4. NUMERICAL SIMULATION FOR MALE', HULHULE AND HULHUMALE'

4.1 Male' Seawall Project

Any serious damage caused by extremely high tides may not have been recorded before 1986 in the Republic of Maldives, but thereafter high waves attacked Male' and its surrounding islands three times and caused considerable damages to seawalls, private houses, airport facilities, etc. in April 1987 and in June and September 1988.

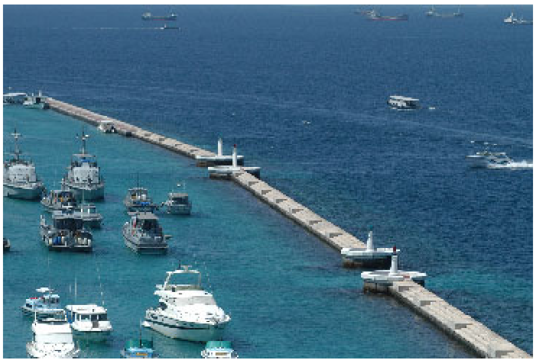
Immediately after the flood disaster in 1987, the Japanese Government dispatched an urgent mission to study the flood disaster in response to the request of the Republic of Maldives. Based upon the recommendation of the mission, the detached breakwaters on the southern coast in Male' and was completed in 1990 by the Japan's Grant Aid Project.

Since the seawalls at that time was not robust in their construction (being constructed of coral boulders 10 to 20 cm in size, capped with cement mortar), there were sections of seawall which were missing and therefore the waterfront was neither stable nor safe. The ground elevation of the entire island with its high density population is barely a few meters above sea water level and once the seawall is breached and the island is inundated, all the functions of the capital city come to a grinding halt and social and economic activities are suspended. In order to prevent such calamities, it was imperative that a permanent and secure seawall be constructed to keep the people of Male' Island free from the ravages of the nature and so be able to conduct a normal and safe life, and maintain the social and economic base.

Then a series of the construction of seawalls around the Male' Island have implemented by the Japan's Grant Aid Project after a feasibility study and basic design studies by JICA. West coast seawall was completed in 1996, east coast one in 1998, south coast one in 2000, and north coast one in 2002(Photo4.1.1,Photo4.1.2). The typical sections of each seawall are indicated in Figure 4.1.1.

During the Indian Ocean tsunami, happened on 26th December 2004, despite two-third of Male' Island were flooded (Photo4.1.3), there was no casualty and the Male' Island avoided the catastrophic damage from the tsunami. So it may be said that the effectiveness of the seawalls has been revealed. The study team implements numerical simulation in two cases of "with seawall" and "without seawall" for the 2004's tsunami attacking on Male'. In addition, the influence of tide sea level and topography are to be investigated. The numerical simulation is to clarify the propagation process of the tsunami having attacked Male' and to verify the effect of the seawall.

Photo.4.1.1 Male' Island



(a) North coast

(b) East coast

(c) West coast

(d) South-west coast

(e) South coast

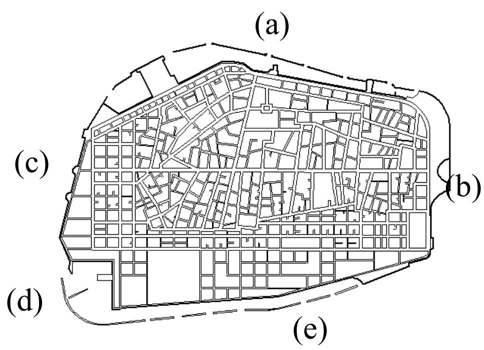


Photo 4.1.2 Seawalls in Male' Island

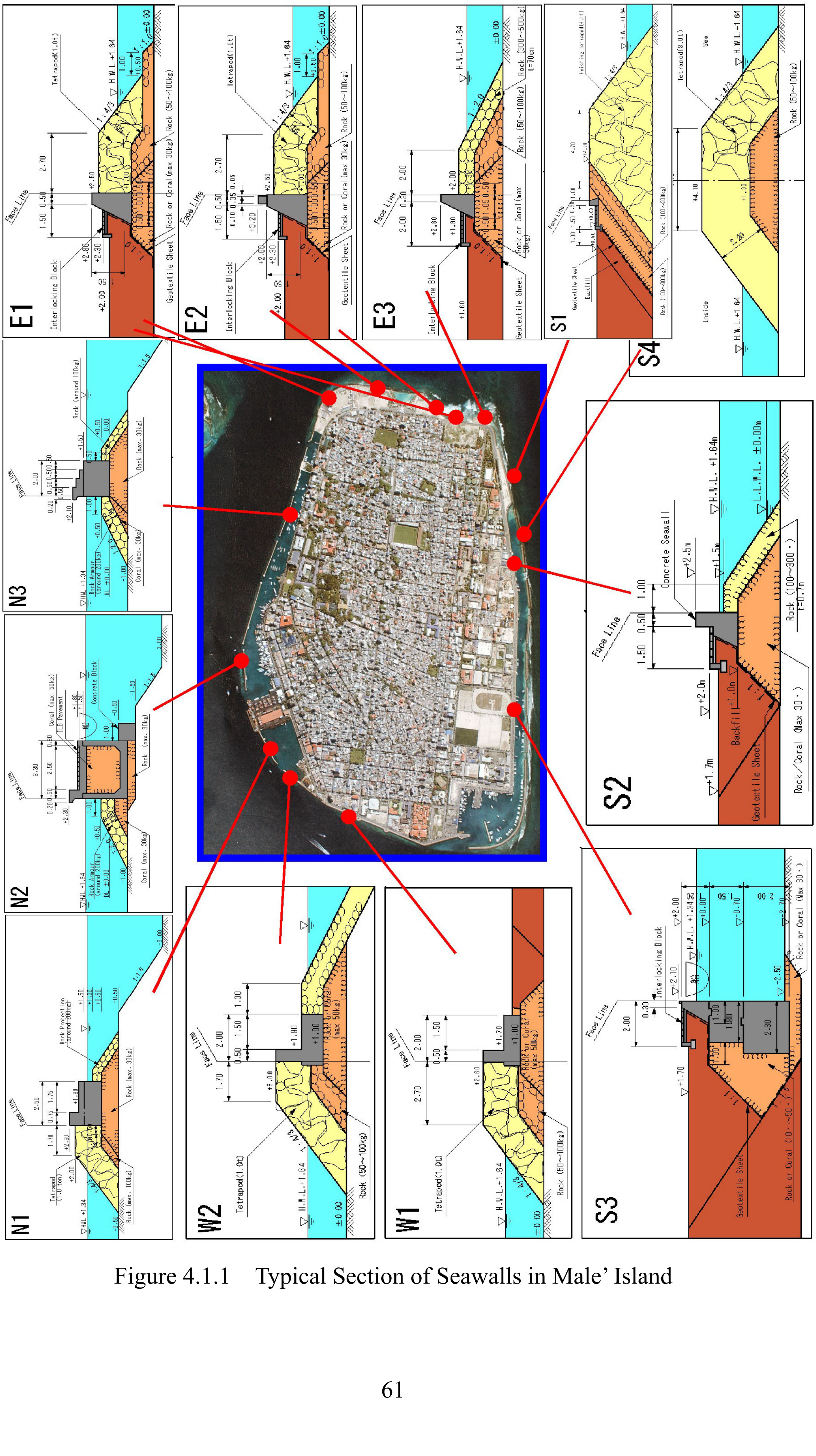


Figure 4.1.1 Typical Section of Seawalls in Male' Island

(a) Urban district

(b) East coast

(c)Port

(d) West coast

Photo.4.1.3 The flood scenes of Male' Island（©MTV）

4.2 Method of the simulation

Delft 3D developed by Delft Hydraulics is applied in this study, which is a three dimensional nonlinear hydrodynamic equation based program. Delft 3D is capable of 3D simulations by using the so-called sigma coordinate approach. In this study, only 2D simulation is executed without defining grids along depth. Two regions are involved in this simulation. One covers a region of 55.47km from east to west, and 29.15km in north and south, which is called as "large region" hereafter, see Figure 4.2.5. The other ranges from 8.6km in east-west, 10.6km in north-south around Male' Island and Airport Island, which is called as the nested "small region" hereafter, refer to Figure 4.2.6. Grid size in the large region is Δx 430m× Δy 530m, while Δx 20m× Δy 20m for the small region. Koshimura's waveform of tsunami shown in Figure 4.2.7 for the large region is used as input data on the eastern boundary at latitude 4° 4' 58.8" , 4° 9' 57.6", 4° 15' 00"north and longitude 73° 45' 00" east (Figure 4.2.8, Section 2 by S. Koshimura). Four boundary conditions of the large region are defined as follows: water level at east, current at west, walls at north and south. "Water level" indicates that the input data on the boundary are defined by water level. “Current” means that the input data are given by velocity or discharge. “Wall” means no exchange of the flow. Boundary conditions of the small region are determined by means of introducing calculation results of the large region. Water level at the east and north boundary conditions, and the current at the west and south boundary conditions are taken.

Here, we assume that the tide level in the Maldives is equal to 0.58m (L.A.T) before arrival of tsunami (0.06m below M.S.L.+0.64m), where L.A.T denotes for a standard level during construction of seawalls which has a relationship with C.D.L as follows: L.A.T+0m= C.D.L+0.08m. Simulation starts from a hypothetical time 1:00 UTC on December 26, 2004. The total duration is 80 minutes and time interval is 6 second. Manning coefficient of roughness, n, is 0.025 for seabed and 0.013 for a densely populated urban area of Male’ Island. We tried to use n=0.09 in simulation of an urban area but the resultants appeared not inconsistent with the real situation because of an excessive friction factor caused by very shallow water condition. The actual measured values of inundation area showed that the water was not at running state but at static state, so the flow resistance may not be an important issue for this simulation.

In Figure 4.2.9, ground elevation, surrounding seawall, breakwater and offshore breakwater in Male’ Island are involved. The image of computational model of breakwater and seawalls are shown in Figure 4.2.10. Ground elevation of Airport island (Hulhule) is shown in Figure 4.2.11, and that of surrounding reef is taken as L.A.T.+0.08m, that is to say, initial water depth on the reef is 0.5m. Calculation cases are listed in Table 4.2.1. If the results of koshimura’s simulation were used for boundary conditions in this simulation, enough inundation in Male’ Island has not been obtained. Therefore we are to use the magnified waveforms of Koshimura’s simulation results as boundary conditions and 1.5 times for Case 1; 2 times for from Case 2 to Case 5. Furthermore, Case 2 is the case without seawall, and Case 3 is with seawall in order to compare effects of seawalls. Case 4 is implemented on the assumption that tsunami happened on 26th December 2004 at the high tide condition. Case 5 is carried out for examining the topographic effects of Airport Island /Hulhumale’ Island.

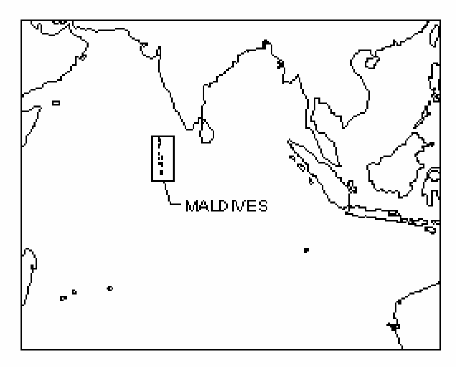


Figure 4.2.1 Location of the Maldives

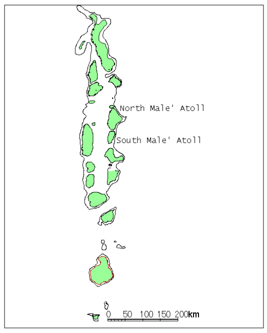


Figure 4.2.2 Atolls

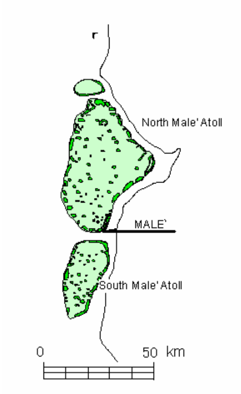


Figure 4.2.3 Location of Male' Island

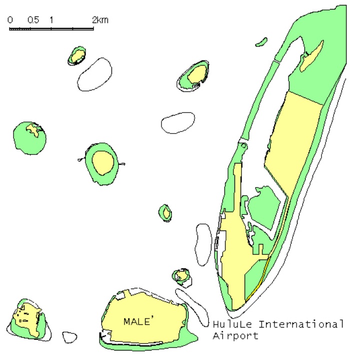


Figure 4.2.4 Male' Island and Airport Island

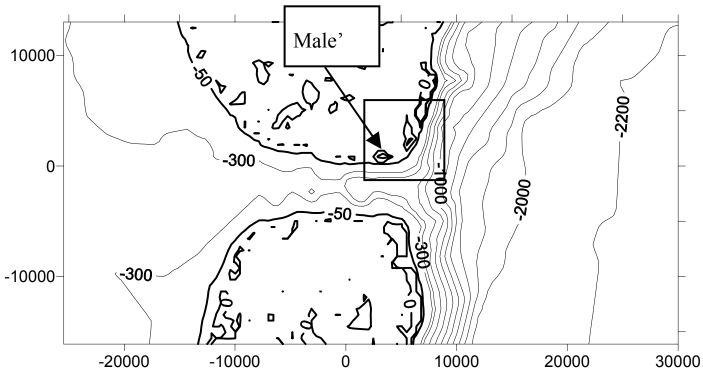


Figure 4.2.5 Large region (m)

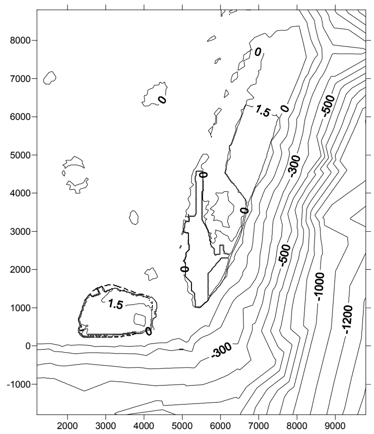
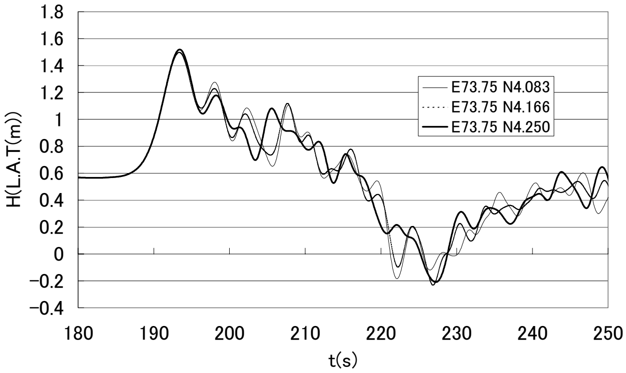


Figure 4.2.6 Small region(m)



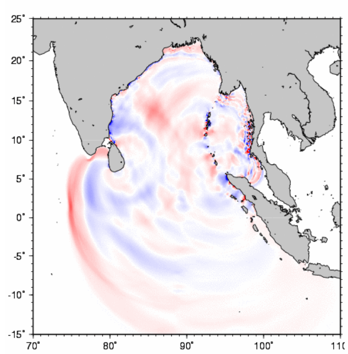
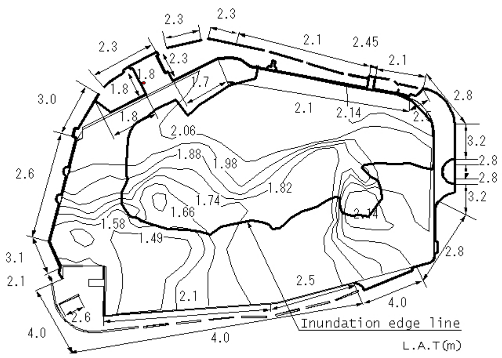


Figure 4.2.7 Time history of water level at east boundary condition (large region)

Figure 4.2.8 Results of tsunami propagation computation (see section 2,Koshimura)



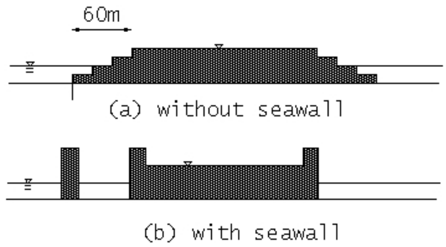


Figure 4.2.9 Ground elevation and height of seawalls in Male' Island

Figure 4.2.10 Computational model of breakwater and seawalls

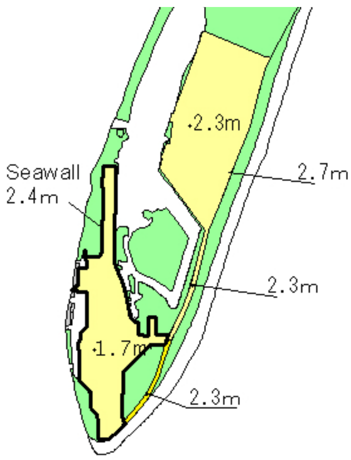


Figure 4.2.11 Ground elevation and height of seawalls Airport Island and Hulhumale' Island

Table 4.2.1 Calculation cases

Case	Initial tide level (L.A.T.(m))	Tsunami sea level (L.A.T.(m))	Tsunami height (Variation above initial level)(m)	Multiplying factor for Tsunami height calculated by Koshimura	Seawall	Airport island and Hulhumale'
1	0.58	1.97	1.39	1.5	with	with
2	0.58	2.43	1.85	2.0	without	with
3	0.58	2.43	1.85	2.0	with	with
4	1.10	2.95	1.85	2.0	with	with
5	0.58	2.43	1.85	2.0	with	without

4.3 Results of the simulation

4.3.1 Calculation and validation of the computational model

Regarding the accuracy of the calculation, a comparison of the tsunami trace height between measurement data and calculation results is carried out. Heights of tsunami in Airport island are illustrated in Figure 4.3.1 (Table 4.3.1). Figure 4.3.2 describes inundated areas in Male' Island at elapsed time of 80 minutes after start of calculation. Here two cases (Case 1 and Case 3) with different boundary conditions are shown. The tsunami height of Case 1 is 1.39m above initial tide level and that of Case 3 is 1.85m at the east boundary of the large region model. Note that the corrected tsunami sea level in Table 4.3.1 is a sum of the measured tsunami trace height and the tide level (L.A.T+0.58m) before arrival of tsunami. As shown in Figure 4.3.1, Case 1 with 1.39m tsunami sea level conducts a little insufficient assessment. On the other hand, Case 3 with 1.85m tsunami sea level results a slight overestimation, even though some scatters have been found. However, we know from distribution of inundated areas in Male' Island shown in Figure 4.3.2 that the inundated areas of Case 3 give closer agreement than Case 1 with measured ones shown in Figure 4.2.9. Accordingly, the actual tsunami height of the offshore of Maldives may be considered to be a value between 1.39m and 1.85m.

As a result, it is no doubt that the waveforms of Koshimura should be magnified by a factor between 1.5 (1.39m tsunami height above tide sea level) and 2.0 (1.85m). The following discussion will be conducted based on the results of using the factor of 2.0, which present closer agreement to measurements in Male' Island.

Table 4.3.1 Comparison of the tsunami sea level between measurement data and calculation results

Latitude	Long tude	Measured tsunami trace height (m)	Tsunami sea level (L.A.T.m) ①+0.58m	Case1 (L.A.T.m)	Case3 (L.A.T.m)
N4° 11’26”	E73° 31’55”	2.57	3.15	2.16	2.46
N4° 11’21”	E73° 31’58”	3.09	3.67	2.51	2.82
N4° 11’21”	E73° 32’06”	3.37	3.95	2.96	3.63
N4° 11’25”	E73° 32’15”	1.64	2.22	2.63	2.92
N4° 12’04”	E73° 32’27”	2.03	2.61	2.75	3.40
N4° 12’59.8”	E73° 32’40.7”	2.43	3.01	2.66	3.42
N4° 12’58.2”	E73° 32’43”	2.05	2.63	2.68	3.44
Boundary Tsunami Height from water surface				1.39	1.85
Initial water level (L.A.T.m)				0.58	0.58

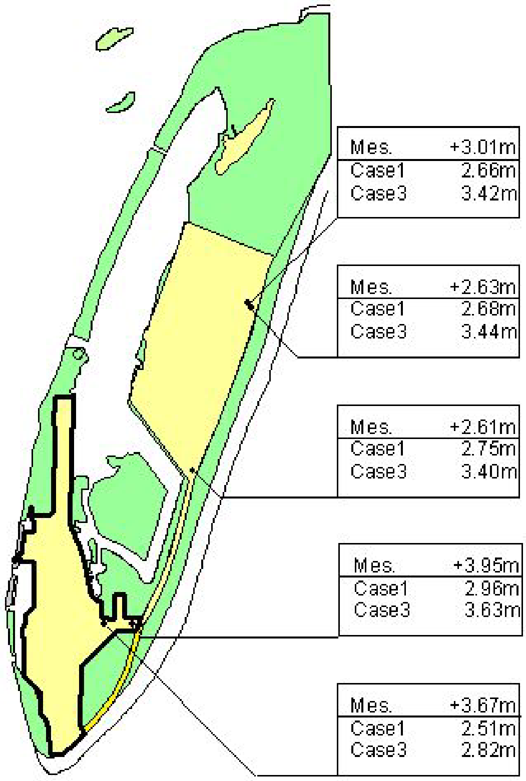
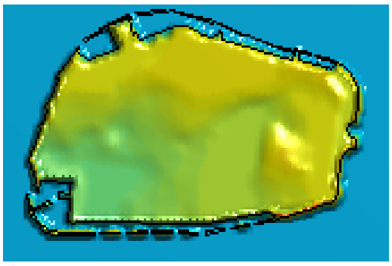
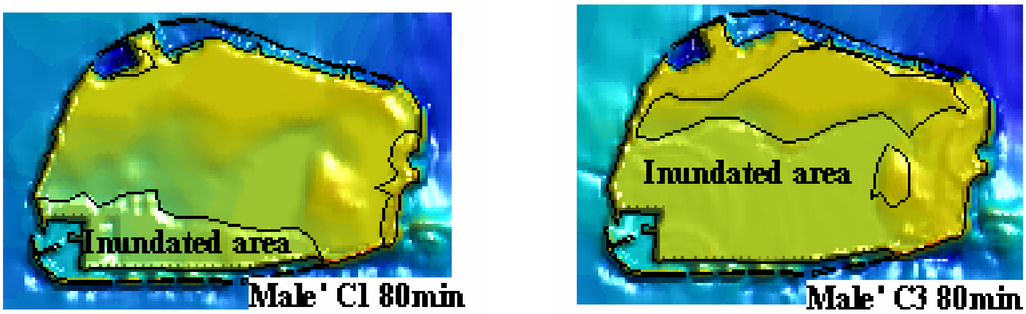


Figure 4.3.1 Tsunami sea level of Airport Island and Hulhumale’ Island



(a)Initial state



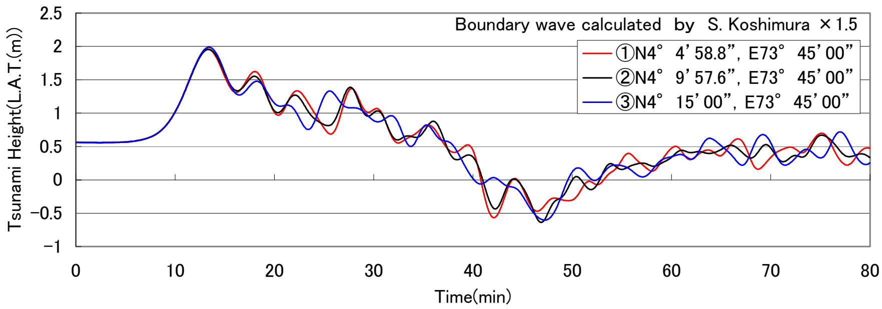
(b)Case 1 (Multiplying factor1.5) (c)Case3 (Multiplying factor 2.0)

Figure 4.3.2 Inundated areas of Male' Island

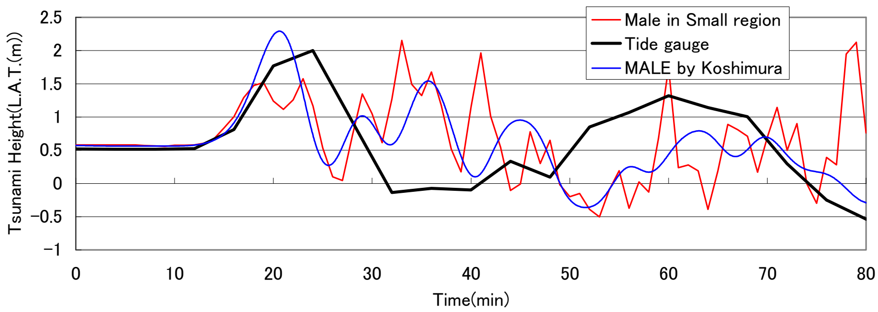
Figure 4.3.3(b) presents a comparison of tidal gauge records and simulations at a same place. It is shown that the tsunami attacking Male' Island starts from flooding and last about 20 minutes, then changes to ebbing tsunami which lasts about another 20 minutes. Time history pattern of the waveform of the tsunami measured by the tidal gauge is somewhat different from that of the calculation results.

The calculated tsunami height waveforms turn to reach higher tide level, just after the water level drops down following the flooding, while the measured one stays keeping the same state during the period from 30 min to 50 min. A deduction may be drawn that tsunami is reflected back from eastern side of north Male' atoll and turns into standing waves which indeed reached to the point of the tide gauge in west of Airport island. These standing waves may be generated by several factors, and the following phenomenon is considered to be one of the factors: the reflected tsunami at the eastern edge of north Male' atoll propagates to east in shape of ebbing tsunami whose height is below L.A.T. +0m. On the other hand, the sea water levels on eastern boundary is still keeping from 0.5m to 1.0m during the period from 20 min to 40 min (Figure 4.3.3(a)). Therefore, the tsunami bounding for east is reflected on the eastern boundary, and it hits north Male' atoll again. As shown in Figure 4.3.3 (b), the first flooding peak of the case (Male in small region) seems to sag. This is due to the complex tsunami's movement in the atoll. The first peak is generated by the tsunami passing between the Airport Island and Male' Island, and the second peak is resulted by the tsunami entering atoll following the first one.

In the following discussions we mainly focus on the results of the first flooding period of the 30 minutes, which involve less effect of reflection during this period.



(a)Tsunami height at the eastern boundary



(b) Tsunami height at the point of the tide gauge

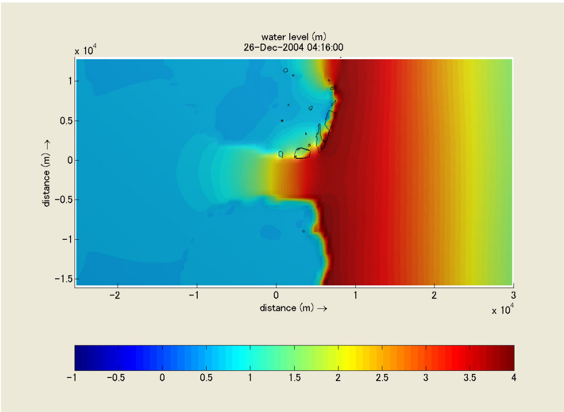
Figure 4.3.3 Comparison of tsunami height at the point of tide gauge and calculation result

4.3.2 Characteristics of tsunami having attacked Male' Island and its surrounding Islands

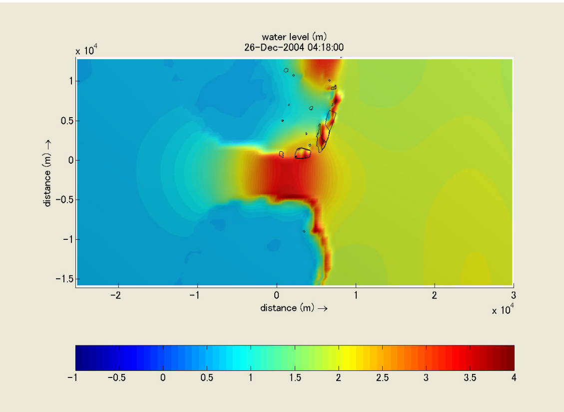
Characteristics of tsunami attacking Male' Island and its surrounding islands are investigated through examining calculation results of large region.

Figure 4.3.4 indicates a process of tsunami propagation over the areas including parts of north Male' Atoll and south Male' Atoll. The sea with the depth of more than 300m spreads over the area between north Male' Atoll and south Male' Atoll. The area between these two atolls form a strait-like topography. In east side of Male' Island, there exists shallow reef (e.g., Hulhule Falhu), on which Airport Island (Hulhule) and Hulhumale' Island locate, spreading from north-east to south-west. The east edge of Hulhule Falhu connects to a 2000m deep ocean with a sharp gradient seabed.

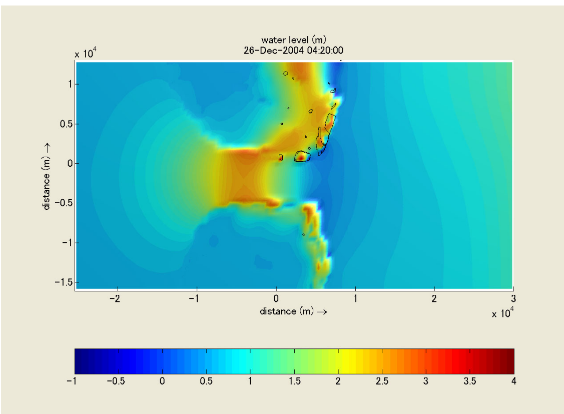
When the tsunami from east hits the atolls, it loses its wave velocity rapidly. Tsunami runs at low speed through these shallow atolls and much time is needed for passing through the atolls. But tsunami concentrates and goes rapidly through the deep straits, which leads to a high water level within strait before rising of water level on atolls. Accordingly, a phase difference of the water level change is generated between atolls and the open sea. That is, despite of the phase related to high water level on atolls, the water level at the open sea gets started to drop down. As shown in Figure 4.3.4(c)(d), this situation is quite noticeable around northern atolls. This can be regarded as one of the characteristics of the tsunami passing through the atolls like Maldives'. In addition, a complex wave condition within atolls has been shown that many reflected waves overlap from number of small islands.



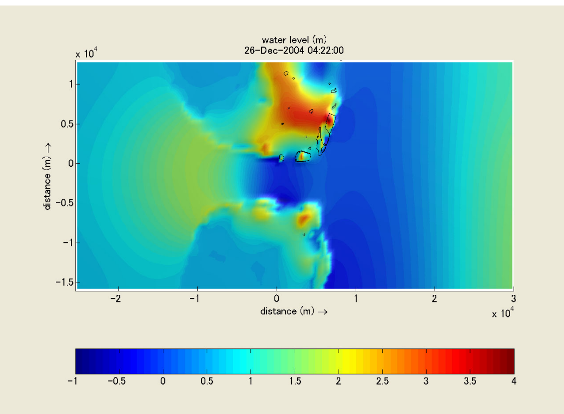
(a) 16 minutes after start of calculation



(b)18 minutes after start of calculation



(c) 20 minutes after start of calculation



(d) 22 minutes after start of calculation

Figure 4.3.4 Calculation results of large region

4.3.3 Propagation of tsunami in Hulhumale' Island & Male' Island and effects of seawalls

The propagation of the first flooding of tsunami having attacked Hulhumale' Island & Male' Island is investigated, and the effect of seawall is discussed. Figure 4.3.5 represents for the case without seawall while Figure 4.3.6 for the case with seawall.

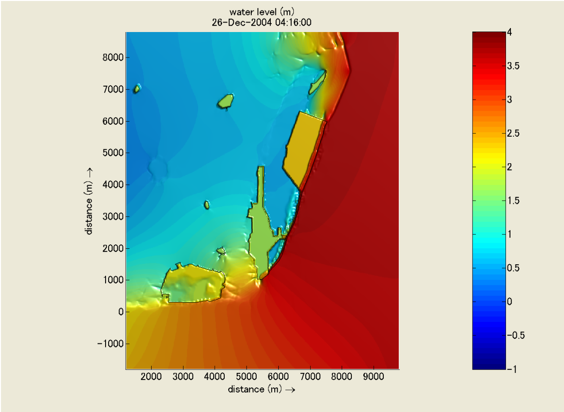
It has been shown that tsunami height reaches its peak in east of Hulhumale' Island at the time of 16 min after start of the calculation while tsunami has already propagated into the strait between north and south Male' atoll. This, therefore, causes a starting of inundation from south side of Male' Island in the case without seawall. At the same time, there is no rising in water level at north side of Male' Island because the water depth on north Male' Atoll is so shallow that the waterfront of tsunami is still passing between Airport island and Male' Island. At the time of 18 min tsunami is running into Hulhumale' Island, simultaneously an island at north of Hulhumale' Island is fully sunk by the tsunami entering from north of Hulhumale' Island. In the east of Airport island, it is also shown that causeway can prevent much tsunami, although it is difficult to stop entry of tsunami completely. As for Male' Island, result of the case without seawall indicates that the run-up of tsunami begins at south, east and southwest coast. However, small area inundated from southern and eastern breakwater is found in the case with seawall. At the time of 20 min, water level outside atolls begins to drop down firstly while tsunami is just arriving at the north coast of Male' Island. It is apparent that north areas surrounded by lower seawalls are to be inundated in both cases. At the time of 24 min, water level around Male' Island goes down, and no more new run-ups take place in both cases. For the case without seawall, most parts of island have been inundated till that time.

Here, we examined some testimony of eyewitnesses from air taxi station of Airport Island where tsunami's height up to above L.A.T. + 3m was observed. It is said that the first waves stroke the air taxi station from eastern side with causeway, and then the second came from northern side which made water level rise up. Based on the results shown in Figure 4.3.6, the air taxi station is attacked by a first flooding of tsunami from east at a time of 18 min, then second flooding of tsunami at the time of 24 min, which turns around from north Hulhumale' Island, runs towards south along the east side of Airport island. Finally, at the time of 30 min, the second flooding of tsunami runs up at a corner of air taxi station and its water level rise up high. Since the air taxi station is located on head of a bay, gathered tsunami increases the water level there. The anotherwitness also said that the first tsunami was higher. So it is possible that tsunami which had been going towards south was confused with the first one.

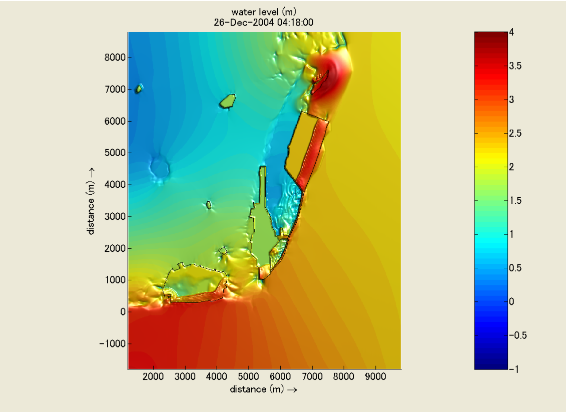
Next, we will summarize the effects of seawall on the inundation prevention from the inundation process of Male' Island. The peak of tsunami happens during the period 16 min to 20 min after start of the calculation. At the same time, water level in front of south seawall reaches its peak above L.A.T+3m and tsunami can run up easily into Male' Island in the case without seawall because the ground elevation is lower than +2m. On the contrary, in the case with seawall, only a little flood within the above mentioned 4 minutes overflows into Male' Island due to the height increased by seawall. In other words, the seawalls played an important role of peak-cut of the tsunami. If so called the protective capacity of seawall to tsunami is defined by tsunami height and its period, the Indian Ocean Tsunami can be regarded as the one that has a little superior period and height over protective capacity of the Male' seawall. Case 4 is implemented on the assumption that the tsunami attack under the condition of high water level. It is shown in Figure 4.3.7, that the whole area of Male' Island has been inundated at the time of 30 min. So it should be noted that the protective capacity of the Male' seawall is not limitless.

The robustness of the Male' seawall in structure also contributed to protect Male' Island from tsunami. Since the seawall in Male' Island was constructed using reinforced concrete and the through-wash protection was braced, it is strong enough for resisting both water pressure and through-wash of the sand. Accordingly, seawall in Male' Island, as shown in Photo 4.1.2, remains to be undamaged.

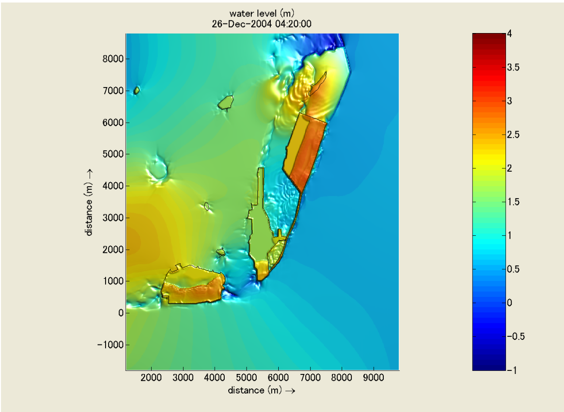
The seawalls of the Airport island, however, was constructed using coral boulders capped with cement mortar, the resistance to water pressure is very weak. Furthermore, because there is no through-wash protection under seawall, once tsunami overflows into inland, the seepage due to the overflow towards sea may draw sand easily and make voids under seawall, finally lead to collapse of the seawall. Photo 4.3.1 shows the damage of the Airport seawall.



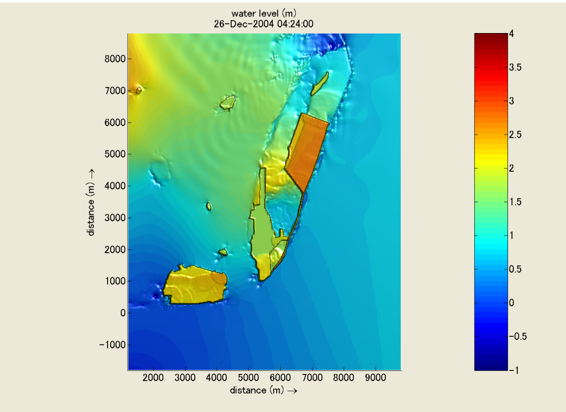
16 minutes elapsed



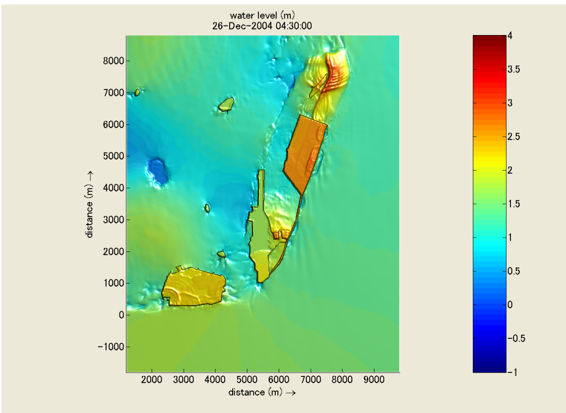
18 minutes elapsed



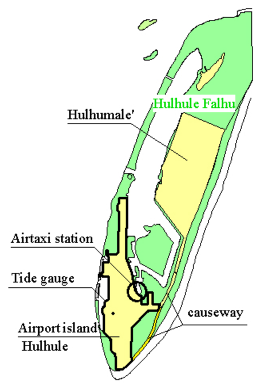
20minutes elapsed



24 minutes elapsed

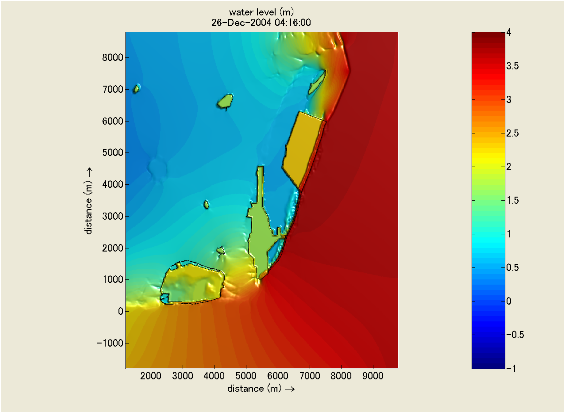


30 minutes elapsed

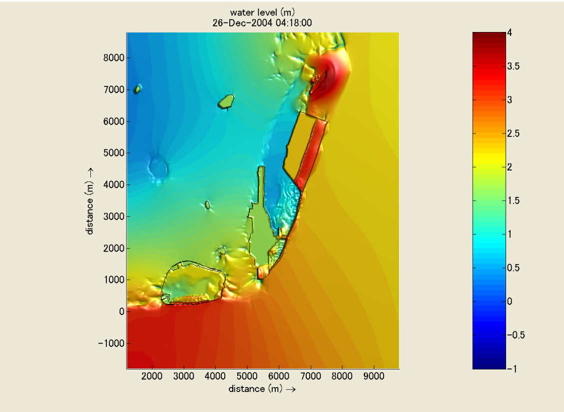


Location names

Figure 4.3.5 Propagation of tsunami in Hulhumale' & Male' Island "without seawall"



16 minutes elapsed



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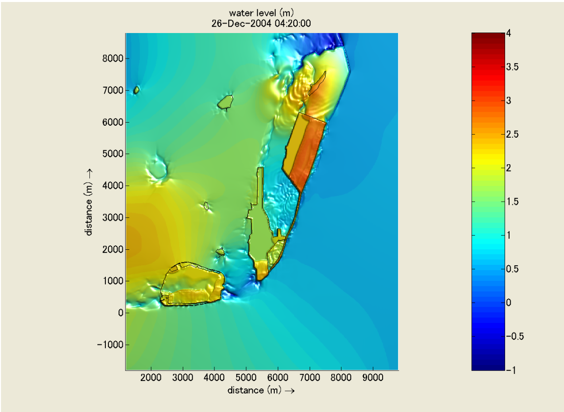

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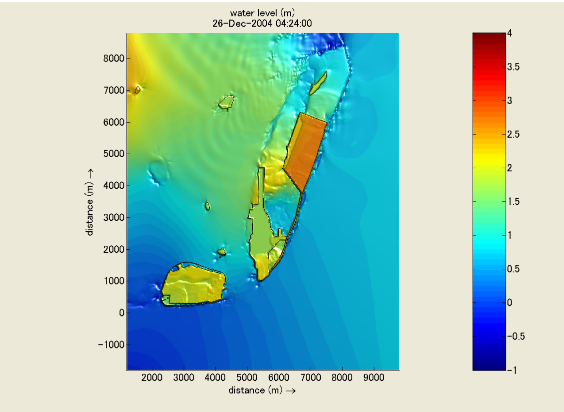

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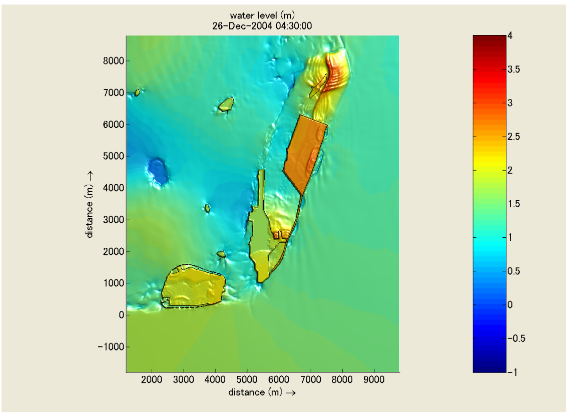

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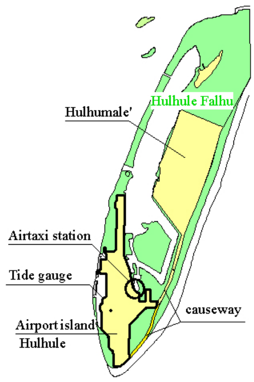
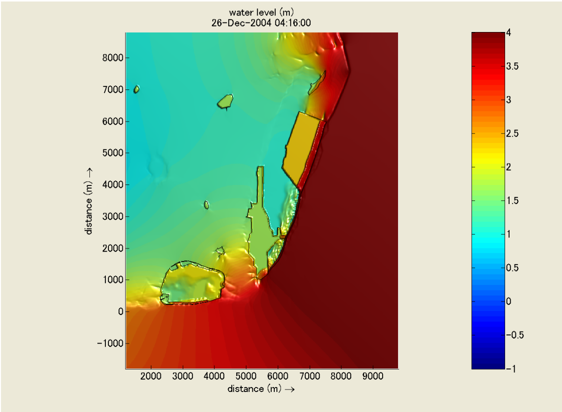


Location names

Figure 4.3.6 Propagation of tsunami in Hulhumale' & Male' Island "with seawall"



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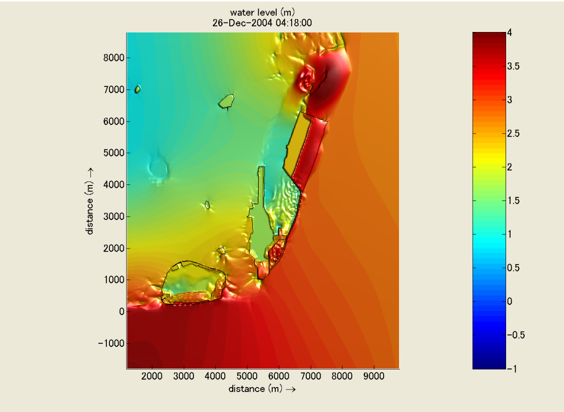

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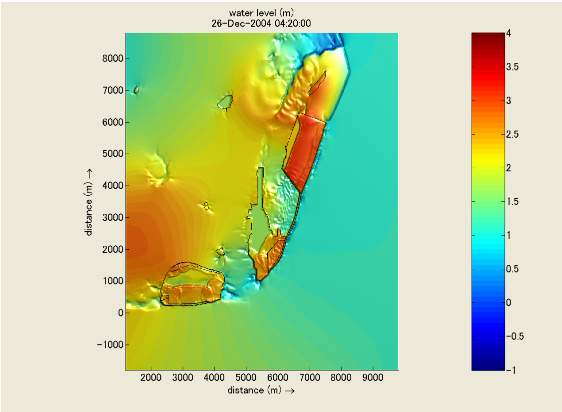

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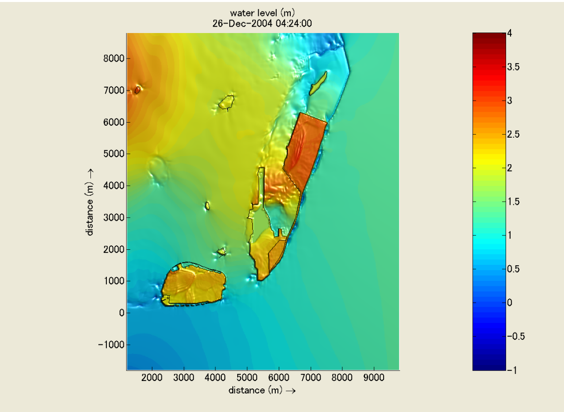

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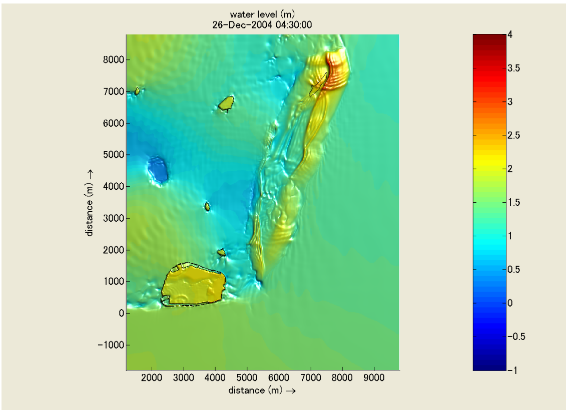

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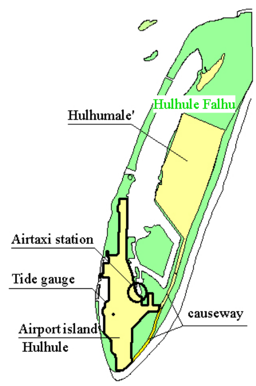


Location names

Figure 4.3.7 Propagation of tsunami in the case at high water level “Case4”

(a)Void caused by through-wash of drainage (b)Completely collapsed Seawall

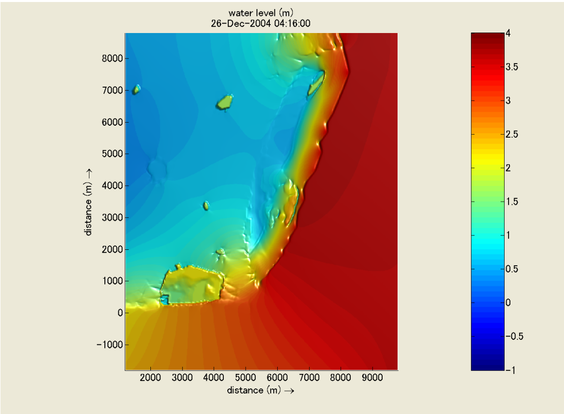
Photo4.3.1 The disaster of seawalls of Airport Island

4.3.4. Effect of Hulhumale' & Airport Island on Male' Island

Since tsunami came from east, it is easy to imagine that Airport and Hulhumale' Island located at eastern side of Male' Island played a role of breakwater to Male' Island. Now, let's discuss how propagates a tsunami having a power over protective capacity of seawall, if there be no Airport island or Hulhumale' Island constructed there. Case 5 is the case neglects the existence of both islands (Figure 4.3.8).

From Figure of 16 min we found that tsunami runs through reef, where both Airport island and Hulhumale' Island should exist, at quite a lower speed than that of open sea. It is noteworthy that the above mentioned tsunami didn't attack Male' Island but went through the reef heading toward northwest. The reason why tsunami didn't attack Male' Island is that the reef has an axis in direction of northeast to southwest and the refraction of the tsunami to the northwest took place. One can verify these facts easily by reviewing Figure 4.3.6.

As might be expected, when considering effect of the existence of Airport island and Hulhumale' Island to Male' Island, tsunami will, of course, lose much energy as it propagates over them. But more influence, we rather to say, on the reduction of the tsunami comes from the reef of the two islands which changed the tsunami's propagation direction. So the location of Male' Island also suggests why it could successfully avoid facing directly to the tsunami from east. It may be, therefore, lucky for Male' Island that the Indian Ocean Tsunami happened to come from east.



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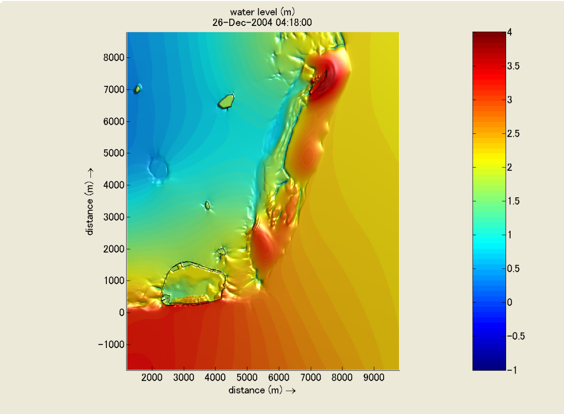

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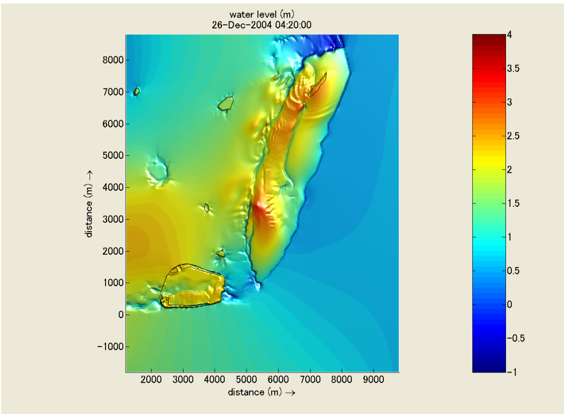

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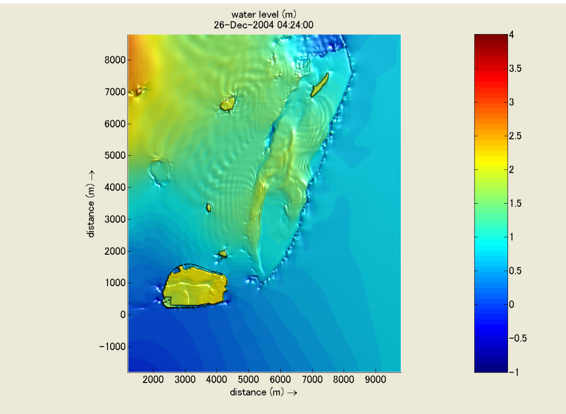

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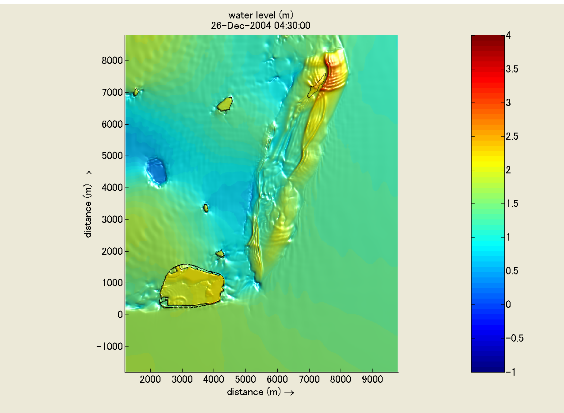

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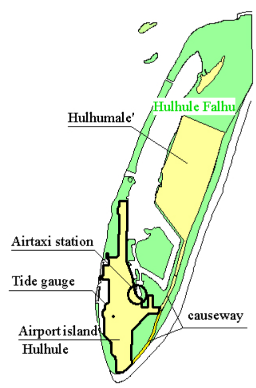


Location names

Figure 4.3.8 Propagation of tsunami without Hulhumale'& Airport Island

4.3.5 Characteristics of inundated area and maximum water height in Male' Island

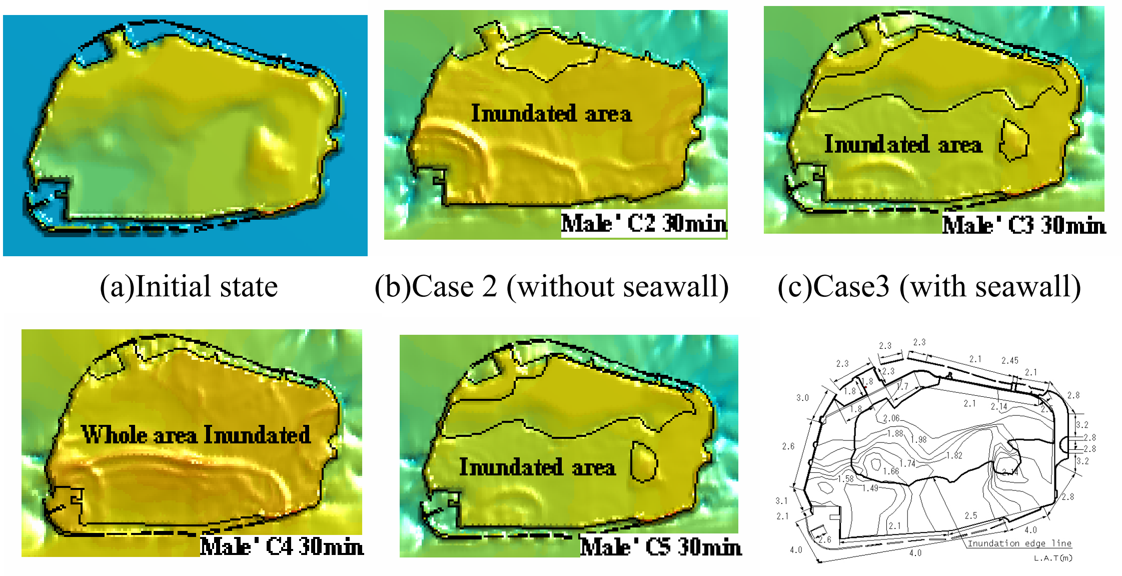
The inundated areas of executed cases at the time of 30 min are shown in Figure 4.3.9. Note that the commonly used friction factor applying to "town areas" hasn't be taken into consideration on Male' Island, instead, the friction factor for "road" is used in this simulation. Hence the propagation of the actual inundation might be more slowly than calculated inundation and the wave crest line could not found apparently as shown in Figure 4.3.9.

Comparing the case without seawall (Figure 4.3.9(b)) to the case with seawall (Figure 4.3.9(c)), it is shown that the inundated area in the case without seawall is larger than that of the case with seawall. Furthermore, the wave crest line can be seen more clearly in the case without seawall. This implicates that the run-up flow may be powerful to run against walls of buildings. In contrast with the case without seawall, the area of the wave crest line is smaller in the case with seawall and it seems weaker. Therefore a conclusion can be drawn that the seawall can be expected to have a peak-cut effect and to decrease the impulse of the overflow.

From Figure4.3.9, we can see that wave crest mainly runs from south. This is also clarified by Figure 4.3.10 and Table 4.3.2. Figure 4.3.10 describes the time series of water levels around Male' Island and Table 4.3.2 gives the maximum level within 30 min after start of calculation. It is shown that the water level on the south side is the highest and rises first. This means that the defensive measures applied to the south coast appear very important.

In the case at high water level (Figure 4.3.9 (d)), whole area of Male' Island is inundated, and the wave crest line can be seen very clearly. Therefore it can be suggested that more damage might have occurred if the tsunami had come to Male' Island about 7 hours earlier when the high tide water took place. As for Maldives where tidal range reaches more than 1m, the water level is a factor determining the scale of damage in Male' Island.

Little difference of inundation area can be found between Case 5 without Airport Island and Hulhumale' Island and case 3 with seawall. It is, as we described in Section 4.3.4, due to the refraction of the tsunami at Hulhule Falhu reef. The refraction effect could not, however, be greatly expected when the tsunami invading from southeast to which Male' Island faces to. It means that the direction of tsunami's coming is important for the safety of Male' Island.



(a)Initial state (b)Case 2 (without seawall) (c)Case3 (with seawall)

(d) Case 4(at high water level) (e) Case5(without Airport island) (f)Measured

Figure 4.3.9 Comparison Inundation areas of Male' Island

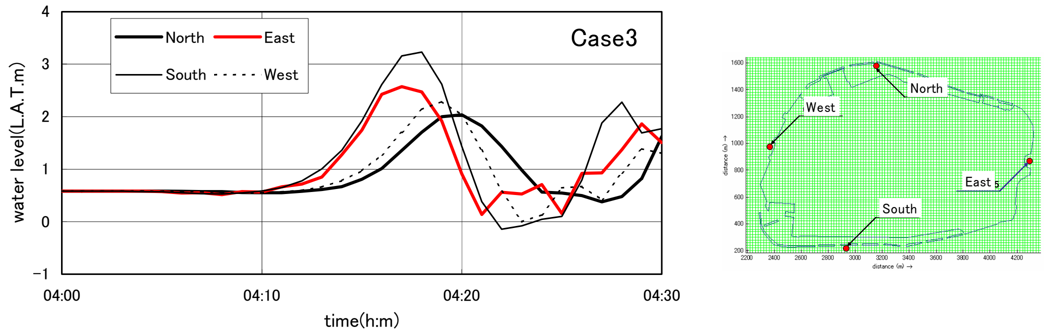


Figure 4.3.10 Time series of water level around Male' Island (Case3)

Table 4.3.2 Maximum water level within 30 min after start of calculation

Case	Seawall	Tsunami Height(m)	Initial W.L (L.A.T.m)	North (L.A.T.m)	East (L.A.T.m)	South (L.A.T.m)	West (L.A.T.m)
1	with	1.39	0.58	1.70	2.20	2.59	1.92
2	with	1.85	0.58	2.04	2.57	3.23	2.29
3	with	1.85	1.1	2.53	2.91	3.72	2.79

4.4 Conclusions

1) Characteristic of the tsunami having attacking the Maldives

Based on the discussion of the calculation condition, offshore tsunami height might be considered between 1.39m high and 1.85m.

The characteristics of the tsunami passing through the atolls in the Maldives could be concluded as follows:

- Tsunami ran at low speed through shallow atolls and much time was needed for passing through the atolls. But tsunami concentrated and went rapidly through the deep straits, which led to a high water level within strait.
- A phase difference was generated between atolls and the open sea. That is, despite of the phase related to high water level on atolls, the water level on the open sea got started to drop down.

2) Effect of Male' seawall

The peak of tsunami happened between 16 min to 20 min after start of the calculation. At the same time, water level in front of south seawall reached its peak above L.A.T+3m and tsunami could run up easily into Male' Island in the case without seawall due to the lower ground elevation below +2m. On the contrary, in the case with seawall, only a little flood within 4 minutes overflow into Male' Island due to the height increased by seawall. In other words, the seawalls played an important role of peak-cut of the tsunami, and the Indian Ocean Tsunami could also be called as a tsunami that had little superiority over protective capacity of seawall.

In the case assuming the high water level whole island was inundated. So it is noted that the protective capacity of Male' seawall is not limitless.

The robustness of the Male' seawall in structure also contributed to protect Male' Island from tsunami. Since the seawall in Male' Island was constructed using reinforced concrete and the through-wash protection was braced, it was strong enough for resisting both water pressure and through-wash of the sand.

3) Examination of testimony in Airport Island

It is said that the first waves stroke the air taxi station from eastern side with causeway, and then the second came from northern side which made water level rise up. The calculation could also obtain the similar answer. Based on the results, the air taxi station was attacked by the first flooding of tsunami from east. Then second flooding of tsunami, which ran towards south along the east side of Airport Island, ran up at a corner of air taxi station and its water level rose up high. Since the air taxi station was located on head of a bay, the gathered tsunami increased the water level there.

4) Effect of Airport / Hulhumale' Island

As might be expected, when considering effect of the existence of Airport island and Hulhumale' Island to Male' Island, tsunami will, of course, lose much energy as it propagates over them. But more influence, we rather to say, on the reduction of the tsunami came from the reef of the two islands. The reef changed the tsunami's propagation direction. So the location of Male' Island also suggests why it could successfully avoid facing directly to the tsunami from east. It might be, therefore, lucky for Male' Island that the Indian Ocean Tsunami just came from east.

5) Characteristics of Inundated area and maximum water height in Male' Island

From the results of case without seawall and with seawall, it was shown not only that the inundated area in the case without seawall was larger, but also that the run-up flow might be more powerful than that of the case with seawall. Therefore a conclusion could be drawn that the seawall can be expected to have a peak-cut effect and to decrease the impulse of the overflow.

The water level on the south side was the highest and rose first. This meant that the defensive measures applied to the south coast had appeared very important.

From the results of the case at high water level, in which whole area of Male' Island was inundated and the wave crest line happened clearly, it was clarified that the water level was a factor determining the scale of damage in Male' Island where tidal range reaches more than 1m.

From the discussions on the case without Airport and Hulhumale' Island, the refraction effect could not be greatly expected when the tsunami invading from southeast to which Male' Island faces. This meant that the coming direction of tsunami was important for the safety of Male' Island.