1.3 EXTENT OF DAMAGE

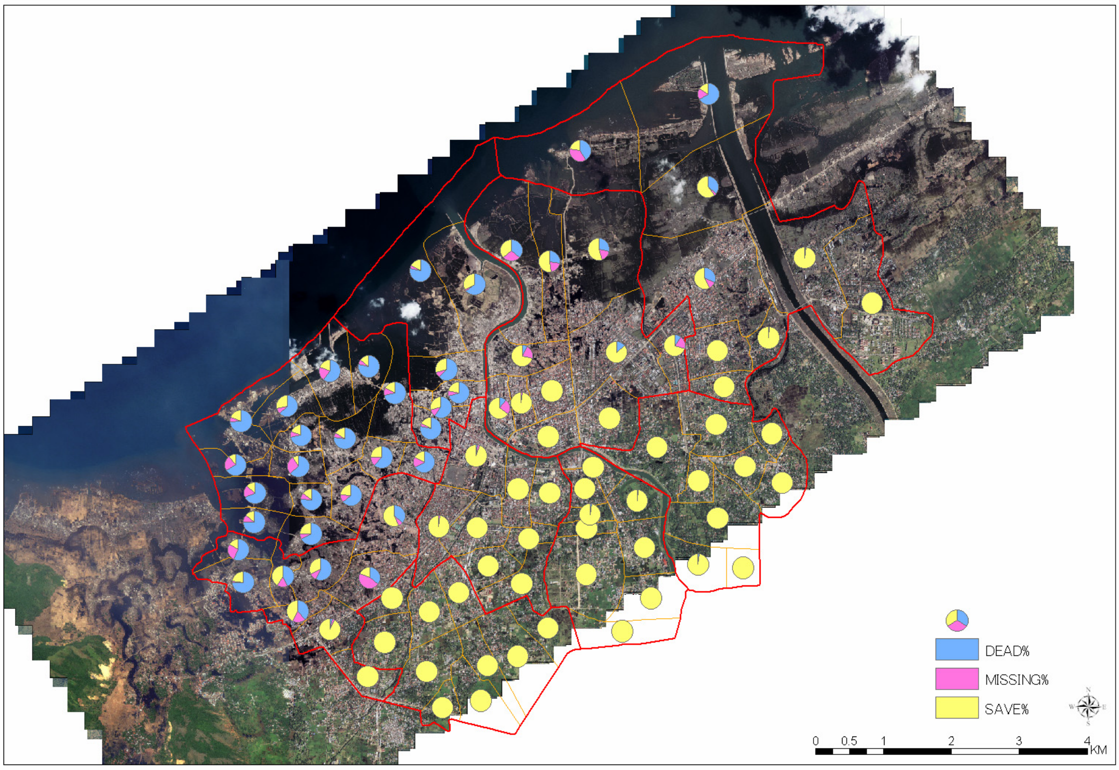
1.3.1 Casualties

The City of Banda Aceh is organized administratively into 9 Districts (Kecamatan) and 89 Villages (Desa). According to the population census carried out by the city office, the pre-tsunami population of 263,369 was reduced to 192,194. Casualties (dead and missing) reached 71,475 on 12 April 2005, and the dislocated families of 65,500 persons were living at resettlement houses (Table 1.5 and Figure 1.10).

Table 1.5 Population in Banda Aceh City

District (KECAMATAN)	Village (DESA)	Population		Dislocated People
		Pre-tsunami	Post Tsunami	
1 Meuraxa	16	31,218	5,657	867
2 Banturrahman	10	37,449	36,783	5,052
3 Kuta Alam	11	55,062	43,113	23,971
4 Ulee Kareng	9	17,510	17,388	8,126
5 Jaya Baru	9	22,005	11,348	6,163
6 Banda Raya	10	19,072	19,015	9,451
7 Lueng Bata	9	18,360	18,254	5,229
8 Syiah Kuala	9	42,776	35,514	6,411
9 Kuta Raja	6	20,217	5,122	230
Total	89	263,669	192,194	65,500

Source : City Office of Banda Aceh (April 12, 2005)

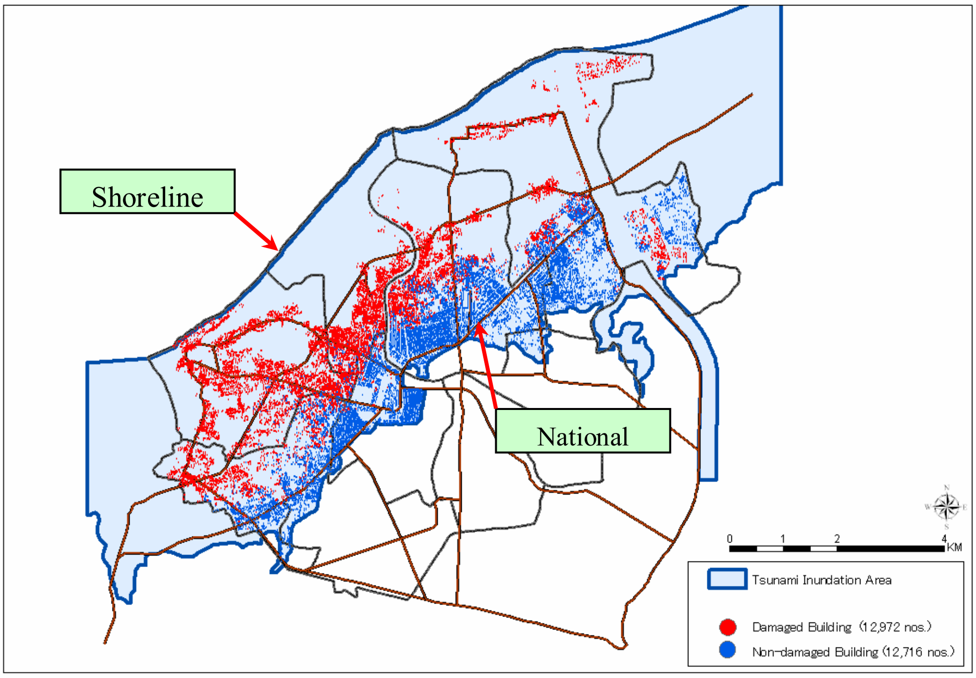


Source: City Office of Banda Aceh (April 12, 2005)

Figure 1.10 Casualties by District (Kecamatan)

1.3.2 Houses and Buildings

The tsunami from the northern shoreline destroyed whole wooden houses and reinforced-concreted building within a radius of 2 km, and houses and building remained as a distance increased over 2 km from the coastline. The totally and partially collapsed houses and buildings were counted based on the GIS-retrieved satellite photos (Figure 1.11). The totally and partially collapsed houses and building located in tsunami inundation area reached 12,972, about 50.4% of 25,688 in total.



Source: JICA Study Team

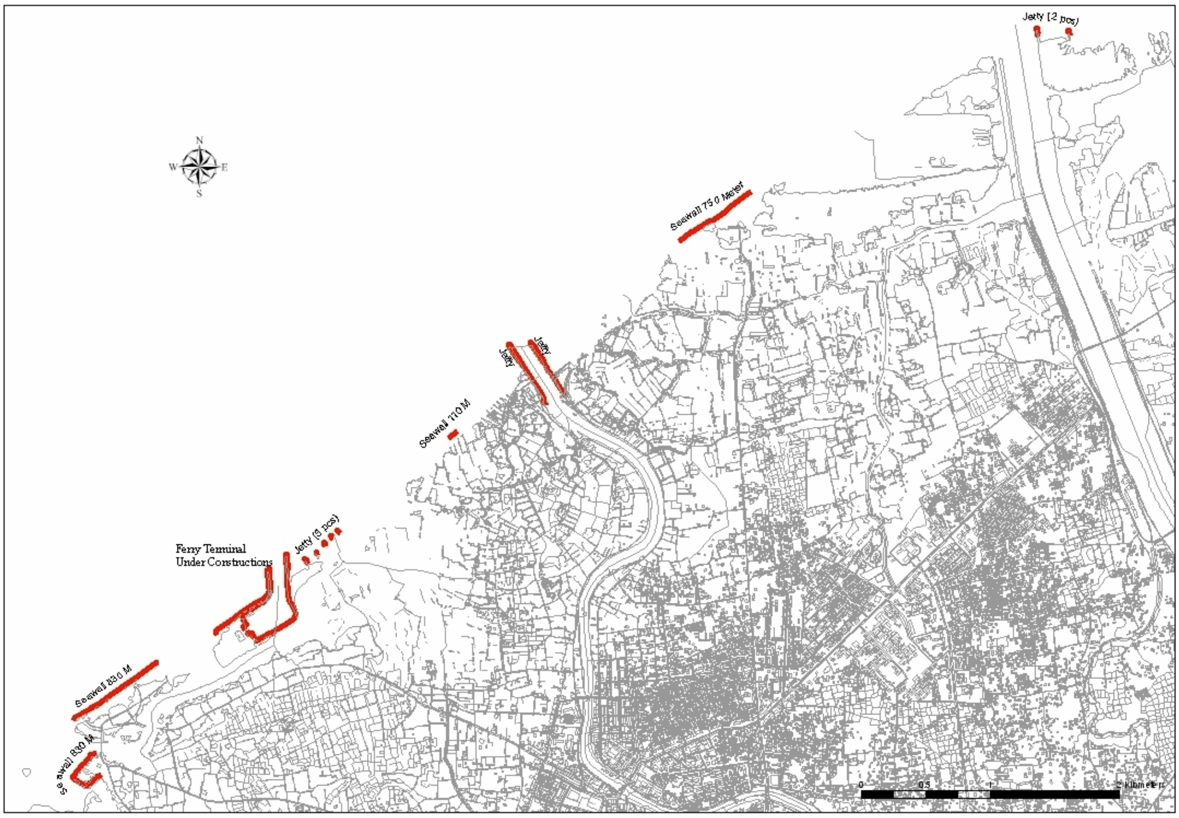
Figure 1.11 Damaged and Non-damaged Houses and Buildings

1.3.3 Infrastructure at Shoreline

Basic infrastructures had constructed along shoreline are listed below (Table 1.6 and Figure 1.12). These structures were collapsed completely.

Table 1.6 List of Structures at Shoreline (Pre-tsunami)

	Structure	Length	Remarks
(1)	Seawall	2 m high, 510 m long	Meuraxa, approach to ferry terminal
(2)	Seawall	2 m high, 830 m long	Meuraxa, approach to ferry terminal
(3)	Seawall	2 m high, 110 m long	Kuta Raja, protection fishpond from high tide
(4)	Jetty	300 m at river mouth of the Aceh River	Kuta Raja, training for the river flow of the Aceh River and protection river mouth from siltation.
(5)	Seawall	2 m high, 750 m long	Syiah Kuala, protection of cemetery from high tide
(6)	Ferry Terminal		Construction work of ferry terminal at Ulee Lheu was commenced in 2001. The terminal was partially opened 2003. About 60% of construction works were completed as of December 2004. The terminal was destroyed completely. Five pieces of jetty were constructed at eastside of main jetty for ferry terminal for the purpose of maintaining construction road and stockyard.



Source: Delineated based on satellite photo (IKONOS)

Figure 1.12 Pre-tsunami Structures along Shoreline

CHAPTER 2 DISASTER PREPAREDNESS

2.1 BASIC CONCEPT ON DISASTER PREPAREDNESS

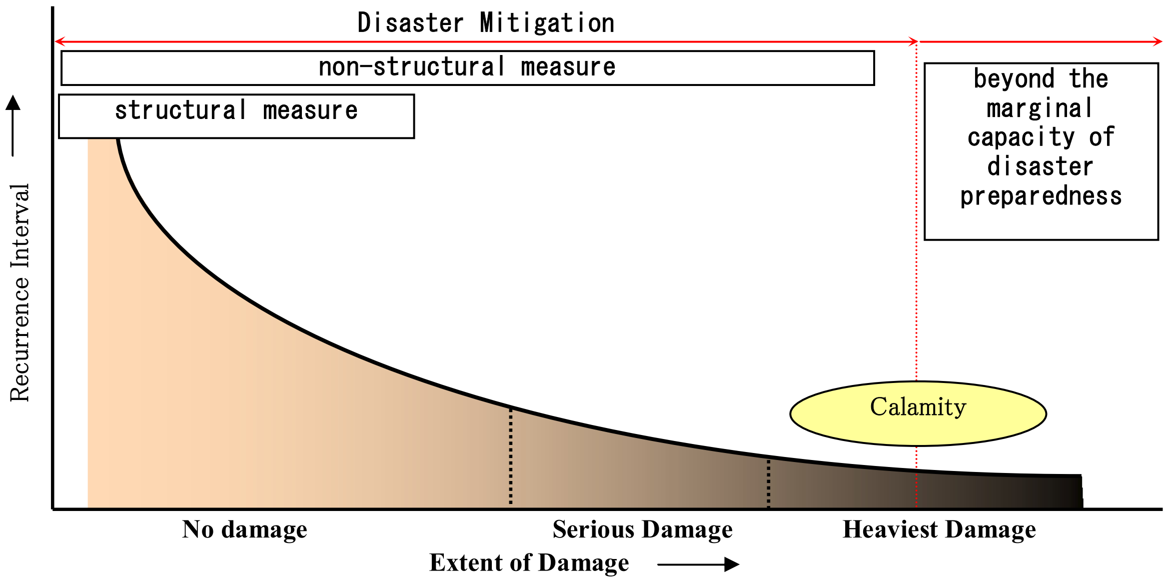
City planning with disaster preparedness will be formulated in combination with both disaster control and disaster mitigation systems. Major concerns for the disaster preparedness are;

(1) The City of Banda Aceh expands southward; namely, more safely side against natural disasters such as tsunami, high tide and flooding,

(2) Plan of disaster preparedness is organized into both structural and non-structural measures, and

(3) Phased disbursement of public investment in rehabilitation and reconstruction of basic infrastructures.

A concept on integrated disaster preparedness is shown schematically in Figure 2.1. Vertical axis shows recurrence interval of natural disaster while horizontal axis is extent of damage. It shows disaster management system mainly consists of structural measure mainly for disaster control and non-structure measure mainly for disaster mitigation.



Source: Yoshiaki Kawata, Characteristics of Catastrophic Disasters and Philosophy of their Reduction, Journal of Geography, 2001

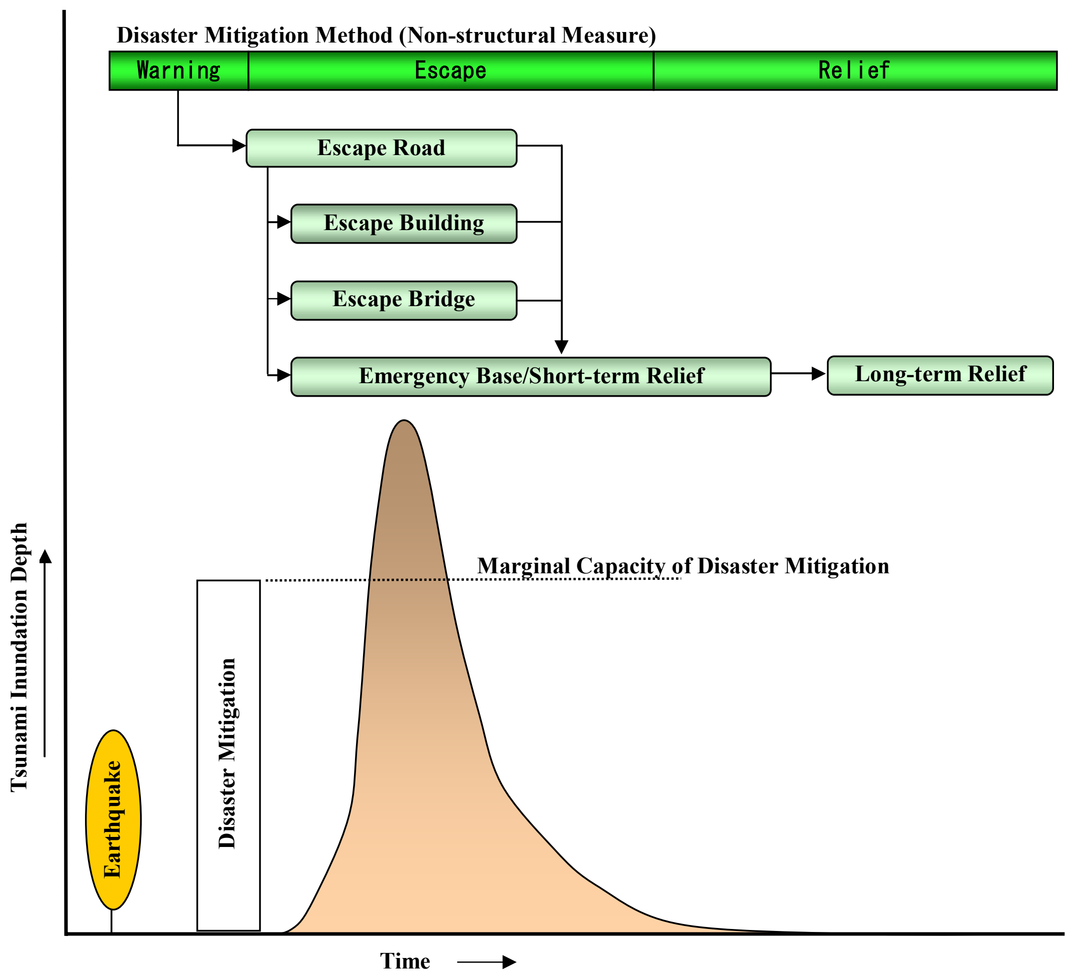
Figure 2.1 Schematic Diagram of Integrated Disaster Preparedness

In general, disaster preparedness by structural measure is formulated on the basis of design criteria for the magnitude of natural disaster. Take design criteria for flood control structure for instance, the dike along river channel is designed against flood with a probability of once in 20-year or more. The safety against flood with a probability of design flood is ensured, once the flood control structures are constructed in accordance with the said design criteria.

However, there is a likelihood of natural disaster beyond the design criteria. In case of natural disaster beyond the capability of structural measure, the non-structural measure would be more effective in mitigating damage and reducing duration.

In the City of Banda Aceh, tsunami is the most serious disaster among natural disasters such as flooding, earthquake, big fire, and so on. Although structural measures against large-scale tsunami can reduce inundation area and tsunami run-up height, the measures can not control tsunami completely. Thus, the efficient disbursement of public investment taking into account marginal capacity of structural measures is required in rehabilitation and reconstruction of basic infrastructures.

Applying the concept on disaster preparedness (Figure 2.1), the integrated disaster management system for the City of Banda Aceh is illustrated in Figure 2.2, in which horizontal axis indicates time and vertical axis for tsunami run-up height. Also, the upper part of the figure, implementation process of disaster mitigation methods is illustrated.



Source: JICA Study Team

Figure 2.2 Schematic Diagram of Integrated Disaster Management System in Banda Aceh

2.2 HAZARD POTENTIAL

To evaluate the Hazard Potential is one of the important issues where a particular natural hazard could potentially be a problem. The maps are constructed by establishing risk factors, such as topographic condition, road space, density of population, etc., then noting where such factors exist in combination. The areas meeting the risk factors are illustrated by coloring then on a base map.

Hazard potential in the Banda Aceh City was then evaluated preliminary based on the limited physical data with satellite photos. The topographic condition was characterized by classifying broadly into coastal (lowland) and inland (upland) zones, which were further sub-divided into 8 zones (Table 2.1).

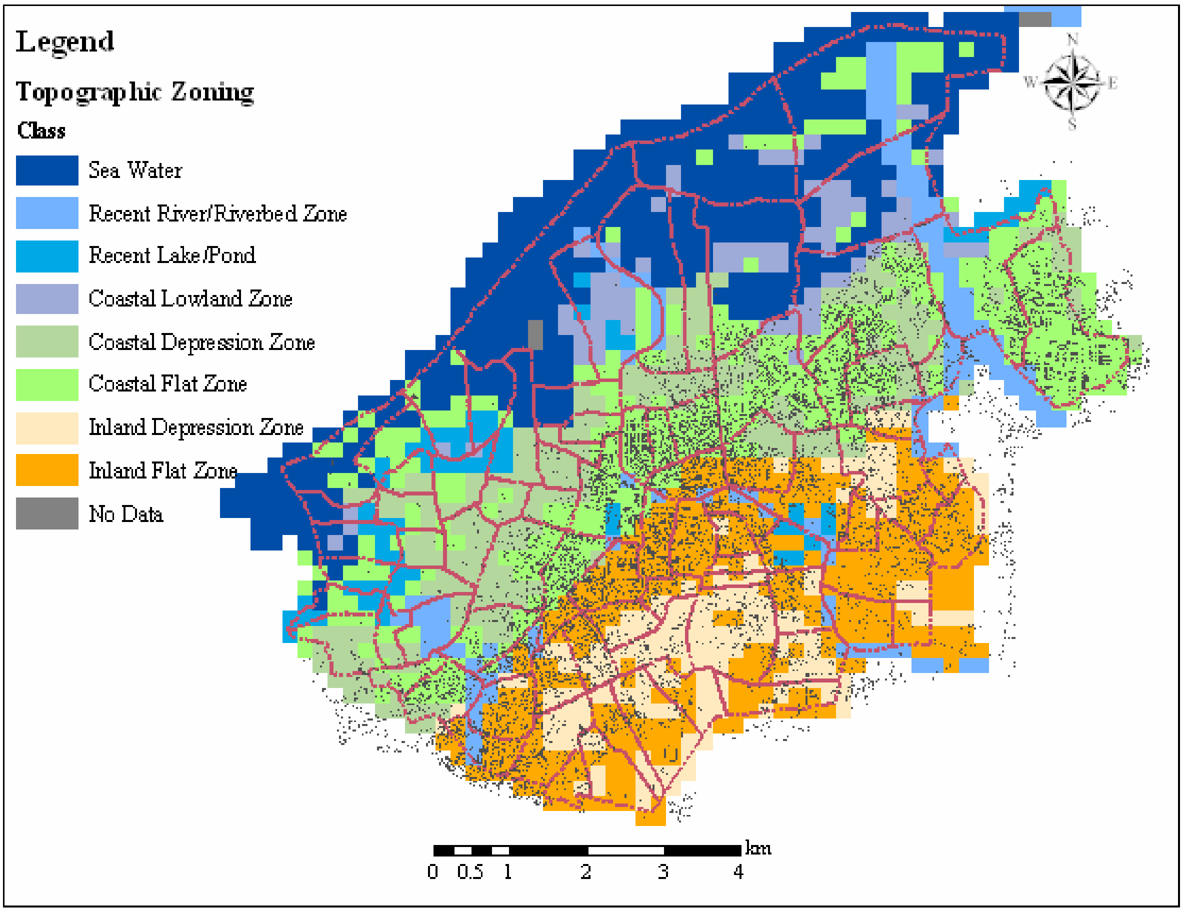
Table 2.1 Topographic Zoning

Topographic Zone		Remarks
COASTAL TOPOGRAPHIC ZONE		
C.1	Sea Water Zone	Land surface elevation is lower than the low water level of the sea. Land is submerged into sea water.
C.2	Recent River/Riverbed Zone	River channel traversing coastal and inland areas.
C.3	Recent Lake/Pond Zone	Retarding water zone without drainage
C.4	Coastal Lowland Zone	Part of coastal depression zone under pre-tsunami condition became land submerged frequently by high tide. Land subsidence due to earthquake may be occurred.
C.5	Coastal Depression Zone	Area of coastal depression located as part of coastal flat zone. Drainage system was malfunctioned..
C.6	Coastal Flat Zone	Housing area affected by tsunami inundation. Surface soil was washed out by tsunami.
INLAND TOPOGRAPHIC ZONE		
I.1	Inland Depression	Mainly due to the trace of river meandering, the land surface elevation is lower than that of inland flat zone. The wet land is formed because of malfanctining of drainage.
I.2	Inland Flat Zone	Housing area not affected by tsunami inundation. Surface soil still remains. Land surface elevetaion is relatively higher than that of tsunami-affected area.

Source: ARRIS (GIS) prepared by JICA Study Team

Topographic zoning map (Figure 2.3) shows that zone of sea water extends with a radius of 1 to 2 km from shoreline, and coastal lowland zone where hampered diurnal change of tide level is located around sea water zone. The land subsidence due to earthquake would occur in and around the sea water zones.

Both in the lowland and upland zones, depression zone (wetland zone) occupies widely where the malfunctioning of drainage system is identified.



Source: ARRIS (GIS) prepared by JICA Study Team

Figure 2.3 Topographic Zoning

Hazard risk due to natural disaster is used to indicate the potential for either physical or financial (damage to property) harm that might occur as the result of some natural process, such as earthquake, flood, or fire spreading. The level of hazard risks has both a probability and a severity component. For example, risk can be high for a relatively rare event if the consequences are severe enough. Determination of risk levels may be subjective.

Risk factors (Table 2.2) are the criteria to decide where a particular hazard is present. The following factors are evaluated by Desa against natural hazards; namely, tsunami inundation, liquefaction, drainage, fire spreading and escape from hazard. The baseline data were analyzed by ARRIS (GIS) and enumerated by Desa as given in Table 2.3.

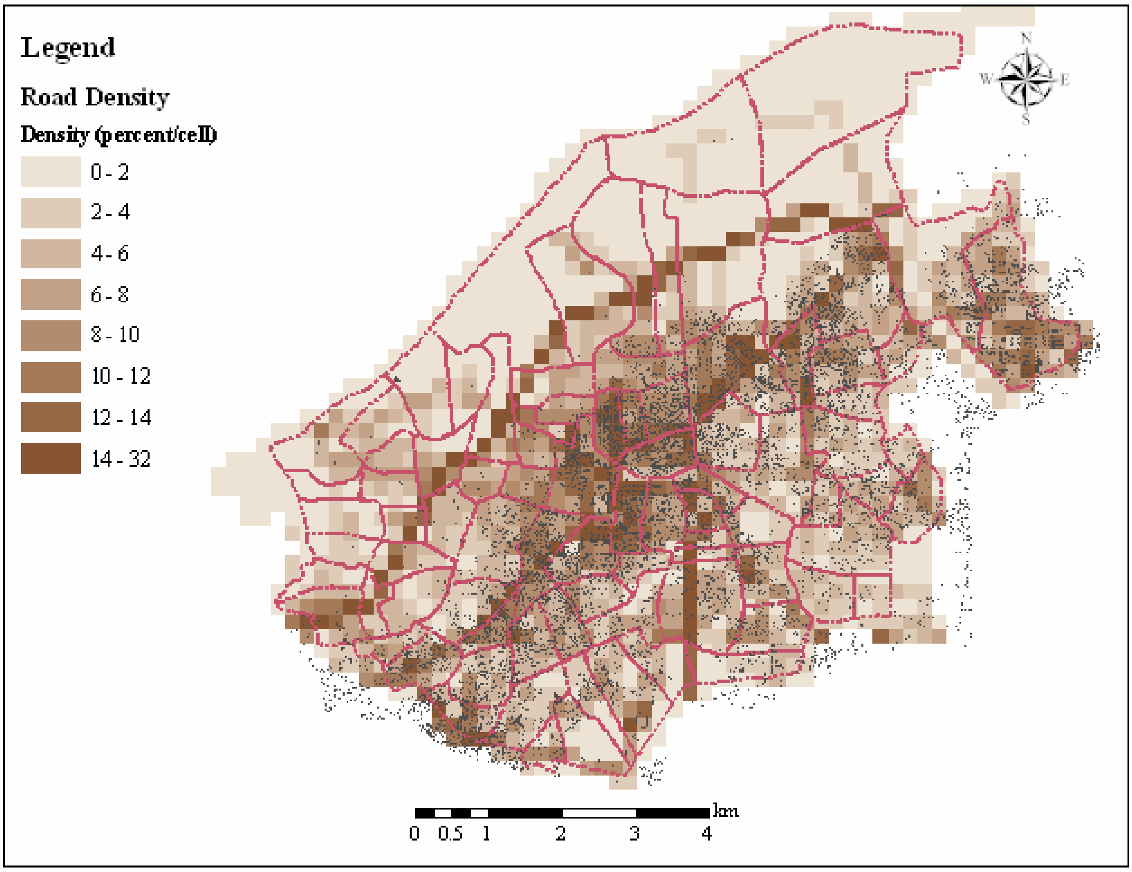
Table 2.2 Risk Factors for Natural Hazard

Natural Hazard	Topographic Factors	Physical Factors
(1) Tsunami inundation	Coastal lowland zone	Land area of Desa
(2) Earthquake (Liquefaction)	Depression/Lowland zone	Land area of Desa
(3) Flood (drainage)	Depression/Lowland zone	Land area of Desa
(4) Fire spreading	none	Building density/Land Area
(5) Escaping activity	none	Road density/Land Area

Table 2.3 Topographic Zoning by Desa

DESA		Area	Population		Infrastructure (sq.m)		Topographic Zone (sq.m)								
							Coastal Zone					Inland Zone			
No.	Name	(sq.m)	2005/04/12	Density	Road	Building	Riverbed	Depression	Flat Area	Wetland	Sea Water	Depression	Flat area	Wetland	No Data
1	Lampuoet	259,380	2,418	9,322	12,759	22,527	0	0	0	0	0	40,361	219,019	0	0
2	Mibo	596,575	1,161	1,946	13,572	27,174	0	0	0	0	0	228,628	367,947	0	0
3	Geuceu Menara	373,332	2,702	7,238	31,680	71,828	83,867	0	0	0	0	14,334	275,131	0	0
4	Lam Ara	703,629	1,360	1,933	30,232	75,493	0	0	0	0	0	341,504	362,125	0	0
5	Lhong Cut	448,380	1,355	3,022	12,987	37,698	0	0	0	0	0	183,989	264,391	0	0
6	Geuceu Inem	589,334	1,909	3,239	30,054	96,139	123,510	0	0	0	0	59,428	406,396	0	0
7	Lamdom	563,806	1,080	1,916	20,551	28,445	0	0	0	0	0	225,639	338,167	0	0
8	Lhong Raya	905,236	1,767	1,952	49,759	71,809	0	0	0	0	0	418,176	487,060	0	0
9	Lamtemen Barat	549,457	2,366	4,306	46,406	89,114	70,612	116,973	321,877	0	0	39,927	68	0	0
10	Penjeurat	517,031	1,275	2,466	21,123	25,045	0	0	0	0	0	348,584	168,447	0	0
11	Emperon	257,358	874	3,396	12,367	20,493	13,611	97,600	146,147	0	0	0	0	0	0
12	Cot mesjid	618,676	2,581	4,172	34,339	65,098	29,001	0	0	0	0	369,498	220,177	0	0
13	Geuceu Komplek	496,363	2,350	4,734	34,631	91,506	16,705	0	0	0	0	220,221	259,437	0	0
14	Geuceu Kaye Jato	297,550	1,008	3,388	32,851	64,311	123,272	0	63,134	0	0	20,572	90,572	0	0
15	Lamjamee	598,820	412	688	48,548	7,690	0	362,922	186,255	0	0	0	0	49,643	0
16	Lamlagang	407,044	4,412	10,839	32,471	90,526	0	0	0	0	0	206,536	200,508	0	0
17	Lamtemen Timur	640,207	746	1,165	29,546	80,063	137,809	239,816	261,581	0	0	0	1,001	0	0
18	Pango Deah	272,331	322	1,182	7,097	6,753	11,448	0	0	0	0	94,757	166,126	0	0
19	Neusu Aceh	386,232	3,571	9,246	18,206	51,423	0	0	0	0	0	215,464	170,768	0	0
20	Ateuk Jawo	578,110	1,382	2,391	25,724	47,142	0	0	0	0	0	506,669	71,441	0	0
21	Bitai	540,328	367	679	19,920	6,845	301,499	158,882	79,947	0	0	0	0	0	0
22	Lampoh Daya	261,840	510	1,948	16,765	997	51,852	87,314	70,193	0	0	0	0	52,481	0
23	Ulee Patah	340,123	157	462	8,134	167	0	0	133,180	0	49,663	0	0	157,280	0
24	Batoh	1,241,409	3,769	3,036	90,194	114,835	0	0	0	0	0	885,633	355,776	0	0
25	Pango Raya	539,663	1,063	1,970	25,170	19,592	91,789	0	0	0	0	0	447,874	0	0
26	A. D. Tanoh	255,558	958	3,749	13,941	36,910	0	0	0	0	0	98,164	157,394	0	0
27	Blang Cut	157,702	1,655	10,494	9,854	9,228	0	0	0	0	0	105,166	52,536	0	0
28	Lueng Bata	561,864	3,033	5,398	38,212	66,037	42,993	0	0	0	0	197,925	320,946	0	0
29	Surien	448,830	311	693	30,647	2,151	50,738	167,047	112,351	0	0	0	0	118,694	0
30	Asoe Nanggroe	344,129	170	494	7,471	317	0	0	159,543	0	88,639	0	0	95,947	0
31	Lampaloh	159,660	473	2,963	11,032	17,086	0	0	0	0	0	76,134	83,526	0	0
32	Kel. Neusu Jaya	582,107	2,591	4,451	47,929	140,406	16,322	16,065	21,666	0	0	0	528,054	0	0
33	Kel. Sukaramai	634,616	5,010	7,895	76,210	167,969	26,536	23,935	448,233	0	0	322	135,590	0	0
34	Lamjabat	288,515	170	589	23,306	1,867	0	201,268	65,862	0	0	0	0	21,385	0
35	Gampong Blang	517,340	83	160	8,522	2	0	0	87,813	73,852	179,571	0	0	176,104	0
36	Punge Blang Cut	971,946	3,214	3,307	53,412	96,977	0	608,470	363,476	0	0	0	0	0	0
37	Panteriek	448,243	903	2,015	14,667	27,500	31,684	0	0	0	0	14,572	225,820	176,167	0
38	Sukadamai	249,114	2,103	8,442	29,892	50,771	0	0	0	0	0	39,017	210,097	0	0
39	Ilie	1,027,738	2,090	2,034	42,825	70,820	23,878	0	0	0	0	121,575	882,285	0	0
40	Gampong Baro	492,243	344	699	26,531	8,446	0	415,535	76,708	0	0	0	0	0	0
41	K. A. Pahlawan	499,931	4,715	9,431	37,689	89,754	4,462	0	0	0	0	7,229	488,240	0	0
42	Lamteh	277,069	2,006	7,240	14,467	44,289	0	0	0	0	0	36,352	240,717	0	0
43	Gampong Pie	274,319	94	343	2,254		0	19,857	0	41,771	166,762	0	0	45,929	0
44	Lamseupeng	310,441	2,657	8,559	23,222	48,550	90,518	0	0	0	0	0	217,363	2,560	0
45	Cot Lamkeweuh	364,678	176	483	16,713	307	0	256,054	78,241	0	0	0	0	30,383	0
46	Kel. Peniti	453,650	7,885	17,381	56,930	119,426	27,509	0	39,785	0	0	0	386,356	0	0
47	Punge Jurong	314,670	1,045	3,321	22,827	15,328	0	199,080	115,590	0	0	0	0	0	0
48	Lam Glumpang	371,199	2,329	6,274	18,109	64,086	0	0	0	0	0	62,570	308,629	0	0
49	Ceurih	590,048	2,579	4,371	36,365	58,875	0	0	0	0	0	81,400	508,648	0	0
50	Punge Ujong	310,573	502	1,616	21,385	4,275	0	231,941	78,632	0	0	0	0	0	0
51	Lambung	284,450	240	844	14,109	876	0	115,789	94,594	0	0	0	0	74,067	0
52	Kuta Alam	486,159	4,180	8,598	63,451	142,862	31,690	0	167,053	0	0	0	287,416	0	0
53	I. M. Ulee Kareng	230,852	1,365	5,913	8,120	25,839	25,266	0	0	0	0	53,228	152,358	0	0
54	Lampaseh Kota	279,958	827	2,954	25,816	11,098	0	279,958	0	0	0	0	0	0	0
55	K. Kampong Baro	900,473	4,709	5,229	125,415	180,701	47,617	74,241	646,696	0	0	0	51,919	80,000	0
56	Blang Oi	510,646	570	1,116	37,131	3,394	0	146,267	160,128	21,094	0	0	0	183,157	0
57	Lambhuk	1,156,605	3,773	3,262	56,400	113,854	109,743	204,302	5,853	0	0	120,009	575,425	141,273	0
58	Kel. Merduati	182,899	1,433	7,835	13,842	11,134	0	131,882	42,852	0	8,165	0	0	0	0
59	Doy	815,943	1,861	2,281	41,910	93,951	31,962	69,424	77,711	0	0	370,535	266,311	0	0
60	Kel. Keudah	255,833	583	2,279	19,654	12,001	0	146,764	94,056	0	15,013	0	0	0	0
61	Beurawe	739,820	6,058	8,188	44,602	124,377	516	253,005	134,682	0	0	40,000	311,617	0	0
62	Laksana	225,311	6,630	29,426	24,125	67,293	0	2,372	222,939	0	0	0	0	0	0
63	Peunayong	339,885	2,843	8,365	62,337	103,274	5,054	8,710	326,121	0	0	0	0	0	0
64	Deah Glumpang	533,937	334	626	19,449	67	0	0	272,067	1,214	129,019	0	0	131,637	0
65	I. M. Kaye Adang	314,657	3,214	10,214	16,079	50,393	34,174	55,201	38,889	0	0	120,000	66,393	0	0
66	Ulee Lheu	932,034	781	838	25,826	1,967	0	73,884	244,311	4,377	604,176	0	0	5,286	0
67	Keuramat	454,336	6,203	13,653	38,911	154,389	0	55,626	397,935	0	0	0	775	0	0
68	Kel. Pelanggahan	504,667	952	1,886	29,233	2,062	0	125,073	131,471	0	248,123	0	0	0	0
69	A. Deah Tengoh	525,862	219	416	8,742	376	0	0	94,386	10,426	293,216	0	0	127,834	0
70	Mulia	563,232	3,044	5,405	42,276	49,118	14,624	480,688	67,920	0	0	0	0	0	0
71	Lampaseh Aceh	732,972	416	568	42,988	2,692	0	265,929	23,289	0	287,257	0	0	156,368	129
72	Pineung	637,987	3,730	5,847	46,181	142,152	9,956	337,676	290,355	0	0	0	0	0	0
73	Deah Baro	826,330	202	244	12,900	3,420	0	0	242,974	47,266	375,123	0	0	160,967	0
74	Lamgugop	337,916	8,542	25,278	17,393	33,355	158,355	88,873	90,688	0	0	0	0	0	0
75	Kota Baro	522,273	1,436	2,750	50,017	112,415	0	224	521,781	268	0	0	0	0	0
76	Bandar Baru	1,545,572	6,557	4,242	145,701	287,424	0	426,323	965,260	140,817	13,172	0	0	0	0
77	Gp. Jawa	1,487,258	1,136	764	61,188	2,045	223,678	1,073	257,977	531,429	280,115	0	0	192,986	0
78	Jeulingke	2,396,187	4,058	1,694	129,694	296,748	8,810	821,067	884,132	374,413	307,765	0	0	0	0
79	K. Darussalam	1,834,388	5,876	3,203	142,996	280,413	45,206	168,191	1,620,991	0	0	0	0	0	0
80	Lambaro Skep	2,059,065	2,334	1,134	67,469	34,016	0	93,848	277,725	375,213	1,312,279	0	0	0	0
81	Lamdingin	811,886	1,522	1,875	27,477	10,791	0	343,896	40,060	8,777	419,153	0	0	0	0
82	Rukoh	1,942,934	8,819	4,539	88,033	121,177	561,409	124,733	992,777	130,888	0	0	0	133,127	0
83	Lampulo	1,491,297	2,306	1,546	52,847	21,126	128,998	219,745	195,118	124,020	823,416	0	0	0	0
84	Gp. Pande	2,691,327	191	71	26,203	223	32,700	6,684	68,378	188,626	2,308,054	0	0	7,014	79,871
85	Tibang	1,947,763	850	436	59,260	1,815	422,025	0	124,573	601,564	799,601	0	0	0	0
86	Deah Raya	2,152,218	346	161	9,988	1,054	0	0	174,292	203,212	1,774,714	0	0	0	0
87	Alue Naga	3,478,348	416	120	7,928		452,598	0	778,422	171,433	2,075,895	0	0	0	0
	TOTAL	61,021,677	186,569		3,095,189	4,853,982	3,713,996	8,324,207	13,678,670	3,050,660	12,558,891	5,964,118	11,330,846	2,320,289	80,000

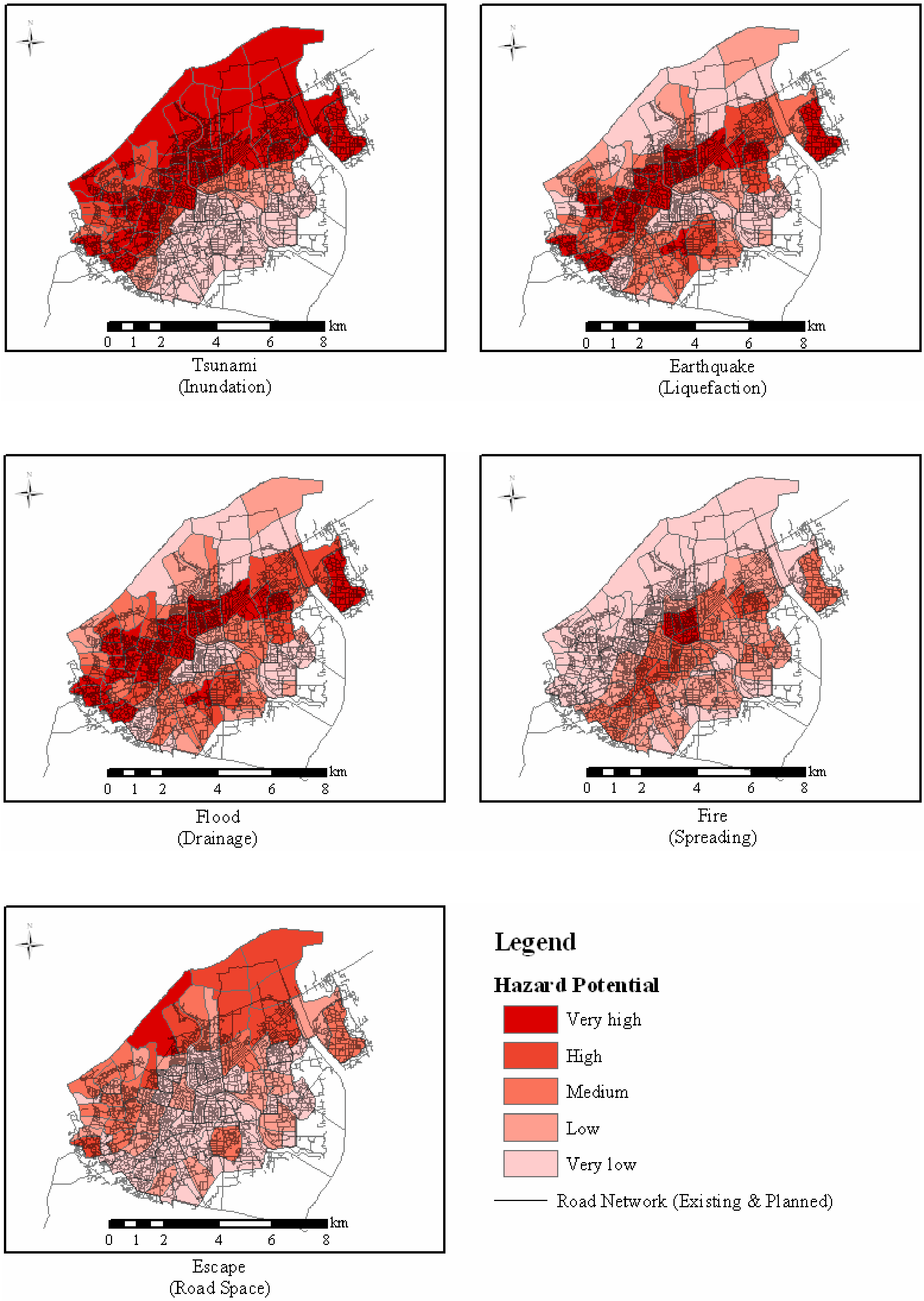
Furthermore, the road density (ratio of road area to land area) is one of the physical factors to ease escaping activity and to prevent fire spreading. Figure 2.4 shows the road density in the Banda Aceh City.



Source: ARRIS(GIS) prepared by JICA Study Team

Figure 2.4 Road Density Map

Each of the natural hazards can be mitigated in various ways. The simplest mitigation for any of the hazards would be to use zoning to restrict land use in any of hazard areas to inland flat area, where would not be strongly affected by natural hazards (Figure 2.5).



Source: ARRIS (GIS) prepared by JICA Study Team

Figure 2.5 Potential Hazard Maps

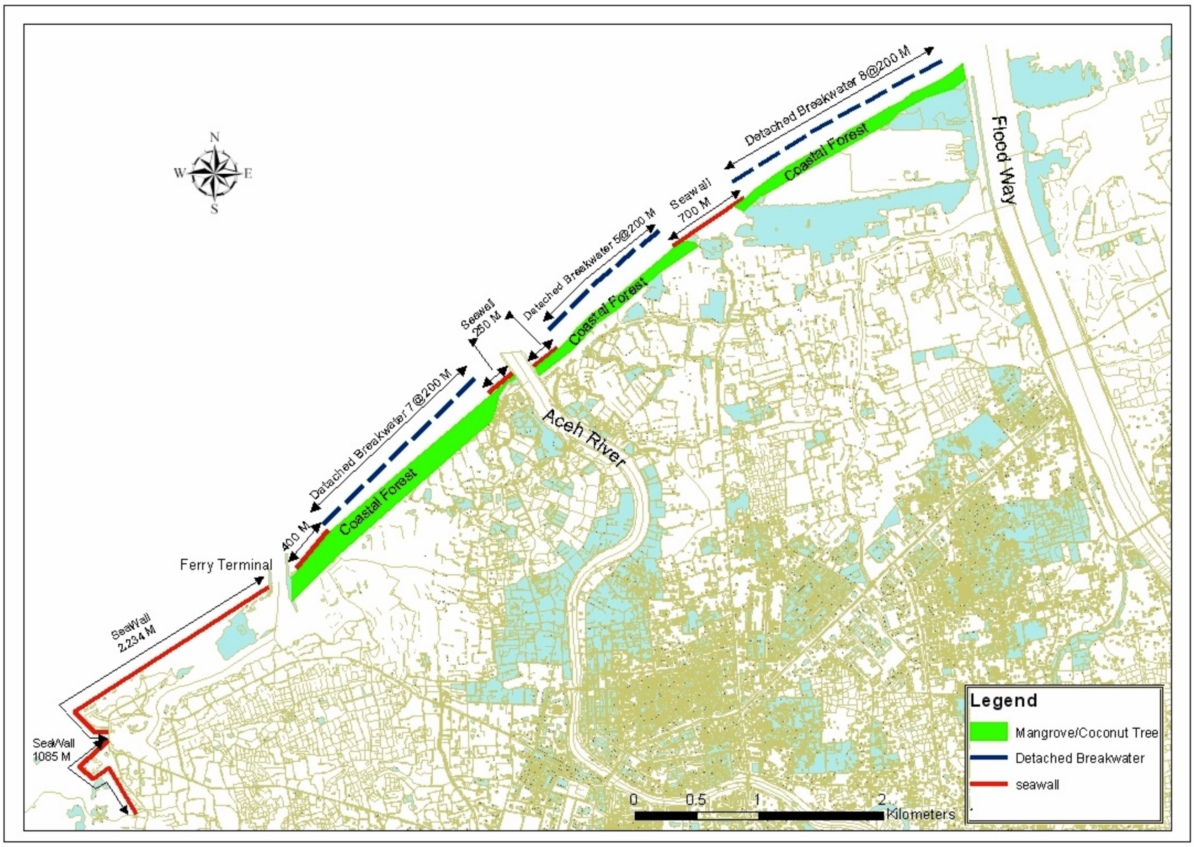
2.3 STRUCTURAL MEASURES AT SHORELINE

2.3.1 General

Tsunami wave height generated by earthquake on 26 December 2004 reached about 10 m at coastline based on the trace on palm trees. For protecting completely the Banda Aceh City from a huge tsunami, the sea wall of 15-m high along coastline is required. However, such a high sea wall requires remarkable amount of public investment and it would be an obstacle from the viewpoint of environmental conservation.

Thus, the structural measures at shoreline cope with small-scale and medium-scale tsunami. The structural measures are arranged in combination with (i) detached breakwater, (ii) sea wall, (iii) coastal forest and (iv) tidal gate at river mouth.

Structural measures at coastline are illustrated as shown in Figure 2.6.



Source: JICA Study Team

Figure 2.6 Structural Arrangements at Coastline

However, the implementation of those structures would have lower priority than that of non-structural measures which requires lesser cost and demonstrates much efficient against huge scale of natural disasters.

2.3.2 Detached Breakwater

A series of detached breakwaters are structures situated offshore and generally parallel to the shore. Detached breakwaters protect the adjacent shoreline by attenuating incoming wave energy due to storm surge, mid-scale and small-scale tsunami.

Figure 2.7 shows the satellite photograph of the jetty at shoreline near ferry terminal shortly before tsunami inundation. This photograph demonstrates the rapid sand accumulation which occurred at the eastside and between jetty, and effectiveness of the structure in attenuating wave energy.

Source : IKONOS

Figure 2.7 Sand Accumulation around Jetty (Pre-tsunami)

Sand transported along the beach is then carried into the sheltered area behind the breakwater where it is deposited in the lower wave energy portion. If the breakwater attenuates much wave energy, sediment may eventually fill in the lee of the breakwater and form a tombolo (Figure 2.8).

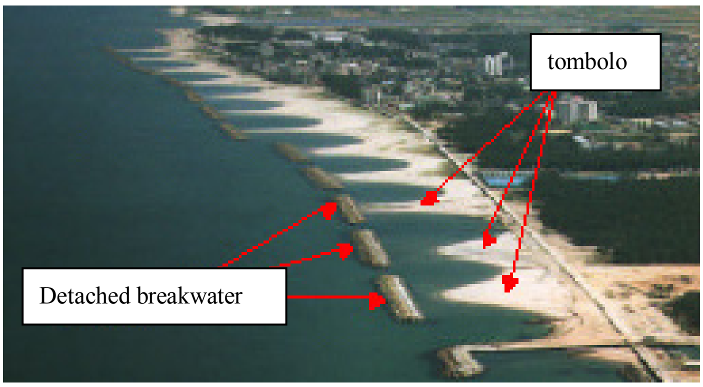
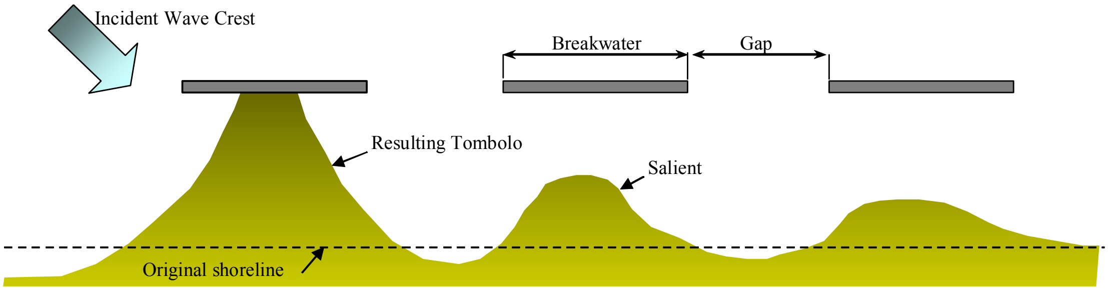


Figure 2.8 A Series of Detached Breakwater

The breakwater-tombolo system may then act as a groin, disrupting the long shore sediment transport processes in the area. A salient is also a seaward growth of the shoreline (Figure 2.9)

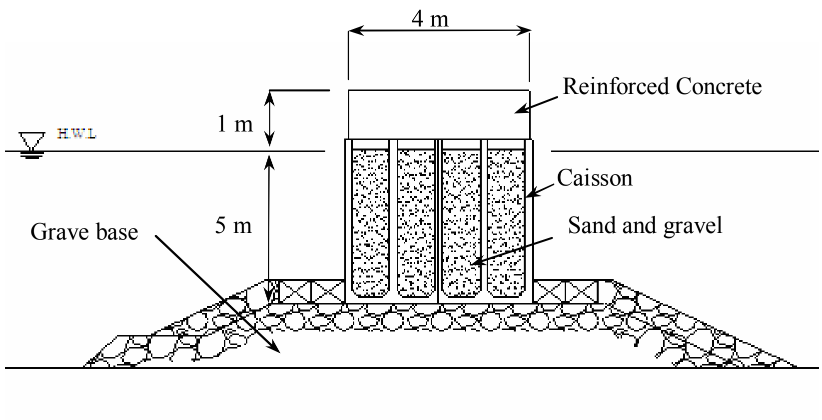


Source : USACE, Coastal Engineering Technical Note, CETN III-48

Figure 2.9 Types of Shoreline Changes associated with Multiple Breakwaters

Detached breakwater with composite wall-type typically consists of caissons[2] (a concrete or steel shell filled with sand and/or gravel) sitting on a gravel base. Exposed faces are vertical or slightly inclined (Figure 2.10). It may protrude above High Water Level.

- Sheet-pile walls and sheet-pile cells of various shapes are common in use
- Reflection of energy and scour at the toe of the structure are important considerations for all vertical structures.
- If forces permit and the foundation is suitable, steel-sheet pile structures may be used in depth up to about 12 m.
- When foundation conditions are suitable, steel sheet piles may be used to form a cellular, gravity-type structure without penetration of the piles into the bottom material.



Source: JICA Study Team

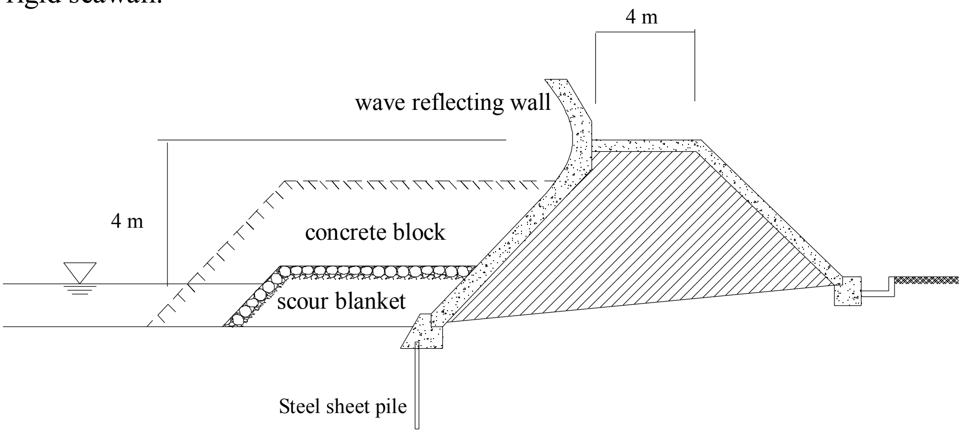
Figure 2.10 Typical Cross Section of Detached Breakwater (Composite Wall-type)

2 A concrete or steel shell filled with sand or gravel.

2.3.3 Seawall

a) Structure

A seawall is a structure built along the shoreline parallel to the beach. Its purpose is to impose a landward limit to coastal erosion and to provide protection to development behind the wall. Seawalls are commonly constructed from dumped rock, concrete and gabions. The face of a seawall may be vertical, curved, stepped or sloping. Figure 2.11 shows typical cross section of a rigid seawall.



Source : JICA Study Team

Figure 2.11 Typical Cross Section of Rigid Seawall

Whilst many rigid seawalls have been built over the world along the shoreline in the past, there is now general tendency away from this form for the following reasons:

- Failure can occur from a single freak wave or group of waves;
- Most rigid structures tend to be highly reflective to incoming waves; and
- Toe scour at the base of the wall can result in failure by undermining.

Because of their sensitivity to freak waves, more severe design wave conditions are adopted for rigid structures than for flexible and semi-flexible seawalls. The high reflectivity of rigid seawalls can result in accelerated sand loss in front of the wall during a storm, and delay beach re-building following a storm. Rock scour blankets, gabion, etc. can be used to protect the foundations of the structure from undermining. Alternatively, this protection can be provided by founding such structures at depth on non-erodible materials.

However, the performance of rigid seawalls can be improved by incorporating various features such as a curved wave deflection barrier (wave reflecting wall) along the crest of the wall, which significantly reduces wave overtopping and enables the crest to be lowered.

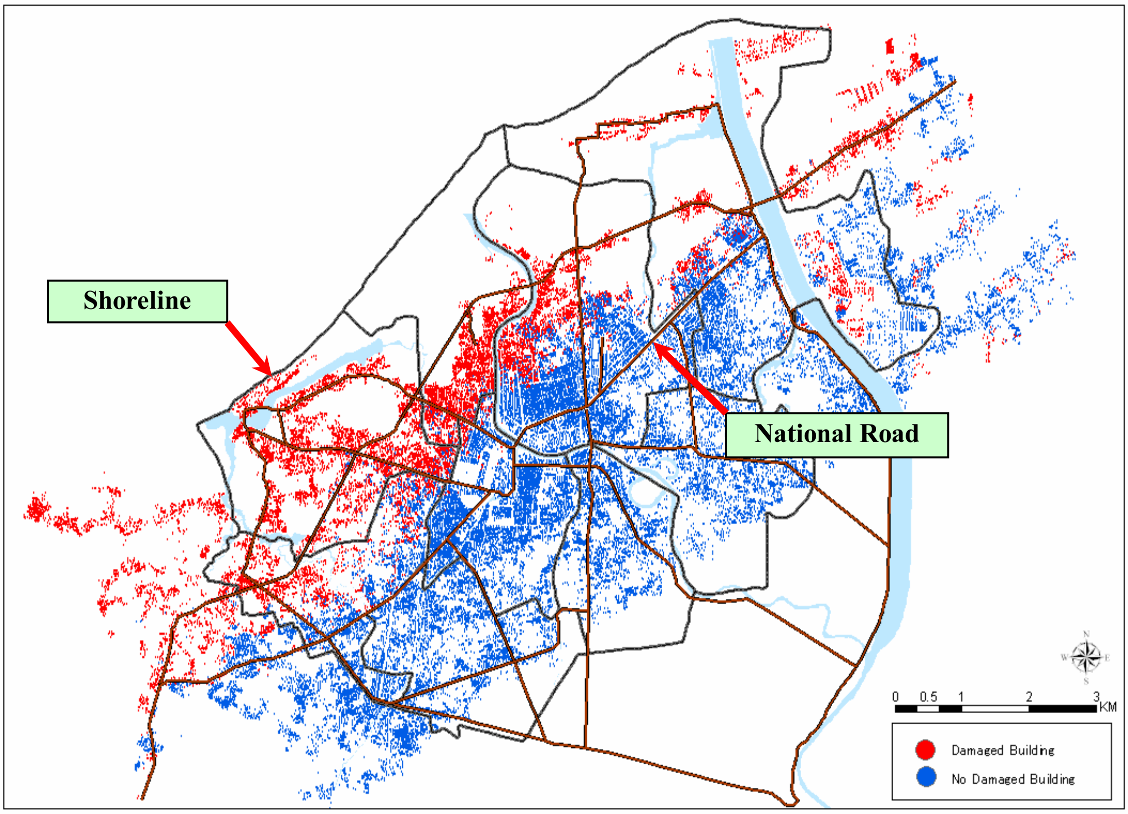
In selecting the foundation level of a seawall, consideration must be given to the possibility of local scour at the toe. This may result in the failure of rigid structures. Flexible structures can tolerate settlement without failure. Incorporation of a scour blanket to protect against toe erosion is commonly provided as a safeguard against failure or damage from this cause.

b) Height of Seawall

Crest level adopted in the design needs special attention. A crest level which is never overtopped will significantly increase the cost of seawall. As the crest level is reduced, the probability of failure caused by overtopping is increased. The crest level for seawall is set at 4 m above mean sea level as discussed below:

<u>Collapsed Houses and Building</u>

Fully and half collapsed houses due to Tsunami on 26 December 2004 are depicted by analyzing satellite images. Figure 2.12 shows the distribution of damaged (fully or partly collapsed) houses in red and non-damaged houses in blue.



Source: ARRIS (GIS) prepared by JICA Study Team

Figure 2.12 Damaged and Non-damaged Houses and Building

Assuming that the tsunami inundation depth varied in proportion to the distance from the shoreline with a radius of 3.5 km for the range from 10 m at shoreline to none at national road, the number of houses by inundation depth is enumerated as given in Table 2.4.

Damage ratio varies for the range from 99.6% at shoreline and 0.2% at the national road. Almost all of the houses and buildings inundated of less than 1m deep were not damaged.

Table 2.4 Tsunami Inundation Depth and Damaged Houses and Buildings

Tsunami Inundation Depth (m)	Houses and Buildings (nos.)			
	Damaged (a)	Non-damaged (b)	Total (c)=(a)+(b)	Damage Ratio % (d)=(a)/(c)
9	510	2	512	99.6
8	632	77	709	89.1
7	1,028	411	1,439	71.4
6	1,240	695	1,935	64.1
5	1,711	1,346	3,057	56.0
4	3,059	1,674	4,733	64.6
3	2,854	1,808	4,662	61.2
2	1,333	2,873	4,206	31.7
1	32	16,094	16,126	0.2
Total	12,399	24,980	37,379	33.2

Source: JICA Study Team

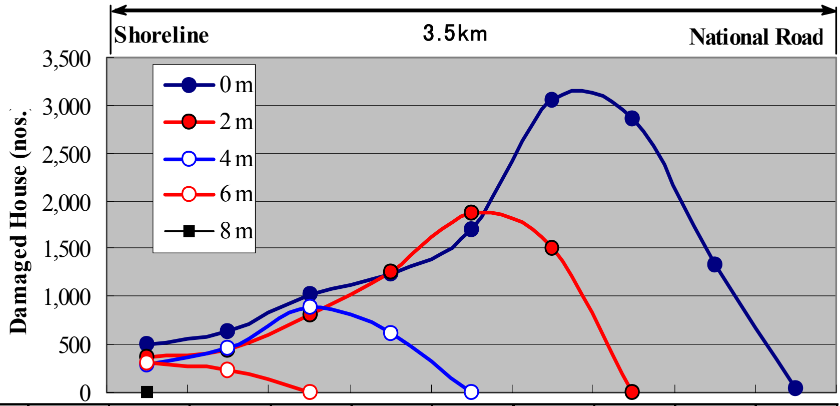
Tsunami peak cut-off by Seawall

Assuming that the seawall enables to cut the tsunami wave height in proportion to the height of seawall; namely, 4-m high seawall attenuates 4-m tsunami wave height, the damage ratio by tsunami inundation depth as given in Table 2.4 is multiplied to the number of houses and buildings (Table 2.5).

Figure 2.13 shows the relationship between damaged houses and buildings and tsunami inundation depth by height of seawall.

Table 2.5 Damaged House vs. Tsunami Inundation Depth

Item	Tsunami Inundation Depth (m)								
	9	8	7	6	5	4	3	2	1
(1) Damaged House and Buidings									
Damaged	510	632	1,028	1,240	1,711	3,059	2,854	1,333	32
Non-damaged	2	77	411	695	1,346	1,674	1,808	2,873	16,094
Total	512	709	1,439	1,935	3,057	4,733	4,662	4,206	16,126
(2) Damaged Houses/Total Nos. of Houses									
Peak Cutoff (m)	9	8	7	6	5	4	3	2	1
0	0.9961	0.8914	0.7144	0.6408	0.5597	0.6463	0.6122	0.3169	0.0020
2	0.7144	0.6408	0.5597	0.6463	0.6122	0.3169	0.0020		
4	0.5597	0.6463	0.6122	0.3169	0.0020				
6	0.6122	0.3169	0.0020						
8	0.0020								
(3) Assumed numbers of Damaged House									
Peak Cutoff (m)	9	8	7	6	5	4	3	2	1
0	510	632	1,028	1,240	1,711	3,059	2,854	1,333	32
2	366	454	805	1,251	1,871	1,500	9		
4	287	458	881	613	6				
6	313	225	3						
8	1								



Seawall Height									
8 m	1								
6 m	3	2	1						
4 m	5	4	3	2	1				
2 m	7	6	5	4	3	2	1		
None	9	8	7	6	5	4	3	2	1
	Inundation Depth (m)								

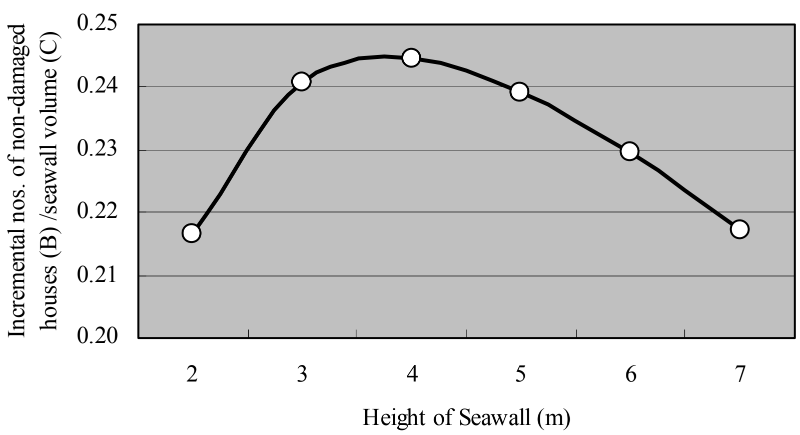
Source: JICA Study Team

Figure 2.13 Damaged Houses by Height of Seawall

<u>Height of Seawall</u>

Besides, the volume of main body of seawall by height is estimated on the basis of the typical cross section (crest width 4 m, slope of seaside 1:0.1, slope of upland 1:0.5 and full length 9,300 m).

The cost-benefit relationship as shown in Figure 2.14 was analyzed by assuming that the volume of seawall is estimated as Cost (C) and the incremental number of non-damaged houses due to the reduction of tsunami inundation depth is counted as Benefit (B). Among various height of seawall, a 4-m high seawall would be the most economical for public investment taking into account the pre-tsunami condition in the City Banda Aceh.



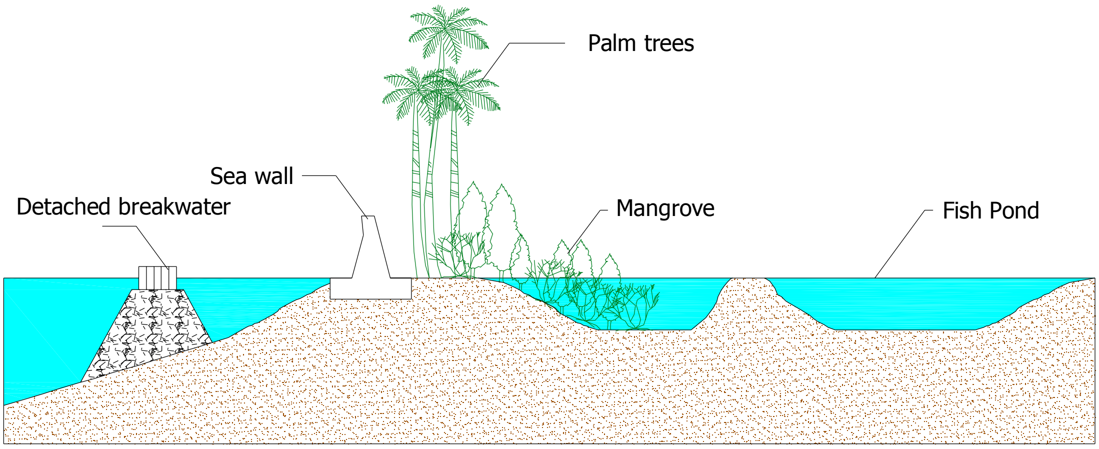
Source: JICA Study Team

Figure 2.14 Height of Seawall and B/C

2.3.4 Coastal Forest

Seawalls and breakwaters are regarded as artificial structural measure against tsunami. However, it may be noted that the artificial measures involve rather high construction and maintenance cost and environmental changes along shoreline.

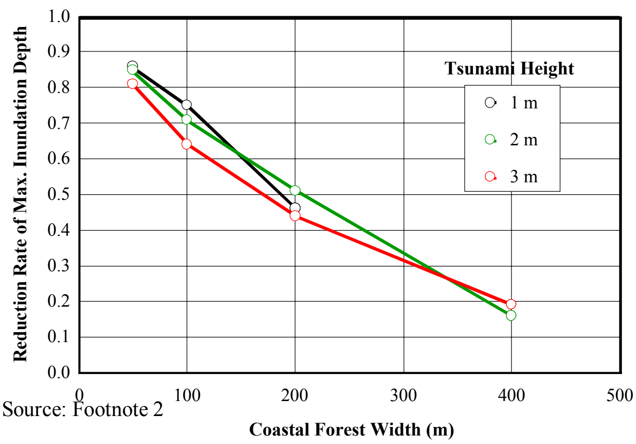
Coastal forest, with mangrove, sago palm, casuarinas tree and coconut tree, is known as natural functions to reduce the tsunami force and it is one of the solutions for disadvantages due to artificial measures. The construction of seawalls and breakwaters combined with coastal forest is likely to ensure the pre-tsunami environmental condition (Figure 2.15).



Source: JICA Study Team

Figure 2.15 Schematic Diagram of Arrangement of Coastal Forest

Quantitative effect due to coastal forest is evaluated preliminary on the basis of the results of numerical simulation in the past3. Coastal forest is generally collapsed by tsunami of over 4-m height. However, in case of tsunami wave height of 3 m, coastal forest with forest density of 30 trees per 100 m2, the diameter of trunk of 15 cm, and forest width of 200 m can reduce tsunami inundation depth to 50-60% and flow velocity to 40-60% (Figure 2.16).



Source: Footnote 2

Figure 2.16 Coastal Forest Width and Reduction Rate of Inundation Depth

[3] Kenji Harada and Yoshiaki Kawata, "Study on the effect of coastal forest to tsunami reduction", Annuals of disaster prevention, Research Institute of Kyoto Univ., No.47C, 2004

Out of the parameters, such as forest density, diameter of trunk and forest width, to evaluate the quantitative effect, the most outstanding parameter is the forest width to amplify the reduction rate of tsunami inundation. Thus, the forest width of more than 200 m would be required to maintain for the purpose of reducing tsunami inundation.

The planting of mangrove forest depends largely on the soil character, density, topography and so on. Also, increasing public awareness of coastal environmental issues means community members will often bring valuable experience, knowledge and skills to coastal management activities and issues. Community consultation and public education about coastal management will be therefore an important part of the restoration of mangrove forest.

As a pilot system, trial-and-error method for planting is required in cooperation with NGO who are keen to restore coastal conservation along shoreline. Increasing public awareness of environmental issues means community members will often bring valuable experience, knowledge and skills to coastal management activities and issues. Community consultation and public education about coastal management is therefore an important part of the Government's coastal management policy.

In combination with detached breakwater, the coastal forest is regarded as the alternative measures against small and medium-scale tsunami until the seawall is completed for the whole stretch of shoreline in future.

2.3.5 Tidal Gate

Tsunami travels in a form of bore into river channel. Tsunami inundation map on 26 December 2004 also shows the furthermost point of tsunami inundation at floodway reached 6.5 km upstream section from river mouth, although the tsunami inundation at inland extended with a radius of 3.5 km from shoreline. The collapse of bridge due to tsunami has been often reported due to hydraulic bore traveling to upstream.

Tidal gates (Figure 2.17 and Figure 2.18) for the river mouth of the floodway and the Aceh River are required to cope with small-scale and medium scale tsunami and to mitigate the damages along river channel, although the lower priority is given to the construction of tidal gate because of high construction cost. The tidal gate would be required when the land use along river channel is developed.

The operation room of the tidal gate on the maintenance bridge can be used for "Tsunami Watch Point". In case of tsunami, the tsunami inspector disseminate tsunami warning and gate operator closes the gate to prevent hydraulic bore intrudes into river channel.

Figure 2.17 Tidal Gate

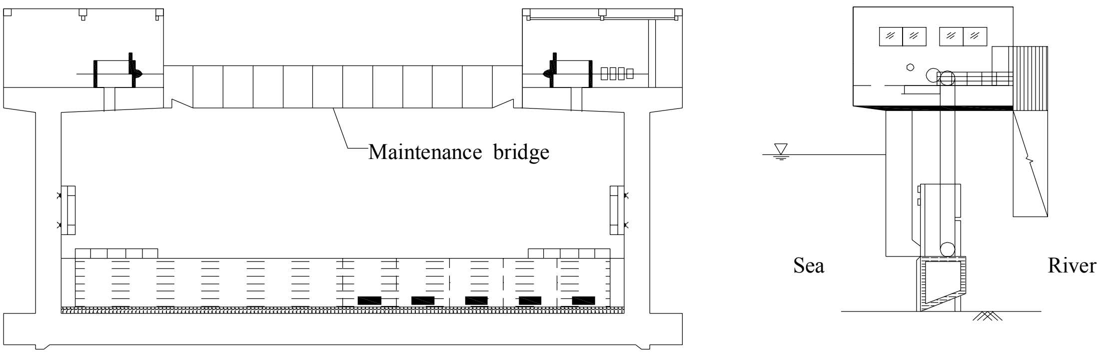


Figure 2.18 General Layout of Tidal Gate

2.4 EMERGENCY FACILITY PLAN

2.4.1 Emergency Road Network

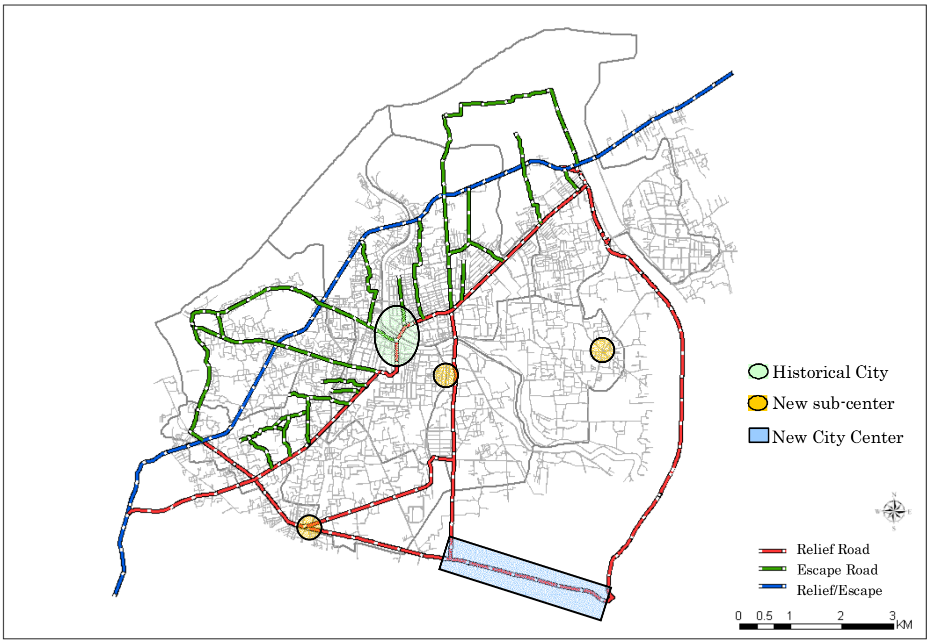
Emergency road network is organized into (i) escape road which citizens are able to escape from disaster in a short time, and (ii) relief road for immediate treatment (first-aid), evacuating citizens, and supplying relief materials. The network ensures to connect with southward area where is much safer against serious disasters.

Emergency road network is provided for smooth activities in an emergency such as people's escape, rescue and relief by relevant government agencies. The relief road plays an important role for providing immediate treatment, evacuating citizens and supplying relief materials, while the escape road leads the citizens to escape from disaster to safer place (Figure 2.19).

The emergency road network forms a belt line linking among historical city center, new city development area, new sub-center, emergency bases and airport. The new sub-centers and emergency bases are located at much safer area against disaster.

The escape roads are connecting coastal zone to national road. The road provides safely escape for the citizens. Escape building are provided along the escape road for the people failed to get out in time

The emergency road network is available not only for escape, rescue and relief activities during disastrous event but also for supplying goods and materials for dislocated families after the disastrous event.



Source: JICA Study Team

Figure 2.19 Emergency Road Network

2.4.2 Relief Road

For the purpose of rescue and relief activities, a peripheral road delineated around the residential area of the City of Banda Aceh connects with southern area, new north-south and east-west arterial roads. The relief road ensures the linkage with the network of escape roads.

The City of Banda Aceh has been developed as a business district of NAD along the arterial national road connecting the eastern side along the Strait of Malacca and the western side along the Indian Ocean. However, the alignment of the road is not in a straight and the traffic congestion used to occur at the center of the city.

Relief road is delineated to ensure the immediate response to stricken area from both directions with the concept of “fail-safe”; namely, access from the eastern side (Syiah Kuala) and the western side (Jaya Baru). The road also provides the linkage with city center, sub-centre and major public facilities (emergency bases). Especially, the relief road is regarded as a belt line connecting with city center and the sub-center as satellite districts.

Along the relief road, emergency bases having relatively wider area are provided for temporary settlement (a shelter tent) of dislocated families and for various relief activities. City parks, plaza in the mosques and schoolyard might be the site of proposed emergency bases. Whilst the low-lying areas extend southward crossing the proposed alignment of relief road, the area by filing up is available for emergency purposes.

2.4.3 Escape Road

The network of escape roads located between the relief road and the east-west national road ensures that the citizens are able to escape from disasters in a short time.

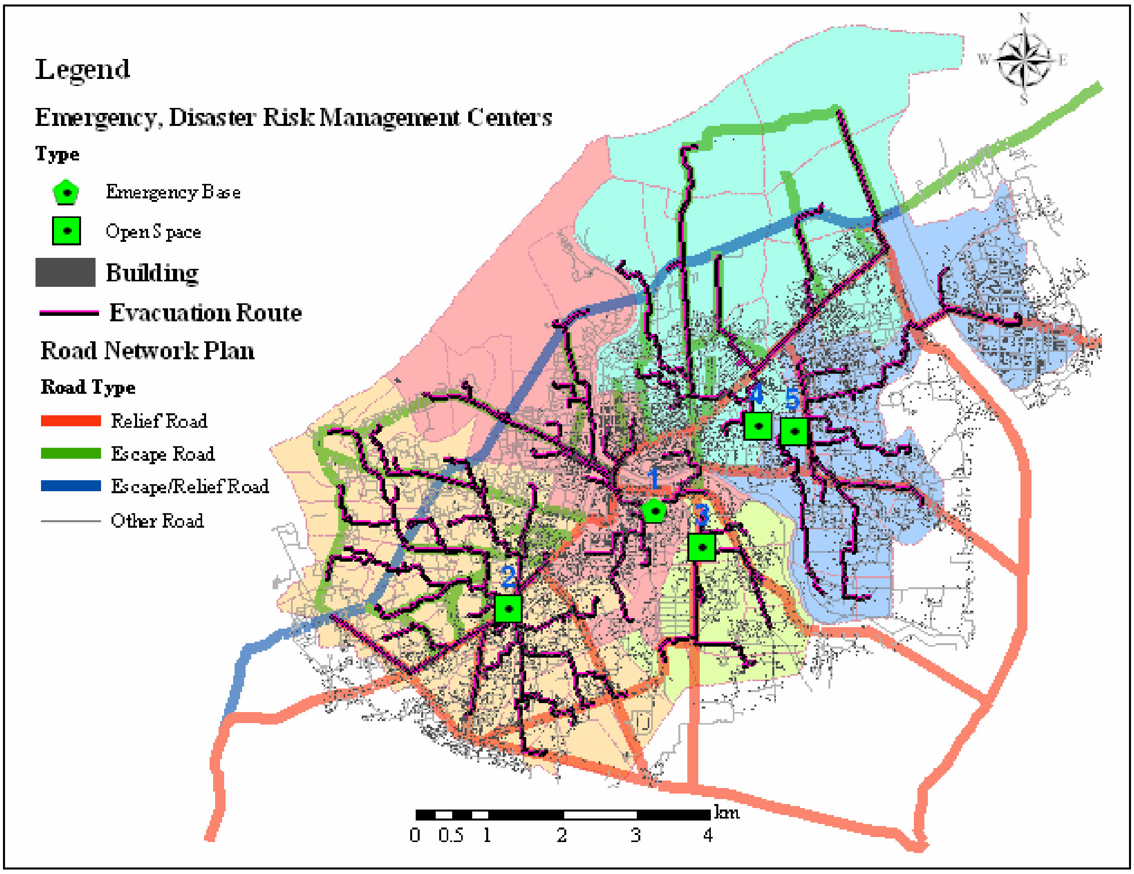
The tsunami run-up on 26 December 2004 ceased along this arterial national road although the road was impassable for all the type of vehicles due to floating logs and debris. The alignment of the road is regarded as the fringe of historic tsunami hazard.

Most serious concerns for the purpose of disaster mitigation are how to lead the citizens lived hazard area to the southward; namely safer side. Several existing south-north roads are proposed as possible escape roads for the citizens. Signboards and lights are provided in case of tsunami in the night time

Time required for escape is quite limited when the tsunami generated by earthquake at the nearest fault. Thus, the place having higher elevation, such as tower, building with public stairs and bridges, are provided along the escape road.

Locations and the number of escape tower, building and bridges are examined taking into account the population distribution, escape road network and distance from the houses. The possible distance for escape on foot is estimated at the radius of 900 m (15 minutes at a walking speed of 1.0 m/sec on the average among the aged, handicapped and children).

The most effective escape route with shortest distance to emergency base and/or emergency management centers (open space) was analyzed by Desa.; The route was analyzed from the center of Desa to the emergency base and open spaces. Figure 2.20 shows the results of analysis by GIS simulation.



Source: ARRIS (GIS) prepared by JICA Study Team

Figure 2.20 Escape Route by Desa