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Study on Tsunami Reduction Effect of Coastal Forest due to Forest Growth

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Synopsis

In order to evaluate the tsunami reduction effect of coastal forest due to forest growth, some case of numerical simulation was examined in this paper. The conditions for growth of coastal forest are selected from field survey data. The effect of coastal forest to tsunami reduction is considering with the equivalent roughness coefficient. This equivalent roughness coefficient of coastal forest is varied by inundation depth, tree shape and forest density. From this simulation result, it is shown that tsunami reduction effect of coastal forest is increased by growth of trees. As the return period of tsunami is long in general, this is important result for the maintenance and utilization of coastal forest.

Keywords: Coastal forest, Tsunami, Forest growth, Tsunami reduction

1. Introduction

The artificial coastal barriers have been constructed in Japan and have played an important role in protecting the city and coastal area from natural hazards such as tsunamis, tidal waves, and high waves. However, the artificial coastal barriers need high cost of the construction and maintenance, change the present environment and have forced inconvenient to use the coastal area. Therefore, the countermeasures against tsunamis by using the artificial coastal barriers are not recommended for all coastal areas. It is required that a new countermeasures corresponding to every area is considering with the combination with artificial and natural functions for more appropriate management for natural disaster reduction and keeping good environment. One of a new way to achieve that is to utilize control forest. Coastal forest can be used not only tsunami prevention but also green-park and scenic beauty area. In order to take the countermeasures for the mitigation of tsunami damage, it is necessary to predict the situation at the time of a tsunami attack, which considering with tsunami control forest. In order to evaluate coastal forest effects quantitatively, tsunami numerical simulation considering with the resistance of forest by using with equivalent roughness coefficient for the some forest conditions relate to tree growth were carried out. The forest density, the tree shape and the inundation depth vary the equivalent roughness coefficients of coastal forest. These values were remodeled from the hydraulic experiment results on coastal forest (Harada and Imamura, 2003). As trees consist of forest grow year by year, tsunami reduction effect is evaluated by numerical simulation for 50 years growth of forest in every 10 year. In this paper, it is reported that the result of tsunami reduction effect is examined by using the growth model of coastal forest.

2. Conditions of Coastal Forest

2.1 Administration of Coastal Forest

In order to evaluate the tsunami reduction effect due to forest growth, some conditions on growth of coastal forest should be selected for numerical simulation.

Generally in Japan, coastal forest is consisted by the pine trees; pinus thunbergi. The young tree of pine tree is planted artificially in sandy coast of Japan by 10,000 trees/ha (1 trees/m^2), usually. As this forest density is too much for tree growth, tree thinning would be done after next decade. It is empirical method for the coastal forest administration in Japan to thin out 1/3 after 10 years and to thin out further 1/3 after 20 years. Therefore, the coastal forest that controlled forest density has approximately 3,000 trees/ha (0.3 trees/m^2). In this study also, it is considering with the tree thinning like that way. The young tree of pine tree would be thin and ineffective to mitigate tsunami damage due to the tree thinning. On the other hand, the return period of tsunami is long in general, for example several decades or several hundred years. This means that these are enough time to grow up coastal forest effectively against tsunami.

2.2 Forest Conditions for Simulation

Harada and Imamura (2003) summarized the relation between forest density and trunk diameter from the field survey data of pine tree forest in Japan (see Figure 1). 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, trunk, leaf and root are controlled 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 diameter of trunk corresponding to the forest density would be selected to 0.15 m and 0.3 trees/m^2, 0.07m and 0.7 trees/m^2, and 0.05 m and 1.0 trees /m^2. The conditions due to growth of coastal forest in this study are summarized in Table 1, which considering with Figure 1 and tree thinning effects. The tree height and the brunch height are selected from field survey data (Aburaya, 2000). Brunch height becomes high, when tree height becomes high. Forest width is an important parameter for tsunami reduction and it varies from place to place in fields. In this study, the forest width is selected to 200m and the forest is put at a distances of 100m from shoreline. And the projected area rate of leaves is given to be 0.65 from field survey data by Aburaya (2000) in this study. These conditions are used to evaluate the effect of tsunami reduction by numerical simulation. From these conditions of coastal forest in Table 1, the coastal forest is modeled to evaluate the effect of tsunami reduction by forest growth.

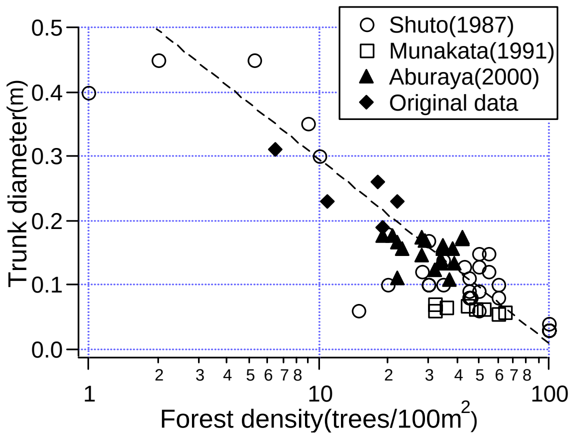


Fig. 1 Relation of forest density and diameter of trunk (Harada et al, 2003)

Table 1 Conditions of Coastal Forest in This Study

Forest Age (year)	Diameter (m)	Forest density (trees/m^2)	Tree Height (m)	Branch height (m)	Forest width (m)
0	0.05	1.0	0.5	0.0	200
10	0.07	0.7	4.0	0.5	200
20	0.09	0.3	7.0	1.0	200
30	0.11	0.3	9.5	1.5	200
40	0.13	0.3	11.5	2.0	200
50	0.15	0.3	13.0	2.5	200

3. Equivalent Roughness Coefficient of Coastal Forest

3.1 Equivalent Roughness Coefficient

Kotani et al. (1998) were assumed the effect of forest with Manning's roughness coefficient n = 0.03. This value was selected as averaged value of previous studies on land flooding and assumed as a constant value. However, the resistance force due to forest would be varied due to tree shape and inundation depth in actuality. In this section, it is introduce the equivalent roughness coefficient that is varied by forest shape and inundation depth.

The resistance force: F_D due to the forest is expressed as equation (1) by using Manning's roughness coefficient: n. Here, τ_x is the resistance force per unit area, $\Delta x, \Delta y$ are the length of control area, ρ is the water density, g is gravity acceleration, D is inundation depth, M, N are discharge to x and y direction. On the other hand, the resistance force can be express as equation (2) by using the drag coefficient of a tree:C_D.

T_{num} is the number of trees in control area of $\Delta x, \Delta y$. d is the diameter of a tree for projected area. From equation (1) and (2), equivalent roughness coefficient of forest: n_{forest} can be expressed by equation (3). This equation (3) shows that the equivalent roughness coefficient is the function of the projected area: $d \cdot D$, the inundation depth: D and the number of trees par unit area: $T_{mun}/\Delta x \Delta y$. As described in conditions of coastal forest, the coastal forest density in Japan is about 1.0 - 0.3 trees/m^2. Harada and Imamura (2003) suggested the drag coefficient: C_D of coastal forest like equation (4). Vo/V is the volume occupation rate of trees under water.

$$F_{Dx} = \tau_x \cdot \Delta x \cdot \Delta y = \rho \frac{gn^2}{D^{7/3}} M \sqrt{M^2 + N^2} \cdot \Delta x \cdot \Delta y \quad (1)$$

$$F_{Dx} = \frac{\rho}{2} \cdot C_D \cdot d \cdot D \cdot \frac{M\sqrt{M^2 + N^2}}{D^2} \cdot T_{num} \quad (2)$$

$$n_{forest} = \left(\frac{C_D}{2g} \cdot d \cdot D \cdot D^{1/3} \frac{T_{mun}}{\Delta x \cdot \Delta y} \right)^{1/2} \quad (3)$$

$$C_D = 8.4 \frac{Vo}{V} + 0.66 \quad (4)$$

3.2 Changes of Equivalent Roughness Coefficient due to Forest Age

From the condition of coastal forest in Table 1 and equation (3) and (4), Figure 2 is shown the relation of equivalent roughness coefficient and inundation depth. Generally in tsunami numerical simulation, the effect of land-use is evaluated as Manning's roughness coefficient.

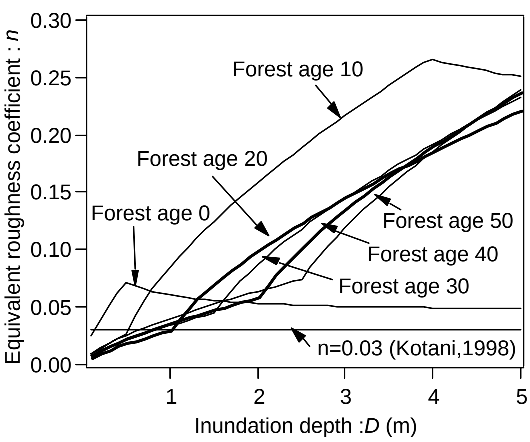


Fig.2 Relation of equivalent roughness coefficient and inundation depth

Each forest age lines are changing the direction at the brunch height level and the tree height. Equivalent roughness coefficient in the case of forestage 0 and 10 year become large by the increase of inundation depth until submerged tree and the value of coefficient become large than 0.03 that suggested by Kotani(1998). On the other hand, in the case over 20 year in forestage, the roughness coefficient of immature forest becomes larger than the mature forest over 2.2 m in inundation depth, as the brunch height becomes high with forest growth in the condition of this study and field coastal forest. However, the roughness coefficient of forest becomes large year by year, even if the forest thins out with growth of trees. This means that the tsunami reduction effect by coastal forest becomes large year by year.

4. Tsunami Numerical Simulation

4.1 Conditions for Simulation

In order to evaluate the effect of tsunami reduction by coastal forest growth, tsunami numerical simulation with run up including the resistance of the control forest is carried out and examined the tsunami reduction effect. In this study, the coastal landform of Gobo Bay is selected as an example. Here is a high-risk area for Tsunami due to the next Tounankai - Nankai earthquake. And there is a large coastal forest that calls " Enjyugahama ". To evaluate the effect of forest growth, the landform is modeled simplify as the slope of 1/500 gradient in land-area and 1/200 gradient in sea-area (Figure 3).

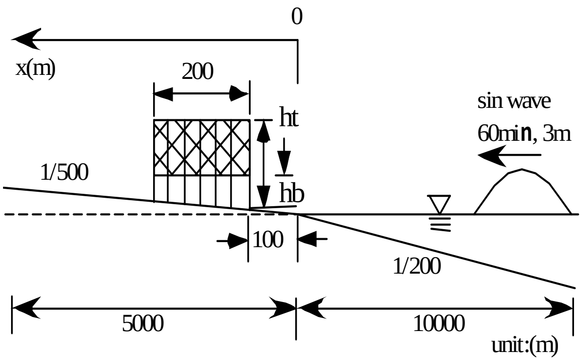
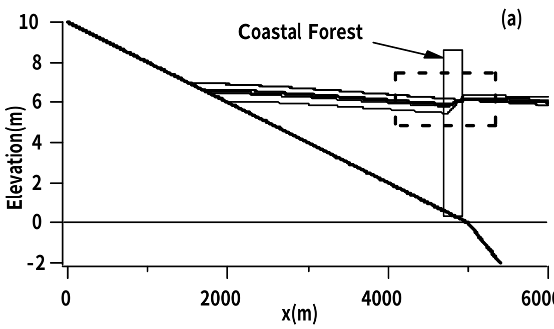


Fig. 3 Numerical Simulation Conditions

The tsunami, which estimated from the model of Tonankai-Nankai Earthquake by Central Disaster Prevention Council of Japan, is roughly 3m in tsunami height and 60minits in period in this area. Therefore the incident tsunami is assumed as the sinusoidal wave of 3m in height and 60 minutes in period. And the calculated time is 2 hours. It is said when the tsunami heights exceed 4 m, tree would start to be broken (Shuto, 1987). In this simulation, trees breaking cannot be properly modeled. Therefore, tsunami height is selected smaller than 4 m.

4.2 Calculated Results

As an example of the numerical simulation results, Figure 4 shows the maximum tsunami elevation due to forest growth. And the reduction rate of maximum tsunami height is shown in Figure 5. From these figures, it can be realize that the tsunami reduction effect of coastal forest is varied due to the forest growth. Especially, the case of 10 year of forest age is much reduces tsunami height at inland area. As described above the chapter of equivalent roughness, the tree of 10 years old have the low brunch height and the high tree height. This case forest have large equivalent roughness coefficient. And the variation after 20 year is not so large, because the brunch height becomes relatively high to the inundation depth.



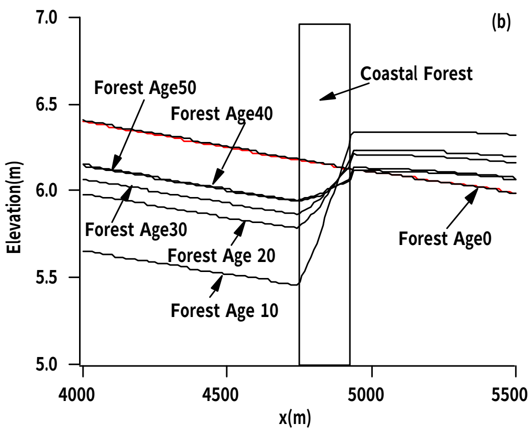


Fig.4 Calculated results of tsunami height.
(a) shows the large area of maximum tsunami height
(b) shows the small area around coastal forest

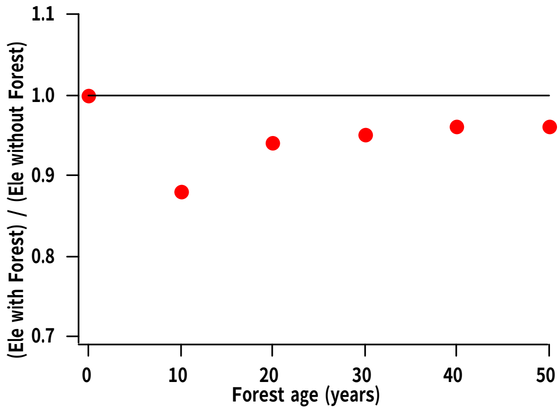


Fig.5 Relation of Reduction rate of maximum tsunami height and Forest years

5. Conclusions

In order to evaluate the tsunami reduction effect of coastal forest due to forest growth, tsunami numerical simulation is calculated on some forest cases and examined. In this numerical simulation, it is shown that the forest growth conditions are varied the tsunami reductions. Especially, the tsunami reduction effect is affected strongly by the brunch height. From these examined results, it can be say that the tsunami reduction effect with high brunch is smaller than the case with low brunch. Therefore, the low brunch would play a important role to reduce tsunami height. Although the brunch effect is included the simplified model in this study, the further investigation would be need to examine the management method of coastal forest to mitigate tsunami disaster.

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海岸林の生長による津波減衰効果の検討

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要旨

海岸林を構成する樹木は生き物であるため生長して形状を変化させる事になるため，樹木の生長に伴い海岸林による津波減衰効果も変化する事が考えられる．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生長および密度管理間伐による津波低減効果の変化を検討した．海岸林樹林構造の変化の検討は，植林後10年ごとの海岸林条件を設定し，植林後50年後までの海岸林の津波減衰効果の変化を数値解析により評価した．

キーワード:，海岸林，津波，津波低減効果，海岸林生長，間伐

海岸林による津波減衰効果の活用について

○原田賢治・河田惠昭

１．はじめに

2004 年スマトラ島沖地震津波は，インド洋沿岸各国へ甚大な被害をもたらしている．このような，広域にわたる津波の対策として，日本のような全ての海岸に長大な構造物による対策をとることは，環境や経済的問題があり，実践的な津波対策としては実現不可能であると考えられる．津波災害は低頻度で甚大な被害をもたらす災害になるため，その対策には対象沿岸域に対する利用・防災・環境の要求を満足する様な工夫が必要である．しかし，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事が非常に有効であるため，構造物に加え海岸林などの自然力を活用した外力低下の対策も必要となってくる．従来，日本においては，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海岸林の防災機能の再評価をすることにより，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海岸林を活用することが可能となる．実際に，今回のスマトラ沖地震津波を受けて，東南アジア各国では海岸整備における津波対策として，海岸林による津波減衰効果を期待しており，その活用手法について注目がされている．ここでは海岸林を考慮した津波数値シミュレーション手法を用いて，津波・海岸林の条件による津波減衰効果の特徴について検討を行った．

２．海岸林の生長と管理状況

海岸林を構成する樹木は生き物であるため生長して形状を変化させる事になるため，樹木の生長に伴い海岸林による津波減衰効果も変化する事が考えられる．そのため，海岸林の生長と管理状況による海岸林条件について，海岸林を造成・管理している営林署等に問い合わせによる調査を行った．日本の海岸林造成の場合, 10,000 本/*ha*（1 本/m^2）でクロマツの幼木を植林する場合が多い．この密度は樹木が生長するためには，密集しすぎているため，植林後 10 年を目安に 7,000 本/ha（0.7 本/m^2），20 年を目安に 3,000 本/ha（0.3 本/m^2）と植林時の 1/3 の樹林密度になるよう間伐をして密度管理をする事が行われている．また，樹林密度と胸高直径の間には，受光量による生長関係があり，樹林密度が濃いと胸高直径は細くなる事が既に分かっている．

３．海岸林の機能の活用について

（１）海岸林の生長による津波減衰効果の変化

海岸林の生長による樹林構造の変化の影響を検討するため，植林後 10 年ごとの海岸林条件を設定し，植林後 50 年後までの海岸林の津波減衰効果の変化の数値解析を行った. 海岸林は 10,000 本/ha で植林し，10 年後に 7,000 本/ha，20 年後に 3,000 本/ha になるよう本数調整間伐を行う設定とした．津波数値シミュレーションの結果，植林後 10 年後として設定した海岸林条件の時に津波減衰効果が大きくなり，その後徐々に減衰効果が小さくなる傾向となった．これは，密集した樹木の生長に伴い下枝が枯れ上がる事により枝下高が高くなり，津波に対する抵抗が小さくなるためであることが示された．これらの数値シミュレーションの結果から，海岸林の管理において，下枝が枯れ上がる前に本数調整間伐をする事により，津波に対して効果的な海岸林に管理することが出来ると考えられる．

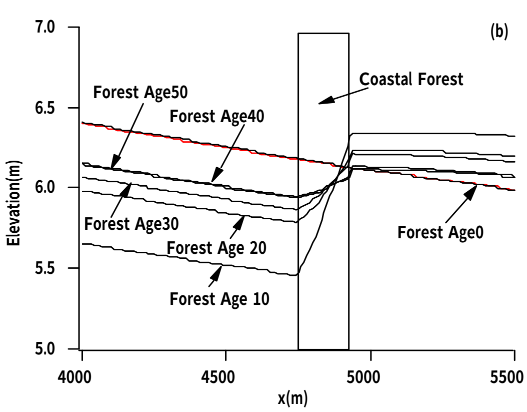

Fig.1　海岸林の生長による津波減衰効果の変化