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STRENGTH OF THE LANDWARD SLOPES OF SEA DIKES IN VIET NAM

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Abstract: The landward slopes of sea dikes in the north of Viet Nam are steep and solely constructed by soil covered with grass due to the budget constraints and also the out-of-date design guideline. The resistance against erosion due to wave overtopping of several grass covered slopes were tested with the Wave Overtopping Simulator to show if a slope covered with grass could withstand a certain amount of overtopping. An analysis of all test results obtained in the Netherlands and Viet Nam is made as an attempt to establish a reference for empirically assessing the strength of grass covers. Slope classification should be based on its specifications whether it is a plain slope or a slope with existing damages and obstacles.

Keywords*: grass covered slope; landward slope; overtopping; sea dike; simulator.*

THE SEADIKES IN THE NORTH OF VIETNAM

In the north of Vietnam, the first sea dikes were built in Thai Binh and Nam Dinh province in the 12th and 13th century, during Ly dynasty (1010 – 1225) and Tran dynasty (1225 - 1400) to create extra land for royal family members (Tran, 1919). Later on, sea dikes have been continuously enlarged and lengthened by local communities. The present sea dike systems are clearly defined along the coastline of Quang Ninh, Hai Phong, Thai Binh, Nam Dinh and Ninh Binh province with a total length of more than 700 km including sea dikes and estuary dikes. In areas of some estuaries such as Van Uc, Thai Binh, Ba Lat and Ninh Co, where are subjected to accretion polders have been built. Later dike stretches extend toward the sea protecting thousands of hectares, for instance Binh Minh dike in Kim Son district, Ninh Binh province. In some other areas, where are subjected to erosion dikes have been built with two defensive lines (a primary line and a secondary line) and sub-crossing dikes in order to eliminate damages in case of flooding (Mai Van, 2010). This master plan is based on the coastline retreat strategy. The dike system therefore consists of two or three defensive lines. Sea dikes have been also constructed around some islands, such as Ha Nam dike in Quang Ninh and Cat Hai dike in Hai Phong. The fundamental functions of the sea dike systems are to protect agricultural land from sea flooding and prevent salt water intrusion.

A comprehensive report of the sea dike systems of Viet Nam was first made in 1991 (MWRI, 1991). Since 1996 to 2000, 308 km of sea dikes were upgraded, 76 km of revetments were constructed from Quang Ninh to Ninh Binh within the framework of the project PAM 5325 which was funded by World Food Program and Vietnamese government (MARD, 2004). During the period from 2006 to 2010, Vietnamese

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government invested more than 3000 billion Vietnam Dong to upgrade 272 km of sea dikes and plant 132 hectares of mangrove from Quang Ninh to Quang Nam (MARD, 2010).

Theoretically, the safety standard applied in the sea dike designs is mainly 1/20 per year (before 1990s, about 1/10 per year). Basically, sea dike cross-sections have a trapezoidal shape. The dike crests are narrow with an average width of 3 to 4 m. The crest levels seem rather low varying from MSL +3.5 to MSL +5.0, some parts with the crown wall reaching MSL + 5.5. The sea side slopes have $\tan\alpha$ of 1:2 to 1:3, some newly upgraded stretches with $\tan\alpha$ of 1:3 to 1:4. Dike body is mainly composed by an outer layer of light clay and a sandy core, some dike stretches are made from sandy clay only. The seaside slopes are protected by concrete blocks with thickness of 25 to 35 cm. Concrete cylinders filled with quarry stones are popularly utilized to strengthen the seaside toes. Figure 1 illustrates a general cross-section of sea dikes in the north of Viet Nam.

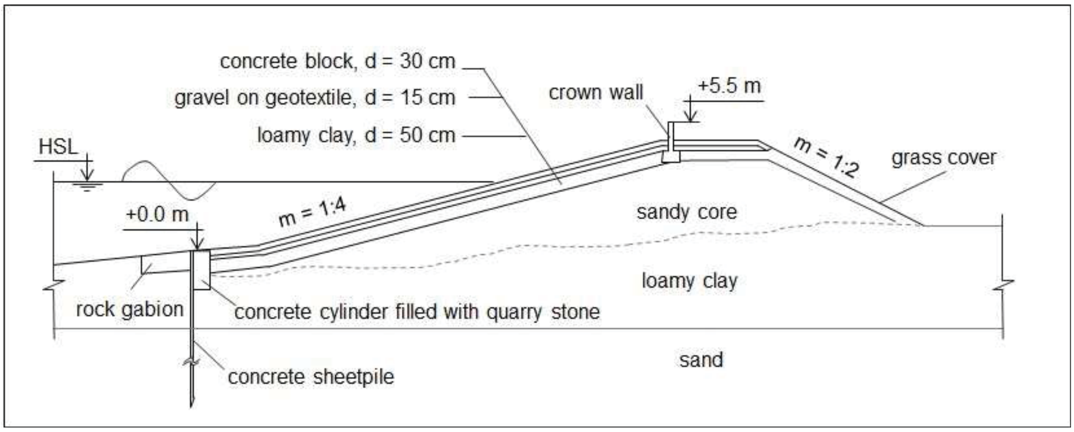

Fig. 1. Cross-section schematization of the sea dikes in the north of Viet Nam.

THE LANDWARD SLOPES

The sea dike systems have been built up and upgraded from year to year, however due to budget limitation and the present design guideline, priority is always given to the seaward slopes and recently the crest. Up to 1991, all landward slopes were covered with grass and about 98% of which were not gentler than 1:2, see Figure 2.

In 2007, several different measures of protection could be found on the landward slope such as grass within concrete frames or hard revetment constructed by concrete blocks (less than 3%). More than 90% of the landward slopes were not gentler than 1:2 and there was only 4% gentler than 1:3, see Figure 3. It was also reported that landward slopes were even shortened in order to enlarge the rice field areas of local famers. These data indicate that the landward slope have been remained both the steepness and material in the last decades. In the Netherlands, after 1953, sea dikes have been designed with gentle landward slopes in the order of 1:3 or smaller, as steep slopes might fail by a deep slip circle what were recorded in the past.

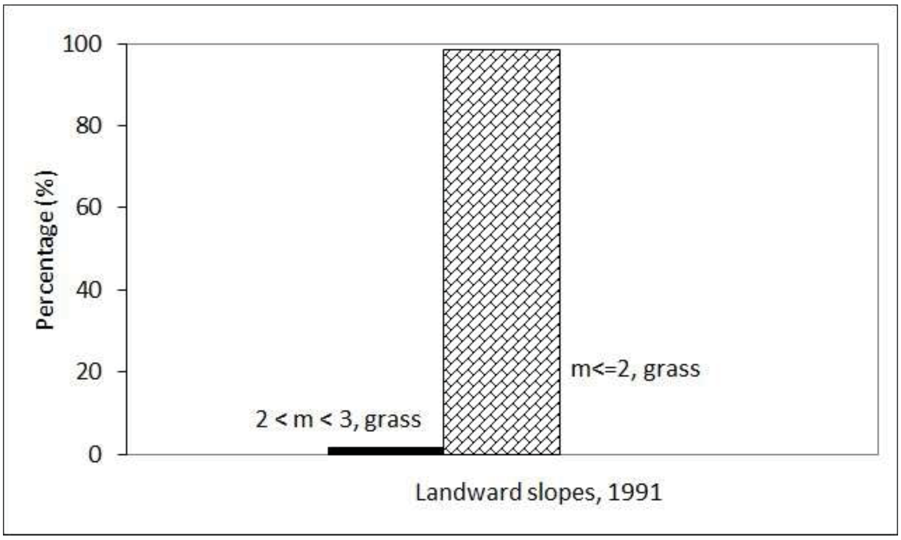

Fig. 2. Protection of the landward slope of the sea dikes in the north of Viet Nam, 1991.

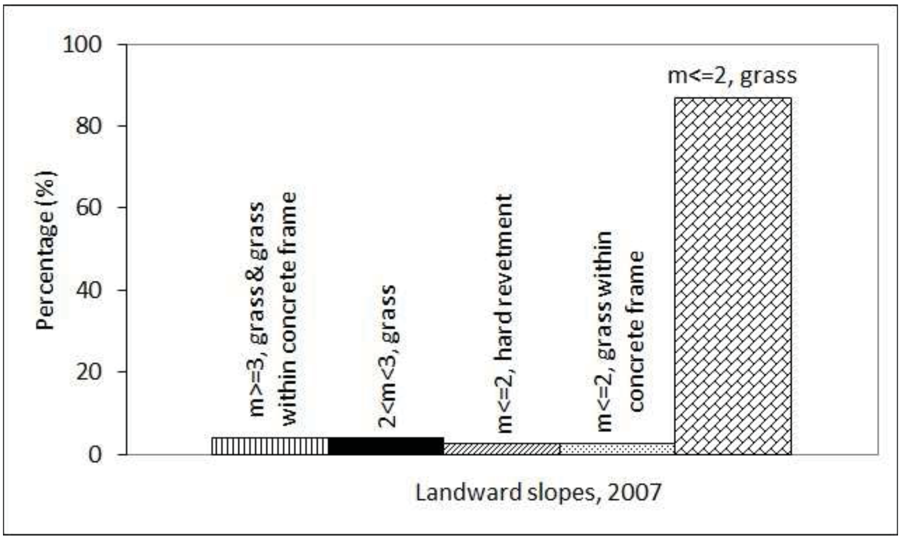

Fig. 3. Protection of the landward slope of the sea dikes in the north of Viet Nam, 2007.

FAILURE MECHANISMS OF THE LANDWARD SLOPES

Historical breaches of the sea dikes in Nam Dinh

In case of storm surges, Nam Dinh sea dikes usually fail due to two common mechanisms slide of the seaward slopes and slide of the landward slopes induced by wave attack and large wave overtopping. These failure mechanisms could lead to dike breaches, with widths in order of kilometers. A number of dike breaches in Nam Dinh caused by storms are given in Table 1 with water level, length of breach and dike crest level. The entire stretch of about 30 km in Hai Hau district was broken in a storm in 1890, there was no record of the wind speed, water level and cross-section specification at that time. In 1971, 1987 and 2005, dikes collapsed at many points along the coast of Hai Hau district resulting severe inundation of the hinterland during and after the storms, for instance 545 hectares in 1971, 4550 hectares in 2005 (PDDND, 2007).

Table 1. Historical breaches of the sea dikes in Nam Dinh.

Time	Storm	Water level	Breaching length	Community, District	Crest level
1890			entire stretch	Hai Hau	
11/08/1971			72 1770	Hai Hoa, Hai Hau Hai Trieu, Hai Hau	
22/08/1987	Cary (Ising)	1.5	2 x 200 100	Hai Hoa, Hai Hau Thinh Long, Hai Hau	
27/09/2005	Damrey	2.65	100 to 2000 1000, 300, 500 700 40 – 300 40 to 174	Giao Hai + Giao Long, Giao Thuy Bach Long, Giao Thuy Hai Chinh, Hai Hau Hai Hoa, Hai Hau Thinh Long, Hai Hau	4.5 ~ 5.0 4.8 5.0 4.5 ~ 5.0 4.5 ~ 5.0

Estimation of wave overtopping discharge during Damrey storm, 2005

Damrey storm originated on 21st September, 2007 in the Northwest Pacific and hit Nam Dinh coastline at 07:45 am on 27th September. The wind force reached Beaufort scale 12 (133 km/h). The precipitation on the attacking day was estimated 150 mm/ day in the whole Nam Dinh province. The typhoon caused a high storm surge which coincided with high tide level resulting extremely large wave overtopping at the sea dikes. In order to estimate the wave overtopping discharge at the Nam Dinh sea dikes during the Damrey storm a calculation is made. Wave boundary condition and specifications of sea dike cross-section are as follows:

- Dike crests were varying from MSL +4.5 to MSL +5.0 m;
- Water level recorded at 12:00 pm on 27th September was +2.65 m, which was the highest water level since 1960 (Phu Le station in Hai Hau);
- Foreland level was about MSL -1 to MSL -3, water depth was therefore about 3.65 to 5.65 m;
- As a result wave height was 1.8 to 3 m (roughly estimated equal to ½ of the water depth);
- Wave period was 5.9 to 7.6 s with an assumed wave steepness of 0.04;
- The seaward slopes had $\tan\alpha$ of about 1:3 to 1:5.

The unit discharge of wave overtopping is calculated according to EurOtop 2007 as:

$$\frac{q}{\sqrt{gH_{m0}^3}} = \frac{0.067}{\sqrt{\tan\alpha}} \gamma_b \, \xi_{m-1,0} \exp\left(-4.3 \frac{R_c}{H_{m0}} \frac{1}{\xi_{m-1,0}\, \gamma_b \, \gamma_f \, \gamma_\beta \, \gamma_v} \right) \tag{1}$$

For simplicity, all correction factors for a berm γ_b, for the permeability and roughness of or on the slope γ_f, for oblique wave attack γ_β and for a vertical wall γ_v are given the value of 1. All relevant parameters are given in Table 2, calculation is made for different combination of wave conditions and dike specifications. Overtopping discharge is found to significantly vary between 0.004 and up to 0.636 m^3/s per m. The estimation illustrates that an excessive amount of wave overtopping could be generated during the storm at the Nam Dinh sea dikes.

Table 2. Wave overtopping calculation during Damray storm for sea dikes in Nam Dinh.

H_{m0} [m]	T_p [s]	$\tan\alpha$	R_c [m]	q [m^3/s per m]
1.8 ~ 3.0	5.9 ~ 7.6	1 : (3 ~ 5)	1.85 ~ 2.35	0.004 ~ 0.636

Failure mechanisms of the landward slope due to wave overtopping

Wave overtopping may cause damage of the crest and the landward slope of a sea dike. In principle, two different mechanisms are distinguished. Overtopping flow can damage the surface of the crest and the landward slope, if initial damage or erosion occurs, it can extend to the underneath material layer that may lead to dike breach. The second mechanism mainly happens on steep slope (especially 1:1.5 and 1:2.0) due to water infiltration and sliding. These slide failures may directly cause dike collapse. However, they are not likely due to wave overtopping as such, but because of large infiltration quantities of water. This process may be aggravated by heavy rainfall. It is possible that these failures take place on slope which is gentler than 1:3. Figure 4 schematically gives impression of the two different failure mechanisms of the landward slope. Erosion is induced by fast wave overtopping (left panel) while sliding is caused by an increase in water pressure, water infiltration and decrease in the shear resistance in the slip circle (right panel).

In Nam Dinh, the 1:2 landward slopes were attacked by excessive amount of wave overtopping and considerable rainfall during the Damrey storm. Consequently, erosion and sliding of the landward slope took place resulting severe dike breaches. These illustrate the fact that the quality of the landward slopes (actually the entire dike structure) could be only examined during real storms.

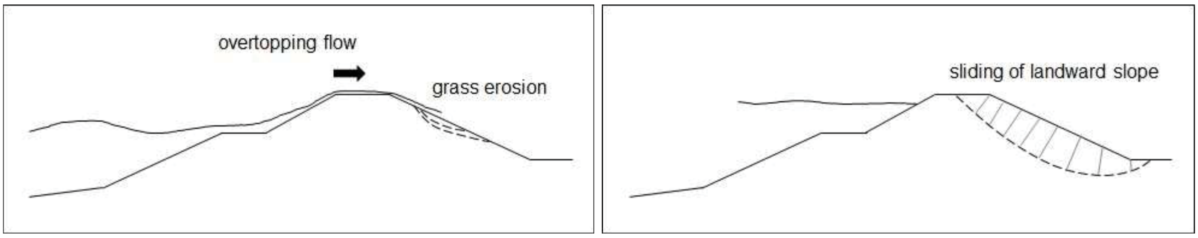

Fig. 4. Failure mechanisms of the landward slope. Left: erosion by wave overtopping. Right: slip failure.

TESTS WITH THE WAVE OVERTOPPING SIMULATOR

The wave overtopping simulator is a device which is able to simulate (generate) overtopping waves on the crest and landward slope of a dike. The principle is that it is not necessary to simulate the entire overtopping wave but only the water tongue on dike crest and then the landward slope. When the flow velocity and flow depth are generated by the simulator similarly to the real correspondent characteristics on the dike crest, the flow will respond identically on the landward slope. The simulator was first developed in the Netherlands (Van der Meer et al., 2006) and later on in 2008, the second version was made in Viet Nam (Le et al., 2010). The simulator is aimed at simulating the slope erosion induced by wave overtopping (left panel of Figure 4) and it has been used to test various kinds of dike slope in the Netherlands, Belgium and Viet Nam.

Tests in the Netherlands

Since 2007, destructive wave overtopping tests have been carried out at some 19 sections in the Netherlands including various slope specifications. In Delfzijl, Groningen, the dike is constructed by clay only, three different slope specifications were tested: a normal grass cover, a section which was reinforced with geotextile and a bare clay slope where the grass sod was removed. At the Boonweg dike in Friesland, 4 grass slopes were managed and maintained in different manners for over 15 years. The resistance against erosion induced by wave overtopping of these sections were examined with the same maximum discharge of up to 75 l/s per m. At a single point in St Philipsland, Zeeland, a steep slope of 1:2 was covered with a bad grass cover. In Kattendijke, Zeeland, the dike consists of a sand core and an outer clay layer of 60 cm thick. Two grass covered slopes which were naturally or manually damaged and two other sections which were reinforced with Elastocoast or open asphalt concrete. The cross-section of the Afsluitdijk is constructed by two layers, 40 cm of clay on 1 m boulder clay. Influence of obstacle such as a staircase on the slope and transition between grass and a horizontal parking lot pitched with stone bricks were investigated at three separate sections. The Vechtdijk is a sand dike and covered with a 15 cm layer of soil where the grass root system is found. At the first section, there was a maintenance road crossing the slope while at the second section, a tree with a trunk of 0.8 m was on the berm. At the third and the forth section, the irregular slopes were covered with grass and a lot of mole activities were visually found.

Overtopping rates used in all tests were gradually increased from small to large, for instance 0.1; 1.0; 10; 30; 50; 75 l/s per m for slopes covered with grass and 125 l/s per m for specially reinforced slopes. The same hydraulic conditions with a significant wave height of 2 m and a peak period of 6 s (wave steepness of 4%) were applied for all tests with the exception of two sections at Vechtdijk, a wave height of 1 m and 3 m, respectively. The wave conditions were considered representative of the Dutch coast and river dikes. Each test of a overtopping discharge lasted for a duration of 6 hours.

Tests in Viet Nam

Destructive tests have been performed at three dike stretches in Hai Phong, Nam Dinh and Thai Binh province in the north of Viet Nam in 2009 and 2010. In Hai Phong, the Do Son sea dike was reinforced with concrete on three faces: seaward slope, dike crest, upper part of the landward slope and the landward berm. The 5-m-long lower part of the landward slope was protected with Vetiver grass of 2 years old. The grass covered part was a 1:2 slope and tested with the simulator. In Nam Dinh, the Thinh Long sea dike was constructed by a sand core and an outer layer of clay, the 1:3-inclination slope was covered with Bermuda grass and sometimes in combination of Casuarina trees. Ray grass was found on the horizontal dike toe. Tests were conducted at three slope sections within a stretch of about 50 m long. Sections were selected to reflect different slope characteristics and quality, for instance: regular slope covered with good grass, slope with a big Casuarina tree in the middle and slope with eroded holes. Another short stretch of estuarial dike in Thai Thuy, Thai Binh province was chosen to be tested with the simulator. The dike body was constructed by good clay, the slope was reinforced with concrete frames from the crest to the toe. A mixture of Vetiver grass and Bermuda grass were planted together within the concrete beams resulting a approximately 1:3 slope. The horizontal berm was regularly covered with a dense sward of Ray grass. Three sections were tested with variety of concrete beam configuration and grass quality.

The erosional resistance of different grass slopes were put under attack of increasing wave overtopping discharge, from small values as 10 and 20 l/s per m up to large ones of 100 and 120 l/s per m. Each overtopping rate was representative of a storm which was simulated by the simulator within 4 hours. The same wave condition was applied in all tests, the significant wave height was 1.5 m and the peak period was 6.0 s. Similar to the Dutch tests, a seaward slope of 1:4 was used in overtopping calculation for the Vietnamese tests.

Main test results

The cross-sections, the grass species, the soil characteristics of sea dikes in the north of Viet Nam are definitely different from those of sea dikes in the Netherlands. The hydraulic conditions applied for tests in Viet Nam and the Netherlands were also not comparable. However, the grass covered slopes were likely damaged at identically vulnerable points. These could be either the transitions between different materials (grass and concrete for instance) or the transitions of the geometry (e.g. between the steep part and the horizontal berm). Erosions were often found to be initiated at existing holes and around obstacles on the slopes.

At the first section in Thinh Long, erosion happened under discharge of 40 l/s per m at the transition between the slope and the horizontal toe where the cover of Bermuda grass and Ray grass were poorer than on the higher part of the slope, Figure 5. At this area soil was more directly exposed to overtopping flow which was enhanced due to the rough guidance in the flow course. At the first section at Afsluitdijk, initial damage occurred at a small irregularity at the dike toe during the discharge of 10 l/s per m. Maximum overtopping rate applied at these two sections were 70 and 75 l/s per m, respectively, the dike however did not fail at the end of the tests.

Fig. 5. Damages at transition between the steep part and the horizontal toe, left: Thinh Long dike and right: Afsluitdijk.

On the Thai Thuy slope, the grass slope is divided into separate cells by a system of concrete beams. Around the concrete beams, the grass was found to be poorer than on areas further away from the beams. Transitions between the concrete beams and the grass covered soil could also introduce flow concentration. Damages took place around concrete beams at three sections tested in Thai Thuy, Thai Binh. A similar instance of using different materials on the same dike slope was demonstrated at the Vechtdijk, where concrete blocks (40 x 40 x 12 cm) were laid on the riverside berm. During the discharge of 50 l/s per m, blocks were swept away from the original positions (Steendam et al., 2010).

Fig. 6. Damage at a tree on the grass slope, Thinh Long dike, Nam Dinh province.

Sometimes due to different reasons, objects such as tree, fence, and even staircase are located on the dike slopes. At the second section of the Thinh Long dike and also the second section of the Vechtdijk, a tree with trunk of 7 cm and 80 cm wide alternatively were present. The areas around these trees were quickly damaged at small discharge of 10 and 5 l/s per m, Figure 6. The Casuarina tree at the former section collapsed at overtopping rate of 20 l/s per me while a discharge of 50 l/s per m caused large erosion around the 80-cm-trunk tree on the Vechtdijk. It was observed that flow tended to concentrate along both sides of the staircase on the third Afsluitdijk section resulting early erosion under a discharge of 10 l/s per m. The staircase was damaged considerably when higher rates of overtopping were applied. Test was finished at 75 l/s per m, a hole depth of 1 m was measured, the dike core however was not reached yet.

Fig. 7. Damages initiated at existing holes, Thai Thuy dike, Thai Binh province.

It is hardly possible to prevent a grass cover from being eroded or damaged, causing factors can be activities of animals and activities of dike maintenance and dike inspection. At test sections of Boonweg, Kattendijk, Afsluitdijk, Vechtdijk, erosions were first recognized at the existing damaged points which were induced by mice and moles or by tractor tires. Some small size holes were the starting points of damage development at sections tested in both Thinh Long and Thai Thuy, Figure 7. Later on, holes seemed likely to extend larger from these initial weak points resulting severe damages of the dike slopes.

The grass cover of 20 cm thick was removed at the third section in Delfzijl to create a slope of bare clay. Damage was initiated at the low discharge of 1 l/s per m and the bare slope was seriously eroded under attack of 10 l/s per m. This early failure bears out the role of the grass cover against erosion due to wave overtopping. Dike slopes protected with special materials like elastocoast and open asphalt concrete were also tested with the simulator at two sections of Kattendijke, Zeeland. A maximum discharge of 125 l/s per m did not cause any damage yet to these reinforced slopes (van der Meer et al., 2008).

STRENGTH OF THE GRASS COVERED SLOPES

On the basis of all the test results obtained in the Netherlands and Vietnam a reference which is used in empirically assessing the resistance against wave overtopping of grass covered slopes can be established. Test result analysis is based on two ways classifying the tested sections, grass quality and slope specifications. The former consists of three categories dependent on grass quality (e.g. according to VTV 2006, the Dutch guidelines for the safety assessment of primary dikes or visual evaluation): Good, Medium and Bad. The later includes four classes: Plain slope which are regularly covered with grass; Damages which are manually or naturally eroded before or during testing; Objects which are slope with obstacles such as staircase or trees; and Special are slope protected with open asphalt concrete and elastocoast. The Vetiver grass slope in Do Son, grass slope with concrete frames in Thai Thuy are ranked amongst Special. The maximum value of overtopping discharge q released at every section is made dimensionless by dividing to q_{clay} = 10 l/s per m which was the rate causing considerable damage of the bare clay slope in Delfzijl.

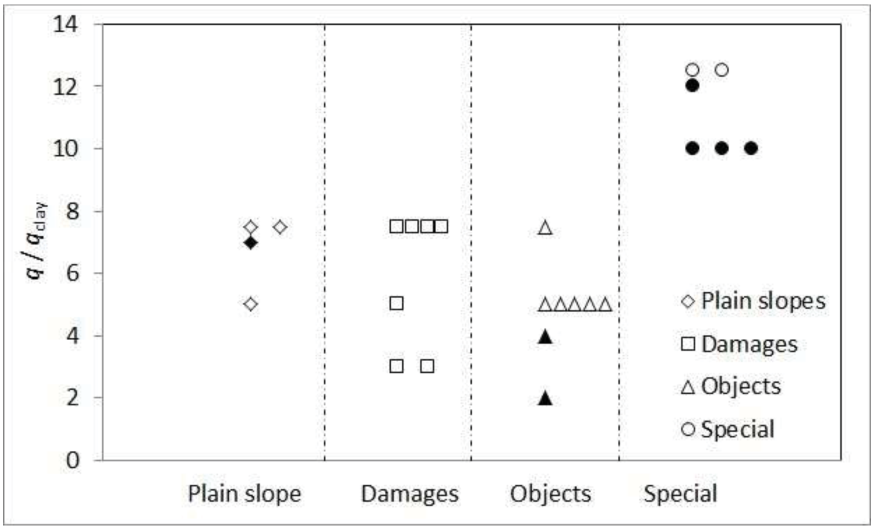

Fig. 5. Strength of various dike slopes in comparison with a bare clay slope, classification based on slope specification.

26 points of the ratio q / q_{clay} are plotted on the Figure 5, the horizontal axis indicates slope specification and the vertical axis shows the relative strength of the grass slopes. The Dutch data points are depicted by hollow dots while solid ones present the Vietnamese results. The resistance against erosion induced by overtopping of grass covers increase when damages or objects are found on the slope, for instance a discharge of 20 l/s per m caused the collapse of a Casuarina tree on the second section of the Thinh Long dike. Slopes with existing damages and obstacles also show a wide range of resistance with q / q_{clay} varying from 2 to 7.5 while q / q_{clay} of plain slopes fluctuate between 5 and 7.5. The difference between the Plain slope and the Damages is in order of 1 which is comparable to the distinction between the Damages and the Objects, see also Table 3.

Within categories of Plain slope and Objects, the Vietnamese grass covers seems likely less resistant against erosion than the Dutch ones. Sorted into Special, the mixture of Vetiver grass and Bermuda grass within concrete frames in Thai Thuy and the short slope protected with Vetiver grass in Do Son show a considerable strength with the value of q / q_{clay} not smaller than 10.

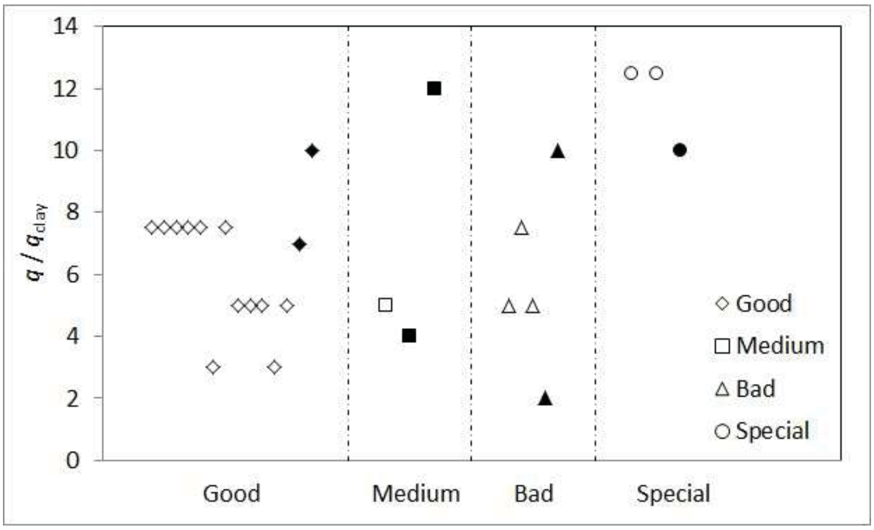

Fig. 6. Strength of various dike slopes in comparison with a bare clay slope, classification based on grass quality.

The grass quality of 23 sections is classified as Good, Medium and Bad. Figure 6 shows the dimensionless maximum overtopping discharges of these sections and also three special sections including an open asphalt concrete, an elastocoast in Kattendijke and a Vetiver grass cover in Do Son. Bad or Medium quality do not show very clear difference in strength compared to Good quality. The average strength of the Medium category is even higher than that of the Good category, 7.00 compared to 6.29, see Table 3. By comparing Figure 5 and 6, it can be seen that data points generally scatter more widely in Figure 6 than in Figure 5. Besides, the squared variance σ^2 of q / q_{clay} are calculated for two ways of classification and given in Table 3. Classification based on grass quality gives larger values of σ^2 than those derived from slope specification: 3.67, 12.67, 7.24 and 1.39 compared to 1.06, 3.98, 2.00 and 1.39. As we have seen, slope classification based on grass quality is likely not reliable and appropriate for practical application.

Table 3. Two ways of classification: Slope specification and Grass quality.

Slope specification	**Plain**	**Damages**	**Objects**	**Special**
μ of $\left(q / q_{clay}\right)$	6.75	5.86	4.81	11.17
σ^2 of $\left(q / q_{clay}\right)$	1.06	3.98	2.00	1.39
Grass quality	**Good**	**Medium**	**Bad**	**Special**
μ of $\left(q / q_{clay}\right)$	6.29	7.00	5.90	11.67
σ^2 of $\left(q / q_{clay}\right)$	3.67	12.67	7.24	1.39

CONCLUSIONS AND RECOMMENDATIONS

Simple calculation was made based on the data recorded during the Damrey storm in 2005 resulting wave overtopping discharge at the Nam Dinh sea dikes which could reach more than 600 l/s per m. Excessive amount of overtopping together heavy rain attacked the low dikes, consequently a number of dike breaches which were initiated from the steep and poorly protected landward slopes did occur during and after the storm. It is obviously clear that the dike crest levels must be significantly heightened to reduce the amount of overtopping during storm surges.

Statistic data shows that more than 90% of the landward slopes in the north of Viet Nam is steeper than 1:3 and mainly covered with grass. To reduce the likelihood of a slip circle it is recommended to apply a steepness of 1:3 or gentler to the landward slopes of new dikes or dikes which are upgraded.

The resistance against erosion induced by wave overtopping of several grass covered slopes along the Vietnamese northern coast was tested with the means of the wave overtopping simulator. Observations revealed that grass covers were able to withstand a certain amount of overtopped water; however the number of simulator tests is still very few. If the test is growing it may serve to support the findings of the resistance against overtopping of grass covered slopes. The sea dike design guidelines are being upgraded, if higher rate of wave overtopping is accepted, dike crest is therefore lower. As a developing country, Viet Nam is always facing constraint of budget; high dikes with almost no overtopping are hardly affordable.

The moderate number of destructive tests with the simulator in the Netherlands and in Viet Nam suggests that empirically estimating the strength of a grass cover should be based on the slope specification whether it is a plain slope or a slope with existing damages or/ and obstacles. It should be stressed that each destructive test is unique and unrepeatable as it was performed at a single section (4 m wide) of a dike stretch. More tests are highly encouraged to confirm this classification method.

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