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LESSONS AND VIEWS ON HARDWARE COUNTERMEASURES WITH EARTH BANKS AGAINST TSUNAMI ESTIMATED IN 2011 GREAT EAST JAPAN EARTHQUAKE

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ABSTRACT: Through the field survey after the 2011 Great East Japan Earthquake, 13 damaged and/or non-damaged earth banks and 10 eroded dug pools related to the tsunami flood stream are investigated to focus on the effects of earth banks against the tsunami. Based on the investigations, important lessons on the hardware countermeasures against the tsunami with the earth banks are learned, and the performance-based design concepts for the reconstruction in this earthquake and the future tsunami disaster can be proposed.

Key Words: Tsunami, earth bank, dug pool, countermeasures, performance-based design

INTRODUCTION

However it is afraid that the reducing functions of the structures such as sea walls, sand beaches, forests etc. couldn't perform against the tsunami enough in the 2011 Off the Pacific Coast of Tohoku Earthquake, some kinds of the structures can be indicated to resist the tsunami attacks based on the field survey after the earthquake on April 30, May 1 to 3, July 8 to 10 and September 10 to 12 in 2011 conducted by the authors etc. (Tokida 2011c, 2011d, 2011e, 2011f). Then the reducing and/or resistant functions of the above structures should be investigated in detail and estimated more properly for the future countermeasures against the tsunami.

In this paper, the earth banks are focused on and the 13 damaged and/or non damaged ones located in Miyagi Prefecture, Chiba Prefecture and Ibaragi Prefecture are found and selected to investigate the resistant functions of the earth banks against the tsunami (Tokida 2011a, 2011g). Furthermore, the 10 dug pools eroded by the tsunami flood stream temporarily at the back side of the sea walls or earth banks are also investigated to know the reducing characteristics against the tsunami to consider the future hardware countermeasures hinted by the dug pool (Tokida 2011b).

Based on the above investigations, very important lessons on the hardware countermeasures against the tsunami with use of the earth banks are discussed and obtained, and the performance-based design concepts for the reconstruction in this earthquake and the future tsunami disaster are proposed from the engineering view points (Tokida 2011a, 2011f, 2011g).

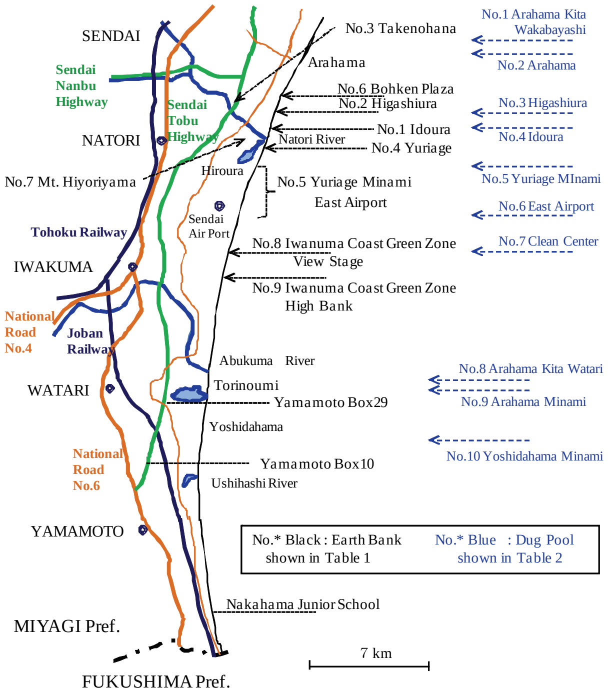
RESISTANT FUNCTION OF EARTH BANK AGAINST TSUNAMI

Objective Earth Banks

In this paper, the earth banks which aren't covered with the structures such as blocks and don't touch the water area daily are focused on to investigate the resistance characteristics against the tsunami. Then, the river levee and road embankment similar to the above conditions are included. The objective earth banks found at the field are shown in Table1 and the their detail locations at Sendai Plane in Miyagi Prefecture and Asahi Coast in Chiba Prefecture are shown in Fig. 1 and Fig. 2, respectively. As shown in Table 1, the research objects are 2 river levees, 1 road embankment, 2 banks and 4 artificial banks at Sendai Plane, and as shown in Table 1, the research ones are 3 banks at Asahi Coast. Furthermore, the one object at Oarai Coast in Ibaragi Prefecture shown in Fig. 3 is a sand dune which is selected because the eroded slope at the sand dune can be referred to consider the resistance function of the earth banks.

Table 1 Objective earth banks and each condition

No.	Type of Bank	Site of Bank		Content of Earth Structure				Condition of Tsunami	
				Height (m)	Condition of Slope	Slope of Front Slope	Others	Flooded Depth (m)	Overflowed Depth (m)
1	River Levee	Miyagi Pref.	Idoura	Front 3.9 Back 3.2 Teizan Canal 5.0	lawn	1 : 2.7	Front Slope L10.7m/H3.9m, Crest Width6.9m、 Back Slope L10.9m/H3.2m, As-Pavement	7.75*	3.85*
2			Higashiura	Back2.7 Teizann Canal 4.5	lawn	1 : 3	Levee:L9.7m/H2.1m, Crest Width6.5m, Not paved	6.8*	4.1*
3	Road Embankment		Takenohana	6**	Block・Grass・Low Tree	-	4 lanes, Block：H2m	1.6	None
4	Bank		Yuriage	5.6	bare:soil	1 : 2.7	Front Slope L15m/H5.6m, Crest Width 24m, L150m, Crest Surface :netted	6.1**	0.5**
5			Yuriage Minami～East Airport	1.5	grass, low tree	1 : 7	Front Slope W11m, Back Slope W4m, Surface Layer 0.6m, Covered Net	6.1**	4.6**
6	Artificial Bank		Bohken Plaza	14.9	tree, grass	Upper 1 : 4 Lower 1 : 5	Ship Shape W50ｍ, L400m	10.55～13.8	None
7			Mt. Hiyoriyama	6.55	grass	1 : 2.5	Top : 12×20m	8.65	2.1
8			Iwanuma Coast Green Zone : View Stage	9.8	low tree	Front 1:2 Back 1:4	Top : φ 10m, Circle	6.8	None
9			Iwanuma Coast Green Zone : High Bank	9.5	grass	1 : 2.8	Top : 20m×30m Base :60m×280m	3.9	None
10	Bank	Chiba Pref.	East Ashikawahama	1.5～2.5	grass	1 : 1**	Block Wall : H3.5m, Non Parapet, Slope Shoulder W3.5m＋Walking Way W3m,	2.5**	1.0～0**
11			Nishiashiarai	2.0	grass	1 : 1**	Vertical Sea Wall H2m, Palapet H0.7m, Cycling Way W3m	3.2以上**	1.2以上**
12			Mikawa	2.0	grass	1 : 1**	Vertical Sea Wall H2m, Palapet H0.9m, Crest W2.5m, Back Slope H1.5m～2m, Cycling Way W3m	2.5～3.0**	0.5～1.0**
13	Sand Dune	Ibaragi Pref.	Oarai Coast	Parking15m**、Toilet13m**	grass, toe:bare	1 : 3.3 ～1 : 10**	General Section 1 : 3.3, Reef Section 1 : 10	Run Up Height : Parking 9**, Toilet 13.8**	Non at Parking, Toilet 0.8
Note	* is estimate based on the tsunami height of 10m.				** is estimated.				



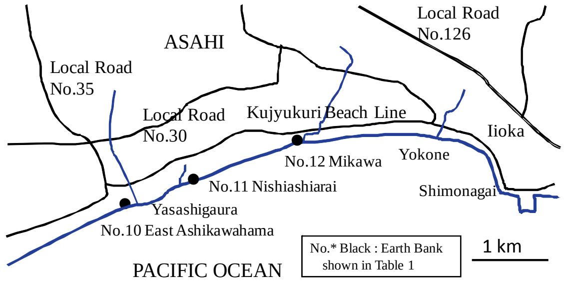


Fig. 2 Sites for field survey at Asahi Coast

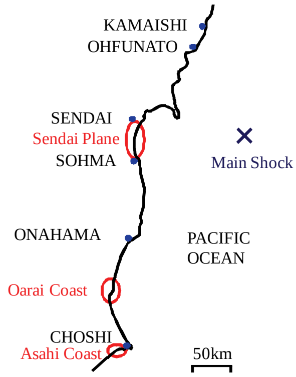


Fig.1 Sites for field survey at Sendai Plane

Fig. 3 Three sites for field survey

In Table 1, the structure contents of the earth banks such as the height, condition of slope, slope and others are shown and compared based on the field survey and the related references. Because the conditions of the tsunami such as the flooded depth and run up height can't be measured, these factors at Sendai Plane are estimated based on the height of the earth structures and the ground level measured in the field, the tsunami height of 10m which is estimated in general, and those at the other sites are estimated based on the overflow and /or run up conditions.

Typical Earth Banks and Lessons on Resistant Function

Typical earth banks which show the resistant function against the tsunami flood and the effective lessons obtained are shown as follows. As for the other earth banks, it can be known by the references of Tokida 2011c, 2011d, 2011e and 2011f.

Site No. 1: Idoura

Photograph 1 is the satellite photo (Google 2011) around the levee newly constructed along the existing Teizan Canal at Idoura of Wakabayashi Area in Sendai City. The arrow in Photo 1 shows the direction of the leading wave which is same as follows in this paper. The new levee is about 3.9m high and about 1.5km long and located around the lagoon of 200m width. The purpose of the levee is supposed to reinforce Teizan Canal with the height of 2m along the lagoon. The coastal zone can be seen to be flooded away.

As shown in Table 1, however the overflow depth of the tsunami is estimated to be lower than 4m, the lawn planted on the surface at the front slope of the levee shown in Photo 2 can be seen not to be eroded however the sand washed by the tsunami is settled a little. Furthermore, the crest of the levee is paved with the asphalt of 10cm thickness is partially come off shown in Photo 3, but the performance of the levee can be almost kept. On the other hand, Photo 4 which shows the conditions at the back slope and the toe by the tsunami indicates that the erosion at the back side of the levee is more severe than those of the front slope and crest. Photo 5 shows the water pool made by the flood stream

Photo 1 Around new river levee on April 6

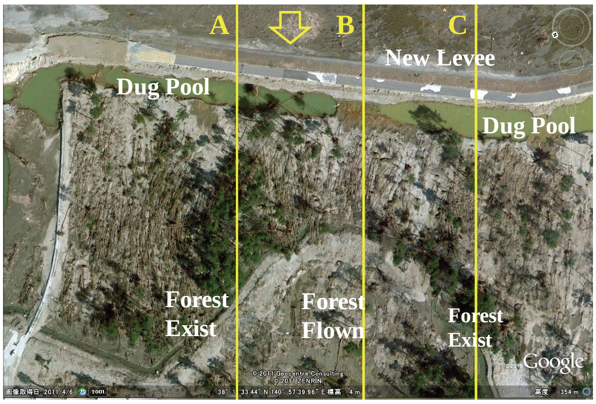


Photo 6 Dug pool and forest on April 6

Photo 2 Front slope on May 2

Photo 3 Bank crest on May 2

Photo 4 Back slope and toe on May 2

Photo 5 Slight slope failure on May 2

named “dug pool” as follows in this paper and the slope failure, but the failure scale, i.e. the reduced performance level seems to be small from the engineering view point.

The dug pool shown in Photo 5 is very interesting from the engineering view point which can be known more clearly in the satellite Photo 6 (Google 2011). It can be indicated that the forests located at the back side of the dug pools through the section A and section C seem not to be flown away severely and existed after the tsunami, and on the other hand, the forest at the back side of the levee without the dug pool through the section B seems to be flown away severely and not to be existed. Considering the difference of the damage level on the forests at these sections, very important lesson that the dug pool is effective to reduce the flow velocity of the tsunami can be obtained.

Site No. 4: Yuriage

At the sand beach located at the east side of the Yuriage Fishing Port, the sand bank can be found during the field survey on July 9. As shown in Photo 7 (Google 2011), the bank is about 5.6m high and about 150m long and the crest is about 24m wide and the front slope at the sea side is about 1: 2.7. Photo 8 (Japan Coast Guard 2011) shows the tsunami just attacking the bank and the tsunami wave around the bank can be seen to be almost stopped and the forest at the back side of the bank is flooded slightly. However the bank wasn’t aimed to be constructed as the countermeasures against the tsunami, the sand bank indicates the effectiveness against the tsunami. However the tsunami attacking the sand bank goes around the both edges of the sand bank and into the forest, the flooded depth at the cycling terminal in the forest is about 4.3m to 5.0m which seems to be reduced by the sand bank. If the length of the sand bank was more than 150m, the effectiveness of the sand bank against the tsunami could become larger.

The net covered on the sand bank seen in Photo 8 can be verified also before the earthquake in the satellite photograph on August 14 in 2009 (Google 2009), and then the net seems not to be covered with the surface soils when the tsunami attacked. However the net is almost flown away at the time of July 9, the crest of the bank seems to be flooded slightly and the flooded depth is estimated about 0.5m shown in Table 1 because the net and the small pine tree of 30cm high can be observed at the field survey on July 9.

On the other hand, Photos 9 and 10 show the conditions of the front slope and the back slope, respectively which seems to be eroded slightly at the time of on July 9. Additionally, Photo 10 shows the back side of the bank where the low bank whose height is 1.6m and the base width is 12.8m and the surface isn't eroded because of the reduction of the flood by the front sand bank. Photo 11 shows the view at the right edge of the sand bank shown in Photo 7 and can be known that the trees are fallen down in the direction of from the left side to the right side of the photograph which means that the tsunami flood went around the edge of the bank. The flown net can be also seen.

As known from the above discussions, the lesson that the sand bank can reduce the tsunami however the small overflow with about 0.5m deep occurs can be obtained.

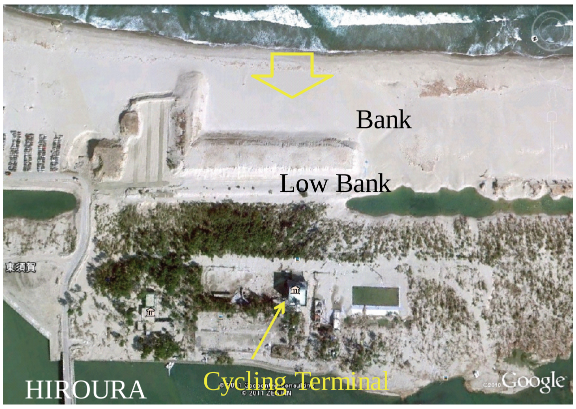


Photo 7 Bank after tsunami on April 6

Photo 8 Just attacking by tsunami

Photo 9 Front slope of bank on July 9

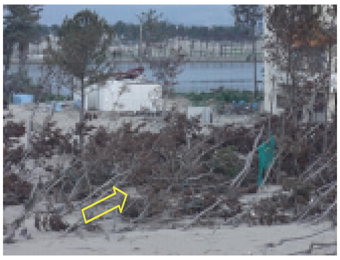


Photo 11 Trace of flow on July 9

Photo 10 Back slope and background on July 9

FUNDAMENTAL CHARACTERISTICS OF DUG POOL ERODED BY TSUNAMI

Objective Dug Pools

At the back sides of the earth bank shown in Photo 6 and the sea wall shown in Photo 12, many dug pools appeared in this earthquake and as shown in Photo 6, the reducing function against the tsunami of the dug pool can be known. Then the dug pools are investigated from the views of the reducing functions against the tsunami. The 10 dug pools are selected and the characteristics such as the scales of the trenches, tsunami conditions and structural conditions of sea wall and banks are investigated as follows.

The objective sites selected based on the field survey are summarized in Fig. 1 and Table 2 where the scales of the dug pool such as the width *B*, depth *D* and eroded area *A*, the overflowed depth H_0 at the parapet of sea walls or the crest of banks by the tsunami and the structure conditions such as the height H_B of the back slope and the one H_F of the front slope are estimated. Here, each index of *W*, *B*, *A*, H_0, H_B and H_F is identified as in Fig. 4. The overflowed depths at the sites of No.4 and No.5 are estimated based on the overflowed height at the Yuriage Bank which is same with the earth bank of No.4 in Table 1, and the ones at the other 8 sites are estimated based on the tsunami height of 10m assumed at Sendai Plane in general. Typical relations can be obtained as follows.

Photo 12 Dug pool at sea wall on June 9

Table 2 Conditions of dug pool

Objective	Site	Dug Pool			Tunami	Banke or Sea Wall	
		Width	Depth	Area	Overflowed Depth	Height of Back Slope	Height of Front Slope
No.		B(m)	D(m)	A(m^2)	H_0(m)	H_B(m)	H_F(m)
1	Arahama Kita Wakabayashi	19.9	1.9	22	5.7*	2.6	2.3
2	Arahama Kita Wakabayashi	12.2	2.2	20	6.8*	1.4	1.2
3	Higashiura	13.6	3.4	34	4.1*	2.7	2.1
4	Idoura	16.8	4.6	54	3.85*	3.2	3.9
5	Yuriage Minami	12.5	1.5	19	4.6**	1.5	1.5
6	East Air Port	8.8	2.2	17	4.6**	3.0	1.5
7	Clean Center Iwanuma Coastal Green Zone	11.8	2.8	29	2.8*	2.8	5.2
8	Arahama Kita Watari	13.1	3.4	37	3.05:	2.6	2.0
9	Arahama Minami Watari	26.3	4.1	88	3.05*	2.7	2.0
10	Yoshidahama Minami	16.0	3.7	48	5.5*	3.4	1.5

Note :* : sumani height is assumed to be 10m.
Note ** : This is estimated based on the overflowed depth at Yuriage Bank.

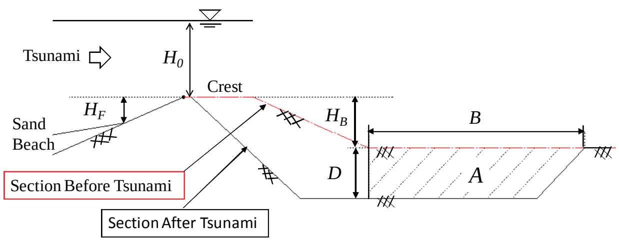


Fig.4 Identification of dug pool

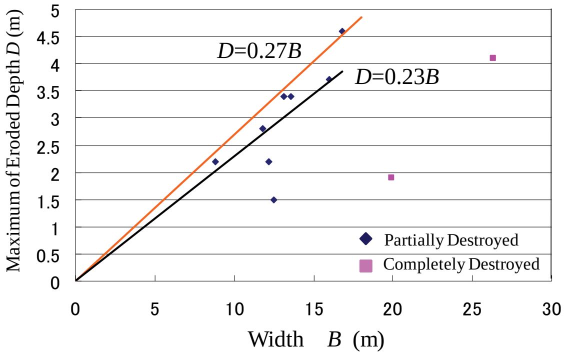


Fig.5 Relation between *D* and *B*

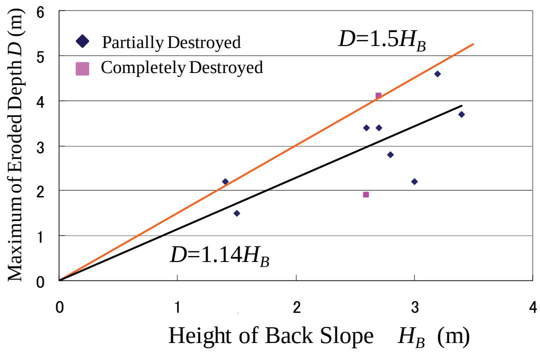


Fig.6 Relation between *D* and H_B

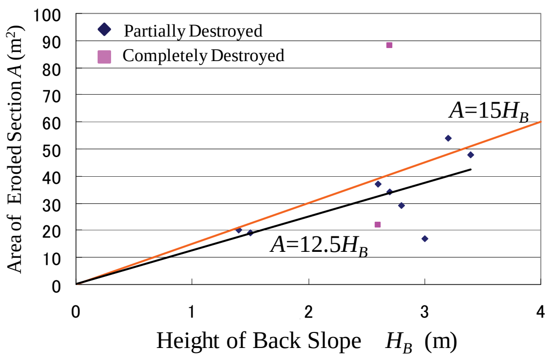


Fig.7 Relation between *A* and H_B

The relation between D and B can be drawn in Fig. 5 and the average relation and the upper limit can be estimated, respectively as

$$D = 0.23\ B \tag{1.1}$$

$$D = 0.27\ B \tag{1.2}$$

where D : depth of dug pool (m), and B : width of dug pool (m).

The relation between D and H_B can be drawn in Fig. 6 and the average relation and the upper limit can be estimated, respectively as

$$D = 1.14\ H_B \tag{2.1}$$

$$D = 1.5\ H_B \tag{2.2}$$

where H_B: height of back slope of sea wall or earth bank (m).

The relation between A and H_B can be drawn in Fig. 7 and the average relation and the upper limit can be estimated, respectively as

$$A = 12.5\ H_B \tag{3.1}$$

$$A = 15\ H_B \tag{3.2}$$

where A : area of eroded section of sea wall or bank identified in Fig. 4 (m^2).

Based on the above mentioned relations, the width or depth or area of the dug pool can be estimated with use of the height of the back slope at the objective sea wall or earth bank simply and applied to the design of the sea walls or earth banks in the future.

PERFOMANCE-BASED DESIDN CONCEPT WITH USE OF EARTH BANKS

Performance against Tsunami

In order to consider the software and/or hardware countermeasures against the tsunami for the future, the fundamental concepts against the tsunami should be established firstly and clearly. In this study, the fundamental design concept is considered not only to save the human life but also to protect the assets such as houses etc. And this design concept can be conducted based on the performance-based design which can show the performance of the objectives protected from the tsunami flood actually. However the view point of the performance-based design against the tsunami is similar to that in case of other design codes such as highway bridges etc. considering the safety, usability and recovery, another performance concerning the protected objects such as the houses should be considered in case of the tsunami flood.

The two fundamental view points on the performances necessary for the hardware countermeasures against the tsunami flood can be indicated as follows firstly.

View Point 1: The hardware countermeasures should be stable even if the tsunami doesn't overflow.

View Point 2: The hardware countermeasures should be stable when the tsunami overflows, in other words, the damage level is small however the countermeasure is overflowed.

Additionally the third following performance should be considered to estimate the effects of the countermeasures against the tsunami flood.

View Point 3: The damage level of the houses flooded by the tsunami should be satisfied the required performance level of the objectives.

The classification of the performance levels considering the flood levels and the damage ones of the wooden houses quantitatively is necessary for the performance-based design and can be proposed as follows.

Class 1: A house isn't flooded.

Class 2: A house is flooded at the depth under the floor of the first floor. For example, the upper limit of the flooded depth is about 0.5m.

Class 3: A house is flooded at the depth of 1m high above the floor of the first floor, and the house isn't destroyed severely and flown away. This damage condition is named "middle level". The upper limits of the flooded depth and the water flow velocity are 1.5m and 4.2m/s, respectively.

Class 4: A house is flooded at the depth over the first floor and the house is destroyed severely and/or flown away. This damage condition is named "large level". The flooded depth and the flow velocity are more than 1.5m and 4.2m/s, respectively.

These classifications are summarized in Table 3. The identification of the middle and large levels of the damaged house, the limits of the flooded depth of 1.5m and the water flow velocity of 4.2m/s are referred the research results by Iizuka & Matsutomi 2000.

Table 3 Performance class and level based on flooded depth and flow velocity

<table>
<tr><th>Performance Class</th><th>Performance Level</th><th>Flooded Depth H (m)</th><th>Flow Velocity u ((m/s)</th></tr>
<tr><td>1</td><td>Not flooded</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>Flooded under the floor of first floor</td><td>0 < H ≦ 0.5</td><td rowspan="2">0 < u ≦ 4.2</td></tr>
<tr><td>3</td><td>Flooded under the 1m high above the floor and house isn't destroyed in the middle level and flown away.</td><td>0.5 < H ≦ 1.5</td></tr>
<tr><td>4</td><td>Flooded over the first floor and house is destroyed in the middle and/or large level and/or flown away.</td><td>1.5 < H</td><td>4.2 < u</td></tr>
<tr><td colspan="4">Note: Identification of the middle and large level of house, flooded depth of 1.5m and water flow velocity of 4.2m/s are referred from Iizuka&Matsutomi(2000)</td></tr>
</table>

The fundamental design steps to apply the performance-based design for the hardware countermeasures against the tsunami can be proposed as follows.

Step 1: The fundamental concept is that the tsunami should be contained in the water areas such as the sea, river and sea port etc., in other words, the flood by tsunami into the back ground isn't permitted. The containment of the tsunami is performed with use of the fundamental structures such as detached breakwater, sea wall, sand dune, river levee etc. considering the collaboration with the banks whose reduction effects against the tsunami is discussed in this paper.

Step 2: When the containment of the tsunami is difficult or the possibility of the tsunami overestimated is considered, the overflow of the tsunami is permitted. The reducing performance of many kinds of the hardware countermeasures such as the bank, levee, forest, canal, water zone etc. which are located between the sea coast zone and the objectives such as the houses should be estimated.

Step 3: The flood by the tsunami should be estimated based on the performance level of the wooden houses or the lightweight steel frame houses considering the estimated indexes of the flooded depth and the flow velocity which are very related the damage level of the houses. The permitted performance for the houses should be designed selecting from the Class 1 to Class 3 shown in Table 4 by which the houses are not destroyed severely and flown away.

The above proposal is tentative at present and necessary to be checked and improved to recover the damage in this earthquake and reduce the future damage induced by the tsunami.

Example of Use of Earth Bank

The typical structures or factors related to reduce the tsunami which are clarified in the field survey at the Sendai Plane are the detached breakwater, natural reef, sand beach, lagoon, sea wall, forest, canal, river levee, manmade bank and road embankment and so on (Tokida 2011a, 2011b, 2011c, 2011d).

When the reducing function of each factor as mentioned above can be estimated quantitatively, the performance-based design concept shown in Fig. 8 can be proposed in general. As shown in Fig. 8, the input conditions of the tsunami at the coastal line such as the run up height and the flow velocity are reduced to the output conditions such as the required flooded depth and flow velocity through each factor gradually. The factors considered in the above design can be selected and 3 examples are shown in Fig. 8. The selected factors in the Example 1, Example 2 and Example 3 are the various factors, the sea wall & earth bank and the sea wall & earth bank & canal, respectively. In other words, the combination of various reducing factors against the tsunami may be the one kind of the multiple defenses.

Furthermore, considering the reducing functions by the dug pool and the forest learned from the lessons shown in this paper, the combination of the sea wall, earth bank, trees planted on the earth bank and manmade canal can be proposed under permitting

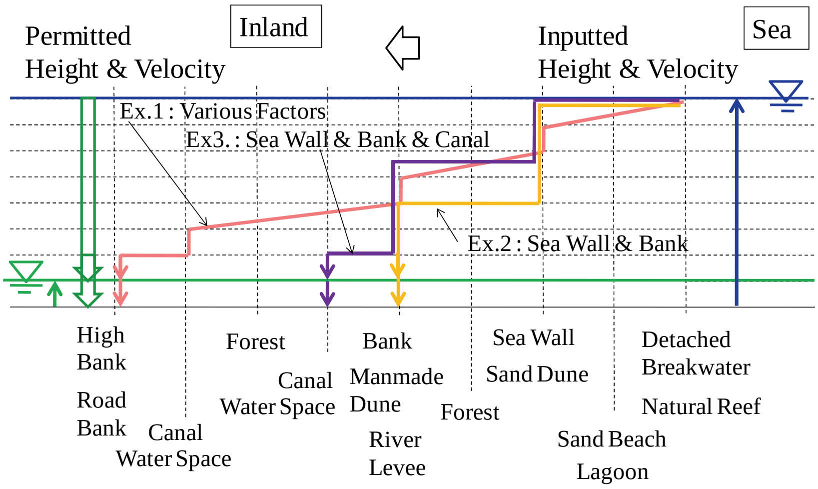


Fig. 8 Performance-based design concept by combination of each factor

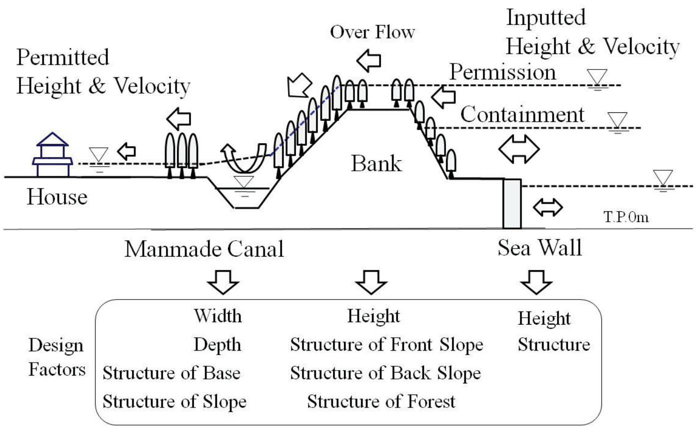


Fig. 9 Design concept against tsunami with sea wall, earth bank and manmade canal

the overflow by the tsunami as shown in Fig. 9 where the manmade canal is constructed in advance instead of the dug pool. Additionally, the design factors necessary to be researched in the future to apply the design concepts to the sea wall, earth bank and canal are also shown in Fig. 9.

In order to apply the design concepts shown in Fig. 8, the reducing function of the selected factors are necessary to be investigated and estimated quantitatively from now on. As for the dug pool or the manmade pool against the tsunami flood, the detail field survey on the conditions of the dug pool at Idoura was conducted by the authors (Tanimoto 2011).

Flooded Depth and Its Reduction

In order to estimate and/or check the effectiveness of the hard countermeasures such as earth structures etc. quantitatively, the flooded depth at the back ground by the tsunami is necessary to be clarified. In this study, the flooded depth and the distance from the coastal line at the Sendai Plane are tried to be gathered through the field survey and the related references by other researchers. The results are shown in Table 4 where 14 sites by the authors and 1 site by the Institute of Port and Airport (2011) and 3 sites by Shibayama etc. (2011) are compared.

Table 4 Flooded depth and distance from coastal line

No.	City	Observed Site	Distance from Coastal Line X (m)	Flooded Depth H (m)
1.	Sendai	Arahama （Sea Port&Air Port Ins. ）	223	4.4
2		Arahama Junior School （Shibayama etc.)	720	5.05
3		Bohken Plaza、High Bank	350	10.55
4		Higashiura、House	650	3.5
5		Takenohana at Sendai Tobu Highway	2400	1.6
6	Natori	Yuriage, Hiyoriyama	600	8.65
7		Yuriage Fishing Port（Shibayama etc.）	440	8.3
8		Sendai Air Port (Shibayama etc.)	1120	2.98
9	Iwanuma	Iwamuma Coastal Green Zone, Baseball Ground	350	6.7
10		Iwamuma Coastal Green Zone, View Stage	300	6.8
11		Fujisone, House	900	3.7
12		Iwamuma Coastal Green Zone, Office House	800	3.9
13	Watari	Torinoumi Hotel	270	5.0
14		Fisshing House	600	4.6
15		West Side of Fishing Port, House	810	3.9
16		Box 29 at Sendai Tobu Highway	2450	1.5
17	Yamamoto	Box 10 at Sendai Tobu Highway	3150	0.8
18		Nakahama Junior School	400	9.1

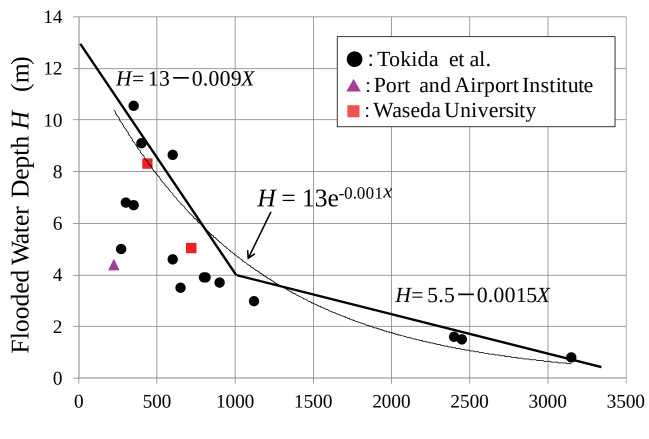


Fig. 10 Relation between flooded depth and distance from coastal line at Sendai Plane

The relations between the flooded depth and the distance from the coastal line can be drawn as in Fig. 10 where the relation is shown as

$$H=13\times EXP(-0.001\times X) \quad (4)$$

where H : flooded depth (m), and X : distance from the coastal line (m).

As shown in Fig.10, because the flooded depth at the sites close to and/or far from the coast line is afraid to be under estimated by Eq. (4), two lines identified by Eq. (5) are drawn shown as in Fig.10 to improve the relation between H and X and to estimate the large flooded depth from the engineering view point to estimate the flooded depth safely.

$0m \leqq X \leqq 1,000m$

$$H= 13 - 0.009\times X \quad (5.1)$$

$1,000m \leqq X \leqq 3,500m$

$$H=5.5 - 0.0015\times X \quad (5.2)$$

As for the above two lines identified by Eq. (5), the flooded depth at the coastal line is estimated to be 13m similar to that by Eq. (4). According to Eq. (5), the example of the flooded depth at X =1,000m and 2,000m can be estimated to be 4.0m and 2.5m, respectively.

CONCLUSIONS

The resistance characteristics of earth banks and dug pools which were found in the field survey conducted after the 2011 Great East Japan Earthquake are investigated based on the field survey and other references. The following lessons on the hardware countermeasures with the earth banks for the future recovery and reconstruction against the tsunami can be obtained and proposed.

1. The 13 earth banks at Sendai Plane, Asahi Coast and Oarai Coast which are considered to be effective to reduce the tsunami flood can be found through the field survey.
2. The earth banks which are covered with many kinds of materials such as soils, asphalt, lawn, grass and low or high tree are eroded only at the surface and difficult to be destroyed severely although the height of the earth bank is larger than about 4m. On the other hand, the earth banks lower than about 1.5m are possible to be flown away when the overflowed depth of the tsunami is larger than 3m to 4m.
3. When the tsunami flows over the earth banks, the dug pools are easy to be made at the back side of them. Because the tsunami flood can be reduced by the dug pool, the canal or the water area can be estimated to be effective against the tsunami.
4. The 10 dug pools are selected and investigated and the relations between the width, depth, section area and the height of the back slope are investigated and the simple equations to estimate their relations are proposed.
5. The ground surface at the background of the earth bank seems to be eroded when the ground surface isn’t solid and/or covered with plants and the sediment can be observed when the dug pool is a little large, for example, with the eroded depth of about 4m.
6. For the hardware countermeasures, the performance-based design concepts are necessary and effective to clarify the required performance of the objectives which should be protected.
7. The earth banks are necessary to perform the seismic stability firstly and then very effective to contain the run up of the tsunami combining with the existing sea wall or satisfy the required performance of the objectives against the overflow of the tsunami.
8. The flooded depth of the tsunami can be known to be reduced according to the distance from the coastal line based on the traces by the tsunami at the houses etc. through the field survey, and the relation between the flooded depth and the distance from the coastal line at the Sendai Plane is proposed with the simple equations.

The future research subjects are necessary to be investigated through the experiments and the numerical analysis applying the simulated tsunami in detail to propose the hardware countermeasures against the tsunami with use of the earth banks.

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