

# 巨大地震・地震災害に対する 統合シミュレーションの開発

堀宗朗

東京大学地震研究所

# HIGH PERFORMANCE COMPUTING

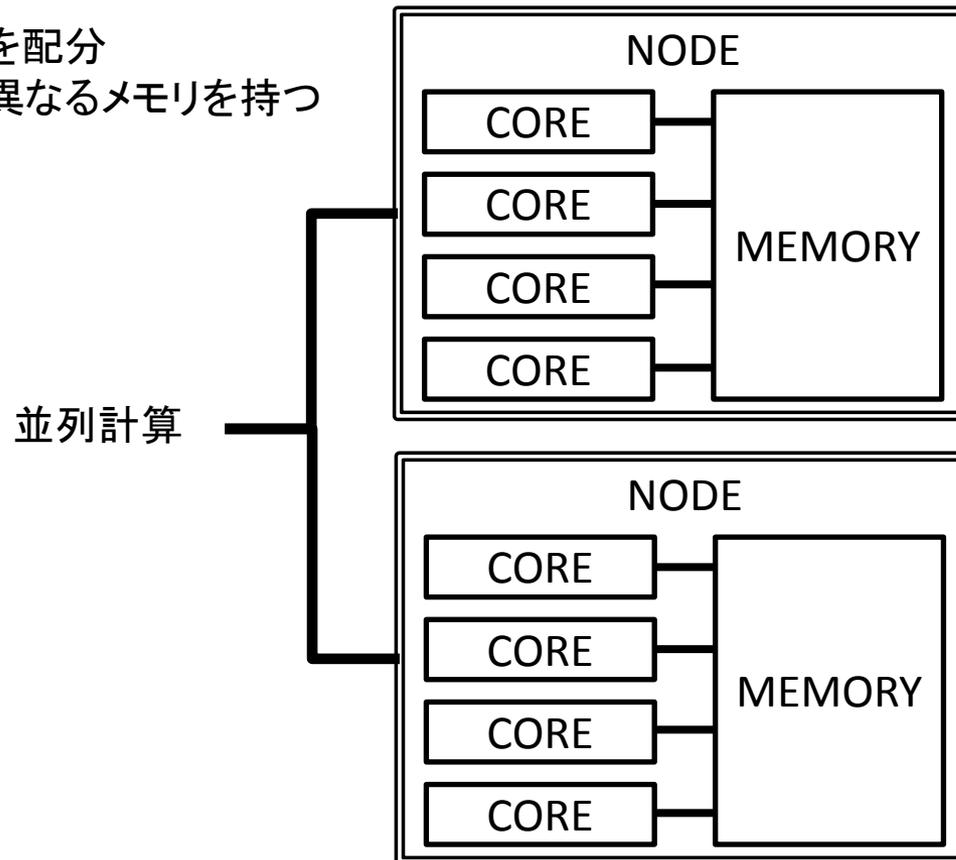
## 高性能計算(並列計算)

- 多数の計算ユニットを使用することで, 計算速度を向上
- 計算ユニット間のデータのやり取りの削減が重要



ノードに計算を配分

- 各ノードは異なるメモリを持つ
- MPIを使用



コアに計算を配分

- コアは同じメモリを使う
- OpenMPを使用

# 構造物のシミュレーション

- 超高層ビル

- High Fidelity モデル 

- 地盤-構造連成の大規模計算 

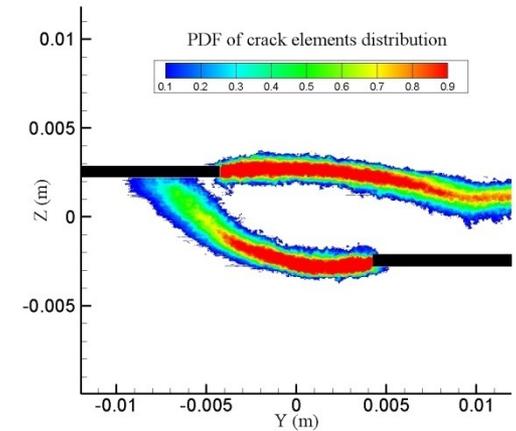
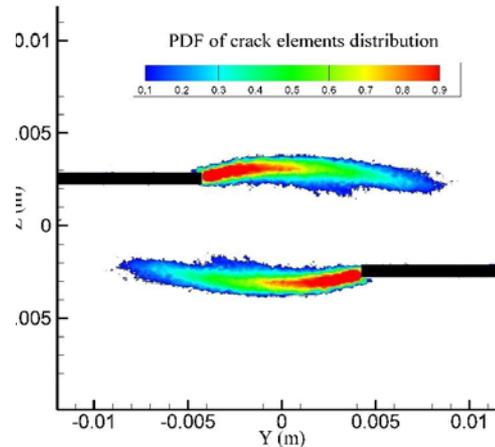
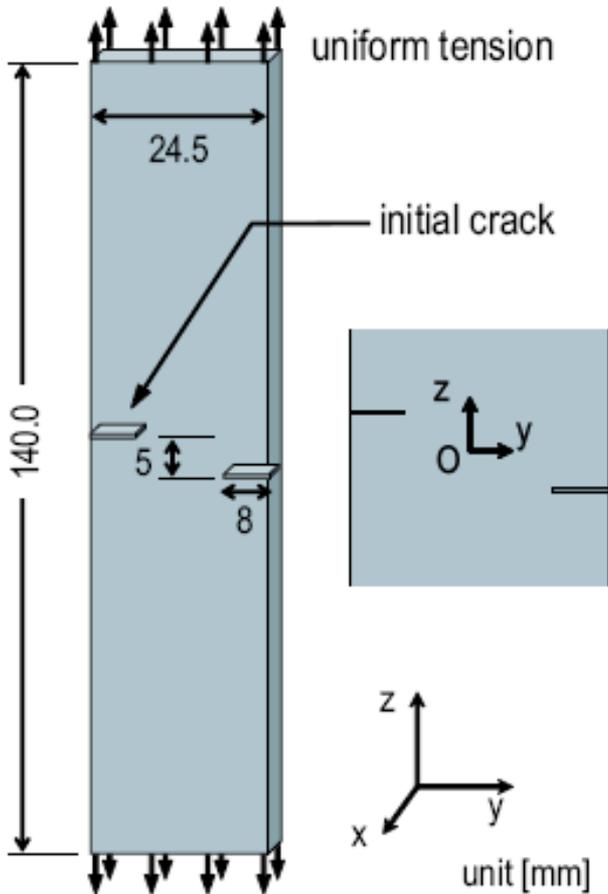
- RC橋脚

- 破壊モデル  

- 鉄筋コンクリートの破壊現象 



# PHYSICS: CHAOTIC BEHAVIOR

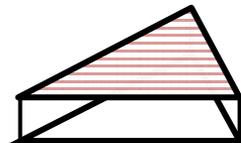
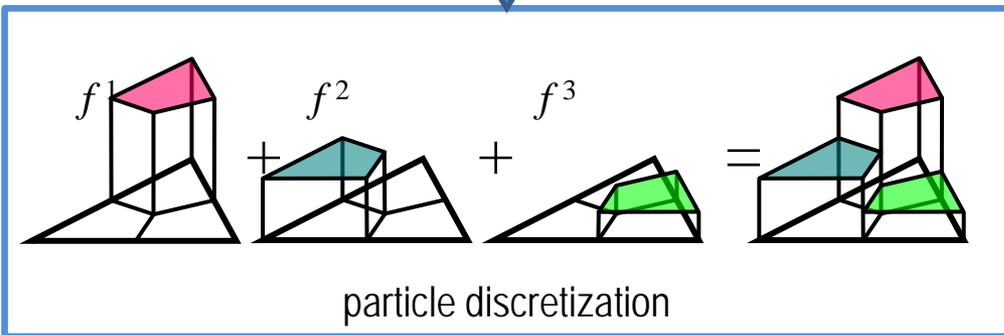
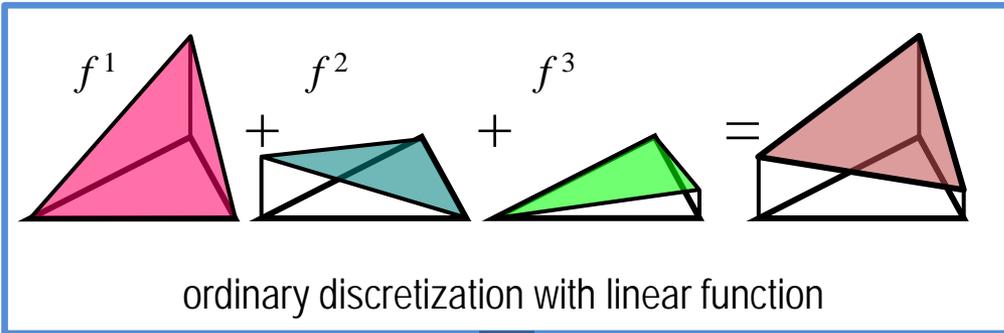


Loading rate [ $V^r$ ]	0.1	10.
not anti-symmetry [%]	5	99
anti-symmetric [%]	95	1

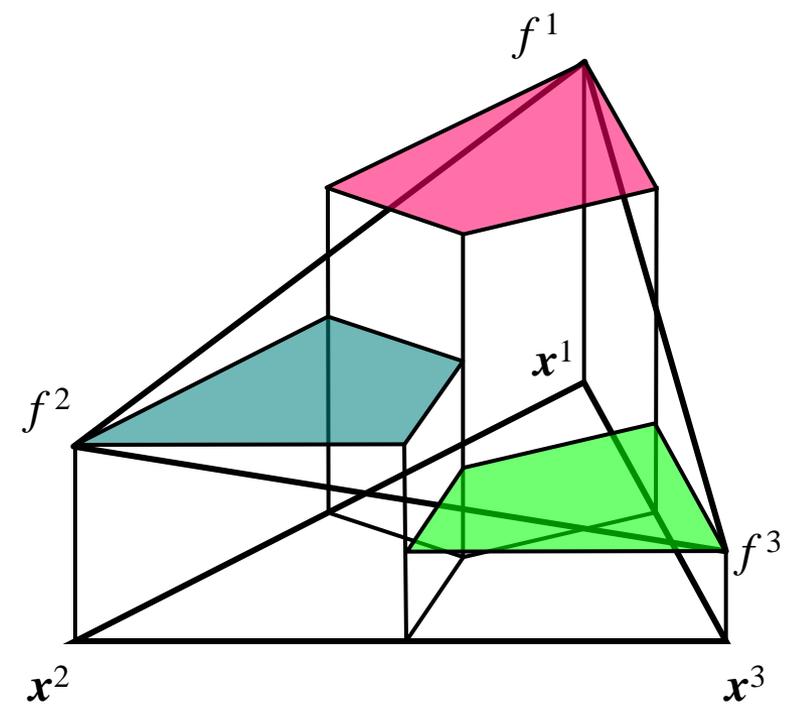
breakage of anti-symmetry in cracking pattern at high loading rate



# MATHEMATICS: DISCRETIZATION



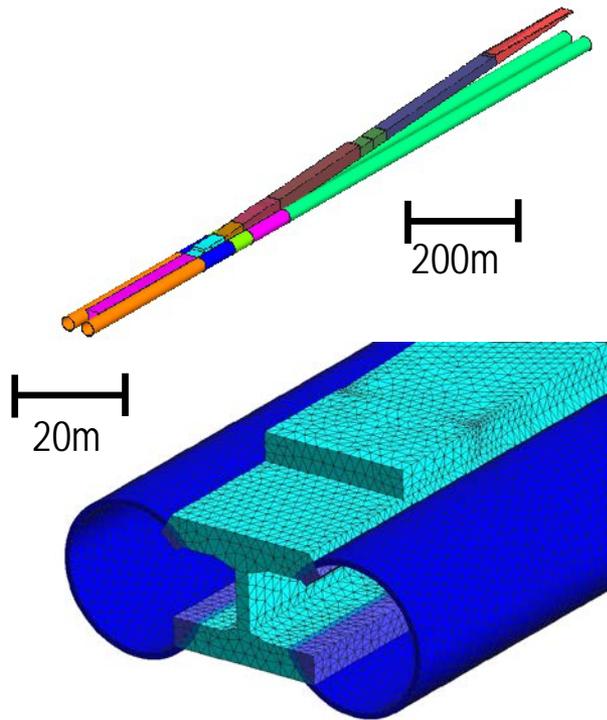
derivative coincides with ordinary discretization



Use of non-smooth basis functions of discretization, in order to efficiently treat multiple-cracking

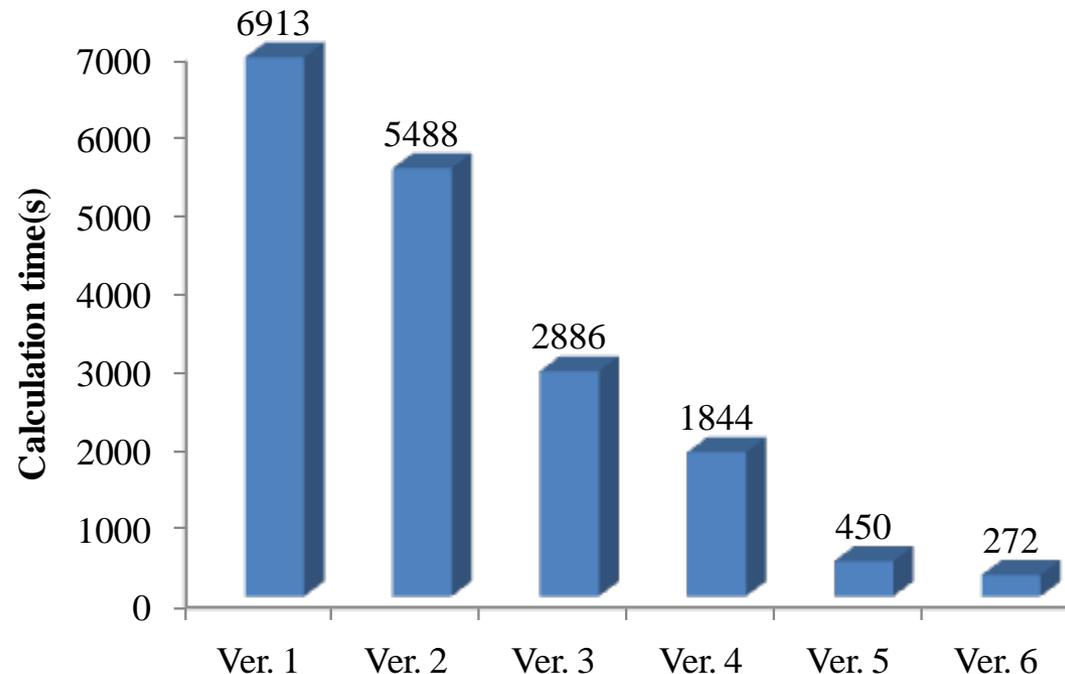
# COMPUTATION

Metropolitan Expressway: Yamanote Tunnel



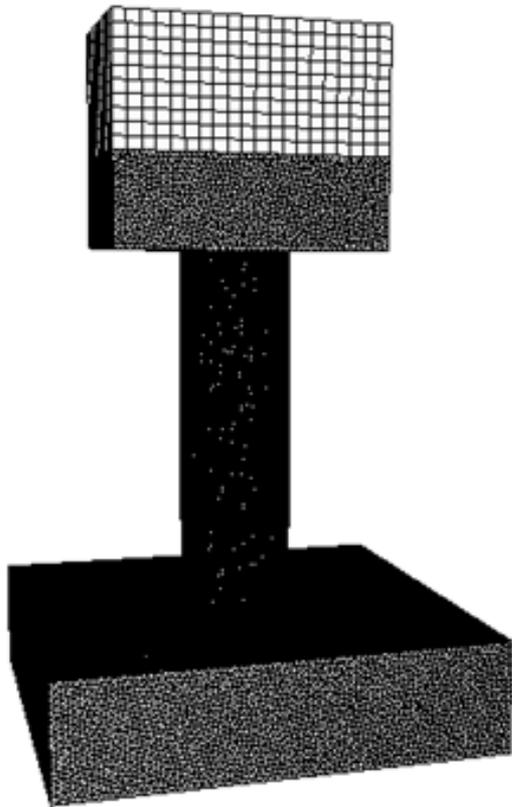
Node	1,673,489
Element	2,456,212
DOF	7,368,636

- Ver. 1 original code
- Ver. 2 reduction of memory conflict
- Ver. 3 variable preconditioned iterative solver
- Ver. 4 multiple precision arithmetic
- Ver. 5 multi-GPU computing
- Ver. 6 reduction of GPU communication

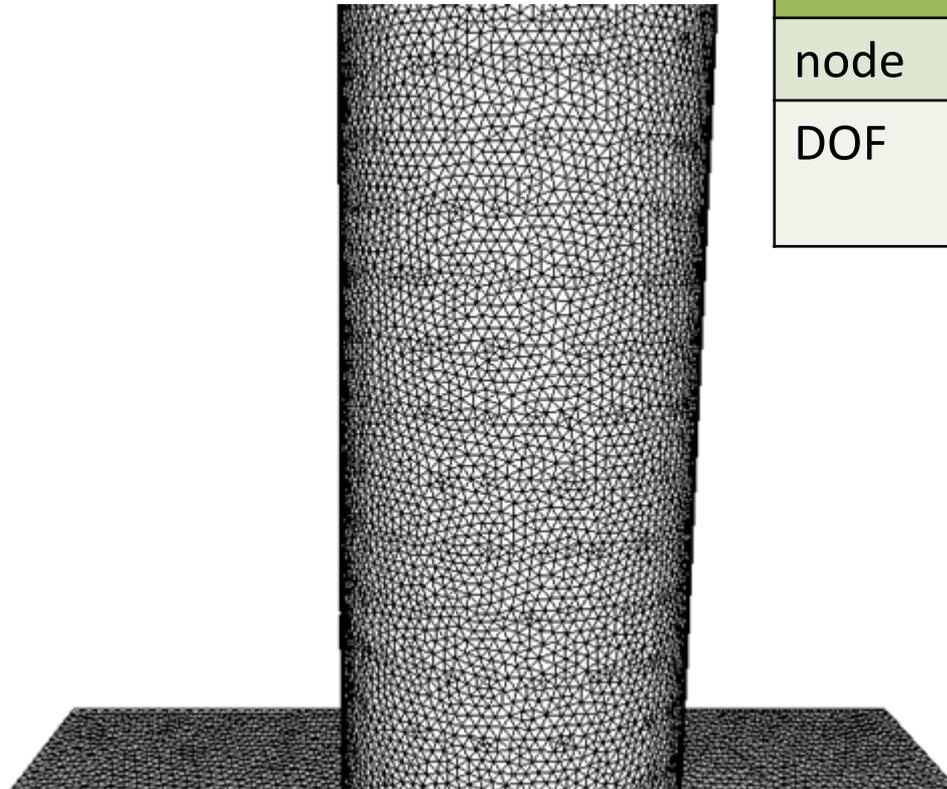


25 times faster (CPU time: 51 to 2 [day])

# DETAILED MODELING



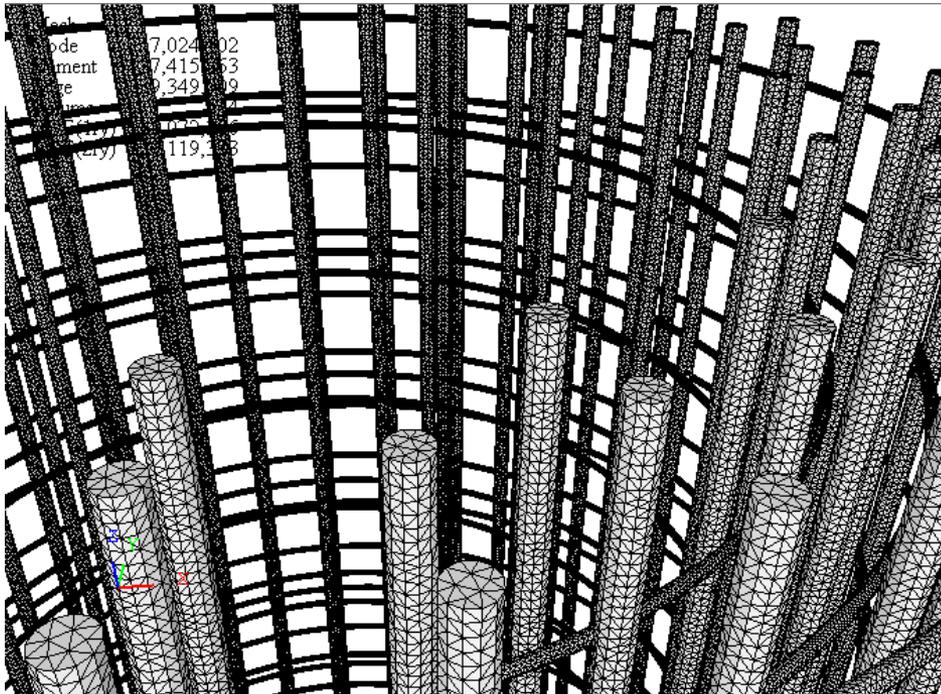
a) whole view



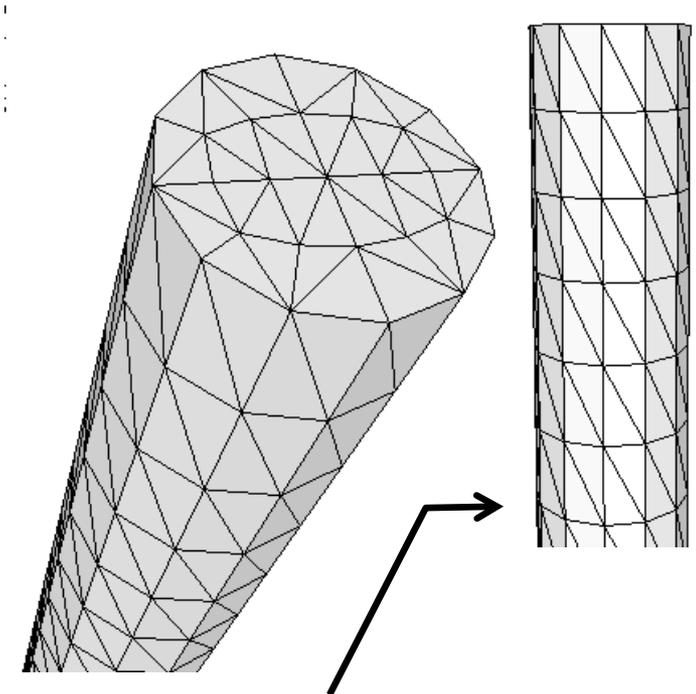
b) column

element	29,740,000
node	4,860,000
DOF	14,580,000

# DETAILED MODELING

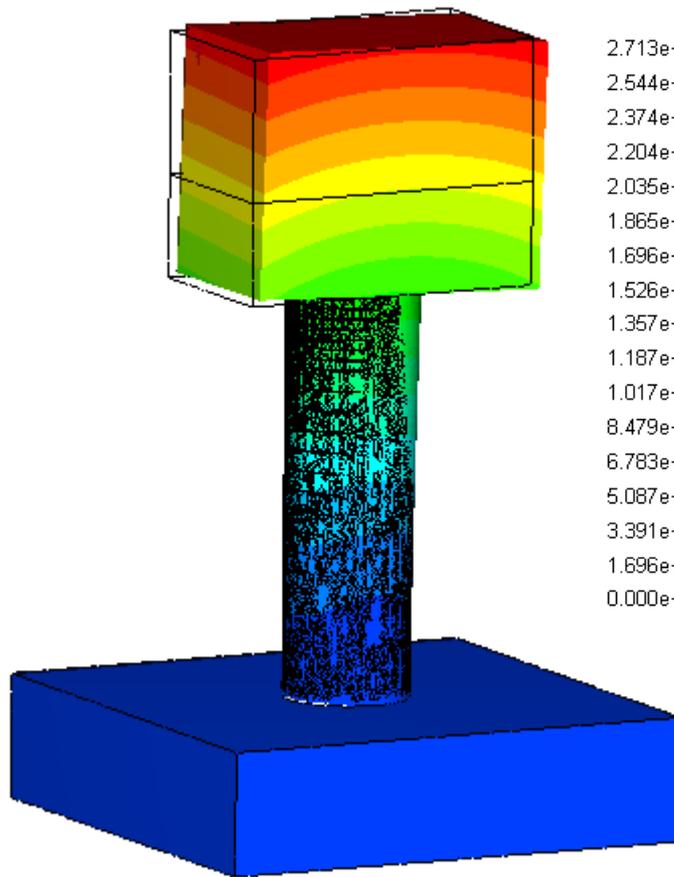


a) steel bar embedded in pier

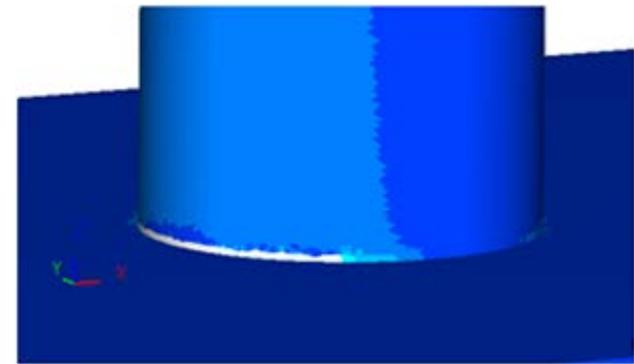
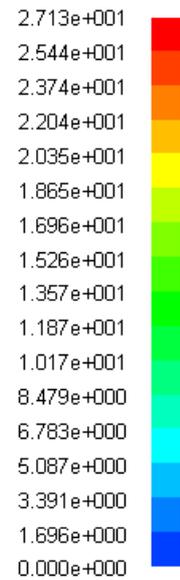


b) surface covered by rectangular elements of 15 x 7.4 mm

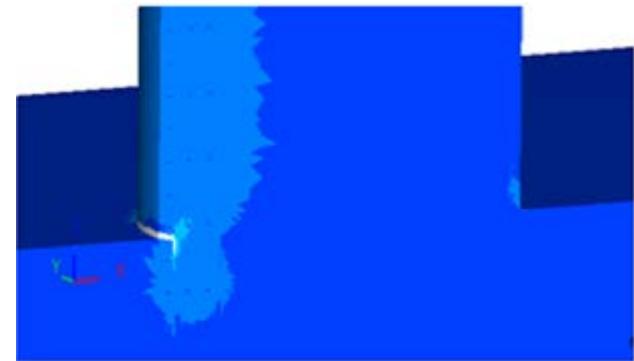
# TENATIVE RESULTS



a) whole view



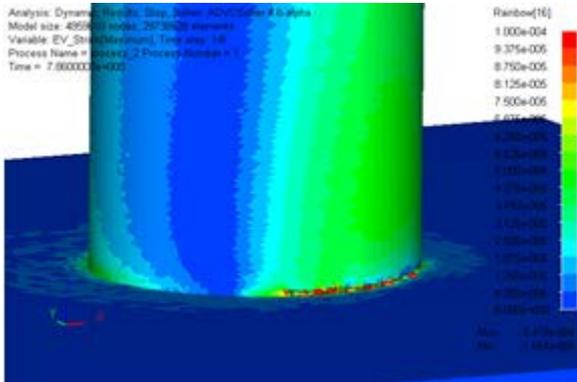
b) connecting part



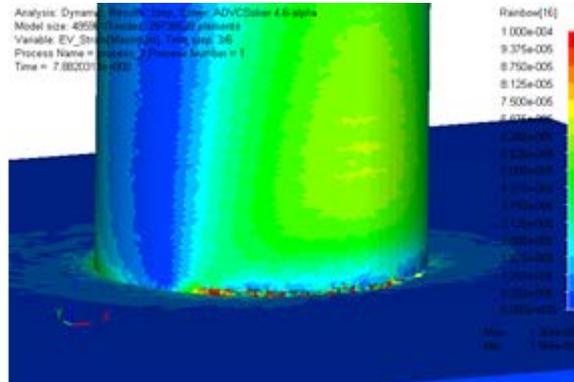
c) cross section at connecting part

# TENATIVE RESULTS

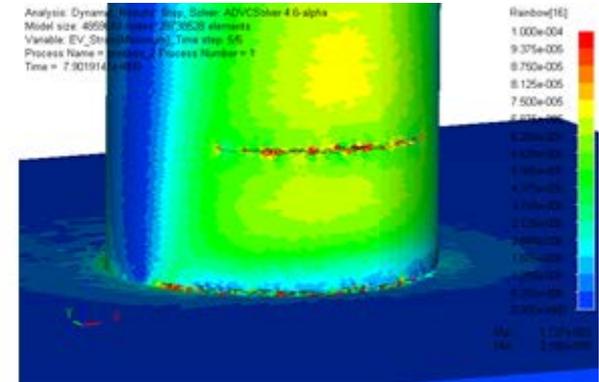
0.86 [s]



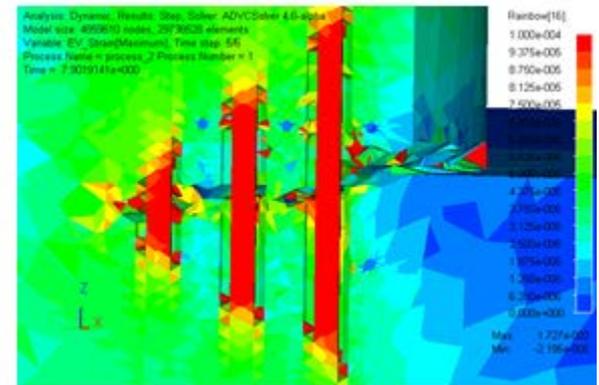
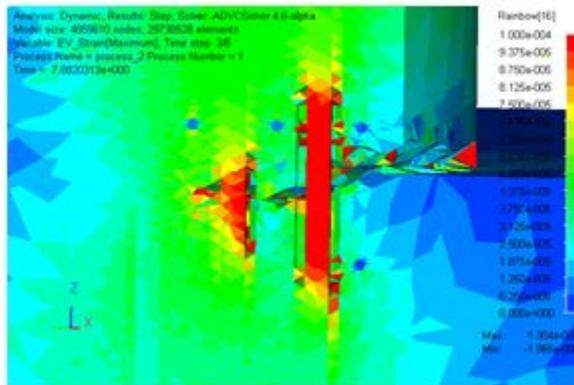
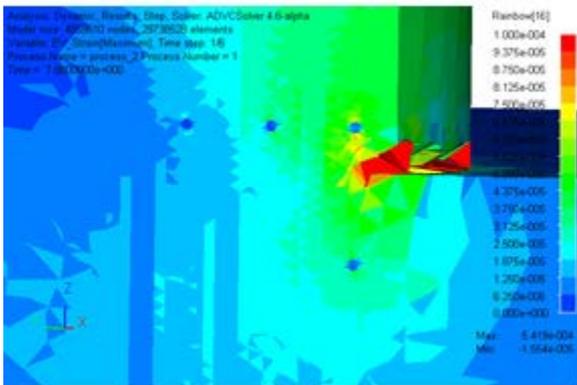
0.88 [s]



0.90 [s]



a) surface



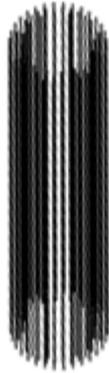
b) stress distribution inside of column

concrete



Node	3,248,903
Element	16,345,277

reinforcement



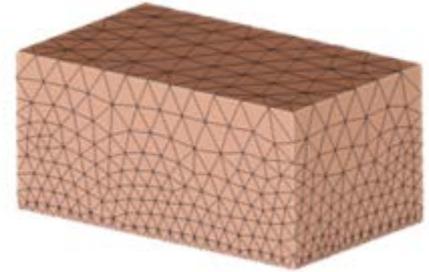
Node	650,745
Element	1,913,132

hoop reinforcement



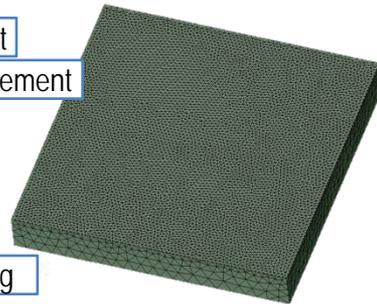
Node	882,508
Element	2,885,185

support



Node	6,159
Element	30,242

footing



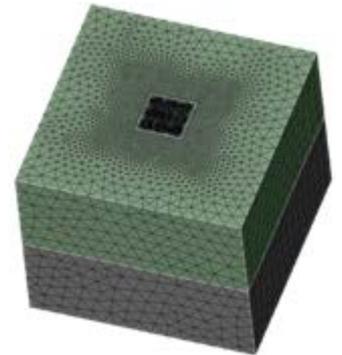
Node	44,796
Element	252,664

pile foundation

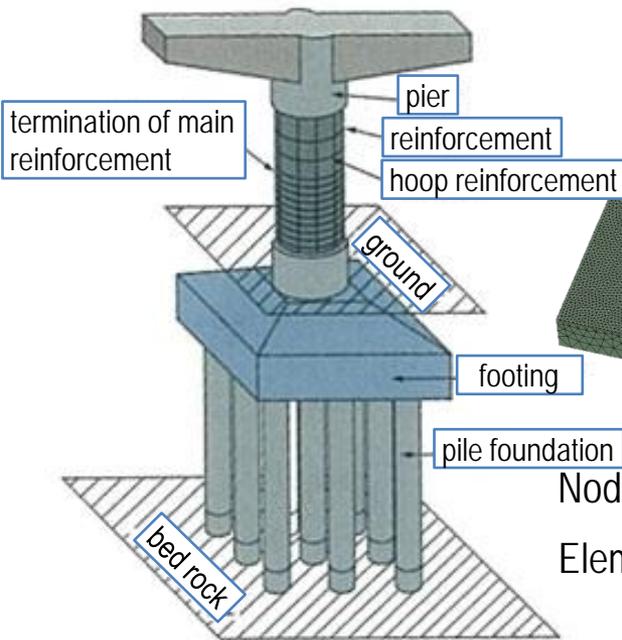


Node	1,558,818
Element	8,529,380

soil

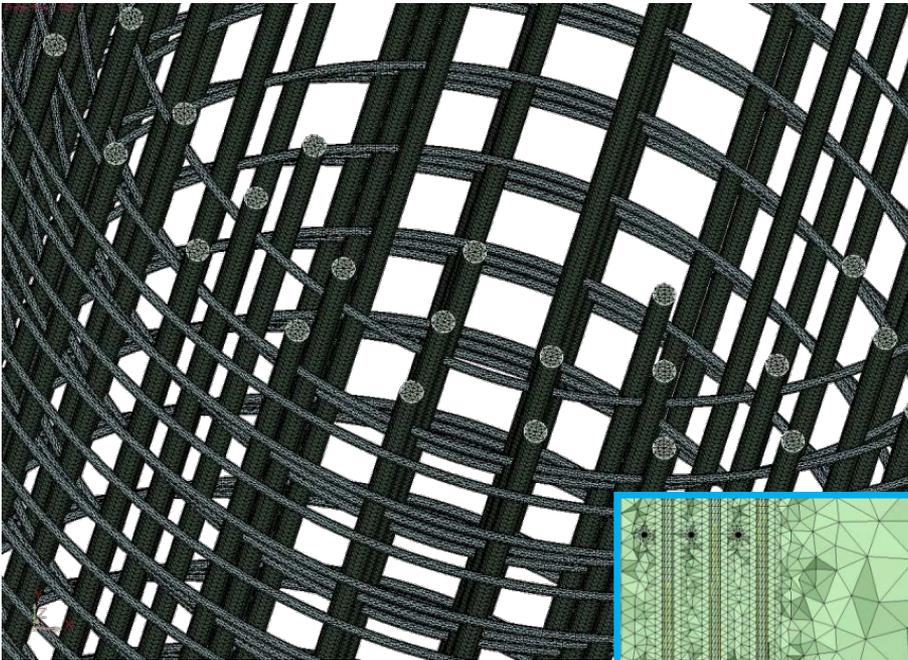


Node	1,027,196
Element	5,751,000

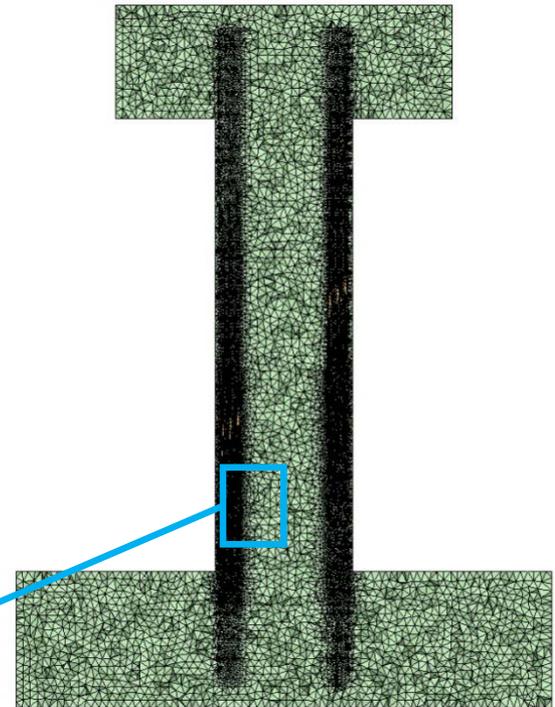


# MODEL DETAILS

reinforcement

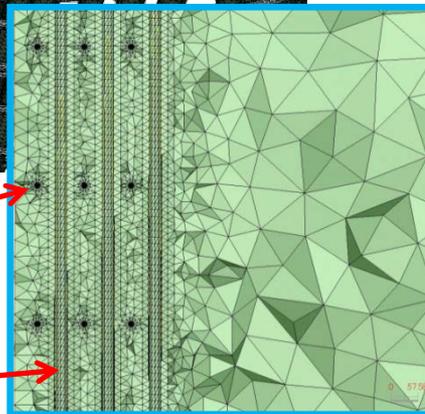


cross section



hoop reinforcement

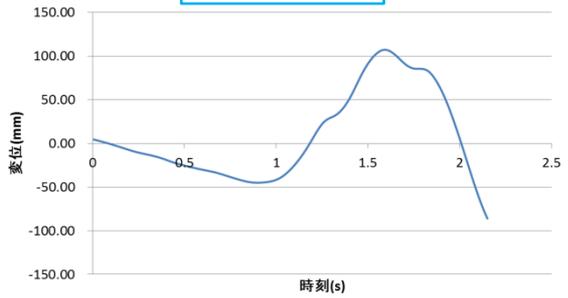
main reinforcement



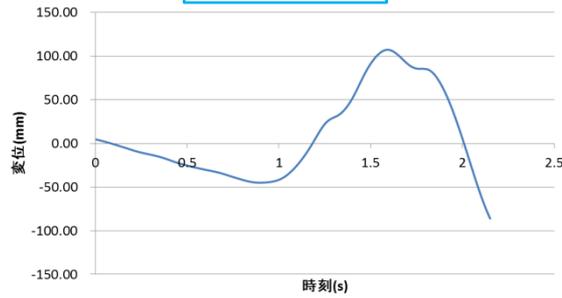
# RESPONSE

input

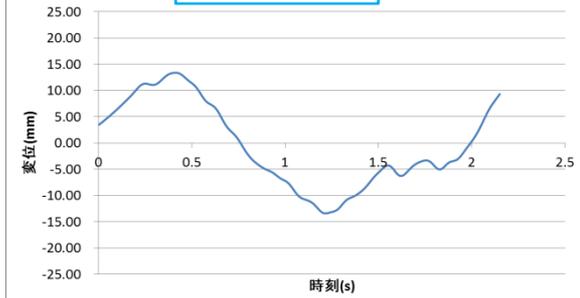
x-direction



y-direction

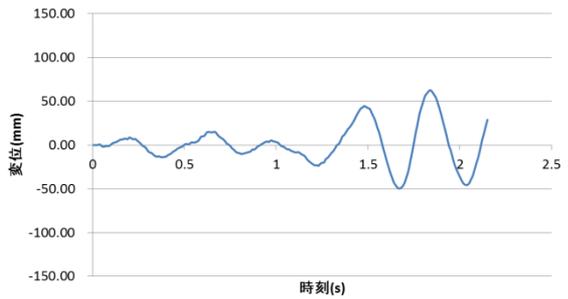


z-direction

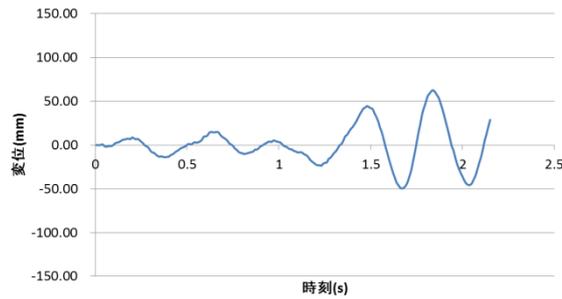


ground

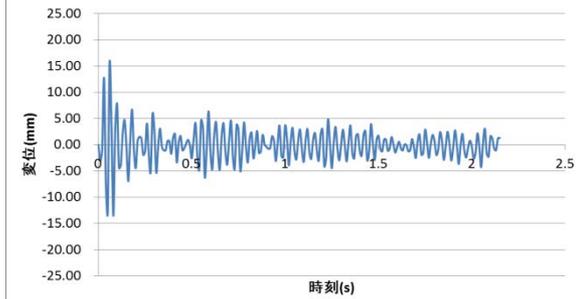
x



x

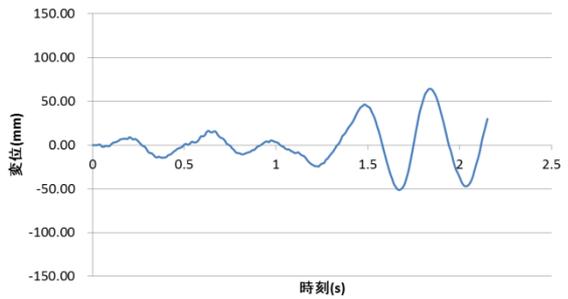


z

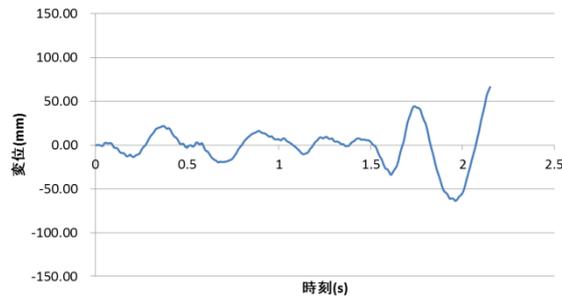


footing

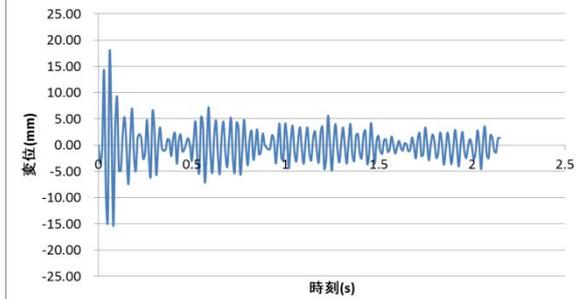
x



y

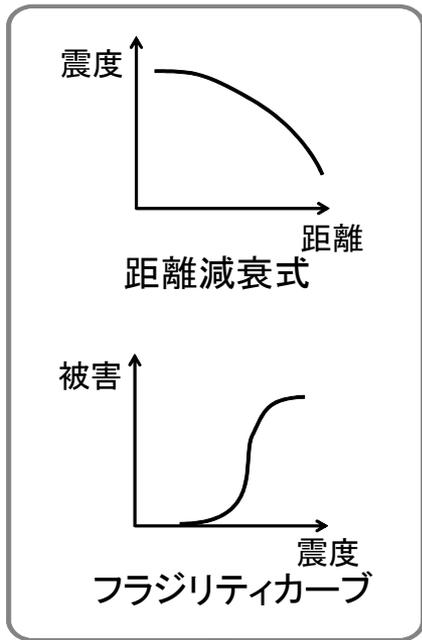


z

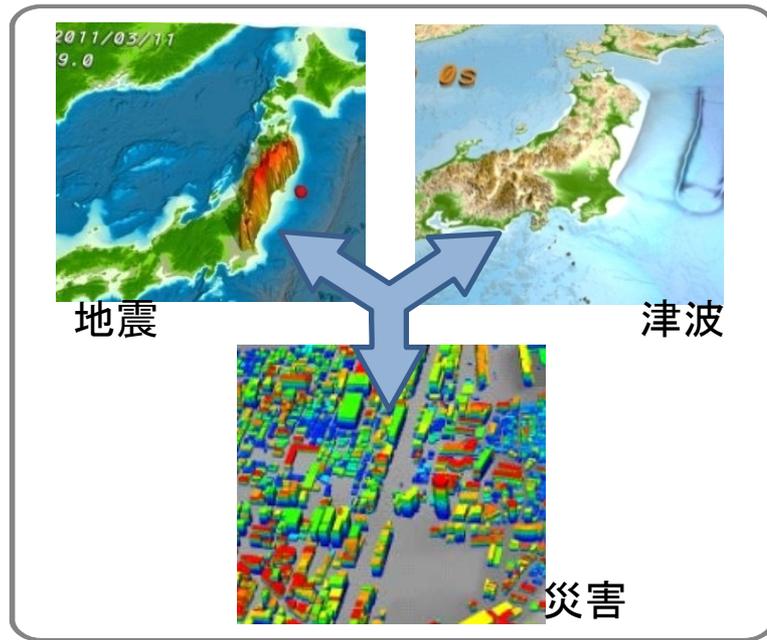


# 巨大地震津波による災害予測の現状と将来

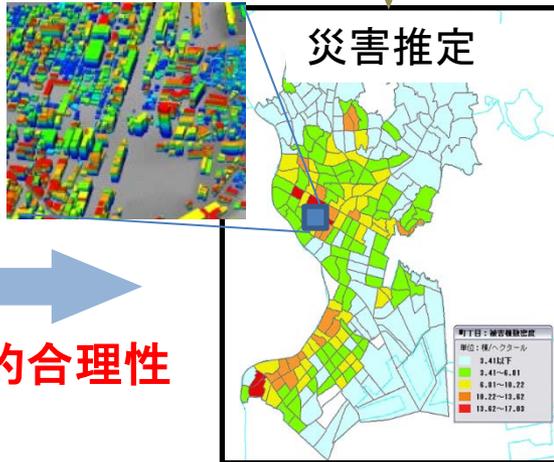
## 現状 経験ベース



## 将来 計算ベース



都市を1km程度四方の領域に分け、過去のデータの統計解析を基に、各領域での地震動と被害を計算する。経験ベースであるため信頼度は決して高くない。他に代替がなかったため、経験ベースの予測に頼らざるを得なかった。

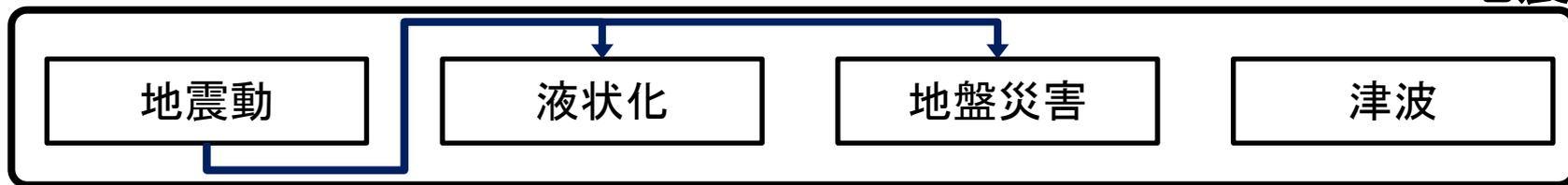


科学的合理性

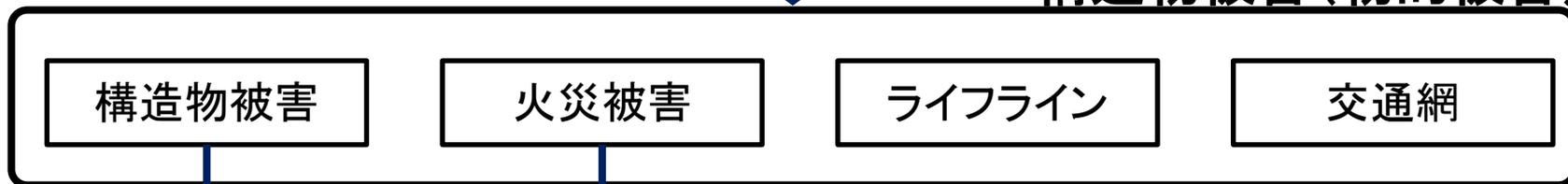
地震・津波の物理過程のシミュレーションと構造物一棟一棟の応答シミュレーションから、災害を予測する。図示された予測は、現状と一見、変わらない。しかし、信頼度は大きく改善されることが期待できる。計算科学の進歩を最大限利用した計算ベースの予測は高い科学的合理性を持つからである。

# 地震被害想定

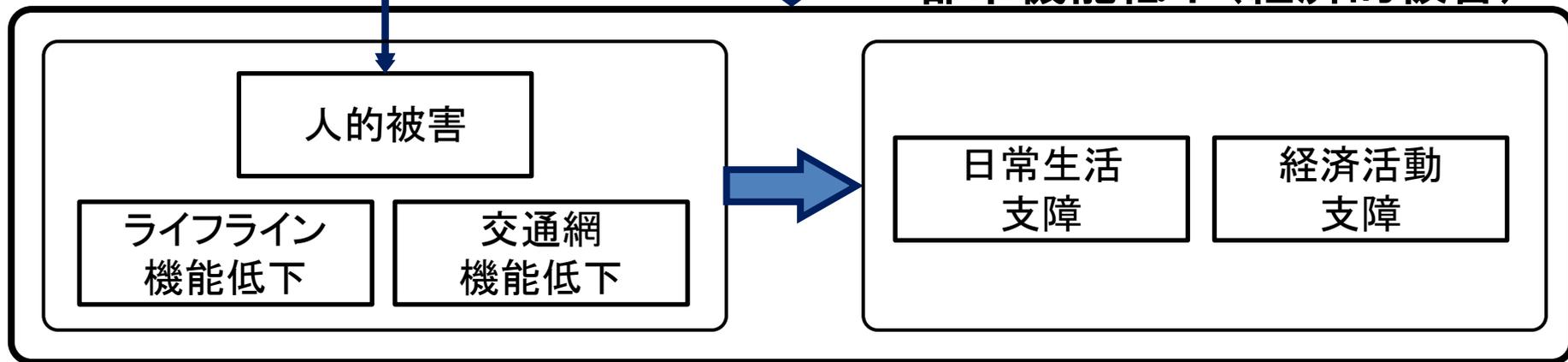
地震



構造物被害(物的被害)



都市機能低下(経済的被害)



# 防災・減災に資するシミュレーション

- リスクマネジメントの枠組み
  - 想定 地震・津波・災害の予測
  - 判断
  - 対処    ハードウェア                    耐震設計, 耐震補強  
             ソフトウェア                    保険
- シミュレーションの役割
  - 経験ベースからシミュレーションベースへ
  - 保険産業の信頼を得る科学的合理性

# 都市のシミュレーション



- 東日本大震災の事例再現

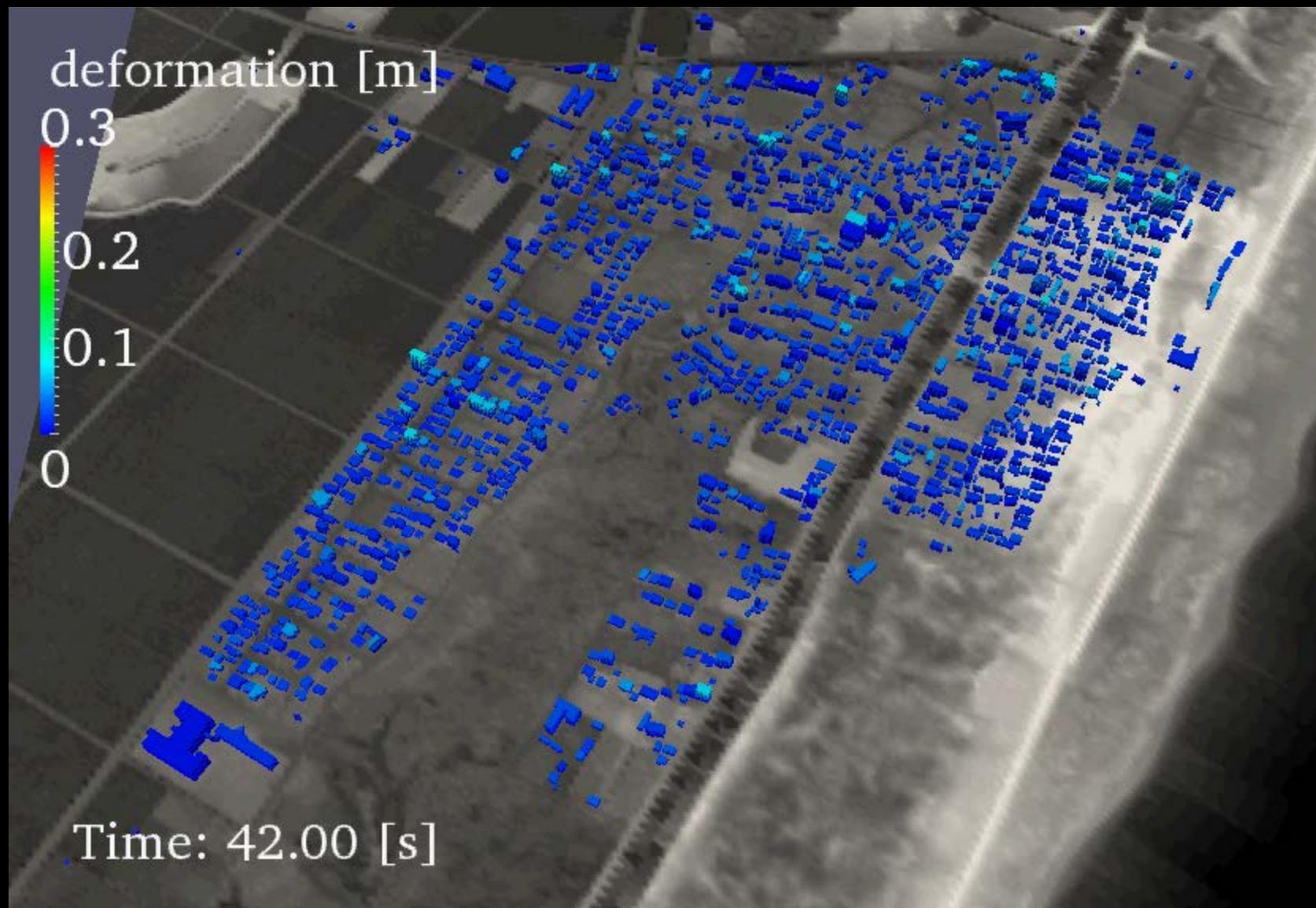


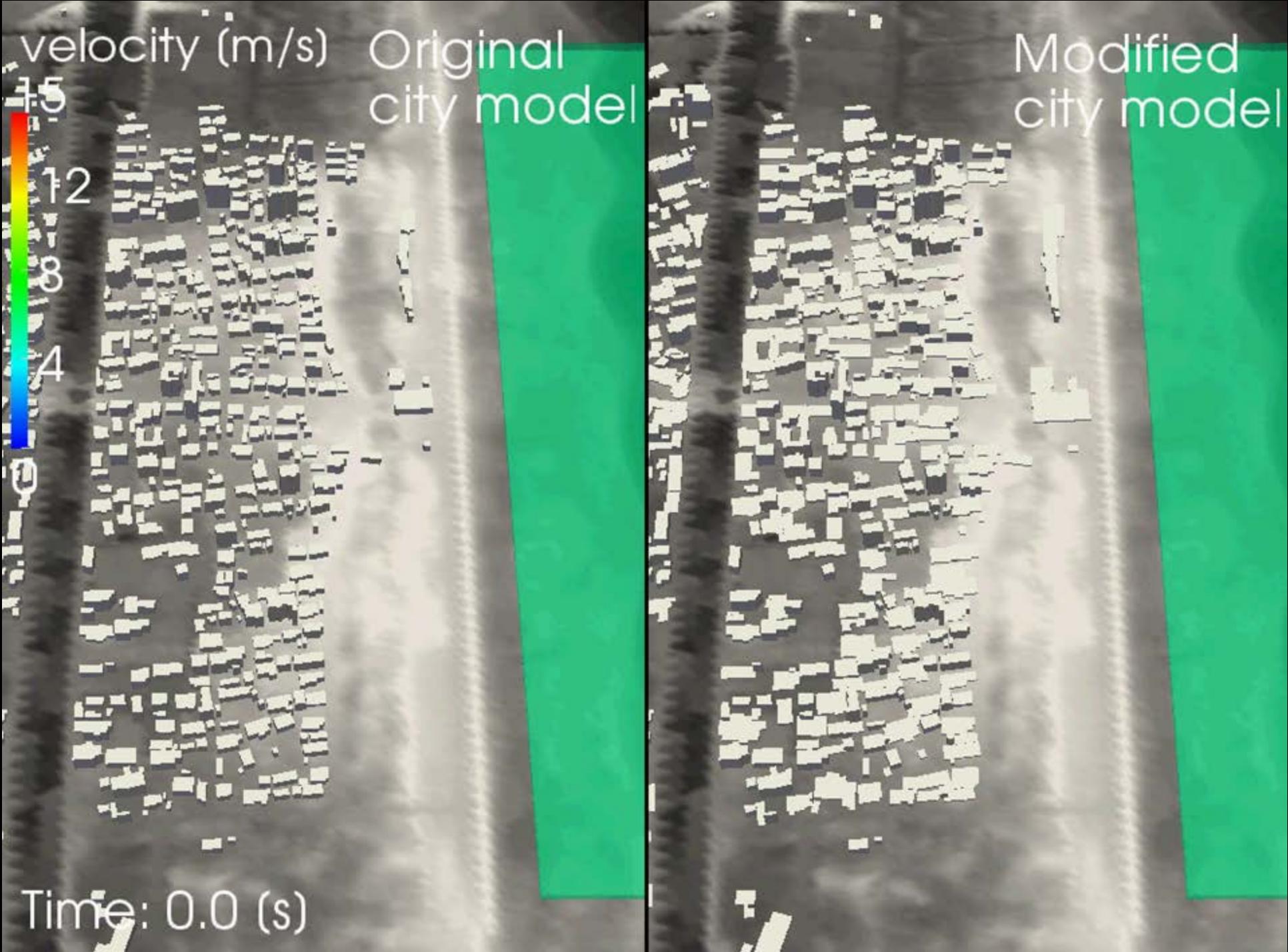
- 首都直下地震の事例予測



- 南海トラフ巨大地震の群衆避難







# Target Area

## Center of Tokyo Metropolis



Gray Buildings © 2008 ZENRIN

Image © 2012 DigitalGlobe

Google earth

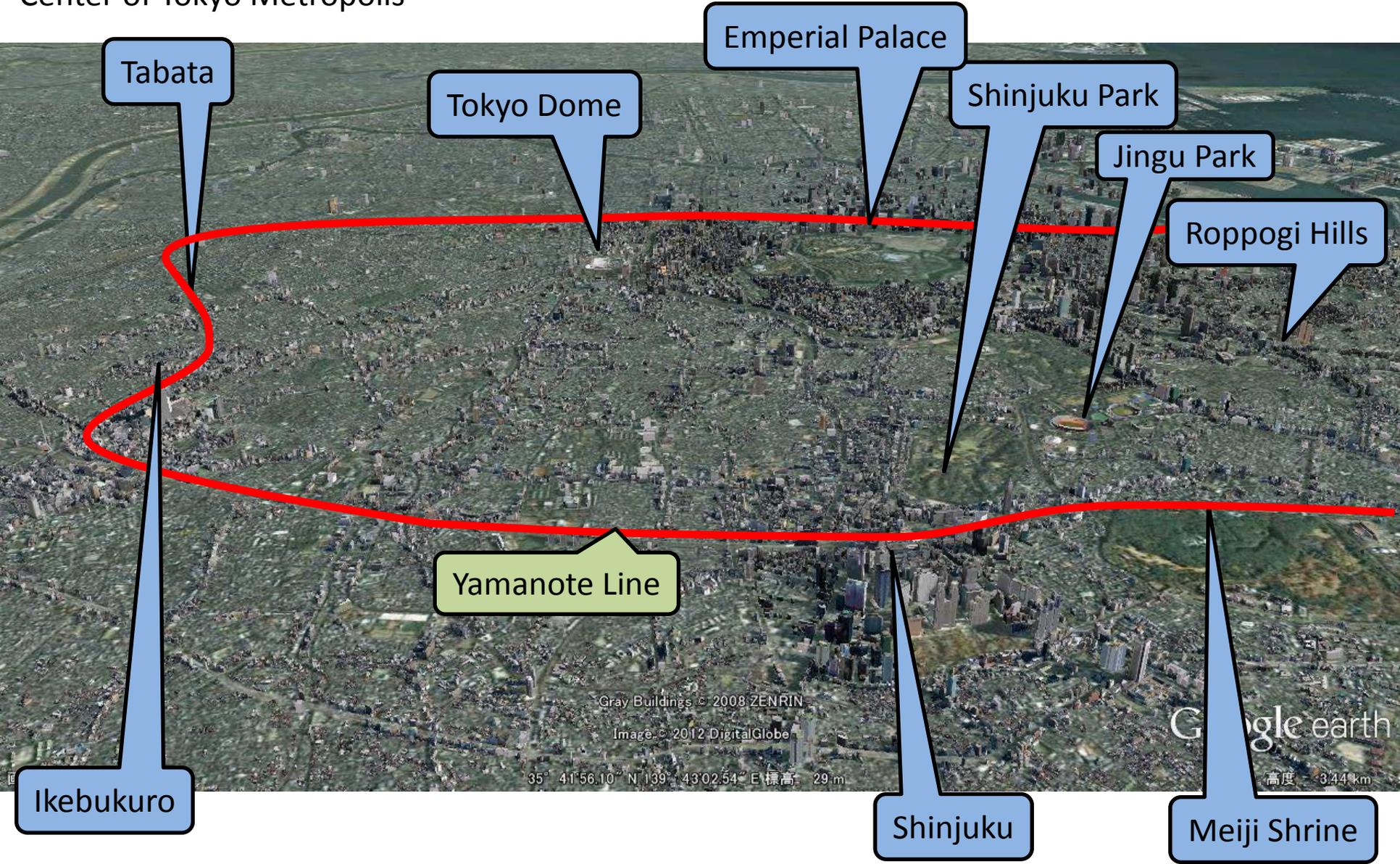
画像取得日: 2009/10/1

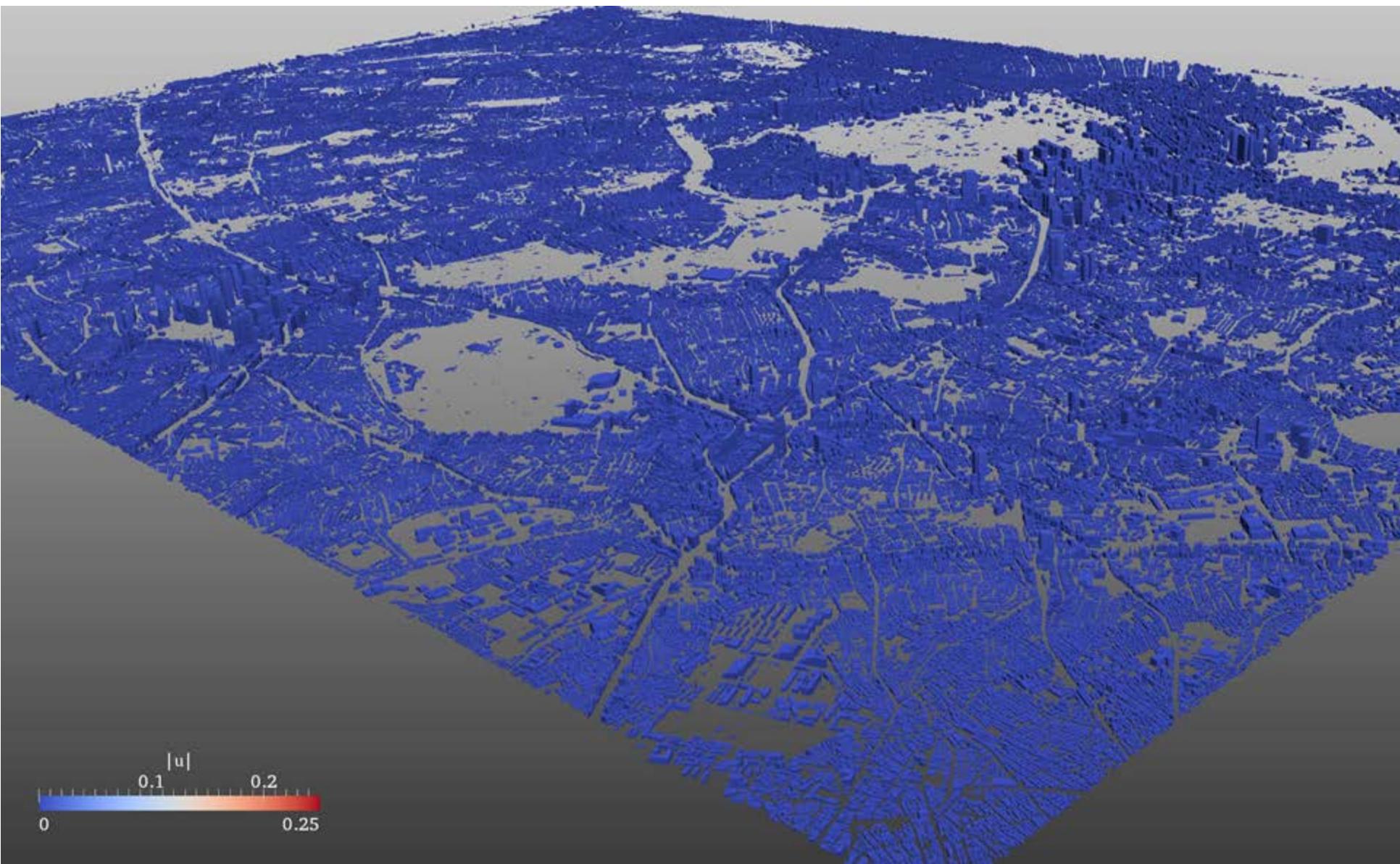
35° 41' 56.10" N 139° 43' 02.54" E 標高 29.m

高度 3.44 km

# Target Area

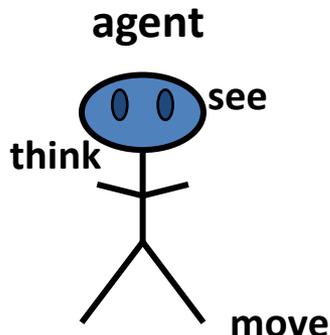
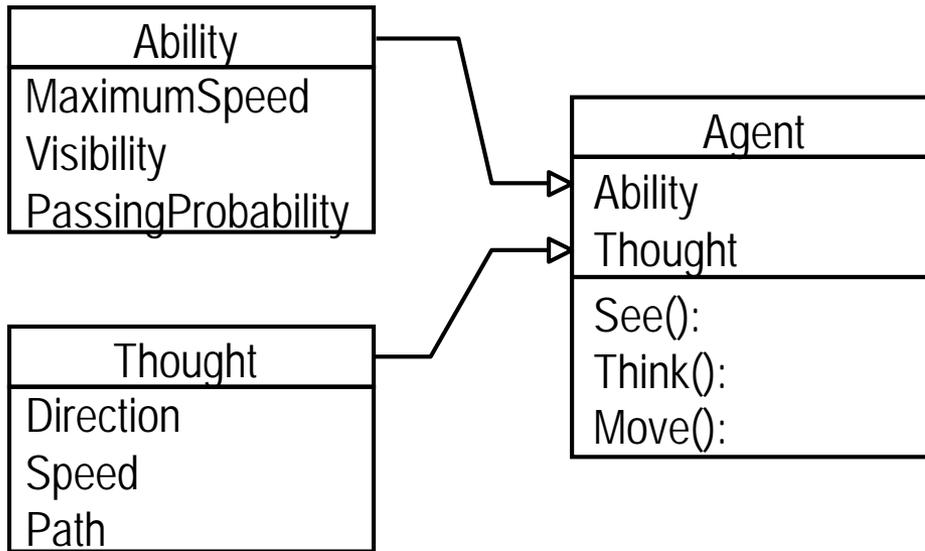
Center of Tokyo Metropolis





# エージェントの設計

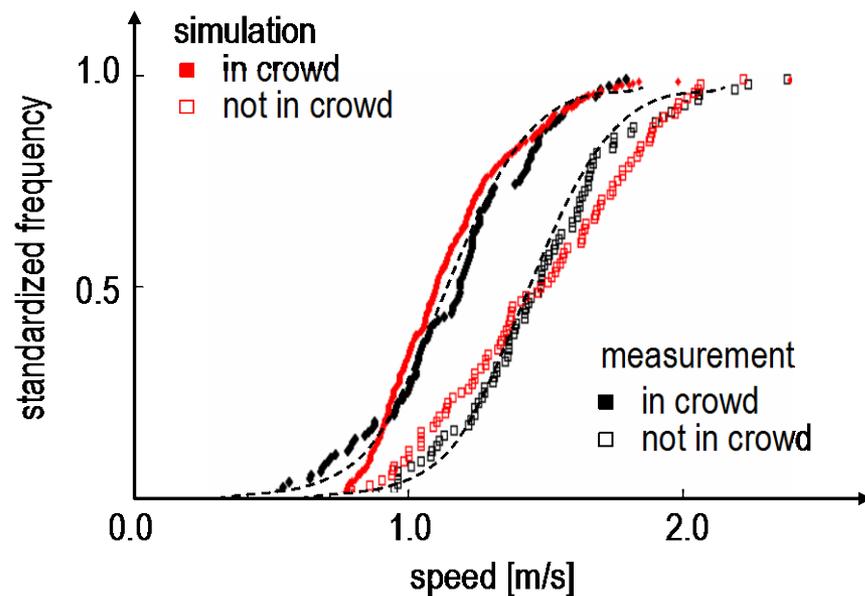
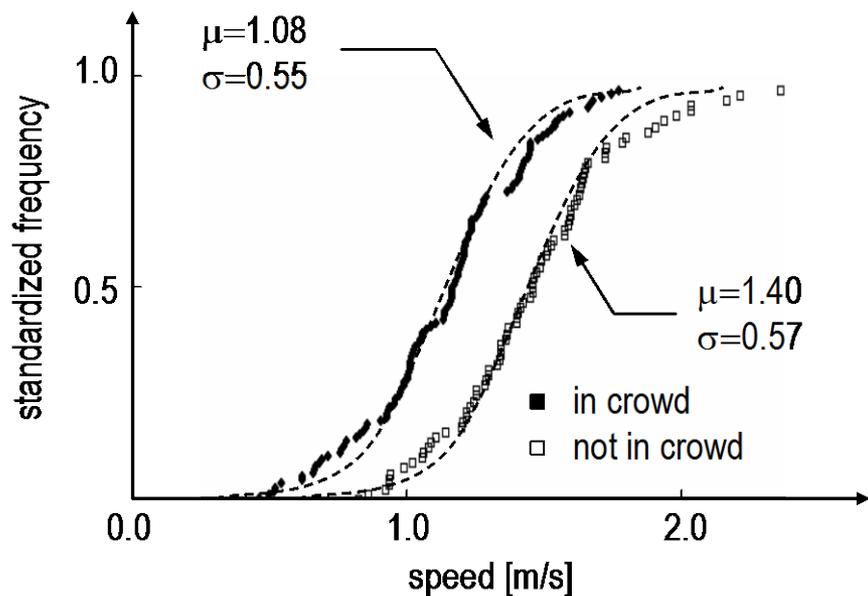
class diagram



parameters

$\mu$	average of agent maximum speed [m/s]
$\sigma$	SD of agent maximum speed [m/s]
$R$	visibility radius [m]
$D$	dimension of forward domain [m] (domain: $D \times 2D$ )
$m$	speed reduction rate in passing
$\theta$	modification of moving angle in passing [deg]
$P$	probability of making forced passing

# 計測された歩行速度分布の予測と再現



	計測値		シミュレーション	
	混雑	非混雑	混雑	非混雑
平均値 [m/s]	1.08	1.40	1.06	1.39
標準偏差 [m/s]	0.55	0.57	0.51	0.59

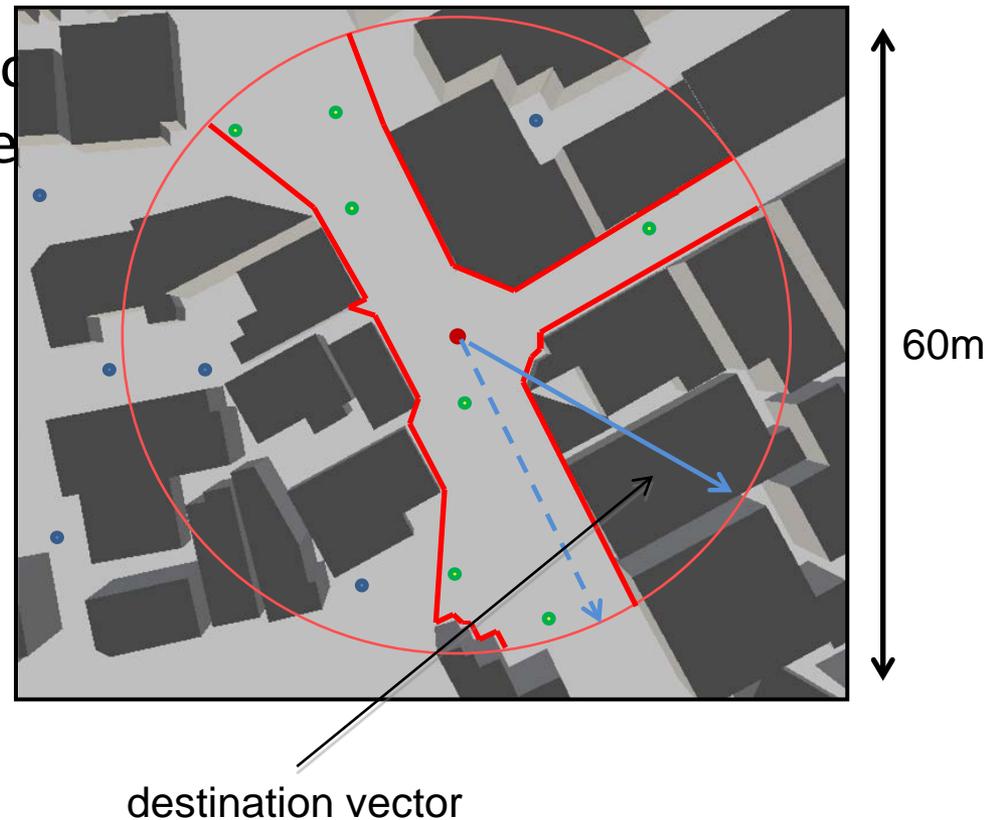
# MULTI-AGENT SIMULATION



- KISS Principle  
from “Keep It Simple, Stupid” to  
“Keep It Smart and Sophisticated”

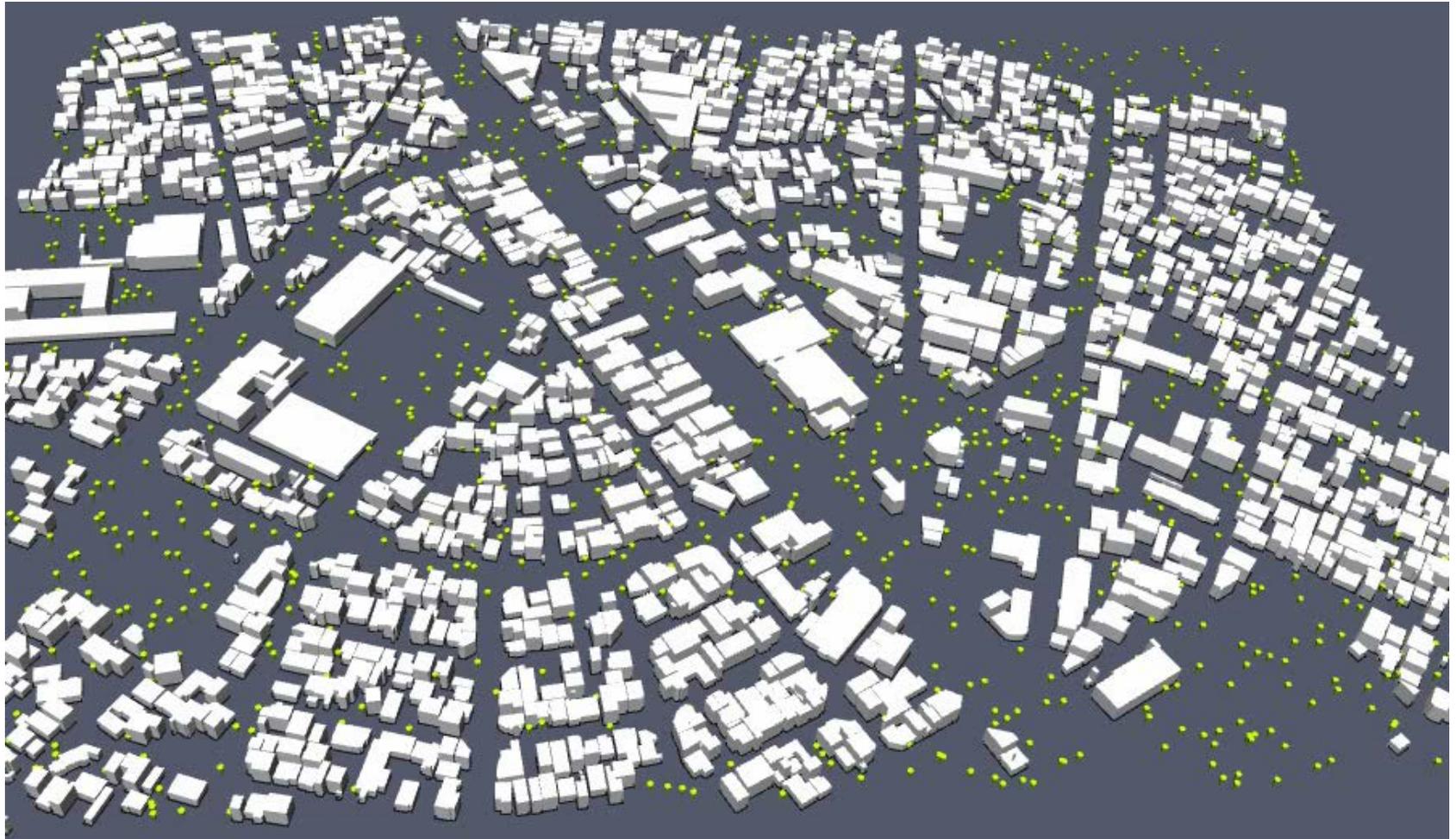
- Agent functionalities
  - see environment
  - think terminal
  - move speed
  - take-over/pose

agent visibility

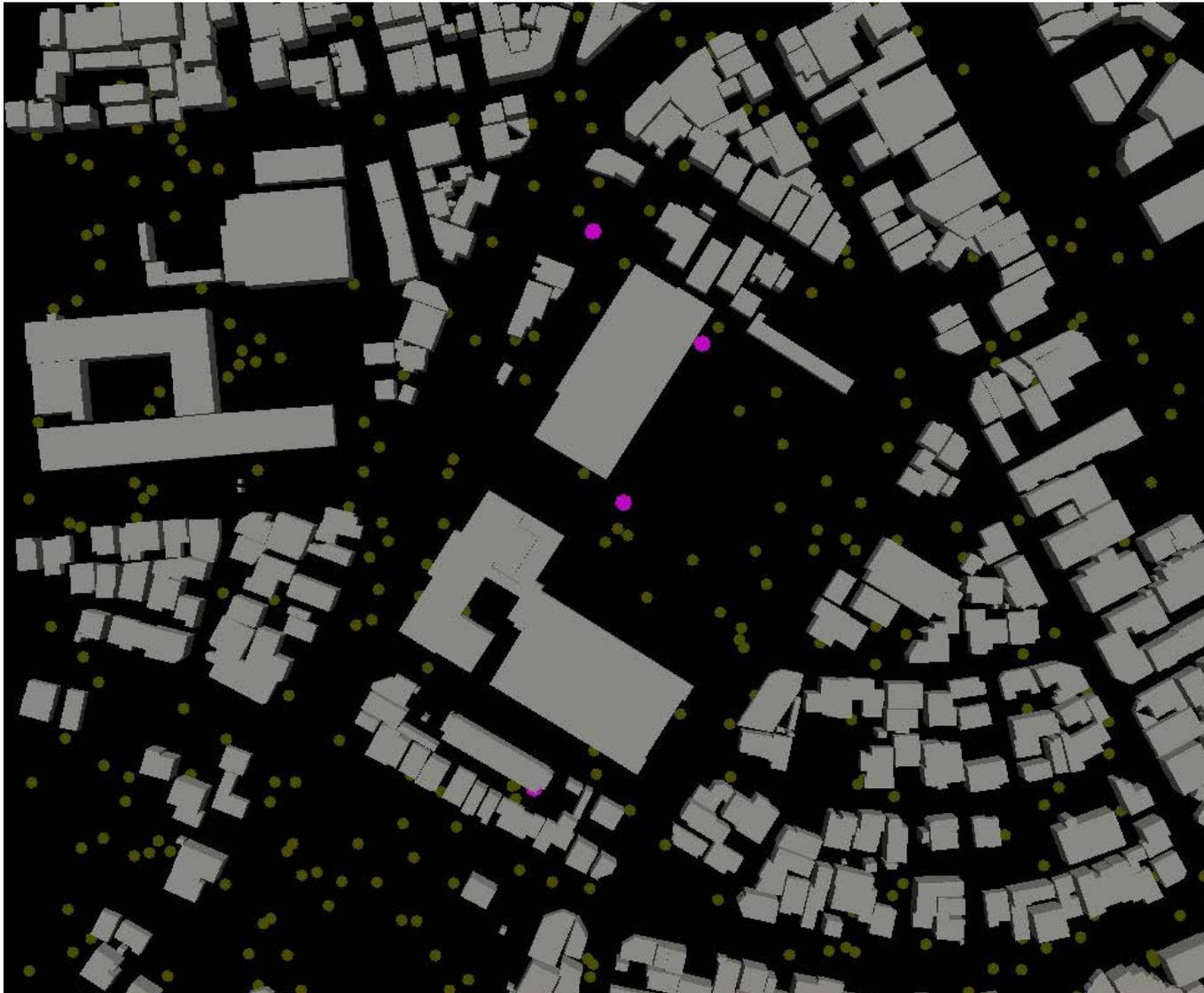




# IMPROVEMENT OF AGENT NAVIGATION



# INTRODUCTION OF OFFICIAL AGENT



# おわりに

- 建造物のシミュレーション
  - 基礎研究
  - 詳細モデルの構築と超高性能解析
- 都市のシミュレーション
  - 統合技術
  - 複合災害：地震動と津波，被害と対応