Investigation Report on the Storm Surge Disaster by Cyclone SIDR in 2007, Bangladesh

(Transient translation)

June 2008

Investigation Team of Japan Society of Civil Engineering

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I. Focus of Investigation and Team Members

The powerful Cyclone SIDR hit the south-western coast of Bangladesh on 15th, November, 2007. According to Disaster Management Center in DMB (reported in December 18, 2007), the cyclone resulted in the severe damages of 3,363 deaths, 871 the missing, 8.9 million affecting people, 2,472,944 acres crops damage and estimated over 3.1 billion US dollars economical loss.

Japan Society of Civil Engineering (JSCE) and NPO - Engineers Without Borders, Japan (EWBJ) decided to dispatch an urgent investigation team to Bangladesh in order to investigate and assess the states and mechanisms of damage from the storm surge.

I-1. Focus of Investigation

The investigation team mainly focused the following objects:

(1) Feature of Cyclone SIDR as a natural origin of the disaster.
(2) Survey on the field trace of storm surge along the coast and in the riparian submerged area.
(3) Assess the present conditions and effectiveness on the hard structures for protection from storm surges and floods.
(4) Assess the present conditions and effectiveness on the vegetation zone for protection from storm surges and floods.
(5) Assess the effectiveness and challenges in non-structural measures such as forecasting, warning, communication, evacuation planning and relief activities.
(6) Structural feature of the damages in this cyclone.
(7) Social problems concerning with damage concentration to the landless peoples.
(8) Assess the strengthening of post-disaster recovery and the reconstruction strategies.

I-2. Team Members

The investigation team was separated into two groups of Coastal Group and River Group.

The members of Coastal Group are five investigators those were recommended by Coastal Engineering Committee in JSCE. The survey was conducted from December 26 to 28, 2007 under cooperation with Bangladesh University of Engineering and Technology (BUET) and Non Government Organization, Engineers without Boarder Japan (EWBJ).

Tomoya Shibayama （Professor, Yokohama National University） Team Leader
Yoshimitsu Tajima （Associate Professor, University of Tokyo）
Taro Kakinuma （Associate Professor, Kagoshima University）
Hisamichi Nobuoka （Lecturer, Ibaraki University）
Tomohiro Yasuda （Assistant Professor, Disaster Prevention Research Institute, Kyoto University）
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Raquib Ahsan (Associate Professor, Bangladesh University of Engineering and Technology)
Mizanur Rahman (Associate Professor, Bangladesh University of Engineering and Technology)
M. Shariful Islam (Assistant Professor, Bangladesh University of Engineering and Technology)
（Members from EWBJ）
Toshiya Tsukamoto (Tokyo University of Foreign Studies) Leader of EWBJ Members
Koji Hayashi (Pacific Consultants Co. Ltd.)

The members of River Group are six investigators recommended by Committee on Hydroscience and Hydraulic in JSCE, and two Enginees dispatched from Ministry of Land, Infrastructure, Transport and Tourisum (MLIT). The survey was conducted from January 19 to 23, 2008 under cooperation with Bangladesh University of Engineering and Technology (BUET).

Kazuyoshi Hasegawa (Foundation of River & Watershed Environment Management), Team Leader
Hajime Nakagawa (Professor, Disaster Prevention Research Institute, Kyoto University)
Kazutoshi Kan (Professor, Shibaura Institute of Technology)
Norio Tanaka (Professor, Saitama University)
Sadayuki Hironaka (NEWJEC Inc.)
Shoji Okada (Associate Professor, Kochi National College of Technology)
Hitoshi Baba (Hokkaido Development Bureau, MLIT)
Katsuhito Miyake (International Center for Water and Risk Management, Public Works Research Institute)
（Members from BUET）
Md. Munsur Rahman (Professor, Institute of Water and Flood Management, BUET)
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II. Features of Cyclone SIDR

II-1. Strength and course of Cyclone SIDR (Comparison with those in 1970 and in 1991)

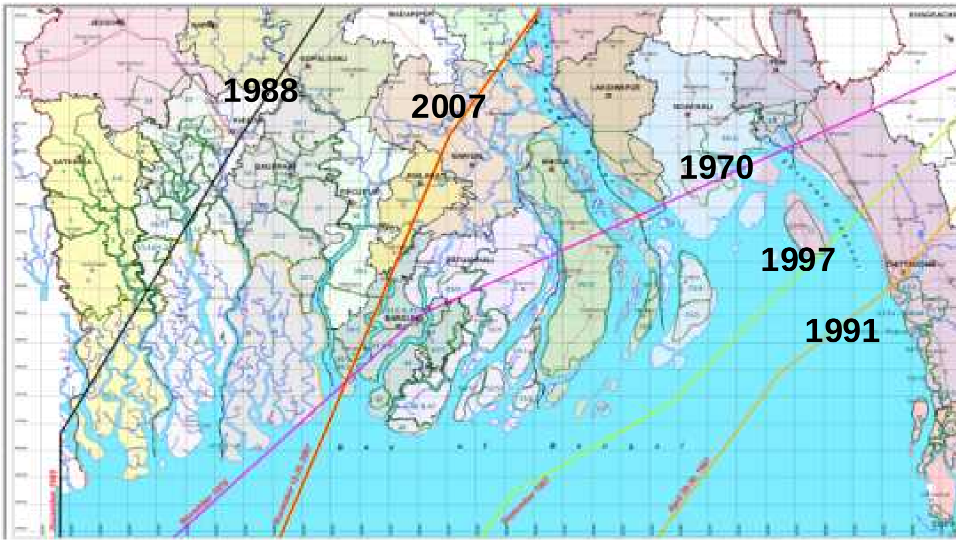

Figure II-1 Courses of Recent Major Cyclones. By courtesy of IWM

Cyclone SIDR was born in Bay of Bengal on 11th, November, 2007 and disappeared on the 17th. It landed on around 15th 18:30, .November. As seen in Figure II-1 (offered from IWM), the landfall point of Cyclone SIDR is almost same as that of the cyclone in 1970. The maximum wind speed of SIDR was 69m/s (250 km/h, average for one minute), and the lowest atmospheric pressure was 944hPa.

In the cyclone in 1991, the maximum wind speed 72m/s (260 km/h) and the lowest atmospheric pressure 898hPa were recorded. Furthermore, in the cyclone in 1970, the maximum wind speed 71m/s (205 km/h) and the lowest atmospheric pressure 966hPa were recorded. From the comparison of these data, it is understood that if estimated from the lowest atmospheric pressure, the strength of the cyclone in 2007 was stronger than that in 1970 while weaker than that in 1991, and that from the maximum wind speed, the strength of the cyclone in 2007 was almost same as in 1991.

According to the material of BWDB, Cyclone SIDR is one of the ten strongest cyclones that landed on Bangladesh during 131 years from 1876 to 2007.

II-2. Comparison of damages by cyclones

To compare the damage in 1991 and in 2007, the damage population, the death toll, the house damage, the arable land damage, and the damage amounts such as educational facilities, the road, bridges, and embankments are shown in Table II-1. The damage of typical social infrastructures such as harbors, the airport, the electric power, communications, and railways were limited to the provincial one in this Cyclone, because the stricken regions corresponded to comparatively small towns and villages. On the other hand, the infrastructures had suffered nationwide damage in the cyclone in 1991, because the stricken regions were typical big city like Chittagong with important port and airport.

According to the trial calculation of a Bangladesh government, it is assumed 3.1 billion dollars in 2007, while the damage total was about 7.6 billion dollars in 1991 (It is shown in Emergency Response and Action Plans Interim Report, Dec.2007, MoFDM with 2.3 billion dollars.) .

The dead, missing, and the injured person of the personal suffering in 2007 were more greatly less than that of 1991. This is an important feature in respect of the damage from Cyclone SIDR. The followings are thought as the factors.

1) The route of the SIDR passed the region where population density and scale of city are small compared with the case of 1991 cyclone.
2) The SIDR attacked in the dry season , while the cyclone in 1991 was in the rainy season.
3) Facilities for disaster prevention such as embankments have been constructed or maintained successively.
4) Cyclonic shelters have been increased.
5) The disaster prevention education that has been done after 1991, the enlightening activity such as CPP, and maintenance and the enhancement of the system of information transmission have advanced.
6) Enhancement of weather warning system
7) Improvement of resident's understanding for cyclone disaster.

Table II-1 Cyclonic damage comparison in 1991 and 2007

Cyclonic damages in 1991 (Baba：Bangladesh cyclonic disaster report, 1991 magazine "River" July edition.pp.91-105)		Cyclonic damages in 2007 (Emergency Response and Action Plans, Interim Report, MoFDM, Dec.2007)	
Damaged zila	14	Damaged zila	30
Damaged upzila	75	Damaged upzila	200
Damaged union	8	Damaged household	2,064,026
Number of victims	10,721,707	Number of victims	8,923,259
Death	**138,866**	Death	**3,363**
Disappearance	1,195	Disappearance	871
(100,000 people or more in a report.)		(Only reported number)	
Injured persons	138,849	Injured persons	55,282
Damaged houses		Damaged houses	
complete collapse	780,081	complete collapse	563,877
half collapse	850,462	half collapse	955,065
Arable land damage area		Arable land damage area	
complete collapse	117,753 acre	complete collapse	742,827 acre
part collapse	791,621 acre	part collapse	1,730,117 acre
Domestic animal damages	10,030,656	Domestic animal damages	1,778,507
Educational facilities damages		Educational facilities damages	
complete collapse	3,749	complete collapse	4,231
half collapse	5,618	half collapse	12,723
Road damages	764 miles	Road damages	
Bridge, Culvert damages	496	complete collapse	1,714km
Bank damages		half collapse	6,361km
complete collapse	112 miles	Bridge, Culvert damages	1,687
half collapse	585 miles	Bank damages	1,875km
		(There is a description of the complete destruction 362.45km and the partial destruction 1,927.55km in the report.)	

II-3. Astronomical tide level, river water level (Comparison with those in 1970 and 1991)

Continuous water level data in Cyclone SIDR , 2007 was obtained at the several observation points as shown in Figure II-2 (IWM offer). According to these data, a change of water level like hydraulic bore seems to be raised by a rapid change of wind direction in Hiron Point which became the west side of the cyclone course. However, the change was not so big to exceed the range of a normal tide greatly. On the other hand, the storm surge with about 4 m height was likely driven by the effects of low atmospheric pressure and the wind blowing at Khepupara point which was on the course of east side. The storm surge reached also Galachipa where is from the coast about 50km inland on the course of the east side. Moreover, the storm surge inundated the city of Pirojpur with 3m water depth, although the city is located about 80 km inland far from the coast.

Flather, R. A. (1994) conducted the reproducing calculations on the storm surges in 1991 and in 1970 covering the east coast region. He pointed out that the water level formed by the both of storm surge and tidal change was 4-6 m high from MSL in the case of cyclone in 1991as shown in Figure II-3 left. In respect of the cyclone in 1970, there were several places where the water level formed by the both of storm surge and tidal change became 4-6 m high from MSL, however, the water level rise was smaller than that in 1991 at Kutubdia, Cox'sBazar and Shapri Island in the southeast region as seen in Figure II-3 right.

In the case of SIDR, although the cyclone had landed in the dry season, the maximum water level, which was formed by the superpose of storm surge and full tide, exceeded about 6m from MSL in the coastal area. The height would be comparable to the maximum water level in 1991. This means that SIDR had the same scale of power as the cyclone in 1991.

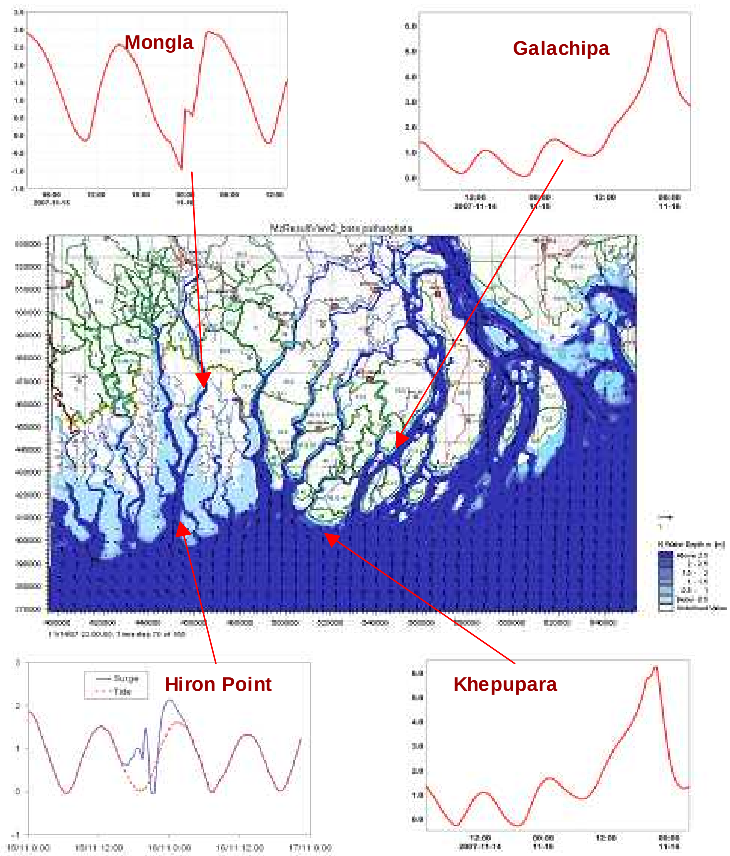

Figure II-2 Records of Water Level by courtesy of IWM

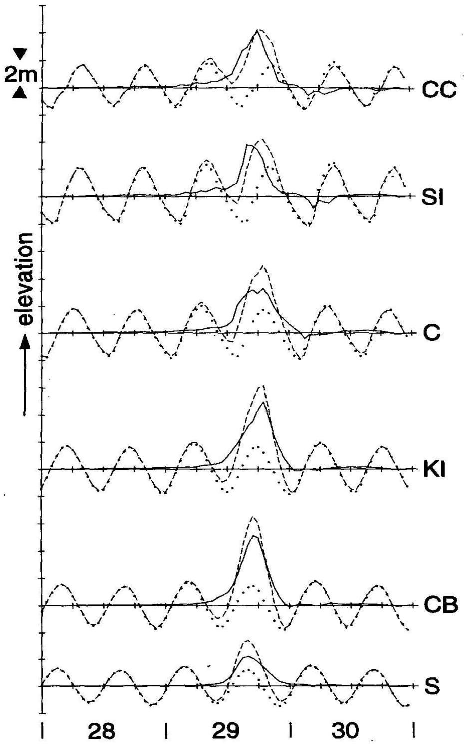

FIG. 3. Variation with time of the computed total water level (broken line), tidal elevation (dotted line), and the storm surge residual (continuous line) for the period 0000 UTC 28 April to 0000 UTC 1 May 1991 from the hindcast model simulation for the locations shown in Fig. 1b (CC: Char Changa, SI: Sandwip Island, C: Chittagong, KI: Kutubdia Island, CB: Cox's Bazar, and S: Shapuri Island).

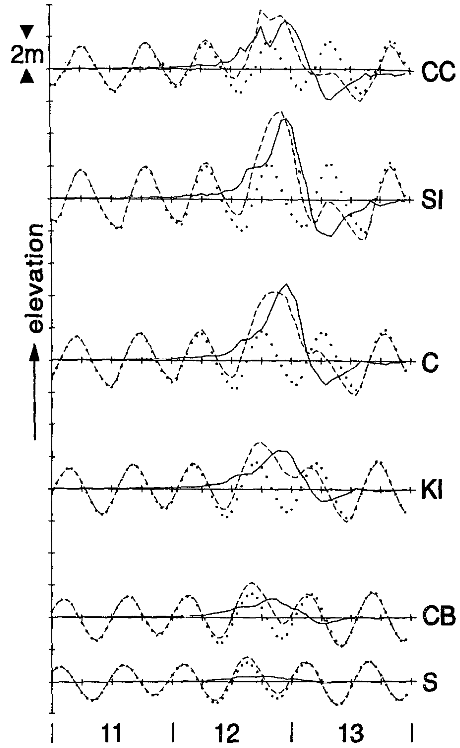

FIG. 10. Variation with time of the computed total water level (broken line), tidal elevation (dotted line), and the storm surge residual (continuous line) for the period 0000 UTC 11 to 0000 UTC 13 November 1970 from the hindcast model simulation.

Figure II-3 Simulation of Storm Surge in 1970 and 1991 Cyclones. Roger A. Flather (1994)

II-4. Feature on the storm surge based on a simulation result of IWM etc.

The inundation simulation for the storm surge was conducted by IWM with using two-dimensional inundation flow analysis shown in Figure II-4. It will be useful to understand a basic inundation phenomenon of the storm surge by the cyclone, though the reproduction accuracy of the simulation cannot be known.

The figure shows a part of the flood simulations on 11:00PM, 15th, November which corresponds to the time testified by the residents through our interview as the water level was the highest. Specifically, it well reproduces concentration of the storm surge in the mouth of Baleswar River and flow propagation to the upstream.

Flooded sea water estimated from the maximum-inundation-area and the averaged-inundated-depth amounts to about 3 billion cubic meters in volume, which was to be scattered in the area of distress in southern part of Bangladesh by the huge energy of the cyclone.

Many embankments and polders are constructed in the shore frontage in Bangladesh for the purpose of prevention against invasion of seawater and salt damage, and of disaster prevention from river floods, but the bank height and strength of these polders do not well avail to prevent a large-scale storm surge. For the reason, a plan to intend the enlargement and enhancement of all coastal embankments is proposed as a part of opinion. However, it would not be a feasible project to prevent huge energy of a cyclone and a large amount of water only by embankments or polders, when the economic potential, the history of flood control, the geographical features of rivers and coasts so on in Bangladesh were considered.

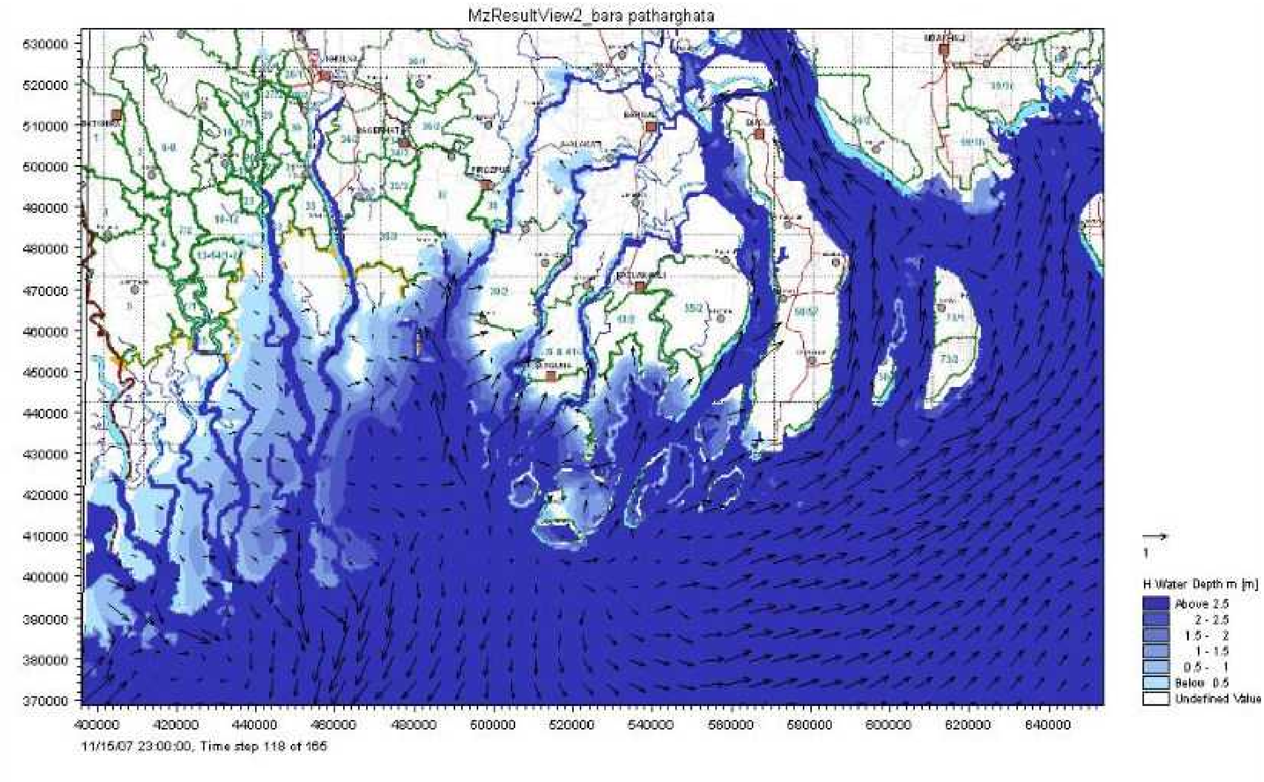

Figure II-4 Simulation of Storm Surge in 2007. By courtesy of IWM

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III. Coastal Survey of Cyclone SIDR by the Coastal Group

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Chapter 1.　Introduction of the Coastal Survey

1-1.　Introduction

Due to Cyclone Sidr that attacked south coast of Bangladesh in November 15, 2007, more than 5,000 lives were lost. Coastal Engineering Committee of JSCE sent Survey group to Bangladesh from December 26 to 28 under cooperation with Bangladesh University of Engineering and Technology (BUET) and Non Government Organization, Engineers without Boarder Japan (JEB).

Members of Survey Team

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Taro Kakinuma　（Associate Professor, Kagoshima University）
Hisamichi Nobuoka　（Lecturer, Ibaraki University）
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（Members from BUET）
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（Members from JEB）
Toshiya Tsukamoto
Koji Hayashi

Fig. 1.1 shows the survey route and distribution of measured storm surge heights. Basic method was to detect flood height and to measure distanced by using laser distance meters and to measure locations by using GPS.

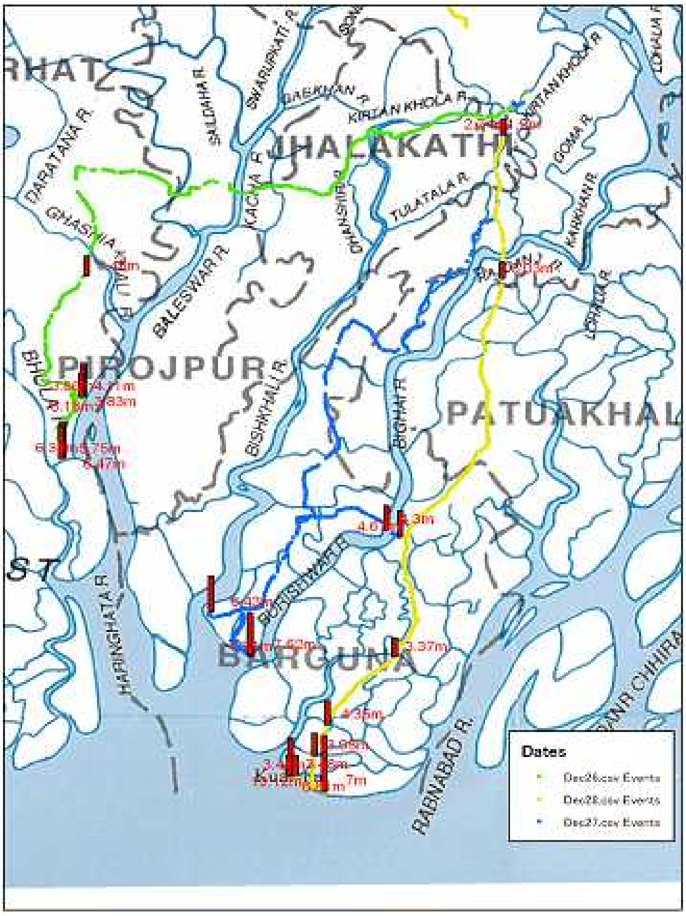

Fig. 1.1 Survey route and measured storm surge height

1-2. Numerical simulation of storm surge (Hisamichi Nobuoka)

The advisory report by India Meteorological Department was used for the basic data of Cyclone Sidr in this simulation. Those data were only for alarms essentially, i.e., it is not good for any assessment. However, the employed reason is limitation of getting data. As OCHA (2007) reported initial landfall point had been around Hiron Point, the track of the data was moved parallel to pass the Hiron point. A radius r_0 of the cyclone is unknown and has to be estimated so that Kato's empirical equation (2005) was employed in this calculation. Equation (1) is rewritten from the line of Kato's Figure 3.3 (2005).

$$r_0 = \begin{cases} 0.769 * P_c - 650.55 & (P_c \leq 950 \text{ hPa}) \\ 1.633 * P_c - 1471.35 & (P_c > 950 \text{ hPa}) \end{cases} \qquad (1)$$

where Pc is barometric pressure at center of cyclone.

Pressure field and geostrophic winds were calculated by classic equation, Meyer's formula, Equation (2), and theoretical Equation, Equation (3).

$$P(r) = P_c + \Delta p \cdot \exp\left(-\frac{r_0}{r}\right) \qquad (2)$$

$$V_{gr} = \sqrt{\left(\frac{rf}{2}\right)^2 + \frac{\Delta p}{\rho_a}\frac{r_0}{r}\exp\left(-\frac{r_0}{r}\right)} - \frac{rf}{2} \qquad (3)$$

where r is distance from center of typhoon/cyclone, $P(r)$ is barometric pressure at the position of distance r, V_{gr} is geostrophic wind and f is Coriolis coefficient.

The radius, surface friction for wind and characteristic of cyclone are important factors for storm surge. However, it is hard to set these values of the factor by the basic data. In case the wind data on the sea/land surface are estimated by use of observed data like satellite or radar data, those wind data should be used for simulation.

In this study, sensitive analysis method was used to take uncertain data. The nine cases shown in table 1.1 were run. Three cases of radius were set. These radius were +20%, ±0% -20% longer than the radius by Equation (1). Surface winds are 0.6 to 0.7 (=C_1) times weaker than geostrophic winds due to land/sea surface friction as Equation (4).

$$V_1 = C_1 V_{gr} \qquad (4)$$

On the other hand, observed winds in tropical cyclone were sometimes stronger than the normal geostrophic winds. These stronger winds are called 'Super Gradient Wind' (SGW). There are two types of coefficients C_1 expressing SGW, those are proposed by FUJII and MITSUTA (1986), and MITSUTA and FUJII (1987). One is constant of maximum coefficient $C_1(x_p)$ (Eauaton-4). The other is variable according to the pressure at center of a cyclone (Equation 5 with Equation 4).

$$C_1(x) = C_1(\infty) + \left[C_1(x_p) - C_1(\infty) \left(\frac{x}{x_p}\right)^{k-1} \times \exp\left\{ \left(1 - \frac{1}{k}\right) \left[1 - \left(\frac{x}{x_p}\right)^k \right] \right\} \right] \qquad (5),$$

where $x = r / r_0$, $x_p = 0.5$, $k = 2.5$, $C_1(\infty) = 2/3$, $C_1(x_p) = 1.2$ and

$$C_1(x_p) = C_1(\infty)\left(1 + 10^{0.0231\Delta P - 1.96}\right) \cdot\cdot\cdot (6).$$

Equation (6) was used by Matoba et al. (2006). Final winds for using the simulation are taken account of the effect of speed of a cyclone body.

Global land one-km base elevation (GEBCO) was employed for land elevation and bathymetry data. The calculated domain were from latitude 10° to 25° N and latitude 80° to 95° E. ADI method, which is one of the solutions of finite differential methods, was used to solve two horizontal-dimensional non-linier long wave equation of governing equation.

Table-1.1 Simulation Cases

Case	Radius of cyclone based on Kato's equation (2004)	Geostrophic Wind and Coefficient of friction
CASE-1	-20 %	Classic
CASE-2	0 %	Classic
CASE-3	+20 %	Classic
CASE-4	-20 %	SGW (variable)
CASE-5	0 %	SGW (variable)
CASE-6	+20 %	SGW (variable)
CASE-7	-20 %	SGW (constant)
CASE-8	0 %	SGW (constant)
CASE-9	+20 %	SGW (constant)

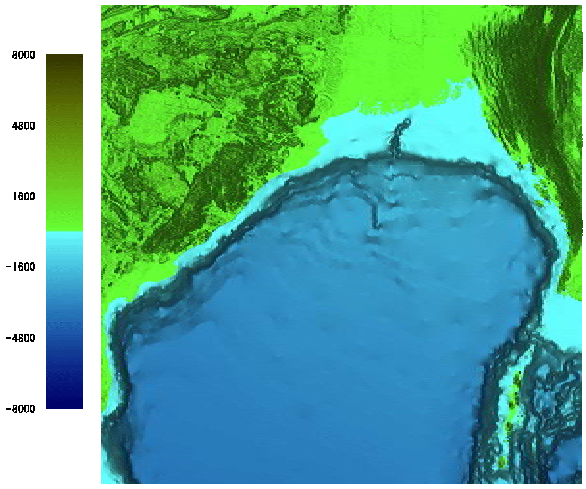

Fig. 1.2 Calculated domain with topography/bathymetry of GLOBE (GEBCO)

1-2-1. Simulated Result of Storm Surge

Comparing sea level anomaly heights with the nine cases of the simulation are shown in Fig. 1.3. The heights were forced by wind set up with pressure suction. The heights at Southkhali, Naltona and Somboniya are varied much by different wind fields. Those points were closed to center of the cyclone, where SGW works much. Beside, results between case-4 to case-6 or case-7 to case-9 show a radius affects the heights. For the results at Barisal, an effect of radius and SGW to height is not so strong.

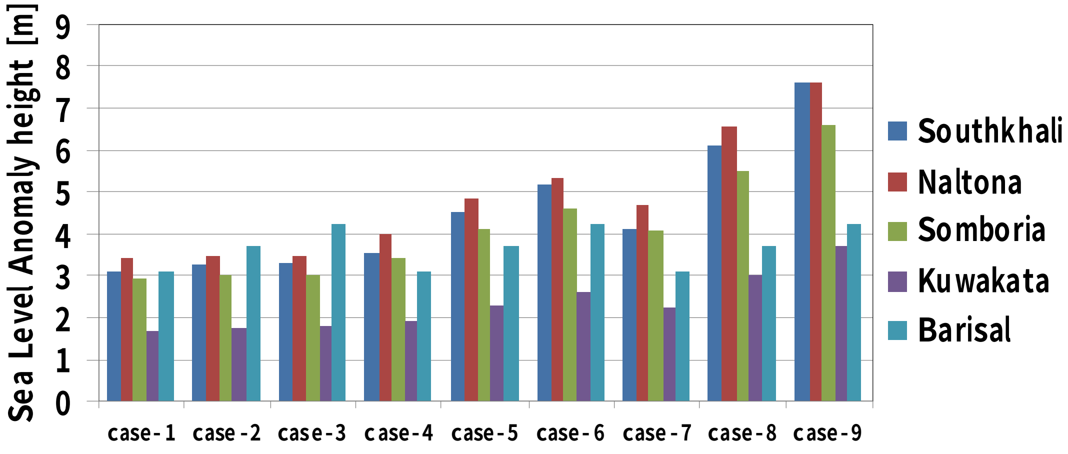

Fig. 1.3 Comparing sea level anomaly height (by wind set up with pressure suction) with the nine cases.

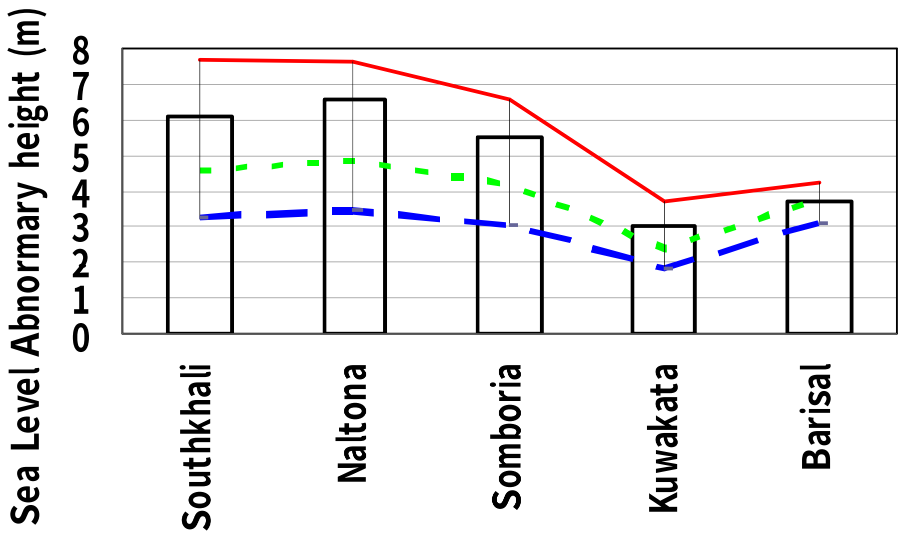

Fig. 1.4 Maximum, minimum and average of sea level rising by wind set up with pressure suction in the nine cases.

Fig. 1.4 shows sea level anomaly at 5 points due to wind setup and barometric pressure suction except wave setup. Bars are result of case-8 and three lines, a solid line and a dotted line and a broken line, are maximum, average and minimum results of all cases. Maximum and Minimum line is the result of case-9 and case-1 respectively. The difference heights of both lines at Southkhali and Naltona, that are 4.4 to 4.2 m, were calculated by the uncertain of pressure and wind field. At Southkhali and Naltona, the peak heights of case-8, '6.1m and 6.5m', are the closest to the measured height, '6.2 m and 6.8m' on survey results by our team, respectively. The heights become lower from Southkhali to Kuakata, that direction is as same as west to east. Barisal faces to large river mouth of the Ganges and Brahmaputra River, which are like a bay. This is the reason why the height at Barisal is higher than that at Kuakata, though Barisal is west.

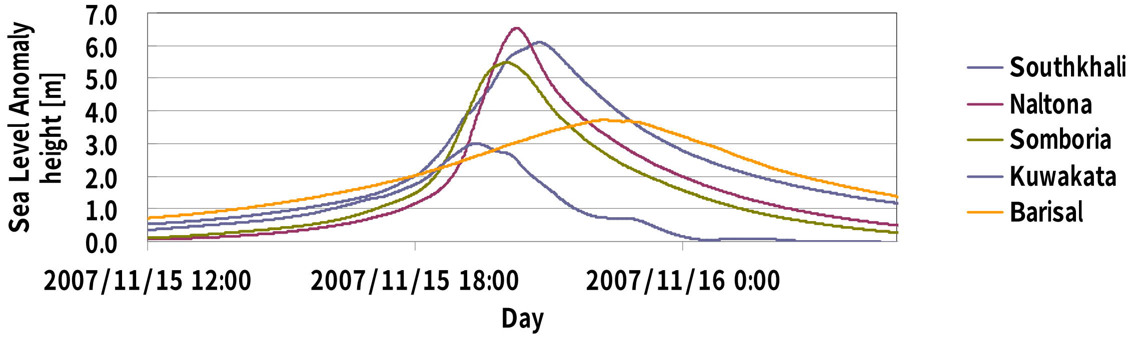

Fig. 1.5 Time series of the sea level anomaly height (case-8)

Time series of the sea level anomaly of case-8 is shown in Fig. 1.5. The time of peak height at Southkhali and Naltona are 20:15 to 20:45 on 15th November. These times are almost good agreement with the time gotten in survey. The time spans from 5m to peak at each point are 57 and 34 minutes respectively. These speeds of sea level rise are slower than the speed gotten in survey, 15 minutes.

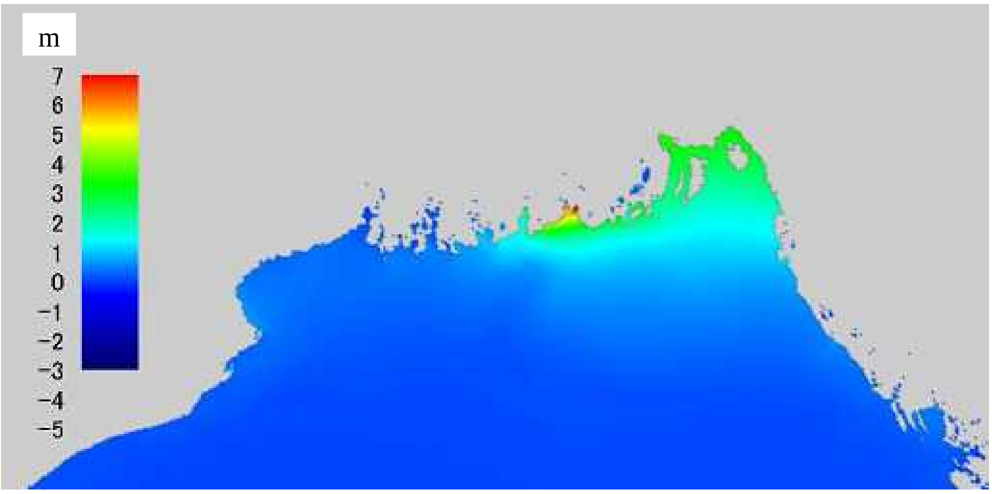

Fig. 1.6 Time series of the sea level anomaly (case-8)

Fig. 1.6 shows the maximum heights at each point. The high anomaly height occurred along the coast from Hiron Points to river mouth of the Ganges and Brahmaputra River. The sever area, where the height is over 5 m in the simulation, concentrates along the Baleswar River and Burishwar River.

1-2-2. Discussion

These results of sea level anomaly indicate that the height over 6 m was generated by the concentration of energy at river mouth and shallow depth. The height is good agreement by case-8 used SGW (constant) suggest that quite strong wind blew near the radius of maximum geostrophic wind of the cyclone. None of the cases of simulation expressed three bore like a witness in Solombaria. Change of wind speed at the moment might occur in real field. The calculated height at Kuakata was much different with that gotten in the survey. The reason may be not the effect of wave setup because the setup is generally low on 3m of water level or higher at the mild slope of sea topography. The calculated wind field may be not good for the height at Kuakata.

The remarkable point in these discussions is that wind fields are very important for assessments of storm surges in Bangladesh. If possible, it is good for assessment of storm surge to use mesoscale model of meteorology, which can support to get better wind field data.

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Chapter 2   Along Baleswar River

2-1   Departure of the survey team

The survey team got going from the guest house in Barisal at 6:00 in the early morning. We used three cars as shown in Photo 2.1. After filling up the tanks with gas (Photo 2.2), we set our direction to the southwest.

Photo 2.1 Cars of the survey team   **Photo 2.2 Gas station**

At 8:16 we passed Pranghat (N22 36 8.1, E89 51 50.8), where there were many fallen trees. The trees lied towards southwardly, which suggested that the strong north wind attacked this area.

2-2   Survey in Solombaria

We arrived at the ferry gate on the left bank of the Baleswar River in Solombaria at 8:58. As shown in Photo 2.3, the ferry gate consisted of a landing stage and a higher land, where shops were lined up along a road. There were a lot of people waiting the coming of ferry. In such typical ferry gates friendly Bangladesh people gave us valuable information on inundation.

Photo 2.3 Ferry gate in Solombaria

At 9:18 we started sounding of inundation height in Solombaria till our embarkation. The position of the starting point, whose level is the benchmark on the river-water surface, was (N22 28 1.2, E89 51 37.2).

Several people, including a boy (Photo 2.4), showed inundation at a depth of 1.5 m over the road. The measurement result of a cross section is shown in Fig. 2.1.

Photo 2.4 Boy showing the top level of inundation clearly

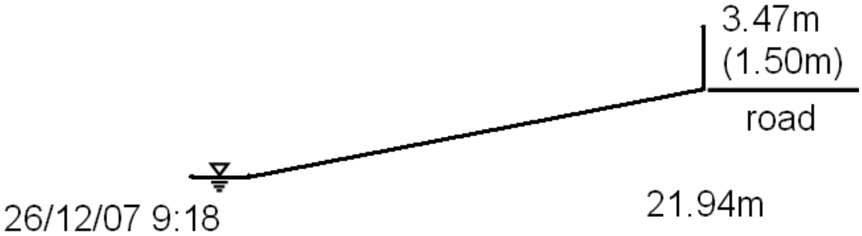

Fig. 2.1 Measurement result of a cross section in Solombaria

As shown in Fig. 2.1, the inundation height over the river-water surface at this time was 3.47 m. In the figures of the present report, the horizontal distance between the starting point on the water surface and a measurement point, *x*, is shown below the drawn ground surface, while the inundation height over the water surface at the measurement time, *z*, is shown over the drawn ground surface. In Fig. 2.1, the parenthetic value shown below the inundation height, (1.50 m), shows the height of the top level of the inundated water surface over the ground surface, which was obtained through our hearing.

A ferryboat stranded by the high tide due to Sidr was left near the ferry gate on the left bank of the Baleswar River (Photo 2.5).

Photo 2.5 Stranded ferryboat

Several people said that after strong winds the water surface rose at once in about ten minutes (Some people said the water surface rose in five to seven minutes.) and the high tide continued for about twenty minutes, after which the northeast winds changed to southwest winds and the water surface began to come down.

In the upriver district on the left bank of the Baleswar River in Solombaria, many houses near the river were flashed away, where some people died, while in the downriver district, the houses were not flowed because they were built on a height. It is also supposed that the ferryboat which was stranded in front of the houses in the downriver district, worked as a breakwater against the high tide. According to Photo 2.6, there is a height under the houses in the downriver district, while the ground slope in the upriver district is mild without a height.

Photo 2.6 Downriver (left-hand side) and upriver (right-hand side) districts on the left bank of the Baleshwar River in Solombaria

After going over the river on board a ferryboat, we advanced southward by land. At 10:03 we passed a place (N22 26 38.9, E89 50 14.0), where an elementary-school building was broken. We saw students attending a class under a temporal tent.

2-3 Measurement of inundation in Royenda Bazar, Sarankhola

We arrived at Royenda Bazar, Sarankhola at 11:00. On the way towards a river on foot, we got the following information:

(1) Inundation at a depth of 1.97 m over the ground surface was shown on a house wall (N22 18 48.1, E89 51 13.7).
(2) Inundation at a depth of 1.98 m over the ground surface was shown over a house roof of a ground floor (N22 18 49.4, E89 51 19.6).
(3) Inundation at a depth of 2.5 - 3.0 m over the ground surface was shown in several places.

We reached a bank of the Baleswar River in Royenda Bazar, where we started the second measurement of inundation at 11:30. We extended the traverse line upward, where a lot of collaborative people gave us in-depth information. The measurement result of a cross section is shown in Fig. 2.2.

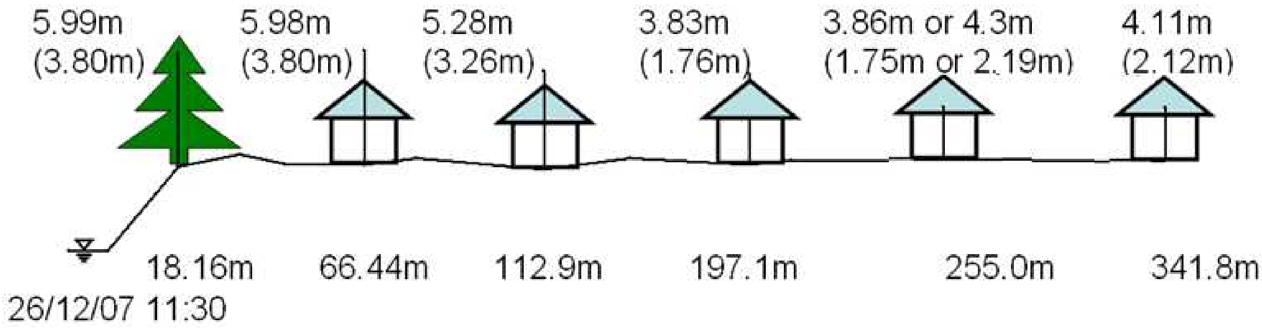

Fig. 2.2 Measurement result of a cross section in Royenda Bazar

In Fig. 2.2, the inundation level at x = 18.16 m was shown on a palm tree. Several people, who climbed upcountry palm trees during the high tide, watched the riverside trees having a soak of water. Eight people were died at x = 66.44 m. At x = 255.0 m, one person said the inundation depth was 1.75 m over the ground surface, while another person said the water depth was 2.19 m covering the top of a house door. At x = 341.8 m, the inundation depth was 2.12 m inside a house. Outside this house, three different values of inundated-water depth were shown by three persons of a family, one of which was 1.54 m; these three values possess lower reliability.

Photo 2.7 shows examples of riverside houses built after Sidr. These houses follow the places where they were built before the disaster.

Photo 2.7 Houses built after Sidr

We visited a shelter (Photo 2.8) in the southern area of Royenda Bazar at 12:50. This shelter is an elementary school building, the ground floor of which is also used as a class room without concrete walls.

Photo 2.8 Appearance of a shelter in the southern area of Royenda Bazar (upper side) and its ground floor (lower side)

We left Royenda Bazar at 13:24. On the way to Southkhali, we found many fallen trees, whose falling direction was southward.

2-4 Measurement of inundation in Southkhali

At 14:00, we arrived at Southkhali, where many trees were fallen towards southward. Near a river, however, several trees were fallen toward northward, which suggested that some trees were fallen by flow of the high tide. Rather mighty trees were also fallen because they had shallow roots as shown in Photo 2.9.

Photo 2.9 Fallen trees in Southkhali

We started measurement of inundation at 14:15. The position of the starting point on the river-water surface was (N22 14 3.8, E89 50 3.8). The measurement result of a cross section is shown in Fig. 2.3.

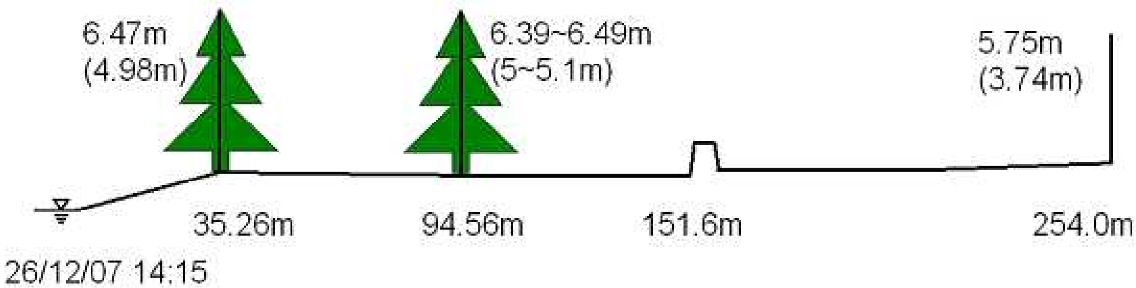

Fig. 2.3 Measurement result of a cross section in Southkhali

River banks were built around thirty years ago but they were broken due to erosion as shown in Photo 2.10 before Sidr attacked them. Though newer banks had been built recently about 150 m inside from these older banks, the high tide due to Sidr flowed over their top of about 2.5 m over the river water at the measurement time. These newer banks are shown in Fig. 2.3 around $x = 151.6$ m.

The river depth decreases every year due to erosion, resulting in wider width of the river. Sand sample was taken from the older river bank.

In Fig. 2.3, the inundation levels at $x = 35.26$ m and 94.56 m were shown on palm trees.

Photo 2.10 Broken river bank in Southkhali

We visited a shelter located at x = 254.0 m in Fig. 2.3. According to our hearing, the first wave of the high tide came to the newer bank at x is about 150 m, after which the second wave flowed over the newer bank. The third wave of the high tide advanced on this shelter. The wave period of these bores was around one minute. The high tide continued about fifteen minutes. The inundated water was flushed.

Women and children took mainly refuge in the next level of the shelter, where the inundation depth was 0.59 m over the floor, whose height was 2.99 m over the basement surface of the shelter. Some water entered through windows, the lower edges of which were of 3.8 m height over the basement surface of the shelter.

When the water came into the next level, the refugees were frightened and wanted to go outside but they could not open doors because of strong winds. Some traces were left when they forced themselves to open the doors. Thousand people evacuated on the shelter top, where they felt the space was not enough. Many people were flowed before they reached this shelter, including a child flowed about 3 km. Several children caught trees to be spared. In this area about 300 people were died.

The high tide appeared at around 20:00 before the full tide at 24:00, so that people did not imagine such a high tide because they embraced the mistaken perception that a high tide should occur at the same time of a full tide. Many people did not evacuate at their dinner time.

Two days ago, before the high-tide day, although the Meteorological Agency of Bangladesh gave an alarm of Category 10 with 5 m tide through TV and Radio, a high tide did not appear on that day. On the day before the high-tide day, blizzard became stronger and an alarm of high tide was given again but a high tide did not appear also on this day.

On the high-tide day, many people could not catch information of high tide because they could use only radios and mobile phones without televisions because of power cut.

After missing by several alarms, many people did not believe the alarm on the high-tide day in no hurry to escape disaster. Before the high-tide approached, the severe blizzard felled trees, such that many people did not want to evacuate outside of houses. Though evacuation of people was done in heavy rains and strong winds, the thunder lamping roads helped them to reach the shelter.

As wind velocity becomes larger, the east winds changed to north winds. The direction of flow due to the high tide over the banks changed from northeastward to southwestward. Although the warning system shows velocity and direction of winds caused by a cyclone, as well as information of its category etc., it does not show inundation information such as predicted values of inundated-water depth. People do not start their evacuation when they know only category because they have experience of no high tide even when the alarm shows Category 10. Moreover, when a tsunami alarm was given in the month before the month of Sidr, people evacuated, but at that time no tsunami came, resulting in damp of their evacuation against Sidr.

In regard to evacuation, the following points are important: 1) education of disaster prevention, 2) certain communication channel of evacuation information (e.g. speaker for Alcoran), 3) construction of shelters considering adequate evacuation distance and enough capacity.

2-5 Measurement of inundation in Baraikhali

On our return route to the guest house in Barisal, we reached Baraikhali (N22 27 53.5, E89 51 23.1) on the right bank of the Baleswar River, where we started an easy survey at 17:05.

According to our hearing, the inundated-water surface came up to the level of about one meter over a road, i.e., 5.75 m over the river-water surface at the measurement time. The top level of a river bank was 1.75 m over the river-water surface at the measurement time.

2-6 Measurement of inundation in Solombaria

After getting across the Baleswar River by ferryboat, we started measurement of ground configuration on the left bank of the Baleswar River in Solombaria at 17:37. Although this site is the same as that in **2.2**, the measurement was performed to know the accurate height of the basement of the unflowed houses in the downriver district of the ferry gate. The position of the starting point on the river-water surface was (N22 28 1.1, E89 51 37.5). The measurement result of a cross section of the ground configuration is shown in Fig. 2.4. The height of the basement of the unflowed houses in the downriver district of the ferry gate was about 2.5 m over the river-water surface at the measurement time. The aforementioned ferryboat, which was stranded by Sidr, was left where *x* was about 57 m, in front of these houses.

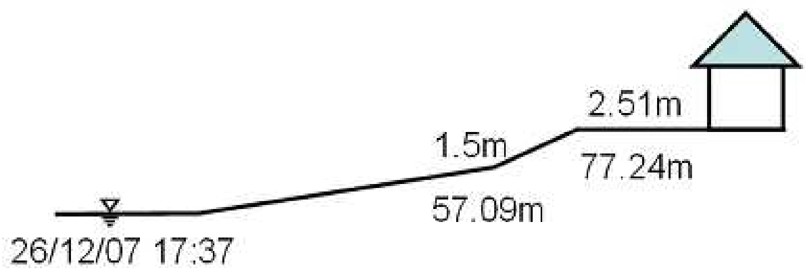

Fig. 2.4 Measurement result of a cross section of the ground configuration in Solombaria

Chapter 3 Along Burishwar River

The outline of the survey along Burishwar River on December 27, 2007 is shown below.

6:15 Departure from Barisal
7:10 Kitton Kohla River (left bank) Dop Dopiya Ferry Ghat
7:35 the other side of Ghat (N22 38 41.2, E90 20 35.4)
9:45 Arrival at Barguna guesthouse (N22 9 32.7, E90 07 41.2)
10:45 Arrival at Garjanbunia (N22 02 31.2, E90 02 22.1)
Movement by motorbike on the road damaged in storm surge
11:48 Somboniya :
Survey (1) : High water : 7.2 to 7.6 m from water surface of river at the time of survey.
12:20 Movement by motorbike
12:50 Back to Garjanbunia
13:15 Movement to Naltona riverside on foot
13:30 Arrival at Naltona riverside
13:35 Naltona :
Survey (2) : High water : 6.43 m from water surface of river at the time of survey.
16:00 Departure from Borguna
16:20 Amtali Ferry Ghat, Barguna (right bank) :
Survey (3) High water: 4.3 m from water surface of river at the time of survey.
17:29 Amtali Ferry Ghat, Barguna (Left Bank)
Survey (4) High water : 4.62 m from water surface of river at the time of survey.
18:05 A ferry Ghat (N21 59 6.0, E90 13 5.1)
18:20 The other side of the ghat
18:52 Next Ferry ghat (N21 53 50.7, E90 8 25.6)
19:03 The other side of the ghat. (N21 53 42.7, E90 8 52.2)
19:15 Last Ferry ghat (N21 51 22.8, N90 7 30.6)
19:25 The other side of the ghat
20:30 Arrival at Kuwakata

3-1 Definition of confidence

Confidences of water level are defined as following four categories

A: High Confidence: There were one or more traces such as mud at almost same level.

B: Normal confidence: There were many witnesses at the difference points and the water level was almost same.

C: Low Confidence: There were some witnesses at the difference points and the water level was almost same.

D: Lower Confidence: Only information by a few witness

3-2 Dop Dopiya

The high water level at the ferry Ghat bus stop was 1.21m from water level, 0.3m from the ground. This level was based on evidence of two store-owners at the Ghat, who said "water rose about at 0.3m from the ground, the shop got no damage." The information of inundation depth as only 0.3 m supports the confidence of information of no damage. However, it is hard to say that actual depth or water level is 0.3m so that the confidence of the information defined [D].

Photo 3.1 Dop Dopiya

Photo 3.2 Erosion in Somboniya

3-3 Somboniya, Barguna

Somboniya is the south-west of Barguna, where survey team accessed finally by motorcycle. One side of the embankment on the access road was collapse at many points. As the hollows on the surface of the road were repaired simply by use of bricks, the height of embankment may be lower than the initial high. Palm trees stood on slope of the embankment were uprooted completely with foundation and fell down to the direction of downstream of storm surge.

The survey on water level of storm surge was started from the surface water of Burishwar River, where riverbank had eroded into 50m in shape of a semicircle. (Photo 3.2 and Fig. 3.1). The old location of riverbank before storm surge was 500m forward all over a few kilometer of river line.

The high water level at one high palm tree nearest the river ((1)-1 in Fig. 3.1) was based on two witnesses of inhabitants. The one is that some people watched water level on the palm tree from trees on the embankment (right side in Fig. 3.1) during the storm surges. The other is that some people climbed the palm tree and checked the trace of water line on the next day of storm surge. There was other witness about water level at other palm tree on the embankment ((1)-2 in Fig. 3.1). This water height was almost same as height of the palm trees on embankment based on information of another inhabitant who had survived at other tree. Both water levels were almost same and the levels were agreed in almost of the inhabitants so that the height is confidence [B].

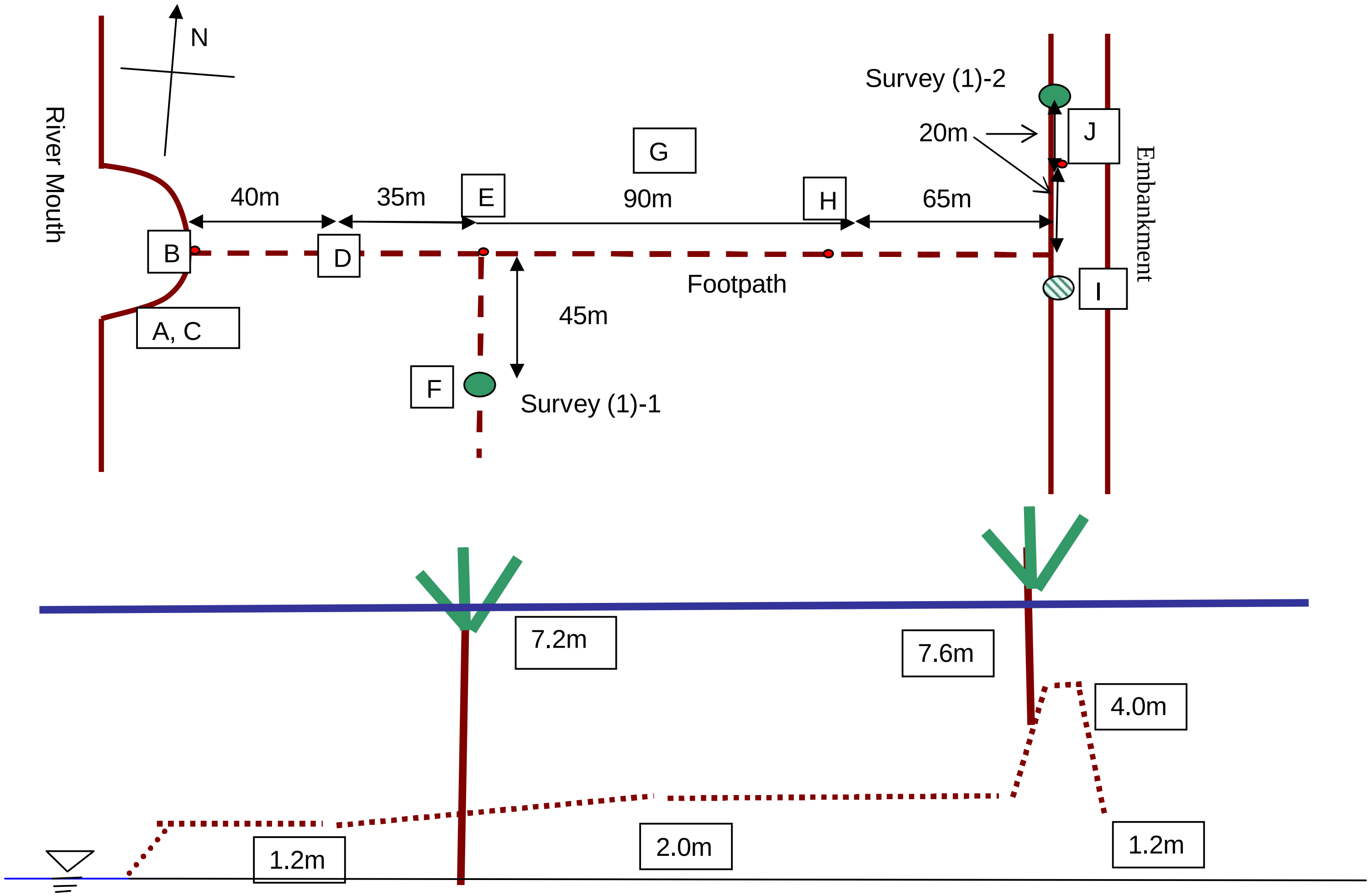

Fig. 3.1 Survey result of high water in Somboniya

Photo 3.3 Inundated palm tree ((1)-1 in Fig. 3.1) **Photo 3.4 Palm tree on embankment ((1)-2 in Fig.3.1)**

Situations of storm surge and evacuation told by inhabitant are as follows. Strong Wind had blown since daytime. At river, water level had suddenly sunk; inhabitants had thought something had happened. After about 5 minutes, inundation had started. At that time, the people had understood a storm surge had been coming, and had evacuated. High water level had marked 15minutes after flood had started. Storm surge wave had been one time. Many people, especially woman and children had flushed away and had not come back. One elder person (Photo 3.5) had caught floating box or driftwood and had survived while being flushed away for 3 km distance by the storm surge.

Photo 3.5 The old man right of front row was flashed away for 3 km.

In this village, volunteer team had run by motorcycle and had informed people of alarm on storm surge in the daytime just before that. Unfortunately, these affected inhabitants, however, had not gotten the information. All of inhabitants really have asked for cyclone shelter in their area. Nearest cyclone shelter is 5 km far from this area; this distance is impossible for escaping to a cyclone shelter in less than 10 minutes. Photo 3.6 shows the situation of water supply by US AID in Garjanbunia for supporting victims.

Photo 3.6　Child who came to draw support water by US AID in Garjanbunia

Photo 3.7　Bank erosion of Naltona

Photo 3.8 Ship launched on land by Naltona

Photo 3.9　Tree which the Naltona seashore surveyed

3-4 Naltona, Barguna

Dyke break due to large-scaling erosion in front of river had occurred before cyclone Sidr also in Naltona (Photo 3.7). Storm surge of cyclone Sidr, threw one ship (Photo 3.8) up to land where it is about 400m far from the present river. The storm surge also carried a house completely away and the foundation of the house only remained.

The high water level in this area was 6.43 m based witnesses. Some people watched that water surface reached the reef of one measured palm tree (photo 3.9), from other trees which is about 300 m far from the measured tree. Other person climbed the measured tree and checked the water level next day. As other two people, however, told other water level, confidence of this level becomes [C].

The inhabitant told the situation of storm surge. Though they had got alarm of storm surge, cyclone shelter around this area is far from there. They had climbed some trees to survive. The location of the nearest shelter is 1km from the center of this area, and 2km from the people who had lived along the river. They have demanded new four to five cyclone shelters in this area. Photo 3.10 is temporary mosque made after original one was carried away by the storm surge. Photo 3.11 shows that one mother with her child reenacted the survival in the storm; she had caught the trunk of this tree by one hand and had held her child by the other hand.

Photo 3.10 Temporary Mosque

Photo 3.11 Survival Situation

3-5 Amtali Ferry Ghat, Barguna (Right Bank)

There was a scratch of water level which the old man of store-owner made at a pole of the store just after storm surge had sunk down (Photo 3.12). He came back to his store soon to check sales goods and checked the water level. That level was 4.3 m measured from water surface of the river at the time of the survey. Many people in this area, Amtali Ferry Ghat, looked the storm surge at the top of slope of main road from the ferry terminal (Photo 3.13). They had evacuated to 1km far from this shop at once, and had returned to the top of slope to care for their stores. The water level had been just under the top that many people had looked at that time. The level of the top is 4.5 m. at the time of the survey. Therefore, high water level must be 4.3m at the time of the survey that confidence is [A].

The flood direction based on witness had inclined 22.5 degree against the main road. The path of direction is shortcut of daily river path. The water must have come not from main road, but from the riverbank.

* One of survey member, Shariful Isram of the BUET, selected the suitable witness from this point to save the time.

Photo 3.12　Owner and scratch

Photo 3.13　Top of sloped. foundation

Photo 3.14　Interview at Ferry Ghat

Photo 3.15　Measuring high water

3-6　Amtali Ferry Ghat, Barguna (Left Bank)

The high water level in the other side of Amtali Ferry Ghat was 4.62m at the time of the survey (Photo 3.15). This level was also scratched at the pole of a store. The owner had evacuated to higher ground, where it had been too far for seeing the store. However, he had come back to his store quickly after storm surge and had scratched the pole, where it was maximum water level [C].

The water body took the path of shortcut from riverbank. This means that water body came from backside of store along one side of main road and run through the front of stores in the other side of road. Some people told the flow in this ghat side had been stronger than that in the opposite area of the river.

Chapter 4 Kuakata Coast

4-1 Outline of Kuakata district

Field survey Kuakata around Kuakata district was carried out on December 27th, 2007. Fig. 1.1 shows the location of Kuakata district. Since this area faces the Bay of Bengal and is located on the right-hand side of the path of Cyclone Sidr, Kuakata seemed to be one of the area which suffered most severe forces due to storm surges as well as stormy waves. Coast around Kuakata has about 150m-wide mild sloping beach. The beach is covered by fine sand grains whose grain sizes are clearly larger than silts which are the primary sediment components of surrounding land and river banks. This clear difference of the bed materials also suggests that Kuakata coast has been developed under wave forces.

Fig. 4.1 shows satellite image around Kuakata with measured inundation heights based on mean water level. White line running east to west along the shoreline is the embankment filled in 1962. Figure 4-2 shows the picture taken on the embankment. Around West Kuakata, width and height of embankment were 12m and 5m above the mean water level, respectively. Behind the embankment, various buildings such as fishermen's houses and hotels were constructed and wide and low area behind the houses were used for farming. Ground elevation behind the embankment was about 1.2m above the mean water level.

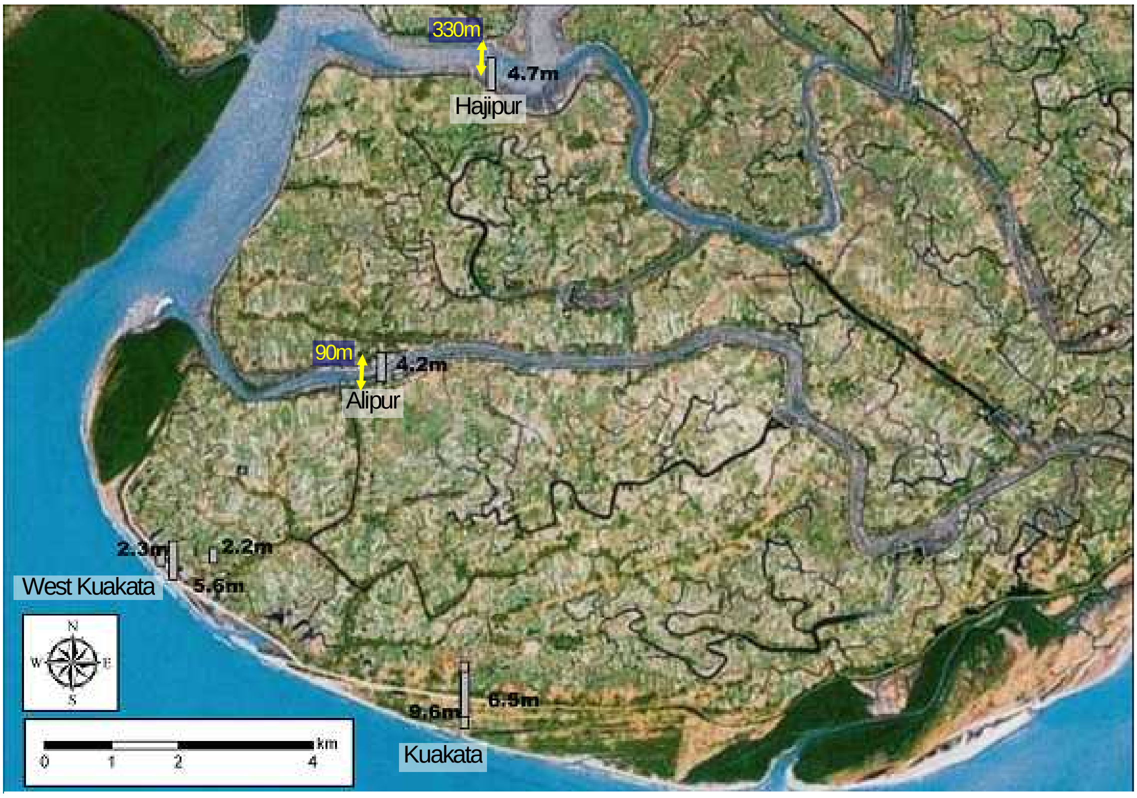

Fig. 4.1 Spatial distributions of measured inundation heights around Kuakata district

Fig. 4.2 Embankment at West Kuakata (Looking westward on the embankment. Seaside is on the left.)

4-2 Inundation heights around Kuakata

Fig. 4.1 shows measured inundation heights along the coast as well as at ferry stations along the waterways such as Alipur and Hajipur. The highest inundation heights observed around West Kuakata was 5.6m on the crest of the embankment. Storm surge overtopped the embankment and inundated the area behind. However the inundation heights behind the embankment was relatively low, i.e., we observed inundation height, h=2.3m at the fisherman's house (Fig. 4.4) just behind the embankment and h=2.2m at cyclone shelter (Fig. 4.5). This feature clearly shows the embankment significantly functioned to reduce the damage of the residential area behind.

Inundation heights at Alipur and Hajipur were higher than those behind the embankment by about two meters. Although Hajipur is located further from the coast, the inundation height at Hajipur was higher than the one at Alipur. Hajipur however is closer to the river mouth and the width of the waterway, B=330m, was wider than the one of Alipur, B=90m. We also found two ferries washed on the bank in Hajipur (Fig. 4.6). According to these observed features, we deduced that the momentum forces due to storm surge were greater around Hajipur rather than Alipur. It is therefore essentially important to consider the run-up flow not only from the coastal area but also along the river, branches and waterways.

Fig. 4.3 Water mark found on a tree on the embankment along the coast of West Kuakata

Fig. 4.4 Fisherman’s house placed just behind the embankment of West Kuakata

Fig. 4.5 The shelter in West Kuakata was built in the school where is about 610m away from the embankment. .

Fig. 4.6 Two ferried washed on the north bank of Hajipur

In the south end of Kuakata coast, we found two water marks. One is straw entwined on wire to support a steel tower which was about 140m away from the shoreline (Fig. 4.7). The other mark was found on the wall of botanical garden which is about 330m away from the shoreline (Fig. 4.8). Although only one straw was found when we measured the inundation heights, a seen in Fig. 4.7, we confirmed that multiple marks of straw and debris were witnessed just after the storm. The reason why inundation height at a steel tower, h=9.6m, is much higher than the other measured inundation heights may be because the area faces to the sea and thus should have strong influence of stormy waves.

Fig. 4.7 Straw on a wire

Fig. 4.8 Water mark on the wall of botanical garden

4-3 Characteristic features observed in West Kuakata

Fig. 4.9 shows overview of West Kuakata. Characteristics features observed in West Kuakata are as follows:

- Height and width of the embankment were 5m above the mean water level and 12m, respectively.
- Depth of the flooding water on the embankment was about 60cm. Kiosk built on the embankment was washed in the northward and reached around 55m behind the embankment (Fig. 4.10).
- The storm surge overtopped the embankment for 10 to 15 minutes.
- Front slope of the embankment was about 1:2 and sandbags were placed where the front surface was severely eroded due to stormy waves (Fig. 4.11 and 4.12).
- Many houses, built on the seaside of the embankment before the storm, were all washed away.
- Backside slope of the embankment is 3:10. Several scours were observed behind the crest of embankment.
- Inundation depth at fisherman's house just behind the embankment was 72cm. This house was not settled on the foundation and was washed around 1m without suffering structural damages (Figure4.14).
- Stormy waves were witnessed although their heights' and periods were unknown.
- Most of residents took a shelter while some survived by tiring themselves to a tree.
- Inundation depth around the shelter was about 1m.
- The shelter was built beside school since the school provided the land for the shelter.

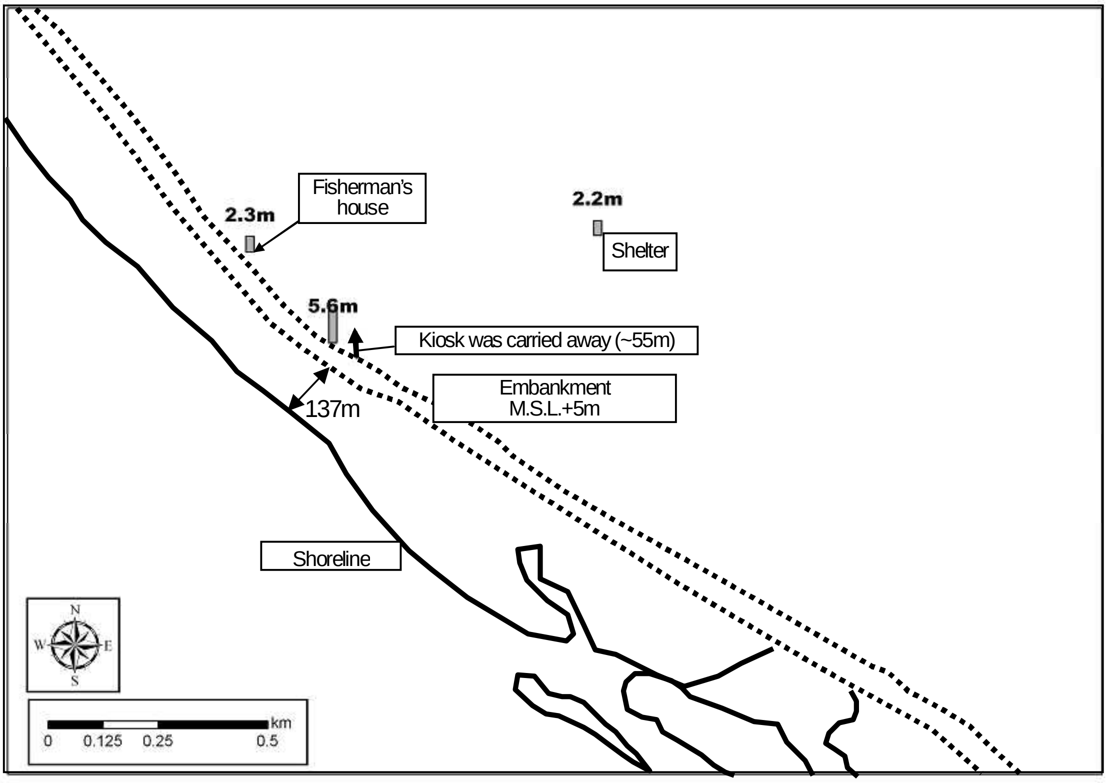

Fig. 4.9 Overview of observed features in West Kuakata

Fig.4.10 Kiosk placed on the embankment in West Kuakata was washed and reached 55m behind the embankment

Fig. 4.11 Front side of the embankment in West Kuakata

Fig. 4.12 Front side of the embankment with sandbags in West Kuakata

Fig. 4.13 Scour behind the crest of embankment in West Kuakata

Fig. 4.14 Foundation of the fisherman's house

4-4 Observation in Kuakata

Finally, characteristic features observed in Kuakata are outlined as follows. Fig. 4.15 overviews observed features in Kuakata.

- Since the distance from the shoreline to the embankment was relatively long, *L*= 690m, and various plants were vegetated on the mild slope to the embankment, storm surge did not overtop the embankment.
- Strong wind from southwest was predominant during the storm.
- Before the storm, 1.5m-high sand dune was developed (dune A in Fig. 4.15) and restaurant house was built on the dune. Storm surge completely washed both house and the san dune although the surface of the dune was fully vegetated. Estimated volume of the washed sand dune is about 8000m^3.
- Sand bed around the roots of pine trees planted beside the steel tower was eroded for about 50cm (Fig. 4.17).
- A part of sand dunes (dune B in Fig. 4.18) was also washed away. The width and height of the washed sand dune were about 30m and 1m, respectively.
- All the walls around the botanical garden parallel to the shoreline were collapsed while some walls perpendicular to the shoreline survived (Fig. 4.20).

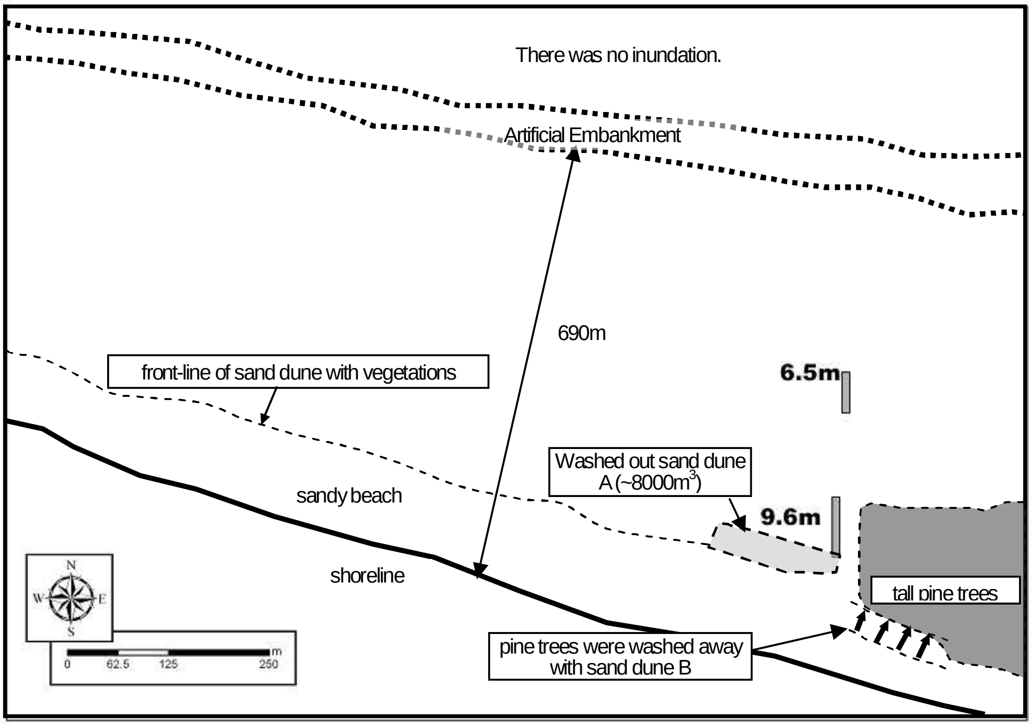

Fig. 4.15 Overview of observed damages around Kuakata

Fig. 4.16 There used to be sand dune (A) which were washed away due to the storm

Fig. 4.17 Pine trees near dune (A). Sand bed was eroded for 50cm around the roots.

Fig. 4.18 Beach that used to be covered by sand dune (B) with pine trees.

Fig. 4.19 Washed pine trees at dune (B)

Fig. 4.20 Concrete walls around the botanical garden. Walls parallel to shoreline were all collapsed while some walls perpendicular to the shoreline survived.

Chapter 5 Concluding Remarks

Many people witnessed that storm surges inundated with bore-like waves. Counter measured against storm surges should account for the physical mechanisms for the development of such bore-like waves and possible damages due to such waves. As observed in Kuakata and Somboniya, embankment showed significant roles to minimize the damage. Development of riverbanks especially around the river mouth is one of most essential countermeasures to be carried out in Bangladesh. Shelter functioned to save significant number of lives although the numbers of shelter still needs to be increased to match the number of residents.

IV. Investigation for Disaster Prevention Structures and Activities against Cyclone SIDR by River Group

Table of Contents

Chapter 1. Introduction and Field Survey of River Group

1-1. Introduction

The members of River Group are six investigators recommended by Committee on Hydroscience and Hydraulic in JSCE, and two Enginees dispatched from Ministry of Land, Infrastructure, Transport and Tourisum (MLIT):

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Hajime NAKAGAWA (Professor, Disaster Prevention Research Institute, Kyoto University)

Kazutoshi KAN (Professor, Shibaura Institute of Technology)

Norio TANAKA (Professor, Saitama University)

Sadayuki HIRONAKA (Dr., NEWJEC Inc.)

Shoji OKADA (Associate Professor, Kochi National College of Technology)

Hitoshi BABA (Dr., Hokkaido Development Bureau, MLIT)

Katsuhito MIYAKE (Dr., International Center for Water and Risk Management, Public Works Research Institute)

Following investigators from Bangladesh University of Engineering and Technology (BUET) joined and made an important contribution to the investigation of River Group.

Md. Munsur Rahman (Professor, Institute of Water and Flood Management, BUET)

Hamidul Huq (Research Coordinator, Institute of Water and Flood Management, BUET)

Nazim Uddin (Master Course student, Institute of Water and Flood Management, BUET)

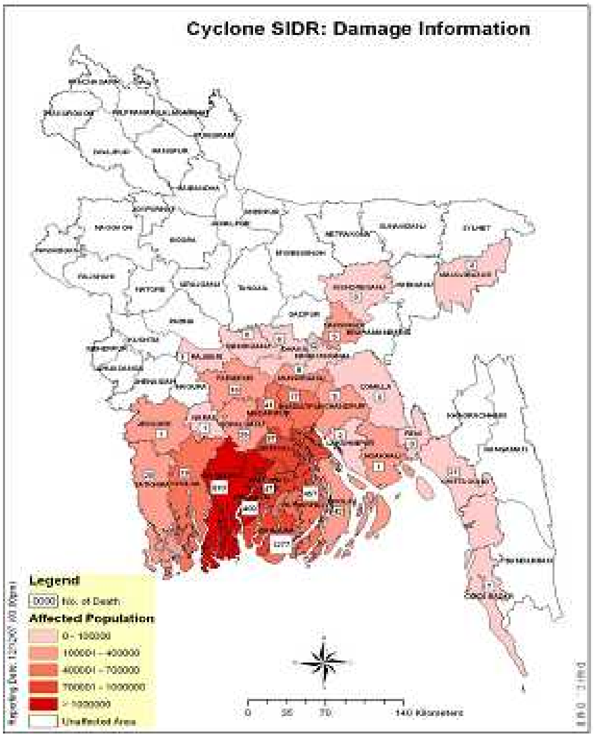

Figure 1-1-1 Delineation of Affected Population.

Source: Situation Report of Cyclonic Storm "SIDR", TUE-18-DEC-2007.

Disaster Management Information Centre, Disaster Management Bureau (DMB), Ministry of Food and Disaster Management

As shown in Figure 1-1-1, the districts where victims concentrated were Barguna, Bagherhat, Patuakhali, and Pirojpur. Damage in the coastal region was the largest in Barguna District, and damage concentrated in the districts of Pirojpur and Bagherhat along the Baleswar River (Red region in Figure 1-1-1).

Cyclone SIDR moved to the north-northeast direction parallel to the Baleswar River, blowing the huge volume of sea water to the coastal area in the east side, and raised a surge of 5-6m near the mouth of Baleswar River. The surge run up to over 100km upstream inland and inundated the right and left shore areas of the river to cause a big damage.

River Group focused on the left and right shore area of the downstream of Baleswar River to be investigated in consideration of the time schedule (Figure 1-1-2). Main investigation area and visit destination are as follows.

Date	Investigation area and Visit destination
January 19, 2008	Royenda, Dakshinkhali, Sarankhola Bazar
January 20, 2008	Pirojpur, Mathbaria, Sapleza
January 22, 2008	BDPC, MoFDM, BWDB
January 23, 2008	BUET, Japanese Embassy, JICA, JBIC, CEGIS, IWM

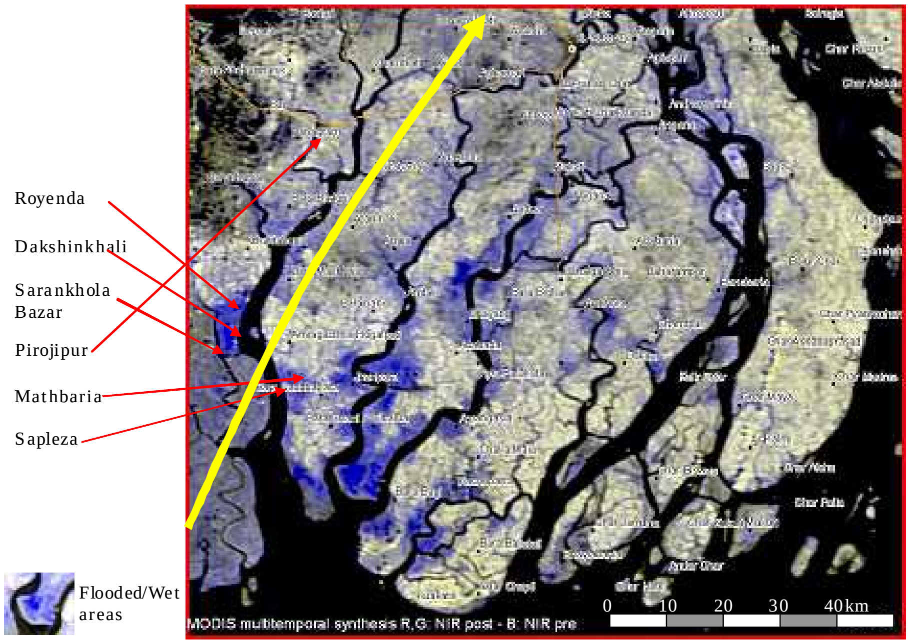

Figure 1-1-2 Flooded /Wet Areas and Visited Places.

Source:Bangladesh Tropical Cyclone SIDR, November 2007 MODIS change detection analysis, 12-19/11/2007 produced by ITHACA in cooperation with WFP.

http://www.reliefweb.int/rw/rwb.nsf/db900sid/CMAS-79579R?OpenDocument&rc=3

On January 19, our group went to Bagherhat District in the right side of the Baleswar River and carried out flood mark survey and questionnaire survey to residents in Royenda Union and Dakshinkhali Union of the Sarankhola. Next day, we went to the Pirojpur District in the left side of the Baleswar River and conducted the investigation similar to previous day at Pirojpur and Sapleza Union.

After the investigation in two days on the situation of stricken villages neighboring to the Baleswar River, we moved to Dhaka on the 21st, and performed information gathering and opinion exchange on the cyclonic disaster in few related organizations on the 22nd and 23rd.

1-2. Survey of damage in the right bank area of the Baleswar River

1-2-1. Damage and Evacuation around Royenda Union

Figure 1-2-1 shows Kadamthala Cyclone Shelter near Royenda Bazar which was constructed in 1990 with donation by German Red Cross. There is a primary school in the site. Ground elevation of the site is 2.8m, height of peak flood mark is 3.96m (those are the data before tidal level correction, at N22 18.4, E89 50.8, 9 :50AM). According to residents' witness, the storm started to rise at around 19:00, and passed at around 22:30. After that, storm surge attacked the site from around 23:00.

Questionnaire survey was conducted by the team members at the site. Residents told that as many as about 5000 people had taken refuge to the shelter, of which accommodation is only 500, and that many people were forced to give up getting inside the shelter because of this situation. Details of the witness are described in Section 4-1 in Chapter 4.

Fig. 1-2-1 A Cyclone Shelter, Kadamthala in Roenda Bazar

1-2-2. Condition of embankment near Dakshinkhali Union, Sarankhola

Figure 1-2-2 is a part of damaged embankment of a boundary channel between Dakshinkhali and Royenda, taken from the inner side. Here was a water gate with 5m long serving road use. Outside of the embankment was cover by a vegetation zone with 100m width.

Figure 1-2-3 is a water gate near Royenda Union of which both side banks were scoured by the overflow of the storm surge. Four photographs of Figure 1-2-4 show the conditions of river embankment, shelter and flood plane near Dakshinkhali Union in Sarankhola, Bagherhat District. While embankment with 3m height has been constructed along the river, the storm surge overtopped the embankment with over 2m depth and caused complete damage to the inner land. The embankments form Polder Systems enclosing Sarankhola-Upzila along the rivers and channel-nets. Current embankments have been designed and constructed under the Master Plan after the big flood in 1988 (told by a person in charge of BWDB). The height of them is designed as the crest should be 1.5m higher than the mean sea water level in the annual maximum high tide records, to prevent sea water inundation by normal tidal surge. Even for the best coastal embankments, the crest is kept only 5.2m above the mean sea water level.

A part of the embankment had been destroyed before the present cyclone, while newly constructed embankment lies over several kilometers being set back 100 – 200m inner of the land. The land between both embankments is mainly used for rice fields except for vegetation zone. The crest of embankment serves road use, and the both side slopes including outside land are everywhere occupied by landless fishers or poor workless people for their resident spaces. In the settlements in the outside woods, suffers living in temporary tent houses were seen. Embankment is over the woods where people live. It could be gathered from residents' talk that a huge storm surge with over 5m height hit the villages near here and overflowed the embankment with over 2m depth.

Fig. 1-2-2 Boundary Channel between Dakshinkhali and Royenda

Fig. 1-2-3 Damaged Gate cum Bridge

Fig. 1-2-4　Condition of Right Bank in Baleswar River,　Dakshinkhali Union

Figure 1-2-5 shows the state of mangrove protection area of Sundarban. Facilities for forest management can be seen, which were comparatively little damaged. The storm surge caused high tree overturns or branch breakages in the mangrove forest.

Fig. 1-2-5　Sundarban Mangrove Forest

1-2-3.　Damage and Evacuation around Sarankhola Bazar

At Sarankhola Bazar, Khuriakhali Union which is located in the most southern end of Sarankhola Upzira, River Group conducted questionnaire survey to the residents (Fig. 1-2-6). There stretches the protected mangrove forest in the opposite area of the river. People told that 13 persons died and 800 domestic animals were lost in the village. A concrete structure of elementary school in the Union seen in Fig. 1-2-6 could not function as a shelter for storm surge, since it is single story. 20 people took refuge in a cyclone shelter 3km from the village which can accommodate 300 people.　Details of the witness are described in Section 4-1 in Chapter 4.

Fig. 1-2-6 Sarankhola Bazar and their Elementary School

A local house in Figure 1-2-7 slid 0.5m toward west direction pressed by the storm surge. The family told that they took refuge in the neighbor house. Cottage made of floating local materials as seen in Fig. 1-2-8 is useful for refuge, because it can function as a float in an emergency of inundation. Many people had been saved by grasping floating house like this in the 1965 cyclone.

Fig. 1-2-7 Local House slid toward west by the storm surge

Fig. 1-2-8 Typical clasic house made of floating local materials

1-3. Survey of damage in the left bank area of the Baleswar River

1-3-1. Flood marks at BWDB local office at Pirojpur

Fig. 1-3-1 Flood mark at BWDB local office at Pirojpur

Survey at a riverside of the tributary of Baleswar River near BWBD local office at Pirojpur showed that the ground level was 2.78m and the flood mark was 3.38m (before tidal level correction). This site is located at about 80km upstream from the river mouth of the Baleswar River. In the resident's testimony, water level rose up to the height of the waist, and continued for about 20 minutes. Therefore, it is understood that the influence of the storm surge reached upstream with longer distance than that to be predicted.

Field survey for the city of Pirojpur was not able to be carried out for the limited time schedule, although further serious damage was assumed on the lowlands in the urban area.

1-3-2. Damage and Evacuation around Bandapfara Bazar in Mathbaria-Upzira

Fig. 1-3- 2 At Mathbaria Bandapfara Bazar

Survey was carried out on the flood mark and others at Bandapfara Bazar near the border of 10 km south of Mathbaria. It was known from residents' witness that the storm surge rose up to the height of the waist on the road and after continued for about 15 minutes soon subsided. Flow direction was from east. Road surface on the top of a bridge at the border of the Upzila was not submerged by the storm surge.

The storm surge inundated the Bazar up to the height of flood mark upper window flame on the concrete wall of a 2 stories house seen in the Figure 1-3-2 right. Then all single story houses near the place were submerged. The survey resulted that the ground height was 2.65m and the height of flood mark was 6.65m (before tidal level correction).

There had been few people in the Bazar during the time of storm surge since almost all residents have their houses at another place, while they carry on shops in the Bazar only in the daytime.

Fig. 1-3-3 A Bridge damaged by the storm surge and the Rehabilitation work

There is a water gate cum bridge as seen in Figure 1-3-3 (left) near the Bazar. Embankment work was being performed as seen in Figure 1-3-3 (right) to rehabilitate the both side slopes around the gate, which had been damaged to be scoured by the surge flow over the inner side and the outer side. The embankment work was being done only by continuing to throw a block of clayey soil from workers' heads to the bank without any compacting and any density control for soil. It was concerned that the bank will fasten in a dry condition, but that it will be very weak in erosion in a time of overflow.

1-3-3. Damage and Evacuation around Sapleza Union in Mathbaria-Upzira

Survey around the river and coastal embankments along the Baleswar River was carried out at Sapleza Union near the most southern border of Pirojpur. This area is enclosed with the sea bank along the left riverside of Baleswar River in the west, and with the inner banks along the channel-nets spreading in the south and the east. These embankments are constructed in the age of 1960 for purposes of prevention against seawater inundation raised by a normal tide without cyclone storm surge, and of prevention against salt damage in rice crops.

Fig. 1-3-4 Inner banks damaged by the storm surge at Sapleza, Mathbaria

Figure 1-3-4 shows parts of inner banks spreading from east to west along the most southern border of the area. Though many scour holes and breaks rose in the embankments due to the storm surge that provably overtopped the bank crest with over 2m depth, the embankments escaped complete destruction. Severe breaks seemed to occur around trees on the bank; shaking of trees by storm wind, uprooting by overturn of trees and scouring by overflow would give rise to serious damage. Slope of the embankment is to be ranked as 1:2, 1:3 in standards. However, the neat form could not be observed in the actual works in this area. The embankments looked rather thin.


Fig. 1-3-5 Outer sea banks damaged by the storm surge

Embankments facing coasts or big rivers (sea banks) have a standard for construction that the slope of the sea or the river side should be 1:7, and the slope of the land side should be 1:2. However, the standard might not have been satisfied actually, because of the low construction accuracy or the poor maintenance management; the form is rugged and irregular caused by the insufficient compaction for bank soil and the growth of trees so on.


Fig. 1-3-6 Bank Slope being tampered for encroachment by landless people

Fig. 1-3-7 Temporary house of landless people

On the other hand, there is a problem in Bangladesh that room of embankment is encroached by the poor class for their residential space. Landless and workless people make their transient houses of leaves of bamboo, banana, or coco matting and soil on tampered bank slope (Fig. 1-3-6), banking a base of house with 4 to 5 m square seen in Fig. 1-3-7 or flattening a part of bank slope. The encroachment for their living space is repeated every event of disaster. This will be an important social cause of disaster to be solved.

Fig. 1-3-8 Non Sheltered School House and Survived Children

Katachera Village in Sapleza Union is one of the most severely damaged site, where 49 people died. The fatalities totaled to 78 people in whole Sapleza Union.

A primary school built in 2004 lies near the embankment, which is a facility non sheltered (Fig. 1-3-8). Many people took refuge on the roof of the school from the storm surge. The water depth of the surge at the peak stage was round 2 m on the crest of embankment, round 5.2 m on the ground of inner land and also reached round 1.5 m on the roof of the school. So the refugee was floated away up to the far village. The nearest shelter in this area is 3 km from this position.

Not few people including children survived the storm surge to cling onto floating matters like wood or bamboo, although they had been swept away by the surge in the dark night (Fig. 1-3-8 right).

Mr. Md Saidur Rahman the director of BDPC, whom we visited after the field survey, suggested that lifesaving float made of local products like dry coconuts or fishing implement is very useful and cheap compared with life jacket, and BDPC is popularizing the float as peoples' emergency equipment.

Chapter 2. Effectiveness and limitation of the disaster prevention structures

2-1. Effectiveness and limitation of embankments and polders

Many embankments or polders are constructed along the coastal areas of the southern region of Bangladesh, and more small scale sub-polders are built along the many channel-nets within the polders. Effectiveness of these embankments were, however, limitative for the prevention against the storm surge in this time. The causes and problems will be as follows.

1) Embankments and Polders do not provide the enough heights to prevent an overtopping of cyclone storm surge. Entire overtopping occurred in the coastal area and the Baleswar River area in this cyclone.
2) Accuracy of construction for the side slope or the surface of the structures is low. Irregular undulation is seen at any places.
3) Many trees are planted in the surface layer of embankments and polders. A large number of these trees were blown down by the strong wind to cause overturning or uprooting and failure of embankment body.
4) Maintenance for the structures has scarcely been executed.
5) Illegal habitation on the structures.

Road damages involving complete collapse and half collapse amounted to 8,075km, and Bridge, Culvert damages amounted to1,687 in this disaster. In many places, a crest of embankment is used for a road in Bangladesh. Other roads not commonly used with embankments also possess a function as embankment to interrupt flooding water, since they are filled up to the height to avoid submergence by high water in rainy seasons. Therefore, recovery to the function of embankments should be incorporated when restoration of roads is planned. Embankment construction should be adjusted to road construction as disaster prevention for the focused local area can be developed, and appropriate measures should be planned with considering the conversion to retarding basins of specific lands surrounded by embankments, roads and secondary embankments (if those were on the flood action plan).

Regrettably, it seems that simulation technique or measure of planning in Bangladesh has not been sufficiently developed as planners could establish a synthetic plan with considering the total relations of embankments, roads, fill of residential land, culverts and channel networks and so on. Hereafter, computer simulation techniques should be used more practically for the administration of land so as to achieve the purpose.

2-2. Effectiveness and limitation of cyclone shelters

Cyclone shelters played a very important role for the peoples' evacuation. The interim report by MoFDM (Dec., 2007) describes as 'Three million people were evacuated and 1.5 million were accommodated in cyclone shelters'. However, problems to be solved will be remained. The following issues were pointed out regarding cyclone shelters.

1) While number of necessary shelters for the population is short, it is not easy to obtain necessary lands for constructing shelters.
2) There are many local residents who claim that shelters are too far from their locations.
3) Not many shelters are provided with good maintenance.
4) Poor people, who do not have lands (illegal residents?), were not allowed to enter cyclone shelters.
5) There is no refuge or evacuation place for the livestock.
6) There were local residents who refuse their evacuation for the fear to loss the house, land and livestock.

To solve the problems, the following measurements are required together with the measure for poverty dissolution.

1) Increase of shelters for multipurpose use (e.g. schools, community centers) and with high-story.
2) Well balanced distribution of cyclone shelters according with the locations of villages and the evacuation plan.

3) Increase in number of Killa that can be the refuge for livelihood.
4) Development of the system where local beneficiaries can take care of maintenance of the shelters.

Reference:

Emergency Response and Action Plans Interim Report, Draft for Discussion, Ministry of Food and Disaster Management Bangladesh Secretariat, Dhaka, Bangladesh, December 2007.

Chapter 3. Effectiveness and limitation of the coastal vegetation for storm surge disaster mitigation (Tanaka, N.)

3-1. Effectiveness and limitation of the coastal vegetation found in the disaster situation by the Cyclone SIDR

3-1-1. Damaged situation of coastal vegetation:

(1) Classification of the tree damaged pattern

There were many damaged trees in the Cyclone SIDR affected areas where we investigated. The damaged patterns are similar to those by tsunami (Tanaka et al., 2007) or by the river floods. Considering the tree damaged situation, the damaging mechanisms are classified into four types in this study; 1) the trunk bending or breakage, 2) the overturning or uprooting, 3) the loss of the substrate and 4) local scour around the trees. Most of the damaged patterns are related to the mechanisms 1) and 2) in the affected sites. It is important to differentiate the damage mechanism and the cause whether it was caused by the wind of the cyclone or the storm surge. Table 3-1 classified the mechanism for four damaged causes.

The local scouring is caused by the horse-shoe vortices and the wake around the trees which it is usually observed in river floods or tsunamis when the flow velocity is large. In southern part of Bangladesh, the substrate around the tree is usually sand or silt that is easy to be scoured. Then, we can easily found the flood water marks and the scour hole if the large flow velocity is occurred around the tree.

Trunk bending damage or breakage is occurred when the maximum shear stress by the bending moment at the tree trunk section exceeds the critical shear stress for the elastic bending in each tree. The plastic bending deformation occurs when the shear stress at the section exceeds the threshold value for the elastic bending deformation. If the deformation is still within the plastic bending range, we can define it as ‘bending damage, but when the stress exceeds the plastic bending range, the trunk breakage is occurred. This study we don’t classify the trunk bending or breakage damages and call them as ‘trunk damage’.

The overturning or the uprooting is occurred when the maximum shear stress around the root anchoring zone by the tree bending exceeds the critical value.

(2) Typical place at which trees are damaged and the direction of the overturned trees

Fig.3-1-1 shows the typical damaged situation of the trees. The overturning damage were mostly occurred along the bank of the road, the river bank (Fig. 3-1-1a) and the bank of the paddy field (Fig. 3-1-1b). The high trees were overturned (Fig. 3-1-1c) but the low height trees or coconut trees were seldom overturned. The damaged trees similar to those in the figure doesn’t have large root anchoring zone although the aboveground part receives much drag force. The reason why the trees don’t have large root anchoring zone is: 1) the water table is high, and 2) the main root was cut when it was transported from the nursery to the planting site (interview from BWDB). The trunk damage was mostly occurred when the substrate was hard.

Table 3-1 Different breaking pattern with disaster events

	Trunk damage	Overturn	Loss of the substrate	Local scour	Comment
Strong Wind	○	○	×	×	excluding tree in sand beach
Storm surge	○	○	○	○	
(reference) tsunami	◎	○	○	○	Overturn, loss of the substrate and local scour are tend to occurr in front of the forest
(reference) Flood in river	◎	○	○	○	Overturn, loss of the substrate and local scour are tend to occur around the forest region in floodplain

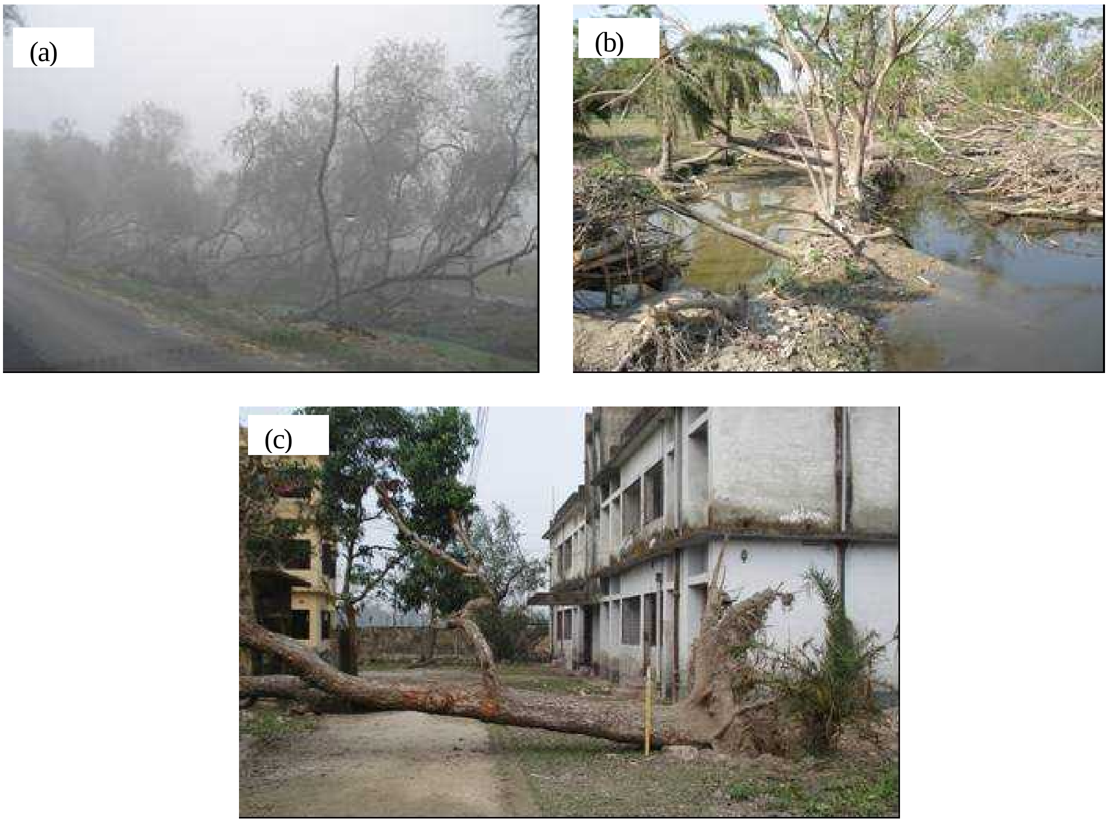

Figure 3-1-1 Situation of the tree damages, (a) at the bank of the load, (b) at the bank of the paddy field, (c) high tree overturned

The direction that the tree was overturned was mostly to the south that is different with the storm surge current direction. The trees overturned within 10m of the water channel in Sarankhola were to the west direction, which is the same direction as the storm surge. The same situation was observed in Mathbaria. Mathbaria is located in the east side of the pathway of the cyclone center and assumed to receive strong wind to the western direction. However, Sarankhola is located at the west side of the cyclone pathway; then, the trees in Sarankhola is assumed to receive not only strong force by the wind but also other forces, i.e. the storm surge, the local scouring, the drag by the short waves.

(3) Approximate estimation of the moment by drag force acting on trees

The moment at the trunk base section by the drag force acting on the trees (trunk diameter at breast height =10-30 cm, tree height=10m) are roughly estimated considering the tree as a circular cylinder. the results are shown in Fig.3-1-2, where the red and the blue lines show the lower limit and the average line for overturning the trees that derived by the tree pulling test in the river floodplains (Technology Research Center for Riverfront Development (TRCRD), 1994). When the wind speed is over 60 m/s, calculated moments are larger than the blue line and the values become lower than the red line when the wind velocity is 20-40 m/s. It shows the small diameter trees are more easily overturned; however, 20-30 cm diameter trees were more often overturned than 10 cm diameter trees in the investigated site. This is because larger trees receive larger moment by drag force and the resistance forces by root anchoring become comparatively smaller with increasing tree diameters.

Similar calculations were also conducted to the storm surge. Here we set the condition as: 1) the diameter at the breast height = 10-30 cm and 2) the velocity = 0.5-3.0 m/s. Figs.3-1-2b and 2c show that for 5m and 2m water depth, respectively. The condition in Fig. 3-1-2b and 2c were assumed for floodplain and the top of the river-bank, respectively. The drag by the moment was assumed as not large because of : 1) large scour holes were not observed in the investigated site, and 2) some people were washed off when the water depth becomes as their breast height. Then, the velocity can be assumed small when the moment becomes as the maximum value. In addition, the flow velocity calculated by the method in 3-2 was about 1-1.5 m/s. The moment by water flow with 5m-water depth is 750-1688 Nm (diameter =10 cm) and 2250-5063 Nm (diameter=30 cm). The moment by the wind with velocity 40 m/s is 6240 Nm for diameter =10 cm and 18720 Nm for diameter =30 cm. The moment by the storm surge is around 10-30% of the wind flow . If the trees are located on the bank, the moments are about 120-270 Nm for diameter=10cm and 360-810 Nm for 30cm in diameter, they are about 2-4% of the moment by the wind (6240 Nm for diameter=10 cm and 18729 Nm for diameter=30 cm) when the wind velocity is 40 m/s. Therefore, the primary damaged force is the wind and plus the moment by the water flow when the velocity is large.

(4) Storm surge mitigation effect by coastal vegetation

In this section, the storm surge mitigation effected by the coastal vegetation is discussed from the damaged situation in Mathbaria (Fig.3-1-3). The tree on the old bank which is inside the vegetation (line A), received about 1.3 m storm surge, but the trunk damage or tree overturning was not occurred. However a little local scour was observed along the trees. This indicates that the 150m-vegetation reduced the wind velocity and the drag moment by the storm surge itself did not exceed the critical value for tree overturning or trunk breakage. This supports the discussion in section (3) for the quantitative estimation of the moment by the drag force for the wind and the water flow by the storm surge. On the other hand, the water depth on new bank in line B was about 2m (both are from the interview). The trees in line B were overturned and large scour hole were made. The bank height in line B is about 0.5m higher than that in line A. Therefore, the coastal vegetation has a possibility to cause 0.5-1.0m water depth difference just behind the 150m-vegetation. This will be discussed in the section 3-2.

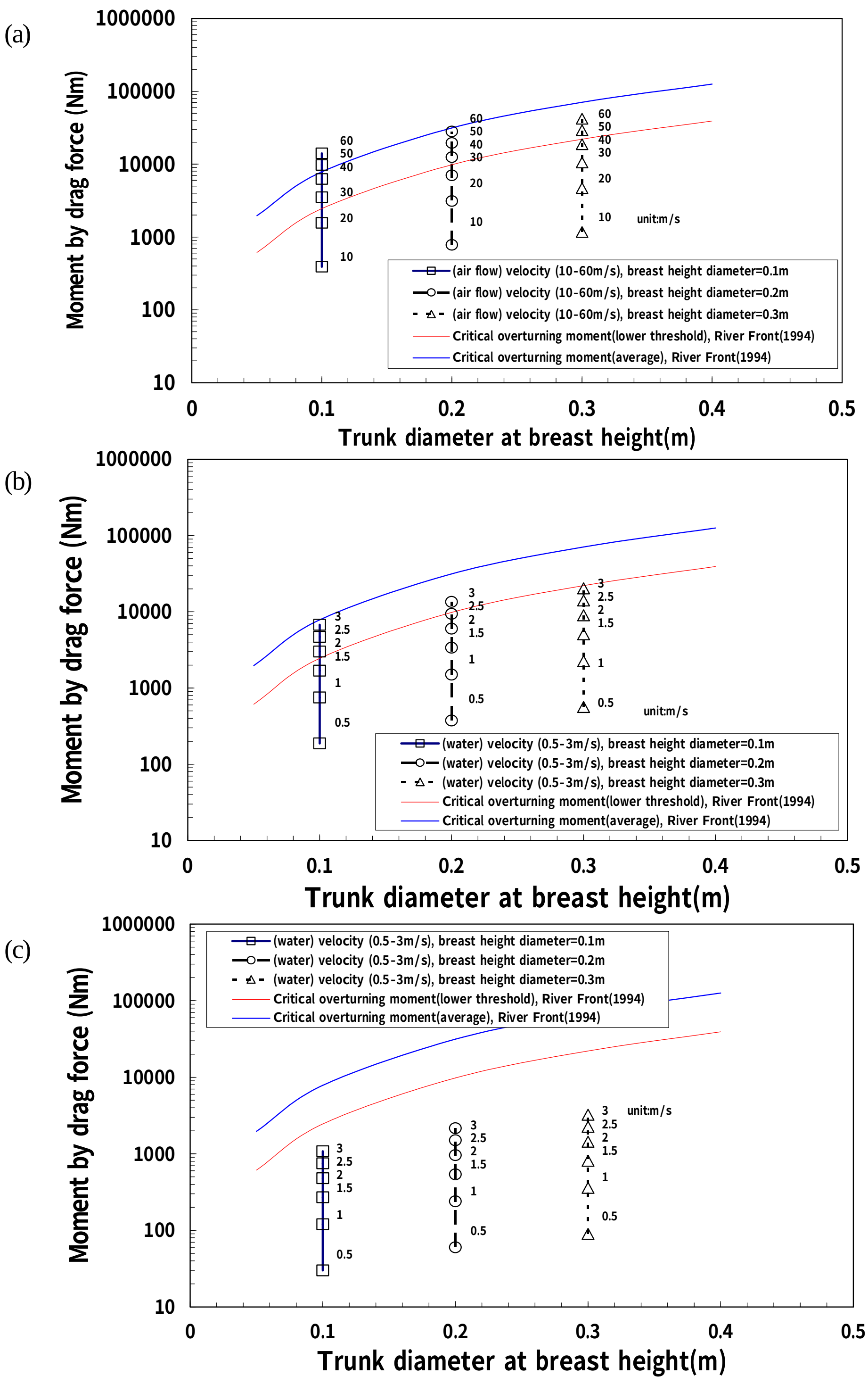

Figure 3-1-2 Evaluation of the moment by drag force acting on a tree, (a)wind (velocity = 10-60 m/s), (b) water flow (velocity = 0.5-3.0 m/s, water depth=5m), (c) water flow (velocity = 0.5-3.0 m/s, water depth=2m), Red and blue line show the lower limit and average line for overturning trees that derived by the tree pulling test in river floodplains (Technology Research Center for Riverfront Development (TRCRD), 1994).

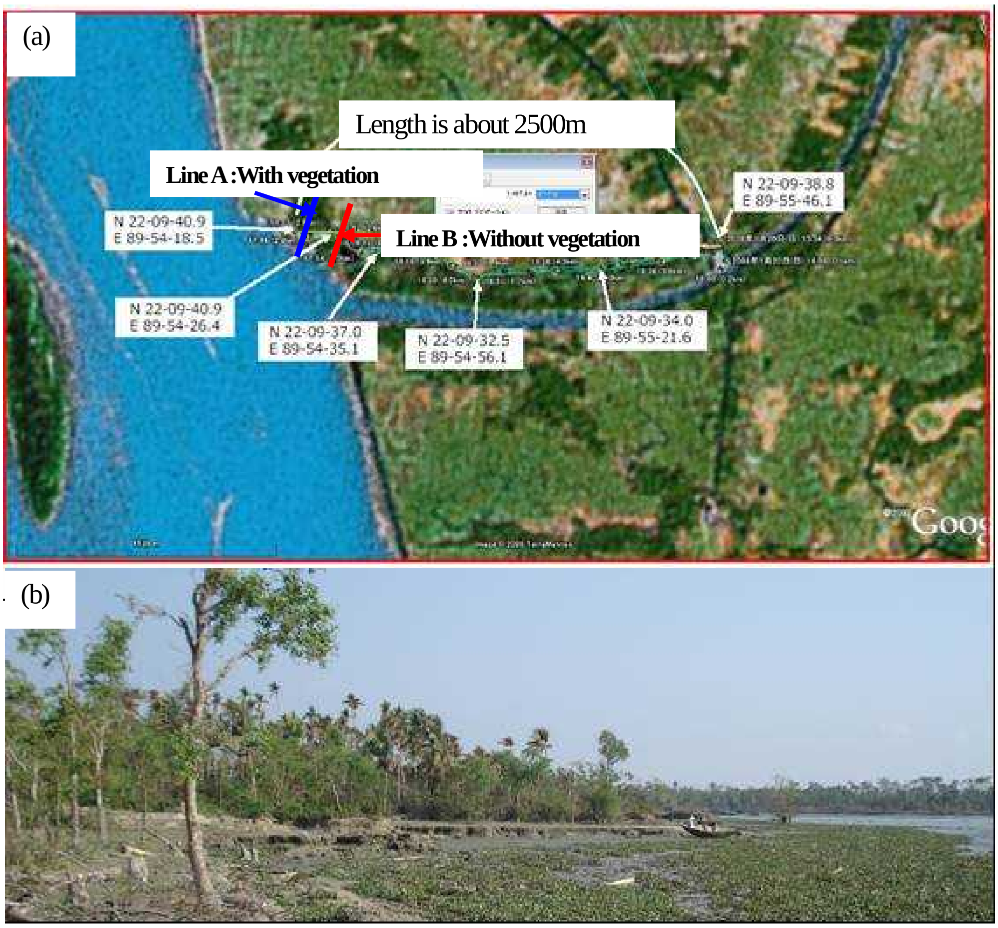

Figure 3-1-3 Representative site that coastal vegetation assume to affect the inundation water depth of the storm surge, (a)Plan view (modified from Google Earth, line A is with vegetation and line B is without vegetation), (b)Photo of the coastal vegetation in line A

3-2. Effectiveness of coastal vegetation for disaster mitigation

3-2-1. Analysis of the coastal vegetation effect for storm surge

In this section, the coastal vegetation effect for reducing storm surge damage is analyzed by using one-dimensional non-linear long wave differential equation.

(1) Geological condition

As it is rather difficult to generalize and reproduce the geological condition of the damaged site strictly, the geological conditions are set like Fig.3-2-1 and the numerical simulation condition (upstream wave generation condition for the boundary condition) is set so that the maximum water level at coast becomes similar.

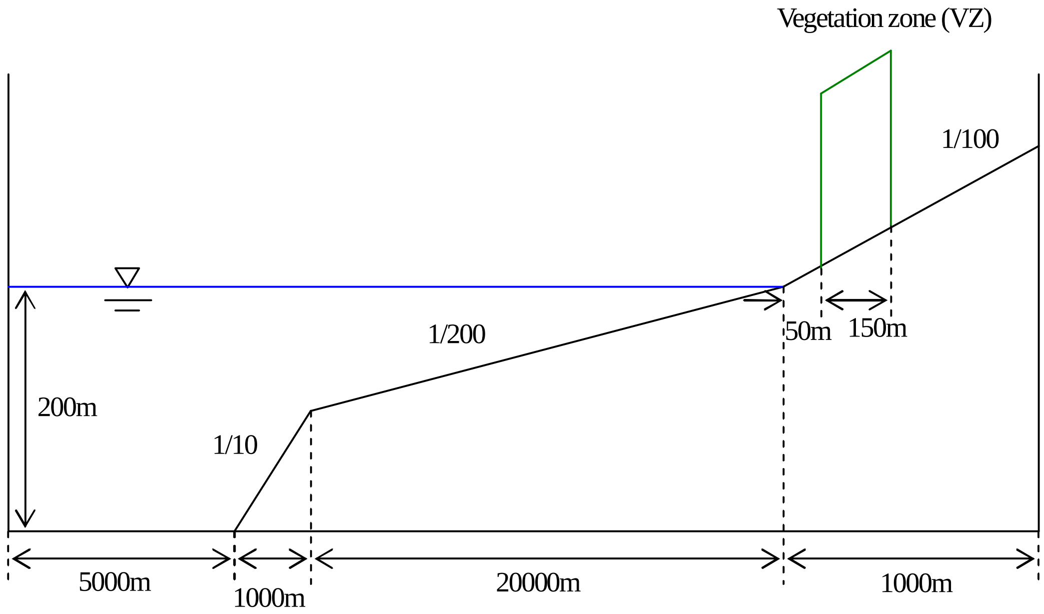

Figure 3-2-1 Geological and vegetation condition for numerical simulation

(2) Fundamental equations

One-dimensional non-linear long wave differential equation is used for the simulation as below:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{d}\right)+gd\frac{\partial \zeta}{\partial x}+\frac{\tau_b}{\rho_w}-\frac{\tau_s}{\rho_w}+\frac{f}{\rho_w}=0$$

Where, Q: the discharge per unit width, d: the total water depth, ζ: the water depth from the sea level, g: the gravitational acceleration, ρ_w: the density of sea water, τ_b: the bed shear stress, τ_s: the shear stress at sea water surface, f: the drag force by the vegetation in the unit area.

The bed shear stress, τ_b, is evaluated as:

$$\tau_b=\frac{\rho_w g n^2}{d^{7/3}}Q|Q|$$

Where, n is Manning roughness coefficient (n = 0.025 in this case).

The shear stress at the sea water surface, τ_s, is analyzed by:

$$\tau_s=\rho_a \gamma_a{}^2 W|W|$$

Where, ρ_a: the air density (1.2kg/m^3), γ_a: non-dimensional friction coefficient at the sea surface ($\gamma_a{}^2$=0.0026 in this study), W: the wind velocity (= 60 m/s outside the vegetation and zero m/s inside the vegetation, in this study).

The numerical model was updated by including τ_s term on the model presented by Tanimoto et al. (2007). The water surface increased by the wind shear forces was almost the same with the value calculated by the Colding equation.

The drag force by the vegetation in unit area is calculated as in (Tanimoto et al., 2007) as;

$$f=\gamma\frac{1}{2}\rho_w C_{D-all} b_{ref}\frac{Q|Q|}{d}$$

Where, $C_{D\text{-}all}$ is the drag coefficient that includes the tree vertical structure (Tanaka et al., 2007), b_{ref}: the tree trunk diameter at the breast height and γ: the number of the trees in the unit area.

$C_{D\text{-}all}$ is proposed by Tanaka et al.(2007) as;

$$C_{D-all} = C_{D-ref}\frac{1}{d}\int_0^d \frac{b(z)}{b_{ref}}\frac{C_D(z)}{C_{D-ref}}dz$$

$$= C_{D-ref}\frac{1}{d}\int_0^d \alpha(z)\beta(z)dz \qquad \text{and;}$$

$$\alpha(z) = \frac{b(z)}{b_{ref}} \quad , \quad \beta(z) = \frac{C_D(z)}{C_{D-ref}}$$

Where, $C_{D\text{-}ref}$ is the reference drag coefficient (=1, considering a circular cylinder in this study), $C_d(z)$, $b(z)$= the drag coefficient and the cumulative width of the tree trunks and branches (in meter) at the height z, respectively, $\alpha(z)$ = additional coefficient for expressing the vertical tree structure, $\beta(z)$ = additional coefficient for representing the effect of the leaves and the inclination of branches. For the value of $\beta(z)$, the previous research indicated that the additional drag by the leaves itself can be assumed as a constant value (=1.25 in this study (Tanaka et al., 2007))

(3) Vegetation conditions

The '*Casuarina equisetifolia* type' in Tanaka et al. (2007) is applied for the vertical tree structure of the vegetation at Mathbalia with a slightly modification. The tree condition is as follows:

Tree height =10 m (the dense type of *Casuarina*),

Breast height diameter =16 cm,

Number of the trees in the unit area = 0.36 trees/m^2 with the triangular arrangement,

The vegetation length to streamwise direction = 150 m

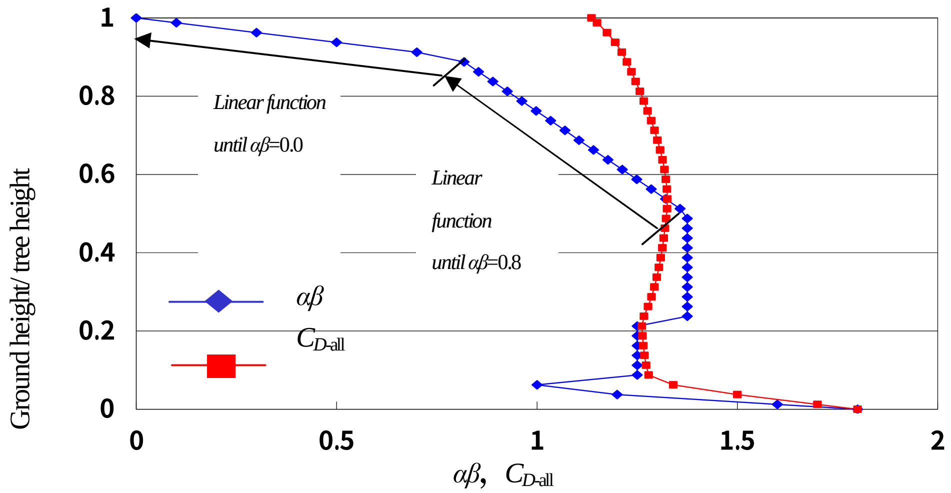

Figure 3-2-2 Vertical distribution of drag characteristics (modified from Tanaka et al. (2007)

(4) Upstream boundary condition for the storm surge propagation:

The storm surge can be considered as the compound phenomena with long wave and short wave. When we analyze the 'vegetation effect', we need to consider mainly two mechanisms as; 1) the decrement of the water depth by reducing the wind friction inside the vegetation compared with the non-vegetation case, 2) the drag effect by the vegetation (water depth is increased in front of vegetation but decrease behind it); moreover, the effect can be considered changeable by the wave period.

Considering the above, the simulation condition is set as:

i) Wind+ No wave, (vegetation effect to prevent the average increment of the water level by the wind),
  CASE1: average sea water level = +5.3m, wind velocity = 60m/s.

ii) No wind + long wave, (vegetation effect to decrease water level increment by the long wave).
  CASE2: the wave period =2 hours, the wave height =4.0 m at the upstream B.C. and =5.3 m at the coast.
  CASE3: the wave period =1 hour, the wave height =3.0 m at the upstream B.C. and =5.0 m at the coast.

iii) No wind + short wave (1-2 minute), (vegetation effect to decrease the water level increment by the relatively short wave)
  CASE4: the wave period =1 minute, the wave height =1.0 m at the upstream B.C. and the average sea level = +4.8m.
  CASE5: the wave period =2 minutes, the wave height =1.0 m at the upstream B.C. and the average sea level = +4.8m.

iv) Long wave (2 hours) + short wave (1-2 minute) (mixture of the conditions ii and iii; relatively close to the storm surge condition)
  CASE6: the long wave conditions: the wave period =2 hours, the wave height =3.5 m at the upstream B.C. and the average sea level = +0.0m.
  Short wave condition is the same with CASE4 and 5.
  CASE7: the long wave conditions are the same as in CASE6, the short wave conditions are the same as in CASE5 (wave period =2 minutes, wave height =1.0 m at upstream B.C.) and the gradient of the land is changed to be 1/250.
  CASE8: the long wave conditions are the same as in CASE6, the short wave conditions are the same as in CASE5 (wave period =2 minutes, wave height =1.0 m at the upstream B.C.) and the gradient in land is changed to be 1/500.

3-2-2. Simulated results of the coastal vegetation effect for storm surge

(1) Vegetation effect to prevent the average increment of the water level by the wind

Table 3-2-1 shows the results for CASE1. In this case, the condition is assumed as the high peak of the storm surge and the average sea water level is +5.3 m. With that condition, the vegetation effect for the wind (wind velocity =60 m/s in this study) is discussed. No difference is observed in the front of the vegetation zone, however, a little difference is caused inside the vegetated zone. The difference is only about 4 cm behind the vegetation (=150 m streamwise length in this study) and this difference does not affect the maximum intrusion height of the storm surge.

Table 3-2-1 Increment of water depth by the wind in CASE1

Location	24000m (water depth =10m)	At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
Without	0.464	0.691	0.701	0.712	0.724	0.737
With	0.464	0.691	0.700	0.700	0.700	0.700

Note:
wind velocity=60m/s， average sea level=+5.3m
Increment (m) =(water depth with wind shear load -water depth without wind shear load)
'Without' means 'without vegetation', 'With' means 'with vegetation', 'VZ' means 'vegetation zone'.

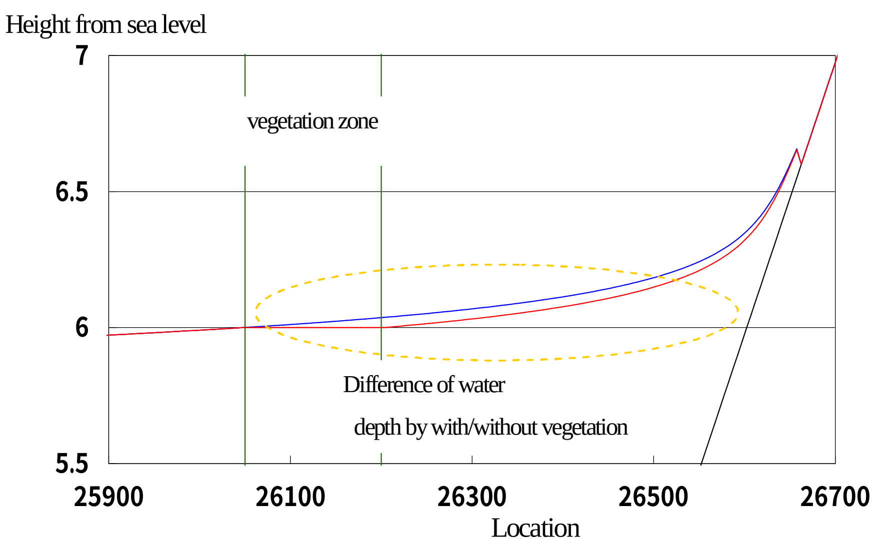

Figure 3-2-3 Simulated results of the vegetation effect to prevent the average increment of the water level by the wind, (——— blue line=without vegetation, ——— red line=with vegetation)

(2) Vegetation effect to decrease water level increment by long wave:

Table 3-2-2 shows the results for CASE2. From this table, long wave (CASE2 = 2 hours period) is found not to cause any difference of the water depth. The drag force by the vegetation has no role to the long wave; however it decreases the velocity a little inside the vegetation zone. In addition it slightly decreases the arrival time of the peak of storm surge. In this case, the delay in the peak arrival time is about 25 seconds and the drag force by the tree is only about 100 N.

The above mentioned trend doesn't change so much in CASE3 (Table 3-2-3), however, the drag force effect by the vegetation is slightly larger than that in CASE2. The difference of the water depth in CASE2 and CASE3 is about 2.0~3.0 cm and the drag force by the tree is only about 250 N.

Table 3-2-2 Maximum water depth and the peak velocity in CASE2

a- Maximum water depth (m)						
	Location	At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
Wind = 0m/s	Without	5.334	4.836	4.339	3.841	3.342
	With	5.334	4.837	4.339	3.841	3.343
b- Peak velocity (m/s)						
		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
Wind = 0m/s	Without	1.54	1.37	1.25	1.13	0.97
	With	1.54	1.22	1.04	0.89	0.90
Note: Wave period =2 hours, wave height =4.0 m at the upstream B.C. and =5.3 m at the coast and the average sea level = +0.0m. 'Without' means 'without vegetation', 'With' means 'with vegetation' , 'VZ' means 'vegetation zone'.						

Table 3-2-3 Maximum water depth and peak velocity in CASE3

a- Maximum water depth (m)						
		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
Wind = 0m/s	Without	5.042	4.552	4.062	3.572	3.081
	With	5.003	4.515	4.027	3.541	3.054
b- Peak velocity (m/s)						
		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
Wind = 0m/s	Without	2.08	1.93	1.79	1.63	1.50
	With	2.08	1.71	1.40	1.22	1.20
Note: wave period =1 hour, wave height =3.0 m at the upstream B.C. and =5.0 m at the coast, the average sea level = +0.0m, 'Without' means 'without vegetation', 'With' means 'with vegetation' , 'VZ' means 'vegetation zone'.						

(3) The vegetation effect to decrease the water level increment by short wave:

Table 3-2-4 shows the results in CASE4 and CASE5. From this table, the short waves are found to be affected more than the long waves. The water depth decrement by the vegetation is 10 cm and 20 cm for 1min and 2min period wave; respectively. The velocity is also decreased inside and behind the VZ. The peak drag force by the vegetation is 150 N, 150 N for 0m/s and 60m/s wind velocity; respectively; for 1min wave period. It is 750 N, 800 N for 0m/s and 60m/s wind velocity; respectively, for 2min wave period. The drag force is larger than that in the long wave case (CASE2 and CASE3) and has a role to decrease the water depth and velocity in CASE4 and CASE5.

Table 3-2-4 Maximum water depth and peak velocity in CASE4 and CASE5

a- Maximum water depth (m)							
period	wind		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
1min	0m/s	Without	5.11	4.59	4.08	3.58	3.07
		With	5.12	4.59	4.05	3.52	3.00
	60m/s	Without	5.85	5.36	4.85	4.35	3.86
		With	5.85	5.34	4.80	4.28	3.76
2min	0m/s	Without	5.46	4.93	4.41	3.89	3.37
		With	5.42	4.87	4.27	3.73	3.18
	60m/s	Without	6.20	5.66	5.17	4.67	4.14
		With	6.10	5.63	5.04	4.50	3.94
b- Peak velocity (m/s)							
period	wind		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
1min	0m/s	Without	0.56	0.56	0.57	0.59	0.65
		With	0.55	0.56	0.54	0.52	0.53
	60m/s	Without	0.55	0.56	0.57	0.62	0.64
		With	0.55	0.56	0.55	0.55	0.50
2min	0m/s	Without	1.10	1.10	1.19	1.25	1.30
		With	1.20	1.19	1.05	0.97	0.86
	60m/s	Without	1.02	1.06	1.11	1.17	1.19
		With	1.15	1.15	1.03	0.93	0.85

Note: wave period =1 min, 2 min, wave height =1.0 m at the upstream B.C., the average sea level = +4.8m, 'Without' means 'without vegetation', 'With' means 'with vegetation' , 'VZ' means 'vegetation zone'.

(4) The vegetation effect to decrease the water level increment by long and short compound wave:

Table 3-2-5 shows the results in CASE6. The water depth decrement by vegetation is 10 cm and 30 cm behind VZ for 1min and 2mints wave period, respectively. The velocity is also decreased inside and behind the VZ. The peak drag force by the vegetation at the front of VZ is 350 N, 400 N for 0m/s and 60m/s wind velocity; respectively, for 1min wave period. It is 900 N, 1100 N for 0m/s and 60m/s wind velocity, respectively for 2min wave period. The drag force is 3 times larger than that in the long wave case.

Table 3-2-5 Maximum water depth and peak velocity in CASE6

a- Maximum water depth (m)							
period	wind		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
2hour + 1min	0m/s	Without	5.01	4.47	3.97	3.47	2.96
		With	5.00	4.49	3.99	3.43	2.88
	60m/s	Without	5.74	5.25	4.73	4.24	3.75
		With	5.72	5.23	4.67	4.15	3.63
2hour + 2min	0m/s	Without	5.34	4.82	4.28	3.77	3.25
		With	5.22	4.73	4.13	3.58	3.03
	60m/s	Without	6.08	5.56	5.06	4.57	4.07
		With	5.96	5.47	4.89	4.35	3.79
b- Peak velocity (m/s)							
Period	Wind		At cost (26000m)	At the front of VZ (26050m)	26100m	26150m	Behind VZ (26200m)
2hour + 1min	0m/s	Without	0.85	0.88	0.89	0.91	0.94
		With	0.89	0.88	0.83	0.80	0.78
	60m/s	Without	0.85	0.83	0.88	0.90	0.95
		With	0.87	0.89	0.87	0.80	0.76
2hour + 2min	0m/s	Without	1.37	1.40	1.47	1.47	1.46
		With	1.52	1.55	1.39	1.23	1.06
	60m/s	Without	1.31	1.41	1.38	1.48	1.46
		With	1.51	1.51	1.35	1.21	1.13
Note: Long wave condition: wave period =2 hours, wave height =3.5 m at upstream B.C., average sea level = +0.0m, Short wave condition is the same with CASE4 and 5, 'Without' means 'without vegetation', 'With' means 'with vegetation' , 'VZ' means 'vegetation zone'.							

Figs.3-2-4 and 3-2-5 show the simulation results for CASE7 and CASE8, respectively. When the gradient on land slope becomes milder like CASE7 or CASE8 than that in CASE6, the water depth behind VZ becomes smaller. The decrement of the water depth in CASE7 is about 40 cm, within which the long wave contributes about 15 cm. In CASE8, the decrement of the water depth is about 80 cm, within which the long wave contributes about 55 cm. From these, the vegetation zone contributes more to decrease the water depth of storm surge when the land slope becomes milder.

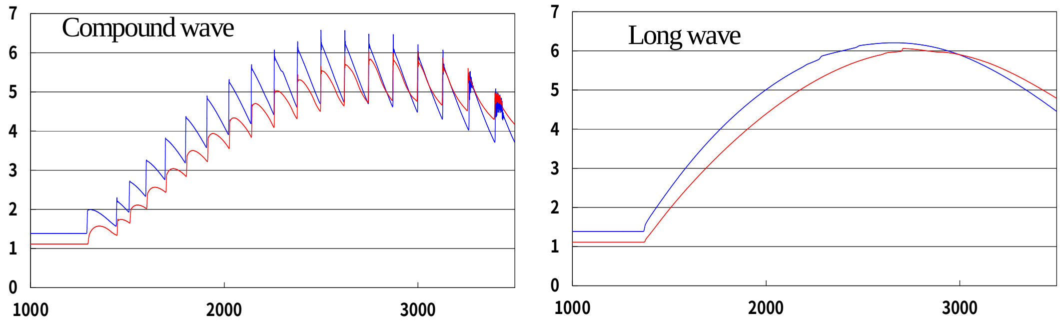

Figure 3-2-4 Simulated time series of water depth behind vegetation zone that show the vegetation effect to decrease the water depth in CASE7 (Long wave condition is the same with CASE6. Short wave condition is the same with CASE5 (wave period =2 minutes, wave height =1.0 m at upstream B.C., Land slope is changed to 1/250, blue line=without vegetation, red line=with vegetation

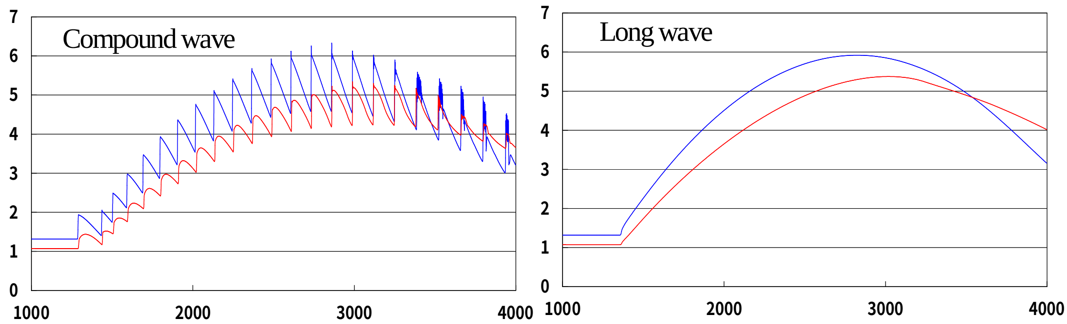

Figure 3-2-5 Simulated time series of water depth behind vegetation zone that show the vegetation effect to decrease the water depth in CASE8 (Land slope is changed to 1/500, other condition is the same with CASE7, blue line=without vegetation, red line=with vegetation

3-2-3. Discussion on the coastal vegetation effect for storm surge:

In usual, the period of wind wave is around a few seconds to 2-30 seconds, however, if the water depth is shallow, a few minute wave motion by groups of waves (called a surf beat) or by the break of the storm surge is occurred. The few seconds' motion is usually declined near coast, but it remains in inland when water intrudes inland and the depth is kept like a storm surge. The differential equation used in this study is for long wave, so we selected 1-2min wave as a representative of the relatively short wave compared with the storm surge.

Without wave condition, this study shows that the 150m-length vegetation in streamwise direction decreases the water depth only 4cm, compared with the non-vegetation case, by decreasing the wind shear stress inside the vegetation. When the land slope is 1/100, the vegetation also decreases the water depth a few centimeters for long waves with 1-2 hours period. On the other hand, when we simulate the compound wave condition (long wave + short wave (period: 1-2min)), the water depth decrement becomes quite large. The water depth decrements by the vegetation existence are 10cm and 30cm for 1 min and 2 mints wave period, respectively. The effect becomes larger with decreasing the land slope (CASE7: gradient=1/250, decrement=40cm, CASE8: gradient=1/500, decrement=80cm).

This study only considered 1-2min short waves included in the storm surge considering the differential equation we use, however, shorter waves, that actual condition has, should be more affected by the vegetation. The water depth decrement by the vegetation at Mathbalia along Baleswar River was confirmed about 0.5 to 1m by the interview (see, 3-1). This difference may be caused by this kind of short waves effect which this analysis indicates. When we consider the vegetation effect for preventing storm surge, the effect for long wave is not enough. We need to consider the effect for the short wave appropriately and plan the bioshield by the vegetation.

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Chapter 4. Effectiveness and challenges in non-structural measures

4-1. Questionnaire Survey on the Consciousness of Local Residents

Questionnaire Survey (QS) was conducted by JSCE team in order to acquire information on how cyclone forecasting, warning, evacuation and relief activities had been conducted before, during and after the Cyclone SIDR. Specifically, the team made on-site survey by posing following questions to selected local people and took note of their answers. Mr. Nazim Uddin (a Master Course student at BUET) played the central role in this exercise as the team member did not have the ability of local language.

(1) How did you know that Cyclone SIDR was approaching？
(2) Was cyclone warning reached to local residents?
(3) What was your first action after knowing the cyclone warning ?
(4) Did you evacuate?
If yes – where did you go?
If no - why you did not evacuate?
(5) Did you know evacuation route?
(6) What damages did you suffer from SIDR?
(7) Current situation and expectation regarding the recovery from damages.
(8) If you also have the experience of 1991 cyclone, what were differences between two cyclones?
(9) Lessons learned by past disaster experiences (in case the above (8) was yes)
(10) What are most necessary in order to prepare for possible future disasters?

As there was severe time limitation for this questionnaire survey, the team could obtain only 5 answers in Sarankhola where all the respondents were farmers between 40 to 62 years old, and 2 answers in Mathbaria where respondents were fishers with 58 and 60 years of age.

(1) How did you know that Cyclone SIDR was approaching？
All 7 respondents said they were informed about the approach of Cyclone SIDR by CPP volunteers and/or local government network, some also know it through the radio.

(2) Was cyclone warning reached to local residents?
All 7 respondents received cyclone warning. Through this we can guess that the cyclone warning and evacuation guidance may have been reached to almost all local residents.

(3) What was your first action after knowing the cyclone warning ?
In Sarankhola, all 5 respondents went to cyclone shelter, while 2 respondents in Mathbaria said they stayed at home.

(4) Did you evacuate?
5 respondents in Sarankhola said they evacuated to Cyclone shelters. 2 respondents in Mathbaria said they had no choice but to stay at home because there was no cyclone shelters nearby.
Also important comments were taken as follows.

a) There was false Tsunami warning and evacuation guidance 2 months before the SIDR event, when many people evacuated to the shelters but no Tsunami happened. Due to this many people assumed this might be false information again.

b) The cyclone danger level was suddenly announced to be upgraded to level 9 from previous 4. Many people did not believe the sudden rise of danger level.

c) It is difficult to find the evacuation place for Livestock.

d) As cyclone shelter was already packed by too many people, many could only stay on the roof of shelters

(5) Did you know the evacuation route?

When there were cyclone shelters, all respondents knew the evacuation route.

(6) What damages did you suffer from SIDR?

All 7 respondents said they suffered severe damages in their houses, crops and fruit trees.

(7) Current situation and expectation regarding the recovery from damages.

3 respondents said they were in temporary tents as their houses were totally damaged. As saline water intruded into the farmland, crops caused severe damage, assistance for food, restoration of houses were highly hoped, which was not sufficiently fulfilled.

(8) If you also have the experience of 1991 cyclone, what were differences between two cyclones?

And (9) Lessons learned.

All seven respondents said 1991 cyclone did not cause severe damage in this area. The 1991 cyclone was with much less wind and with slower and lower water surge. It was not explicitly recognized what were lessons learned from past events.

(10) What are most necessary in order to prepare for future disasters?

All 7 respondents said that "More number of strong Cyclone Shelters" and "Heightened and strengthened embankments" are two mostly desired actions for preparing for future disasters. Physical measures as such are proved to be mostly desired.

Other notable information obtained.

- Cyclone forecasting was reached to people, but as there had been still some time before the timing of high tide, people did not quickly evacuate which resulted in delay in evacuation.
- Even though the capacity of Kadamthala cyclone shelter was only about 500 people, as many as about 5,000 people were packed inside and on the roof of the shelter. Many people gave up getting inside the shelter because of this situation.
- People in the Katachera Village (Mathbaria Bazar) gathered on the dykes as there was no nearby cyclone shelters, on the dykes it was difficult to access appropriate and timely information.
- The key of the shelters was locked and the key for which was only kept by the leader in the area, which contributed to delayed evacuation.

Furthermore, the following issues were pointed out regarding cyclone shelters.

- It is not easy to obtain necessary lands for constructing shelters.
- There are many local residents who claim that shelters are too far from their locations.
- Shelters for multipurpose use (e.g. schools, community centers) are efficient but very costly to construct and maintain.
- Not many shelters are provided with good maintenance.
- Evacuation drills against cyclones at normal times are seldom exercised.
- It is difficult for seasonal workers to receive cyclone-related information.
- Poor people, who do not have lands (illegal residents?), were not allowed to enter cyclone shelters.
- There was broad recognition that storm surge would hit at the timing of high tide and not at low tide timing.

It was clear that cyclone warning was delivered to almost all local residents through various channels such as television, CPP network and local government networks. However, some challenges are still left as follows;

- Upgrading of reliability and preciseness of cyclone forecasting and warning (responsibility of Bangladesh Meteorological Department)
- The need to increase in number and balanced distribution of cyclone shelters
- The need to increase in number of Killa that can be the refuge for livelihood.
- In order to facilitate the evacuation, the need to strengthen disaster preparedness capacities including the poor and so-called illegal residents.
- Provision of basic but precise information is necessary to local people such as the meaning of warning systems, levels of warning, weather-related knowledge. Periodical exercise of evacuation drills.
- Development of the system is needed where local beneficiaries can take care of maintenance of the shelters.

4-2. Effectiveness and challenges in non-structural measures such as forecasting, warning, communication, evacuation planning and relief activities.

4-2-1. Effectiveness and challenges in forecasting, warning and communication

It is clear that Bangladeshi disaster prevention as well as disaster communication systems have dramatically improved in recent years. DRR, under the MoFDM（Ministry of Food and Disaster Management）is playing the central role in this field.

Among the institutions that bears warning communication, CPP (Cyclone Preparedness Program) seems to be most important. The CPP, inaugurated in 1973, based on Bangladesh Red Crescent Association, in collaboration with disaster management sections in GOB, provides overall activities such as disaster preparedness, disaster information communication and evacuation guidance in case of emergencies. CPP volunteers consist basically of 15 members per each villages (10 men and 5 women). At normal times, volunteers are engaged in raising public awareness and disaster education while providing some education materials to the local people.

Their responsibilities during disasters are categorized into following five activities.

1) Warning
2) Evacuation
3) Rescue
4) First aid
5) Relief

In case of cyclone SIDR, 4 days (96 hours) before the expected landfall they could issue forecasts and warnings through radio, TV, local government's networks and CPP volunteers' network. These networks functioned very well during the cyclone SIDR event, however some challenges are still remaining, as follows.

1) Information on storm surge prediction did not seem to be incorporated into cyclone warning.
2) Distinction of Rainy and Dry seasons are so clear that people usually do not have the daily habit of relying on the weather forecasts through radios, etc.
3) People are misunderstanding the relationship between storm surge caused by cyclones and natural fluctuations of sea water level (high tides) – the fact that storm surges can also happen during low tide need to be understood.
4) Failure of Tsunami early warning reduced credibility of forecasts in general that are issued by the authority.

It is necessary that in the future through the establishment of technologies that enables real-time storm surge forecasts and their impact assessments, such results could be incorporated into cyclone prediction systems, so that more accurate cyclone warning could be issued. Also, in order to let people more understood on the weather-related information, education to the children from primary schools levels would be recommended. Furthermore, more efforts need to be made to provide the interpretation between the predicted and real figures and the information on the disasters happened in other areas by the same cyclone.

4-2-2. Problems of Evacuation action plan and its operation

Problems awaiting solution are as follows.

1) Evacuation routes are hardly maintained.
2) Refuge-taking drills are hardly given to people.
3) Some cyclone shelters are not maintained.
4) Poor people possessing no piece of land are liable not to be allowed to enter cyclone shelters.
5) People place little trust in warnings sounded by the authorities concerned. (They place more trust in the men of influence in their communities.)
6) Cyclone warnings do not necessarily cause people to prepare for cyclones and take refuge.

The maintenance of evacuation routes should be done in conjunction with the maintenance of roads. In addition, people should be given evacuation drills and knowledge for disaster prevention should be widely spread.

As to the problems of poor maintenance of cyclone shelters and influential men prevailing over the poor, a democratic system in which the poor can participate in should be established in each area, with the characteristics of the area taken into account.

The present ten-level warning system is designed for the protection of harbors and ships against disasters. The ten warning levels do not mean much for the general public. The education level and literacy rate of the poor who live in the coastal area and possess no piece of land, in particular, are low and they hardly understand the concrete meanings of the ten warning levels. It is necessary, therefore, to develop a warning system practical for the general public and set forth guidelines for the general public's conduct.

Influential men and religious leaders in each community should contribute effectually toward education for, and planning of, disaster prevention and improvement of disaster-preventing capacity of the community.

The disaster-prevention authorities and universities in Bangladesh should further investigate disaster-preventive systems in the area hit by the 2007 cyclone and contribute toward awareness raising through the mass media and educational institutions.

V. Summary and Proposals

(1) Cyclone SIDR that hit the south-western coast of Bangladesh on 15th, November, 2007 was one of the 10 strongest cyclones since 1876, having the same order power as in 1970 cyclone and in 1991 cyclone.

(2) However, the dead, missing, and the injured person of the personal suffering in 2007 were more greatly less than that of 1991 and of 1970. The followings are thought as the factors.

1) The route of the SIDR passed the region where population density and scale of city are small compared with the case of 1991 cyclone.
2) The SIDR attacked in the dry season , while the cyclone in 1991 was in the rainy season.
3) Structures for disaster prevention such as embankments have been constructed or maintained successively.
4) Cyclonic shelters have been increased.
5) The disaster prevention education that has been done after 1991, the enlightening activity such as CPP, and maintenance and the enhancement of the system of information transmission have advanced.
6) Enhancement of weather warning system
7) Improvement of resident's understanding for cyclone disaster.

(3) The storm surge caused by SIDR went up over 100 km upstream through the rivers, specifically through the Baleswar River and inundated the riverside with bringing a big damage.

Although Hajipur is located further from the coast (however closer to the river mouth), the inundation height at Hajipur was higher than the one at Alipur. It is essentially important to consider the runup flow not only from the coastal area but also along the river, branches and waterways.

The maximum inundation height of the surge was 9.6m (the inundation depth 6.5m) in the coastal area Kuwakata, and 6.5m (5m) in the river area Southkhali. Comparison of the data with the past records shows that the storm surge in this time was in the same scale as in 1970 or in 1991.

(4) In the field survey around the coast Kuwakata, failure of coastal embankment, erosion of coast and scouring of sand dune etc. were observed at any place. Bank erosion and bed evolution are continuing near the river mouth. Immediate countermeasure is required for maintaining the function of tide embankment.

(5) Many witnesses were obtained near coastal area that storm surges inundated with bore-like waves. At Southkhali, people witnessed that storm surge came up with three waves of 1 minute period and high water stage continued 15 minutes. On the other hand, there are many witnesses that the storm surge gradually rose up with one wave in inner land areas. Countermeasure against storm surges should account for the physical mechanisms for the development of such bore-like waves and their deformations and possible damages due to such waves.

(6) Coastal embankments and Polders in Bangladesh are constructed as the crest should be 1.5m higher than the mean sea water level in the annual maximum high tide records. Even for the best coastal embankments, the crest is kept only 5.2m above the mean sea water level. Therefore, it is difficult to prevent a storm surge with over 6-9m wave height as experienced in this time. However, in Kuakata and Somboriya, embankment showed significant roles to minimize the damage. Development of riverbanks especially around the river mouth is one of most essential countermeasures to be carried out in Bangladesh.

(7) Embankment and Polder in Bangladesh seem to have the following weakness.

1) Embankments and Polders do not provide the enough heights to prevent overtopping of cyclone storm surge. Entire overtopping had occurred in the coastal area and the Baleswar River area in this cyclone.
2) Accuracy of construction for the side slope and surface of the structures is low. Irregular undulation is seen at any places.
3) Many trees are planted in the surface layer of embankments and polders. A large number of these trees were blown down by the strong wind to cause the overturning or uprooting and the failure of embankment body.
4) Maintenance for the structures has scarcely been executed.
5) Illegal habitation on the structures.

(8) The followings should be considered to strengthen the embankments and polders.

1) Present coastal embankments are besides effective against cyclone storm surge not only to normal high tide. However, they will involve a risk of failure by overtopping of a surge or a flood.
2) The action plan to make all coastal embankments reconstruct with higher bank enable to prevent storm surge seems to have several problems in the present time such the related infrastructures are not fully provided. When considered the nature of bank materials, the present compaction technique for soil, the accuracy control technique, the level of maintenance, the agricultural state in polder lands and the quick drainage system for

inundation area so on, the plan to make all embankments enlarge would be seen difficult to be executed.

3) Embankments and polders should be strengthened with geo-textile or local productive materials like jute. Proper compaction and vegetative protection to the bodies will be effective.
4) Bank protection with Stonemason or Concrete block would not be reasonable in use in Bangladesh, since the stone and concrete block are rarely produced and need high cost.
5) It will be worth while constructing secondary embankments parallel to the present embankments, which are expected in a function of flood storage and energy decay of storm surge. The bounded land by two embankments could be used for a farm field.
6) There are remained or newly formed shorefront rooms in several places of the coastal area. It is effective for prevention and mitigation to a storm surge to make new coastal vegetation zones at the places together with conserving the present coastal vegetation zones.
7) Embankment plan should be adjusted to the road construction as local disaster prevention can be developed. Synthetic measures should be planned with considering the relation between embankments, roads, upping of residential land, channel network and culverts so on. A surrounded land by embankments and roads should be appropriated for a retarding basin.
8) Computer simulation techniques should be used more practically for the land administration to achieve the purpose.

(9) Many trees were damaged in this cyclone with 1) the trunk bending or breakage, 2) the overturning or uprooting, 3) the loss of the substrate and 4) local scour around the trees. Most of the damaged patterns are related to the mechanisms 1) and 2) in the affected sites. The overturning damage was mostly occurred along the bank of the road, the river bank and the bank of the paddy field. The high trees were overturned but the low height trees or coconut trees were seldom overturned. These damages were caused mainly by the strong wind and partially by the water flows.

(10) It was suggested from the local people’s speech and our mechanical analysis that the water depth at the place behind the coastal vegetation with 150m width became the maximum 0.5m-1m lower compared with the water depth at the front of the coastal vegetation, at Mathobaria. When we consider the vegetation effect for preventing storm surge, we need to attach importance to the effect for the short wave not only to the effect for long wave.

(11) Coastal vegetation and riverside vegetation are useful to protect the bank from the erosion. Planting of Coco trees or Guava trees which will be useful for the life of local peoples is recommended judging from the present state that the Mangrove trees are little preserved. However, afforestation on the embankments must be avoided because overturning of tall trees will weaken embankments.

(12) The following issues were pointed out regarding to the cyclone shelters.

1) While number of necessary shelters for the population is short, it is not easy to obtain necessary lands for constructing shelters.
2) There are many local residents who claim that shelters are too far from their locations.
3) Not many shelters are provided with good maintenance.
4) Poor people, who do not have lands (illegal residents), were not allowed to enter cyclone shelters.
5) There is no refuge or evacuation place for the livestock.
6) There were local residents who refuse their evacuation for the fear to loss the house, land and livestock.

(13) To solve the problems, the following measurements are required together with the measure for poverty dissolution.

1) Increase of shelters for multipurpose use (e.g. schools, community centers) with high-story.
2) Well balanced distribution of cyclone shelters according with the locations of villages and establishment of the evacuation plan.
3) Increase in number of Killa that can be the refuge for livelihood.
4) Development of the system where local beneficiaries can take care of maintenance of the shelters.

(14) Bangladeshi disaster prevention as well as disaster communication systems have dramatically improved in recent years. DRR, under the MoFDM（Ministry of Food and Disaster Management）is playing the central role in this field.

Among the institutions that bear warning communication, CPP (Cyclone Preparedness Program) seems to be most important. The CPP, inaugurated in 1973, based on Bangladesh Red Crescent Association, in collaboration with disaster management sections in GOB, provides overall activities such as disaster preparedness, disaster information communication and evacuation guidance in case of emergencies.

(15) CPP volunteers consist basically of 15 members per each village (10 men and 5 women). At normal times, volunteers are engaged in raising public awareness and disaster education while providing some education materials to the local people. Their responsibilities during disasters are categorized into following five activities.

1) Warning
2) Evacuation
3) Rescue
4) First aid
5) Relief

(16) In case of cyclone SIDR, 4 days (96 hours) before the expected landfall they could issue forecasts and warnings through radio, TV, local government's networks and CPP volunteers' network. These networks functioned very well during the cyclone SIDR event.

(17) However, some challenges are still remaining, as follows.

1) Information on storm surge prediction did not seem to be incorporated into cyclone warning.
2) Distinction of Rainy and Dry seasons are so clear that people usually do not have the daily habit of relying on the weather forecasts through radios, etc.
3) People are misunderstanding the relationship between storm surge caused by cyclones and natural fluctuations of sea water level (high tides) – the fact that storm surges can also happen during low tide need to be understood.
4) Failure of Tsunami early warning reduced credibility of forecasts in general that are issued by the authority.

(18) It is necessary that in the future through the establishment of technologies that enables real-time storm surge forecasts and their impact assessments, such results could be incorporated into cyclone prediction systems, so that more accurate cyclone warning could be issued.

Also, in order to let people more understood on the weather-related information, education to the children from primary schools levels would be recommended.

Furthermore, more efforts need to be made to provide the interpretation between the predicted and real figures and the information on the disasters happened in other areas by the same cyclone.

(19) Problems on evacuation action plan awaiting solution are as follows.

1) Evacuation routes are hardly maintained.
2) Refuge-taking drills are hardly given to people.
3) Some cyclone shelters are not maintained.
4) Poor people possessing no piece of land are liable not to be allowed to enter cyclone shelters.
5) People place little trust in warnings sounded by the authorities concerned. (They place more trust in the men of influence in their communities.)
6) Cyclone warnings do not necessarily cause people to prepare for cyclones and take refuge.

(20) Measures in the future to improve evacuation action are summarized as follows.

1) The maintenance of evacuation routes should be done in conjunction with the maintenance of roads. In addition, people should be given evacuation drills and knowledge for disaster prevention should be widely spread.
2) As to the problems of poor maintenance of cyclone shelters and influential men prevailing over the poor, a democratic system in which the poor can participate in should be established in each area, with the

characteristics of the area taken into account.

3) The present ten-level warning system is designed for the protection of harbors and ships against disasters. The ten warning levels do not mean much for the general public. The education level and literacy rate of the poor who live in the coastal area and possess no piece of land, in particular, are low and they hardly understand the concrete meanings of the ten warning levels. It is necessary, therefore, to develop a warning system practical for the general public and set forth guidelines for the general public's conduct.
4) Influential men and religious leaders in each community should contribute effectually toward education for, and planning of, disaster prevention and improvement of disaster-preventing capacity of the community.
5) The disaster-prevention authorities and universities in Bangladesh should further investigate disaster -preventive systems in the area hit by the 2007 cyclone and contribute toward awareness raising through the mass media and educational institutions.

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