midas Gen

Advanced Webinar

- Dynamic Analysis – Time History
Why midas Gen

Versatility

Stadiums
Power Plants
Hangar
Airport
Transmission Towers
Cranes
Pressure Vessels
Machine Structures
Underground Structures

Specialty Structures Applications

Beijing National Stadium
Beijing National Aquatic Center
Beijing Olympic Basketball Gymnasium
Seoul World Cup Stadium
JeonJu World Cup Stadium
DeaJeon World Cup Stadium
USA Pavilion
China Pavilion
German Pavilion
Contents

1. Seismic Design for New Buildings
2. Seismic Design for Existing Buildings
3. Base Isolators and Dampers
4. Mass
5. Damping
6. Modal Analysis
7. Fiber Analysis
Seismic Design Process as per Eurocode8 (New buildings)

1. Performance Requirement
2. Ground Condition
3. Seismic Action
   - Seismic Zone
   - Representation of seismic action
4. Combination of Seismic Action
5. Criteria for Structural Regularity
6. Seismic Analysis
   - Lateral Force method of Analysis
   - Modal Response Spectrum Analysis
   - Pushover Analysis
   - Inelastic Time History Analysis
7. Safety Verification
8. Capacity Design & Detailing
Performance Requirement and Compliance Criteria

**Performance Requirement**

**No-collapse**
- $T_{NCR} = 475$ year
- W/O limitation of collapse

**Damage Limitation**
- $T_{DLR} = 95$ year
- W/O limitation of use

**Compliance Criteria**

**Ultimate limit states**
- Resistance and Energy Dissipation Capacity need to be checked.
- Global level verification
  - Overturning
  - Sliding
- Member Level
  - Ductile component: Plastic Rotation
  - Brittle component: Resistance

**Damage limitation states**
- Global Level: Inter-story drift
- Member Level: Resistance (ULS)
## Table 3.1: Ground types

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Description of stratigraphic profile</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$v_{s,30}$ (m/s)</td>
</tr>
<tr>
<td>A</td>
<td>Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.</td>
<td>&gt; 800</td>
</tr>
<tr>
<td>B</td>
<td>Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.</td>
<td>360 – 800</td>
</tr>
<tr>
<td>C</td>
<td>Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.</td>
<td>180 – 360</td>
</tr>
<tr>
<td>D</td>
<td>Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.</td>
<td>&lt; 180</td>
</tr>
<tr>
<td>E</td>
<td>A soil profile consisting of a surface alluvium layer with $v_s$ values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $v_s &gt; 800$ m/s.</td>
<td></td>
</tr>
<tr>
<td>$S_1$</td>
<td>Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI &gt; 40) and high water content</td>
<td>&lt; 100 (indicative)</td>
</tr>
<tr>
<td>$S_2$</td>
<td>Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or $S_1$</td>
<td></td>
</tr>
</tbody>
</table>
Seismic action

**Importance Factor**

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>T=475 year</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.4</td>
</tr>
</tbody>
</table>

\[ a_g = \gamma \cdot a_g R \]

**Representation of Seismic Action**

a. Response Spectrum
   - Horizontal elastic response spectrum
   - Vertical elastic response spectrum
   - Horizontal design response spectrum (Behavior factor, \( q \), is considered.)
   - Vertical design response spectrum (Behavior factor, \( q \), is considered.)

\[
0 \leq T \leq T_B : S_a(T) = a_g \cdot S \left[ 1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1) \right] \\
T_B \leq T \leq T_C : S_a(T) = a_g \cdot S \cdot \eta \cdot 2.5 \\
T_C \leq T \leq T_D : S_a(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left( \frac{T_C}{T} \right) \\
T_D \leq T \leq 4s : S_a(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left( \frac{T_C}{T} \right)
\]

b. Time history

[Horizontal Elastic Spectrum]
Combination of Seismic Action

- Load Combination of permanent loads and variable loads

- **100:30 Rule**
  
  \[(1.0Ex + 0.3Ey), (0.3Ex + 1.0Ey)\]
  \[(1.0Ex + 0.3Ey + 0.3Ez), (0.3Ex + 1.0Ey + 0.3Ez), (0.3Ex + 0.3Ey + 1.0Ez)\]
Criteria for Structural Regularity

### Structural Regularity

#### Table 4.1: Consequences of structural regularity on seismic analysis and design

<table>
<thead>
<tr>
<th>Regularity</th>
<th>Allowed Simplification</th>
<th>Behaviour factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(for linear analysis)</td>
</tr>
<tr>
<td>Plan</td>
<td>Elevation</td>
<td>Model</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Planar</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Planar</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Spatial$^b$</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Spatial</td>
</tr>
</tbody>
</table>

---

### Analysis Method

- **Lateral Force method of Analysis**
- **Modal Response Spectrum Analysis**
- **Pushover Analysis**
- **Inelastic Time History Analysis**
Safety Verification

Ultimate Limit States

Resistance condition: $M_{Rd} \geq M_{Ed}$, $V_{Rd} \geq V_{Ed}$
Global and local ductility condition: $M_{RC} \geq 1.3 M_{RB}$
Equilibrium condition: overturning or sliding
Resistance of horizontal diaphragm
Resistance of foundations
Seismic joint condition

Damage limitation

Limitation of story drift

a) for buildings having non-structural elements of brittle materials attached to the structure:

$$d_t \nu \leq 0.005 \ h$$

b) for buildings having ductile non-structural elements:

$$d_t \nu \leq 0.0075 \ h$$

c) for buildings having non-structural elements fixed in a way so as not to interfere with structural deformations, or without non-structural elements:

$$d_t \nu \leq 0.010 \ h$$
Capacity Design

Ductility Class

- DCL (Low ductility)
- DCM (Medium ductility)
- DCH (High ductility)

Structure Type & Behavior Factor

\[ q = q_0 k_w \geq 1.5 \]

Table 5.1: Basic value of the behaviour factor, \( q_0 \), for systems regular in elevation

<table>
<thead>
<tr>
<th>STRUCTURAL TYPE</th>
<th>DCM</th>
<th>DCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame system, dual system, coupled wall system</td>
<td>( 3.0 \alpha / \alpha_1 )</td>
<td>( 4.5 \alpha / \alpha_1 )</td>
</tr>
<tr>
<td>Uncoupled wall system</td>
<td>( 3.0 )</td>
<td>( 4.0 \alpha / \alpha_1 )</td>
</tr>
<tr>
<td>Torsionally flexible system</td>
<td>( 2.0 )</td>
<td>( 3.0 )</td>
</tr>
<tr>
<td>Inverted pendulum system</td>
<td>( 1.5 )</td>
<td>( 2.0 )</td>
</tr>
</tbody>
</table>

\[ k_w = \begin{cases} 
1.00, & \text{for frame and frame - equivalent dual systems} \\
(1 + \alpha_0) / 3 \leq 1, & \text{but not less than 0.5, for wall, wall - equivalent and torsionally flexible systems} 
\end{cases} \quad (5.2) \]
Design Procedure

Capacitity Design Feature

- structures to provide the appropriate amount of ductility in the corresponding ductility classes.
- Automatic capacity design capability for beam, column, wall and beam-column joint
- Design action effects are calculated in accordance with the capacity design rule. Special provision for ductile primary seismic walls is considered.
- Detailing for local ductility is considered.
  - max/min reinforcement ratio of the tension zone
  - the spacing of hoops within the critical region
  - mechanical volumetric ratio of conﬁning hoops with the critical regions

Define ductility class and check design results

Capacity design shear forces on beams

Design envelope moments in walls
Design Procedure

Seismic Design for New Buildings

Design member forces (Design moments)

Design Moment

<table>
<thead>
<tr>
<th>Beam</th>
<th>( M_{Ed,B} = \text{Max}{\text{Load Combinations}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uppermost Story</td>
<td></td>
</tr>
<tr>
<td>i ( M_{Ed,B} = \text{Max}{\text{Load Combinations}} )</td>
<td></td>
</tr>
<tr>
<td>( M_{Ed,CT} = 1.3 \times \sum_i M_{RB} \times \frac{\sum_i M_{RB,CT}}{\sum_i M_{RB,CT} + \sum_i M_{EB,CT}} )</td>
<td></td>
</tr>
<tr>
<td>Column</td>
<td></td>
</tr>
<tr>
<td>Middle Story</td>
<td></td>
</tr>
<tr>
<td>( M_{Ed,CT} = 1.3 \times \sum_i M_{RB} \times \frac{\sum_i M_{RB,CT}}{\sum_i M_{RB,CT} + \sum_i M_{EB,CT}} )</td>
<td></td>
</tr>
<tr>
<td>( M_{Ed,CT} = 1.3 \times \sum_i M_{RB} \times \frac{\sum_i M_{RB,CT}}{\sum_i M_{RB,CT} + \sum_i M_{EB,CT}} )</td>
<td></td>
</tr>
<tr>
<td>1st Story</td>
<td></td>
</tr>
<tr>
<td>( M_{Ed,CT} = 1.3 \times \sum_i M_{RB} \times \frac{\sum_i M_{RB,CT}}{\sum_i M_{RB,CT} + \sum_i M_{EB,CT}} )</td>
<td></td>
</tr>
</tbody>
</table>

Where,

- \( M_{RB} \): Beam moment resistance
- \( M_{CE} \): Column member force due to seismic load case
### Design member forces (Design shear forces)

#### Design Shear Force

**Beam**

- \( M_{d,1} = \gamma_M M_{Rb,1 \min}(1, \frac{E I_b}{E I_b}) \)
- \( M_{d,2} = \gamma_M M_{Rb,2 \min}(1, \frac{E I_b}{E I_b}) \)
- \( V_{zd,b} = \frac{M_{d,1} + M_{d,2} + (z + z_d) M_{ce}}{I_d} \)

**Uppermost Story**

\( M_{d,1} = \gamma_M M_{Rb,1} \)
\( M_{d,2} = \gamma_M M_{Rb,2 \min}(1, \frac{E I_b}{E I_b}) \)
\( V_{zd,e} = \frac{M_{d,1} + M_{d,2}}{I_d} \)

**Column**

**Middle Story**

\( M_{d,1} = \gamma_M M_{Rc,1 \min}(1, \frac{E I_c}{E I_c}) \)
\( M_{d,2} = \gamma_M M_{Rc,2 \min}(1, \frac{E I_c}{E I_c}) \)
\( V_{zd,c} = \frac{M_{d,1} + M_{d,2}}{I_d} \)

**1st Story**

\( M_{d,1} = \gamma_M M_{Rc,1 \min}(1, \frac{E I_c}{E I_c}) \)
\( M_{d,2} = \gamma_M M_{Rc,2} \)
\( V_{zd,c} = \frac{M_{d,1} + M_{d,2}}{I_d} \)

#### Capacity design values of shear forces on beams

Where, \( M_{Rb} \): Beam moment resistance
\( M_{Rc} \): Column moment resistance (calculated using same axial force ratio in PM interaction curve)
\( M_{ce} \): Bending moment of column due to seismic load case

#### Capacity design shear force in columns

<table>
<thead>
<tr>
<th>( \gamma_{zd} )</th>
<th>DCM</th>
<th>DCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>column</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Joint</td>
<td>-</td>
<td>1.2</td>
</tr>
</tbody>
</table>
**Seismic Design for New Buildings**

### Design member forces (Wall design forces)

<table>
<thead>
<tr>
<th>Building system</th>
<th>Wall system</th>
<th>Dual system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slender or non slender</td>
<td>Squat wall (h/l ≤ 2)</td>
<td>Slender (h/l &gt; 2)</td>
</tr>
<tr>
<td>DCM</td>
<td>Moment</td>
<td>Calculating from seismic design situation</td>
</tr>
<tr>
<td></td>
<td>Shear</td>
<td>$V_{Ed} = 1.5 V_{Ed}$</td>
</tr>
<tr>
<td>DCH</td>
<td>Moment</td>
<td>Calculating from seismic design situation</td>
</tr>
<tr>
<td></td>
<td>Shear</td>
<td>$V_{Ed} = \gamma_{Ed} \cdot \left( \frac{M_{Ed}}{M_{Ed}} \right), V_{Ed} \leq \gamma \cdot V_{Ed}$</td>
</tr>
</tbody>
</table>

**Key**
- a: moment diagram from analysis
- b: design envelope
- c: tension shift

**Design envelope for bending moments in slender walls**

**Design envelope of the shear forces in the walls of a dual system**
Seismic Assessment of Buildings as per Eurocode8 (Existing buildings)

1. Performance Requirement
2. Knowledge Level
3. Seismic Action
   - Seismic Zone
   - Representation of seismic action
4. Combination of Seismic Action
5. Seismic Analysis
   - Lateral Force method of Analysis
   - Modal Response Spectrum Analysis
   - Pushover Analysis
   - Inelastic Time History Analysis
6. Safety Verification
7. Decision for Structural Intervention
Performance Requirement and Compliance Criteria

**Performance Requirement**

- Near Collapse (NC) \( T_{NCR} = 2475\text{years} \)
- Significant Damage (SD) \( T_{NCR} = 475\text{years} \)
- Damage Limitation (DL) \( T_{NCR} = 225\text{years} \)

**Compliance Criteria**

- **Near Collapse (NC)**
  - Ductile: ultimate deformation (plastic rotation)
  - Brittle: ultimate strength

- **Significant Damage (SD)**
  - Ductile: damage-related deformation
  - Brittle: conservatively estimated strength

- **Damage Limitation (DL)**
  - Ductile: yield strength
  - Brittle: yield strength
  - Infills: story drift
Table 3.1: Knowledge levels and corresponding methods of analysis (LF: Lateral Force procedure, MRS: Modal Response Spectrum analysis) and confidence factors (CF).

<table>
<thead>
<tr>
<th>Knowledge Level</th>
<th>Geometry</th>
<th>Details</th>
<th>Materials</th>
<th>Analysis</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>KL1</td>
<td>Geometry</td>
<td>Simulated design in accordance with relevant practice and from limited in-situ inspection</td>
<td>Default values in accordance with standards of the time of construction and from limited in-situ testing</td>
<td>LF-MRS</td>
<td>CF_{KL1}</td>
</tr>
<tr>
<td>KL2</td>
<td>Geometry</td>
<td>From original outline construction drawings with sample visual survey or from full survey</td>
<td>From original design specifications with limited in-situ testing or from extended in-situ testing</td>
<td>All</td>
<td>CF_{KL2}</td>
</tr>
<tr>
<td>KL3</td>
<td>Geometry</td>
<td>From original detailed construction drawings with limited in-situ inspection or from comprehensive in-situ inspection</td>
<td>From original test reports with limited in-situ testing or from comprehensive in-situ testing</td>
<td>All</td>
<td>CF_{KL3}</td>
</tr>
</tbody>
</table>

NOTE: The values ascribed to the confidence factors to be used in a country may be found in its National Annex. The recommended values are CF_{KL1} = 1.35, CF_{KL2} = 1.20 and CF_{KL3} = 1.00.
**Pushover Analysis**

**Why Pushover Analysis?**

a) To verify or revise the over strength ratio values (alpha_u/alpha_1)
b) To estimate the expected plastic mechanisms and the distribution of damage
c) To assess the structural performance of existing or retrofitted buildings
d) As an alternative to the design based on linear-elastic analysis which uses the behavior factor, q

**Process in midas Gen**

1. Pushover Global Control
2. Define Lateral Loads
3. Define Hinge Properties
4. Assign Hinges
5. Perform Analysis
6. Check Pushover Curve and Target Disp.
7. Check Hinge Status
8. Safety Verification

![Capacity Curves Image](image_url)
### Safety Verification

#### Table 4.3: Values of material properties and criteria for analysis and safety verifications.

<table>
<thead>
<tr>
<th>Type of element or mechanism (e/m)</th>
<th>Linear Model (LM)</th>
<th>Nonlinear Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ductile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From analysis.</td>
<td>Acceptability of Linear Model (for checking of $\rho_i = D_i/C_i$ values):</td>
<td>In terms of strength. Use mean values of properties.</td>
</tr>
<tr>
<td></td>
<td>From analysis. Use mean values of properties in model.</td>
<td>Use mean values of properties.</td>
</tr>
<tr>
<td></td>
<td>Verifications (if LM accepted):</td>
<td>From analysis. Use mean values of properties divided by CF.</td>
</tr>
<tr>
<td></td>
<td>From analysis.</td>
<td>In terms of deformation. Use mean values of properties divided by CF.</td>
</tr>
<tr>
<td>Brittle</td>
<td>Verifications (if LM accepted):</td>
<td>From analysis. Use mean values of properties divided by CF.</td>
</tr>
<tr>
<td>If $\rho_i \leq 1$: from analysis.</td>
<td>In terms of strength. Use mean values of properties divided by CF and by partial factor.</td>
<td>In terms of strength. Use mean values of properties divided by CF and by partial factor.</td>
</tr>
<tr>
<td>If $\rho_i &gt; 1$: from equilibrium with strength of ductile e/m. Use mean values of properties multiplied by CF.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Objectives of Seismic Isolation Systems

Enhance performance of structures at all hazard levels by:

- Minimizing interruption of use of facility (e.g., *Immediate Occupancy Performance Level*)
- Reducing damaging deformations in structural and nonstructural components
- Reducing acceleration response to minimize contents related damage

Characteristics of Well-Designed Seismic Isolation Systems

- Flexibility to increase period of vibration and thus reduce force response
- Energy dissipation to control the isolation system displacement
- Rigidity under low load levels such as wind and minor earthquakes
Applicable Base Isolators in midas Gen

**Base Isolators:**
- Lead Rubber Bearing Isolator
- Friction Pendulum System Isolator

**Geometry of Elastomeric Bearings**

**Spherical Sliding Bearing:**
Friction Pendulum System (FPS)

- Stainless Steel Concave Surface
- Housing Plate With PTFE Coating Above Slider
- Concave Plate
- Articulated Slider With PTFE Coating

*Concave Plate and Slider for FPS Bridge Bearing*
*Seismic retrofit of Benicia-Martinez Bridge, San Francisco, CA*
*7.5 to 13 ft diameters*
*Displ. Capacity of 13 ft bearings = +/- 4.3 ft*
Applicable Dampers in midas Gen

Viscoelastic Damper

$\dot{f} = c \cdot \text{sign}(d) \cdot \frac{d}{|v|} = k_d \dot{d}$

$\dot{d} = d_d + d_b$

Hysteretic System Damper

$\dot{f} = r \cdot k \cdot d + (1 - r) F_y \cdot z$

$\dot{z} = \frac{k}{F_y} [1 - \alpha \cdot \text{sign}(d \cdot z) + \beta] \cdot d$

Figure 3: Seismic Energy Dissipation Devices – each device is suitable for a certain building.
Analysis Results (Graph & Text output)

[Hysteretic Graph of Friction pendulum system isolator]

[Time History Graph at 1st story and 3rd story]

[Hysteretic Graph of Lead rubber bearing isolator]
Analysis Results (Time History Graph)

[Without Isolators]

Shear force at 1st story column

Displacement - Frequency

f=0.93Hz → T=1.08 (sec)

[With Isolators]

Shear force at 1st story column

Displacement - Frequency

f=0.56Hz → T=1.79 (sec)
Mass

- Nodal Masses
- Floor Diaphragm Masses
- Loads to Masses
- Consistent Mass
- Self-weight to Mass

[Lumped Mass and Consistent Mass]

**Lumped Mass**

$$I_c = \frac{\rho A L}{420}$$

\[
\begin{bmatrix}
140 & 0 & 0 & 70 & 0 & 0 \\
0 & 156 & -22L & 0 & 54 & 13L \\
0 & -22L & 4L^2 & 0 & -13L & -3L^2 \\
70 & 0 & 0 & 140 & 0 & 0 \\
0 & 54 & -13L & 0 & 156 & 22L \\
0 & 13L & -3L^2 & 0 & 22L & 4L^2
\end{bmatrix}
\begin{bmatrix}
u_1 \\
v_1 \\
\theta_1 \\
u_2 \\
v_2 \\
\theta_2
\end{bmatrix}
\]

**Consistent Mass**

$$I_L = \frac{\rho A L}{420}$$

\[
\begin{bmatrix}
210 & 0 & 0 & 0 & 0 & 0 \\
0 & 210 & 0 & 0 & 0 & 0 \\
0 & 0 & 210 & 0 & 0 & 0 \\
0 & 0 & 0 & 210 & 0 & 0 \\
0 & 0 & 0 & 0 & 210 & 0 \\
0 & 0 & 0 & 0 & 0 & 210
\end{bmatrix}
\begin{bmatrix}
u_1 \\
v_1 \\
\theta_1 \\
u_2 \\
v_2 \\
\theta_2
\end{bmatrix}
\]
Modal
User defines the damping ratio for each mode, and the modal response will be calculated based on the user defined damping ratios.

Mass & Stiffness Proportional
Damping coefficients are computed for mass proportional damping and stiffness proportional damping.

\[ \overline{C}_g = \overline{a}_0 \overline{M}_g + \overline{a}_1 \overline{K}_g \]

Strain Energy Proportional
Damping ratios for each mode are automatically calculated using the damping ratios specified for element groups and boundary groups in Group Damping, which are used to formulate the damping matrix.
Modal Analysis

Eigen Vectors

Subspace Iteration
This method is effectively used when performing eigenvalue analysis for a finite element system of any scale and commonly used among engineers.

Lanczos
Tri-diagonal Matrix is used to perform eigenvalue analysis. It is particularly useful for finding decompositions of very large sparse matrices. The performance of Lanczos method is superior to that of the Subspace Iteration.

Ritz Vectors
Unlike the natural eigenvalue modes, load dependent Ritz vectors produce more reliable results in dynamic analyses with relatively fewer modes. The Ritz Vectors are generated reflecting the spatial distribution or the characteristics of the dynamic loading.
Fiber Analysis

Section division for Fiber Model definition

Inelastic Material Properties (Stress-strain curve)

Fiber Cell Result Plotting

Kent & Park Model

Menegotto-Pinto Model
Thank You!