INTEGRATED EARTHQUAKE SIMULATION
Program Architecture and Plugged-in Components

M. HORI
Earthquake Research Institute, UTokyo
Advanced Institute of Computational Science, RIKEN
CONTENTS

◆ Integrated Earthquake Simulation
  ● Examples of seamless simulations
  ● System computing that uses numerous components

◆ Plugged-in Components
  ● FEM for ground motion analysis
  ● SDOF for seismic structure response analysis
  ● PDS for failure analysis
  ● MAS for mass evacuation analysis
EARTHQUAKE DISASTER ASSESSMENT

CURRENT
empirical

attenuation relation

index
distance

fragility curve

damage
index

estimation

FUTURE
simulation

earthquake
tsunami
disaster

scientific rationality
OVERVIEW OF IES

- Computer model of city
  - Houses/buildings
  - Lifelines
  - Public spaces
  - Infrastructures

Structure response simulation

Earthquake
  - Amplification
  - Propagation
  - Fault mechanism

Earthquake simulation

Action against earthquake
  - Crisis management
  - Evacuation
  - Retrofitting
  - Recovery

Action simulation
Result

Fiber Model (high-rises are not included)

| steel bar deterioration considered | steel bar deterioration not considered |
Kochi City
• large population
• road network and rivers
• visitors

Countermeasures for Tsunami
• tsunami shelter
• retrofitting infrastructures
• fast information delivery
• education

Evacuation guiding/forcing
• official agent that finds agents which do not start evacuation and lets/makes it start evacuation
• determination of guiding/forcing official number, considering local road network and composition of resident characteristic
spatial uniform

maximum benefit

day: 40

day: 85

day: 130

day: 163
SYSTEM COMPUTING

◆ Software Engineering
  ● One generous programmer vs system engineer group
  ● Quality control/guarantee of software: V & V

◆ Integrated System
  ● Transparency for developers of generations
  ● Robustness error minimization
  ● Extention-ability reuse of modules

IES employs object-oriented programming that uses object hierarchy and aspect-oriented programming that uses template.
template class<S> void Analyze( S &x )
{
  double acc=x, vel=0.;
  while( … ) vel += x dt;
  …
}

- algorithm -

template<class C1, class C2>
class X : public C1, public C2
{
  public:
    void Analyze( … );
}

- class -

object hierarchy

IES Structure
  SDOF
    -stiffness
      MDOF
        -stiff. set
      Fiber
        -strength
      OCM
FINITE ELEMENT METHOD

◆ Standard Numerical Method for Engineering
  - Linear/non-linear PDF in domain of complicated configuration
  - Utilization of smaller grain modules
  - Development of good commercial packages

◆ Research on New Features
  - Dynamic problems
  - Failure problems: 2D to 3D
  - Materials of complicated constitutive relations
SEISMIC STRUCTURE RESPONSE

◆ Lagrangian Formulation

\[ L[v, \varepsilon] = \int \frac{1}{2} \rho v \cdot v - \frac{1}{2} \varepsilon : \varepsilon \, dv \quad (v, \varepsilon) = (u, \text{sym}\{\nabla u\}) \]

◆ Rigid-body Motion and Response

\[ u(x,t) = g(t) + u^r(x,t) \]

◆ Smart Approximation

\[ u^r(x,t) = U(t)A(x) \]

\[ L = \frac{1}{2} MU^2 \tau_2 - \frac{1}{2} KU^2 \varepsilon + GU \quad (M,K) = (\int \frac{1}{2} \rho A \cdot A \, dv, \int \frac{1}{2} \nabla A : c \nabla A \, dv) \]
SMART SOLUTION

wave equation

rigid-body motion
response as relative deformation

smart approximation

$L[v, ε]$

$L[g + u^r, ε^r]$

$L[g + UA, U∇A]$
URBAN AREA MODEL

horizontal polygon with height

polygon 1

polygon 2

polygon 3

virtual polygon

GIS data

polygon for floor

polygon 1

polygon 2

polygon 3

vertical polygon

Refined Polygon

Shape

structure member

slab with beam

column

wall

Structure Model
AUTOMATED MODEL CONSTRUCTION

Two Major Difficulties

- Cognition of floor configuration using plural polygons
- Presumption of floor arrangement using floor configuration

![Diagram with symbols: plural polygons, floor configuration, rectangular of equal width and breadth, grid-wise arrangement of column, current compromise]
TEMPLATE FITTING

polygon

rotation, stretch, mirror-image

pattern

template set

matched

flame

rotation, stretch, mirror-image

template flame
Two methodologies

- B-GRID: cast polygon into Boolean grid
- Polygon Algebra: manipulate polygons’ configuration

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<thead>
<tr>
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<th>B-GRID</th>
<th>POLYGON ALGBRA</th>
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<tbody>
<tr>
<td>coding</td>
<td>easy</td>
<td>difficult</td>
</tr>
<tr>
<td>robustness</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>error</td>
<td>grid size dependence</td>
<td>principally zero</td>
</tr>
<tr>
<td>computation time</td>
<td>long</td>
<td>short</td>
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COGNITION: B-GRID

GIS data

Template

B-Grid

(relative difference) = (number of different cells) / (number of cells)
(relative difference) = \frac{\text{area of difference polygons}}{\text{area of template}}
SEQUENTIAL TEMPLATE GENERATION
# LIFELINE MODEL

## GIS Data Conversion

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<tr>
<th>Control Data</th>
<th>Company ID</th>
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<table>
<thead>
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<th>Attribute</th>
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<th>Thickness</th>
<th>Construction Date</th>
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<table>
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<tr>
<th>Coordinate sets</th>
<th>$(x_1, y_1, z_1)$</th>
<th>$(x_2, y_2, z_2)$</th>
<th>$(x_n, y_n, z_n)$</th>
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## Model Data Conversion

GIS → converted GIS → structure model
SEWAGE PIPELINE NETWORK
CONCLUDING REMARKS

◆ Integration of Many Data Sets and Analysis Methods
  ● Earth science simulation  wave propagation analysis
  ● Engineering simulation  seismic response analysis
  ● Social science simulation  mass evacuation analysis

◆ Collaboration of Computer/Computational Science
  ● Capability computing for large-scale simulation
  ● Capacity computing for multi-scenario simulation
  ● Software engineering aspects in developing IES