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The State of the Art and Science of Coastal Engineering

Development of Tsunami Inundation Evaluation Method Considering Damage Level of Seawall

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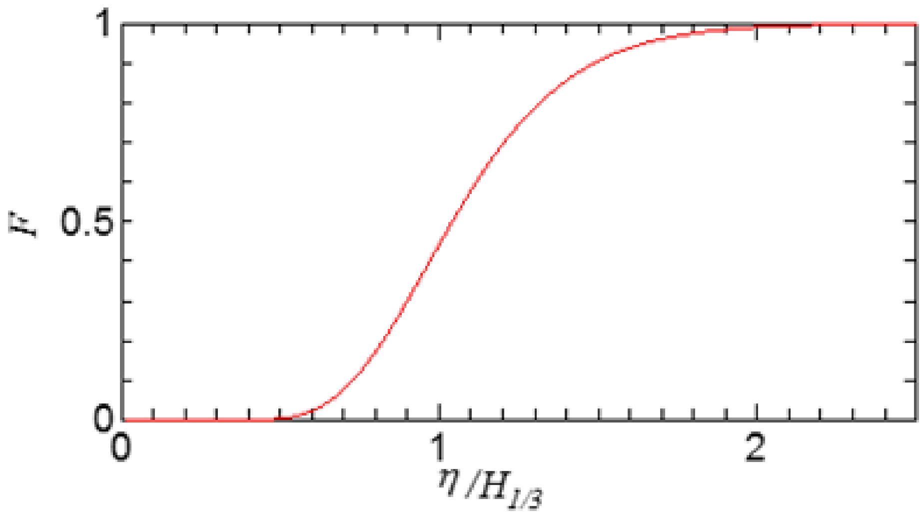
1. Introduction

Against the huge tsunami, structures such as breakwater and seawall are constructed. The expected effects of these structures are to reduce the inundation depth and inundation area.

It is necessary to reflect the situation of these structures in the numerical models when estimating tsunami inundation phenomena.

However in the present technology, it is difficult to predict while to estimate and reflect the destruction process by earthquake and tsunami attack.

In this study, we assume that the damage level of structures are uncertain phenomenon and we develop that evaluated the tsunami inundation stochastically using Monte Carlo method.



Fragility curve of breakwater (PIANC,2013)

2. Numerical Model and Condition

2.1 Numerical Model

2.2 Calculation Setup

2.3 Concept of Seawall Condition Considering Damage Level

2.1 Numerical Model

STOC-ML is a quasi-3-dimensional model for calculating fluid dynamics that result from a tsunami by using hydrostatic approximation. The numerical simulator named STOC (Storm surge and Tsunami simulator in Oceans and Coastal areas) was developed by Port and Airport Research Institute (PARI).

Continuity Equation

$$\frac{\partial}{\partial x}(\gamma_x u)+\frac{\partial}{\partial y}(\gamma_y v)+\frac{\partial}{\partial z}(\gamma_z w)=0$$

Free Surface Equation

$$\gamma_z \frac{\partial \eta}{\partial t}+\frac{\partial}{\partial x}\int_{-H}^{\eta}\gamma_x u\,dz+\frac{\partial}{\partial y}\int_{-H}^{\eta}\gamma_y v\,dz=0$$

u,v,w: flow velocity
γ_v: Porous values (porosity)
γ_x, γ_y, γ_z: Porous values (permeability in each direction)
η: Water level
H: Water depth
f_0: Coriolis parameter
ν_H: Horizontal kinematic viscosity coefficient
ν_V: Vertical kinematic viscosity coefficient

Momentum Conservation Equation (x)

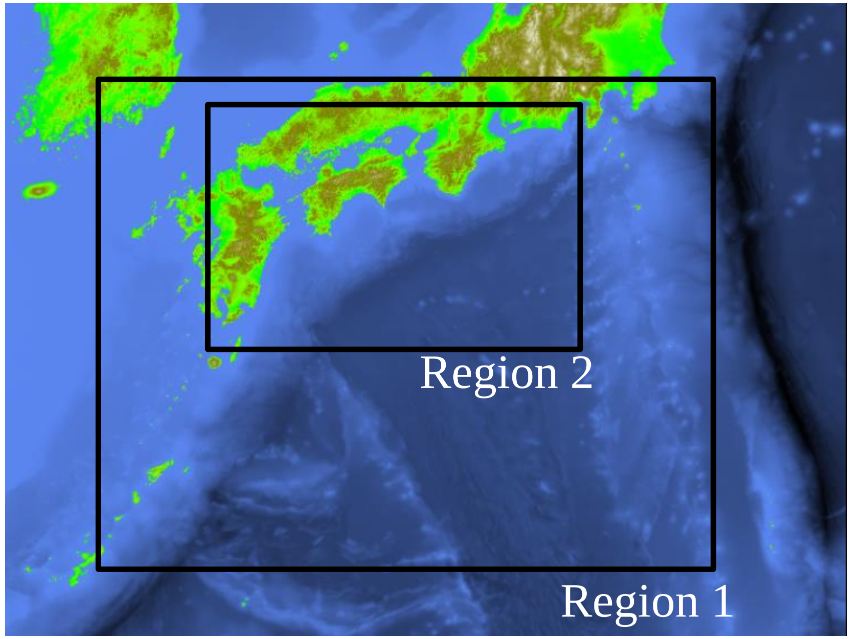
$$\gamma_v \frac{\partial u}{\partial t}+\frac{\partial}{\partial x}(\gamma_x uu)+\frac{\partial}{\partial y}(\gamma_y uv)+\frac{\partial}{\partial z}(\gamma_z uw)-\gamma_v f_0 v$$
$$=-\gamma_v \frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(\gamma_x \nu_H 2\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left\{\gamma_y \nu_H\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right\}$$
$$+\frac{\partial}{\partial z}\left\{\gamma_z \nu_V\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right\}$$

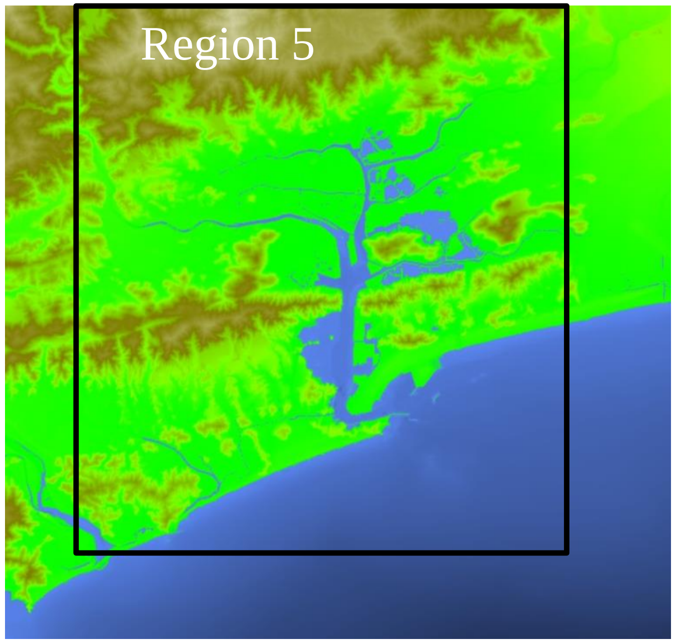
Momentum Conservation Equation (y)

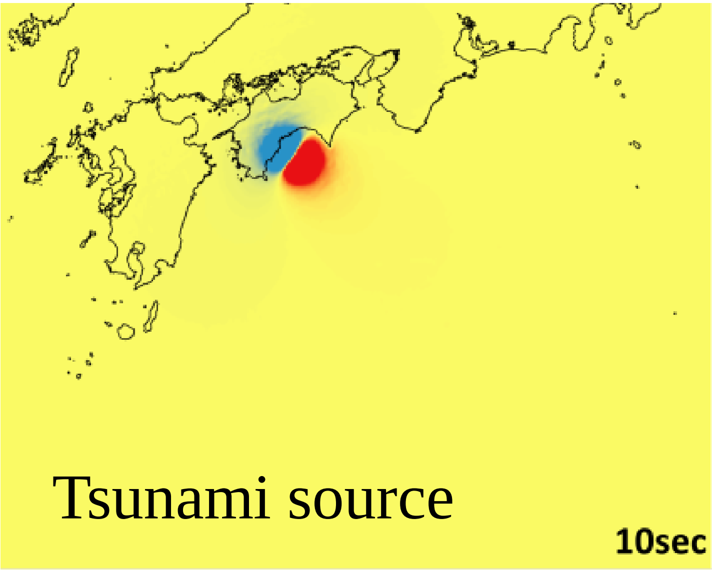
$$\gamma_v \frac{\partial v}{\partial t}+\frac{\partial}{\partial x}(\gamma_x vu)+\frac{\partial}{\partial y}(\gamma_y vv)+\frac{\partial}{\partial z}(\gamma_z vw)+\gamma_v f_0 u$$
$$=-\gamma_v \frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left\{\gamma_x \nu_H\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right\}+\frac{\partial}{\partial y}\left(\gamma_y \nu_H 2\frac{\partial v}{\partial y}\right)$$
$$+\frac{\partial}{\partial z}\left\{\gamma_z \nu_V\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right\}$$

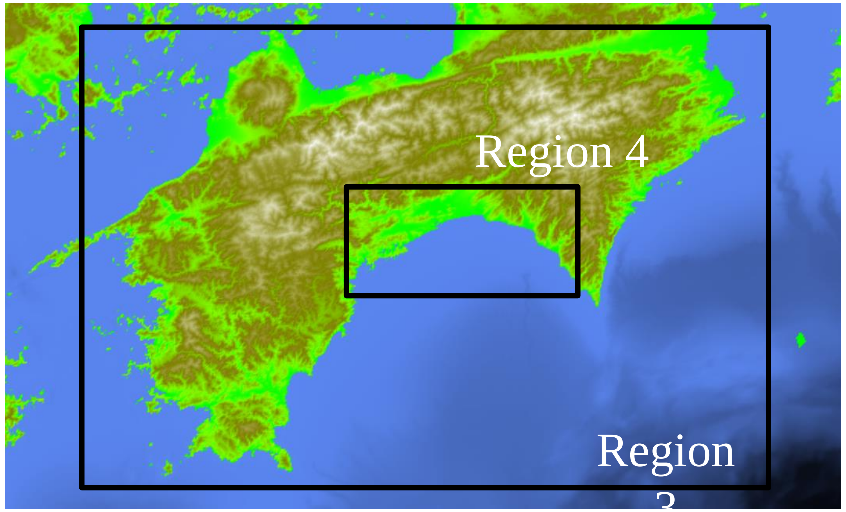
2.2 Calculation Setup

Calculation Area









	Grid size	Number of cells (X direction)	Number of cells (Y direction)
Region 1	2430m	500	400
Region 2	810m	900	600
Region 3	270m	900	600
Region 4	90m	900	420
Region 5	30m	480	540

2.3 Concept of Seawall Condition Considering Damage Level

Situation

(1) Without Seawall (Damage rate P=1.0)

(2) No damage for seawall (P=0.0)

(3) Cases with some damage in seawall ($0<P<1$)

(3)-1 The crown height of seawall decrease

⇒Decrease the crown height of all seawall uniformly according to the damage rate P.

(3)-2 Case that collapse of seawall occurs

⇒Set the crown height to 0 at the ratio corresponding to the damage rate P for all seawall.

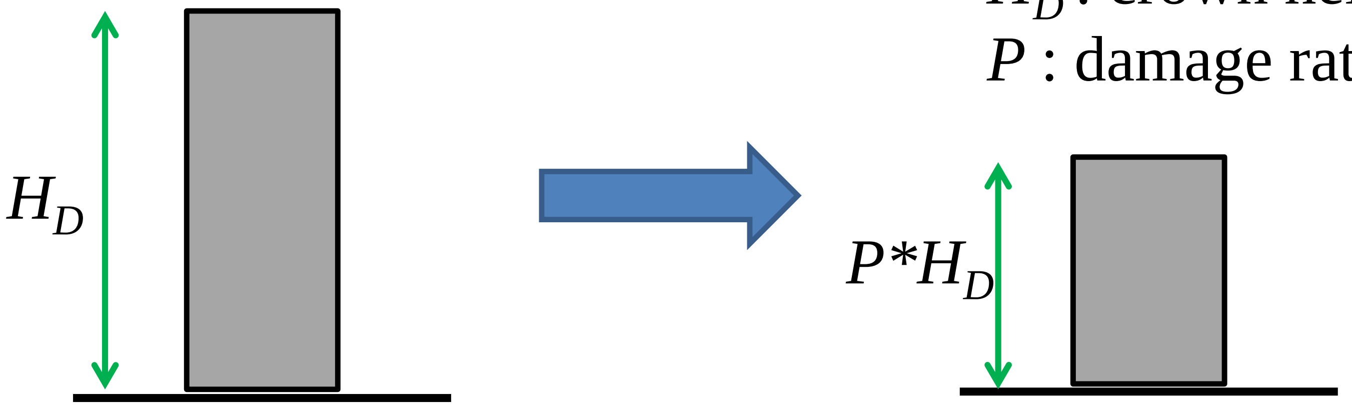
(4) Collapsed the seawall at overflow start

2.3 Concept of Seawall Condition Considering Damage Level

(3) Cases with some damage in seawall

(3)-1 The crown height of seawall decrease (situation of subsidence)

⇒Decrease the crown height of all seawall uniformly according to the damage rate *P*.



H_D : crown height of seawall

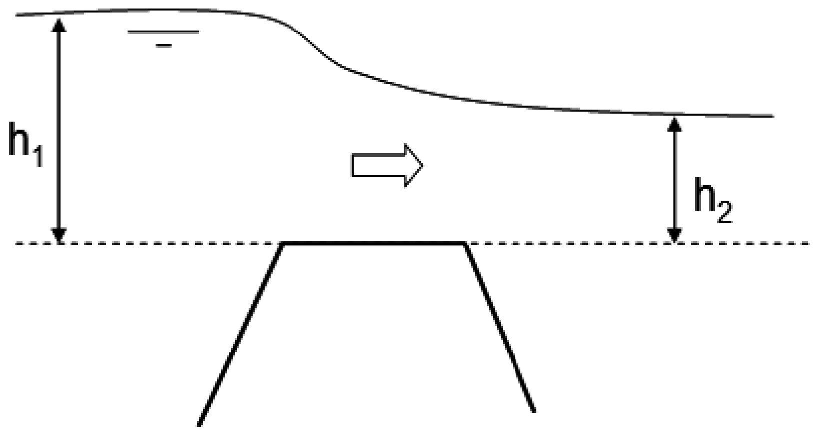
P : damage rate

Cross-section view

Overflow Model (Homma's formula)

$$q = 0.35 h_1 \sqrt{2 g h_1} \qquad h_2 \le \frac{2}{3} h_1$$

$$q = 0.91 h_2 \sqrt{2 g (h_1 - h_2)} \qquad h_2 > \frac{2}{3} h_1$$

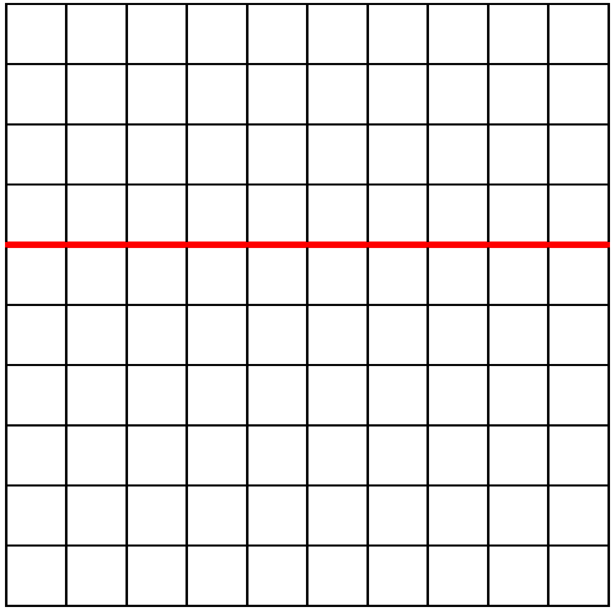


2.3 Concept of Seawall Condition Considering Damage Level

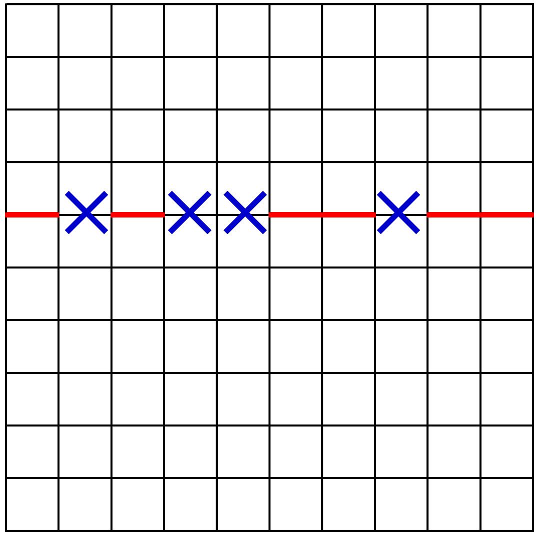
(3)-2 Case that collapse of seawall occurs

⇒Set the crown height to 0 at the ratio corresponding to the damage rate *P* for all seawalls.

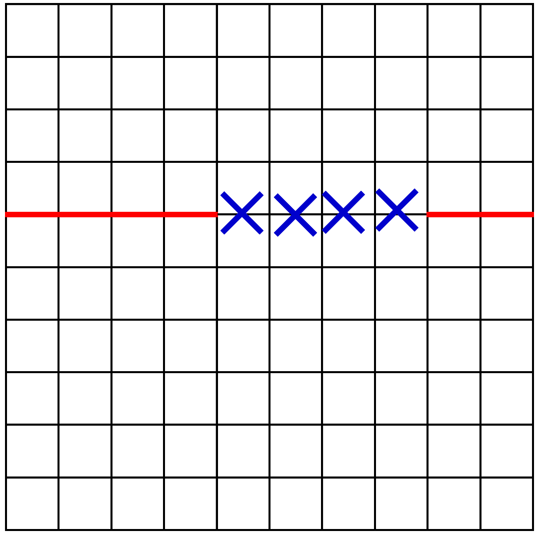
Red line : Seawall



P=0



P=0.4 pattern 1



P=0.4 pattern 2

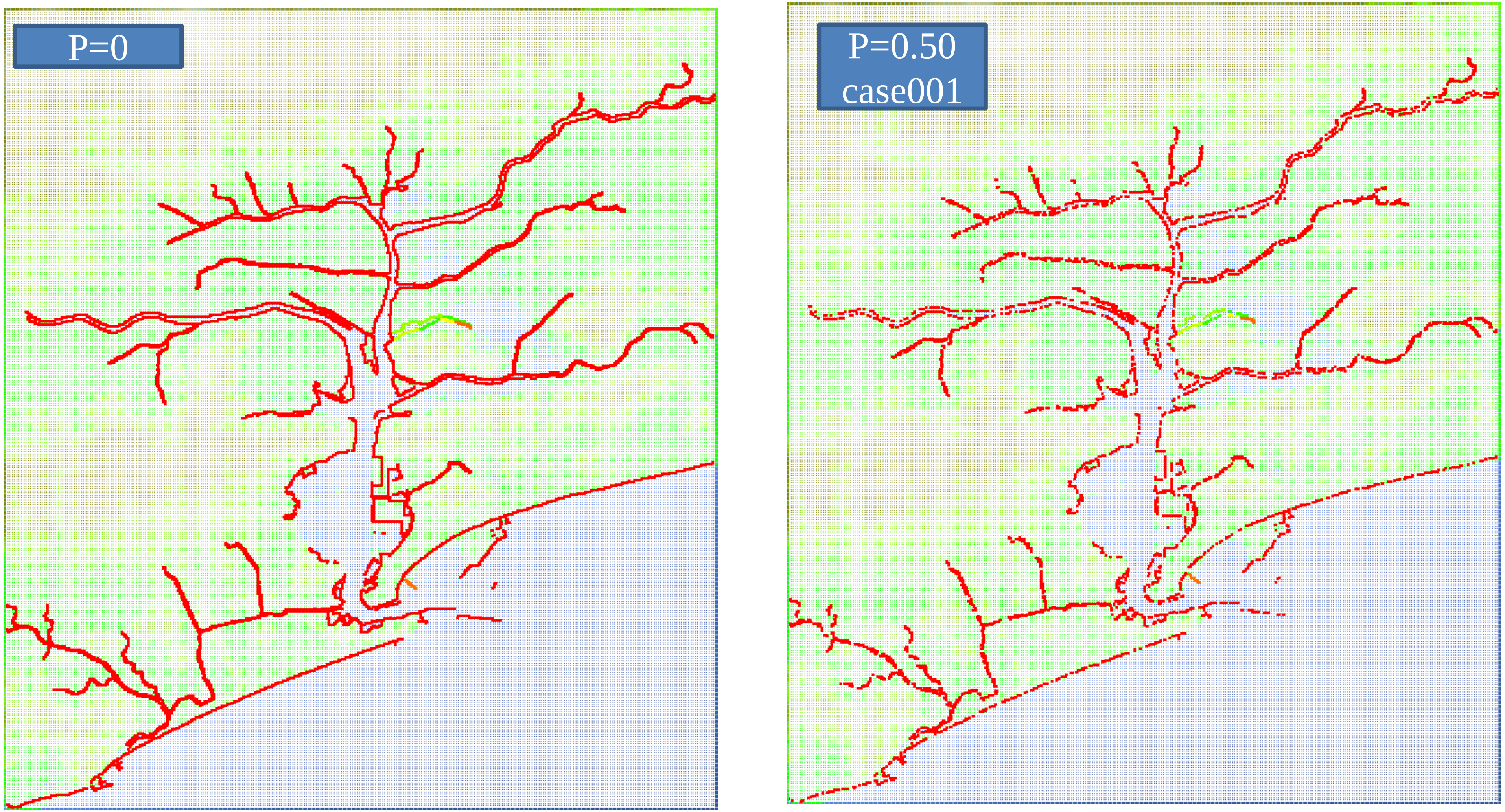
…

We determined the at random using uniform random number applying Monte Carlo Method.

We carried out the 100 cases each damage rate.

Plan view *P*=0.4 example

2.3 Concept of Seawall Condition Considering Damage Level



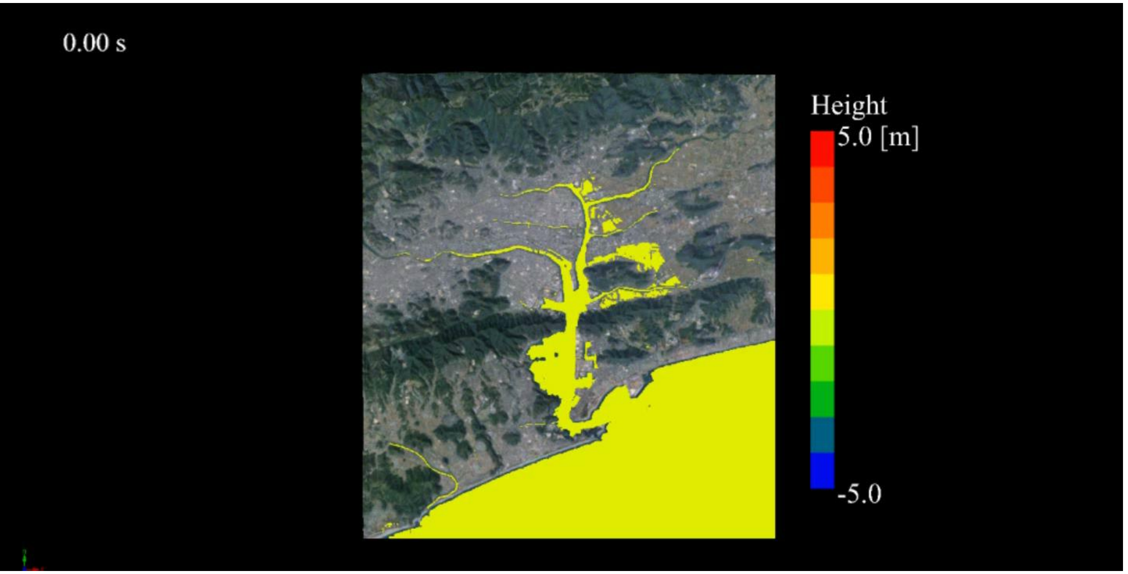
Arrangement of seawall sample of case *P*=0.5

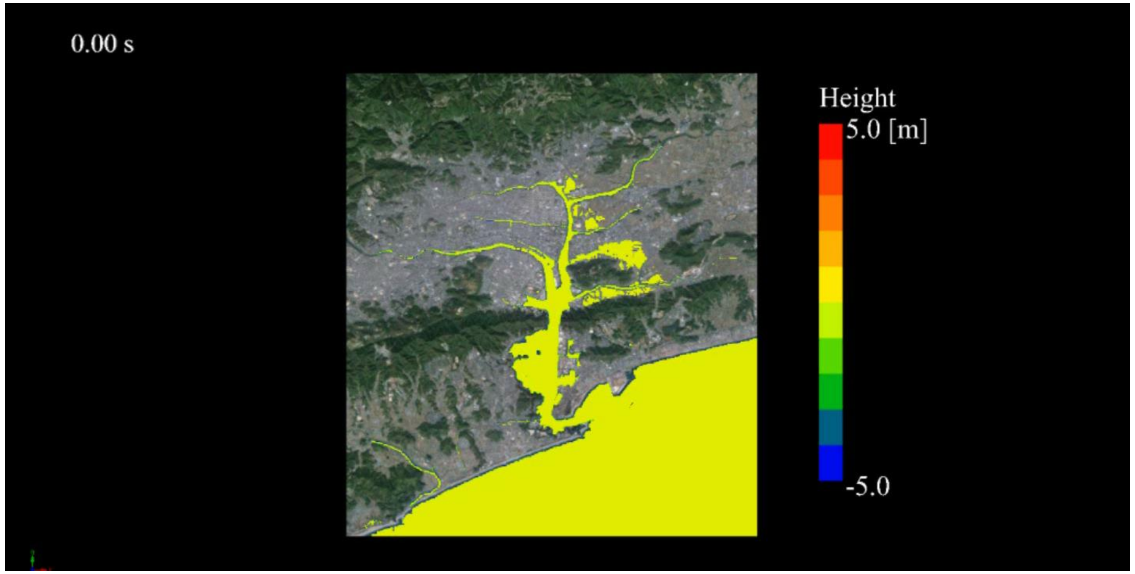
2.3 Concept of Seawall Condition Considering Damage Level

List of calculation cases
Total 913 cases

Damage Rate P [%]	Situation (3)-1	Situation (3)-2	Memo
0	1		Situation (2)
10	1	100	
20	1	100	
30	1	100	
40	1	100	
50	1	100	
60	1	100	
70	1	100	
80	1	100	
90	1	100	
100	1		Situation (1)
Collapsed the seawall at overflow start			

Animation





P=0 No Damage

P=1.0 Without Seawall

3. Influence of Damage Level of Seawall on Inundation

3.1 Influence of Subsidence

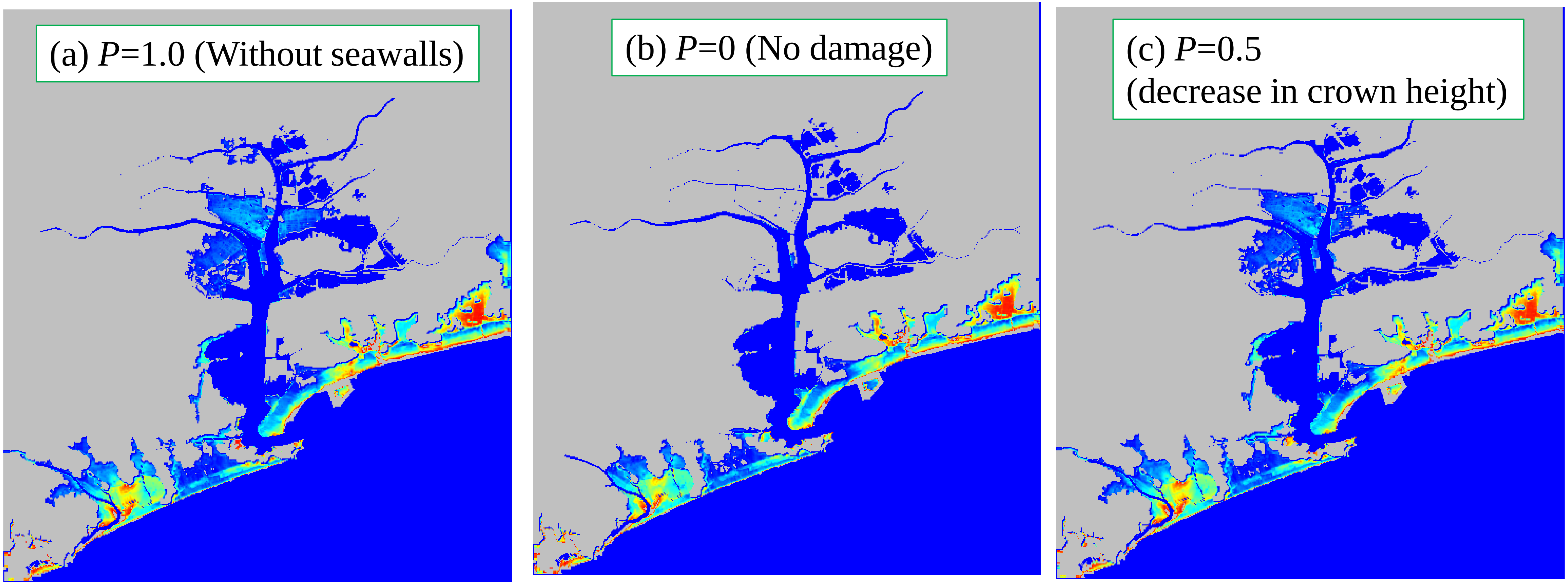
3.2 Difference in Inundation Area

3.3 Difference in Inundation Start Time

3.4 Inundation Probability

3.5 Influence of Tsunami Source Area

3.1 Influence of decreased crown height

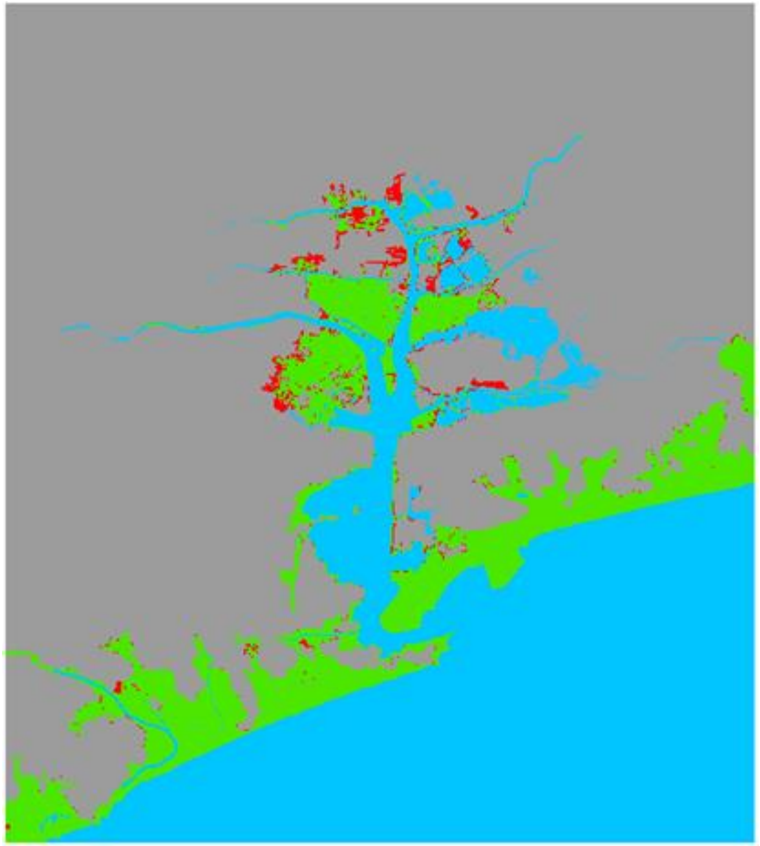


Maximum
inundation depth

Case (a) and (b) have big different, but the difference of case (a) and (c) is small.

3.2 Difference in Inundation Area

(a) Decrease in crown height (10～90%,　9 case)



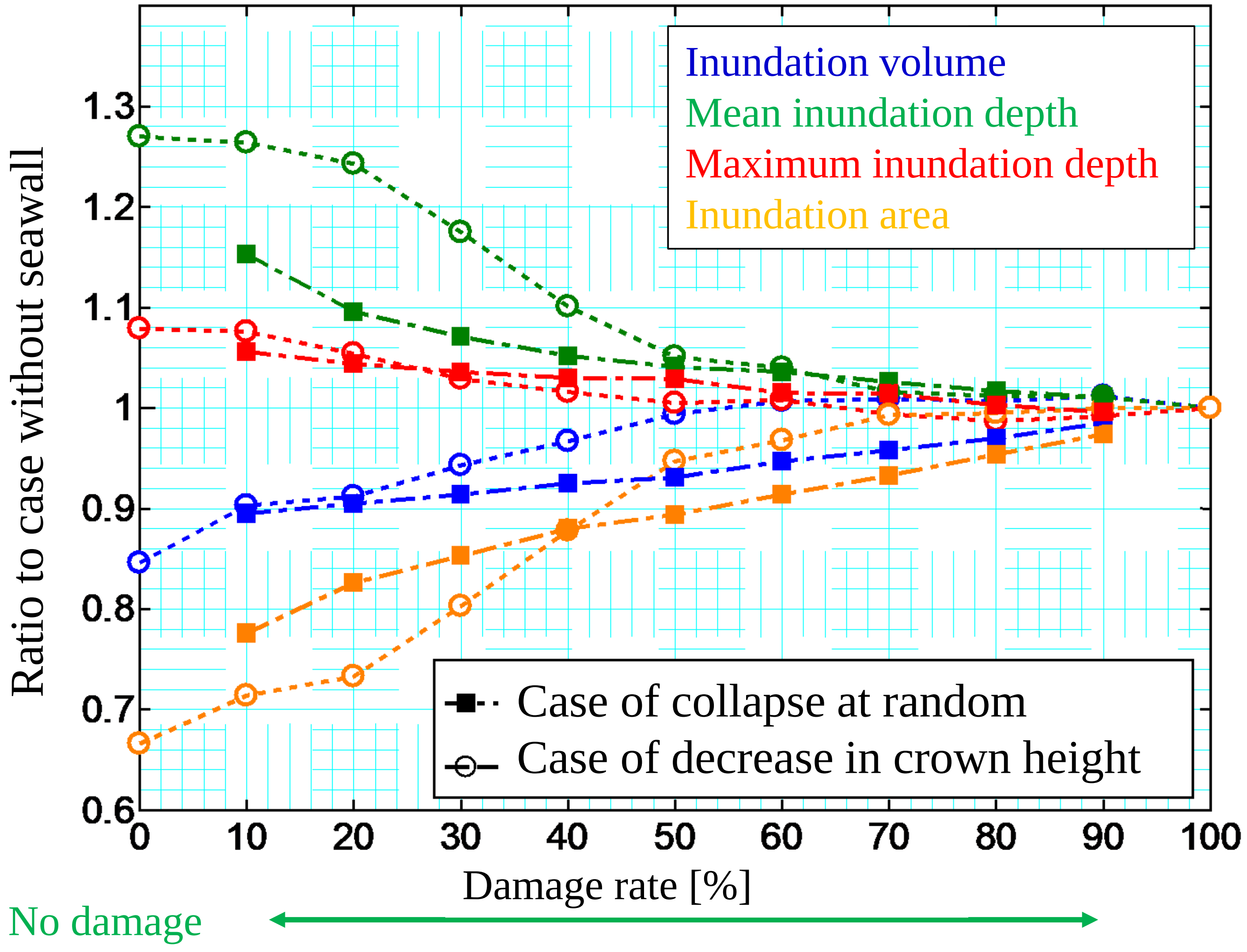
(b) Collapsed at random (10～90%,　900 case)

(c) Collapsed the seawall at overflow start(1 case)

Red area：Increased inundation area compared to Case without seawall.

Increasing inundation area in case of collapsed at random is larger then another case.

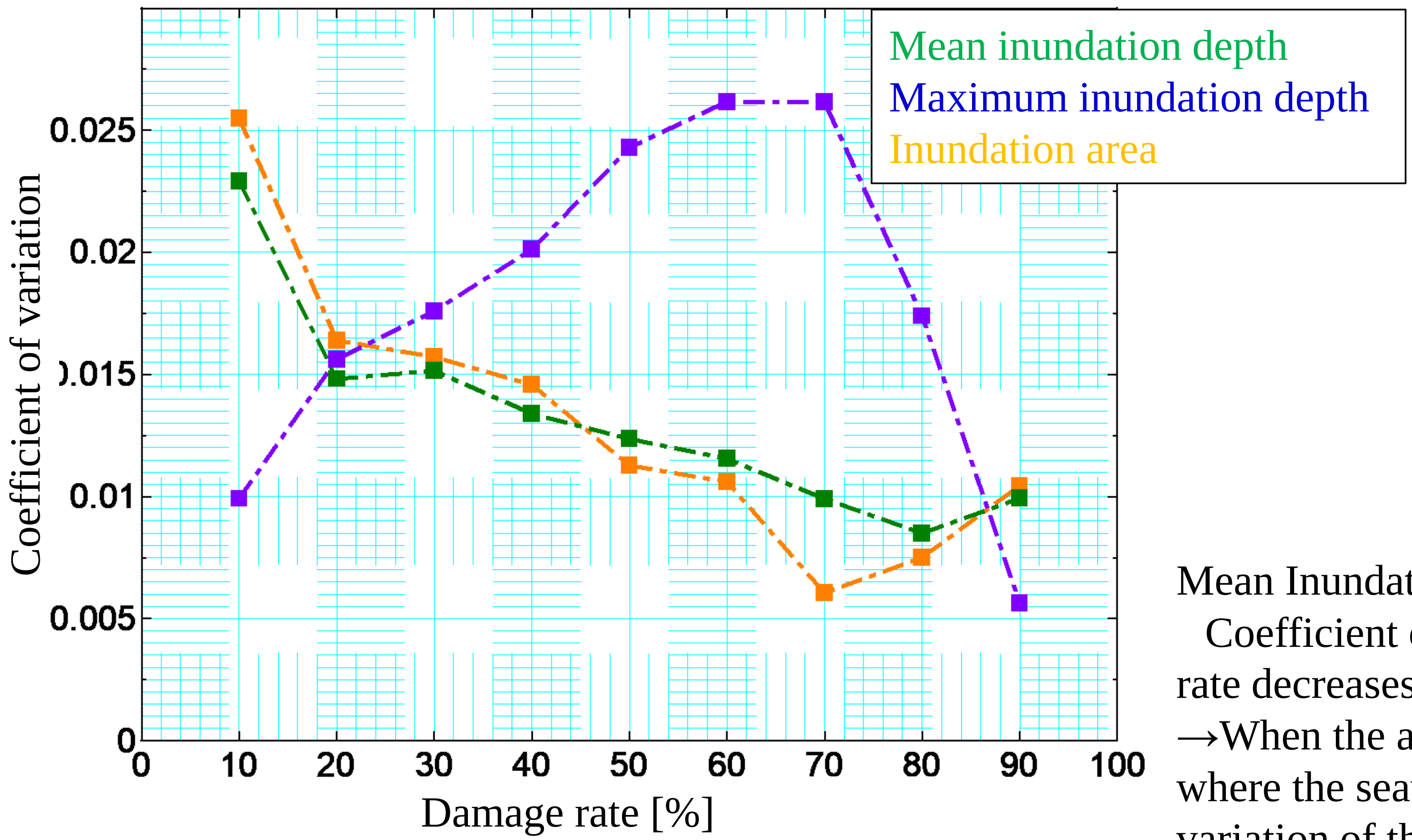
3.2 Difference in Inundation Area



The inundation volume and inundation area is decreased due to seawalls.
However, the average and maximum inundation depth is increased compared with the case without seawalls.

3.2 Difference in Inundation Area

Case of collapse at random

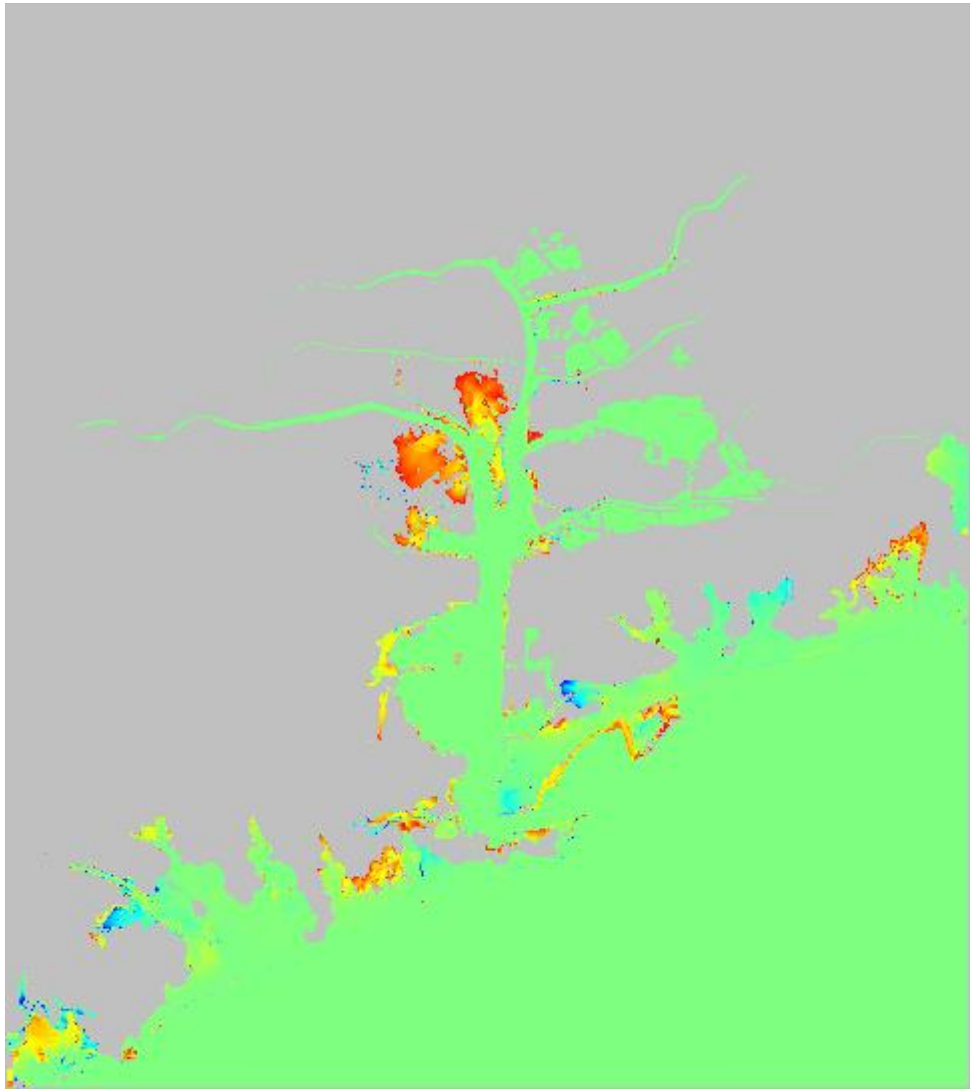


Coefficient of variation = standard deviation/mean value

C.V. is a standardized measure of dispersion of a probability distribution or frequency distribution.

Mean Inundation depth and Inundation Area:
Coefficient of variation increases as the damage rate decreases
→When the amage rate is small, the influence of where the seawalls are collapse is large, and the variation of the data becomes large
Maximum inundation depth:
There is a maximum value in range of 0.6 to 0.7 about damage rate.

3.3 Difference in Inundation Start Time

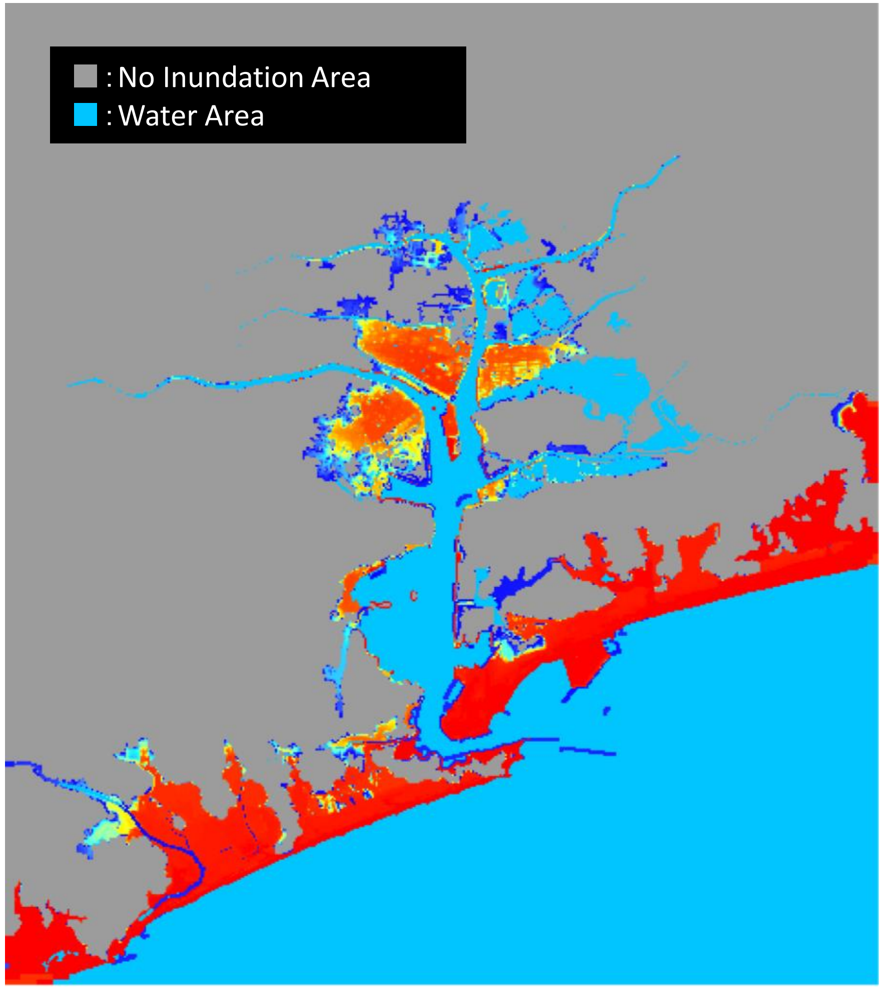


Difference of inundation start time

At inner bay, seawalls have the effect of delaying the inundation start time by about one or two minutes.

Difference of inundation start time in the case of all collapse at the beginning and seawall height of P=0.5.

3.4 Inundation Probability



Red : Inundation anyway

Blue : Inundation depending on the destruction situation of seawalls

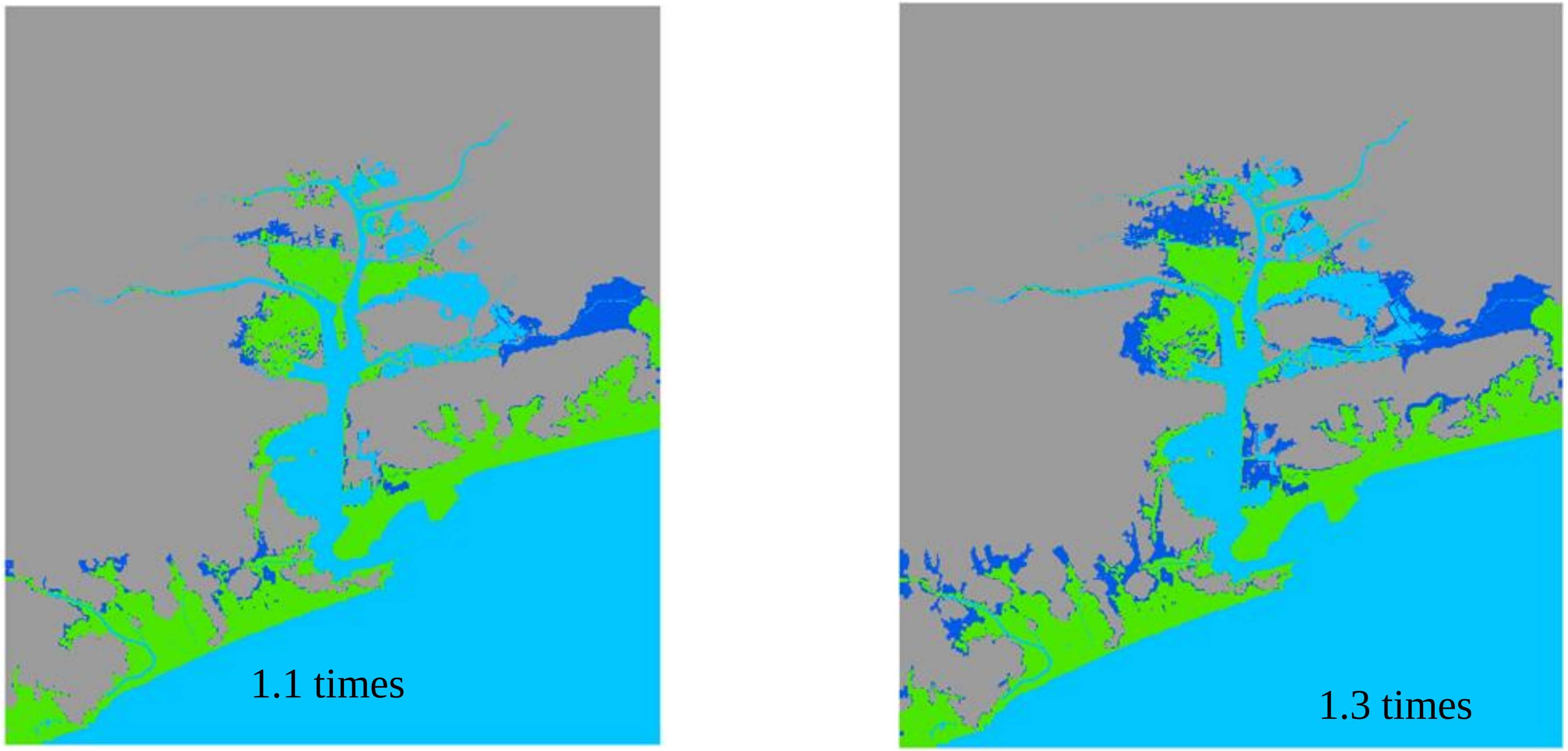
In the case of the huge tsunami we examined this time, the difference in destruction situation of seawalls becomes relatively small.

Need more consideration

Calculation result of inundation occurrence probability

Number of inundation cases for each cell/Number of calculation cases

3.5 Influence of Tsunami Source Area



Difference of inundation area when tsunami source is increased
（■ : Original inundation area, ■ : Increased inundation area）

Thinking on the safe side, there may be a method of predicting by increasing tsunami source.

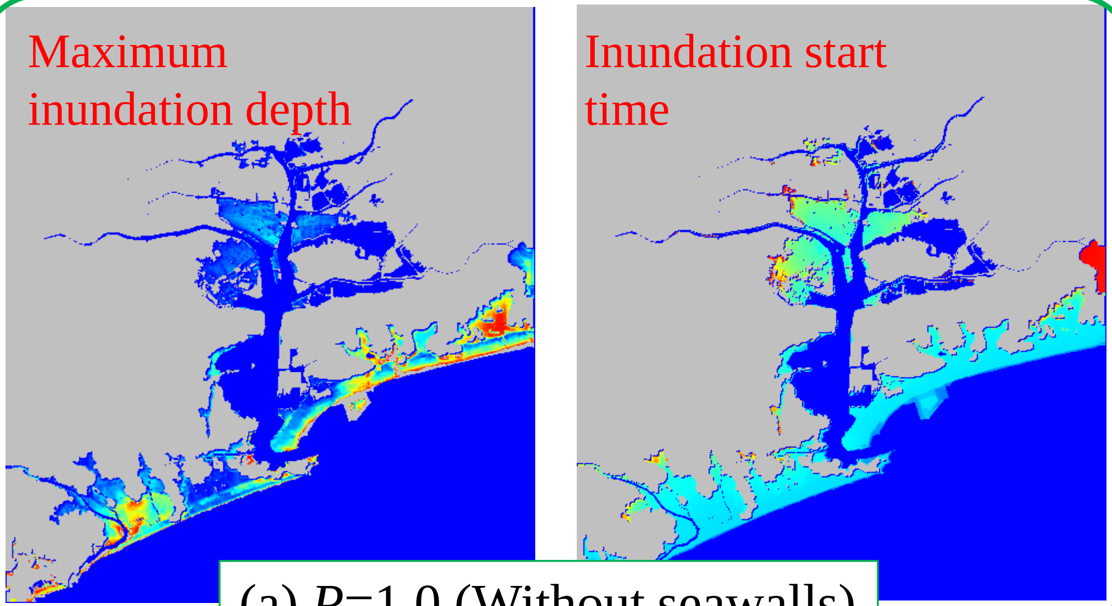
4. Conclusion

In this study, 913 cases with different seawall damage levels were calculated.
And we developed the method to evaluate the inundation probability considering damage level of seawall.

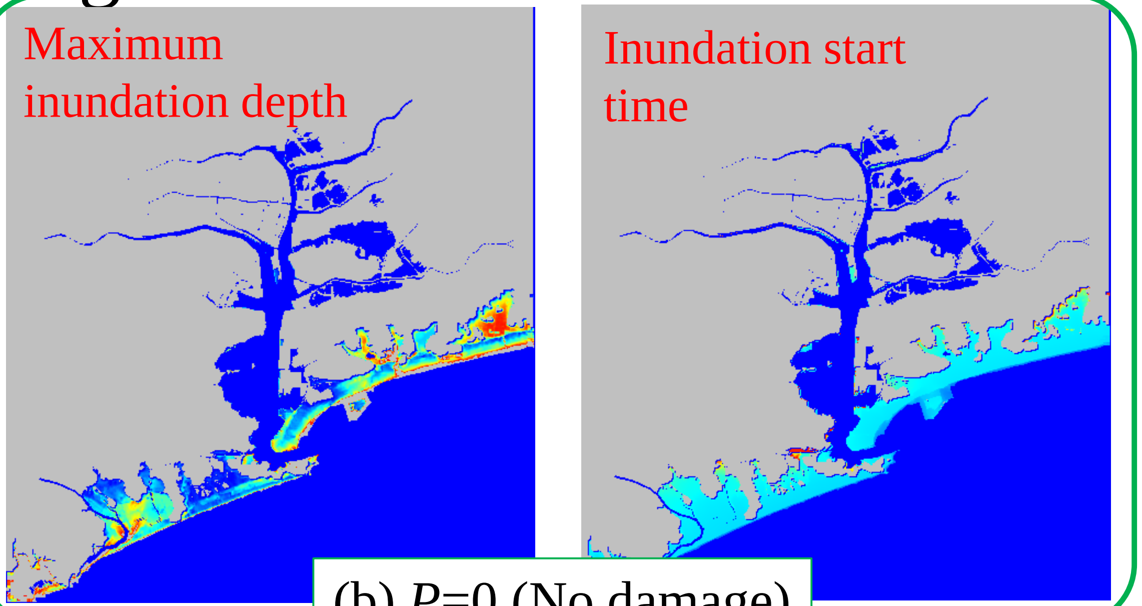
The inundation volume and inundation area is decreased due to seawalls.
However, the mean and maximum inundation depth is increased compared with the case without seawalls.

Seawalls have the effect of delaying the inundation start time by about one or two minutes.

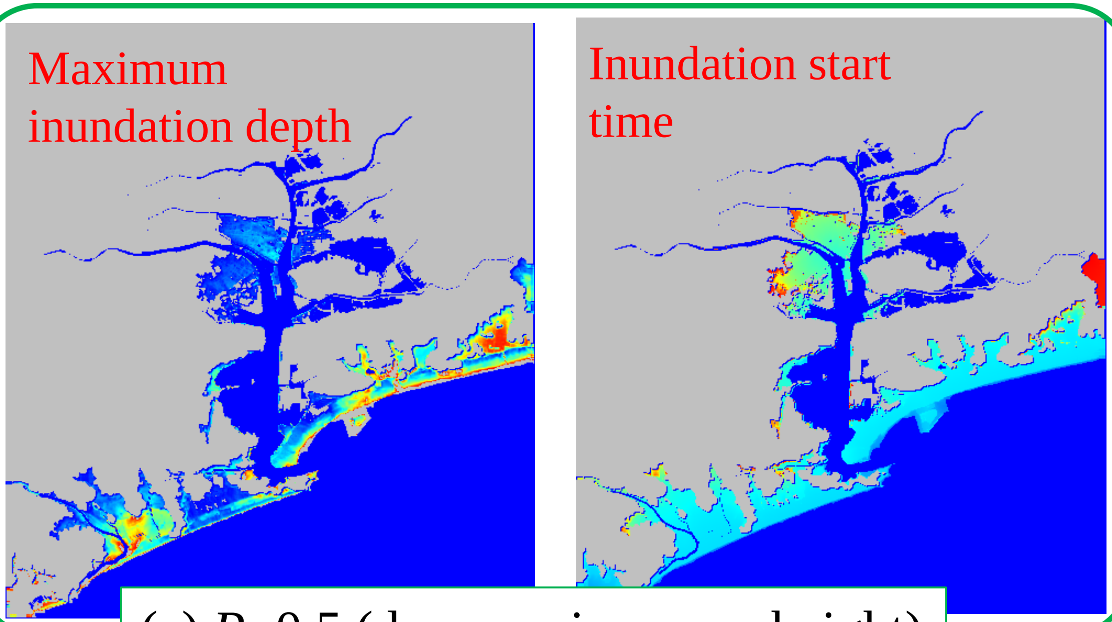
3.1 Influence of decreased crown height



(a) P=1.0 (Without seawalls)



(b) P=0 (No damage)



(c) P=0.5 (decrease in crown height)

influence on inundation depth (left) and inundation start time (right) by damage rate of seawalls