

INTEGRATED EARTHQUAKE SIMULATION

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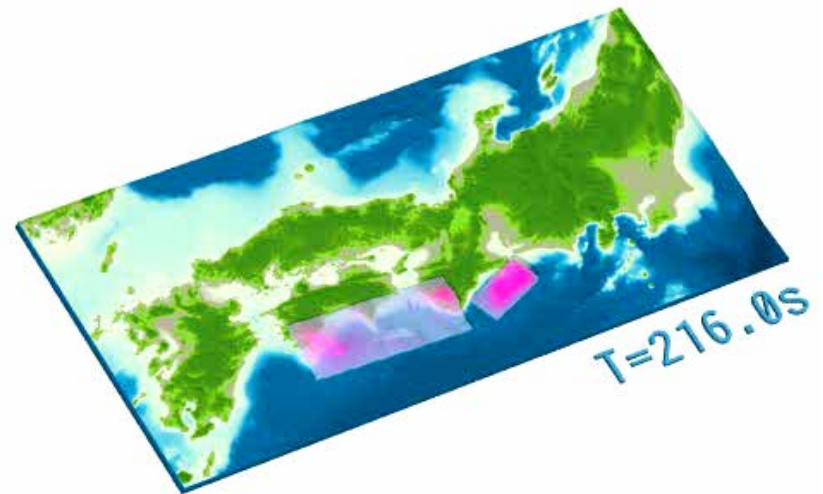
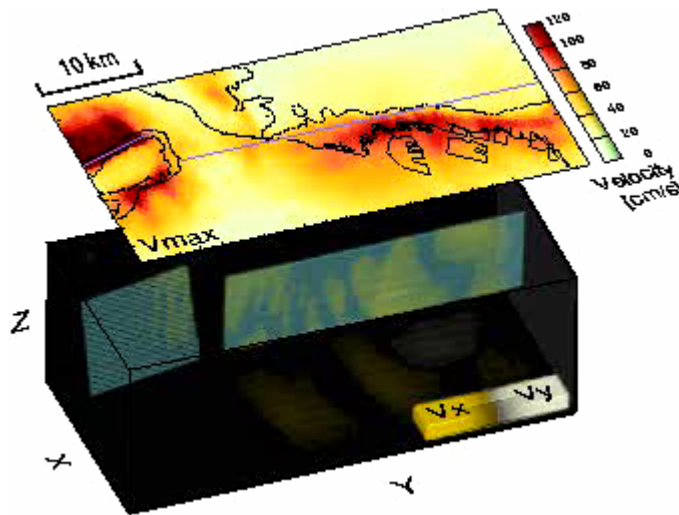
CONTENTS

- ◆ Full computation of earthquake hazards and disasters
- ◆ Examples of integrated earthquake simulation

Recent Achievement on Earthquake Research

◆ Computation of Earthquake Wave Propagation

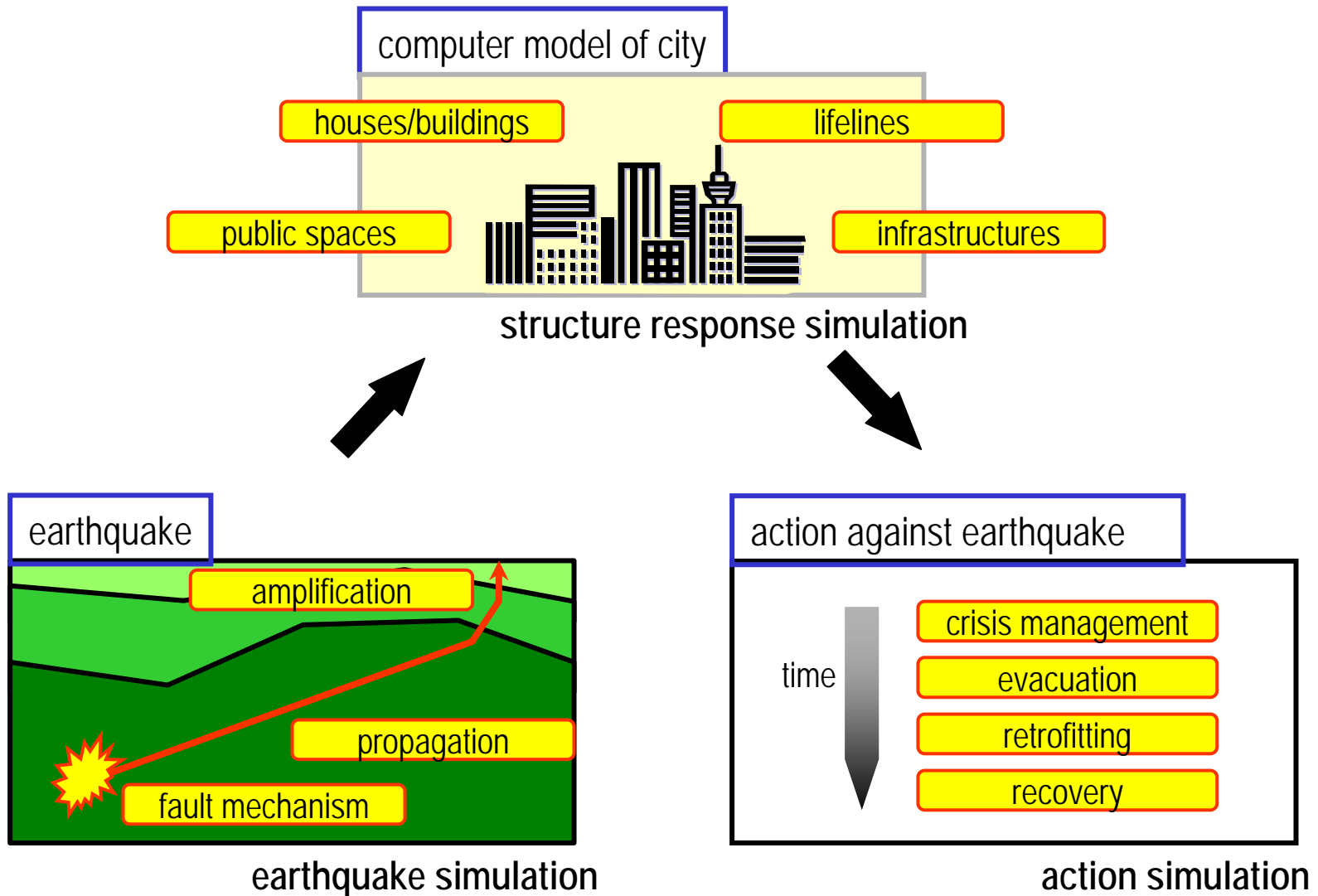
- Prof. Furumra (ERI, U. Tokyo): use of Earth Simulator



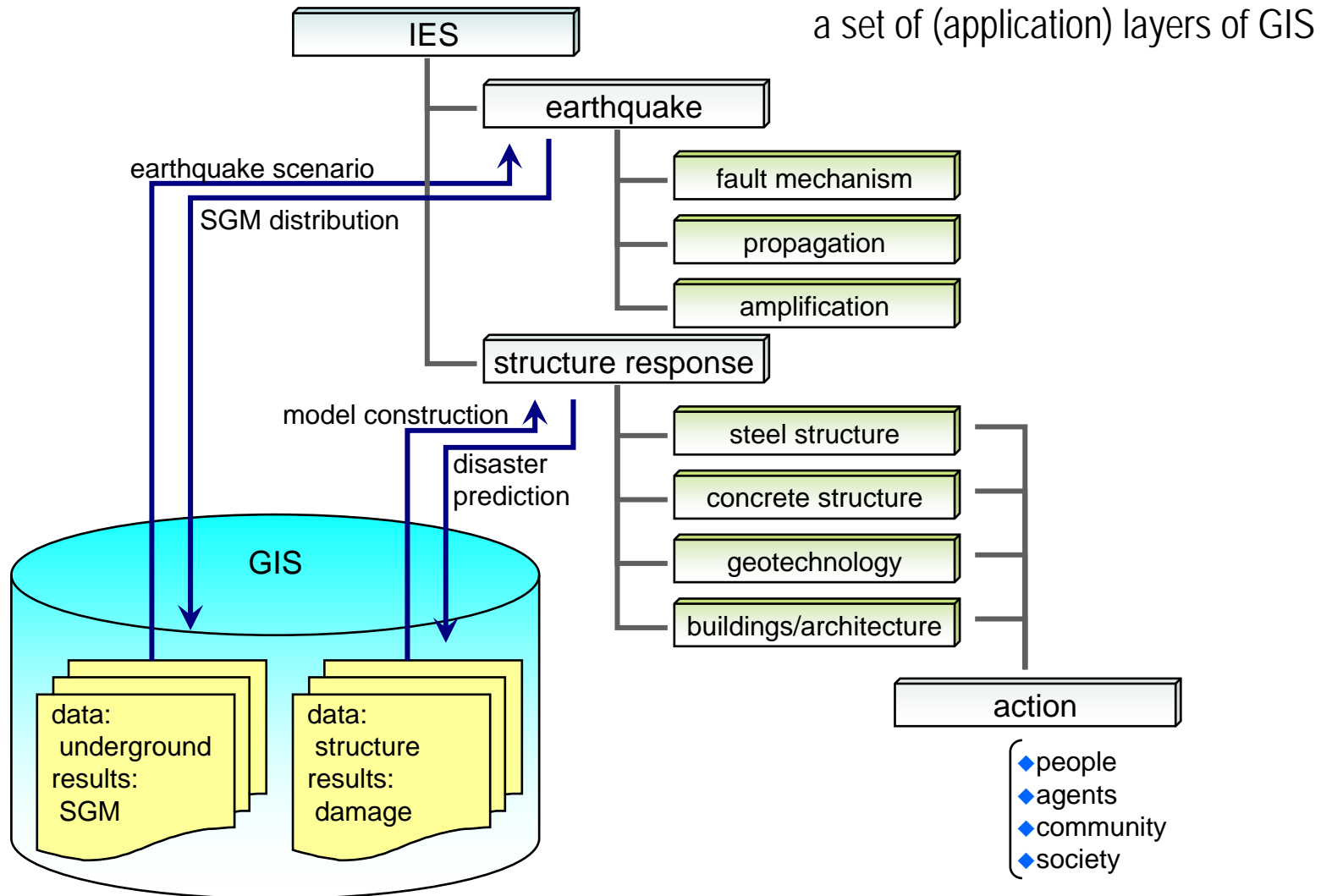
- Dynamic structure analysis methods used for design non-linear due to materials and large-deformation

◆ Development of GIS Storing Structure Data

OVERVIEW OF IES

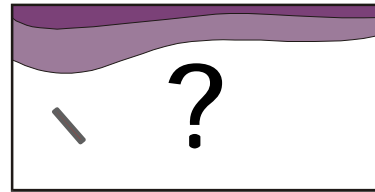


SYSTEM OF IES



MACRO-MICRO ANALYSIS METHOD

stochastic modeling of
underground structure



bounding medium theory

multi-scale analysis

pessimistic

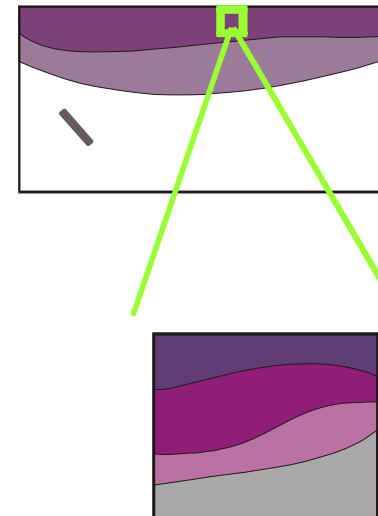
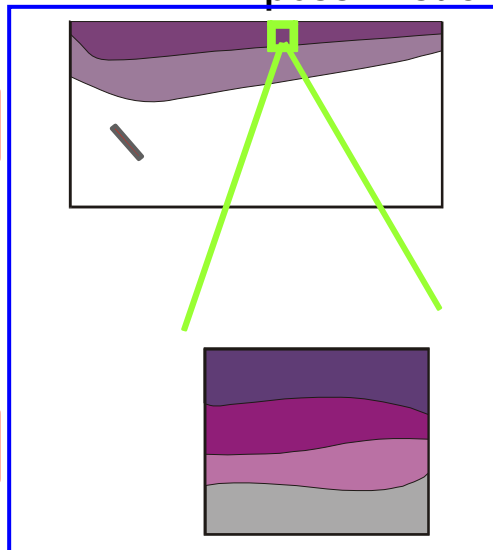
optimistic

macro-analysis

geological scale

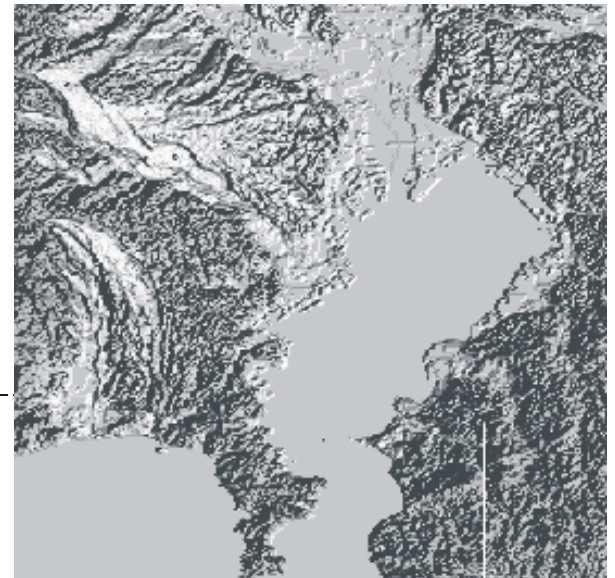
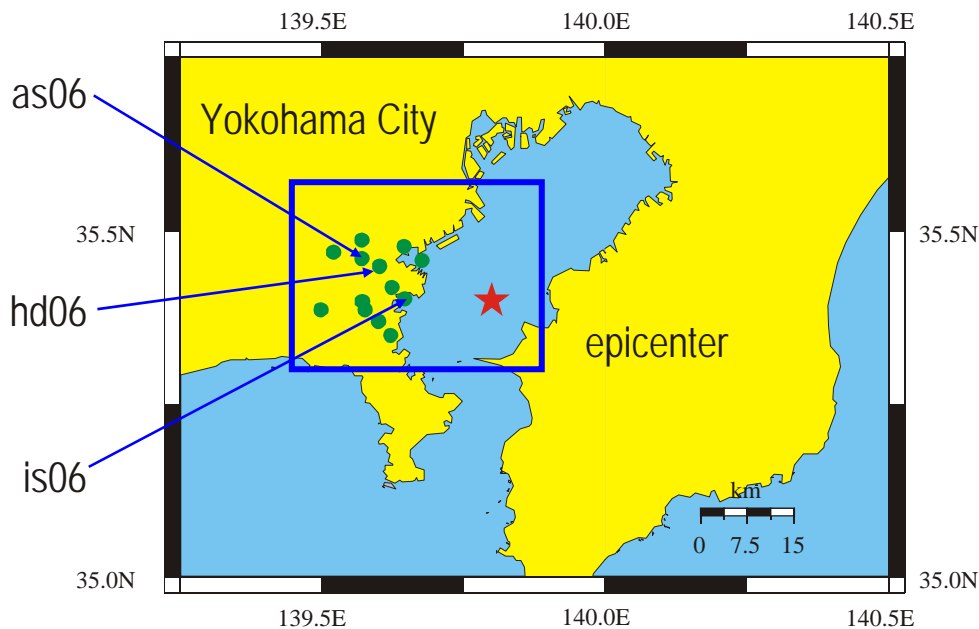
micro-analysis

engineering scale



EXAMPLE OF MACRO-MICRO ANALYSIS: YOKOHAMA CITY SIMULATION

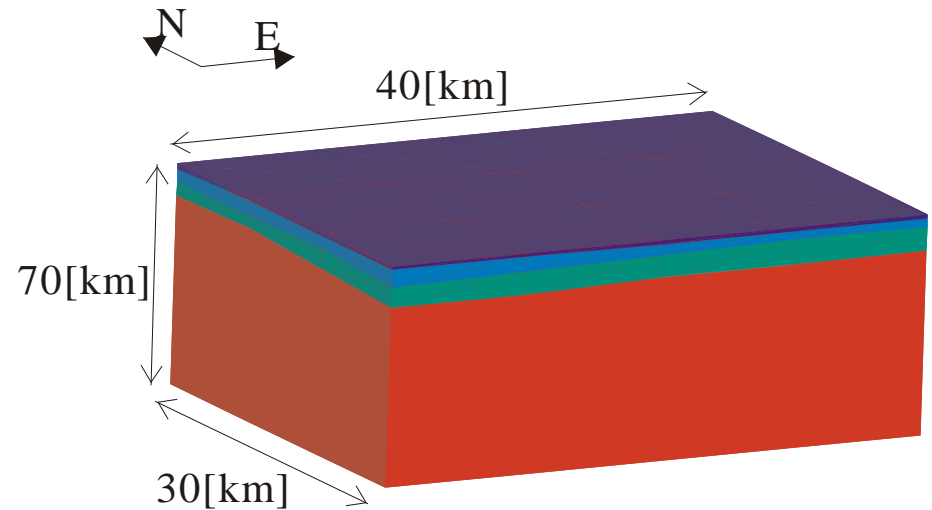
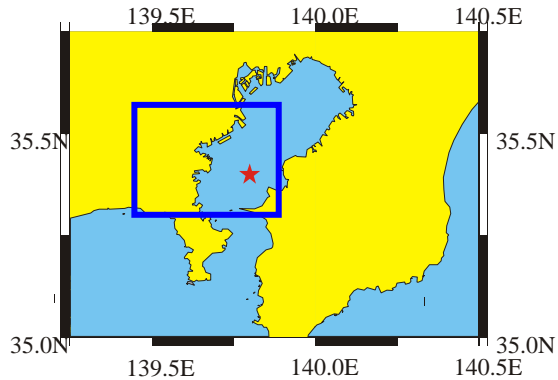
- ◆ Comparison of synthesized strong ground motion with data observed at 13 seismograph sites



August 11, 1999

Lat.	Long.	Depth	Strike	Dip	Rake	Mag.
35.4N	139.8E	53km	62	85	73	4.0Mw

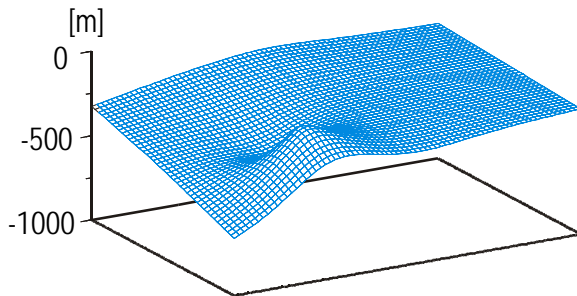
MODEL FOR MICRO-ANALYSIS



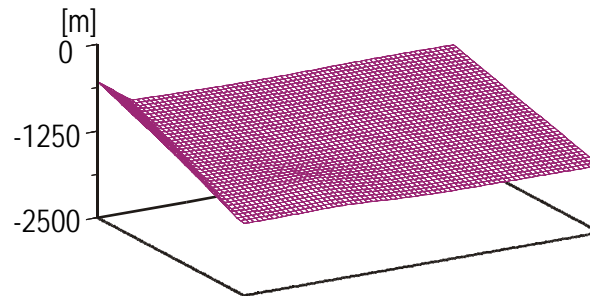
	mate.1	mate.2	mate.3	mate.4
p wave veloc.[m/sec]	1040	1730	2950	5200
s wave veloc.[m/sec]	600	1000	1700	3000
density ¹ [kg/m ³]	1800	2000	2300	2500



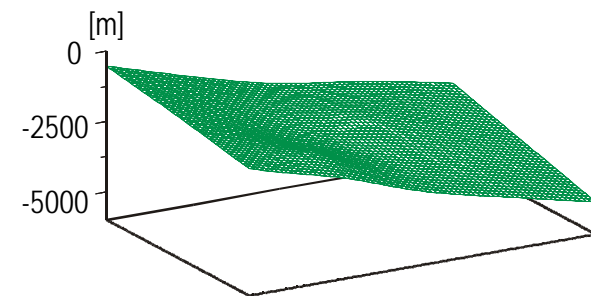
between 1st and 2nd layers



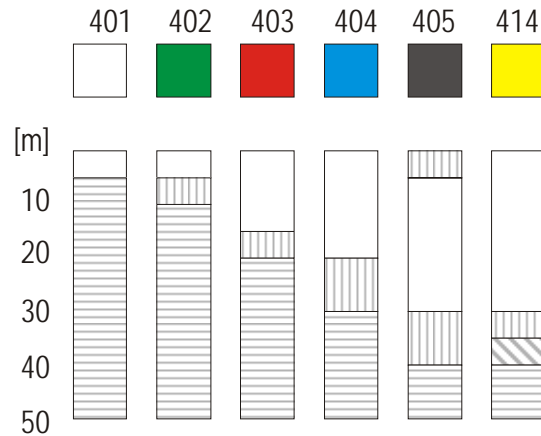
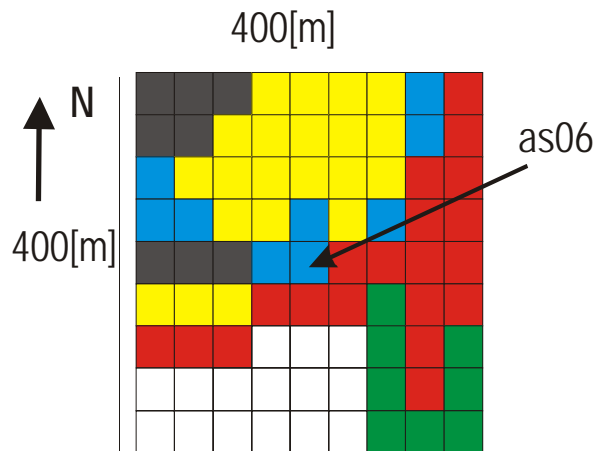
between 2nd and 3rd layers



between 3rd and 4th layers



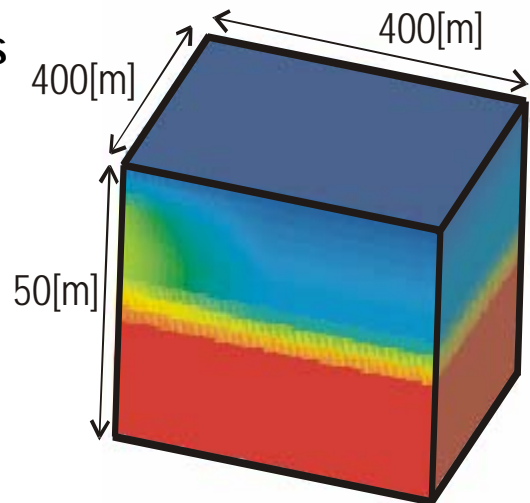
MODEL FOR MICOR-ANALYSIS



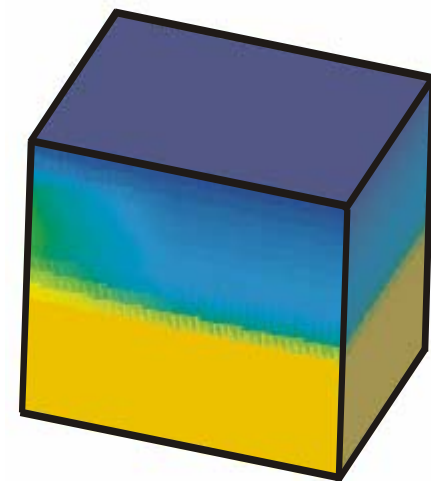
properties of layer

	layer	$\rho[\text{kg/m}^3]$	$\beta[\text{m/sec}]$
	Ac1	1500	100
	Ac2	1600	140
	As2	1800	210
	T	2100	700

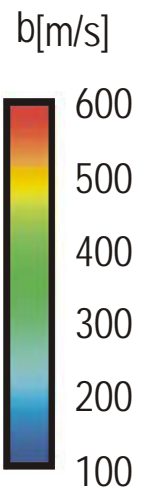
model of site as06s



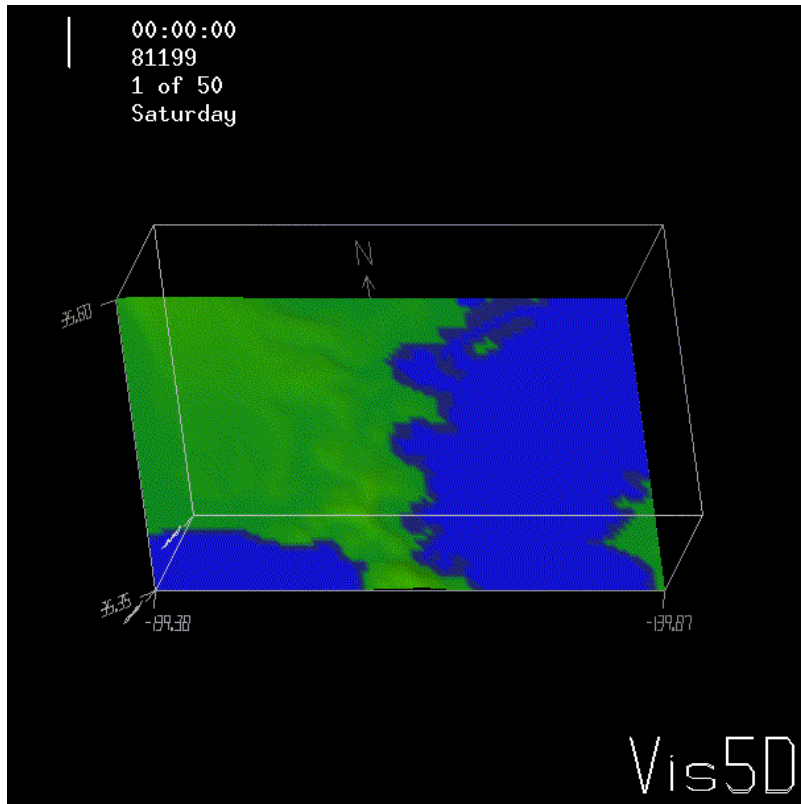
model 1 (optimistic)



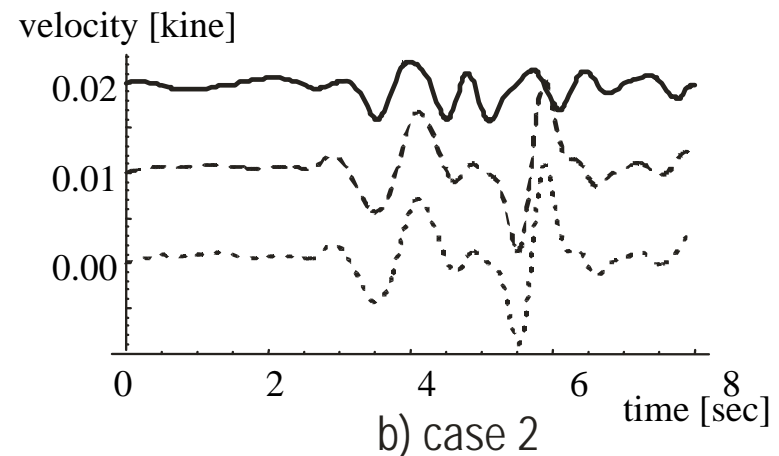
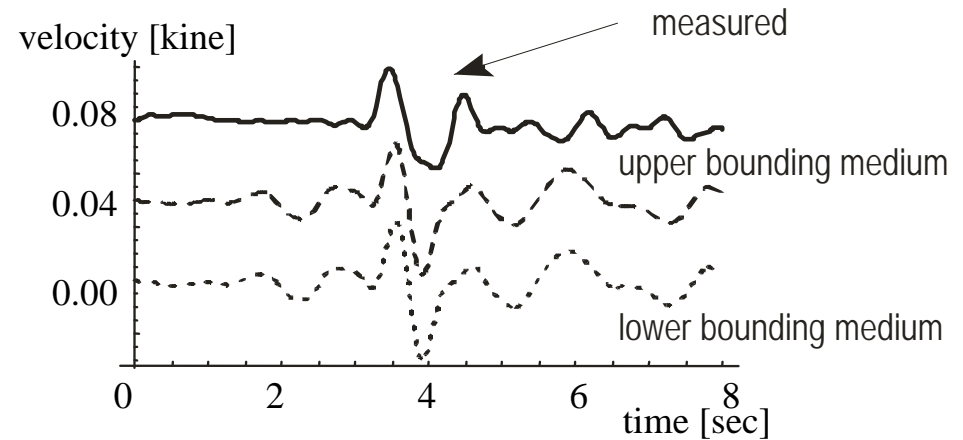
model 2 (pessimistic)



MACRO-ANALYSIS RESULTS



simple fault mechanism used
accuracy guaranteed up to 2[Hz]



agreement with observed data

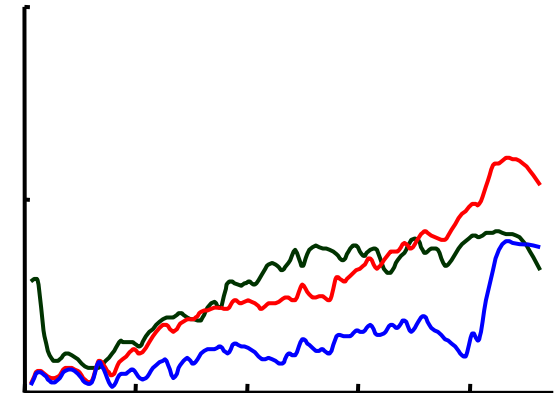
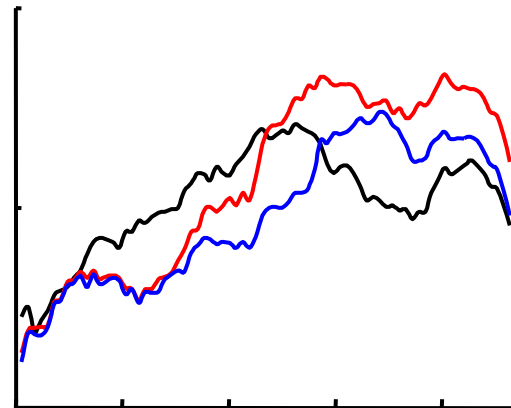
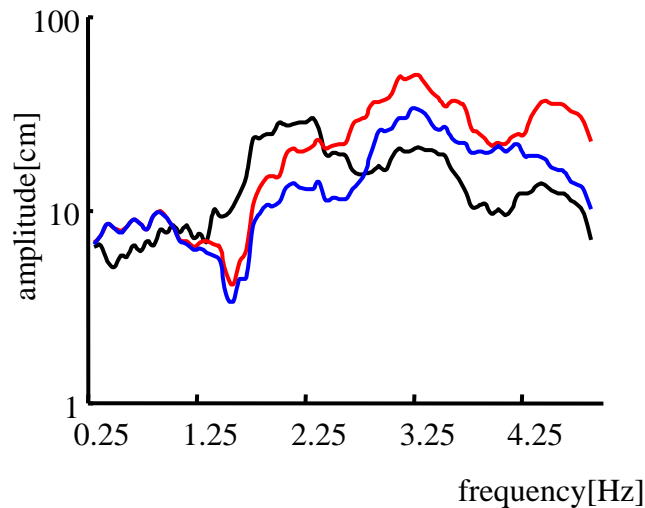
MICRO-ANALYSIS RESULTS (1)

— meas. — opt. — pes.

north/south

east/west

up/down



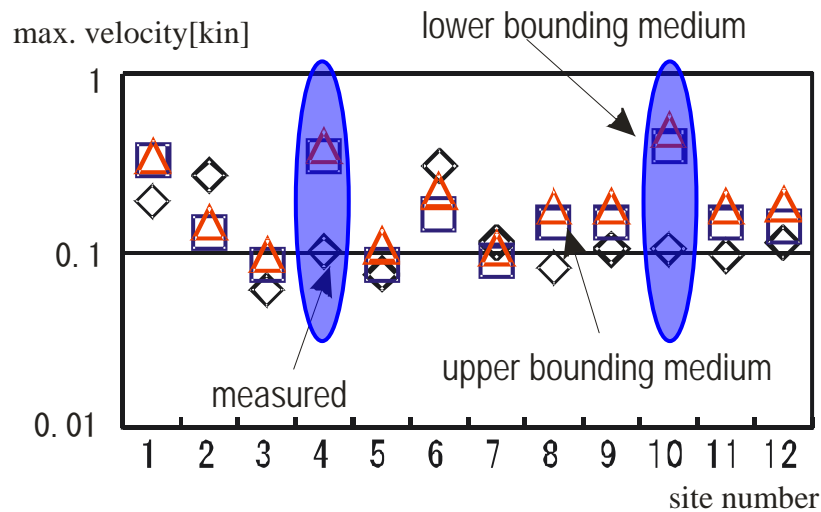
	meas.	opt.	pes.
PGV [kine]	0.170	0.264	0.292
SI	0.191	0.318	0.339

	meas.	opt.	pes.
PGV [kine]	0.234	0.316	0.391
SI	0.295	0.348	0.415

	meas.	opt.	pes.
PGV [kine]	0.049	0.093	0.133
SI	0.053	0.073	0.101

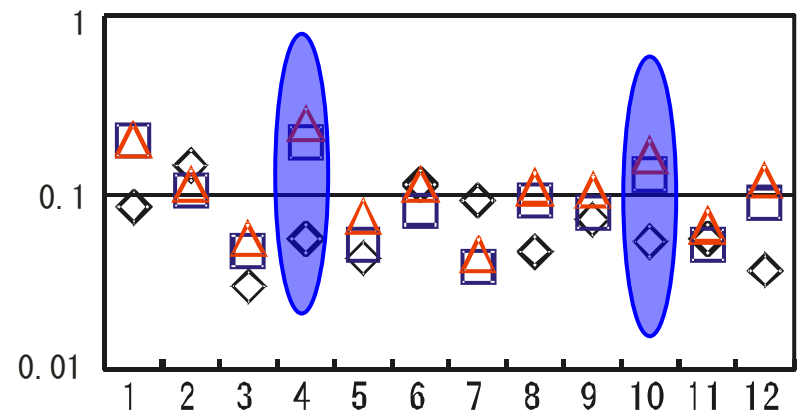
fair agreement with observed data

MICRO-ANALYSIS RESULTS (2)



a) case 1

2 sites have consistent errors, probably due to poor modeling



b) case 2

fair agreement with observed data

SIMULATION USING GIS DATA

◆ Structure Data Stored in GIS

- basic properties (location, owner)
- configuration
- structure type

◆ Construction of Models

- presumption of *standard* material and structure properties
standard structure model

◆ Automatic Construction

- automatic construction of GIS data to standard structure model
- highest redundancy needed

EARTHQUAKE DISASTER SIMULATION DEVELOPMENT OF VIRTUAL TOWN/CITY

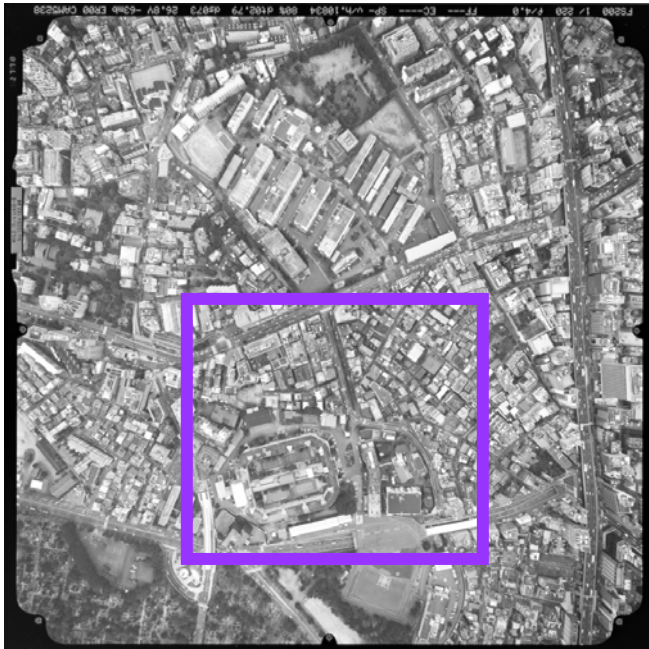
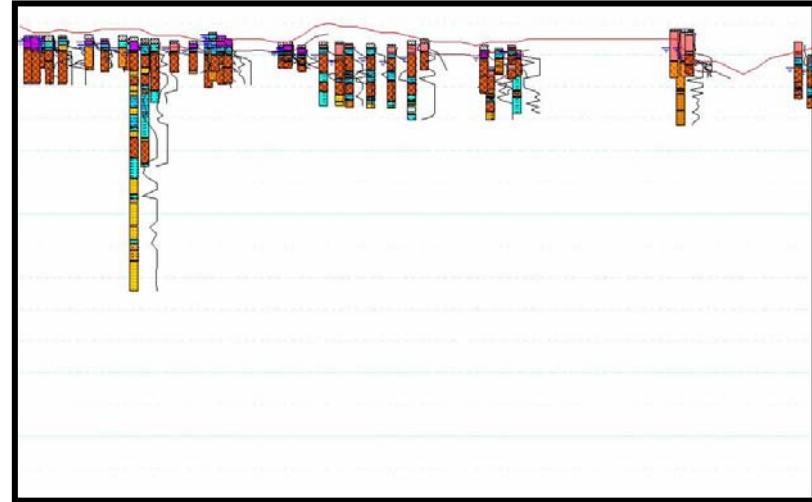
	size [m]	data	earthquake	structure	action
virtual town	300x300	GIS	MMAM	SDOF for building	none
virtual city 1	1,000x2,000	GIS with CAD	MMAM	VFEM for buildings	none
virtual city 2	400x440	GIS with CAD	MMAM	VFEM for infrastructures	none
virtual city 3	300x300	GIS with AI	MMAM	FEM based on ERD	Multi-Agent Simulation

VFEM Voxel Finite Element Method
MMAM Macro-micro Analysis Method
ERD Earthquake Resistant Design

VIRTUAL TOWN

GIS for bore holes
(surface layers)

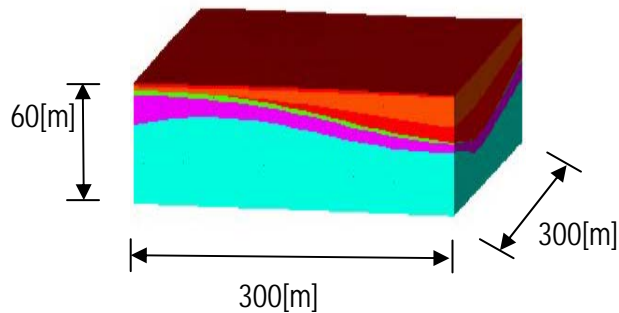
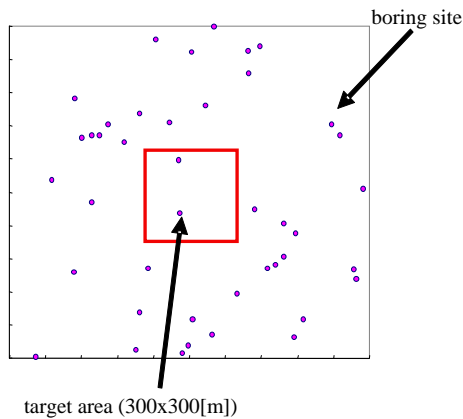
Roppongi Area: 300x300[m]



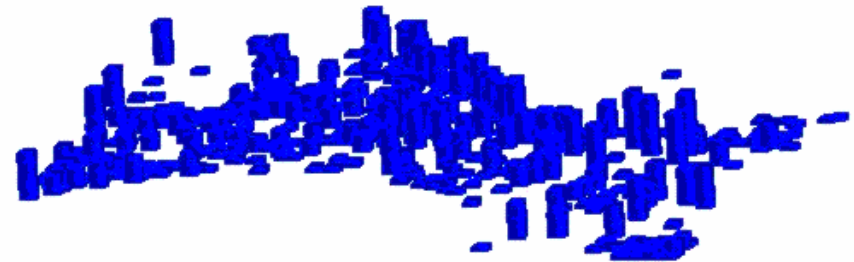
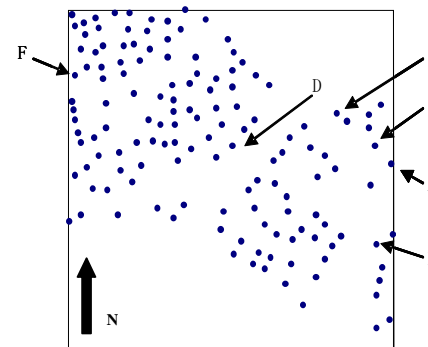
GIS for buildings



DATA AND COMPUTER MODEL



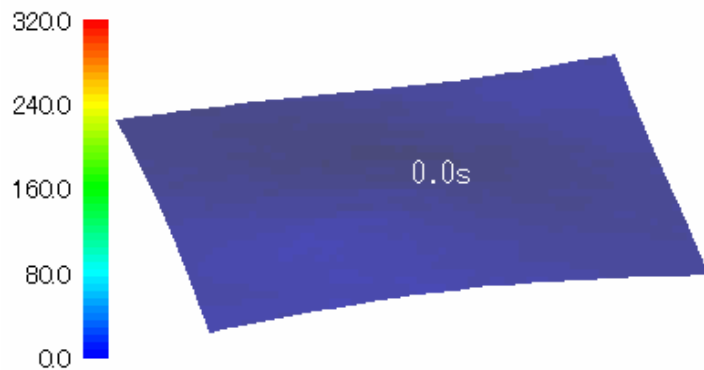
number of layer	soil type	density(g/cm ³)	S _v (m/s)	P _v (m/s)
1	surface soil	1.625	120.0	204.0
2	loam	1.550	135.0	229.5
3	sand	1.800	400.0	680.0
4	clay	1.750	200.0	340.0
5	fine sand	1.900	425.0	722.5
bottom	rock	1.850	600.0	1020.0



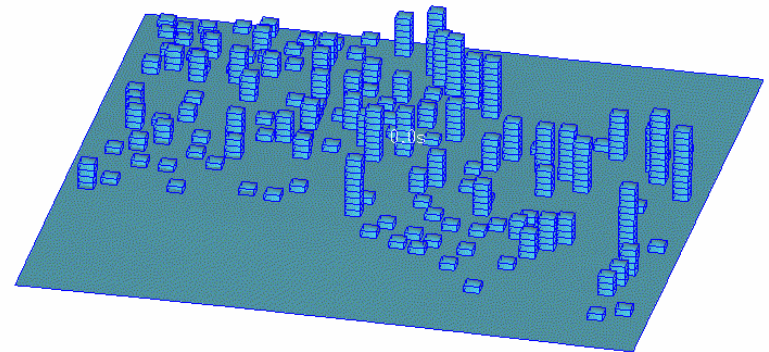
147 buildings

Materials	Fundamental Period
Wooden buildings	varies from 0.2 sec. to 0.7 sec.
R.C.	T=0.02H
S.R.C.	T=0.03H

SIMULATION OF VIRUTAL TOWN

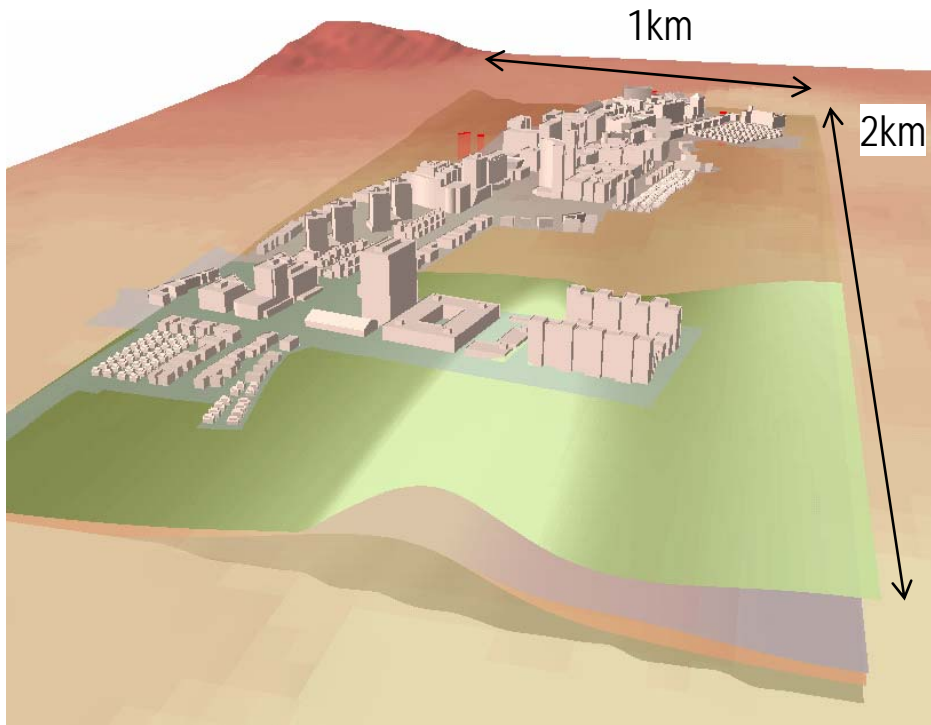


high spatial resolution

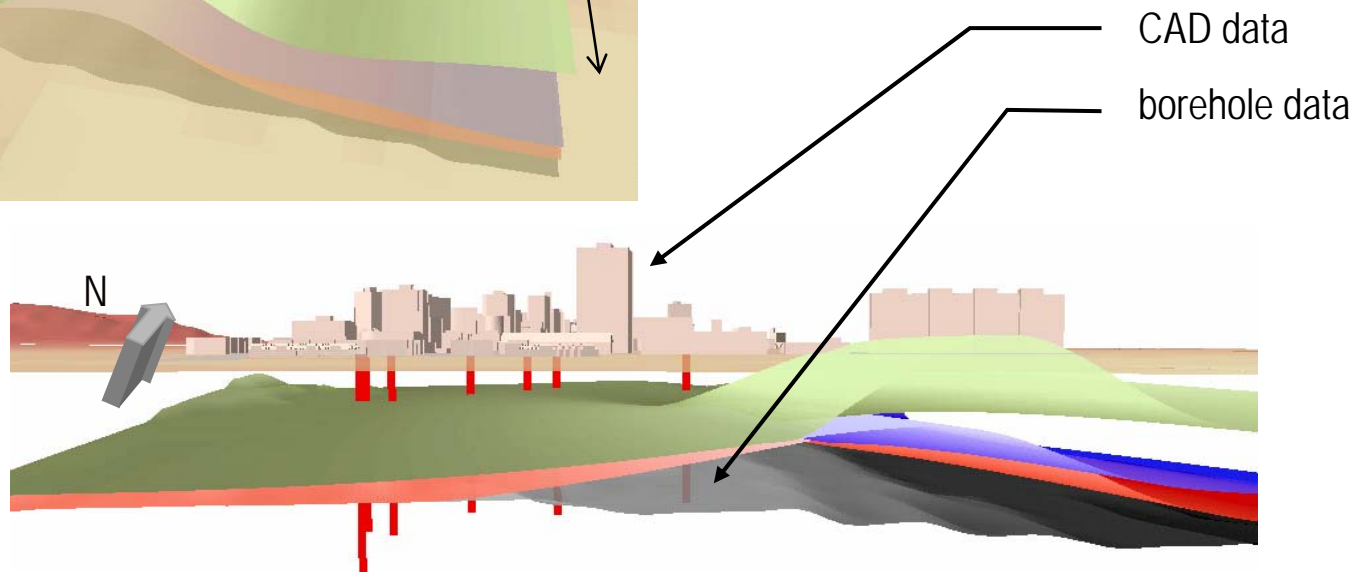


large variability in response

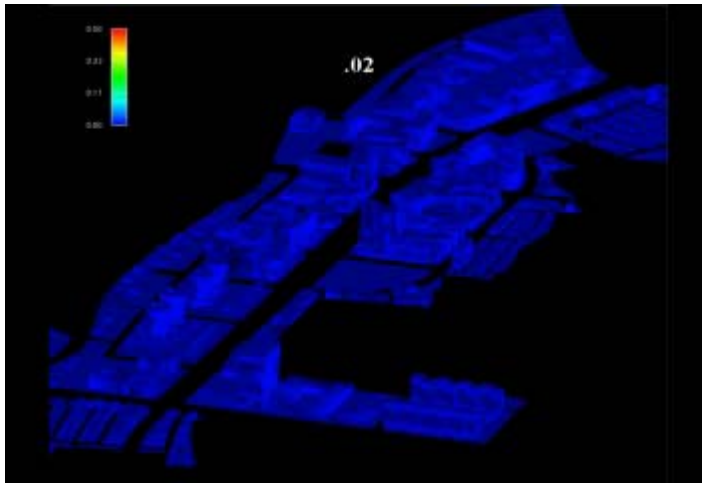
VIRTUAL CITY 1



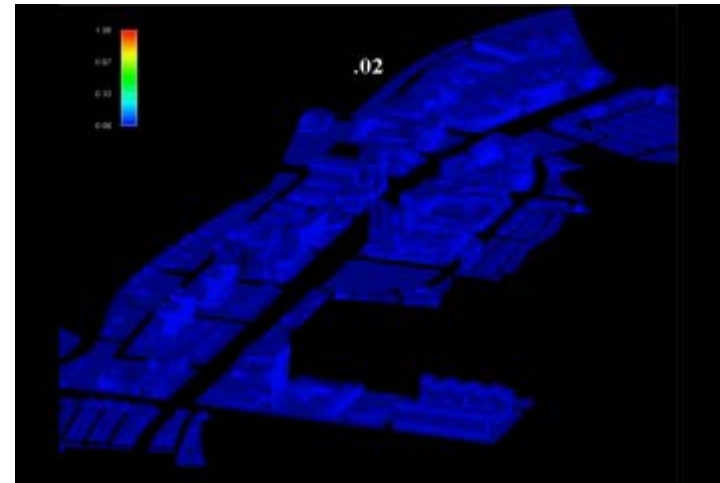
data
CAD data for all buildings
borehole data for underground



RESPONSE OF BUILDINGS IN VIRTUAL CITY 1

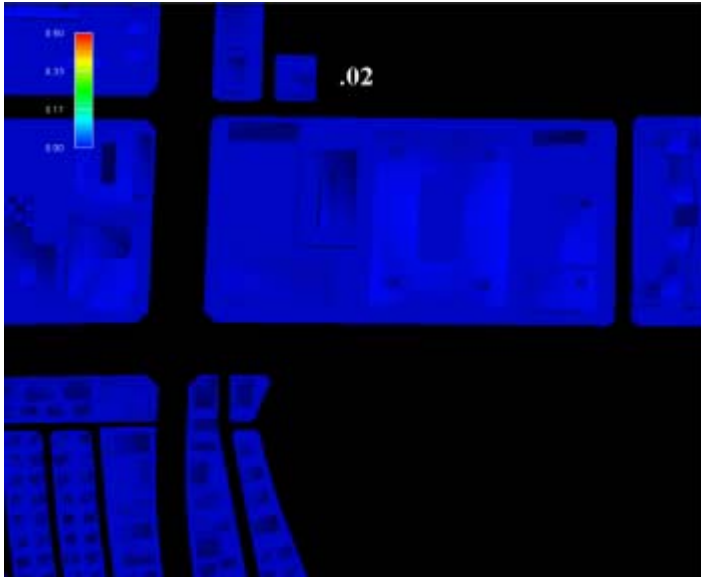


high frequency dominant

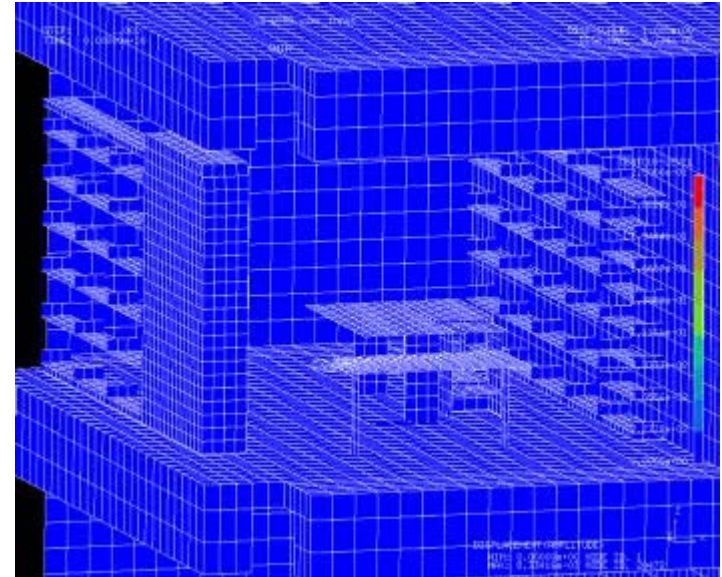


low frequency dominant

HIGH RESOLUTION OF IES

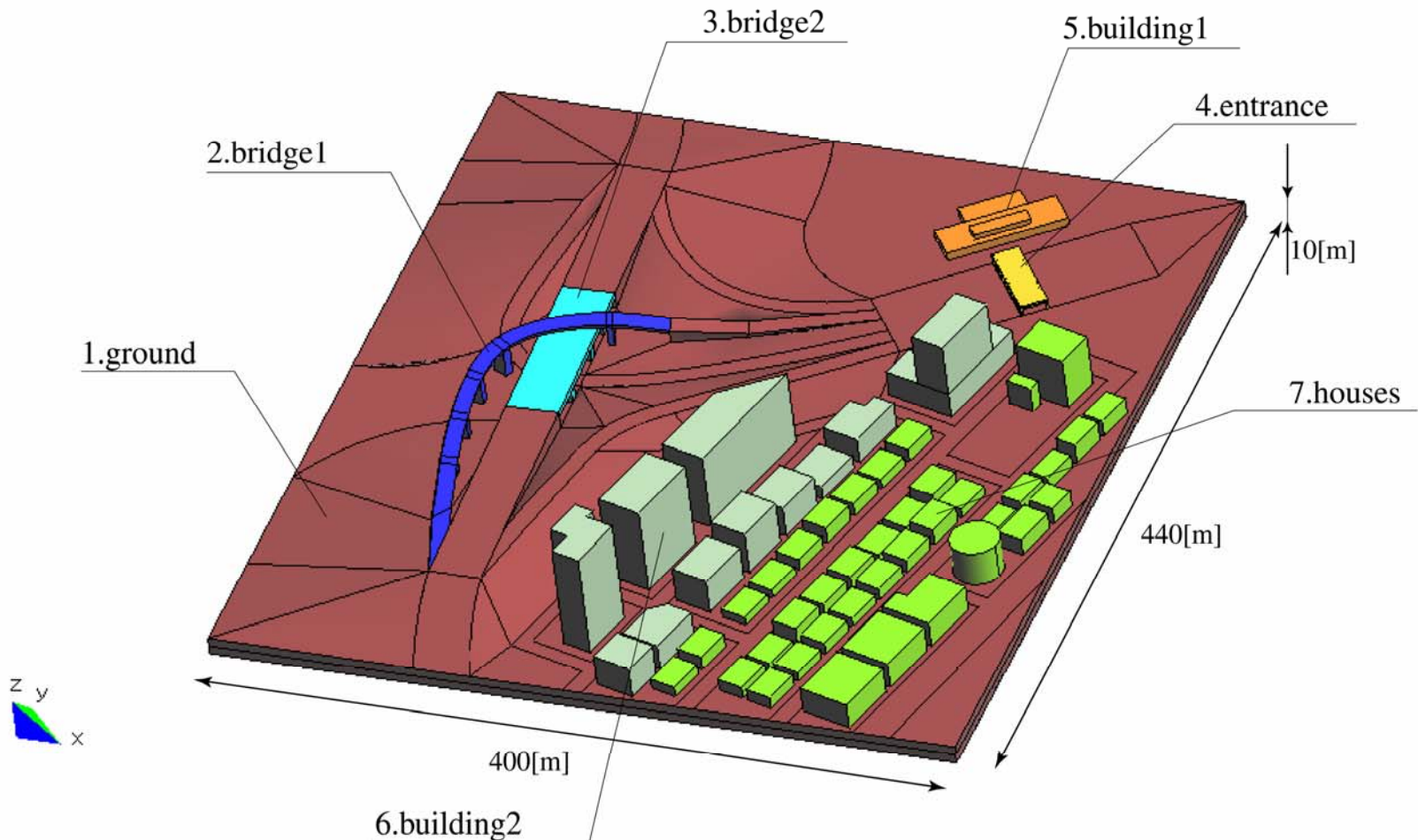


part of virtual city



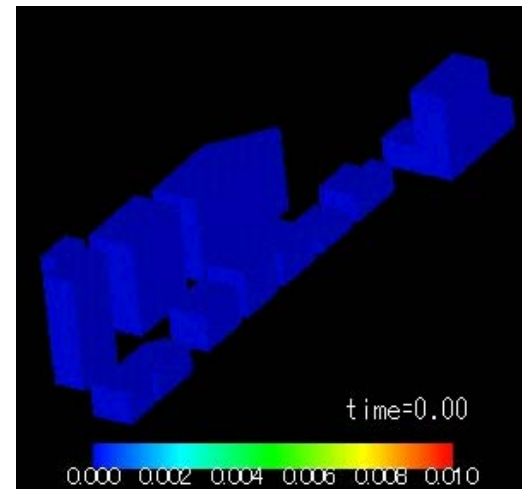
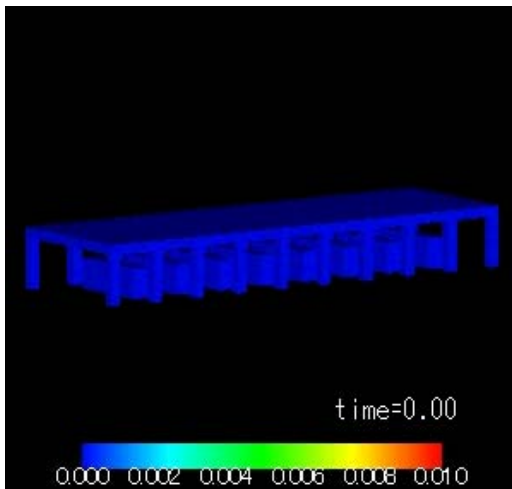
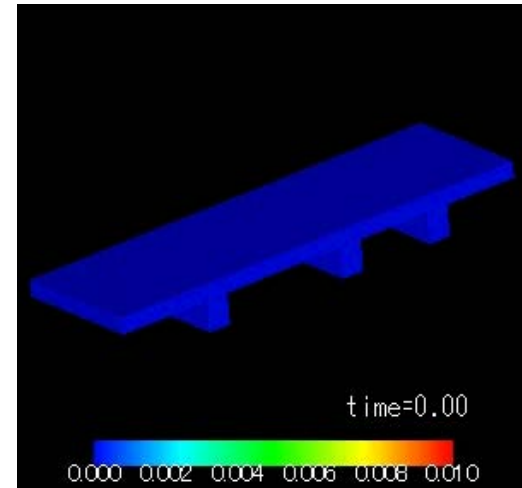
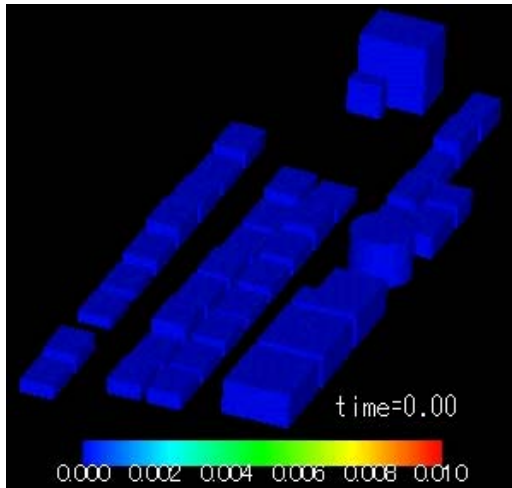
room

VIRTUAL CITY 2

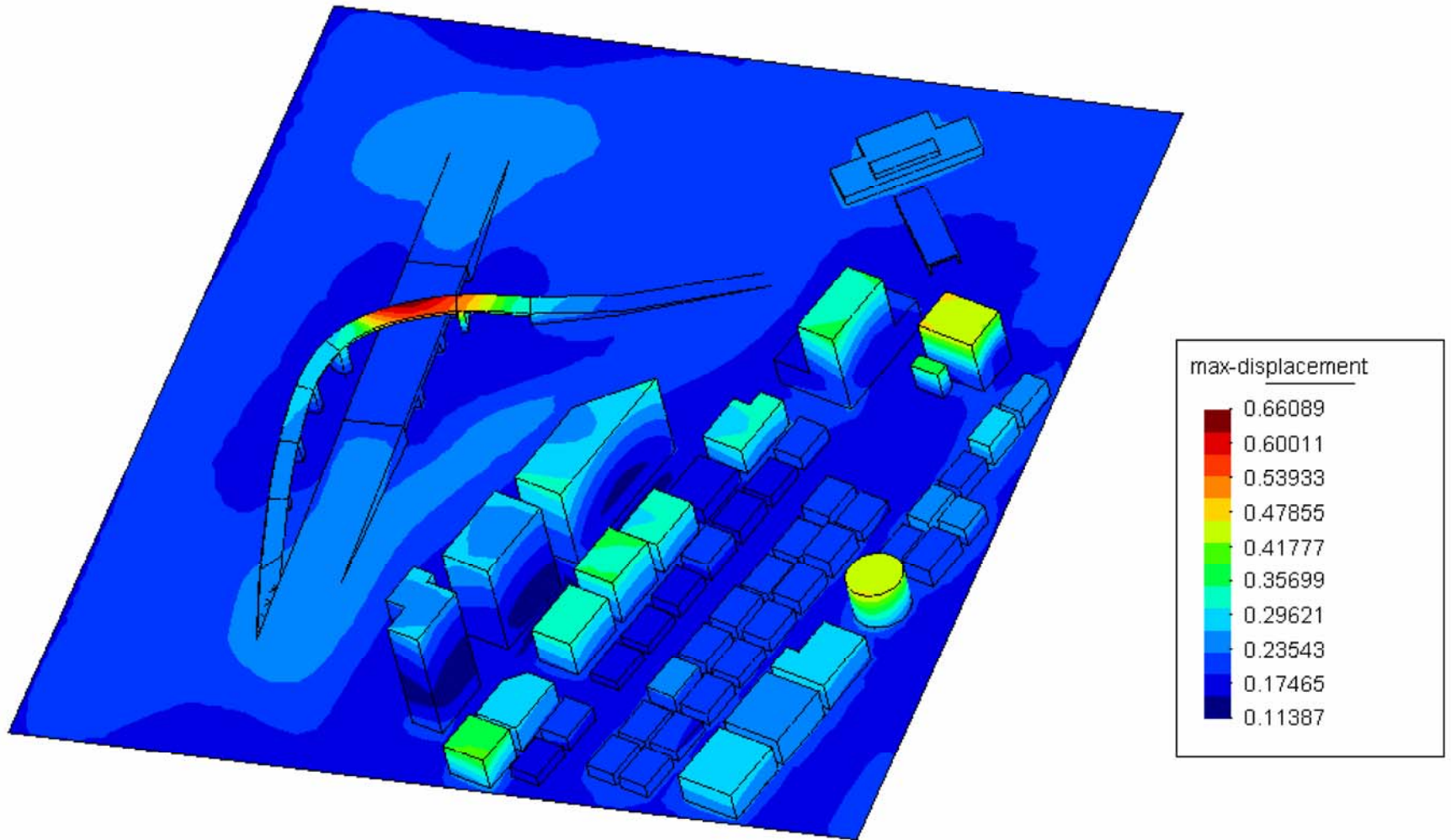


borehole data for underground

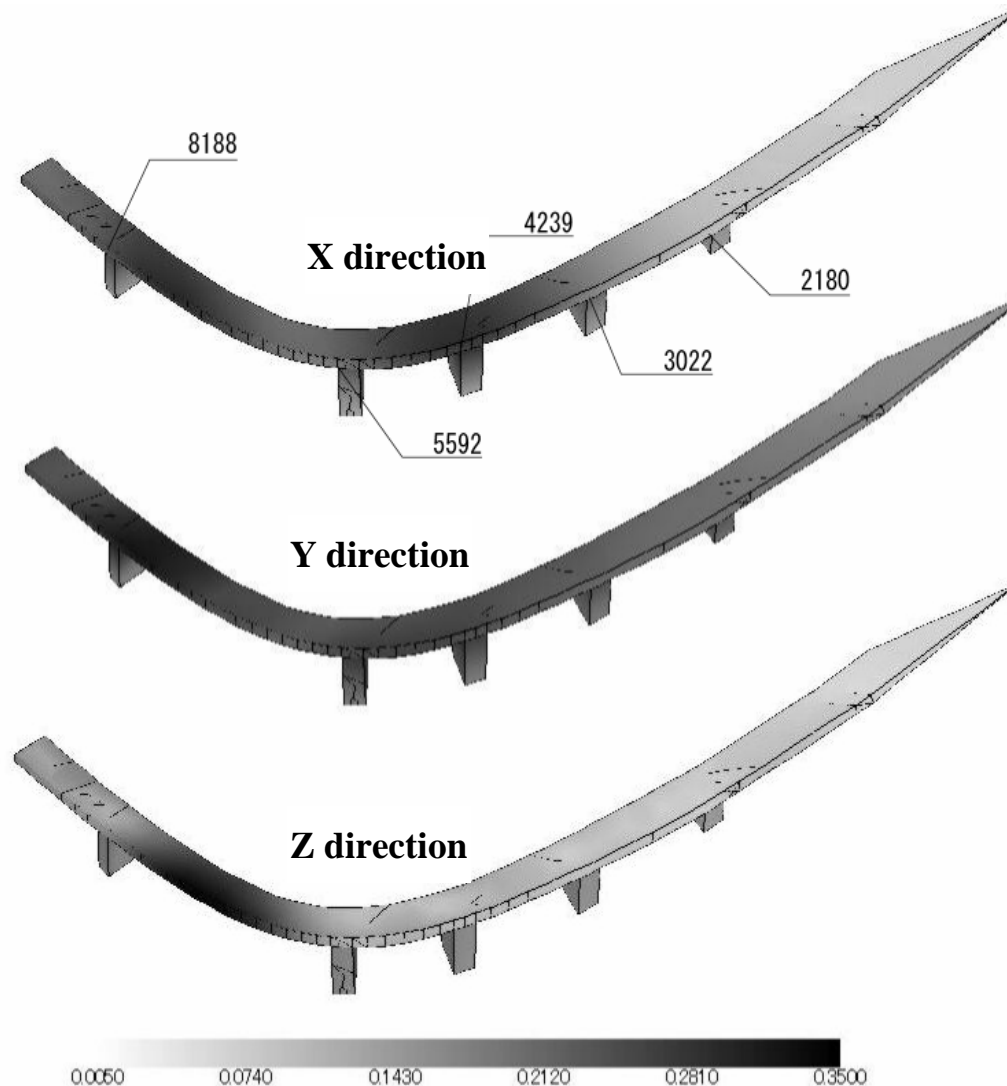
RESPONSE OF INFRASTRUCTURES AND BUILDINGS IN VIRTUAL CITY 2



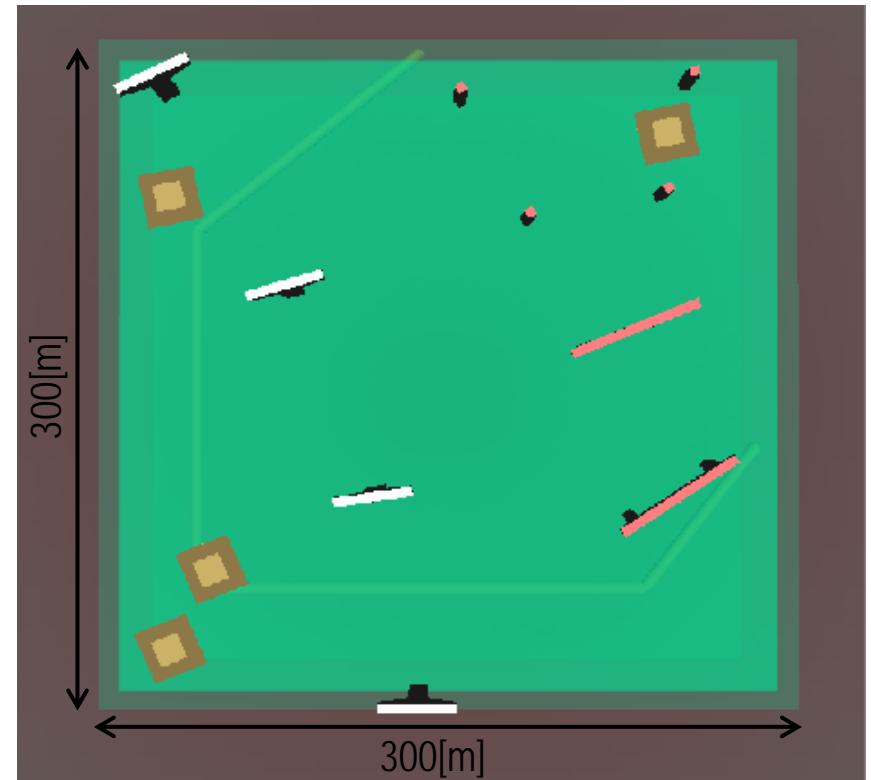
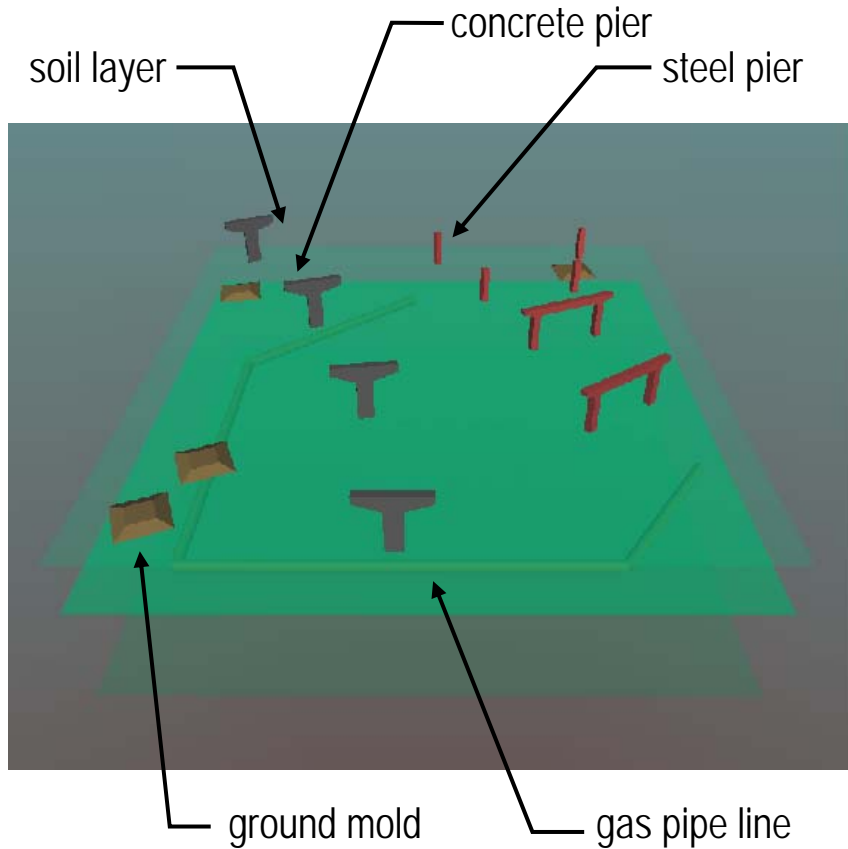
RESPONSE OF VIRTUAL CITY 2



CLOSE-UP VIEW OF STRUCTURE: DYNAMIC RESPONSE OF BRIDGE 1



VIRTUAL CITY 3



PLUG-IN OF NUMERICAL METHODS

PLUG-IN: request programmer to modify source codes such that I/O can be made through common protocols

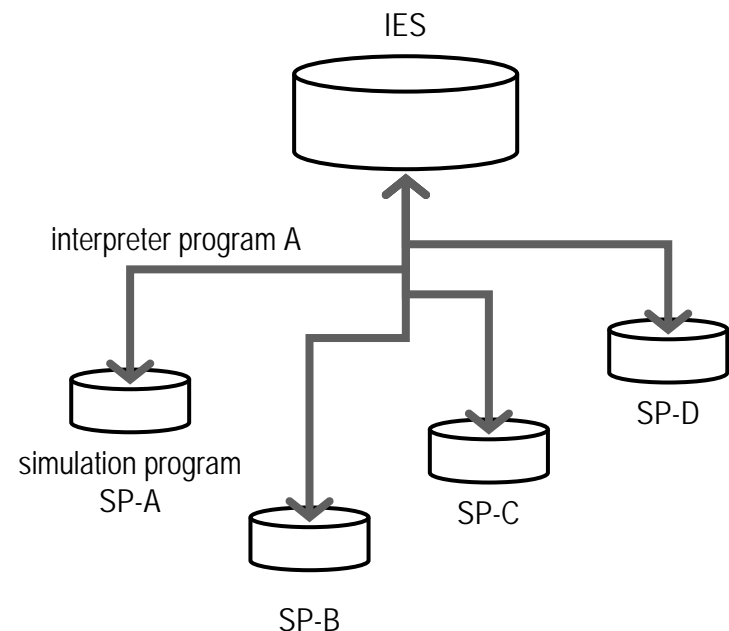
heavy task for programmer due to variety of structure data

◆ Methodology of Integration

- Application of DataBase management techniques

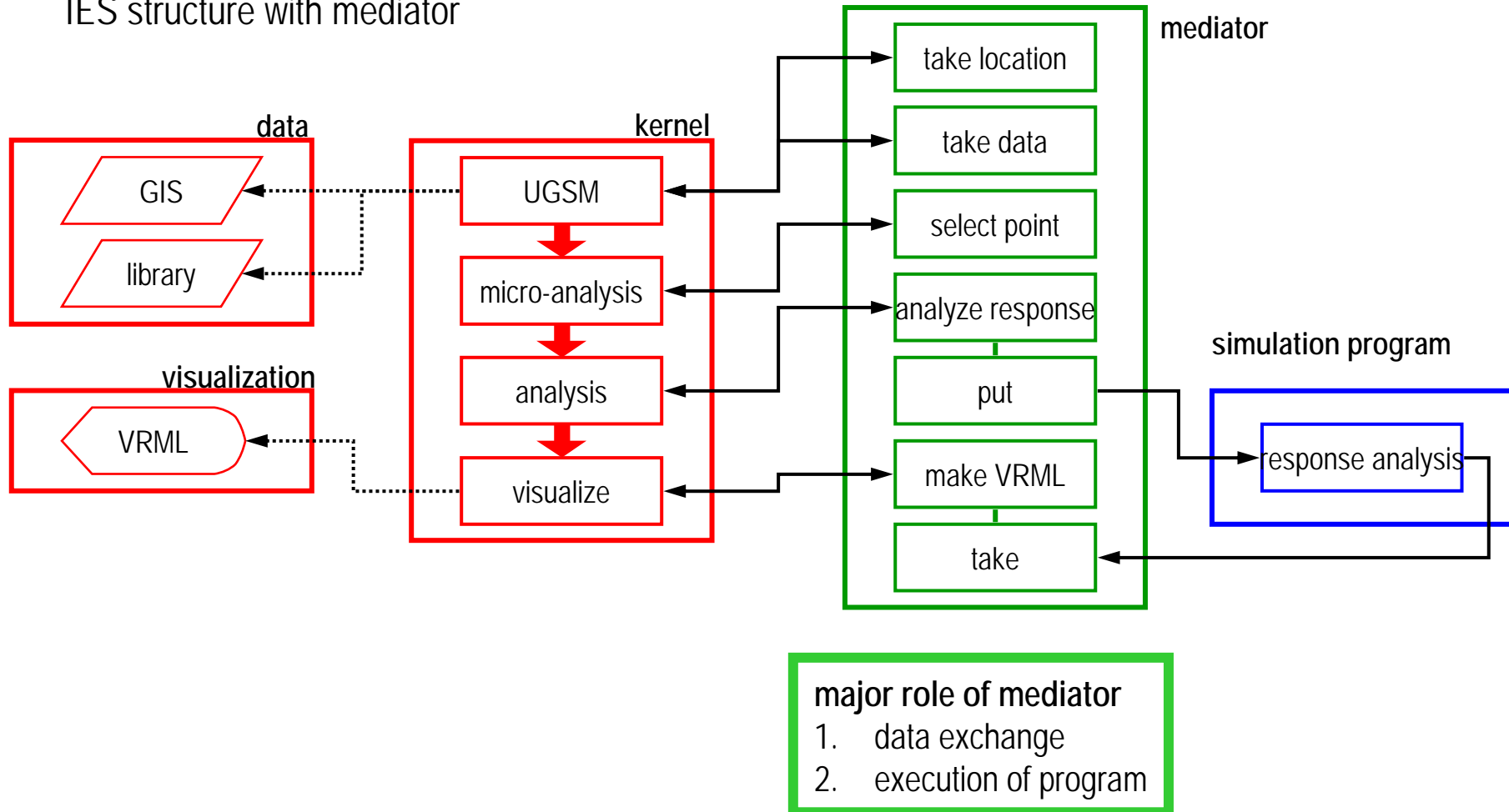
Federation-type DataBase with aid of interpreting programs (agents)

interpreting program:
supports data exchange between kernel and each simulation program



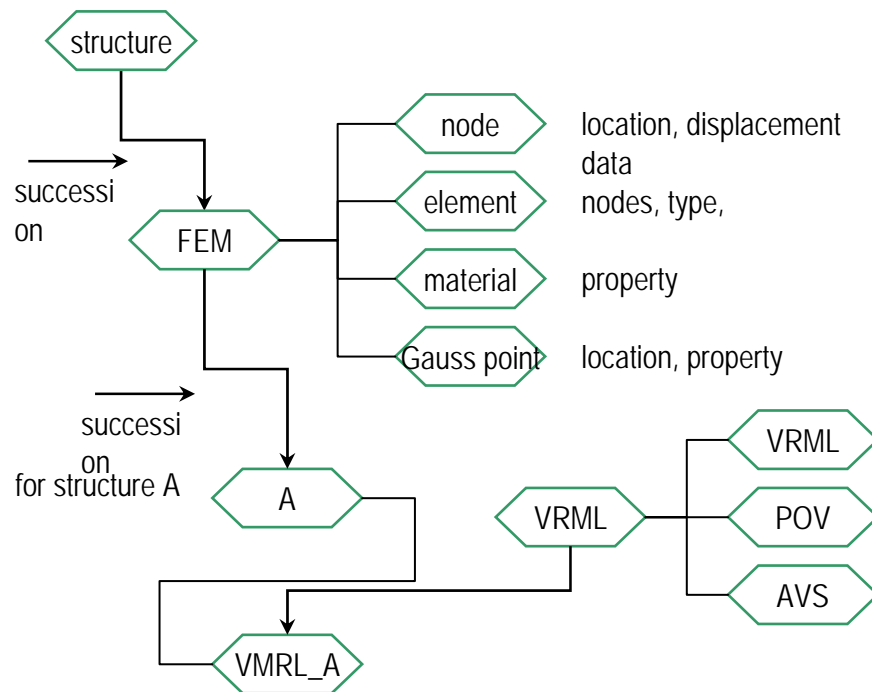
MEDIATOR AS INTERPRETING AGENT

IES structure with mediator

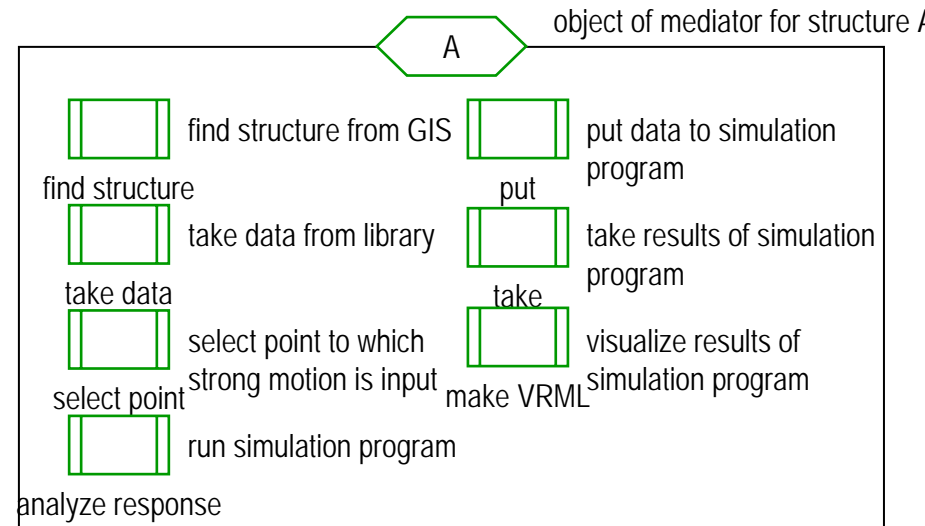


INHERETANCE OF MEDIAOTR OBJECT

Program Structure of Mediator



Methods



Computational Science Approach:
seek to automatic coding of mediator program
by taking full advantage of inheritance

MEDIATOR MAKER AS AI

◆ Mediator Maker

- artificial intelligence of automatically generating a mediator for a given simulation program
- mediator maker analyzes source code of a simulation program, and constructs a code of a corresponding mediator

◆ It is possible to make mediator maker by taking advantage of

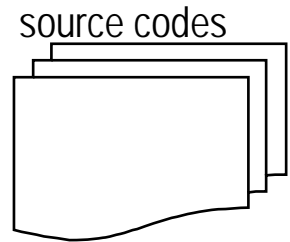
- common structure of source code (FEM-based)
- usage of common key variables (such as number of nodes, elements, etc.)

analysis of source code

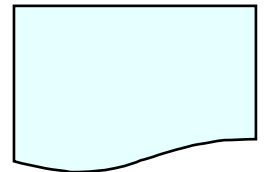
- ◆ subroutine
- ◆ common memory

construction of mediator

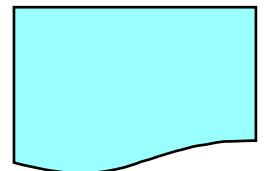
- ◆ analysis of I/O
- ◆ analysis of loop and condition
- ◆ prediction of variable



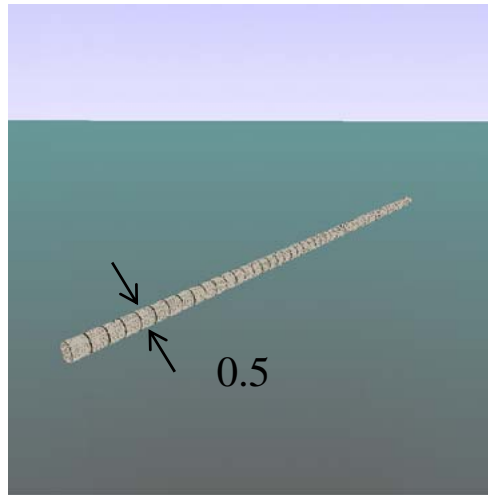
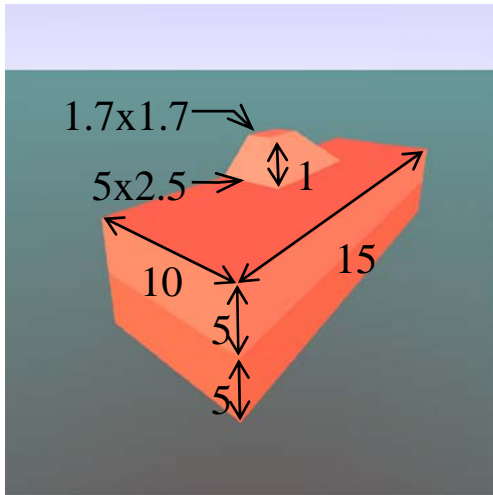
digested code



code for mediator

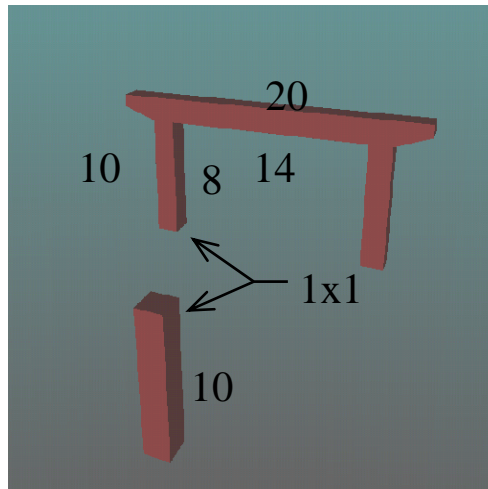
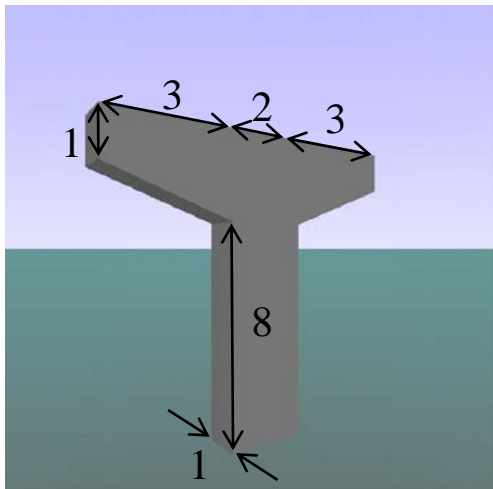


MODELS OF INFRASTRUCTURES IN VIRTUAL CITY 3



- infrastructures
- gas pipe line
 - concrete pier
 - steel pier
 - ground mold

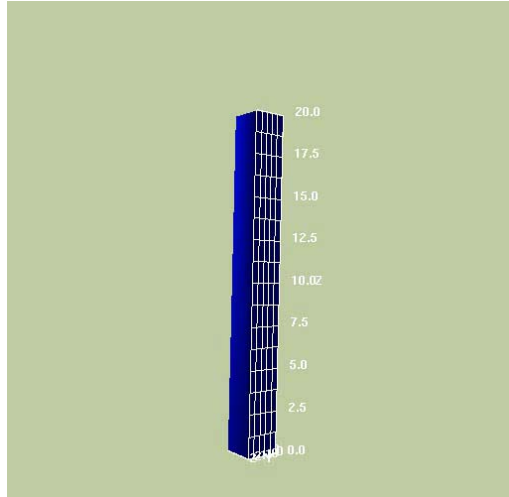
particular material properties & mechanism for earthquake resistance



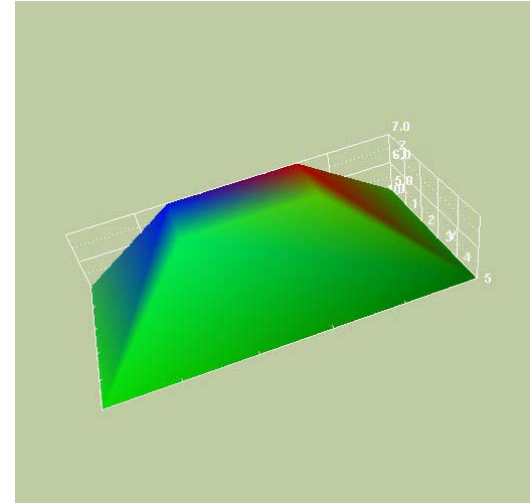
reliable analysis methods used in ERD are plugged in IES

NON-LINEAR RESPONSE OF INFRASTRUCTURES IN VIRTUAL CITY 3

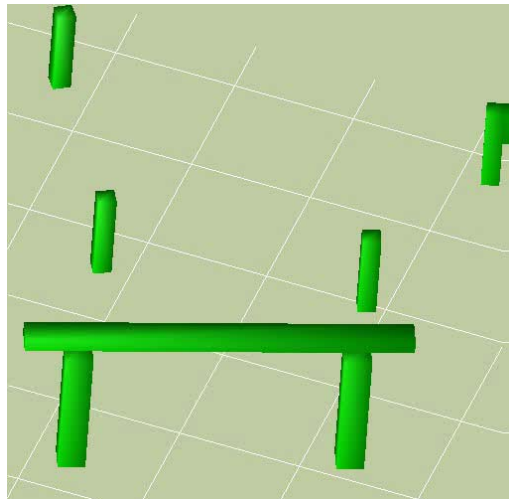
steel pier



ground mold

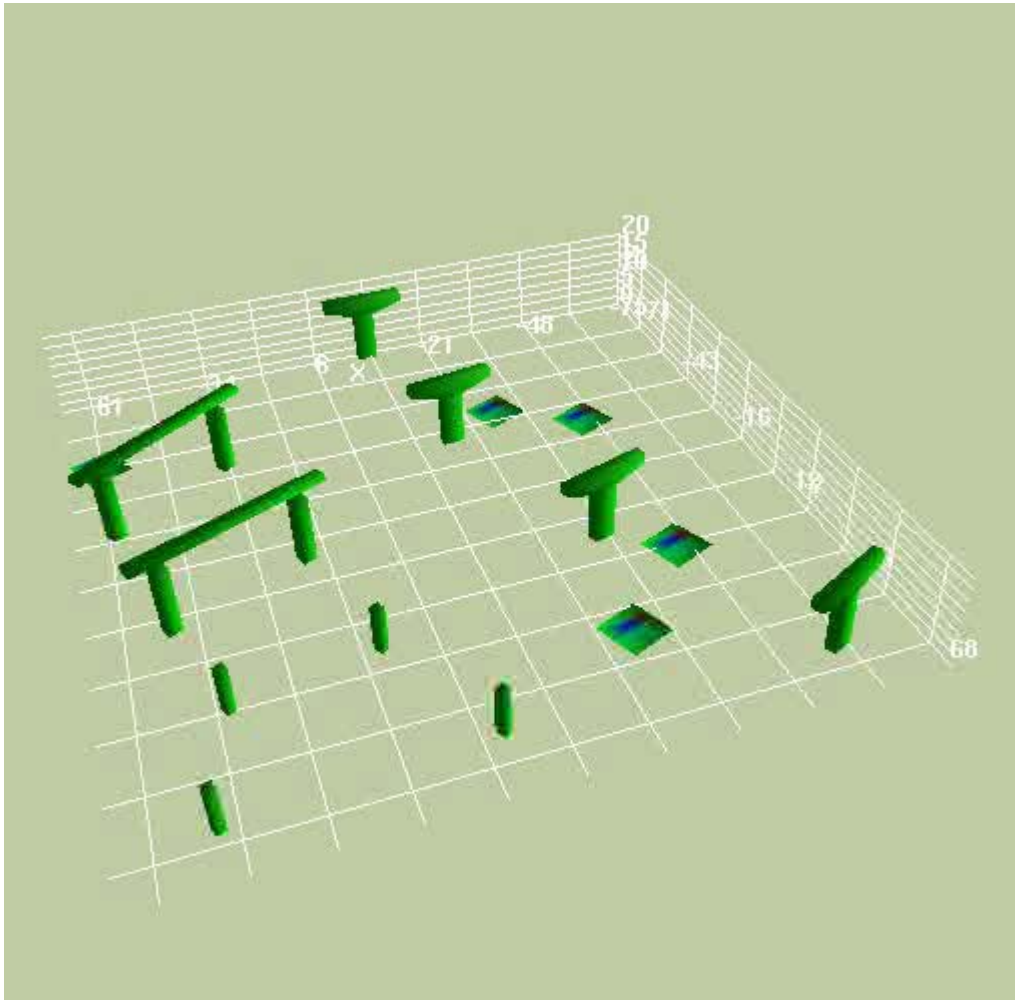


concrete pier



plugged-in simulation programs work in IES

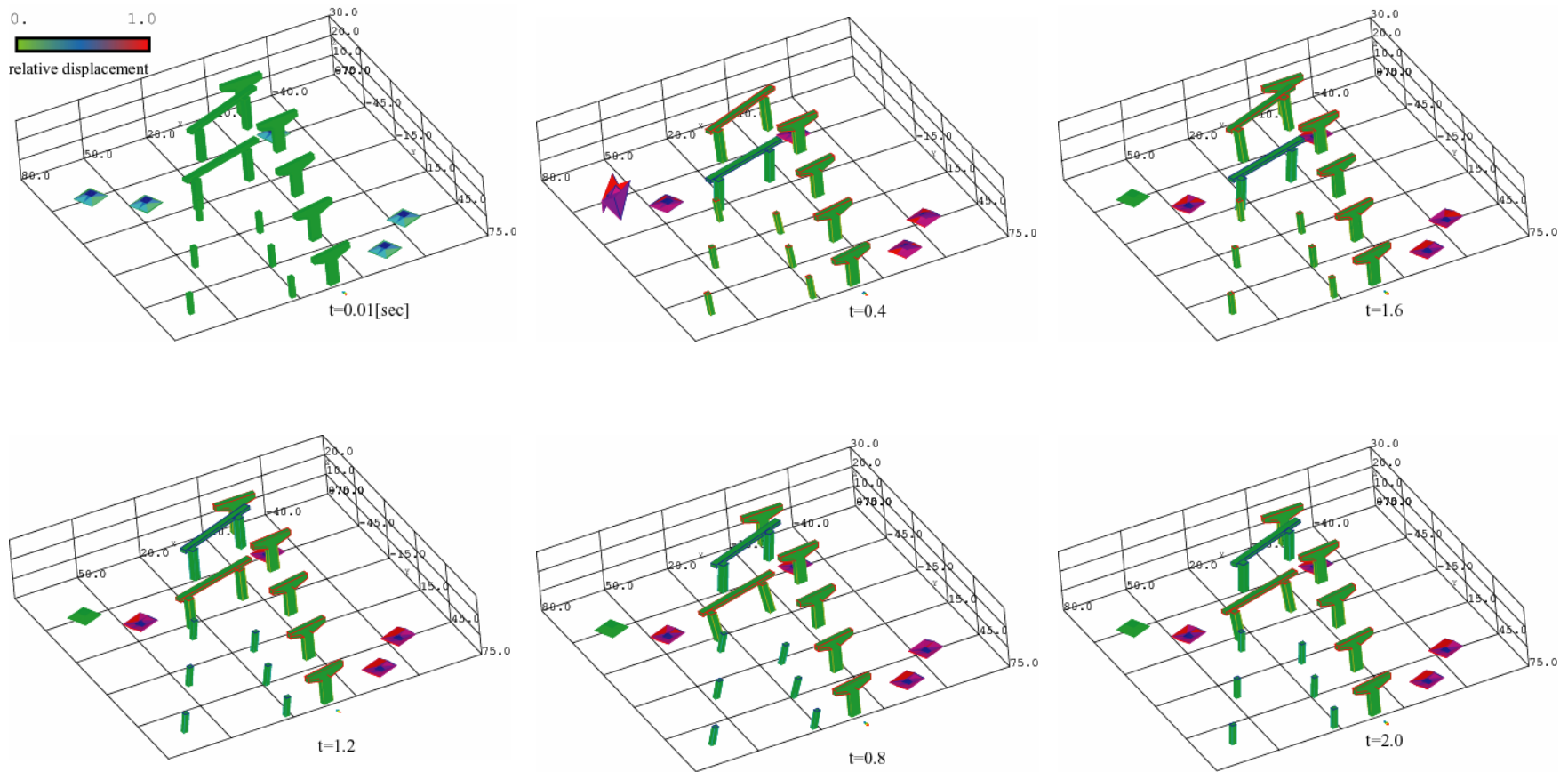
RESPONSE OF VIRTUAL CITY 3



- all numerical analysis of structures are
- non-linear
 - based on earthquake resistant design

unified visualization will contribute to form *common recognition* of possible earthquake disaster

SNAPSHOT OF RESPONSE AND DAMAGE



SIMULATION OF ACTION

◆ Evacuation Simulation

- physical simulation model based on flow, potential, etc.
- multi-agent simulation intelligent agents

✓ need to estimate *panic* in evacuation process

◆ Damage and Loss Simulation

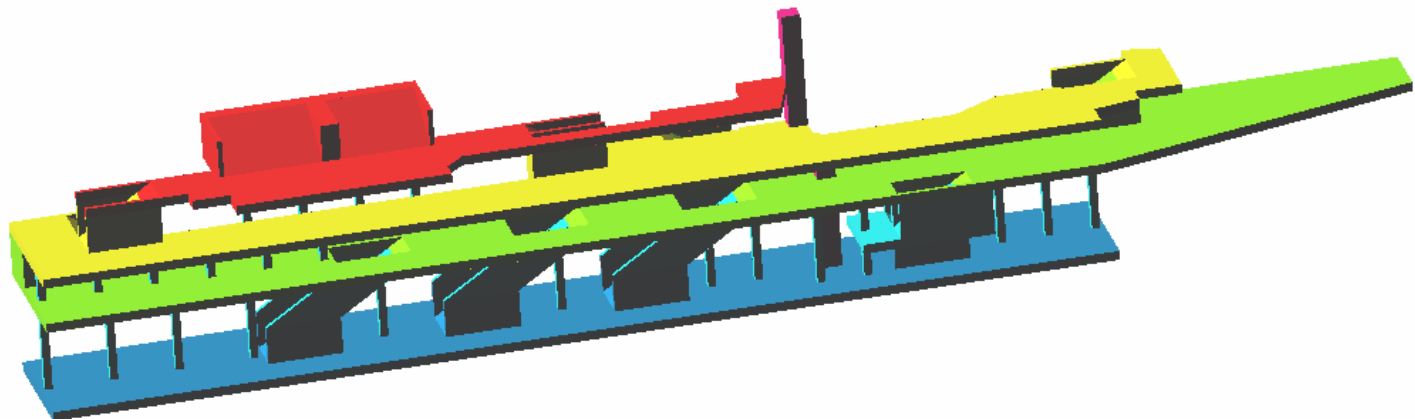
- micro: evaluation of damage and repair cost
- macro: based on past record of damage
- risk analysis/management

✓ prediction of damage and loss of future society

ACTION SIMULATION: EVACUATION SIMULATION USING MAS

◆ Evacuation Simulation

- predict evacuation process in underground towns, high-rise buildings, department stores, schools, etc.
- use intelligent agents to mimic people in panic state



underground subway station

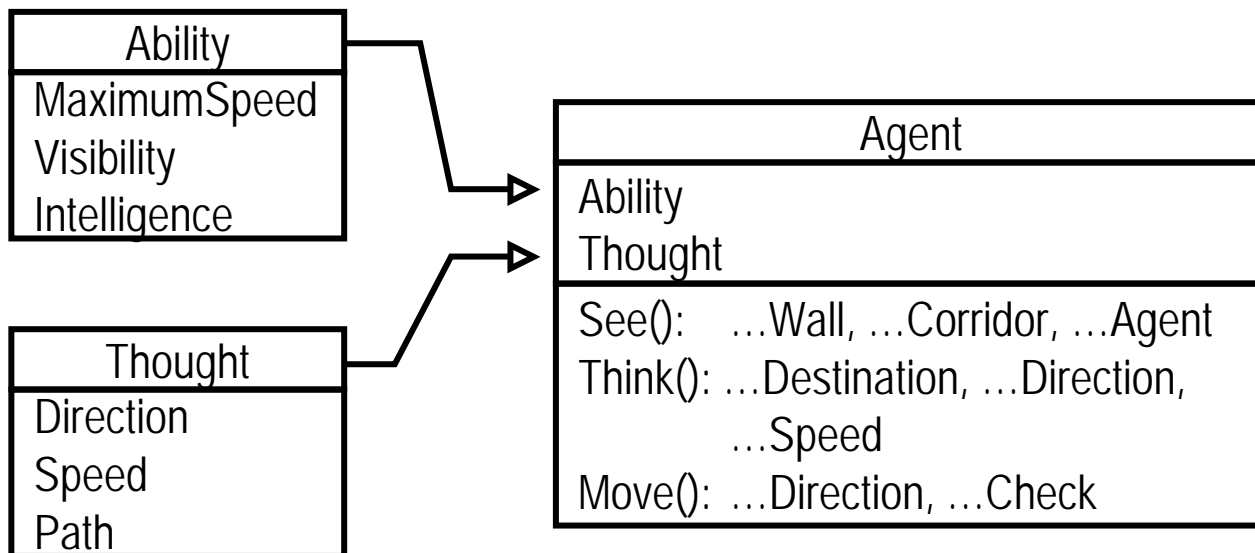
■ 4 floors

■ 3 elevators

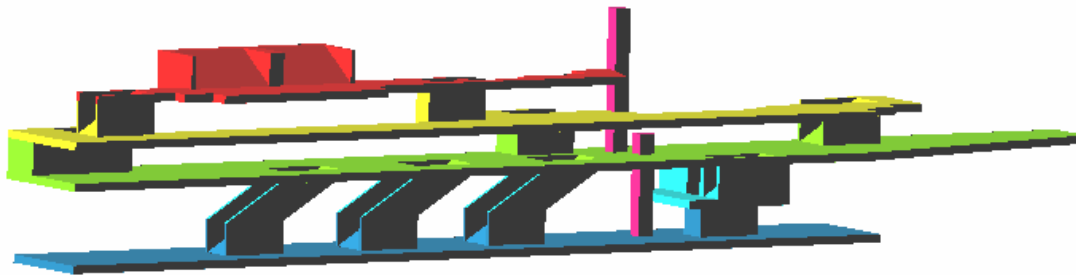
MULTI-AGENT SIMULATION

◆ Utilization of *Intelligent Agent*

- input internal variables (max. speed, intelligence, memory)
 external state
- output see surrounding environment, agent, etc.
 think judge most suitable path
 move go to next position



MODELING FOR DYNAMIC STRUCTURES & EVACUATION ANALYSIS



modeling strategy

- structure data for each floor
- data for escalator

evacuation path

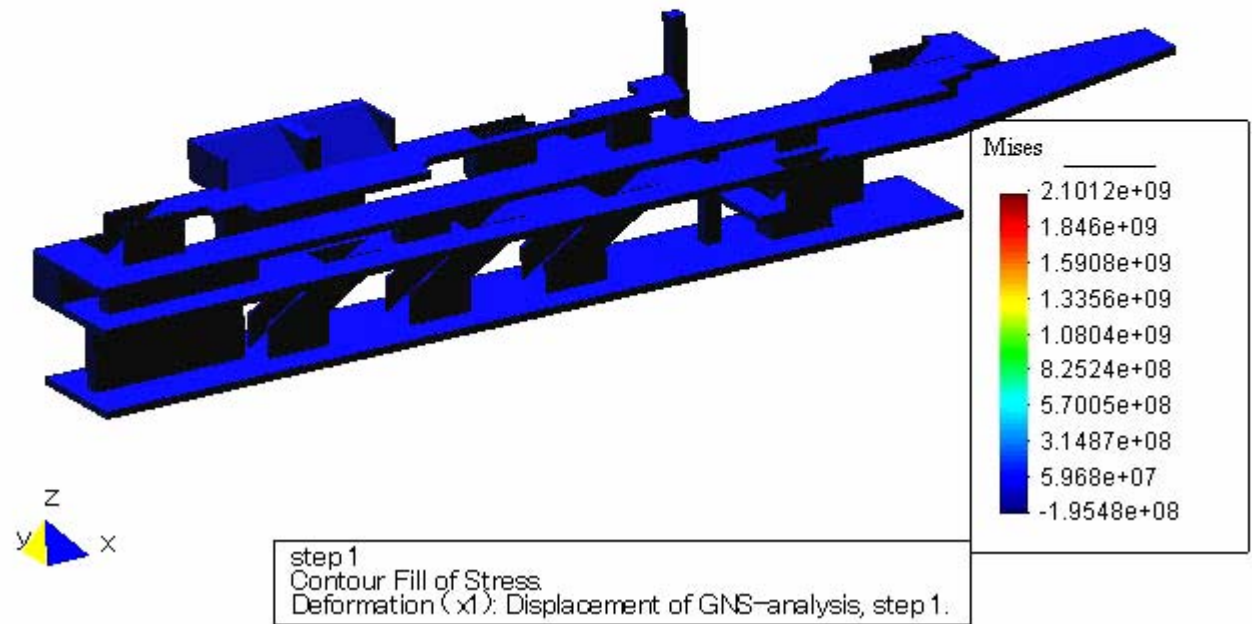
- corridors determined from structure data
- Exit determined from escalator

data structure is arranged to be used for structure analysis and for evacuation analysis

RESULTS OF SIMULATION (1)

dynamic structure analysis

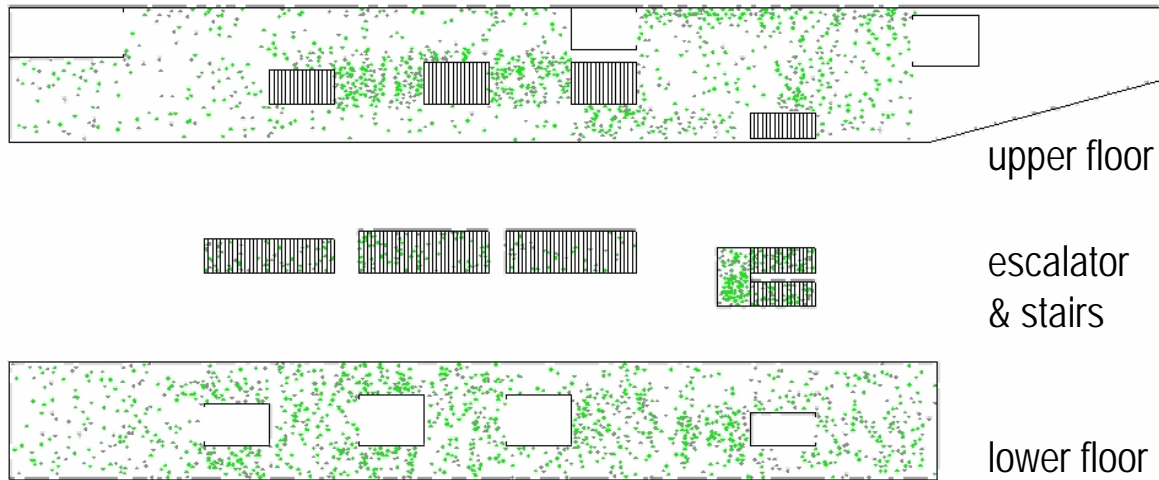
- model
structure & ground
- simulation
MMAM



structure response analysis is made by accounting
for soil-structure interaction effects

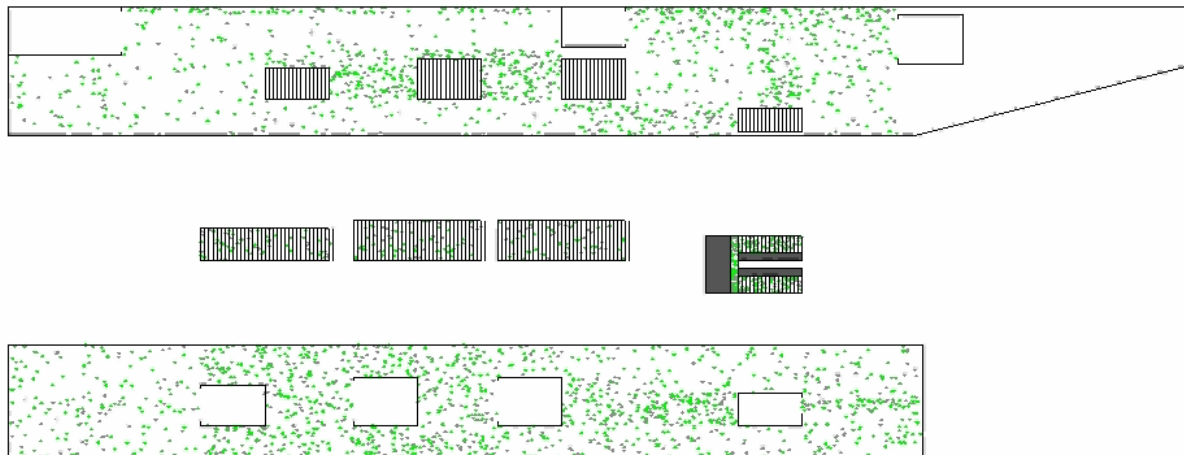
RESULTS OF SIMULATION (2)

no damage



green less intelligent agent
- slow think
gray more intelligent agent
- quick think

damage

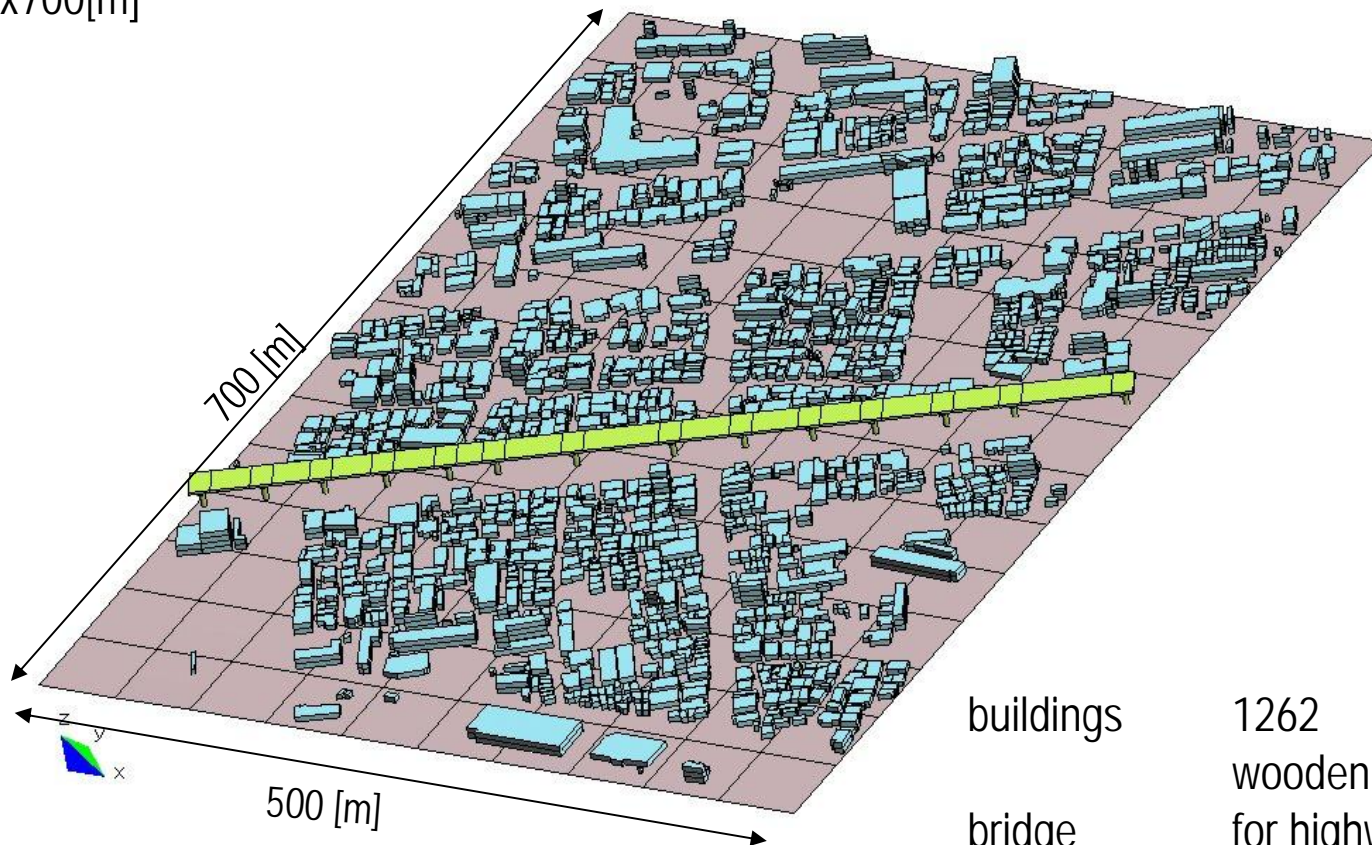


multi-agent analysis is possible for structures to which dynamic structure analysis is made.

DIGITAL KOBE

Kobe City, Higashi-Nada District

500[m]x700[m]



buildings

1262

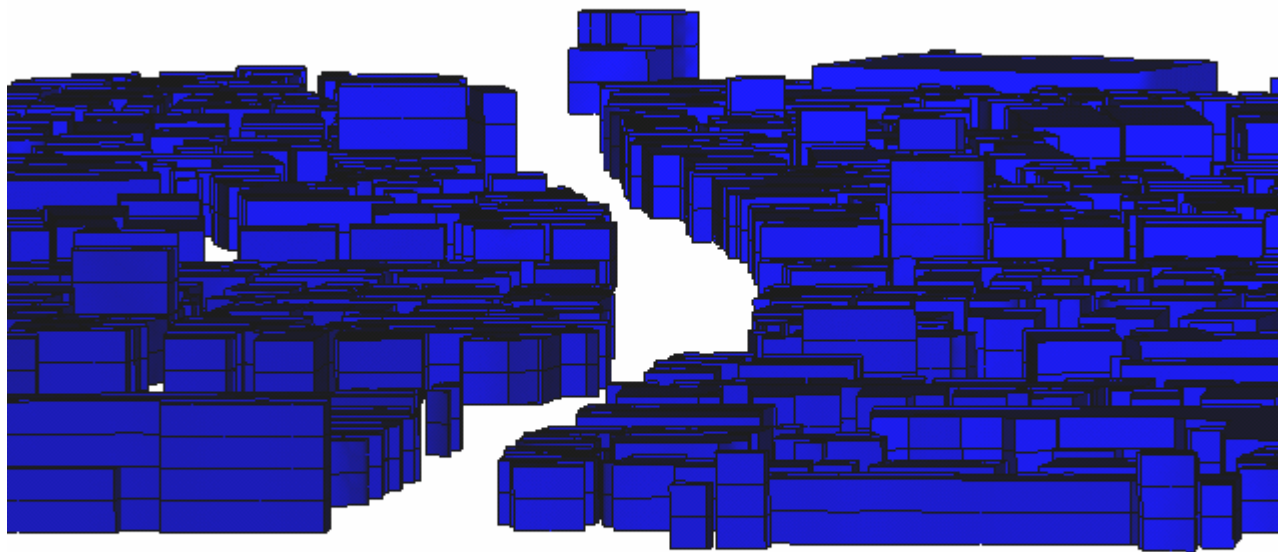
wooden, RC/SRC

bridge

for highway

14 RC piers

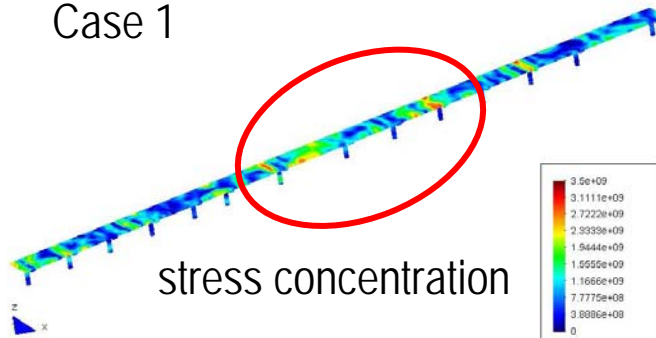
SIMULATION RESULTS (1)



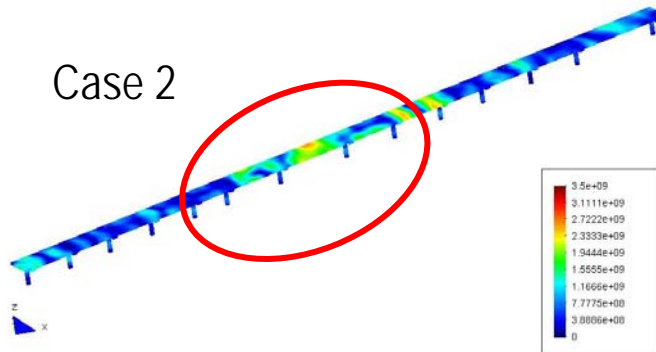
step 1
Contour Fill of Displacement, |Displacement|.
Deformation (x10): Displacement of GNS-analysis, step 1.

SIMULATION RESULTS (2): THREE EARTHAUEK SCENARIOS

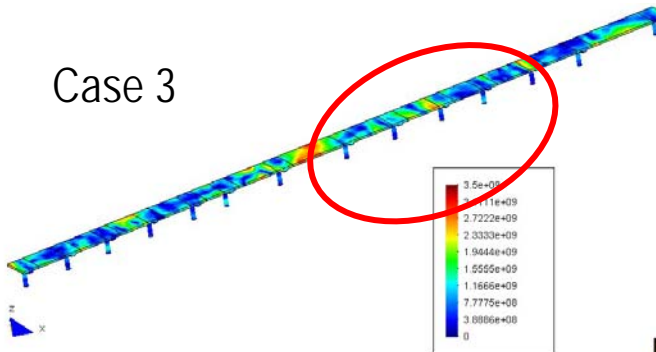
Case 1



Case 2



Case 3



Case 1



Case 2



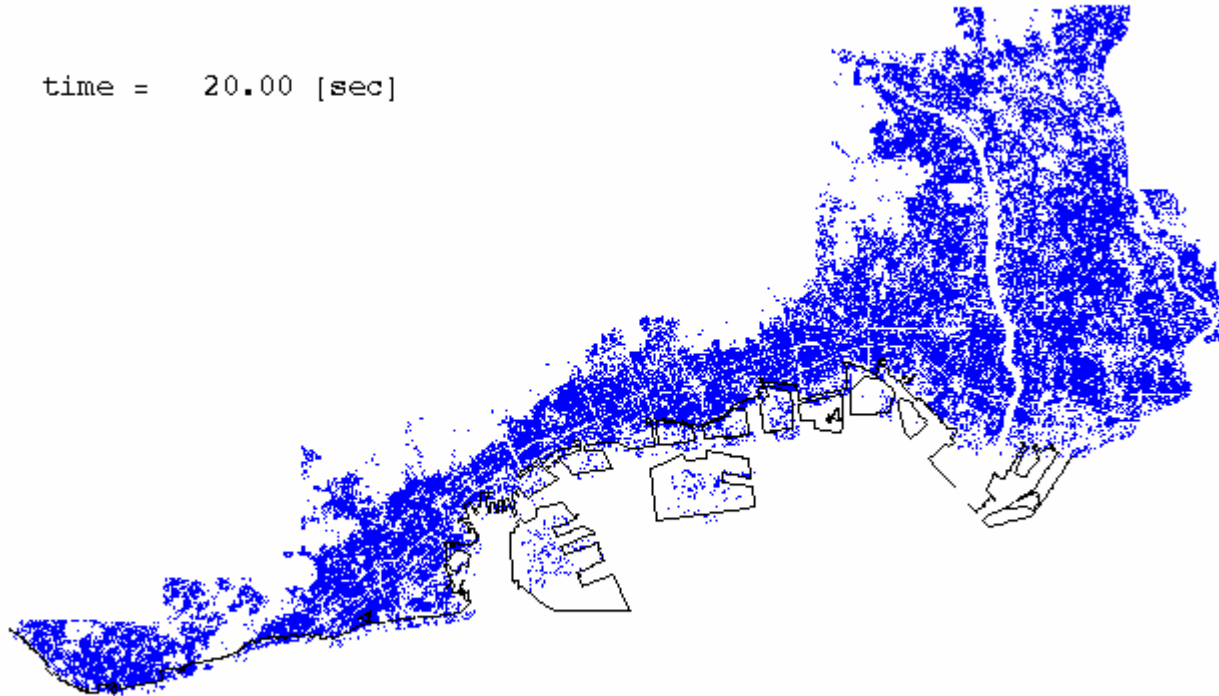
Case 3



differences in earthquake disaster due to difference in earthquake scenario

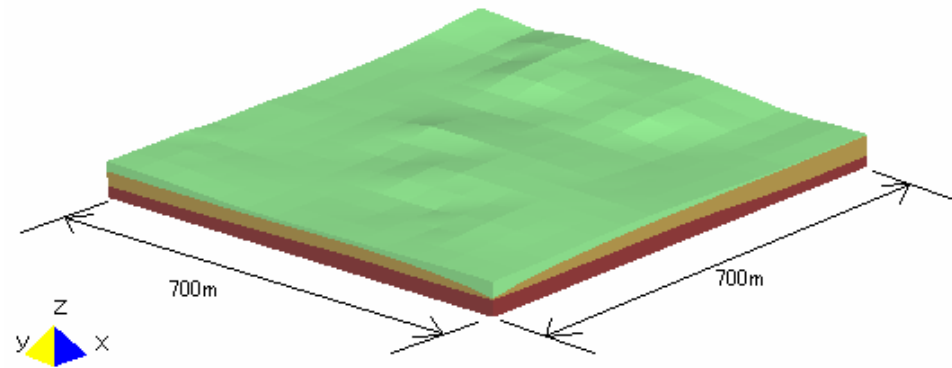
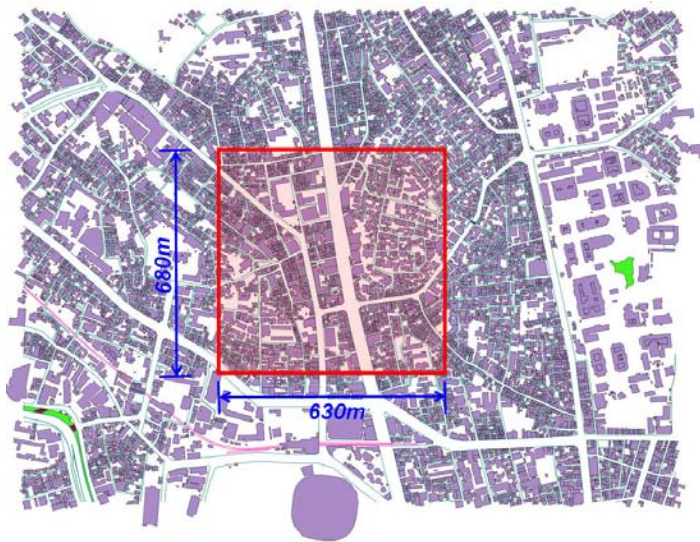
FULL CITY SIMULATION

time = 20.00 [sec]

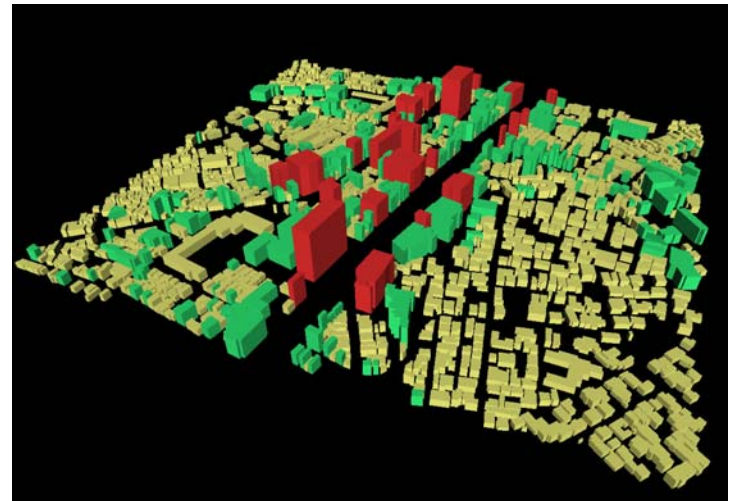


DIGITAL BUNKYO CITY

ground structure model
700[m]x700[m]x40[m]
3 layers



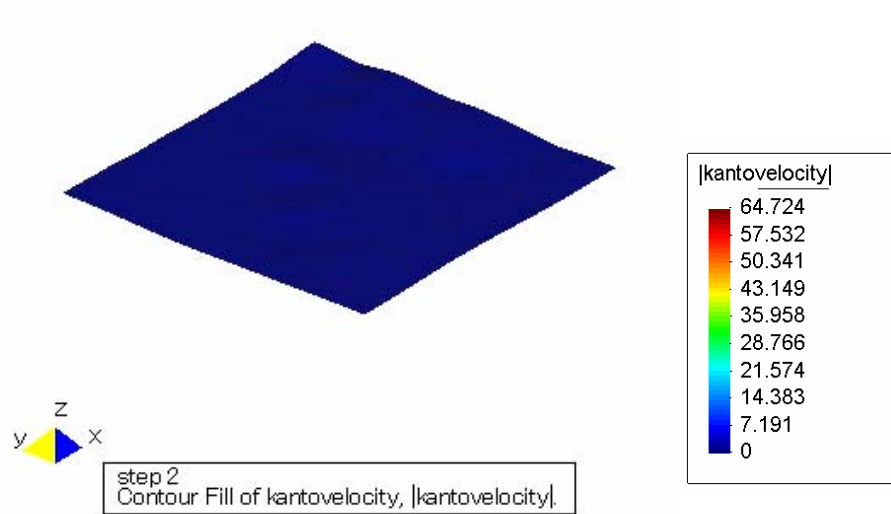
building models
around 2000
MDOF system



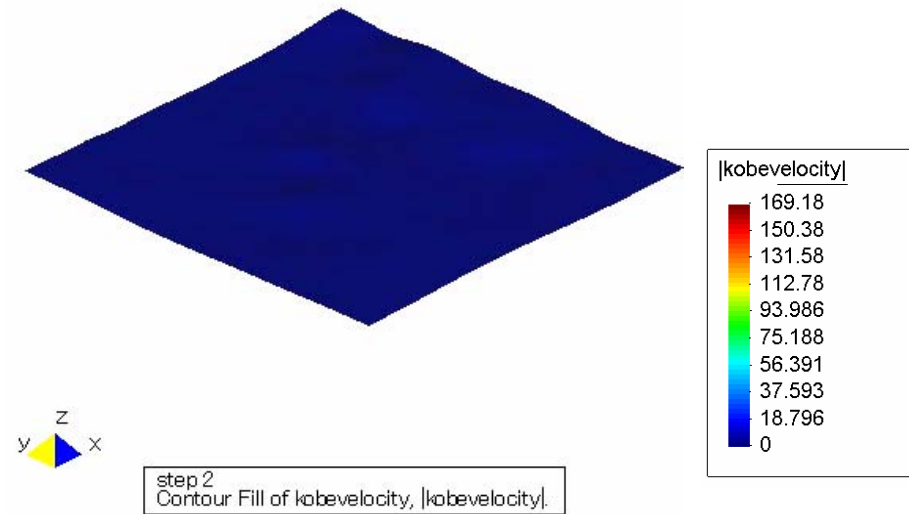
data source

- ◆ GIS of boring data of Tokyo Metro-police
- ◆ commercially available GIS for structure data

STRONG GROUND MOTION DISTRIBUTION

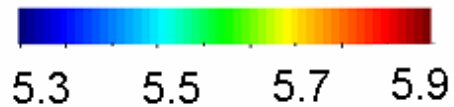
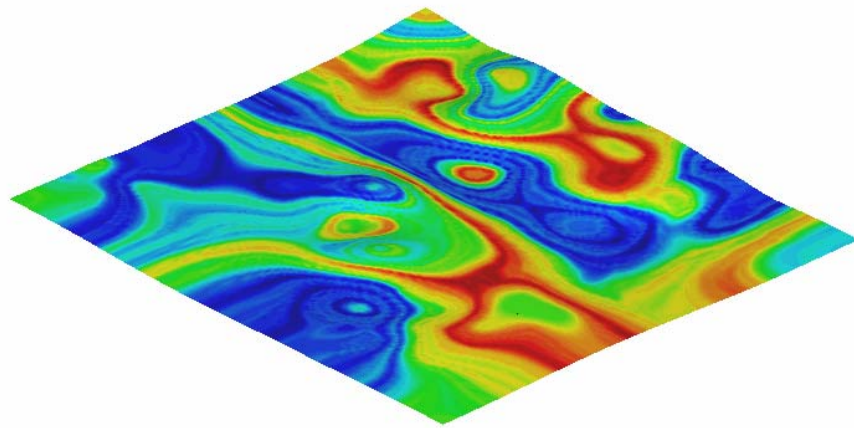


Expected Kanto Earthquake

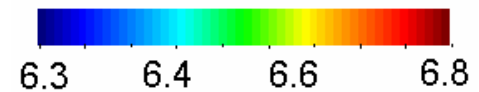
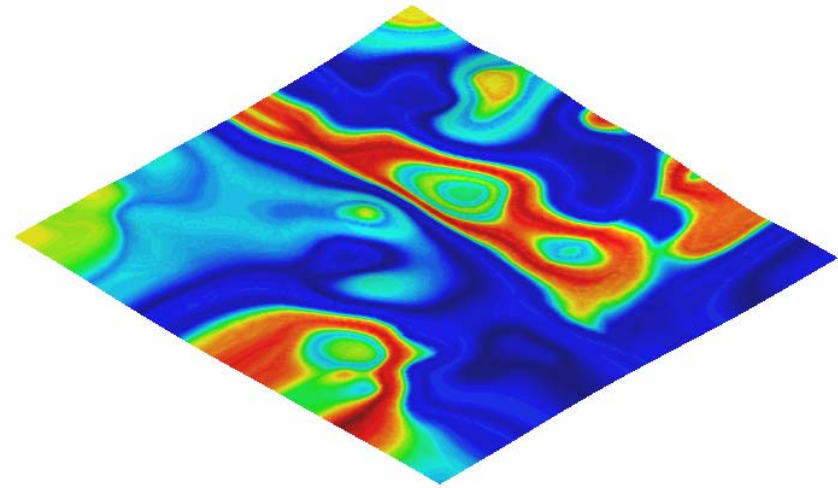


Recorded Hanshin-Awaji Earthquake

STRONG GROUND MOTION DISTRIBUTION

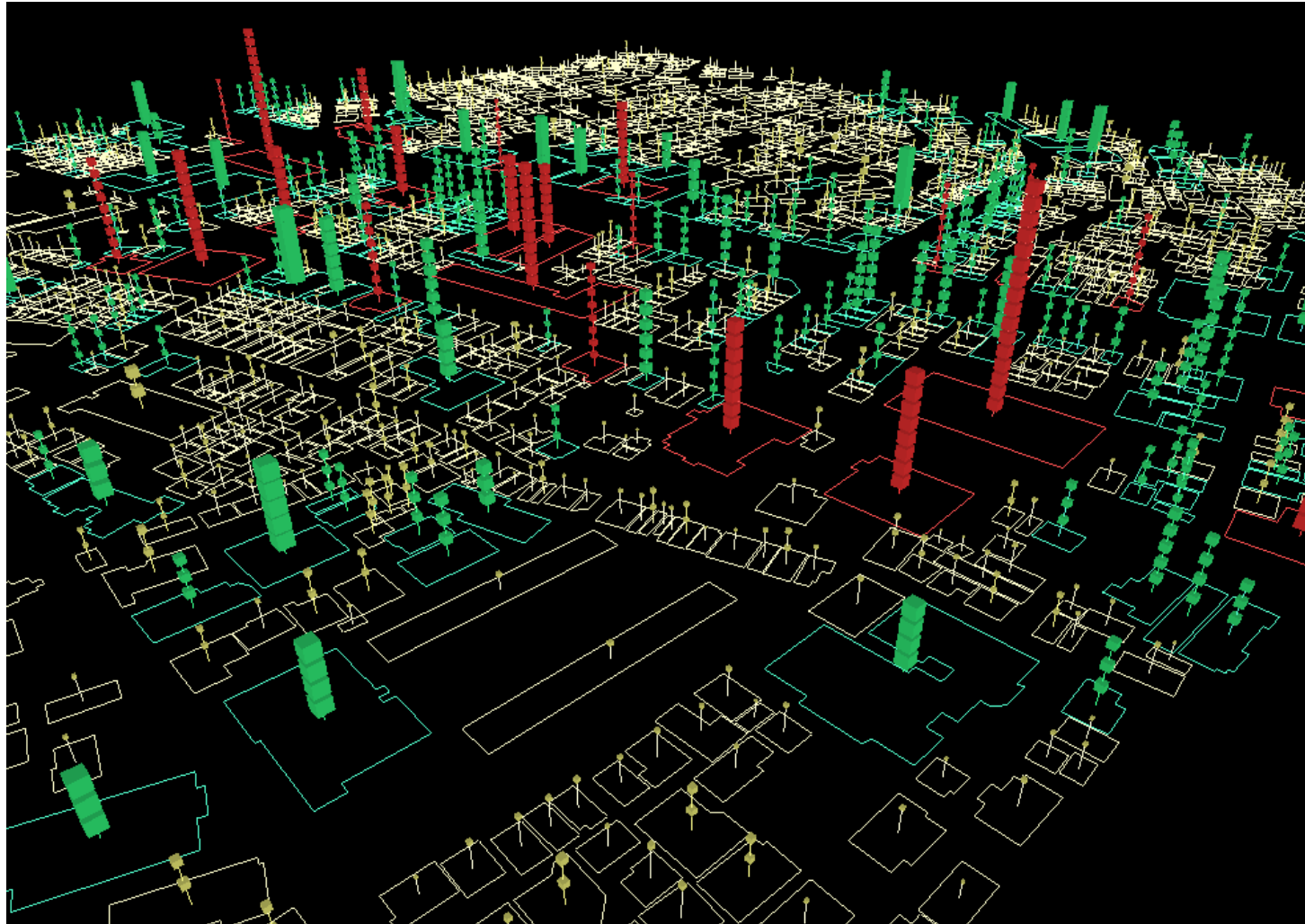


Expected Kanto Earthquake

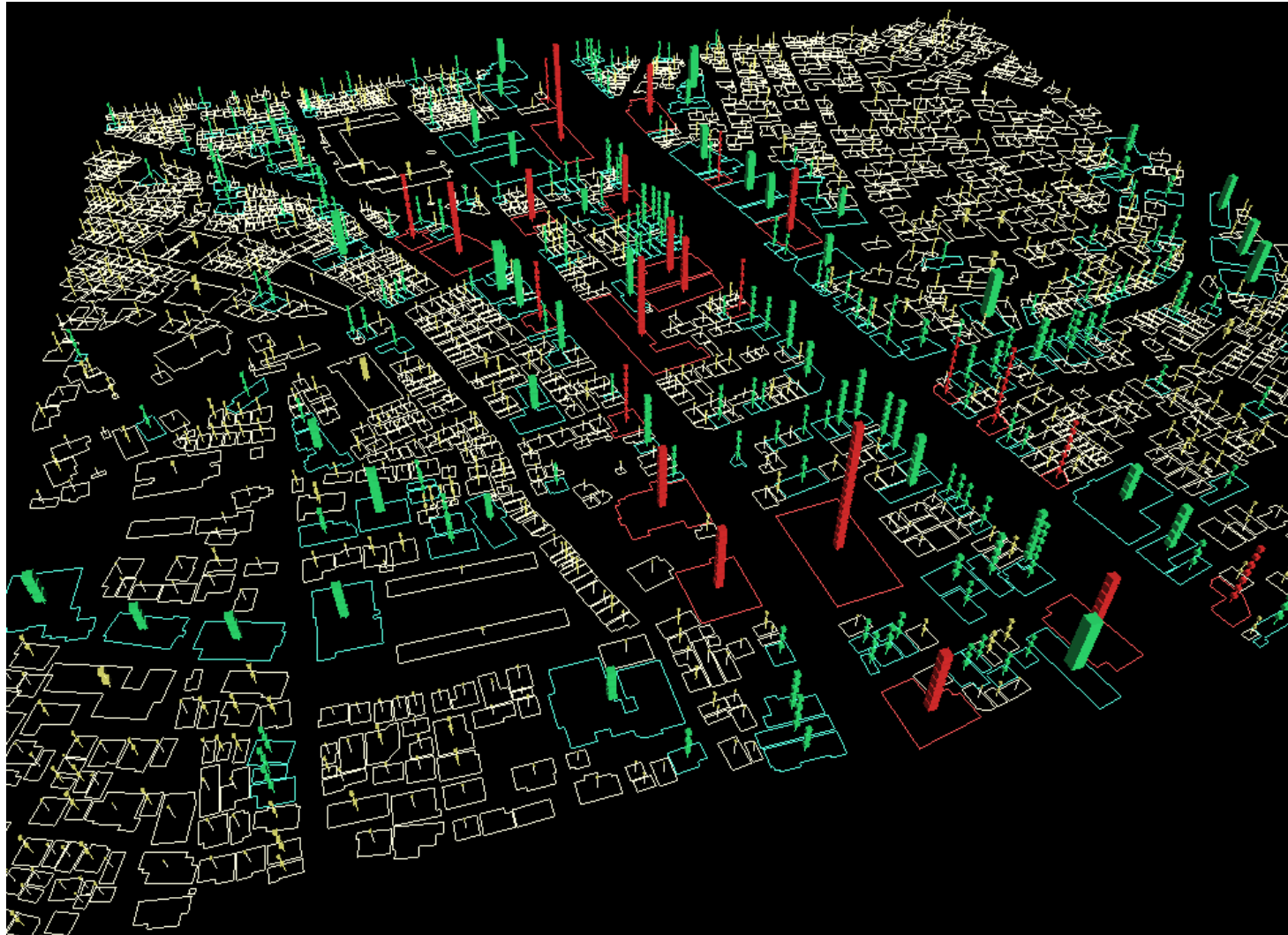


Recorded Hanshin-Awaji Earthquake

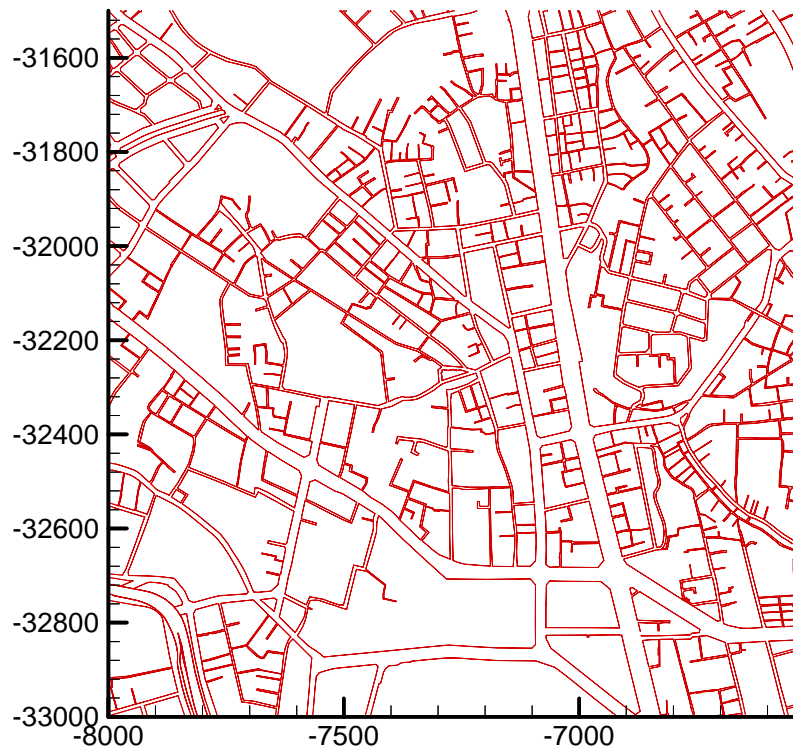
VIBRATION OF BUILDINGS



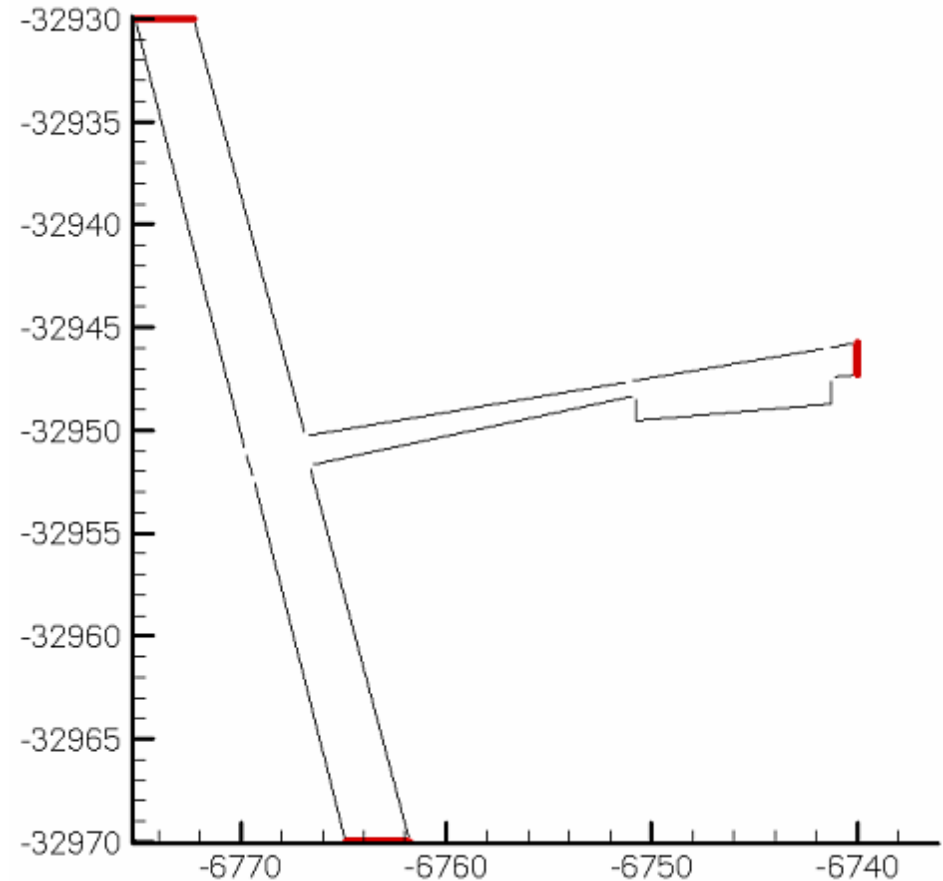
VIBRATION OF BUILDINGS



EVACUATION OF RESIDENCES



road network model



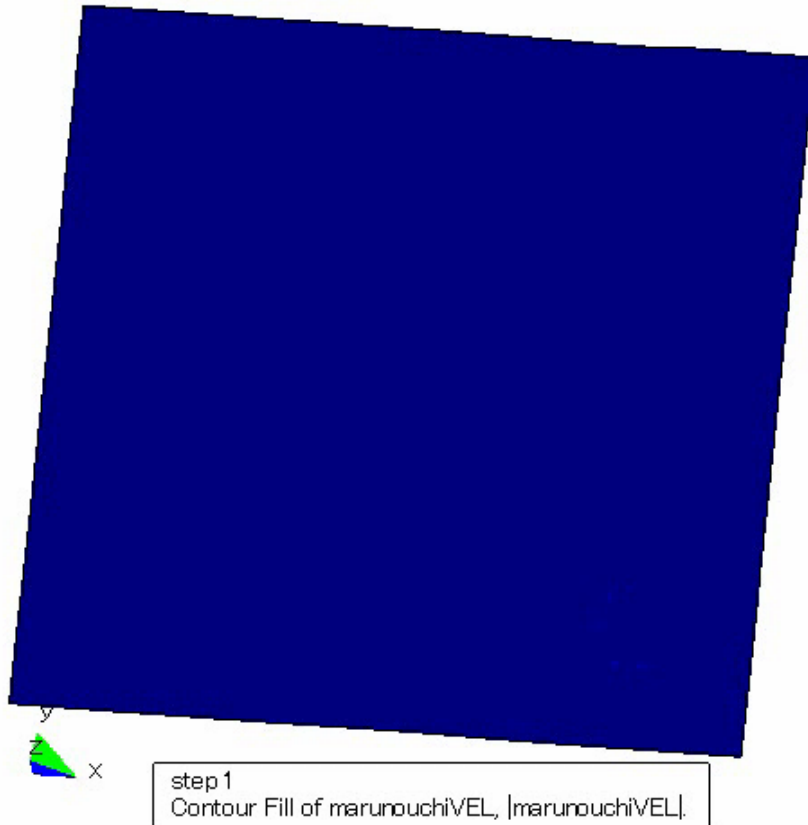
multi-agent simulation

simulation for various situations is possible.

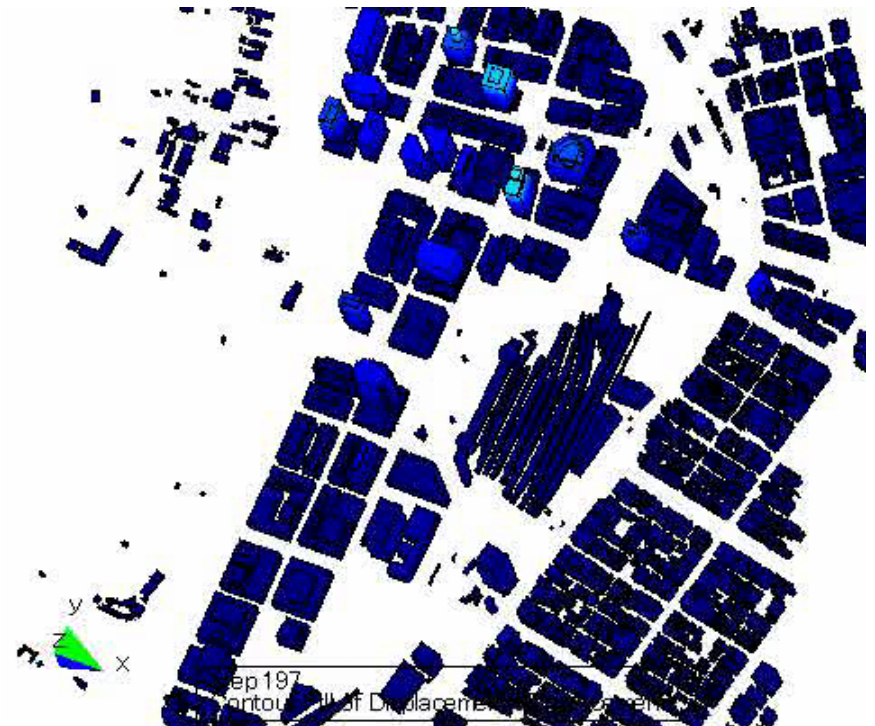
SIMULATION OF TOKYO STATION



EXAMPLE 1

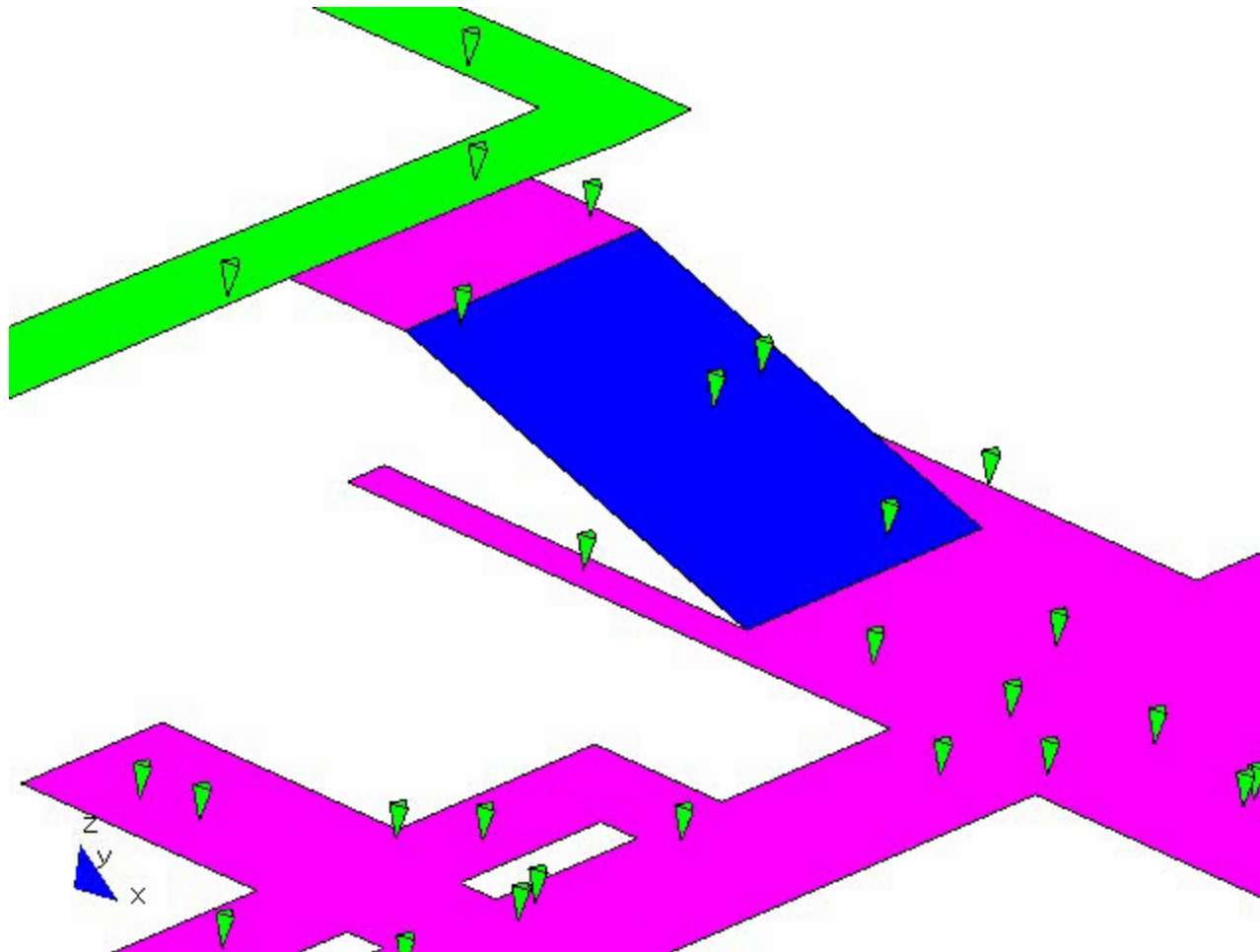


strong ground motion

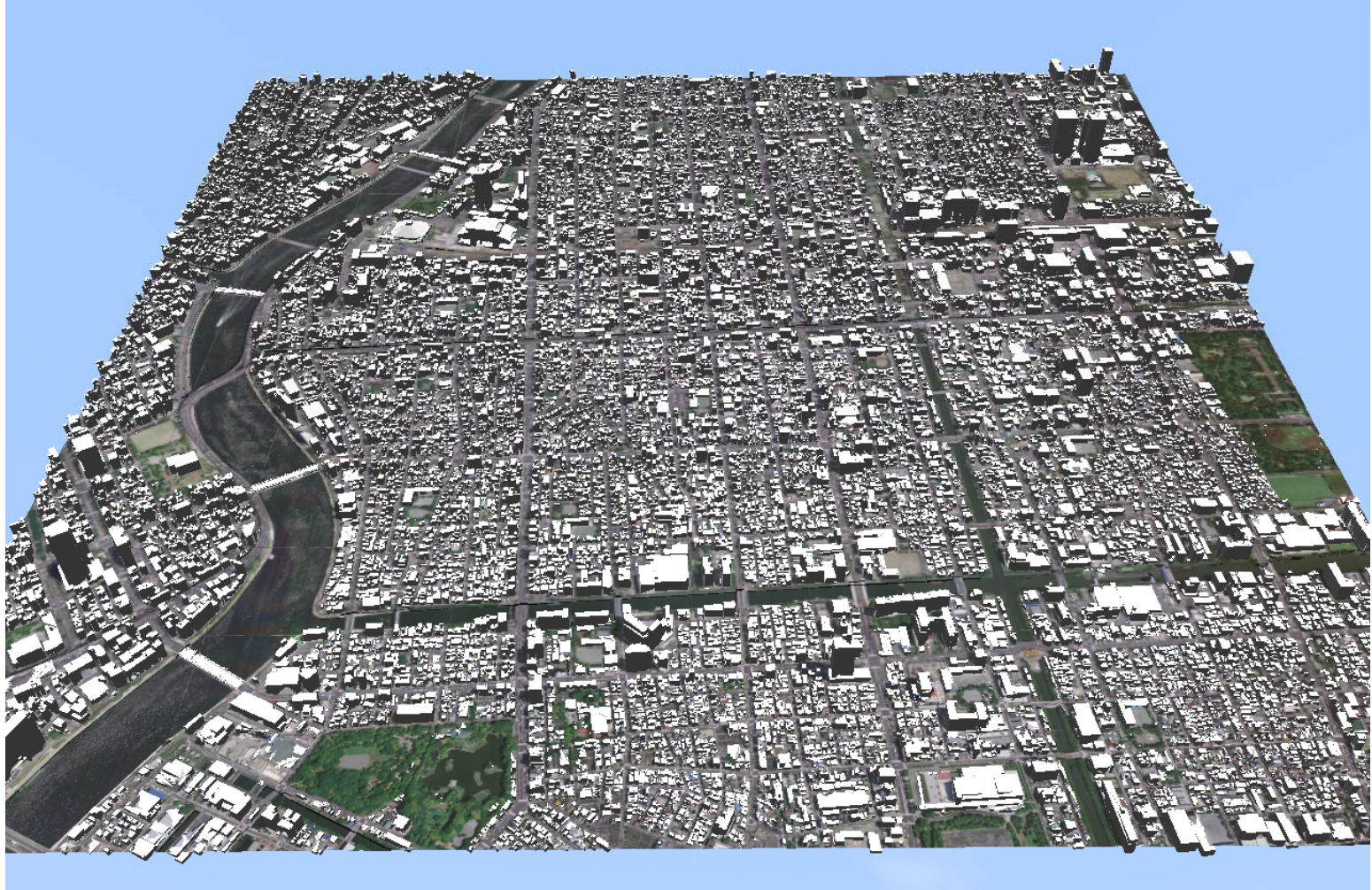


structure-wise damage evaluation

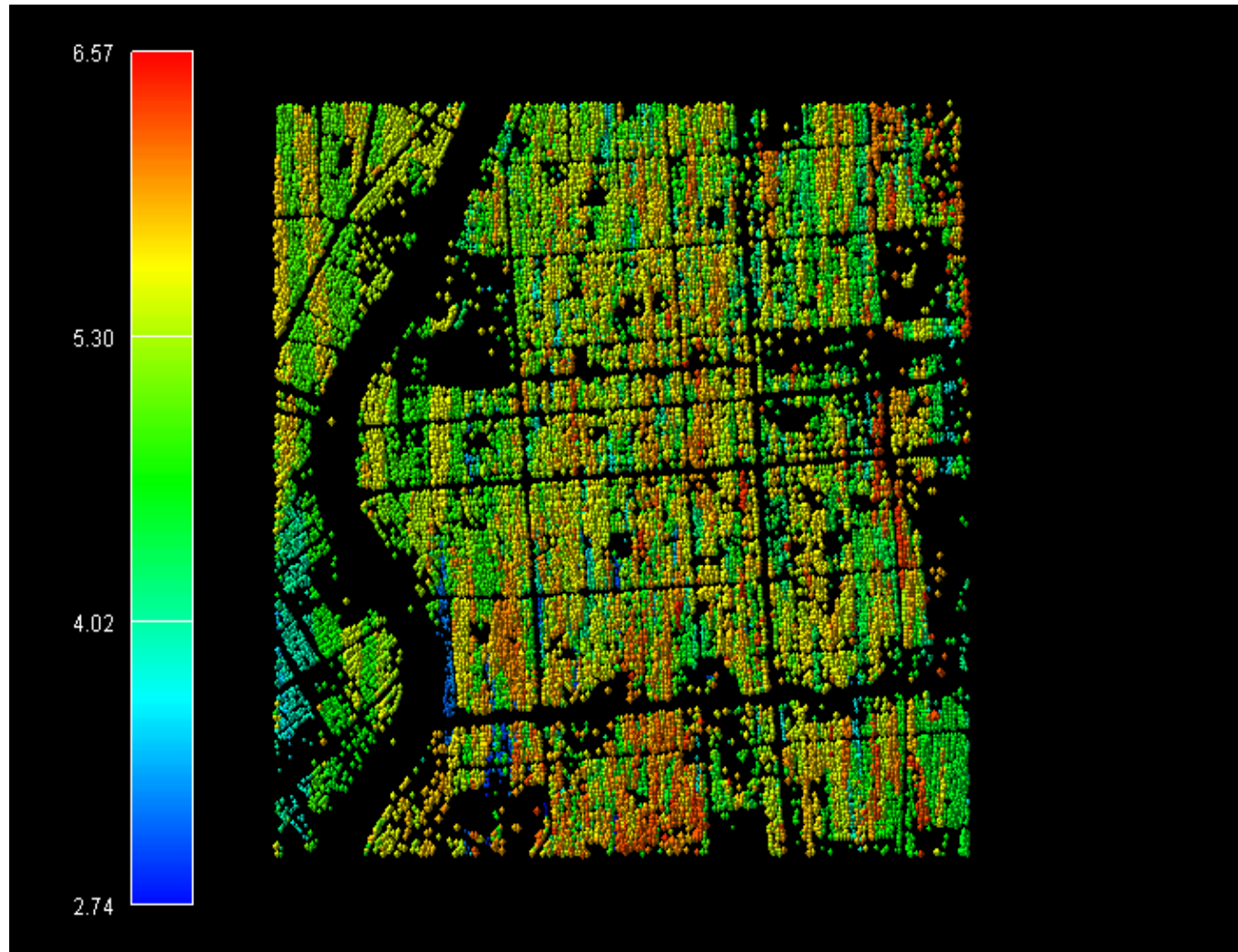
EXAMPLE 2



TOKYO DOWNTOWN



EXAMPLE 1



strong ground motion

EXAMPLE 2



structure response

CONCLUDING REMARKS

◆ Potentials of IES

- Generation of new information on natural disaster risk and hazard by applying numerical simulation to data stored in GIS
- Improve residents awareness on natural disaster risk and hazards and form common recognition of them among community

◆ Future Tasks

- Advancement of structure data stored in GIS
new exclusive sensing of buildings and structures
- Advancement of natural disaster preparedness, mitigation and recovery
significant need for *integration* of technologies for natural disasters