1542 districts) which are selected from the total of 11143 districts to be further design and construction stage. Areas with grade A, the most needed for protection, is only 3%. The low percentage indicates that the low portion of populated areas such as communities and beaches. This corresponds to the fact that the Andaman coast of Thailand is mainly composed of forest and highland. However, even if these areas are graded, to design the tsunami protective systems, more considerations will be needed in the next stage of study such as engineering constraints, national economics, and social and environmental impacts.

5. Conclusion

By using MCA, it helped the decision making for selecting district areas to be designed and construction of tsunami protective systems. Three important criteria that are tsunami severity, land occupancy and affected population, were chosen to be study criteria. Although there are several more criteria that should have involved in the decision, but the three criteria used in the multi-criteria analysis to select the areas seemed to be sufficient and reliable. Tsunami severity is the most influence criteria due to its largest score weight. The range of tsunami surface elevation on land is between 1 to 7 meters. Only 14% of all areas along the Andaman coast were qualified to the design stage. They are mostly in Phang-Nga and Phuket prefectures. Most of the areas selected are with high and moderate severity. Communities and beaches tends to be the key land use for area selection. Affected population is another meaningful criterion. Most areas with the population over 500 tend to be selected. It has been found, however, that the affected population factors in this study influence the numbers slightly. They should be researched to determine the more reasonable values. Although the results of study is satisfying, the application of GIS may be taken into consideration to make better results.

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