Bank Protecting Functions of Common Reed and Ditch Reed

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ABSTRACT

Through field observation and hydraulic experiments, we have revealed the mechanism by which reeds growing along river banks reduce bank erosion by mitigating the erosive force acting on natural banks of. for instance. flooding and waves produced by boats. We also theoretically assessed the critical velocity at which the bank-protecting functions of a vegetation revetment can be brought out; the engineering validity of this critical velocity was proved in field research.

KEY WORDS: natural vegetation / bank protection / vegetation revetment /flood current / boat waves /

INTRODUCTION

Channel vegetation not only represents a component of flow resistance during flooding and affects the water level of a river, but it also plays an important role in terms of the scenic beauty, ecosystem and other environmental aspects of the river.

Because of the necessity of determining the role played by channel vegetation in resistance during flooding and river environment, in recent years much hydraulic and environmental research on channel vegetation has begun to be performed(Fujuoka and Fujita, 1990). Some research is being carried out from the perspective of the ecology of channel vegetation(Okuda, 1976) and we have come to know the types of vegetation that grow in a channel and the types of locations in the channel where they grow.

In this research, which focuses on the soil-maintaining effects of vegetation -- particularly common reed and ditch reed -- growing near river banks, investigations have been carried out with the objective of determining the viability of using common reed and ditch reed in bank protection works. Up until now there has been almost no research from the standpoint of actively using, in bank protection, living vegetation that can be obtained in actual rivers(Fukuoka, 1993). However, recent close-to-nature river improvement work involves using natural vegetation in river improvement. and while this trend is a positive one, technical evidence of its effectiveness is still necessary. The objective in this research is the collecting of just such evidence. Then, we investigated over time the relationship between common reed growing along river banks and the amount of bank erosion in order to confirm the effectiveness of common reed in reducing bank erosion. First, we after conductied field investigation on the growth environment of common reed and on bank protection conditions. In addition, field experiments on tensile strength of bank covered with reed and analysis based on these results was conducted to determine the velocity up to which banks with common reed can withstand erosion.

THE EFFECTIVENESS OF COMMON REED IN REDUCING BANK EROSION

In order to gain an understanding of the overall effectiveness of common reed in reducing bank erosion. we investigated the relationship between the amount of bank erosion (as determined with cross-sectional surveying) and

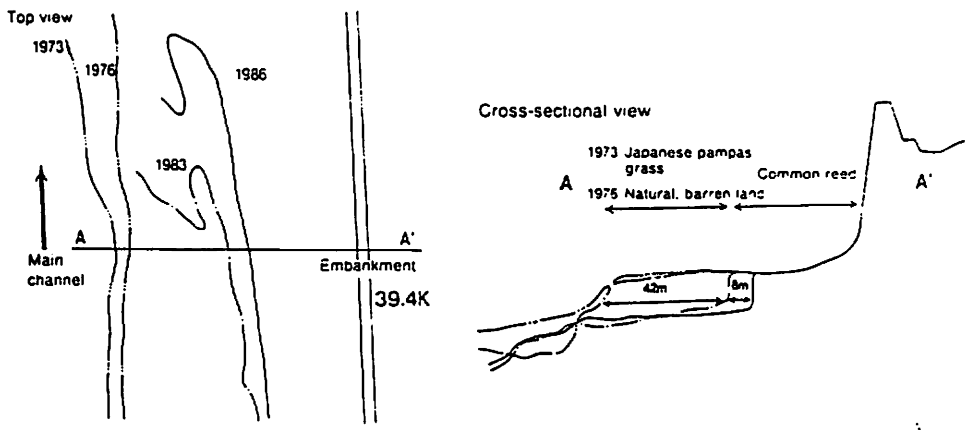
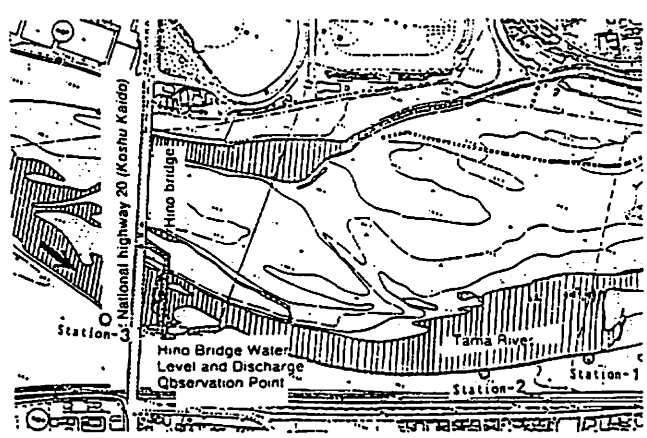


Figure 1: Change over time in bank vegetation and flood channel vegetation



Figiure 2: Field survey area

changes over time in flood channel vegetation in the middle reaches of the Tama river (right bank at the 39-40 km point; see Figure 1).

Floods in which water entered the flood channel occurred in 1974, 1979 and 1982 (August and September). Although the vegetation in the flood channel was colonies of Japanese pampas grass (Miscanthus sinensis) in 1973, the effects of large-scale flooding in 1974 had transformed the flood channel into natural barren land by 1976. This is believed to be because suspended sediment accumulated in the colonies of Japanese pampas grass, eventually burying and killing it. Four floods occurred thereafter in the seven-year period between 1976 and 1983 causing the banks to erode and recede, but we found that bank erosion had nearly stopped around the boundary of the common reed colonies in the flood channel. Examination of the bank in 1986 showed that erosion has progressed insignificantly since 1983, a fact that demonstrates the effectiveness of common reed in reducing bank erosion in the flood channel.

THE STATE OF BANK VEGETATION IN ACTUAL RIVERS

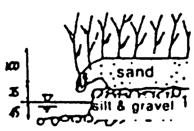
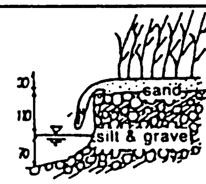
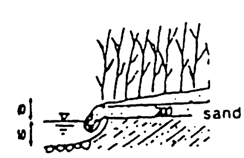
Common Reed And Their Growth Environment

We performed a field survey on how common reed protects river banks in stations 1, 2 and 3 in the research area (see Figure 2). Located here is the Hino Bridge Water Level and Discharge Observation Point. Stations 1 and 2 are where the current strikes the bank during flooding; at station 3, although the current is concentrated at normal water level, during flooding the main current shifts to the center of the channel. Compared to other locations, the erosive force of flood currents is lower here.

Common reed is a herbaceous plant often found in flood channels and shoal sandbar in the middle and downstream reaches of rivers with thick deposits of sediment. Common reed, in fact, is known for sprouting anew after being covered with sediment during flooding, and can grow to heights of three to four meters. It also grows in quite dense colonies with a distance between stems of roughly 10 centimeters, and although above ground a cluster may appear to be comprised of individual reeds, they are interconnected through subterranean stems. Around the research area the bed slope is 1/280, distance between embankments 300 meters, and flood channel width roughly 100 meters. Since 1960 the bed height has dropped roughly three meters, and so the banks were formerly river bed, and the banks of the main channel are mostly gravel containing silt, atop which fine sand transported during flooding has accumulated to a maximum thickness of 70 centimeters. Throughout this layer of fine sand common reed spreads its roots and grows in colonies.

Table 1 shows the characteristics of the three locations in the research area and the common reed in these locations. Research here shows that the distribution of vegetation colonies in the channel is greatly affected by the frequency of inundation there; that the common reed grows in places where inundation never exceeds medium-scale flooding; and that since the subterranean stems grow only in the sand layer, reed growth is greatly affected by the thickness of this sand layer, more so than by such factors as the diameter of sand particles or the particle-void ratio.

Tabel 1: Characteristics of common reed and their location

	Station 1	Station 2	Staion 3
Height (m)	3.0	3.0	2.0-3.0
Density (reeds/m^2)	40-60	120-140	170-250
Stem Diameter (cm)	1.0	0.5-0.8	0.7-1.0
Subterranean stem depth (cm)	15-50	20	10-30
subterranean stem diamter (cm)	1.5-2.0	0.7	0.7-1.0
Bank conditions			
Partial diameter (mm)	Fine Sand (50cm deep) d_{10} 0.05 d_{30} 0.11 d_{50} 0.18	Fine sand (10cm deep) (30cm deep) d_{10} 0.03 0.04 d_{30} 0.09 0.12 d_{50} 0.19 0.30	Fine sand (50cm deep) d_{10} 0.03 d_{30} 0.08 d_{50} 0.15
Volume ratio (%)	Soil particles 35-45 Water 20-30 Air 30-40	Soil particles 40-50 Water 30-40 Air 20-30	Soil particles 40-50 Water 15-35 Air 25-40
Void ratio	1.2-2.0	1.0-1.7	1.0-1.2
Coeffient of permeability (cm/s)	$5.5x10^{-3}$	(10cm depp) (30cm deep) $1.1x10^{-3}$ $1.3x10^{-3}$	$0.84x10^{-3}$

<u>The Mechanism Of Erosion In Banks Where Common Reed, Etc., Grow</u>

The state of reeds during flooding is shown in Figure 3(a) as can be seen in Photo 1 and Figure 3(b), after flooding the bank layer containing the reeds has an overhanging shape. This shape results from the soil-maintaining properties of the subterranean stems, which gives the bank's upper layers a relatively high erosive resistance compared to the lower layers. This shape is actually an important one as a technique for countering flooding. And although there are

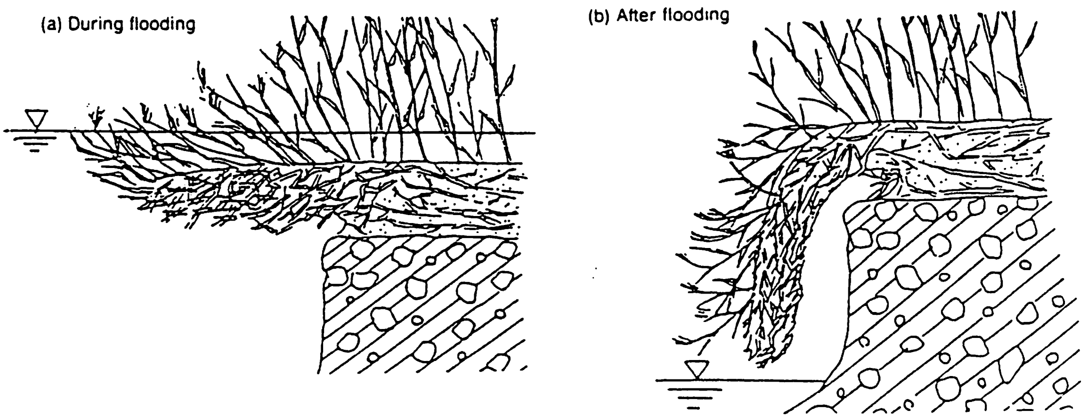


Figure 3: Shape of a bank with common reed

Phot 1: A bank with common reed after flooding

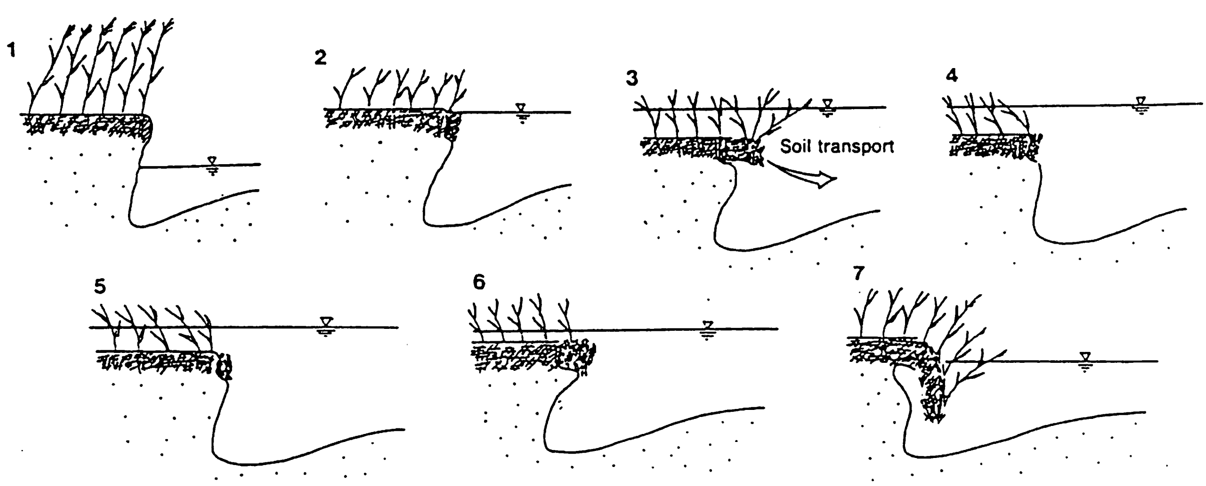


Figure 4: The process of erosion in banks with common reed

differences in lengths of overhang, the upper layers of banks with vegetation other than common reed generally take on this overhanging shape through erosion.

We will now describe the process by which a bank with reeds takes on this overhanging shape.

Figure 4 shows the process of bank erosion during flooding as changes over time. As the water level rises, the river bed undergoes scouring and the lower layers of the bank are eroded. The upper layers are firmly maintained by the subterranean stems and therefore relatively resistant to erosion. As the sand around the subterranean stems (which comprise a continuous mat-shaped mass in the upper layer) is washed away, the erosive force reaches the subterranean stem cluster. At this point, it is believed, the lower layers of the bank have been considerably eroded. These subterranean stems grow out from the nodes, and as force is concentrated on these nodes, some of them snap. As erosion in the bank's lower layers progresses even further, stability in the upper layer, which is comprised of soil and the reed cluster, is lost. As a result, the subterranean stems are overcome by the force and undergo tensile damage, and bank erosion continues. Repetition of this process results in bank erosion progressing further. Buoyancy acting on reeds causes them to exist in a floating state when the water level is high, but they and the soil hang down when the water level during flooding drops below the height of the flood channel. While the velocity at this water level is quite fast, the floating upper layer that covers the bank not only results in increased roughness around the bank and hence reduces velocity, but also serves to reduce the amount of water that directly strikes the bank.

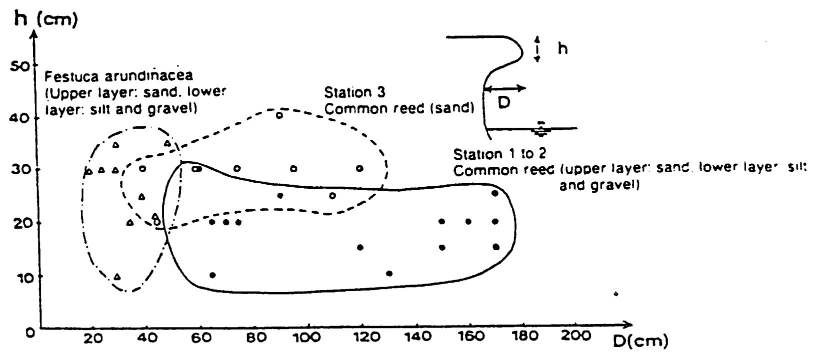


Figure 5 : Diagram of erosive shapes

A velocity of roughly 1.5 m/s was measured, when the water level dropped to the height of the flood channel.

After investigating the bank's overhanging shape, an erosive shape diagram (see Figure 5) was created with overhang length D as the horizontal axis and overhang thickness h as the vertical axis. The overhang length is the length that the sagging overhang would have were it straightened out.

This illustration hence shows that common reed can maintain the upper layers of the bank even if the lower layers are considerably eroded (although this depends on the conditions of the location and the thickness of the upper layer in which the roots have spread). The reason that longer overhangs were maintained at stations 1 and 2 than at station 3 is because of the greater depth of the main channel here, which allowed the upper layer to hang down with a longer overhang shape.

THE STRENGTH OF COMMON REED AS A BANK PROTECTION WORK

The longer the overhang is, the greater is the effectiveness in preventing bank erosion. But in order to plant common reed as a bank protection work, it is necessary to determine the velocity up to which the overhanging shape can be maintained; learning this would make it possible to determine the locations where common reed could be planted as a bank protection work. We therefore decided to measure the tensile strength of underground stems of common reed in an actual river, then use these measurements to determine the relationship between velocity and critical overhang length.

The Tensile Strength Of The Subterranean Stems Of Common Reed

An overhanging soil mass is held in place by the subterranean stems of common reed. In field research after flooding, overhanging soil masses that had collapsed from their own weight were observed in the water. We therefore roughly estimated the force that had to be assigned per subterranean stem to support these collapsed soil masses. To do this, we first calculated the weight of the collapsed soil mass from its volume and the specific gravity of the soil mass containing subterranean reed stems, then divided by the number of subterranean stems left in the soil mass in order to determine the tensile strength per subterranean stem. The value obtained for strength per subterranean reed stem was an average of 23.0 Kgf. Then, in order to accurately measure this tensile strength, we built the in-situ tester shown in Photo 2.

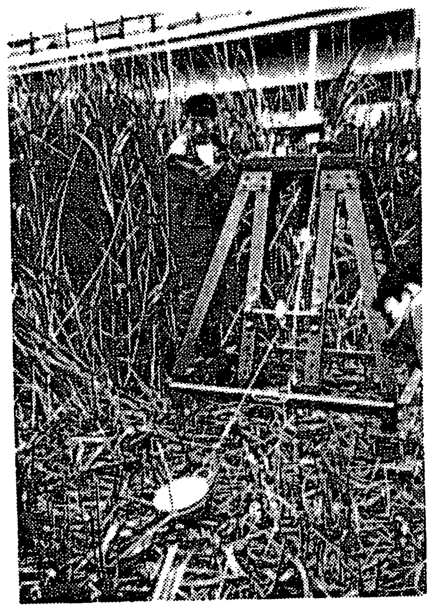


Photo 2: In situ tester

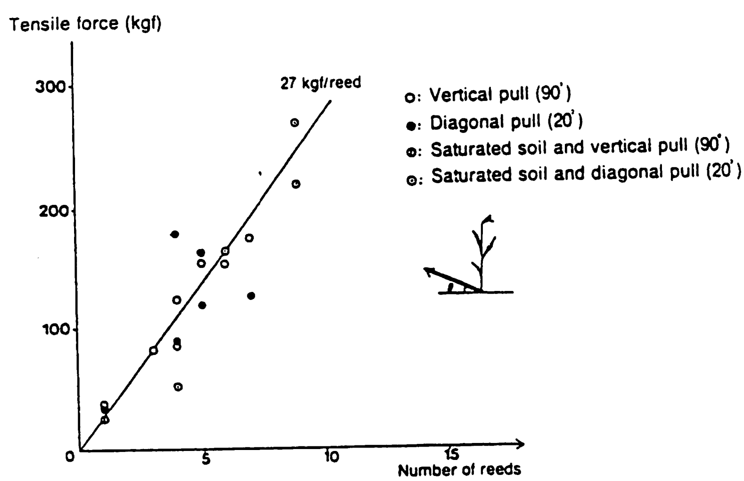


Figure 6: Results of measurement of common reed subterranean stem tensile strength

This tester was comprised of a scale attached to an arm suspended from the truss-structure base. A reed stem protruding from the surface was clamped at its base between two testing plates, then pulled by turning the handle to apply tension. The angle of pull can be changed by raising or lowering the position of the pulley on the base. This experiment was performed four times in different locations: with a vertical angle of pull; a diagonal (roughly 20 degrees from horizontal) angle of pull; with unsaturated soil; and with saturated soil. Reeds were always pull out by the node of the subterranean stem. The measured results for tensile strength are shown in Figure 6.

Figure 6 shows that the tensile strength of common reed is approximately 27 kgf per reed, a value that remains roughly constant regardless of the conditions. The reason for this is that the flexibility of the subterranean stem enables the reed to change its orientation in accordance with the direction of external force.

Erosive Critical Velocity For Banks With Common Reed

Now let us estimate the erosive critical velocity (the velocity at which an overhanging bank breaks) from the balance between the external force produced by the current and the tensile strength of the subterranean reed stems. Figure 7 shows our model for overhanging banks.

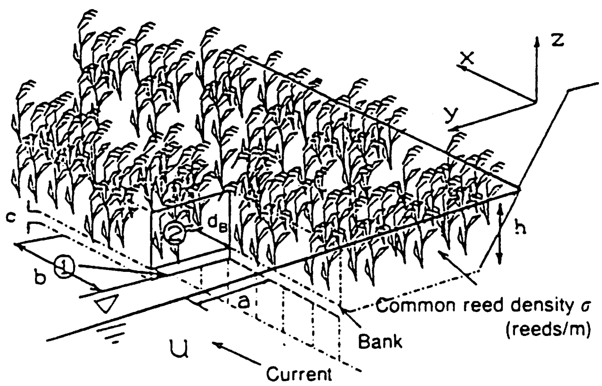


Figure 7: Model of overhanging bank

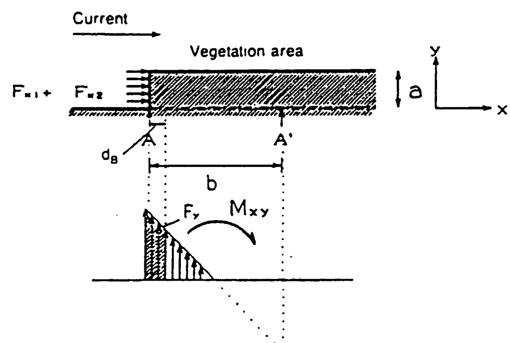


Figure 8: Distribution of bending stress in x-y section

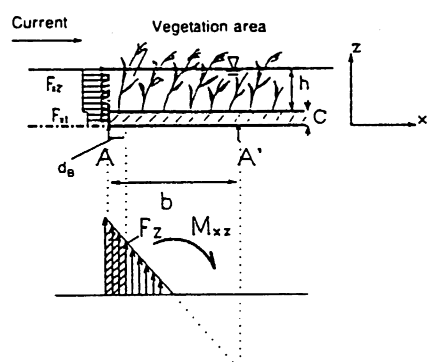


Figure 9: Bending stress in x-z section

Equations (1) and (2) below are used to represent the external forces produced by the current, i.e., 1) F_{x1}, the fluid force acting on the front surface of the overhang, and 2) F_{x2}, the fluid force acting on the reeds in the overhang.

(1) $$F_{x1} = C_D \cdot \rho \cdot a \cdot c \cdot u^2 / 2$$

(2) $$F_{x2}(x) = C_D \cdot \rho \cdot \phi \cdot \sigma \cdot a \cdot h \cdot \int_0^x u'^2 / 2 dx'$$

where C_D is the drag coefficient (1); ρ, water density; ϕ, reed stem diameter; σ, reed density; a, overhang length; u, approach velocity of the main current; and u', velocity inside a reed colony (u·exp [-2.15x]). Reed colony velocity u' attenuates exponentially in the downstream direction, and the attenuation constant (2.15) was determined through hydraulic model experiments. b is the distance it takes for the velocity to sufficiently attenuate. (Here, this experiment was performed with a distance b of 0.8, 1.0 and 1.2 meters, in which the velocity attenuated 82%, 90% and 93%, respectively.)

The fluid force in the downstream direction that acts on the most upstream break position of the overhang (length in downstream direction: d_B) is represented with the following equation.

(3) $$F_x = F_{x1} + F_{x2}(d_B)$$

Fluid force F_x causes the overhanging bank to undergo bending moments in the xy surface and the xz surface (M_{xy}, M_{xz}; see Figures 8 and 9). These moments are represented by the following equations.

(4) $$M_{xy} = \{F_{x1} + F_{x2}(b)\} \cdot a / 2$$

(5) $$M_{xz} = F_{x2}(b) \cdot (c + h) / 2$$

Bending stresses F_y and F_z (produced by these bending moments and occurring on A-A' plan) are assumed to have triangular distribution.

Also, this distribution of the bending stress allows us to determine the stresses in the y and z directions acting on the portion d_B as shown below.

(6) $$F_y = \int^{d_B} 6M_{xy}(1 - 2x / b) / b^2 dx$$

(7) $$F_z = \int^{d_B} 6M_{xz}(1 - 2x / b) / b^2 dx + \{(\rho_m - \rho) a \cdot c + (\rho_v - \rho) a \cdot h \cdot \sigma' \pi \cdot \phi^2 / 4\} g d_B$$

The above enables us to determine the resultant force F vector (F=(Fx,Fy,Fz)) of the external forces acting on d_B, the area where breakage occurs, and from the balance between this external force F and the tensile strength of the subterranean reed stems at the breaking surface, we can determine u_{cr}, the critical velocity for the overhang.

(8) $$R = r \cdot \sigma' \cdot d_B$$

(9) $$u_{cr} = [2g \cdot r \cdot \sigma' \cdot d_B / \{\rho \cdot C_D a \cdot (K_1^2 + K_2^2 + K_3^2)^{1/2}\}]^{1/2}$$

$$K_1 = c + \phi \cdot h \cdot \sigma \int_0^{d_B} f(x')^2 dx'$$

$$K_2 = 3a / b \cdot d_B / b \cdot (1 - d_B / b) \cdot \{c + \phi \cdot h \cdot \sigma \int_0^b f(x')^2 dx'\}$$

$$K_3 = 3d_B / b \cdot (1 - d_B / b) \cdot \{\phi \cdot h \cdot \sigma (c + h) \int_0^b f(x')^2 dx'\} \cdot b$$

where u_{cr} is the critical velocity; r, tensile strength of the subterranean reed stem (27 kgf/reed); σ', number of subterranean reed stems per unit of downstream distance; and f(x')=exp (-2.15x').

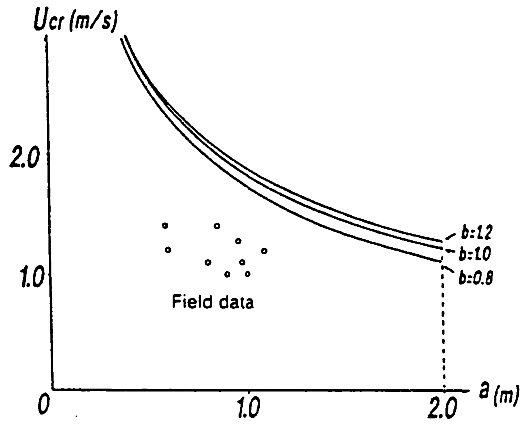


Figure 10: Length of over hanging bank (a) and critical velocity

Figure 10 is a comparison of field data (for the 40-km point on the Tama river) and the results for calculations to determine critical velocity u_{cr} when overhang length a is the variable and the submerged depth (h) is one meter. The field data has been plotted with the value for a determined through bank surveying after flooding, and a value for u determined by measuring the velocity during flooding.

The Figure shows that the calculated values correspond to the results of field measurement. The reason why the overhang length (a) ends at 2.0 meters is that when the difference in height between the flood channel and the water level in the main channel is greater than two meters, bank stability becomes extremely low and, as a result, the bank-protective properties of the reeds becomes ineffective. According to this graph, when the velocity is 2 m/s or less, an overhang length of 0.8 m or more can be maintained, and this overhang can be counted on to mitigate bank erosion.

THE EFFECTIVENESS OF DITCH REED IN ATTENUATING THE ENERGY OF BOAT WAVES (Fukuoka et al.,1992)

The increase in pleasure boats in rivers has been accompanied by illegal docking and other new problems, one of which is the waves produced by commercial and pleasure boats. When a boat passes, the waves it produces negatively affect areas used by people enjoying the river and also cause considerable bank erosion.

In North America and Europe, where boat usage is advanced, research and damage reduction countermeasures concerning bank erosion caused by boat waves are already being carried out.(Hemphill and Bramley, 1989). In many places in Southeast Asia, however, boats are also used as a means of transporting people, and this river transportation causes extensive bank erosion that has resulted in serious land- and housing-related problems.

Ditch reed grows along the banks in the downstream reaches of some rivers. If these ditch reed colonies can keep the water's surface calm and prevent erosion by canceling out the energy of boat waves, then this reed's flood-control and environmental functions should be able to contribute to both conservation and restoration. In order to determine the extent to which ditch reed colonies reflect and attenuate the energy of boat waves, a field experiment was performed in

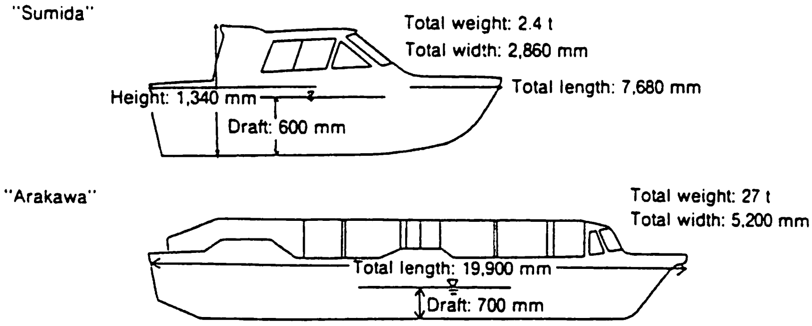


Figure 11 :River patrol boats

Table 2: Characteristics of waves created by boats

		Patrol boat Sumida	Patrol boat Arakawa
Wave height	(cm)	13-23	6-52
wave celerity	(m/s)	1.85-2.67	2.11-3.56
Wave period	(sec)	1.7-2.4	2.2-4.6
Wave length	(m)	5.5-6.6	5.1-15.9
Number of waves		10-12	10-14

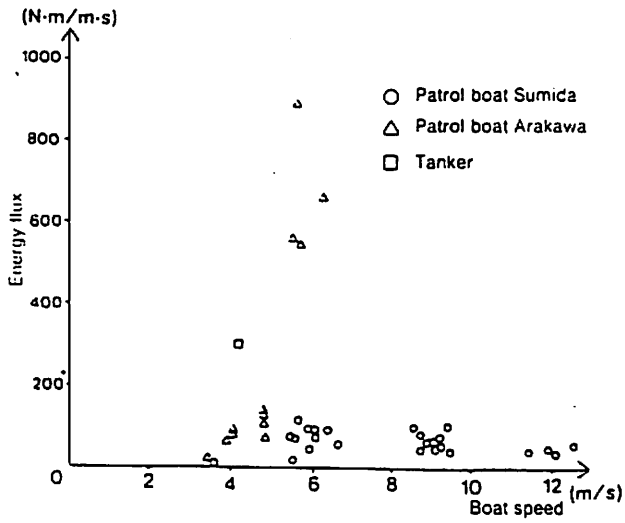


Figure 12: Relationship between boat speed and wave energy flux

the lower reaches of the Ara river, and an experimental wave tank was also used. The site of this research was the right bank at the 14.5-km point. Two boats were used: the "Sumida" and "Arakawa," both of which are patrol boats belonging to the Ara River Lower Reach Construction Office. The dimensions of these boats are shown in Figure 11.

As the test area is in a tidal region, the current velocity is nearly negligible. Depth is approximately six meters where boats pass and 1.0 to 1.5 meters at the front edge of the reed colony.

The dimensions of the waves measured are shown in Table 2, while Figure 12 shows the relationship between boat speed and the average transmitted wave energy per unit crest width and unit time ($W = 1/8\ \rho g H^2 C_g$). The Sumida, traveling at a speed (Vb) of 6 to 9 m/s, produces waves with a large amount of energy that surged towards shore, when traveling at 6 m/s. The waves produced by the Arakawa had a far larger energy flux than those of the Sumida, and maximum energy flux.

Where ditch reed colonies grow, wave energy is comprised of reflected wave energy and transmitted wave energy, with the rest being energy lost inside the ditch reed colonies. The energy conservation law is exprèssed with the following equation.

(10)
$$W_I = W_T + W_R + W_L$$

where W_I, W_T and W_R is the average transmitted wave energies per unit crest width and unit time by, respectively, incident waves, transmitted waves and reflected waves; W_L is the average energy loss per unit crest width and unit time. Equation (10) can be changed to equation (11) when the reflection coefficient K_R is H_R/H_I, the transmission coefficient K_T is H_T/H_I, and K_L is the coefficient of energy loss.

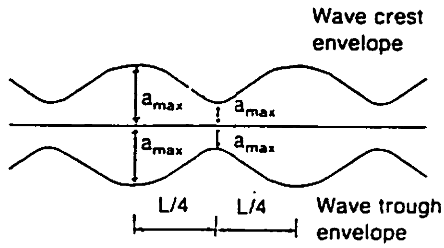


Figure 13: Envelope of partial standing waves

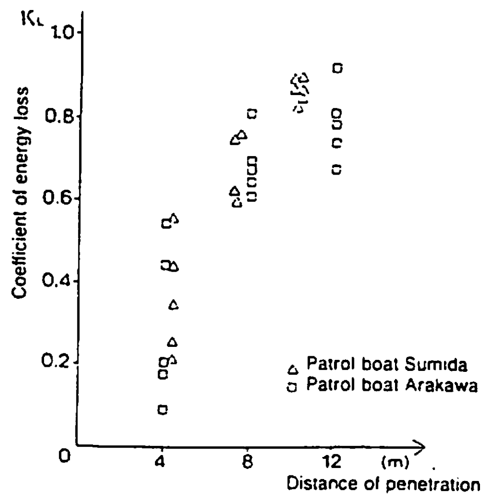


Figure 14: Coefficient of energy loss of boat waves in ditch reed cluster

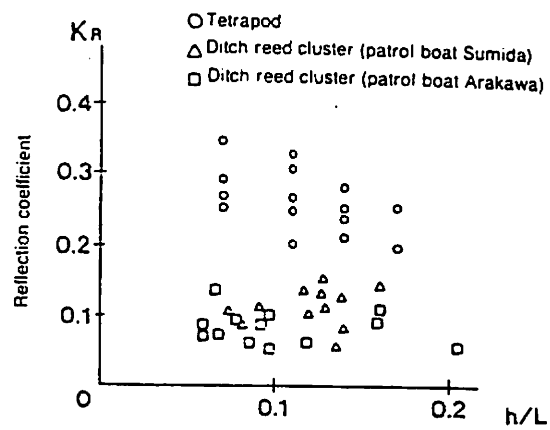


Figure 15: Wave reflection coeffient in ditch reed cluster

(11) $$1 = K_R^2 + K_T^2 + K_L$$

In the ditch reed colony waves reflect incompletely, resulting in crests and troughs like those shown in Figure 13.
Measuring the envelope of the crest and troughs of such waves, the reflection coefficient K_R was determined with Healy's method.

(12) $$K_R = \frac{a_{max} - a_{min}}{a_{max} + a_{min}}$$

The coefficient of energy loss in ditch reeds (K_L) is determined with equations (11) and (12). Figure 14 indicates the relationship between the distance that a wave travel through the ditch reeds and the resulting energy loss coefficient. This coefficient of energy loss approaches 60 to 80% when the wave penetrates eight meters into a ditch reed colony. thus demonstrating that the effectiveness of ditch reeds in attenuating wave energy is considerable even with large waves like those created by the Arakawa, and that the erosive force of waves reaching the bank behind the ditch reed colonies is nearly zero. Also, Figure 15 shows that the coefficient of reflection of waves in a ditch reed colonyis merely 0.05 to 0.15. lower even than that produced by tetrapods (0.2 to 0.35), which shows that ditch reed colonies are capable of sufficiently reducing reflected waves. This means that ditch reed colonies can quickly return the water's surface to a calm state after the passage of a boat, and that they are also effective in the area of water-surface utilization.

The above establishes that the energy-attenuation and reflective characteristics of ditch reeds are sufficiently high in comparison with other artificial wave-dissipation structures. The effectiveness of ditch reed in mitigating bank erosion and returning the water's surface to a state of calm is definitely worth use even from a flood-prevention standpoint. while at the same time, ditch reed's natural environmental functions. in combination with this effectiveness. can be used to create a river environment that is both safe and rich in natural beauty. The administration. conservation and restoration of ditch reed in rivers is therefore called for.

CONCLUSION

The objective of this research was to investigate the use of common reed and ditch reed as bank protection works. The principal conclusions reached through the field research, field testing and experimentation performed for this research are as follows.

1. It was demonstrated that common reed growing along a river bank can maintain the bank's overhanging shape during flooding; also demonstrated was the mechanism by which bank erosion is mitigated during flooding and in the flood attenuation stage by the overhang covering the banks.
2. The tensile strength of common reed was determined, as were the critical velocities for using these reeds as bank protection works.
3. It was confirmed that the growth environment of common reed is affected principally by frequency of flood channel inundation and other hydraulic characteristics, and by the characteristics of the soil in which their roots grow.
4. The effectiveness of ditch reed in attenuating the transmitted energy of waves produced by boats was also demonstrated.

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