Vulnerability assessment to liquefaction hazard induced global climate change by using geo-information database

L'Estimation de la vulnérabilité à hasard de la liquéfaction a induit le changement du climat clobal en utilisant la base de données de la geo-Information

S. Murakami and K. Yasuhara
Department of Urban & Civil Engineering, Ibaraki University, Japan

ABSTRACT
The present study shows a procedure for liquefaction hazard mapping in consideration of global climate change has been proposed and its application of the method to vulnerability assessment to seismic geo-hazard induced by global climate change in a coastal region has been described. The objective region in this study is lowland that lies between the Tama river and Tsurumi river in Yokohama and Kawasaki city, Japan. There are approximately 700 locations of site investigations in the geo-information database. These data have been used for the groundwater flow analysis and liquefaction hazard. Finally, Vulnerability to liquefaction hazard in the objective region has been assessed by comparison of liquefaction hazard maps in the present situation and the future affected by global climate change.

RÉSUMÉ
Les spectacles de l'étude présents une procédure pour projection topographique du hasard de la liquéfaction dans considération de changement du climat global a été proposée et son application de la méthode à estimation de la vulnérabilité à geo hasard sismique induit par changement du climat global dans un ré-gion côtier a été décrite. La région objective dans cette étude est plaine qui repose entre la rivière Tama et rivière Tsurumi dans Yokohama et ville Kawasaki, Japon. Il y a approximativement 700 emplacements d'enquêtes de site dans la geo-information base de données. Ces données ont été utilisées pour l'analyse de fluence du groundwater et hasard de la liquéfaction. Finalement, la Vulnérabilité à hasard de la liquéfaction dans la région objective a été répartie par comparaison de hasard de la liquéfaction dresse une carte dans la situation présente et le futur a affecté par changement du climat global.

1 INTRODUCTION

Ground damage caused by liquefaction is always a very serious problem. Attention should be given to groundwater level (GWL) changes because liquefaction potential is sensitive to rising in GWL. In this century, sea-level rise (SLR) and increase in rainfall intensity due to global climate change (IPCC 2000, JMA 2005) will engender GWL rise, especially in coastal regions. Stability of ground in coastal plain regions affected by sea-level rise and increase in rainfall intensity decreases with rising GWL (Yasuhara et al., 2004). It is important for sustainable development of the region to assess the influence of global climate change on seismic geo-hazard. In addition, the role that geotechnical engineering plays in its contribution to disaster mitigation and risk management is large in development of spatial geo-information database.

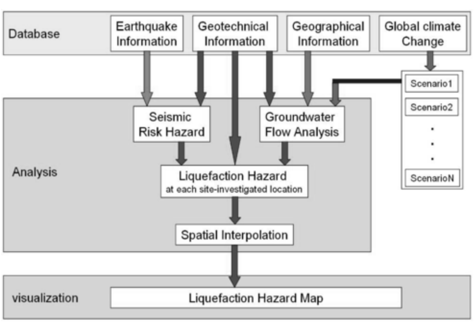

Figure 1. A procedure for liquefaction hazard mapping in consideration of global climate change

The present study shows a procedure for liquefaction hazard mapping in consideration of global climate change has been proposed and its application of the method to vulnerability assessment to seismic geo-hazard induced by global climate change in a coastal region has been described. Finally, Vulnerability to liquefaction hazard in the objective region has been assessed by comparison of liquefaction hazard maps in the present situation and the future situation affected by global climate change.

2 LIQUEFACTION HAZARD MAPPING IN CONSIDERATION OF GLOBAL CLIMATE CHANGE

Liquefaction potential depends on ground properties, seismic magnitude and GWL. Spatial distribution of GWL in an objective region depends on characteristics of rainfall, groundwater abstraction and hydraulic boundary conditions. In the case that the objective area is a coastal zone, one of the hydraulic boundary conditions is the sea-level. Global climate change will influence the balance of water circulation and global warming will cause SLR. Since liquefaction potential increases with ris ing GWL, it is important for disaster prevention and mitigation against earthquakes in a coastal region to consider a future situation of GWL subjected to SLR. Therefore, it is better to take into account the GWL not only at present but also in the future.

Figure 1 shows a procedure for liquefaction hazard mapping in consideration of global climate change (Murakami et al., 2005). Calculating the liquefaction hazard at any location in an objective region usually needs information on soil properties

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with depth, GWL and seismic shear stress. In recent years, geo-information digital databases, that include borehole logs, N-values etc. from the results of site investigations, have been made in some regions in Japan. The geo-information database is available for the prediction of geo-disasters such as liquefaction caused by earthquakes. The database supplies necessary information on soil properties for calculating liquefaction potential. Seismic shear stress in the ground is predicted in consideration of assumed earthquake events or the same value is ordained in a design code. By using groundwater flow analysis, GWL is predicted on the assumption that global climate change causes a scenario of water circulation that is different from the present situation.

Previous studies (Murakami et al., 2005, 2007) demonstrated a procedure for liquefaction hazard mapping considering SLR and an application of the mapping procedure to Yokohama and Kawasaki cities in Japan, after proposing a methodology for evaluating the rise in GWL followed by SLR. Vulnerability to liquefaction hazard in the objective region was assessed through comparison of liquefaction hazard maps before and after SLR caused by global warming.

The present study presents the results of liquefaction hazards in consideration of the effects of GWL caused by not only SLR but also rainfall. For the purposes of this study, groundwater flow analysis based on the finite element method has been performed. The solving equation in the analysis is a 2D model for unconfined groundwater flow in unsteady conditions;

$$n_e \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left\{k\left(h - z_0\right)\frac{\partial h}{\partial x}\right\} + \frac{\partial}{\partial y}\left\{k\left(h - z_0\right)\frac{\partial h}{\partial y}\right\} + n_r r \tag{1}$$

where h is GWL, n_e is effective porosity, k is hydraulic conductivity of permeable soil layer, z_0 is the depth of non-permeable surface, r is rainfall intensity, n_r is infiltration ratio and x, y are coordinates of horizontal plain. Spatial distributions of n_e, k and z_0 in the objective region are able to be determined by using geo-information database (Murakami et al., 2005). The spatial distribution of n_r is also determined by the same procedure by using GIS (Geographical Information System). By using Eq. (1), the distribution of GWL subjected to a certain scenario of SLR and rainfall has been simulated.

Liquefaction hazard at each location has been calculated by a method proposed by "The Japanese Highway Bridge Code (JHBC; so called "*Dorokyo-shihousho*") established by the Ministry of Construction (currently called the Ministry of Land and Transportation) in 1996. This judgment procedure is based on the liquefaction resistance factor, F_L, which is defined as;

$$F_L = \frac{R}{L} \tag{2}$$

where R is dynamic strength ratio determined by cyclic shear strength of soil and correction coefficient concerning earthquake movement. Cyclic shear strength is estimated by using unit weight and fine content of soil, N-value and GWL. L is seismic shear stress ratio generated during earthquakes. L is determined by seismic intensity, which depends on the ground classification and type of earthquake, and the same information as R. Liquefaction takes place when F_L, given by Eq. (2), is below 1.0. Evaluation of possible liquefaction through depth in an objective location can be performed by integration of the liquefaction potential, P_L, with depth using:

$$P_L = \int_0^{20} F\left(Z\right)\cdot w\left(z\right)dz \tag{3}$$

here $F(z)$ is a function that is $F(z) = 1 - F_L$ when $F_L < 1.0$ and $F(z) = 0$ when $F_L > 1.0$. $w(z)$ is weighting parameter defined as $w(z) = 10.0 - 0.5z$ (z : GL-m) (Iwasaki et al, 1980).

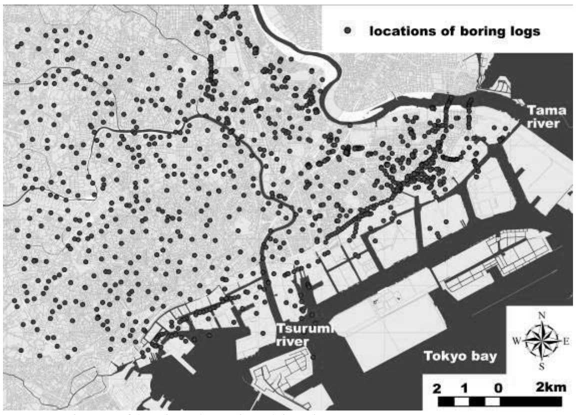


Fig.2 Locations of boring logs in objective area

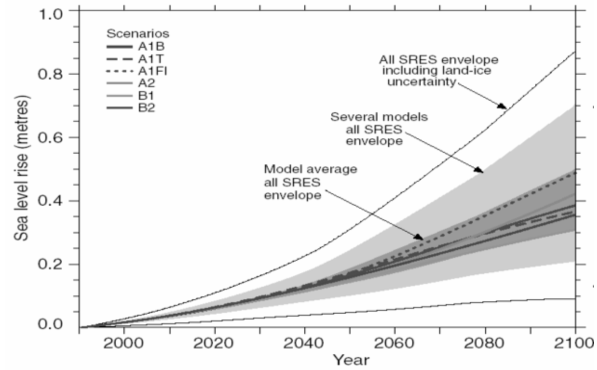
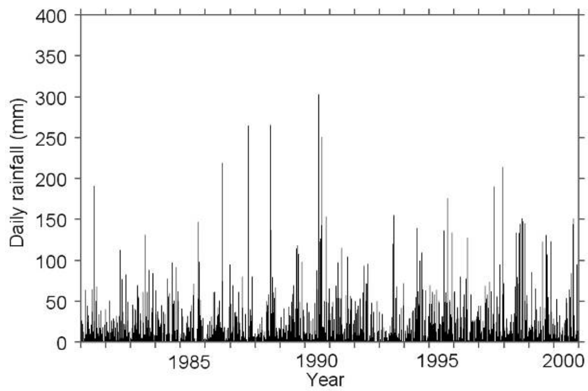
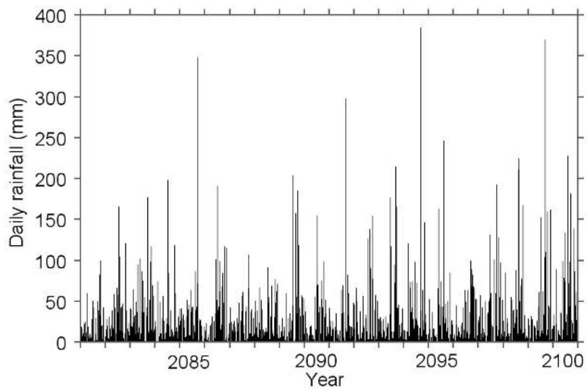


Fig.3 SLR (IPCC, 2001)



(a) from 1981 to 2000



(b) from 2081 to 2100

Fig.4 Simulated rainfall in the objective region
(Simulated results from "*Unified Climate Scenario 2nd ed. (2004)*" supplied by Japan Meteorological Agency)

3 AN APPLICATION OF VULNERABILITY ASSESSMENT TO SEISMIC GEO-HAZARD INDUCED GLOBAL CLIMATE CHANGE

The objective region in this study is lowland that lies between the Tama and Tsurumi river in Yokohama and Kawasaki city, Japan as shown in Fig.2. The figure also shows approximately 700 locations of site investigations in the geo-information database. These data have been used for the groundwater flow analysis and liquefaction hazard.

Groundwater simulations before and after SLR and climate change have been performed using the numerical methods above. Time-series data for Sea-level, which is one of the hydraulic boundary conditions, was set up based on the simulated results due to global warming reported by the Intergovernmental Panel on Climate Change (2000). The report indicated some scenarios of SLR and the worst scenario, in which SLR in 2100 is 0.88m, has been used in the present study (Fig. 3). According to "*Climate Change Monitoring Report 2005*" by the Japan Meteorological Agency, annual rainfall increases in almost all the regions in Japan and the maximum increment of rainfall in a region is predicted as approximately 20% in around 2100. Therefore, it is necessary for investigating vulnerability against seismic geo-hazard to consider the variations of rainfall in the future. Rainfall scenario in the present study have been obtained from the simulated results in "*Unified Climate Scenario 2nd ed. (2004)*" supplied by the Japan Meteorological Agency. Figures 4(a) and 4(b) show transitions of daily rainfall based on the simulated results from 1981 to 2000 and from 2081 to 2100, respectively. Table 1 indicates the rainfall characteristics in two periods. The simulated results in the objective region also show that rainfall characteristics will change in the future and the average annual and daily rainfall and maximum daily rainfall will increase from the present situation.

In order to investigate the vulnerability to SLR and rainfall, the simulations have been performed on the following three scenarios:

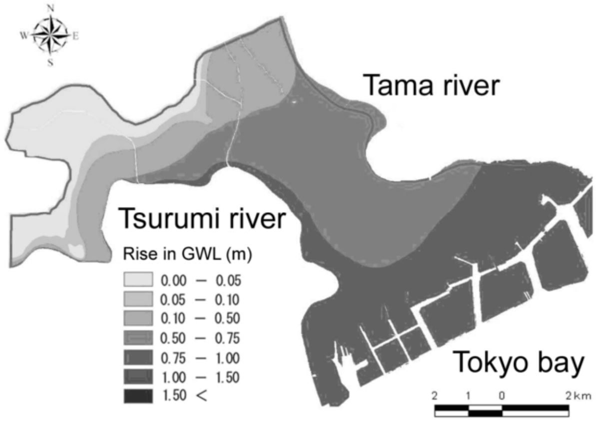
(a) consideration of SLR in 2100,
(b) consideration of rainfall from 2081 to 2100, and
(c) consideration of both SLR and rainfall from 2081 to 2100.

The distributions of the maximum GWL rise in each scenario are represented in Fig. 5. The figures show that the distributions of rise in GWL are different from each other. In particular the rise in GWL is severe in the case of scenario(c) where both influences are considered. Therefore, it is necessary for investigation of geo-disaster concerned with groundwater to consider not only SLR but also climate change such as rainfall.

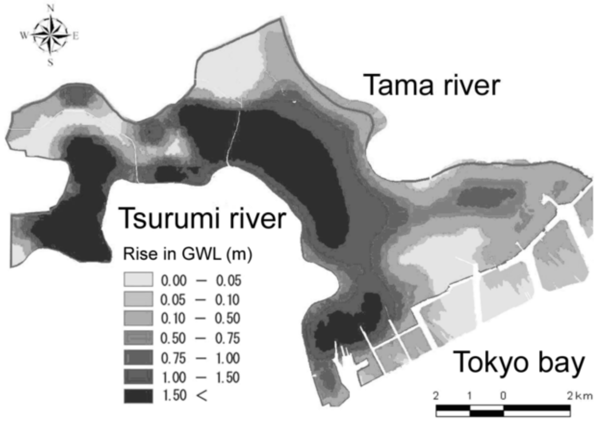
Comparison of liquefaction hazard maps before and after the rise in GWL caused by SLR, rainfall and combined SLR and rainfall, illustrates the changing vulnerability to liquefaction hazard as shown in Fig.6. Table 2 shows the incremental ratios of area in a range of P_L-values to the present situation before SLR in 1990. These results show that the area of high potential liquefaction increases more severely with rising GWL caused by the combined effect of SLR and rainfall than the cases SLR or rainfall alone. Regions in which the liquefaction potential will be high would not only be those around coastlines but also around rivers affected by both SLR and rainfall. Therefore, for prevention and mitigation of liquefaction by earthquakes, it is necessary to consider regional variations of GWL caused by both SLR and rainfall attributable to global climate change.

Table 1 Rainfall characteristics based on simulated results in the objective region (Unit: mm, Simulated results from "*Unified Climate Scenario 2nd ed. (2004)*" supplied by Japan Meteorological Agency)

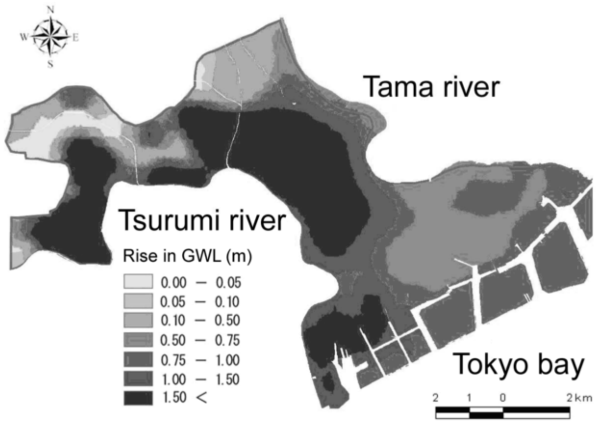
	1981-2000	2081-2100
Annual average	13045	14224
Daily average	36	39
Max. daily	303	385
Standard deviation	89.33	98.78



(a) 0.88m SLR



(b) rainfall from 2081 to 2100

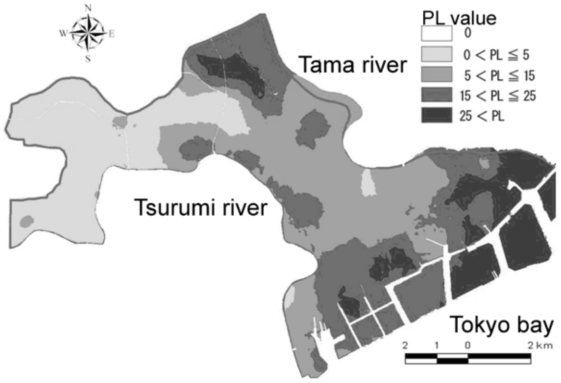


(c) combined SLR and rainfall

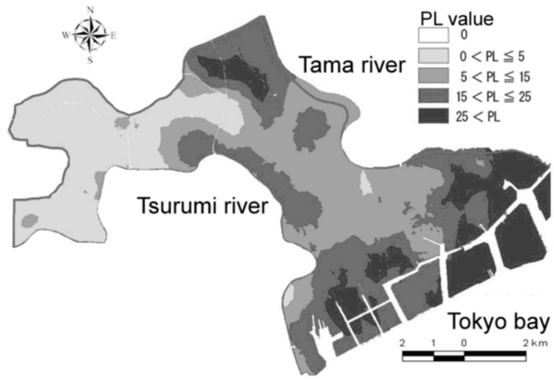
Fig. 5 Rise in GWL subjected to (a)SLR , (b)rainfall and (c) combined SLR and rainfall

Table 2 Incremental ratio of area of P_L-values to the case of the present situation before SLR

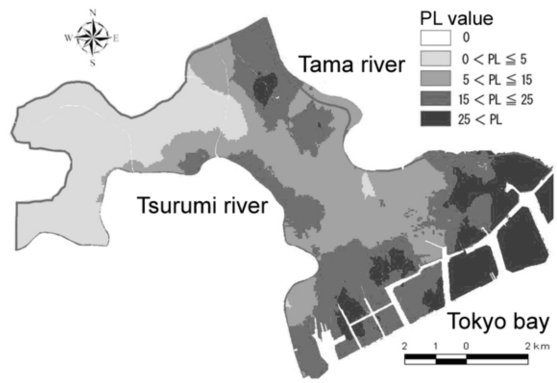
Range of P_L-value	After SLR in 2100	Rainfall from 2081 to 2100	Combined SLR and rainfall from 2081 to 2100
$0 < P_L < 5$	1.03	0.98	0.93
$5 < P_L < 15$	0.98	0.95	0.87
$15 < P_L < 25$	1.09	1.11	1.06
$25 < P_L$	1.14	1.27	1.42



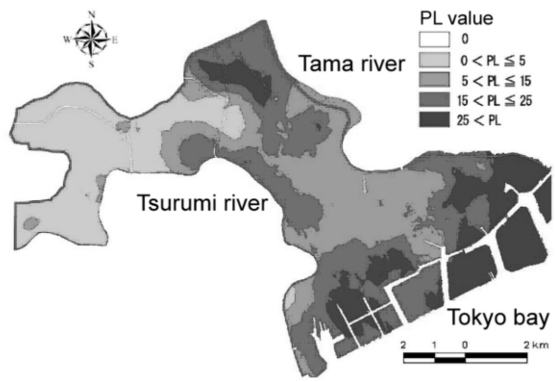
(a) The present situation before SLR (1990)



(b) After SLR (2100)



(c) rainfall from 2081 to 2100



(d) combined SLR and rainfall from 2081 to 2100

Fig.6 Liquefaction hazard maps

4 CONCLUSIONS

A procedure for liquefaction hazard mapping in consideration of global climate change has been proposed and applied to a coastal region in this study. By comparison of liquefaction hazard maps in the present situation and the future situation affected by global climate change, vulnerability to liquefaction hazard has been evaluated. From the results, the area of high potential liquefaction increases more severely with rising GWL caused by the combined effect of SLR and rainfall than the cases SLR or rainfall alone. Regions in which the liquefaction potential will be high would not only be those around coastlines but also around rivers affected by both SLR and rainfall. Therefore, it is necessary for prevention and mitigation against liquefaction by earthquakes to consider the regional variations of GWL caused by global climate change.

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