Special interest was large soil settlement and lateral soil movement developed widely along the coast of Maumere City as shown in Photo 5.43. At this site large settlement probably as deep as 1 – 2 m was developed along the coast. Photos 5.44 and 5.45 shows the settlement of storage yard. Several cracks on soils and road pavement were seen as shown in Photos 5.46 and 5.47 parallel to the coast. It is considered that the lateral spreading due to liquefaction caused such large settlement and lateral movement of top soils. It is known based on the Japanese experience[4)] that the large lateral spreading of soils causes extensive damage to many structures.

5.9 Recommendations

Based on the survey for the lifeline facilities described above, it is recommended as;

1) It is recommended to carefully inspect the bridges in Flores Island with the major attention to the damage of substructures. For those bridges which suffered damage to the abutments in such a manner that the foundations slided to the deck side direction with the top of the abutment being tilted to the back fill side, it is recommended to fully replace the abutment to avoid the possible falling down of the girder. Because those bridges are very old with only one lane, evaluation needs to be made whether they should be repaired or replaced with new structures.
2) Because there are a number of bridges in Indonesia which were constructed at the age when the seismic effects were either disregarded or insufficient, it is recommended to develop a simple seismic evaluation method of existing bridge structures. The evaluation method has to be as simple as possible so that the inspection be made at the sites without complex calculations. The evaluation of the seismic stability of substructures is the key item to be considered. A master plan for seismic evaluation and possible strengthening of existing bridges may be important as a future plan.
3) It is difficult to prevent the failure of cut and natural slope along the road in mountainous area. It is recommended to investigate the possible measures against slope failure from cost and effective point of view. It is advised at this point to widen the road so that at least full two lanes of traffic be guaranteed. This may be effective to provide a space to store the falling soils and rocks from the above of the road during an earthquake. Covering the slope above the road by concrete mortar may be effective to prevent the weathering.
4) Because road network in Flores Island is poor, it is recommended to establish a master plan of future road network so that the major cities be prevented from isolation from other areas by an interruption at one location. Such a master plan may be important for developing the Flores Island.
5) For restoring the Maumere port, it is recommended to consider the soil liquefaction effects in design. Some treatment for preventing the failure of the retaining wall may be effective to reduce the damage of wall and apron. It is also recommended to consider the soil liquefaction effect for reconstruction of important buildings in the port.
6) It is recommended to establish a system to systematically conduct the strong motion observation including the maintenance system. This may be very important to evaluate seismic design force and to evaluate soil and structural response during an earthquake.

References:

1) Kawashima, K. and Aizawa, K.:Attenuation of Peak Ground Acceleration, Velocity and Displacement Based on Regression Analysis of Japanese Strong Motion Records, Earthquake Engineering and Structural Dynamics, Vol. 14, pp. 199-215, 1986

2) Japan Road Association: "Part V Seismic Design" of the "Design Specifications of Road Bridges", 1990

3) Kuribayashi, E. and Tatsuoka, F.: History of Earthquake Induced Soil Liquefaction in Japan, Bulletin of Public Works Research Institute, Vol. 31, 1977

4) Hamada, M., Yasuda, S., Isoyama, R. and Emoto, K.: Observation of Permanent Ground Displacements Induced by Soil Liquefaction, Proc. of Japan Society of Civil Engineers, Vol. 376, III-6, 1986

Photo 5.1 Slope Failure of Road Shoulder (National road, several kilometers from Ende)

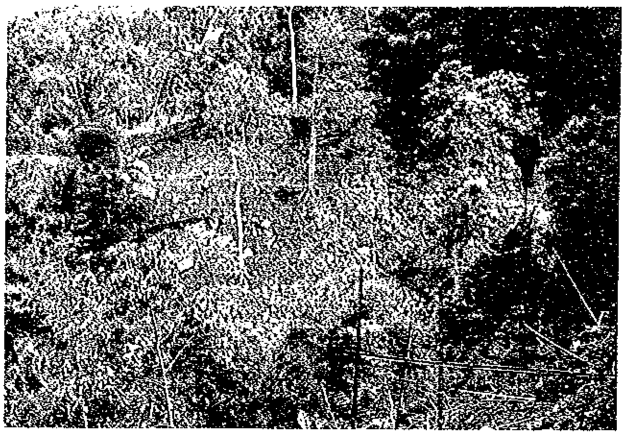


Photo 5.2 Large Slope Failure On and Below Road (National road, severel kilometers from Ende)

Photo 5.3 Destructive Slope Failure On and Below Road (National road, near Lekebai)

Photo 5.4 Slope Failure under Road Presented in Photo 5.3

Photo 5.5 Emergent Evacuation of National Road (near Lekebal)

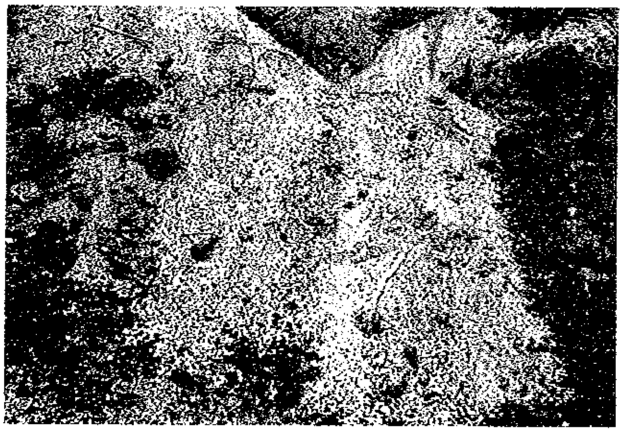


Photo 5.6 Slope Failure of Natural Slope

Photo 5.7 Scoria Layer at the Slope Presented in Photo 5.6

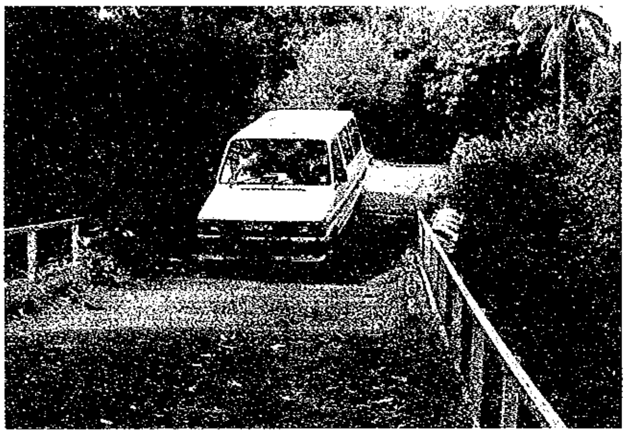


Photo 5.8 Settlement of Bridge Abutment and Back-Fill

Photo 5.9 Failure of Parapet Wall and Back-Fill

Photo 5.10 Large Soil Movement (Sliding) near a Bridge Abutment

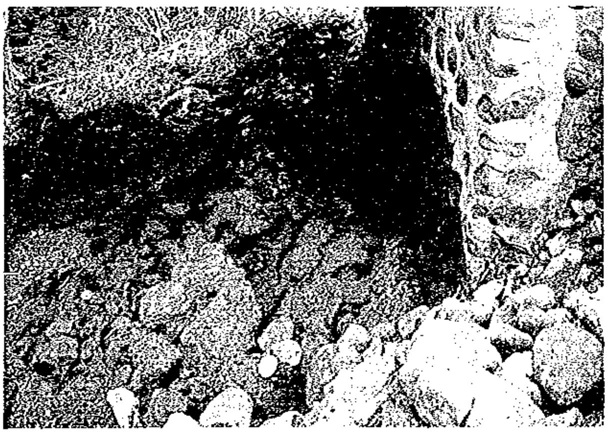


Photo 5.11 Soil Failure in Front of a Bridge Abutment

Photo 5.12 Failure of Abutment due to Contact with Deck

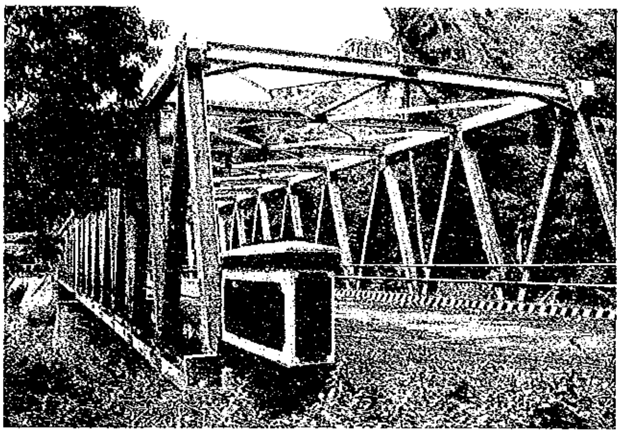


Photo 5.13 Truss Bridge

Photo 5.14 Longitudinal Stopper with Rubber Cushion

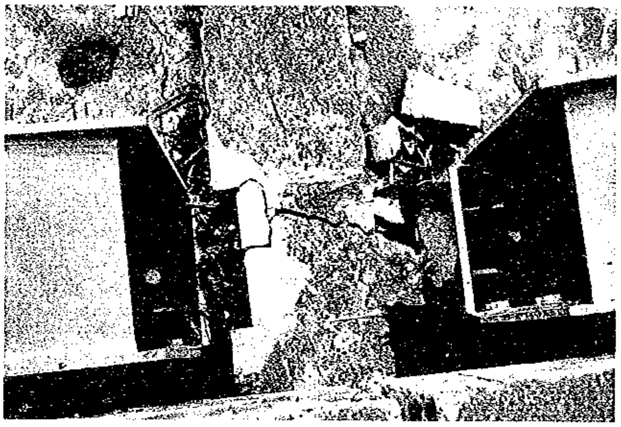


Photo 5.15 Failure of Concrete Block for Stopper

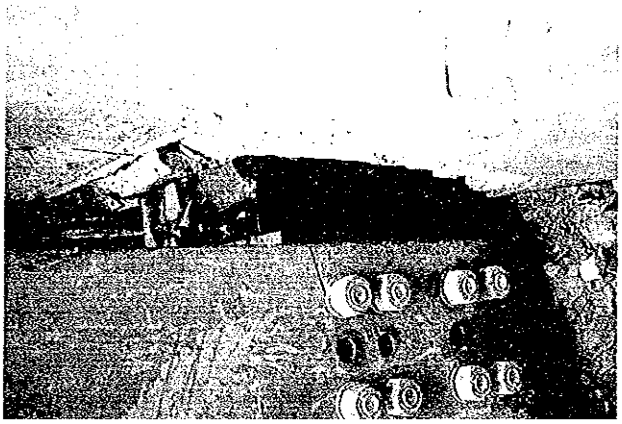


Photo 5.16 Failure of Abutment due to Collision with Deck

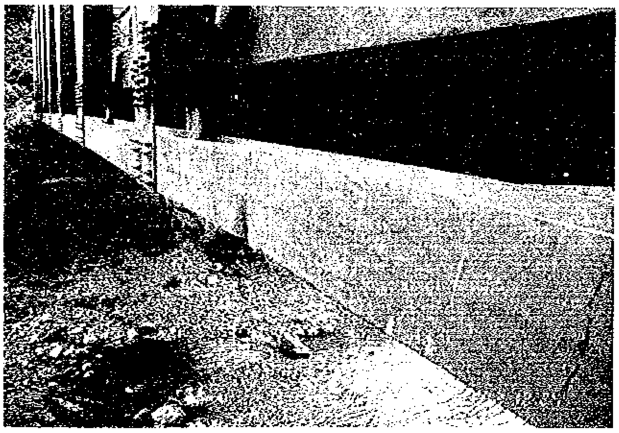


Photo 5.17 Buckle of Lower Cord of a Truss Bridge

Photo 5.18 Cracks on Pavement

Photo 5.19 Cracks and Settlement of Pavement

Photo 5.20 A Large Hole Caused by Soil Liquefaction

Photo 5.21 Settlement of a Bridge due to Failure of Abutments

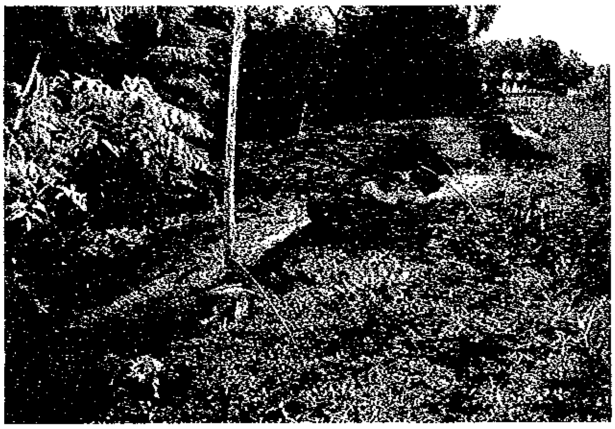


Photo 5.22 Large Sliding of Soils around the Bridge Presented in Photo 5.21

Photo 5.23 Stone Falling

Photo 5.24 Damage of Control Tower at Maumere Airport

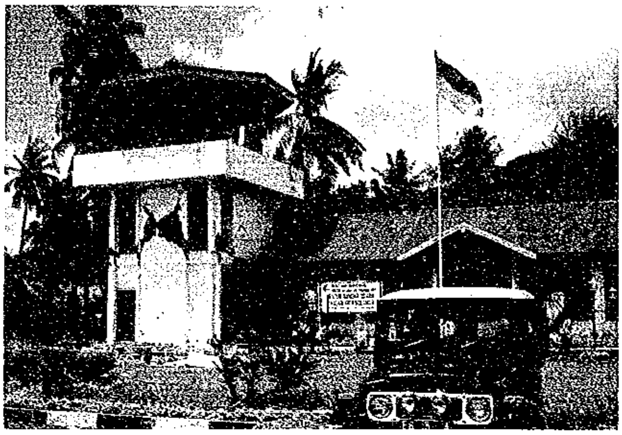


Photo 5.25 Damage of Control Tower at Ende Airport

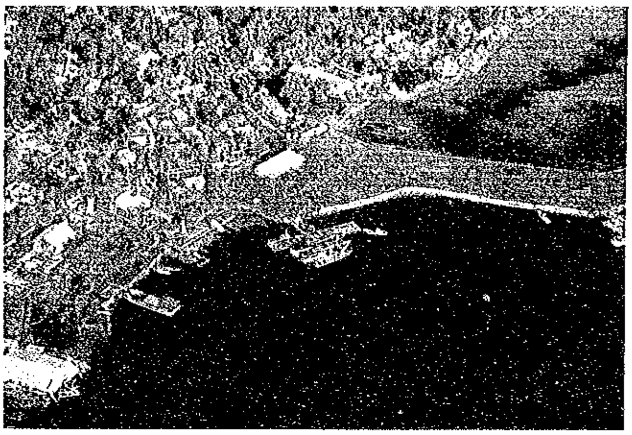


Photo 5.26 Maumere Port

Photo 5.27 Tilting of Retaining Wall and Settlement of Back-Fill

Photo 5.28 Settlement of Apron and Failure of Wall (A Ship and A Boat which were surged by the Tsunami could be seen)

Photo 5.29 Cracks of Retaining Wall at New Port

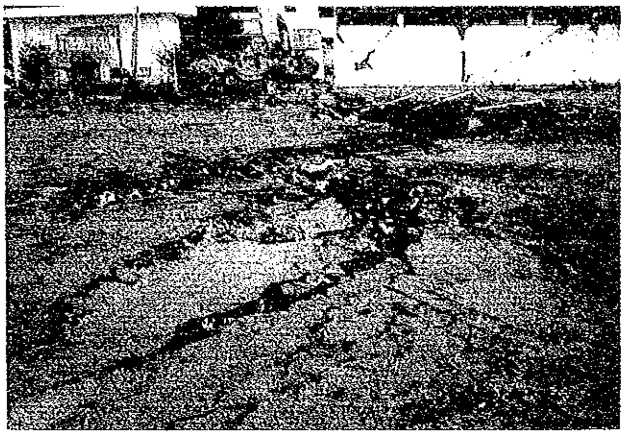


Photo 5.30 Settlement of Pavement due to Soil Liquefaction

Photo 5.31 Cracks and Settlement of Pavement due to Soil Liquefaction

Photo 5.32 Settlement of Foundation of Building at Maumere Port

Ph(,.33 Settlement of Gate Building at Maumere Port

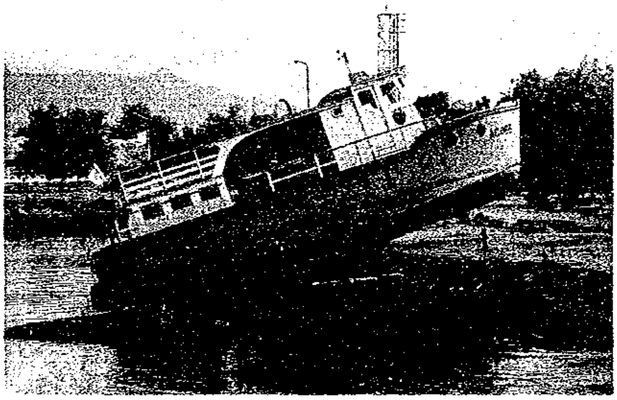


Photo 5.34 A Boat Floated by Tsunami

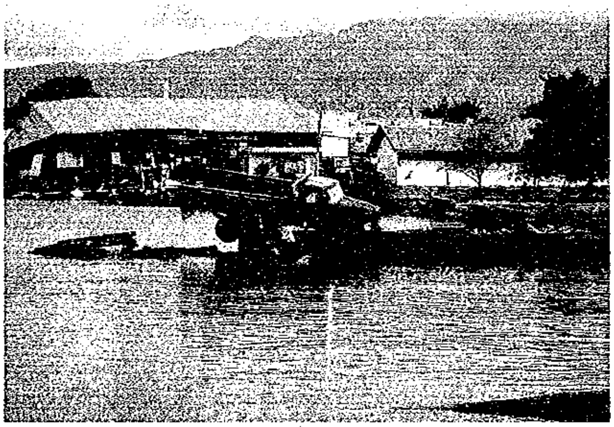


Photo 5.35 A Truck Floated by Tsunami

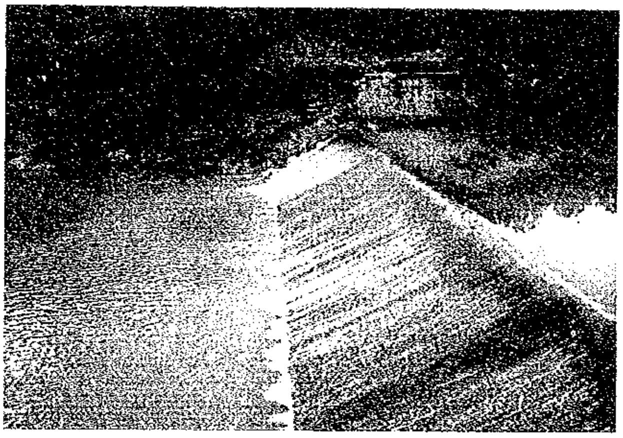


Photo 5.36 Damage of Concrete Block Cover along Water Barrier

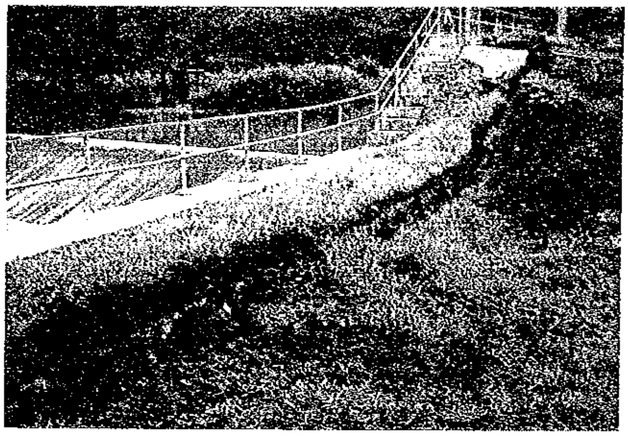


Photo 5.37 Tilting of Parapet Wall and Settlement of Back-fill

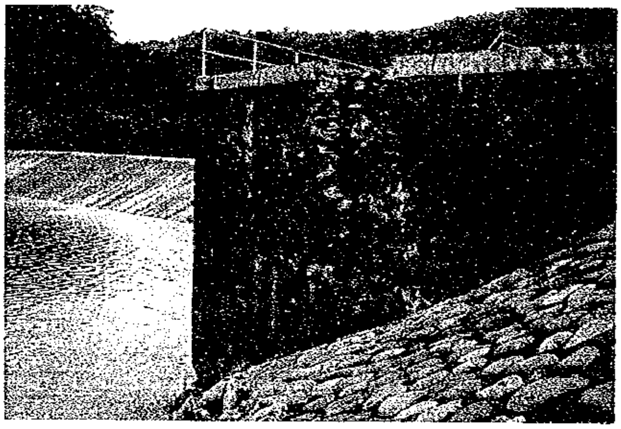


Photo 5.38 Cracks of Parapet Wall

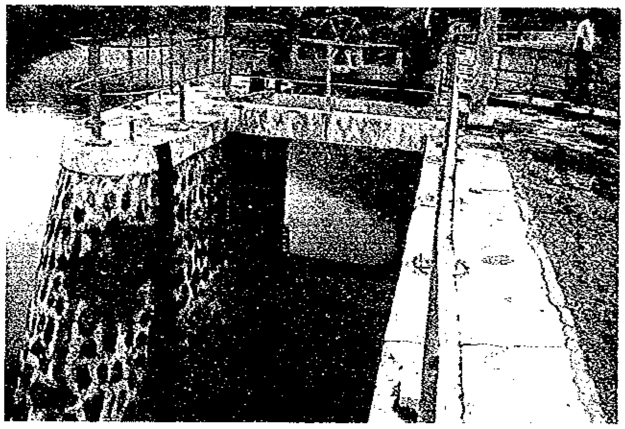


Photo 5.39 Cracks of Parapet Wall near Intake Tower for Irrigation

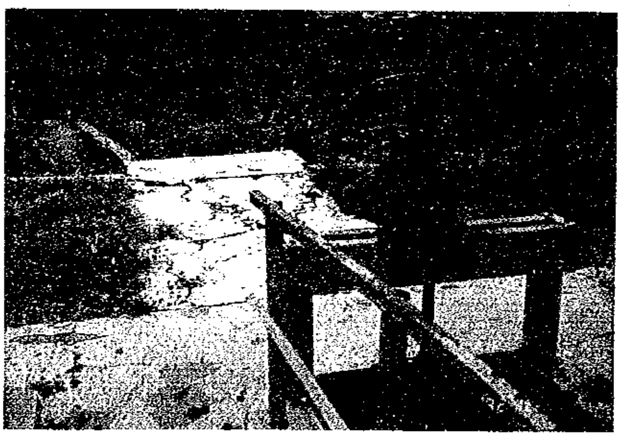


Photo 5.40 Cracks of Water Gate

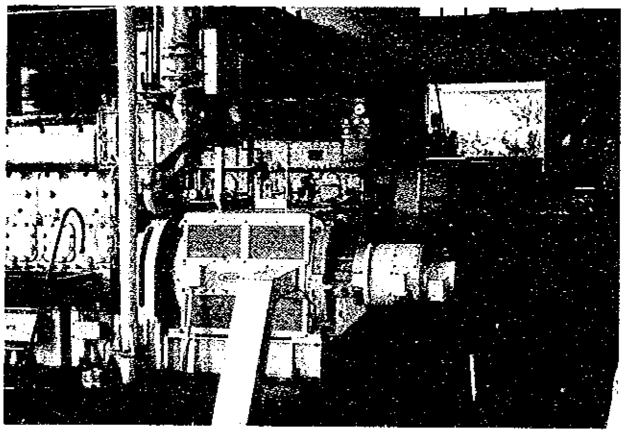


Photo 5.41 Diesel Generator for Electricity at Ende

Photo 5.42 Emergency Water Supply by Water-Tank Vehicle near Ende

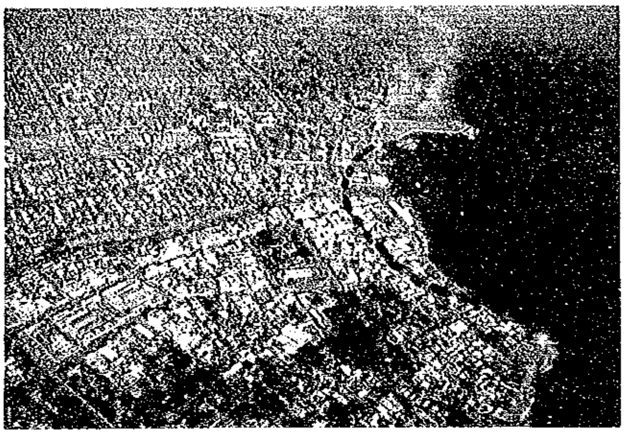


Photo 5.43 Lateral Spreading and Settlement (Maumere City)

Photo 5.44 Settlement of Storage Yard along the Coast

Photo 5.45 Settlement of Coast Line

Photo 5.46 Cracks along the Coast (Maumere City)

Photo 5.47 Cracks on Road Pavement along the Coast (Maumere City)

6. Landslides and Soil Liquefaction

In this chapter, landslides, soil liquefaction and geomorphological changes are described. And the description of landslides includes various kinds of slope failures, which are landcreeps, landcollapses, big collapses of mountainous area, roadside slop failures and others.

6.1 General Description of Landscapes

6.1.1 Flores Island

Flores Island is located in the eastern part of Indonesia. Indonesian Islands consist of many islands from Sumatra via Timor to Buru from the west to the east which are called Great and Small Sunda Islands.

Flores Island is located among them from 8 – 9° S, to 120 – 123° E. It is about 1,700 km far from Jakarta to the east. This island is located between Asian plate and Australian plate. Indo-Australian plate subducts from the south under the island. (Fig. 6.1)

Many volcanoes are distributed beltlike in the central part of the long island, Flores Island. Present coral reefs and coast lines are distributed in the outermost of the island. Outer sea becomes deeper rapidly.

Based on these physical settings, secondary natural landscapes have been formed for a long period. Palm and other kinds of trees form forests in mountainous area. Mangrove forests grow in sites along the coast line. People live in such an area with good relations to natural environments without urban development.

Population is about 1,400 thousands in the island. People consists of nine races which are transitional zone from the west islands races to the east islands ones. Largest cities are Ende and Maumere cities. Areal extent of the island is about 17,000 km^2. (Photo 6.1, Fig. 6.2A, B).

6.1.2 Geomorphology and Geology

Geology of the research area consists of Tertiary and Quaternary series including limestone and volcanic rocks. The weathering of rocks in the area remarkably developed.

Each volcano has main body with one or plural craters and relating mountainous area. And well developed volcanic fans have been formed at the foot of mountains. In eruption, a volcano supplies a great amount of lava flow, pyroclastic flows and other materials to the surroundings.

As for relief of the area, mountainous area (volcanoes) consists of very steep slopes. And surrounding volcanic fans are very gentle and undulating (Photo 6.2). Near Ende, mountainous area consists of many ridges with summit recordance in pinnate type of drainage systems.

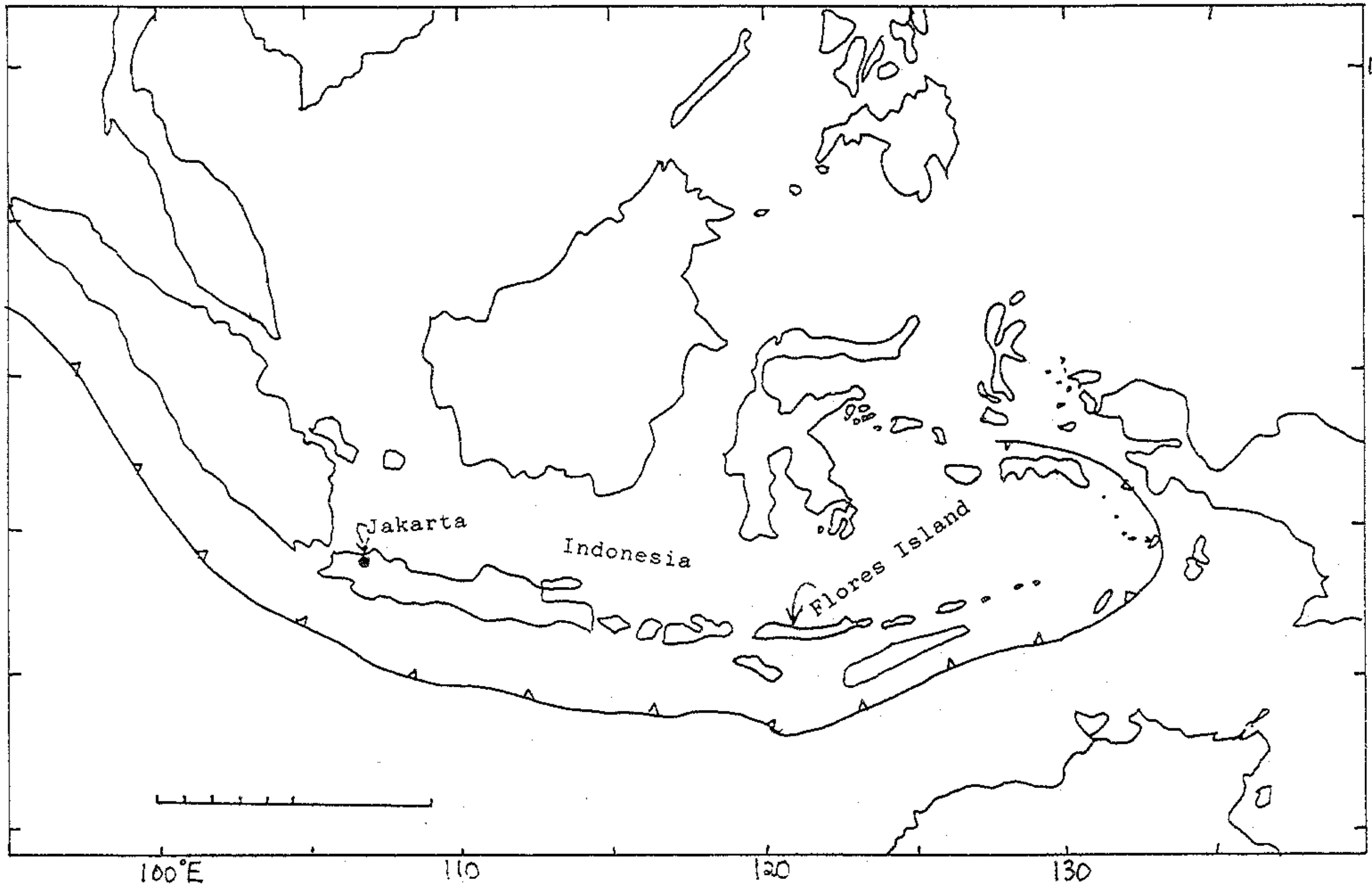


Fig. 6.1 Index of Flores Island

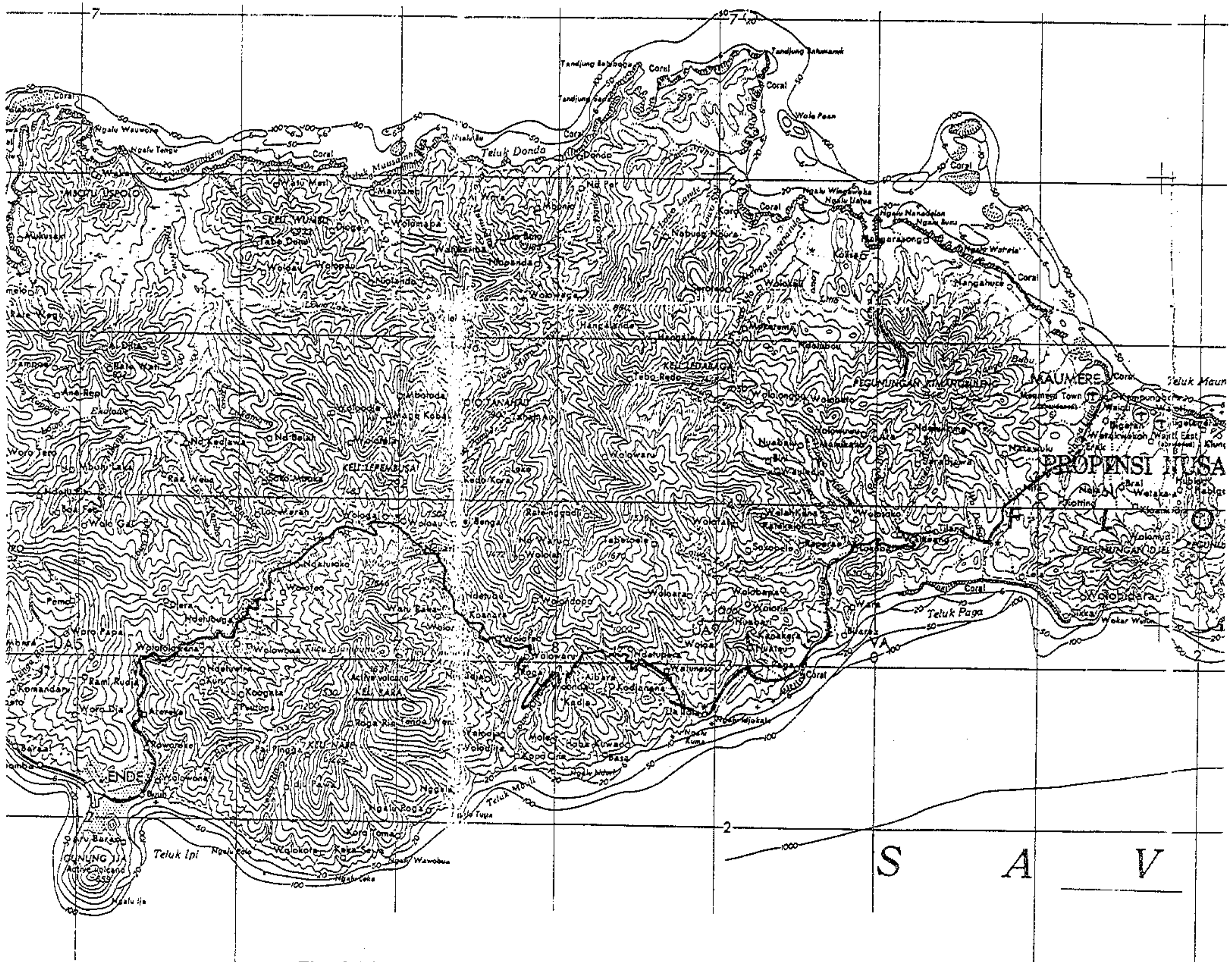


Fig. 6.2A Map of Flores Island, Maumere, Ende and Surroundings

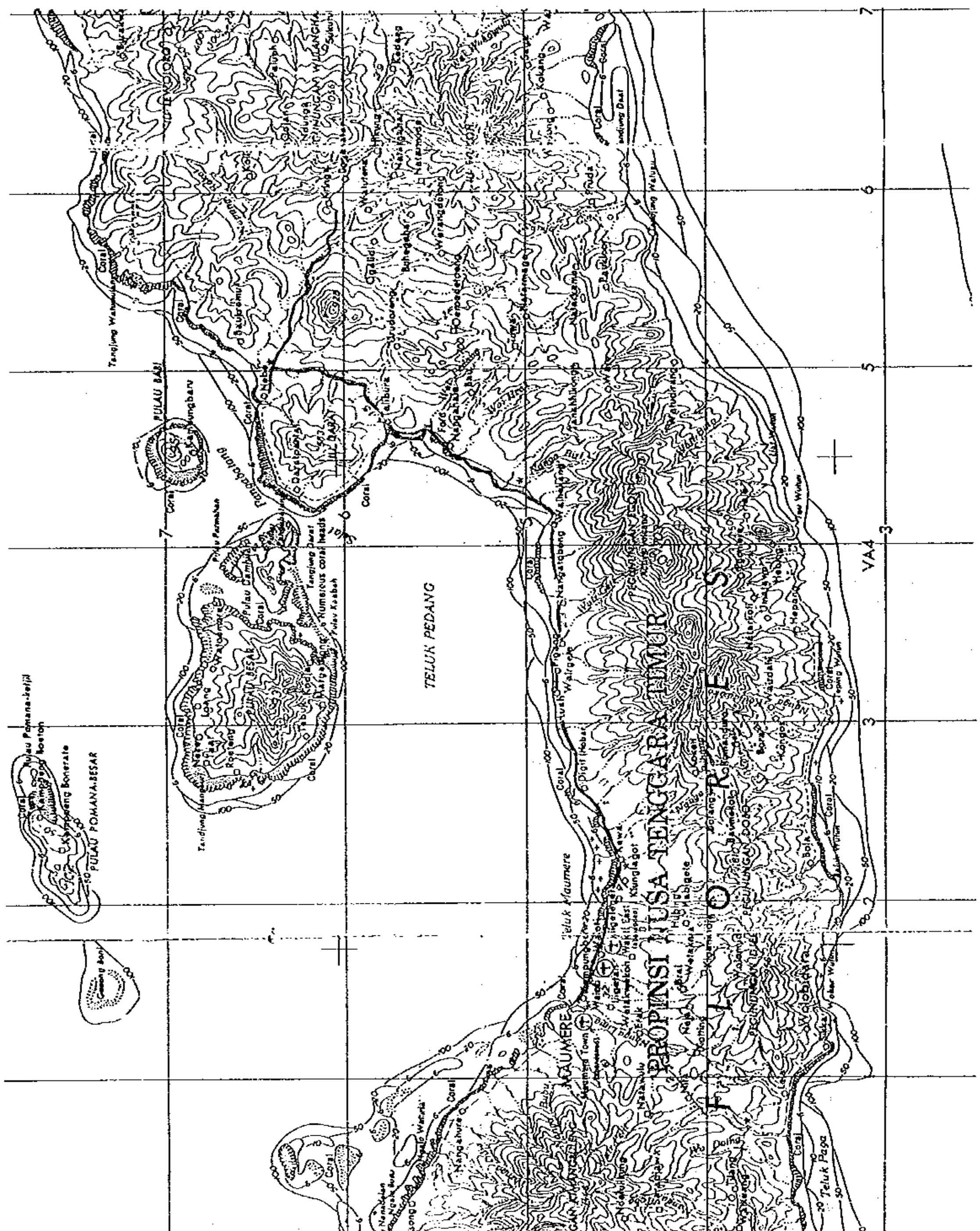


Fig. 6.2B Map of Flores Island, Maumere, Babi and Surroundings

The process of dissection and transportation are very strong to supply material from the remarkably dissected upper drainage basin to the lowermost delta of which subsoil is very young and soft. And mangrove forests can grow along the coastline. The forest also can easily form very soft layer.

In the mountainous area, the researchers did not find severe artificial changes along the river courses.

This shows that in Flores island, fluvial process is still natural, and characteristics of fluvial process are not influenced remarkably by artuficial changes like the one in Japan.

Consequently the area is very weak against natural hazards, for example, landslides, collapses and slope failures of road sides, and boulder flows caused by heavy rainfalls and earthquake shock.

Followings are evidently clear in combination with geology, relief distribution, geomorphological characteristics, soil distribution map and aerial photo interpretation.

1) Mountainous area consists of remarkably weathered rocks which can be easily dissected.
2) River drainage basins have not been artificially changed remarkably. And rivers keep natural forms still in the present.
3) It is clear that the research area is never safe from natural hazards.

6.2 Soil Liquefaction

6.2.1 Soil Liquefaction

Soil liquefaction is a phenomenon as shown in the followings: Subsoil receives earthquake shock (repeated shearing). And pore water-pressure increases very suddenly and rapidly, subsequently effective stress decreases. And the sub-soil layer loses shear strength.

It means that soil layer loses the nature of a solid and gets the nature of liquid. Subsequently lighter material rises to the surface and heavy material sinks into the bottom in the liquefied soil layer.

Figure 6.3A shows the condition before soil liquefaction, Fig. 6.3B shows the condition in liquefying, and Fig. 6.3C shows the condition after soil liquefaction.

Usually, soil liquefaction is caused in a limited sites geomorphologically, which are reclaimed land by landfill and at the edges of sandy landforms saturated with ground water, for example, natural levees, former river courses with landfill. In the objective areas, there are deltas, fans, coastal lowlands where the upper parts of backshore. The sites are consolidated.

6.2.2 Outline of Soil Liquefaction in the Research Area

Soil liquefaction is caused in many sites in the lowlands. In most cases, the earthquake shock first, and spout of water with sand second, and finally tsunami came with a few exceptions. In a few sites, sand boils and spout of water were caused after tsunami.

Mainly the area where soil liquefaction was caused, is grouped into three.

1) Maumere city area including Maumere port and backward residence area,

2) Coastal zones including Wuring via Maumere to Nangorak, probably more broad area along the coastline, and

3) Babi Island.

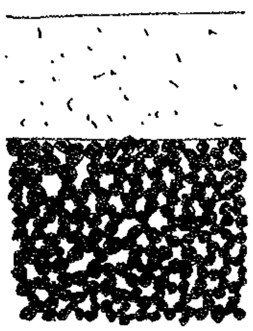


Fig. 6.3A Soil Layer before Soil Liquefaction

Before soil liquefaction, soil layer consists of loose earth of sand grains which forms crumb structure. Sand grains support to each other. The layer has the nature of soilid.

Porosity of this kind of sand layer is about 30 to 40% in the cases of fine sand to medium sand.

Porosity is filled with groundwater. The layer is not so compacted, rather loose. The land surface is covered with compacted artificial layer. Most of the compacted surface layer consists of reclaimed by landfill or compacted-layer by walking for daily life.

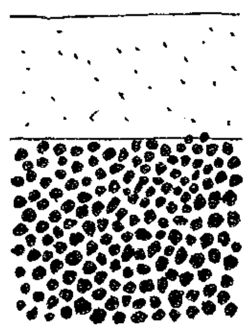


Fig. 6.3B Soil Layer in Soil Liquefying

The earthquake gives shock to the layer repeatedly. And crumb structure is destroyed for a very short period and sand grains float in groundwater. It means that the nature of soilid is lost and the layer get the nature of liquid.

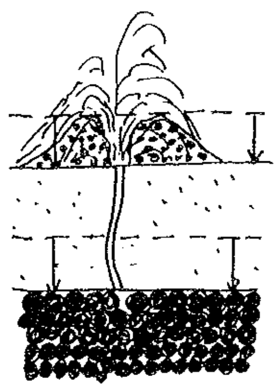


Fig. 6.3C Soil Layer after Soil Liquefaction

The earthquake shock makes cracks in the compacted coverage layer. Groundwater escape through the crack to the land surface. And the water spouted out onto the land surface. The water is accompanied by sand grains. As a result, land surface sinks, water spouts out with earth and weather information boils were formed on the land surface.

If the specific gravity is small, the material is to float out to the upper, for example, culvert. And if it is large, the material is to sink to the bottom, for example, telegraph pole. Houses are easily to be tilted.

Fig. 6.3 Soil Liquefaction

This time, soil liquefaction was caused in the sites where the researchers predicted previously geomorphologically except one landform (the higher part of upper backshore).

6.2.3 Displacement of Soil Layer in Maumere Port

Soil liquefaction was caused in the area of port facilities in Maumere port and its surroundings. Paved area was also destroyed by soil liquefaction (Photo 6.3, 4, 5). Land surface subsided about one meter and formed halls because of spout of water with soil in the area of warehouses, fish market in the wharf in the surroundings of quay and pier along the coast. And some part of the city was drowned by land subsidence. (Photo 6.3, 4, 5, 6)

Liquefied sand was displaced not only vertically but also horizontally toward the sea (Dr. Kawashima's explanation). And according to the author's observation, enough quantity of liquefied sand never spouted out onto the surface of the pavement of the port facilities from the underground to be able to explain the land subsidence and the tilting of houses and facilities at the port area. And horizontal movement of liquefied sand can explain such phenomena. (Photo 6.7). And sometimes horizontal displacement of facilities might occur in a limited zone of port of Maumere area. Sand boils near Maumere port consists of grey sand (gleization) which was in saturated layer with water. (Photo 6.8).

Examples of horizontal displacement of the ground by soil liquefaction caused by the earthquake can be still seen in the surroundings of the bridge crossing the Shinano river in Japan, which the earthquake caused in 1964 (Yasuda and others, GSI aerial photographs, the site can be seen in 1992). And horizontal displacement of paddy fields was measured by photograpmmetric method in Wakamichou town in Akita pref. in Japan, which the earthquake caused in 1983 (First Geographic Division, GSI:1984).

6.2.4 Destruction of Houses Caused by Soil Liquefaction in Maumere City

Many houses were destroyed by the earquake shock and soil liquefaction in the residence area in the suburbs of Maumere Port (Photo 6.9). Sand boils erupted out in the inside of the houses and many cracks also were caused in a part of the houses (Photo 6.10). Such houses became unsuitable to live. Various scales of sand boils were formed in the area. Spout of water caused land subsidence in a dry field. Many fine and long cracks were caused in roads.

Maumere city is located on a very soft ground of which surfaces are consolidated pretty hard artificially by people's habitation. Geomorphologically, the area is classified into reclaimed land surface by landfill, former river courses with landfill and so on in delta.

6.2.5 Soil Liquefaction in Coastal Zones and Wuring

In many points, soil liquefaction was caused along the coastline.

Wuring is located on a sand bar of which surface is consolidated for peoples' habitation. In Wuring, soil liquefaction was caused in the residence area. Water spouted out there, and water was pretty warm (perhaps, ground water was heated in the ground).

As for the other part of the coastline, soil liquefaction was caused in many sites in a long shoreline facing the Flores sea, at the higher part of backshore which is covered by vegetation or yards of houses for daily life. Only traces were seen because most of sand boils were washed away by the tsunami wave. Little sand cover can be seen in the traces of coastal zone, and detailed information is not clear.

6.2.6 Soil Liquefaction in Babi Island

In Babi island, soil liquefaction was caused in many sites in sandy landforms. Most of them were caused in the area which were washed away by tsunami, but some of them keep their initial forms typically (Photo 6.12, 13, 14).

Many traces of soil liquefaction were found in the traces of the village area and their surrounding where was drowned by tsunami waves in Babi Island. And many sand boils, which were not destroyed at all, were found with washed-away sand boils in the eastern village in the Babi Island.

This shows that 1) there are sites where soil liquefaction was caused before tsunami after earthquake shock, and 2) there are sites where soil liquefaction was caused during and after tsunami after earthquake shock. In sand bar, sand boils consist of white sand which are coral sand, very small white snails and various kinds of tips of corals.

In this island, soil liquefaction was caused in the part of sand bar where village yards, under the floors of houses (Photo 6.15) and on the bar covered by grasses of which ground levels are about one meter to three meters high above the sea level, which the areas were inundated by tsunami flood (Photo 6.14). Groups of soil liquefaction were caused at straight in linear, long and fine cracks, but single sand boils were caused under the floors of houses (Photo 6.12, 13, 14, 15).

6.2.7 Characteristics of Soil Liquefaction

Soil liquefied sites were grouped into three areas:

1) Maumere area including Maumere port and backward residence area
2) Coastal zones including Wuring via Maumere to Nangorak, probably more broad area along the coast-line
3) Babi Island.

This time, soil liquefaction was caused in the sites where the researchers predicted previously based on geomorphological classification except one landform: the higher part of upper backshore.

Through the whole objective areas, soil liquefaction was caused in the sites with following conditions. Ground heights are about one to three meters. The sites were consolidated pretty hard by walk on the yards and artificially reclaimed by landfill. Such sites have conditions that the surfaces of the ground are hard on the soft ground with sandy material saturated with groundwater.

6.3 Landslides

6.3.1 General Descriptions

As shown at the beginning of this chapter, in this report, the description of landslides includes various kinds of slope failures, which are landcreeps, landcollapses, big collapses of mountainous area, roadside slope failures and others.

A big earthquake often causes many landslides including roadside slope failures. This earthquake caused so many and various types of landslides in mountainous area mainly. And supplementary road side slope failures in hilly areas. Especially landslides were caused concentratedly into the mountainous area from Maumere to Ende and most of them were caused without relation to road distribution.

The author researched the actual conditions of landslides including road side slope failures in the area using a military helicopter, because it was impossible to reach the slope failures through the ground routes because of disruption of road traffics in many sites in the mountainous area where there was no detour route. And the research was done using a car from Maumere to Nebe (to the east route).

For the reason, the researchers observed the distribution and characteristics of these phenomena by observation based on geologic and geomorphological approaches using oblique aerial photo interpretation taken by the researchers. GSI method of Japan is applied for prediction of road side slope failures caused by heavy rainfall. But in the most cases, the method is also available for making countermeasures against road side slope failures caused by earthquakes (GSI: 1976).

According to the research, it was clarified that more than a few hundreds of sites of slope failures were caused. And road side slope failures were also caused. And road side slope failures were also caused in many sites from Maumere to Ende as already reported. Also the relationships between physical conditions and landslides in the mountainous area caused by the earthquake.

6.3.2 Roadside Slope Failures Along the Coast Line from Maumere to the Eastward Route

Roadside slope failures were caused along the national route from Maumere to the eastward in several sites, and supplementary in hilly area in the volcanic fans which is undulating near Maumere (Photo 6.17 – 23). These sites were recovered temporarily to pass through, but not perfect recovery when the research was done. In these sites, roadside slope failures were caused at the sites where slopes were cut or banked.

Geology of the sites consists of Tertiary limestone, which are originated from raised coral reefs, Tertiary volcanic material and Quarternary volcanic fans including pyroclastic flows and tephra. Through the whole area, it seems that geology is very weak. Constructions against disasters are seen at only the surroundings of bridges.

In the route along the coastline from Maumere to the east, traffics were disrupted for a few days after the earthquake through the whole section. When we researched the route, it was possible to pass partly, and the recovery was still temporary repair.

This route is a national route and important one for inhabitants living in the damaged area. While JDR researched the area, many cars, motorcycles and people used the route. Especially, important for transportation of goods and for students and office workers to go and return their schools and offices.

There were many sites of cracks of the pavement and a few sites of collapsed sites (Photo 6.21). A few of land collapses formed deposit area at each site which consists of volcanic pyroclastic flows and limestone. At one of them, it is evidently clear that land collapse was caused repeatedly in the past at the same site.

6.3.3 Landslides in Mountainous Area from Maumere to Ende

There is the national road from Ende to Maumere through the mountainous area. And the route has been suspended in many sites more than several tens sites. The team for restoration work must work one site by one site from both sides of the route because there is no detour route to the inner damaged sites (Photo 6.40).

The researchers tried to clarify the characteristics of the whole area from a helicopter. Slope failures are several hundreds of sites including mountainous area. Seismic intensity was 5 to 6 in this area.

Using a helicopter, the followings are clear. But the followings are the result based on observation from the helicopter. For the reason, the followings are only a kind of preliminary general observation. But, aerial photo interpretation is available to clarify characteristics of various types of slope failures very effectively.

This area consists of volcanic area, hilly land of summit recordance, which consists of land surface of the former erosion cycle and large scales of complex volcanic fans. Drainage patterns are pinnate type, dendritic type and radiation type in the mountainous area.

Various types of landslides and roadside slope failures were caused in the mountainous area from Maumere to Ende. Some of them have been recovered already temporarily from Maumere to the near-south coast (near Tilan), and short distance from Ende toward inland. But most of other part has not been recovered at all.

The earthquake caused many and various types of landslides. These were caused in the mountainous slopes and at roadsides slopes. These consist of two groups. One is newly failured ones. Another is repeated ones.

6.3.4 Characteristics of Landslides and Roadside Slope Failures

Landslides and roadside slope failures are classified into several groups as shown in the followings. 2) to 7) were caused without any relation to roads.

1) roadside slope failures,
2) surface collapses caused just under the break line of ridges, single,
3) surface collapses caused just under the break line of ridges, complex slides or collapses with broad width,
4) large collapses which forms a long tail with deposit of reddish brown boulder flows,
5) small collapses with a head to tail,
6) landslides with many cracks at the top of collapses.
7) rock wall failures

(1) Roadside Slope Failures

Many small slope failures were caused at roadsides from Maumere to Ende (Photo 6.36 – 42). Some of them have been already recovered. But about one third of the distance was still in recovering construction work (Photo 6.40).

This type is classified into three.

1) Slope failures at mountain side of the road (Fig. 6.4B).
2) Slope failures including mountain side of the roadside slope and valley side through the roadbed, (Fig. 6.4C).
3) Slope failures at valley side of roadside slope. (Fig. 6.4A)

And the type can be classified into another two groups.

4) Road side slops, which were formed by cut and bank, were failured by the earthquake. Previous 1) to 3) are classified into this group.
5) Geomorphologically and geologically, slope failures are easily caused in specified sites. If a road crosses such a site, naturally, the road is damaged. In the research area, there are many sites of this kind in the area. Group 5) can be interpreted systematically using aerial photo interpretation, it is evidently clear whether the collapsed sites are active or not in most cases. (Fig. 6.5D, E)

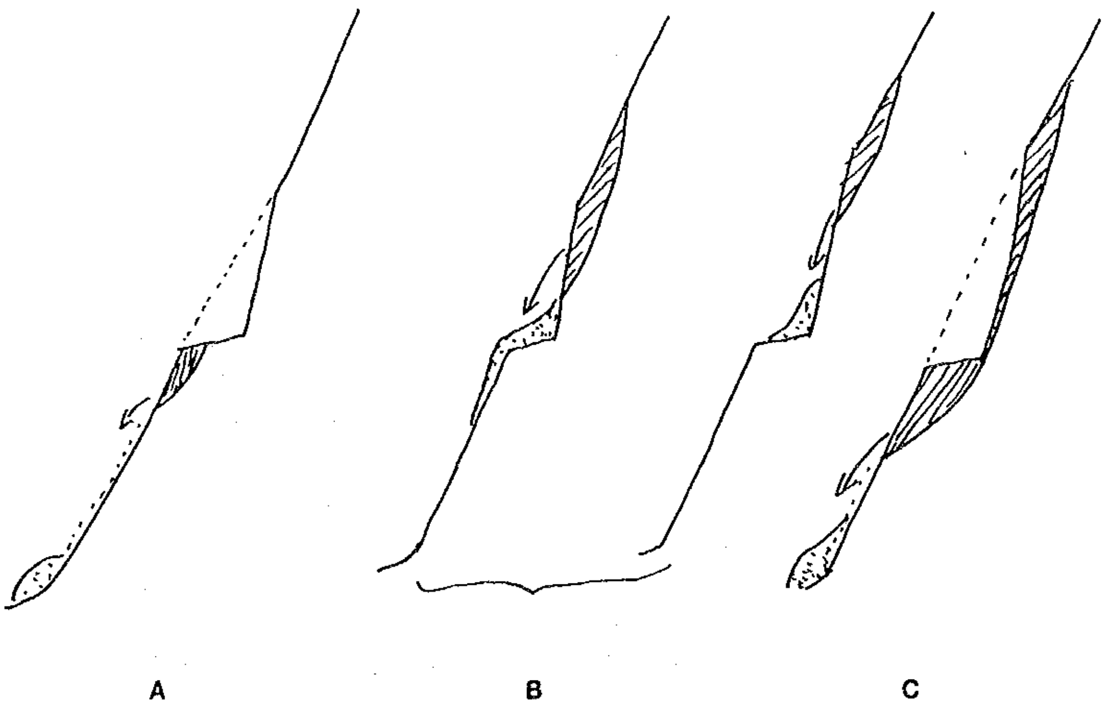
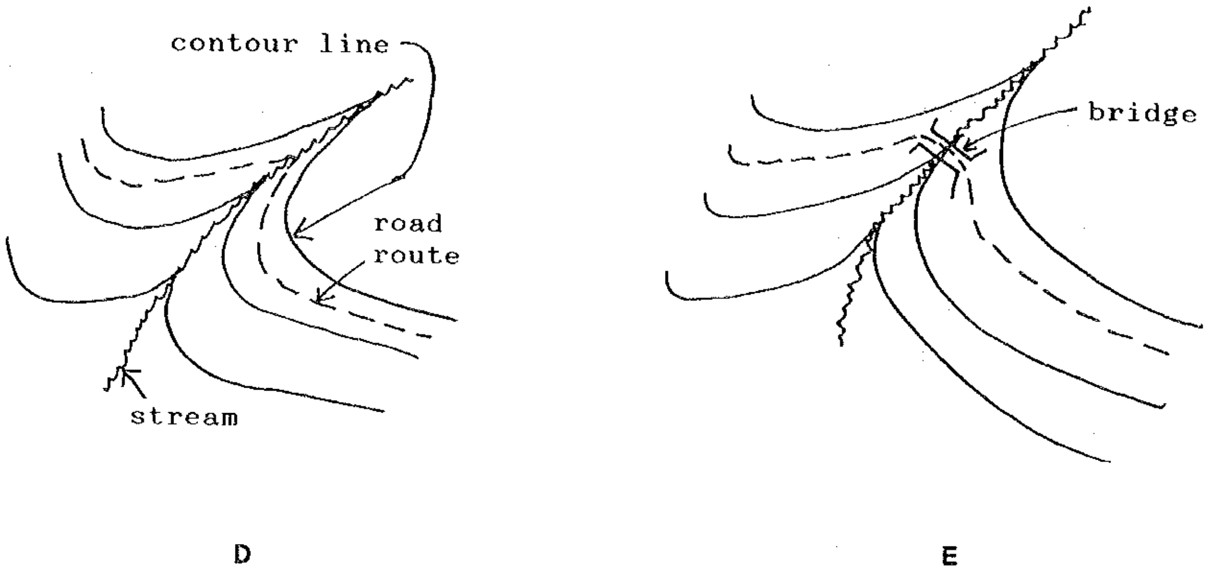


Fig. 6.4 Types of Road Side Slope Failures



In the case of D, a stream flows down and the road crosses the valley course. There is no bridge there, consequently, rock flow, earth-flow and flood water are to hit the road. The phenomena mean the accidental damages caused by such disasters. If a bridge was constructed there before the earthquake, there is no problem for rocks and earth flow, and flood water to pass through the site.
There is nothing against natural disasters. Naturally, various types of natural disasters are easily caused in such sites.
If there are many bridges in the mountainous area, most of destroyed road sites were still kept in initial forms.
In the case of E, there is a bridge at the site where a stream intersects the road consequently.

Fig. 6.5 Damage at the Site where a Valley Intersects the Road

(2) and (3) Surface Collapses in Mountain Slopes.

Many landslides were caused in mountain slopes without any relations to roads. These were caused just under break lines of each ridge (Photo 6.25 – 27). Most of surfaces were collapsed, subsequently reddish soil came out in broad area in the mountainous area. And these types are repeated types of collapses. These are caused at steep slopes of pinnate river drainage systems in mountainous area with summit recordance.

(4) Deep and Large Scale of Collapses

Deep and large scales of collapses were caused in the surroundings of the volcano. There is an active volcano with three craters on the top. The surrounding area is covered by thick accumulative material supplied from the volcano. This type of collapse has a large head (collapsed area) and a long tail (transportation route with deposit, and deposit area) (Photo 6.28 – 30).

(5) A Single Collapses in a Dendritic Drainage System

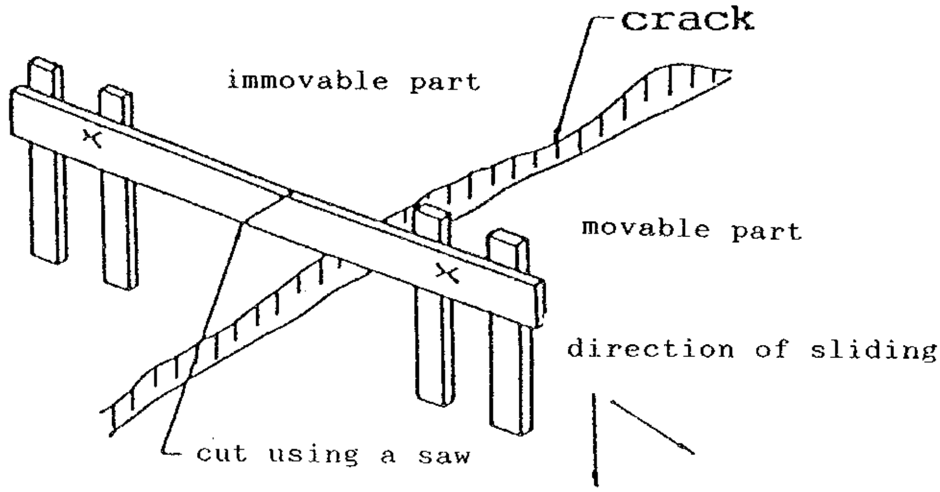
This type of landslides were caused in steep slopes on the mountain ridges. In the research area, 0-order streams in a dendritic (=tree) type. This type has a small head, very long and fine tail (Photo 6.24).

(6) Landcreeps

This type of landslides were caused at the top of a little gentle ridges (Photo 6.31). There are many cracks at the top of the landslides. This is a kind of landcreeps. Slope steak (Fig. 6.6) is available to monitor the behavior of this type of landslides whether the landslides may move soon or not.

(7) Rock Wall Failures

Rock slops were collapsed at the slopes of rocky mountains. Under the vertical cliffs, there are deposits rocks. (Photo 6.33)



This slopestake is set to measure the behavior of landslide quantitatively. This is set on a crack formed at the landslide lying on both movable and immovable part of a landslide. The horizontal plate (1) is separated using a saw.
If the movable part moves, the crack will surely be widened. The indication to begin to urgent guard is shown in the Table 1.

Fig. 6.6 Slope State

Table 1 Standard Value for Evaluation in the Cases of Japan

		corresponding class			
	instrument	attention	warning	refuge	keep out
standard amount	extensometer	over 1mm/day	over 10mm/day	·over 2mm/hour in two hours ·over 4mm/hour	over 10mm/hour is a standard and finally judging by the opinions of specialists
example amount	ground inclinometer	over 10seconds/10days	-	-	-
	pipe strain gauge	over 100 μ (accumulative amount)	over 1000 μ (accumulative amount)	-	-
basic corresponding direction		begin to inform one inspection in a day	*strengthen the inspection *preparation for refuge	*begin to take refuge	*keep inhabitants off the hazardous area of the landslide,as the case may be,they can go home temporarily
major works	supervision of landslide (ministry of construction, prefecture)	*inform city,town and village *patrol *check the system of inspection *inspection by the system (once a day) *confirm the way of giving information	*do and strengthen the followings *ceaseless inspection all day *confirm moving blocks and inspect the potential of block's magnification and the predictable hazardous area	*do and strengthen the followings	*do and strengthen the followings *keep out *saving life has priority over all things
	area disaster prevention work (city,town,village)	*give information to people and enterprise of road ,train and so on *confirm the system of warning	*give information *preparation for refuge *ceaseless inspection all day	*the establishment of a head office for disaster prevention *judge and recommend refuge *set guide persons for refuge *open a place of refuge	*keep out *saving life has priority over all things
a note	When the observational amount is under the standard,we discuss the cancellation of each corresponding class's works. Then finally city,town and village judges and informs inhabitants of the judgement.				

6.3.5 Characteristics of Landslides and Slope Failures

(1) The route between Ende and Maumere is important route for inhabitants and the route must be used at any time. And if some parts are suspended, the sites must be reopened in a few days to one week. The route has been formed through history without detailed design.
When road plans are made, the characteristics of geology should be clarified to decide the gradient of the side slope, whether rocks are weathered or enoughly hard.

(2) This time, we could find a few landslides with cracks, because we flied only along the route. If there are such landslides still in moving, the most important thing is to monitor the movement of the landslides using very simple method called 'slope stake'.

(3) It is one of the most effective ways that civil engineers and planners use aerial photographs to interpret characteristics of the land against natural hazards. For the reason, aerial photographs should be more used for such purposes. GSI method and GSI staff's method are available.

6.4 Geomorphological Changes

Geomorphological changes, which were caused by the earthquake, consist of tectonic movement of the ground, landslides caused by earthquake shocks, cracks of the ground and erosion and accumulation by tsunami.

Tectonic movement is not clarified by us, because the researchers did not research the whole area and also did not survey precisely. The earthquake was one of big earthquakes, subsequently it is natural to consider that ground movement, which consists of uplift and subsidence, had been caused by the earthquake.

Cracks were formed linearly in many places in the forms of very long and fine. Some of them were caused at the higher part of backshore along the coastlines. These are about 100 meters long, one meter deep and one meter wide. Directions of cracks in the coast line were in nearly parallel to the coastline (Photo 6.44).

Even if soil liquefaction was not caused, various types of many cracks were formed in the city of Maumere. The group of displacement and subsidence of Maumere port and its surroundings and the group of cracks in the eastward were independent to each other. And they are very local. But they were displaced toward the sea.

Through the whole area, it can be said that many cracks were formed in parallel to the coastline and were displaced toward the sea. Unfortunately for us, we did not research it quantitatively this time.

The detailed information of erosion and accumulation by tsunami is not well known to us. But a Babi Island, sand bar along the coastline were eroded and washed away about one meter deep, 20 meters wide, and pretty long (Photo 6.43). Tsunami has destructive power and many of facilities and houses were destroyed, but landforms on the land surface were not eroded so severely this time.

6.5 Whole Description

(1) Characteristics of the Earthquake are 1) Bit earthquake, 2) Big tsunami was caused, 3) 30,000 houses were destroyed, 4) Slope failures were caused in many sites, 5) Lost 2,000 persons or more. 1,000 among them were killed by the destruction of houses.

(2) People live in natural landscapes in the limit of natural environments without rapid and intensive artificial changes of the land in Flores Island. There a big earthquake hit the area. People were in the place of the destruction of houses or in the place where tsunami hit without any countermeasure against the earthquake,