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Study on the Effect of Coastal Forest to Tsunami Reduction

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Synopsis

In order to utilize coastal forest as tsunami countermeasures, quantitative evaluation for hydrodynamic effect of coastal forest was examined in this paper. Relation between the forest density and the diameter of trunk is obtained through the field measurement data of control forest and some previous researches, which is useful information for the evaluation of effects. Numerical simulation including the model of control forest effect is performed for evaluating the quantitative effect for tsunami reduction and damage. By using simulation results, effects of reducing tsunamis can be quantitatively evaluated in a relation to the tsunami and forest conditions.

Keywords: Coastal forest; Tsunami; Forest width; Forest density Tsunami reduction

1. Introduction

In recent years, demand to coast management is expanded not only for disaster prevention but also for environment and utilization by a rise of the environmental consciousness and the citizen participation in Japan. On the other hand, artificial coastal barriers such as seawalls and breakwaters have been constructed along the Japanese coast and have played an important role in protecting the coastal area from natural hazards such as tsunamis, tidal waves and high waves. The artificial coastal barriers have some problems, such as high cost of the construction and maintenance, modification of the present environment and inconvenience in utilizing the coastal area. Therefore, the countermeasures against tsunamis by only using the artificial coastal barriers are not recommended for all coastal areas and in future coast of management. For more appropriate management to reduce natural disaster and to keep good environment, it is required that a new countermeasure method corresponding to each coastal area including the combination of artificial and natural functions. One of new ways is to utilize a control forest along coast, which is traditional countermeasure for long time. However, quantitative and concrete functions of coastal forest to reduce a tsunami are not established and formulated, so that no guidance to use control forest is available. In order to use a coastal control forests more effectively as countermeasures against tsunamis, it is important to evaluate the hydrodynamic effect of tsunami control forest, and to further discuss a disaster prevention function. Therefore the present study aims to provide the quantitative guidance of tsunami reduction effect from numerical simulation including the resistance of tsunami control forest.

2. Evaluation to the effect of tsunami reduction by using of numerical simulation

2.1 Conditions of coastal control forest in Japan

In order to evaluate the tsunami reduction effect by the numerical simulation, some conditions of coastal forest, based on using actual forest conditions, should be selected. Harada and Imamura (2003) summarized the relation between forest density and trunk diameter from the field survey data of pine tree forest in Japan. In general, the diameter of trunk is related to the amount of leaves, because the trunk takes the role of pipe between the leaf and root. Therefore, they control themselves and so the forest density becomes small when the diameter of trunk becomes large (Tanaka, 1998). By using this relation, the diameter of trunk can be estimated from the forest density. From Figure 1, the trunk diameter corresponding to the forest density are selected to 0.3 m and 10 trees /100m^2, 0.15m and 30 trees /100m^2, and 0.1 m and 50 trees /100m^2. Forest width is an important parameter for tsunami reduction and it varies from place to place. To examine the forest width effect, forest width is selected to be 50, 100, 200, and 400m and the forest is put at a distances of 100m from shoreline. The tree height and the brunch height are selected 10, 2m and the projected area rate of leaves is given to be 0.65 from field survey data (Harada and Imamura, 2003). These conditions are used for the evaluation of tsunami reduction effect by using tsunami numerical simulation. The conditions of forest are shown in Table 1.

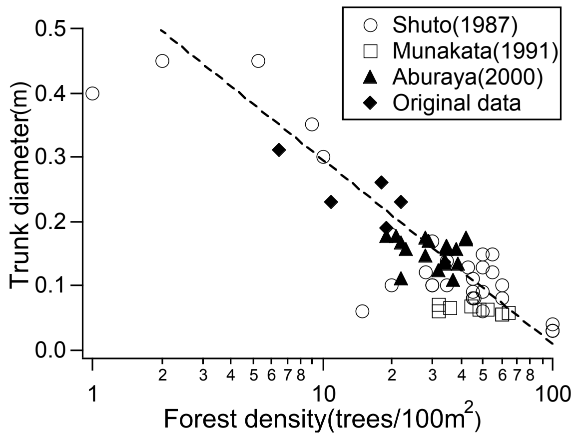

Fig. 1 Relation of forest density and diameter of trunk (Harada et al, 2003)

Table 1 Conditions of coastal forest for numerical simulation

Forest density	10, 30, 50 trees/100m^2
Trunk diameter	0.3, 0.15, 0.1 m
Forest width	50, 100, 200, 400 m
Tree height	10 m
Brunch height	2 m
Projected area rate	0.65

2.2 Resistance of coastal forest in numerical simulation

In the numerical simulation, the effect of coastal forest is included as the resistance force in momentum equation. Harada and Imamura (2000) modeled the resistance force as drag and inertia forces based on Morison's equation and modeled the resistance coefficients of coastal forest against tsunamis by using the results of hydraulic experiment. Equations (1) are the resistance coefficients used by them, where C_D is the drag coefficient; Vo is the volume of tree under water surface; V is the volume of water; C_M is the inertia coefficient. The relation of the inundation depth and the vertical structure of trunk and leaf change this drag coefficient. These resistance coefficients include the effect of tree structure. In the numerical simulation, these resistance coefficients used to calculate the forest effect quantitatively.

$$C_D = 8.4\frac{V_o}{V} + 0.66 \qquad \left(0.01 \le \frac{V_o}{V} \le 0.07\right) \qquad (1)$$
$$C_M = 1.7$$

2.3 Numerical simulation including coastal forests

In order to evaluate the effect of tsunami reduction quantitatively, tsunami numerical simulation of run up including the resistance of the control forest is carried out and the change of hydraulic values on the land are examined. The coastal landform for Sendai Bay is selected as an example to discuss the effect of the control forest (Fig.2). To evaluate the tsunami reduction effects by coastal forest, the tsunami height is selected to 1, 2 and 3 m and wave period is 10, 20, 30, 40, 50, 60 min. When tsunami heights exceed 4 m, tree would start to be broken (Shuto, 1987). In this simulation, trees breaking can not be properly modeled. Therefore, tsunami height is selected smaller than 4 m.

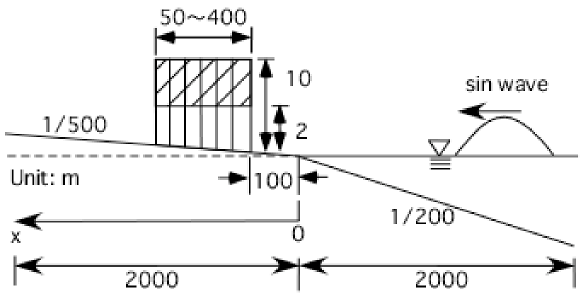

Fig. 2. Conditions for tsunami numerical simulation

Table 2 Conditions of tsunami and landform for numerical simulation

Tsunami height	1, 2, 3 m
Tsunami period	10, 20, 30, 40, 50, 60 min
Gradient of sea floor	1/200
Gradient of land surface	1/500

The governing equation used for the numerical simulation is the momentum equation (2) with the hydraulic resistance force by coastal forest (Harada and Imamura, 2003).

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}}M|M| + \frac{C_D}{2}\frac{A_O}{\Delta x \cdot \Delta y}\frac{M|M|}{D^2} + C_M\frac{V_O}{V}\frac{\partial M}{\partial t} = 0 \qquad (2)$$

where: M is the flux discharge; D ,the total depth, h, the water level; n, the Manning roughness coefficient. A_O, the projected area of trees under the water; Δx, Δy, the grid spatial size; and g, the gravitational acceleration. The grid spatial size are selected as $\Delta x = \Delta y = 50$ m, and time step is $\Delta t = 1$ sec.

2.4 Results of numerical simulation

Figure 3 shows the calculated waveforms without and with the coastal forest. From Figure 3, tsunami is reflected at the coastal forest and reduced the inundation depth and the run-up distance behind coastal forest. In particular, when the inundation depth is over the leaf and brunch height, the reflection effect on seaside and the reduction effect on inland side become large. The large resistance force of the leaf and brunch, which is calculated from equations, causes these tsunami reduction effects.

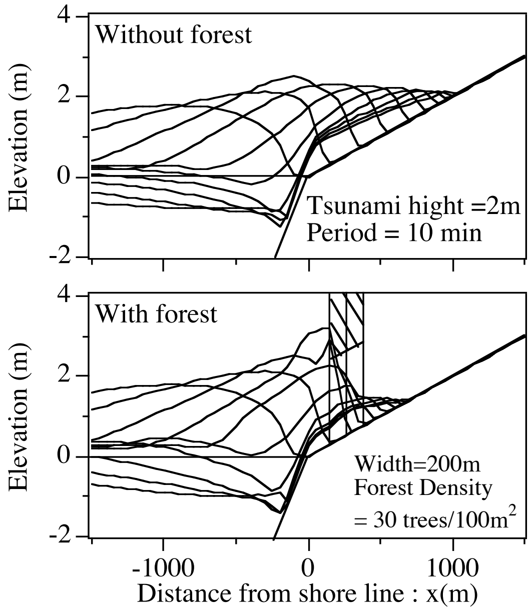

Fig.3 Calculated results without and with forest

2.5 Effect of Forest Width to Tsunami Reduction

The spatial distribution of the maximum inundation depth, current and hydraulic forces are shown quantitatively from the calculated results. Hydraulic force is expressed by the product of fluid density, the inundation depth and the square of current, and used for the estimation of house damage (Hatori, 1984). Figures 4 show the spatial distribution of the rate of maximum inundation depth, current and hydraulic force in the case of forest width of 0, 50, 100, 200, and 400m, fixed the wave height 3m, the wave period 10 min and the forest density 30 trees/100m2, and the reduction rate of maximum values are defined by equation (3).

$$r(Reduction\ rate\ of\ max.\ values) = \frac{(max.\ value\ with\ forest)}{(max.\ value\ without\ forest)} \tag{3}$$

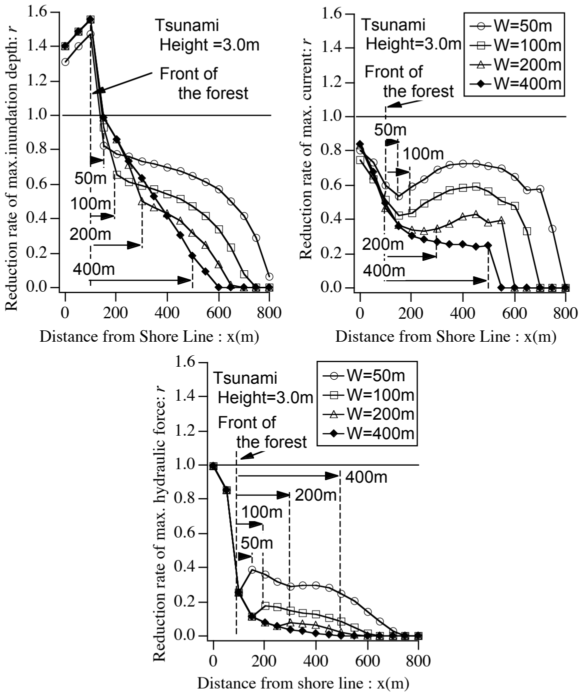

Fig. 4 Spatial distribution on reduction rate of inundation depth, current and hydraulic force (Forest density: 30 trees/100m^2, Trunk diameter: 0.15m, Tsunami height: 3.0m)

The front of the coastal forest is set to be at 100m distances from shoreline and the back is varied with its width. Figures 5 show the relation with forest width and reduction rate just behind forest. From Figures 4 and 5, the reduction rates of inundation depth just behind the forest are decreased from r =0.86 with forest width 50m to 0.18 with forest width 400m. These inundation depths are decreasing with a function of the forest width (see Figure 5). This means that the increasing of forest width can reduce the inundation damage at the back of coastal forest, which related to inundation depth. The reduction rates of current just behind the forest are decreased from r =0.54 with forest width 50m to 0.24 with forest width 400m. The current at the front is decreased due to the reflection at front side of forest, and the current at the back is reduced by the reflection and the energy loss passing throw forest. As the hydraulic force is defined by the products of the square of current and the inundation depth, hydraulic force is influenced by the current strongly rather than the inundation depth. Its spatial distribution inside the forest in Figure 4 is independent of each forest width, dependent of the forest resistance force. The increasing of forest width can reduce the house damage, which related to current and hydraulic force. From these results of numerical simulation, it can be shown that the effects of forest width increasing are large to reduce tsunami inundation depth, current and hydraulic force. By using these numerical simulation results, the effect of coastal forest to tsunami reduction can be evaluated quantitatively. The quantitative evaluation of tsunami reduction would be done in the later section.

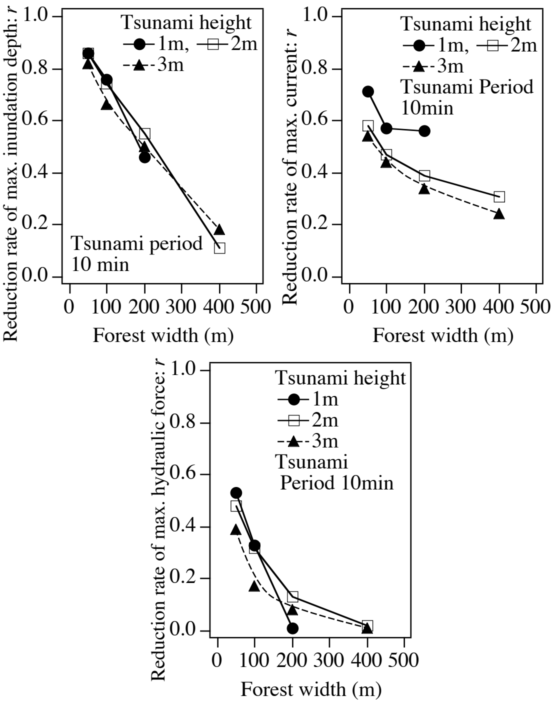

Fig. 5 Effect of forest width to tsunami reduction (Tsunami period 10 min)

2.6 Effect of forest density to tsunami reduction

In this section, the effect of forest density to reduce tsunami is discussed. Figure 4 shows the spatial distribution of maximum inundation depth, current and hydraulic force with forest density 10, 30,and 50 trees/100m2, fixed tsunami height 3m, and the fixed forest width 50m. The values of them are made non-dimension by the case without the forest (Equation 3). The reduction rates of inundation depth just behind of forest (x=150m) are about r =0.8 in each forest density case of 50m forest width. Therefore it can be said that the effect of forest density to reduce inundation depth is small. The reduction rate of current is decreasing with the increase of forest density and this rates are r=0.6, 0.54, 0.51 in the case of 10, 30, 50 trees/100m2 at just behind of forest. However the effect of forest density to reduce current is not large. As same as inundation depth and current, the hydraulic force at just behind of forest is decreasing with the increase of forest density. Figures 7 show the relation with forest density and reduction rate. The fluctuation of reduction rate due to forest density in same forest width is smaller than the effect of forest width. From these results of numerical simulation, it can be shown that the effects of forest density based on actual forest condition are not large to reduce tsunami.

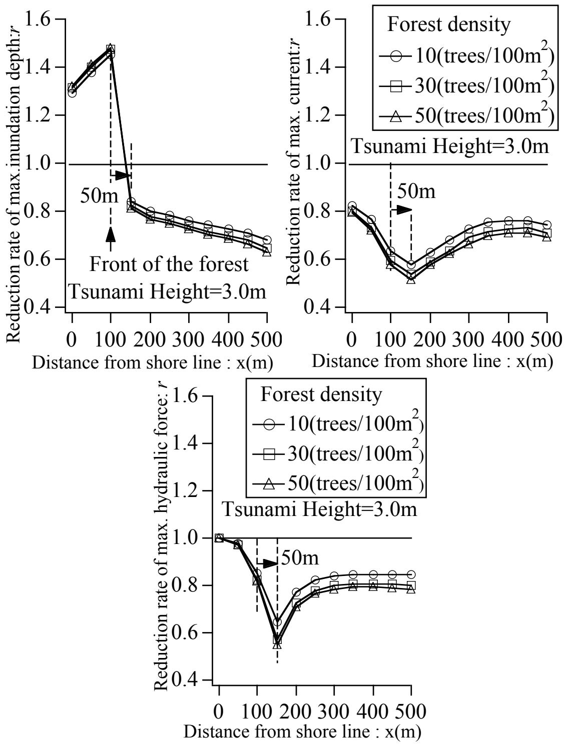

Fig. 6 Spatial distribution on reduction rate of inundation depth, current and hydraulic force (Forest width: 50m, Tsunami height: 3.0m)

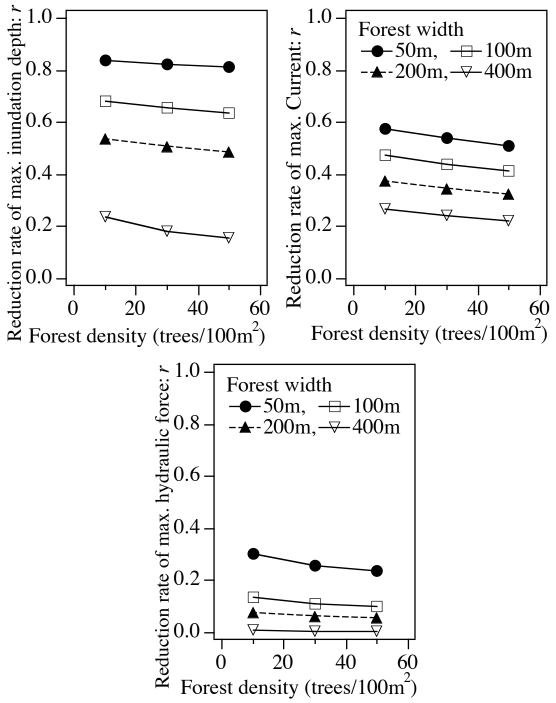

Fig. 7 Effect of forest density to tsunami reduction (Tsunami period 10 min)

2.7 Effect of tsunami period to tsunami reduction

In order to examine the effect of tsunami period to tsunami reduction, the relation with tsunami period and reduction rate are shown in Figure 8. When the tsunami period become long, the tsunami reduction effects become small. In the short period; 10 min, the reduction effect becomes small caused by the inundation depth, which smaller than leaf and brunch height. From these results, it can be shown that the tsunami reduction effect by coastal forest become small to long period tsunami.

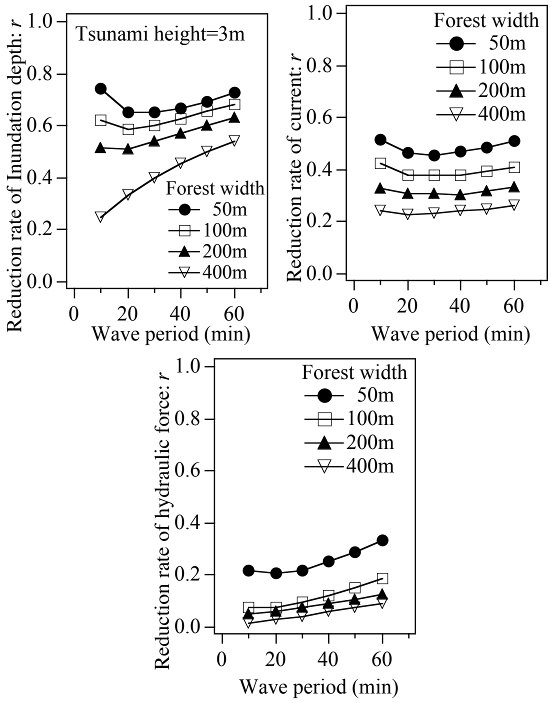

Fig. 8 Effect of tsunami period to tsunami reduction (Tsunami height =3.0m)

2.8 Quantitative evaluation of forest to tsunami reduction

The relationship of the coastal forest damage and the tsunami intensity or the tsunami height is summarized in Table 3 from the old tsunami disaster reports by Shuto (1992). This table shows that the coastal forest can stop drifts in the case of the inundation depth smaller than 4 m, or tsunami intensity is smaller than 2. However, Table 3 does not include the quantitative information for the design of the control forest and the effect of forest condition to tsunami reduction. In this section, the quantitative effects to tsunami reduction by coastal forest are discussed by using the results of tsunami numerical simulation. Table.4 shows the reduction rates of maximum run up distance, inundation depth, current and hydraulic force just behind the forest. In order to evaluate the effect against tsunami damage, these hydraulic values are evaluated for 10 min tsunami period. From the Section 2.5, the effect to tsunami reduction is influenced strongly by the forest width. So the effects are evaluated for the forest width and the tsunami height. As the mature forest conditions, forest density and diameter of trunk are selected 30 trees/100m2 and 0.15m.

Table 3 Relation between tsunami intensity and tsunami damage (Shuto, 1992)

Tsunami intensity	0	1	2	3	4	5
Tsunami height (m)	1	2	4	8	16	32
Coastal control forest	Mitigate damage, Stop drafts, Mitigate tsunami		Partial damage Stop drifts	Complete damage, No reduction effect		

From Table 4, the run up distance is decreased from 0.86 to 0.57 by the increase of forest width and tsunami height. And the inundation depth is also decreased from 0.86 to 0.50 by the increase of forest width and tsunami height. These results are the same results of Aburaya (2000). For further understanding of the effect of damage reduction by tsunami flow, current and hydraulic force would be evaluated from calculated result. The current is decreased from 0.71 to 0.34 and the hydraulic force is decreased from 0.53 to 0.01 by the increase of forest width and tsunami height. However the reduction rates of currents and hydraulic force are larger than run up distance and inundation depth. Additionally, the reduction effects of hydraulic force are larger than the inundation depth and the current, which indicate the most effective mitigation to the tsunami. This means that the reduction effect of coastal forest is larger on house damage than on inundation damage. Table 4 could compensate quantitatively the effect of coastal forest to tsunami reduction of Table 3 (Shuto, 1992). Additionally Table 4 could evaluate the effect of coastal forest to reduction tsunami damage by the current. Moreover, Table 4 can be used for a quantitative standard of the tsunami reduction effects by coastal forest for the coastal forest planning.

Table 5 shows the evaluation table of forest effect, which is converted from Table 4. The reduction rates are categorized by three stages, 0.99-0.7 as “a little effective”, 0.69-0.4 as “effective” and 0.39- as “much effective”. The run-up distance and the inundation depth are considered as the tsunami reduction, and the current and the hydraulic force are considered as the damage mitigation. From Table 5, it can be said that the forest width is required to be 200 m or more in order to reduce tsunami, the run-up distance and the inundation depth to less than 70%. And the forest width is required to be100 m or more in order to mitigate tsunami damage and current to less than 40%. By using these calculated results of tsunami reduction, the effects can be evaluated quantitatively related to the tsunami and forest conditions. However, the numerical simulation results in this section are calculated in the limited conditions of the tsunami period and the landform. In order to plan the costal forest for tsunami countermeasure, it is needed to further understand the costal forest effect related to the tsunami period and the landform.

Table 4 Tsunami reduction effect by coastal forest

Tsunami height（m）			1	2	3
Coastal control forest (Shuto, 1987)			Mitigate damage, Stop drafts, Reduce tsunami		
Run up distance	Forest width	50m	0.98	0.86	0.81
		100m	0.83	0.80	0.71
		200m	0.79	0.71	0.64
		400m	0.78	0.65	0.57
Inundation depth	Forest width	50	0.86	0.86	0.82
		100	0.76	0.74	0.66
		200	0.46	0.55	0.50
		400	---	0.11	0.18
Current	Forest width	50	0.71	0.58	0.54
		100	0.57	0.47	0.44
		200	0.56	0.39	0.34
		400	---	0.31	0.24
Hydraulic force	Forest width	50	0.53	0.48	0.39
		100	0.33	0.32	0.17
		200	0.01	0.13	0.08
		400	---	0.02	0.01

Table 5 Forest effect to tsunami reduction

		Tsunami height (m) 1 2 3
Tsunami reduction	Forest width < 200 m	A little effective (run-up, inundation depth: 90-70%)
	200 m< Forest width	Effective(run-up, inundation depth: 70-40%)
Tsunami damage mitigation	Forest width <100m	Effective (current: 70 - 40%) Much effective (hydraulic force: 70 - 40%)
	100m < Forest width	Much effective (current, hydraulic force: 70 - 40%)

3. Conclusions

The coastal forest conditions in the actual field are complied to obtain the relation between the forest density and diameter of trunk. Its diameter can be estimated from the forest density by using of this correlation, which is useful for the plan to coastal forest condition. The numerical simulation with forest model is carried out to evaluate the quantitative effect of tsunami reduction, and the results are summarized in some tables. This can give some quantitative information for the reduction effects of coastal forests. However, the results in this study are calculated in the limited conditions of the tsunami period and the landform. In order to plan the costal forest for tsunami countermeasure, it is needed to further understand the costal forest effect related to the tsunami period and the landform.

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要　旨

海岸林を津波防災対策に活用させるため，本研究では海岸林の流体力学的影響による津波低減効果を定量的に評価・検討した．評価する際に重要となる樹林密度と胸高直径の関係は，入手できた現地観測結果から条件設定を行った．これを用い，海岸林の影響を考慮した数値計算を行い，津波の低減効果を定量的に評価・検討を行った．その結果，いくつかの津波と海岸林の条件による津波低減効果を定量的に検討することのできる表を示した．

キーワード：海岸林，津波，林帯幅，樹林密度，津波低減効果

COE-11

津波災害低減のための防潮林（自然力）の活用について

河田惠昭・〇原田賢治

１．はじめに

低頻度で広域にわたる津波の対策として，全沿岸に長大な構造物による対策をとることは不可能である．しかし，物的津波被害の軽減のためには津波の進入を最小限にとどめる必要があり，構造物に加え防潮林などの自然力も活用した外力低下の対策が必要である．従来，津波対策において付加的要素としてしか着目されてこなかった防潮林の防災機能の再評価により，防災・環境・利用に配慮した海岸整備のひとつのツールとして防潮林を活用することができる．ここでは防潮林を考慮した津波数値シミュレーションを用いて，津波・防潮林の条件による津波低減の特徴について検討を行う．また，防潮林の活用についても述べる．

２．津波数値計算

津波数値計算は非線形浅水方程式を Leap-flog 法により差分化して行った．防潮林を抵抗として運動方程式に取り込み，防潮林幅，樹林密度，津波高さ，津波周期を変化させて数値計算を行った．防潮林の抵抗係数は水理模型実験に基づく抵抗係数モデル（原田,2003）を用いている．

３．防潮林による津波低減の特徴

計算結果の整理の例として，Fig.1,2 に防潮林による津波低減率と防潮林幅，津波周期の関係を示す．津波の浸水深の低減率は防潮林幅と比例関係にある事がわかる．200m の防潮林幅ならば，浸水被害に関係する浸水深を 5～6 割に，流体力による被害に関係する流速は 4～6 割に低下させることができる．また，津波周期が長くなると浸水深の低減率は大きくなる傾向にあるが，周期 20 分以下で防潮林幅 200m 以下の時には周期が短い方が低減率は大きくなる傾向が見られる．これらの検討結果より防潮林による津波低減効果を定量的に推定することが可能となり，防潮林の有効性が示された．

４．防潮林の活用について

津波は防潮林の間を通過することができるので，防潮林だけでは陸上遡上を全て防ぐことはできない．しかし防潮林をひとつの対策ツールとしてとらえ，構造物による対策等と組み合わせることで，防潮堤等の構造物の想定津波以上の津波に対しても多段的な対策をとることができ，津波遡上を低下させ被害を最小限にすることが可能である．防潮林の活用にはこのような組み合わせによる対策を地域の津波防災システムの中に取り込んでいく必要がある．具体例としては，大都市周辺の臨海埋め立て地に見られる未利用地を活用し，埋め立て地周辺の堤防と防潮林を都市公園の一環として整備することにより，防災・環境・利用に配慮した防潮林の利用を期待することができる．

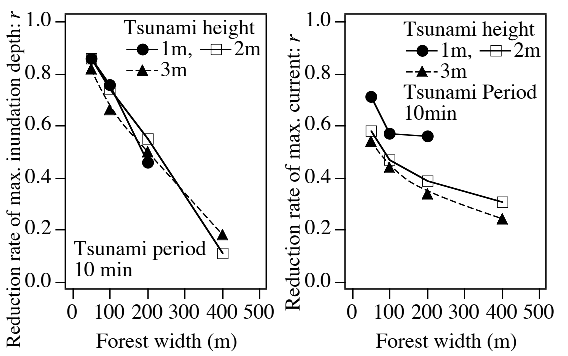

Fig. 1　防潮林幅と津波の減衰効果の関係

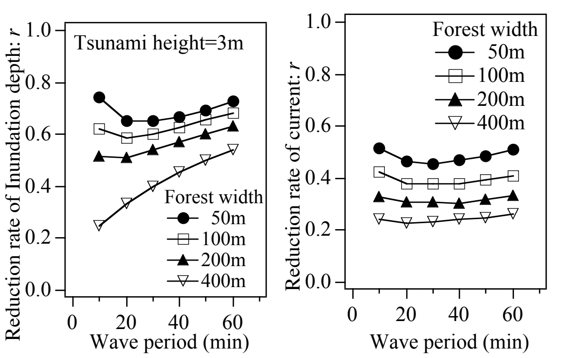

Fig.2　津波周期と津波低減効果