マングローブ林の防災機能に関する研究 : 第4報マングローブ林の防災機能の検討と根系に関する予備水理模型実験(林学科)

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Studies on the protective Functions of the Mangrove Forest against Erosion and Destruction
(Ⅳ) The protective functions of the mangrove forst and a preliminary hydraulic model experiment on the root system of mangrove*

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Summary

The relations between the existence of mangrove forest as a natural environment and its protective functions were examined. The pretective functions of mangrove forest were described from relate the viewpoint of how to with the connection between the human works and the natural phenomenons.

On the effects of the root system of *Rhizophora stylosa* against the flow, a preliminary hydraulic model experiment was carriend out. The followings became evident after examining the experimental results obtained.

1. The root system of *R. stylosa* closely influenced the flow on the shape and resistibility of it.
2. The root system remarkably reduced the velocity in its extent and divided the flow in two and the extent of the influence was larger as the depth of flow became shallow.
3. The influence of the model remained yes at the cross section about 2.5 times the length of the thickness of the model in downflow direction from the lower end of the model.

Introduction

The manifestations of the functions of mangrove forest, as the acceleration of the

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progradation, the protection of the coast lines and the stabilization of channels in the delta, have been pointed out by many researchers.[1] It is satisfactory to consider that these manifestaions result from the buffer function of mangrove forest against the wave and flow actions. I have observed the buffer function of mangrove forest from the viewpoint of the disaster prevention forest. In Langa langa lagoon, Malaita Island in the Solomon Islands, there was a case that the mangrove forest and a chain of small islands, affected brobably by the progradation of mangrove forest, protected many villages and hamlets against a big tidal wave.[6] In the Southeast Asia, there were probably many cases similar to the case mentioned above. We are interested in the examinations on the direction and height of tidal wave, coastal topography, the presence and position of coral reef, the scale, stand density and species of mangrove forest and the extent of damage under such cases. It will become clear if the investigation is done on the data collected about many of such cases that the mangrove forest served as the disaster prevention forest.

In this paper, the protective functions of mangrove forest were examined and shown in relation to the human works and the natural phenomenon. And, furthermore, a preliminary model experiment for the hydraulic investigations on the protective functions of the root system of *Rhizophora* spp. were described.

Protective functions of mangrove forest

Generaly, the word of disaster, and of course also disaster prevention, is a concept to a result from the connection between the human works and the natural phenomenons. Therefore, the protective functions of mangrove forest should be estimated from the viewpoint of how to relate with the connection.

Sometimes, especially in agriculture, strong winds from seawards inflict not only physical damages but also physiological damages by flying salt upon crops. This flying salt witheres up crops and reduces the concentration of sugar of sugar cane.[3] And the flying salt rusts many kinds of metal articles in the coastal regions, and then it inflicts the damages of electric leakage in addition to the rust against power–transmission facilities. In the condition that coral reefs are along the coastline, these damages ara increased as the spray of sea water is carried in the air by the bubbles occurred in the front of coal reef. The strong wind accompanid with rain is not so serious because of the rain sweeps away the salt carried. The mangrove forest in the coastline functions not only as a windbeak but as a prevention forest against the flying salt. It is considered to be effective, furthermore, that the mangrove forest is established on the coral reef along the coast line to be near to the source of supply of the flying salt.

In addition, I estimate from the field observations that forest of *Rhizophora* spp. has the function of reflecting a sound, which seems to be larger against a shrill sound.

As the destructive power of tidal wave is probably buffed and subsided in mangrove forest, it protects inhabitation areas in the coastal region together with the coral reef. In the estuary, it protects the bank against erosion as it resists against stream flow, and prevents channels from shifting the courses of them as it functions liks the pervious spur jetty. Such functions are useful for the water–transpotation through the channels. The mangrove forst established on the coral reef forming lagoon protects the residential area and forms the calm surface of the sea suited for the water–transportion by small boats and canoes in lagoon.[5,6] On the other hand, the function of accelerating sedimentation fulfilles a role of keeping the coastal sea clear.

A maximum–intensity submarine earthquake, centering in latitude 40 degrees 24 minutes north and longitude 138 degrees 54 minutes east, occured on May 26, 1983. The magnitude was 7.7 and induced a mighty tsunami. The area from the northern part of Akita prefecture to the southern part of Aomori prefecture, suffered most from the earthquake and the tsunami, however the damage extended each place along the coast of the Sea of Japan. One hundred and two persons were dead or missing and the damage was estimated to de 148 billion yen.[2] Most of casualties and damage were chiefly due to the tsunami. The coastal protection forest checked an increase of the victim and the damage of farmlands, houses, roads, facilities for traffic and communication behind the forest to a minimum by obstructing to make ways of the waves into the forest or subsiding the destructive energy of the tsunami with the disaster srevention facilities, such as the coastal levee, the revetment for tidal wave and so on. While the coastal protection forest subsided the destructive power of the tsunami, it intercepted large–sized floatages, such as fishing boats, logs and fisherman's sheds by the seaside and so on. It is clear from many examples that such floatages tends to expand the damage in case of the tsunami and the tidal wave.

Taniguchi expressed feelingly this coastal protection forest described above as" the green breakwater".[8] The effect against the tsunami or the tidal wave must be larger if such green breakwater exists in shore or off shore parallel witn the shoreline. As the mangrove forest in shore or off shore surely correspond to this green breakwater, the large effect against the tsunami and the tidal wave is expected.

As mentioned above, it is considered that the mangrove forest has multifaced protective functions against the wave, flow and wind. Figure 1 shows the above matters arranged systematicaly. As shown in Fig. 1, the disaster is just the action caused by several kinds of the natural phenomenon against the human works, the disaster prevention is just to reduce the action. Generally, the disaster prevention is a kind of human works, but we can recognize that the mangrove forest fulfills the roles of the disaster prevention under natural condition. In case of that the purpose of disaster prevention is to reduce the damage by the flying salt, it will be more effective to increase the function of mangrove forest, espectally the crown that catches the flying salt and intercepts the salty winds, and in case of that the purpose is to reduce the damage by the destructive energy of wave, it will be more effective to increase especially the function of the root system and stem that resists the wave and flow. But now, it is difficult to difine the limit of

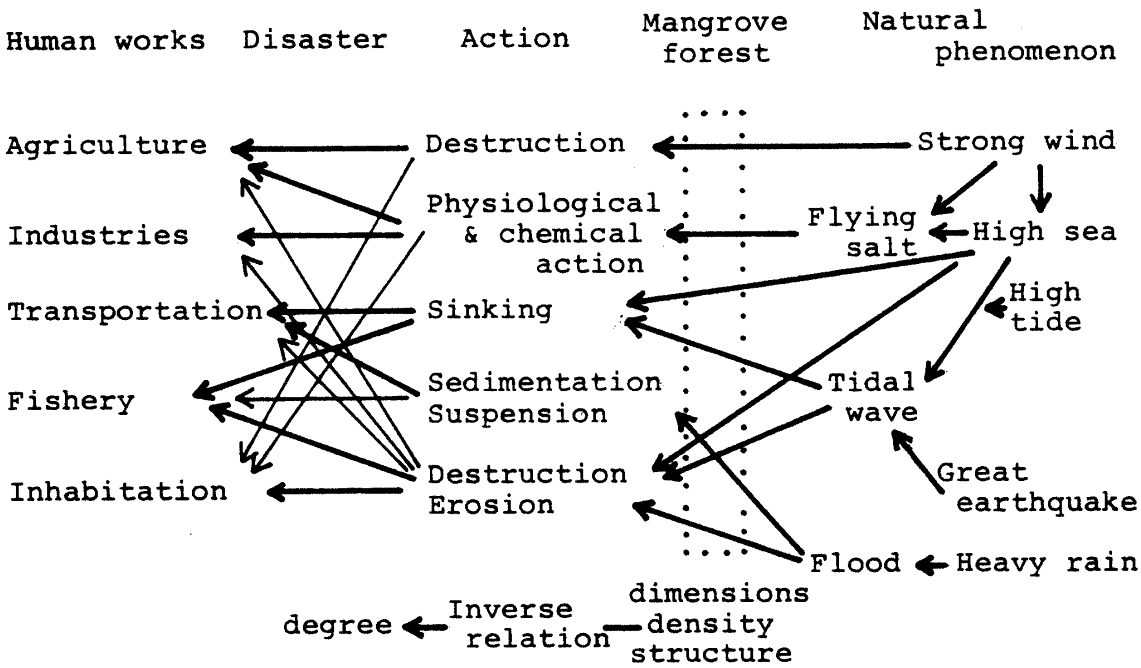

Fig. 1 Relationships between disaster and mangrove forest lie between human works and natural phenomenon

these functions like a ferroconcrete breakwater, and to plan such mangrove forest under the general conditions. In future, we must estimate scientifically the role and utilize actively the protective functions of mangrove forest. In case of an attack of big tidal wave, the mangrove forest may be destroyed, but the destructive energy must be highly reduced. So such mangrove forest may be regard as a selfsacrificing forest.

Preliminary hydraulic expeliment on the root system

The investigation on the characteristics of the root system of *Rhizophora* spp. among the other mangroves is an interesting, important and basic problem for the estimation and utilization of the protective functions of mangrove forest. The model experiment is useful for an understanding of the characteristics as the field observation is accompanied with several difficulties. But there is a problem of modelling of the root system. Indeed, how to model the root system of a tree or a stand will be recognized as problem in future.

On the root system of *Rhizophora stylosa* in Okinawa, the relations between the height from the level of the mud surface around the base of main stem (z) and the number of prop roots (n) were examined.[7] Two regression equations were applied apart above and below a certain height (hc) as one equation was not able to be applied to any investgated trees. The separate exponential functions were well applied above or below hc. A certain height (hc) was expressed as follows :

$$hc = a \cdot hmax + k,$$

where : $hmax$ = highest sprouted point of prop root (cm),
a, k = coefficients.

The regression equations between z and n were obtained as the following forms :

if $0 \leqq z \leqq hc$,

$$n = c \cdot e^{d \cdot \mathrm{H} + f \cdot z},$$

if $hc \leqq z \leqq hmax$,

$$n = c \cdot e^{d \cdot \mathrm{H} + (f - f') hc + f' \cdot z},$$

where : H = tree height (m),
n = number of prop root,
z = height from the base of main stem (cm),
c, d, f, f' = coefficients.

Though these equations have to be examined closely in future, it is considered that the equations are useful for modelling of the root system of *R. stylosa* as a characteristic of increasing suddenly the number of prop roots near mud surface, is expressed well.

A.Methods

1) Experimental flume

The experimental flume was the wooden open flume coated with paint and had the dimension of 50 cm deep by 50 cm wide by 12 m long. The water in a flume was circulated through a return channel. The flow rate of water was measured with a measuring triangular weir and was adjusted to the rate corresponding to a mean velocity of about 11 cm/sec.

2) Model

The model was the geometric model based only on the shape of the root system and was not considered on the Froude model. On the root system imagined, the extent distributing prop roots was 1 m high by 2 m wide by 2 m thick. The length ratio was decided to be 4 in consideration of the dimension of a channel. On the vertical distribution of the number of prop roots, the line shown in Fig.2, was decided to be similar to some examples measured in the field. While the number of prop roots distributed at each height, was considered to take the same value with the line in Fig.2, each root was set on the plywood roughly symmetrically with respect to the stem. The material of the model was wooden bar of diameter 10 mm. The model was fixed by an adhesive on a plywood of the dimension of 10 mm thick by 50 cm wide by 250 cm long. This plywood and model was varnished and fixed on the bed of flume. The gaps at the ends of plywood with the bed of flume were filled smoothly oil clay.

3) Measurements

The flow velocities were measured with a small propeller–type flow meter with a pulse counter. The location where the velocity was measured was expressed in three dimensional coordinates with the unit of centimeter. The origin was set at the bese of the stem modelled. The Y–axis was set up parallel to the side wall of flume. The X–axis as at right angles to the Y–axis. The Z–axis was at right angles to the bed of flume. The positive directions of x,y and z were to the right, downstream and upwards, respectively. The measurements of velocity were done at each depth on the intersections of the two lines drawn through x–and y–coodinates of x = +23, +11, 0, −11, −23 and y = −25, −20, −15, −10, −5, +2, +10, +15, +20, +25, +50, +75, +100, +125, +150. The experiments were done under four kinds of depth, 10cm, 15cm, 20cm, and 25cm.

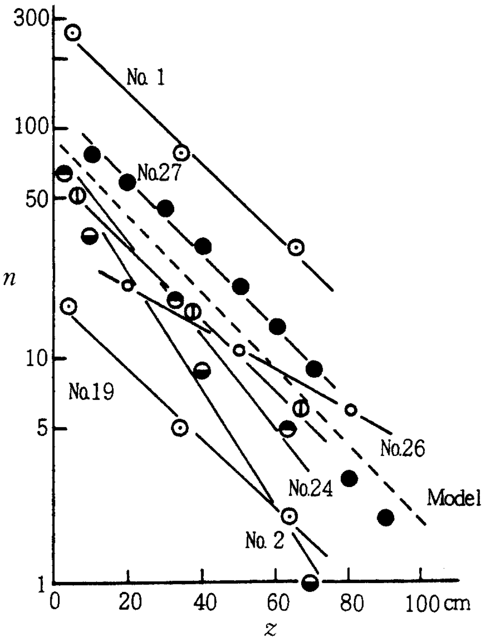

Fig. 2 Relationships between height from mud surface (z) and number of prop roots (n) and regression line of model

B.Results and discussion

In a typical open channel, the velocity of flow is the fastest at mid–flow and is the slowest near by the side walls, and in one profile of velocity, it is the slowest near by the bed of the channel. These matters are explained by the visocosity friction between water and the side walls or bed of the channel.

When only the plywood of the same quality with the plywood attached to the model was set up on the bed, the appearances of velocity distribution could be considered to be roughly similar with the flow in a typical open channel. But the circumstances dissimilar

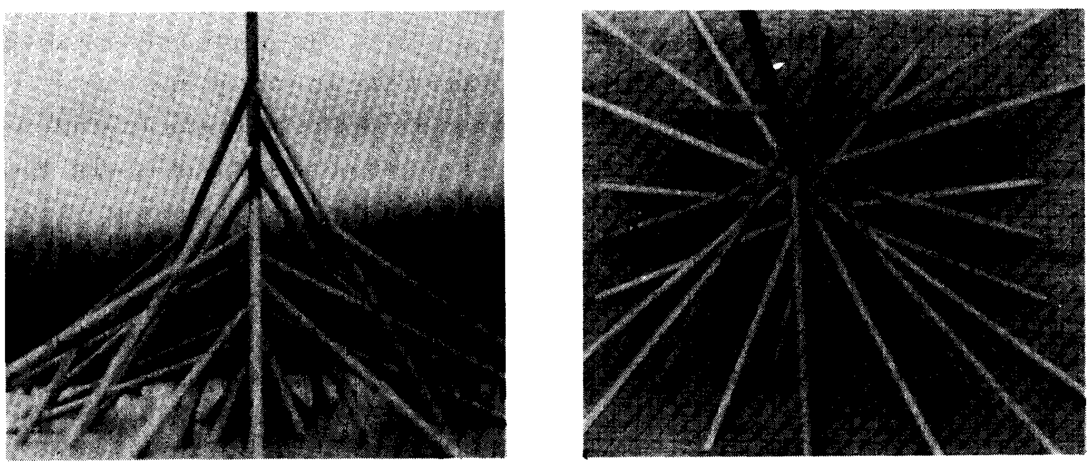

Fig. 3 Model of root system before setting up in experimental flume

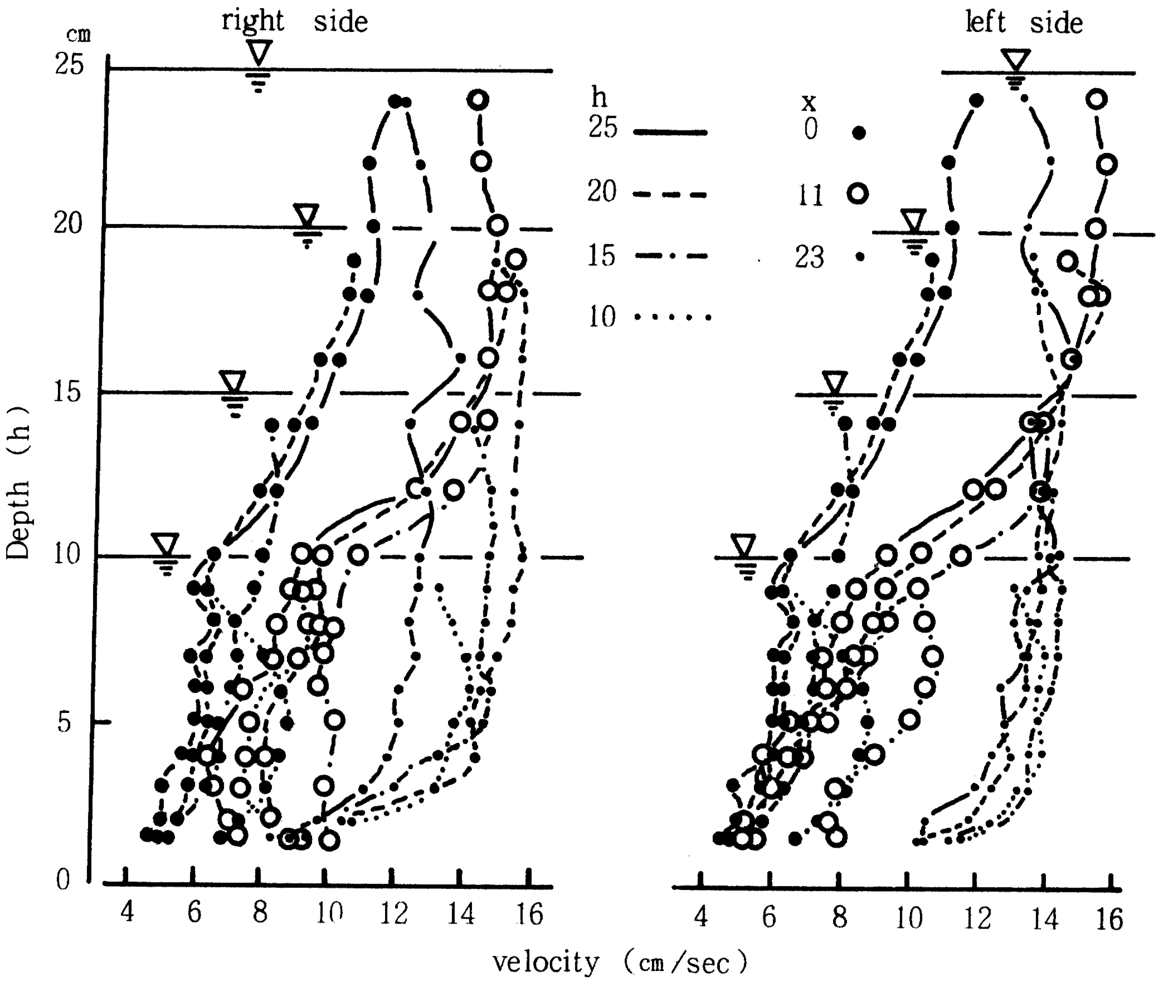

Fig. 4 Vertical velocity profile (y = +25)

to the typical flow were observed partially because the slight meanders of flow occurred as the rectification of flow was not enough in this experiment.

Figure 4 shows each profile at a cross–section (y = +25). The profiles in both right and left sides of channel, can be regarded as showing a similar and roughly symmetrical tendency without any difference. The profile at x = +23 in experiment of h = 25 cm, is different with others. This seems to be influenced by the inclination of root distribution and the meander of flow. The profiles in the right side of Fig. 4 show that the condition of flow in the right side against the downward direction. It seems to be acceptable to consider that these profiles explain reasonably the conditions of flow.

Firstly, within the extent of about 10 cm above the bed the tendency of flow is completely reversed to the flow in channel that is not set up the model, i. e. the velocity of flow is the slowest at mid–flow and is the fastest near by the side wall. This snows that the velocity of flow at mid–flow is reduced by the model, and the flow is divided in two and pushed aside near by the side walls where is relatively less resistance.

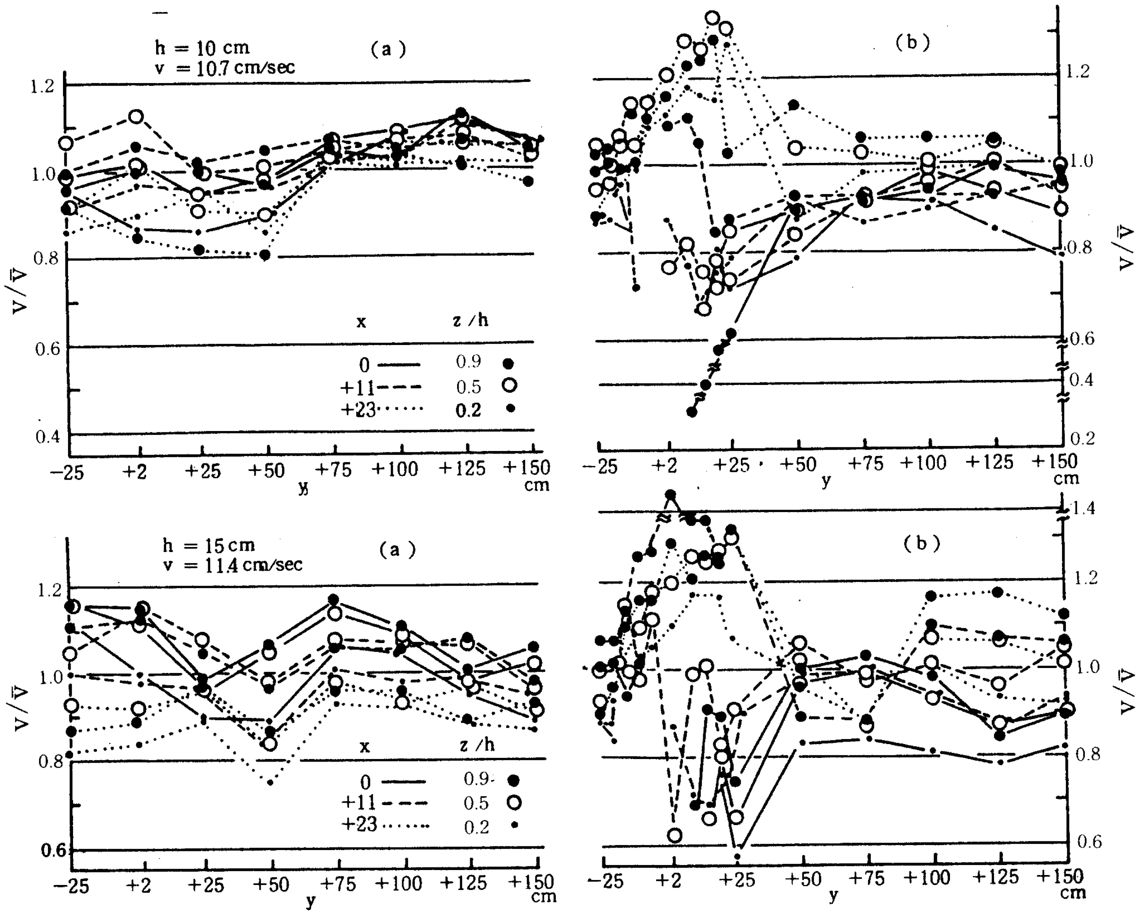

Fig. 5 (1) Change of velocity by Model at each depth
(a) before setting model (b) after setting model

Secondly, above the extent of about 10 cm from the bed, the velocity of intermediate flow between the mid–flow and the flow near by the side wall is fastest as the profiles at x = ±11 and x = ±23 intersect and replace. However the velocity of flow at mid–flow is the lowest in comparison with other profiles and is faster above the extent than below and shows a tendency to become faster as it comes near the water surface. From this matter, it seems to be quite reasonable to consider that the flow above the extent distributed roots modelled presents the circumstances shifting to the condition without the model. In a case at more deeper position, it is assumed that the profile at x = 0 also replaces and each velocity of flow at x = 0, x = ±11, x = ±23 is faster in the same order in upper layer.

Thirdly, at each x–coordinate the velocity is slower in the extent distributed density roots as the depth (h) becomes deeper and, in contrast with this, is faster above the extent as the depth becomes deeper. This matter is shown distinctly in the left side of Fig 4. The strict comparison of each profile is not appropriate for the mean velocity in each

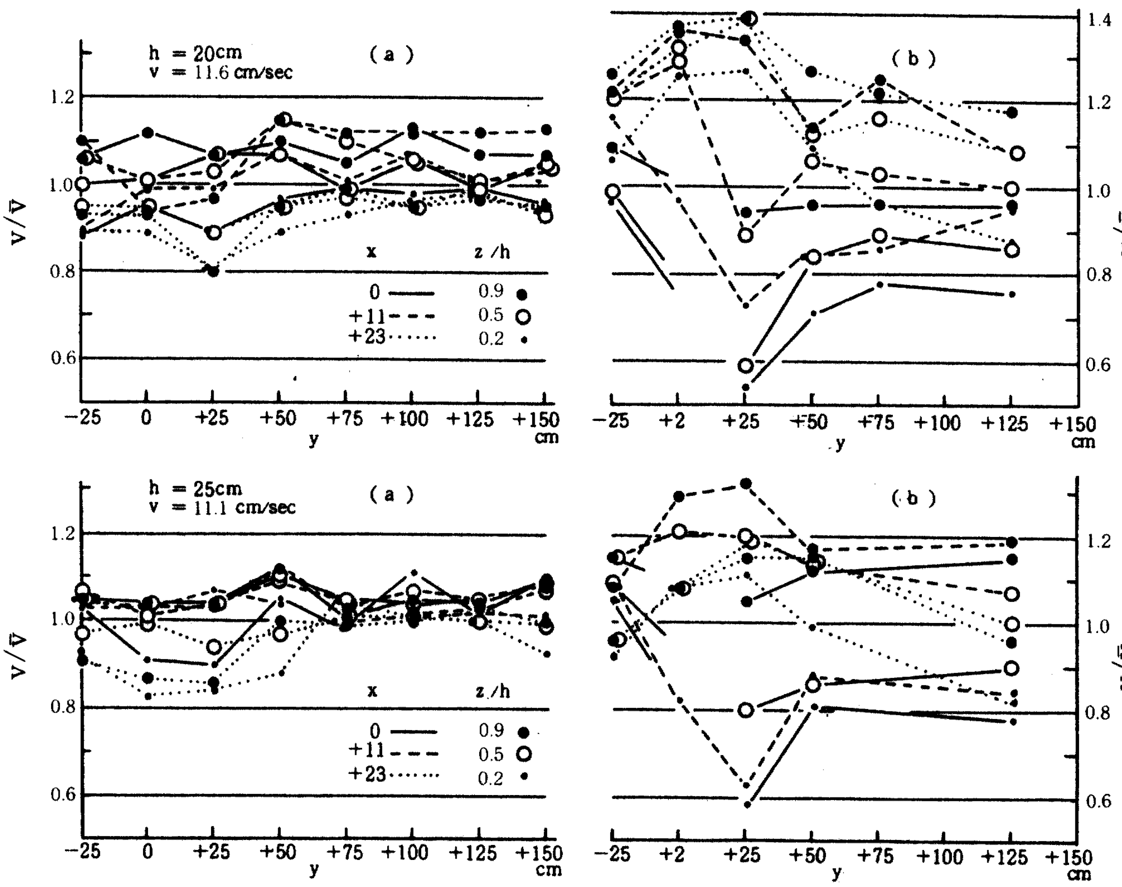

Fig. 5 (2) Change of velocity by Model at each depth
(a) before setting model (b) after setting model

depth is different. But if it can be assumed that these experiments have been carried out under an approximate mean velocity, it is considered that the water can flow faster in space of less resistance above the extent when the depth is deeper as the velocity is slower in the extent of root system modelled. The facts mentioned above suggest that the root system of *R. stylosa* must closely affect flow on the shape and resistibility of it.

Figure 5 shows the comparison of the condition of flow in channel when the model is set up and is not. The velocity at three kinds of the relative position, z/h = 0.9, 0.5 0.2, was drawn with the ratio against the mean velocity.

When the model is not set up, the velocity on each depth is the slowest generally near by the side wall, though the condition of flow is fairly different at each section. Though the condition of flow at x = 0 is not so different from it at x = +11, the velocity at x = 0 can be assumed to be slightly faster than it at x = +11. At each coordinate of x = 0, +11, +23, Fig. 4 shows a general tendency of the velocity to be slower as it becomes near by the bed. As a whole there is disorder by slight meanders, but the condition of flow can be regarded to be generally similar with the flow in a typical open channel. The inclination form the mean velocity is almost within a range of ± 0.2.

When the model is set up, the condition of flow at each x–coordinate is remarkably different in the extent of model. At $x = +23$, the velocity at each relative position is the fastest, and on the contrary at $x = 0$ it is the slowest. At $x = +11$, the velocity at the relative position of $z/h = 0.9$ is faster than the mean velocity ($\bar{v}$), but, at the relative position of $z/h = 0.5$ or 0.2, it is slower roughly. As compared the condition of flow at $x = +11$ with each other at a given depth, in case of $h = 10$ cm, broken lines are below the line of $v/\bar{v} = 1.0$, i. e. the velocity at each relative position is slower than $\bar{v}$, in case of $h = 15$ cm, the broken line of $z/h = 0.9$ is cleary above the line of $v/\bar{v} = 1.0$, in case of $h = 20$ cm, the broken line of $z/h = 0.5$ also get slightly near the line of $v/\bar{v} = 1.0$, and, in case of $h = 25$ cm, the broken lines of $z/h = 0.9$ and 0.5 are above the line of $v/\bar{v} = 1.0$. At $x = 0$, the solid line show that the model has a strong influence on the deceleration of the flow in this part, i. e. the mid–flow. The solid line of $z/h = 0.9$ comes up to the line of $v/\bar{v} = 1.0$ as the depth becomes deeper. In case of $h = 25$ cm, this line is above the line of $v/\bar{v} = 1.0$. This matter shows that the model reduces remarkably the velocity in this extent and divides the flow in two and the extent of the influence is larger as the depth of flow becomes shallow.

In the lower course of flow from the model, the dotted lines at $x = +23$ show a reducing tendency and, on the contrary, the broken lines at $x = +11$ and the solid lines at $x = 0$ show an increasing tendency as the depth becomes deeper. This suggests that the flow tries to maintain its original condition and the degree to return is larger as the depth becomes deeper. The influence of the model remains yet at a section 2.5 times as long as the thickness of the model downflow from the lower end of the model. In the extent of the model or just lower course of flow from the model, the inclination range from the mean velocitv is larger as the depth becomes shallower and, in case of $h = 10$ cm, it is from $+0.34$ to -0.71, in case of $h = 15$ cm, from $+0.43$ to -0.42, in case of $h = 20$ cm, from $+0.39$ to -0.46, in case of $h = 25$ cm, from $+0.32$ to -0.42.

The facts discribed above are considered to expained well that, in the mangrove forest, the sedimentation is accelerated, the grain size of sediment is relatively fine, the sediment once deposited is hard to be eroded, the progradation with the mangrove forest as the total results of these matters is promoted more and the bank in estuary is protected in the similar manner with the previous spur jetty.

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マングローブ林の防災機能に関する研究

第4報　マングローブ林の防災機能の検討と根系に関する予備水理模型実験

佐藤一紘

要　　約

マングローブ林が、自然環境の一つとして存在する事ではたしていると考えられる，種々の防災機能について検討した。自然現象と人間の営為との間で生ずる災害と，マングローブ林のかかわりを，防災という視点から整理し，図示した。

ヤエヤマヒルギ (*Rhizophora stylosa*) の根系のある種の模型を用いて，その流れに与える影響について，予備的水理実験を行った。その結果，おおよそ次の事が明らかになった。

1. 根系の影響を受けている範囲は，根系の形をよく反映している事から，根系は，その低抗性と，全体の形状とで、強く流れに影響を与える。
2. 根系内では，流速が著しく減少し，周囲に流速の増加する部分ができ，流れを大きく二分する。
3. 根系の下流では、徐々に元の流れの状態に復するが，下流側に，根系の範囲の2.5倍のところでも根系の影響は残る。