Analytical Study of Partially-Restrained Steel Frames with Reinforced Concrete Infill Walls Subjected to Cyclic Loading

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含鋼筋混凝土之半剛接鋼構架耐震分析

Analytical Study of Partially-Restrained Steel Frames with Reinforced Concrete Infill Walls Subjected to Cyclic Loading

本論文係黎柏定君（R01512052）在國立臺灣大學土木工程學系碩士班完成之碩士學位論文，於民國103年7月18日承受下列口試委員審查通過及口試及格，特此證明

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ABSTRACT

The analytical study herein focuses on the investigation of structural systems consisting of steel frames with reinforced concrete infill walls (SRCW) for using as the primary lateral-resistance systems for low-rise structures in the seismic zones. Due to need of a richer understanding about the cyclic behavior of this composite structure, the work reported in this thesis attempts to build a model in PISA3D software including partially-restrained steel frames with reinforced concrete infill walls. The lateral behavior of infill walls was predicted by the Simplified Strut-and-Tie (SST) model, and modelled by equivalent truss elements. While the pushover analysis of the equivalent truss elements was carried out by Fracture material in PISA3D, their cyclic response was performed by Degrading material. Moreover, a three-span three-story building in California was designed for seismic resistance by this composite structure. The preliminary design followed ASCE 7-10, then the seismic performance was predicted by the capacity spectrum method (CSM), a nonlinear static analysis with 3 procedures A, B and C which were adopted in ATC 40-96. The performance of SRCW frames was compared with a Self-Centering Braced Frames (SCBF), and a traditional Moment Resisting Frames (MRF) by SEAOC Vision 2000. In addition, although PISA3D software can not run the time history analysis (THA) for SRCW frames, a comparison between the THA and the CSM for the SCBF and the MRF was carried out.

**Key words:** steel frames with reinforced concrete infill walls; strut-and-tie model; partially-restrained; capacity spectrum method; self-centering braced frame; moment resisting frame; PISA3D

含鋼筋混凝土之半剛接鋼構架；自復位消能斜撐構架；PISA3D
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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>SRCW</td>
<td>Steel frames with Reinforced Concrete infill Walls</td>
</tr>
<tr>
<td>SST</td>
<td>Simplified Strut-and-Tie</td>
</tr>
<tr>
<td>CSM</td>
<td>Capacity Spectrum Method</td>
</tr>
<tr>
<td>SCBF</td>
<td>Self-Centering Braced Frames</td>
</tr>
<tr>
<td>MRF</td>
<td>Moment Resisting Frames</td>
</tr>
<tr>
<td>THA</td>
<td>Time History Analysis</td>
</tr>
<tr>
<td>SRC</td>
<td>Steel Reinforced Concrete</td>
</tr>
<tr>
<td>CFT</td>
<td>Concrete-Filled steel Tube</td>
</tr>
<tr>
<td>HWS</td>
<td>Hybrid Wall System</td>
</tr>
<tr>
<td>RC</td>
<td>Reinforced Concrete</td>
</tr>
<tr>
<td>DBE</td>
<td>Design Based Earthquakes (475-year return period earthquakes)</td>
</tr>
<tr>
<td>MCE</td>
<td>Maximum Considered Earthquakes (2500-year return period earthquakes)</td>
</tr>
<tr>
<td>PR</td>
<td>Partially-restrained</td>
</tr>
<tr>
<td>$V_{cr,s}$</td>
<td>Shear cracking strength of walls</td>
</tr>
<tr>
<td>$V_{cr,fs}$</td>
<td>Flexural-shear cracking strength of walls</td>
</tr>
<tr>
<td>$V_{cr}$</td>
<td>Cracking strength of walls</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Modification factor reflecting the reduced mechanical properties of lightweight concrete</td>
</tr>
<tr>
<td>$f'_c$</td>
<td>Compressive strength of concrete, determined by cylinder tests</td>
</tr>
<tr>
<td>$t_w$</td>
<td>Thickness of walls</td>
</tr>
<tr>
<td>$d$</td>
<td>Distance from extreme compression fiber to centroid of longitudinal tension reinforcement</td>
</tr>
<tr>
<td>$l_w$</td>
<td>Length of walls</td>
</tr>
</tbody>
</table>
\[ N \quad \text{Axial load} \]
\[ M \quad \text{Moment} \]
\[ V \quad \text{Shear force or lateral force (chapter 2)} \]
\[ \delta_{cr,s} \quad \text{Shear cracking displacement} \]
\[ \nu \quad \text{Poisson ratio} \]
\[ E_c \quad \text{Young modulus of concrete} \]
\[ H \quad \text{Height of shear elements in single-curvature walls} \]
\[ \delta_{cr,f} \quad \text{Flexural cracking displacement} \]
\[ I_e \quad \text{Effective moment of inertia of walls’ section} \]
\[ I_g \quad \text{Moment of inertia of walls’ gross section} \]
\[ \Delta_{cr} \quad \text{Cracking displacement} \]
\[ V_u \quad \text{Ultimate strength of walls} \]
\[ V_f \quad \text{Flexural strength of walls} \]
\[ V_s \quad \text{Shear strength of walls} \]
\[ M_t \quad \text{Moment at the top of walls} \]
\[ M_b \quad \text{Moment at the bottom of walls} \]
\[ H_n \quad \text{Clear height of walls (or height of shear elements in double-curvature walls)} \]
\[ K \quad \text{Strut-and-Tie index} \]
\[ \zeta \quad \text{Softening coefficient} \]
\[ A_{str} \quad \text{Effective area of diagonal struts} \]
\[ a_w \quad \text{Depth of compression zones} \]
\( f_s \)  
Stress of rebars

\( f_y \)  
Yielding stress of rebars

\( \theta \)  
Angle of diagonal struts

\( l_v \)  
Height of shear elements

\( l_h \)  
Length of shear elements

\( \delta_{u,f} \)  
Flexural ultimate displacement

\( H_{n,b} \)  
Distance from the inflection point to the base of walls

\( H_{n,t} \)  
Distance from the inflection point to the bottom of top beams

\( \delta_{u,s} \)  
Shear ultimate displacement

\( \gamma_{vh} \)  
Average shear strain in walls

\( M_n \)  
Moment corresponding to the maximum strain of the extreme compressive concrete fiber \( \varepsilon_c = 0.003 \)

\( \varepsilon_c \)  
Compressive strain of concrete

\( \Delta_u \)  
Ultimate displacement

\( V_{ps} \)  
Post-strength of walls

\( \Delta_{ps} \)  
Post-strength displacement of walls

\( A \)  
Section area of equivalent trusses

\( \Delta \)  
Lateral displacement of equivalent trusses (chapter 2)

\( \varepsilon \)  
Strain of equivalent trusses

\( \delta \)  
Deformation of equivalent trusses

\( L_o \)  
Initial length of equivalent trusses

\( \alpha_o \)  
Initial angles between equivalent trusses and the horizontal direction
\( \alpha \)  
Angles between equivalent trusses and the horizontal direction at the deformed state

\( H_t \)  
Height of equivalent trusses

\( L_t \)  
Span of equivalent trusses

\( b \)  
Width of equivalent trusses’ section

\( h \)  
Height of equivalent trusses’ section

\( \sigma \)  
Stress of equivalent trusses

\( F \)  
Axial force of equivalent trusses

\( B_x, B_y, C_x, C_y, D_x, D_y, E_x, E_y \)  
Coordinates of 4 points used to define Fracture material in the stress-strain coordinate system in the tension state

\( B'_x, B'_y, C'_x, C'_y, D'_x, D'_y, E'_x, E'_y \)  
Coordinates of 4 points used to define Fracture material in the stress-strain coordinate system in the compression state

\( E \)  
Young modulus of Fracture or Degrading material

\( f'_y \)  
Yielding stress in compression of Degrading material

\( f'^* \)  
Yielding stress in tension of Degrading material

\( S_1 \)  
Stiffness degrading factor for Degrading material

\( S_2 \)  
Strength deterioration factor for Degrading material

\( S_3 \)  
Pinching factor for Degrading material

\( BV \)  
Strain boundary value

SW5  
A squat wall specimen of Pilakoutas

\( f_{\text{average}} \)  
Average yielding stress

\( f'_{\text{web}} \)  
Yielding stress of web plates in coupon tests

\( f'_{\text{flange}} \)  
Yielding stress of flange plates in coupon tests
\( A_{\text{web}} \) Section area of web plates

\( A_{\text{flange}} \) Section area of flange plates

\( f_{\text{Von Mises}} \) Von Mises yield criterion

\( \sigma_1, \sigma_2 \) Principle normal stress in the plane problem

\( \sigma_{12} \) Shear stress in the plane problem

\( A_{eq} \) Equivalent section area

\( I_{eq} \) Equivalent second moment of area

\( A_w \) Section area of walls

\( n \) Transformation factor

\( A_0 \) Section area of steel columns

\( E_s \) Young modulus of steel

\( I_{eo} \) Second moment of area of walls

\( I_{t} \) Second moment of area of tensile columns

\( I_{cd} \) Second moment of area of compressive columns

\( I_0 \) Second moment of area of steel columns’ sections

\( x_t \) Distance from the center of tension columns to the neutral axis

\( x_c \) Distance from the center of compressive columns to the neutral axis

\( x_0 \) Distance from the central axis to the neutral axis

\( M_{cr} \) Moment of the whole section corresponding to \( V_{cr} \)

\( a_s \) Depth of diagonal struts

\( a_w \) Depth of the compression zone

\( d_{cd} \) Depth of steel columns’ section
DOF  
Degree of freedom

Rz  
Rotation about the z axis

Ko  
Initial effective rotation stiffness

f_y\textsuperscript{joint}  
Yielding stress of joint elements

M_y\textsuperscript{joint}  
Yielding moment of joint elements

Uy  
Vertical displacement

MWF  
Frames with infill walls located at the middle of the span

EWF  
Frames with infill walls located at the edge of the span

S_S  
Mapped MCE\textsubscript{R} spectral response acceleration parameter at short periods

S_1  
Mapped MCE\textsubscript{R} spectral response acceleration parameter at 1 s period

R  
Response modification factor

C_d  
Deflection modification factor

T_a  
Approximate fundamental period

C_t  
Coefficient to determine T_a

x  
Coefficient to determine T_a

h_n  
Structural height

C_s  
Seismic response coefficient

S_{DS5}  
Design earthquake spectral response acceleration parameter at short period

S_{DH1}  
Design earthquake spectral response acceleration parameter at 1 s period

T  
Calculated period

T_1  
Fundamental period

T_{max}  
Upper limit of T

C_u  
Coefficient to determine T_{max}
$V$ Design base shear (chapter 4)

$W$ Effective weight of buildings

$F_x$ Lateral seismic force induced at each levels

$C_{vv}$ Vertical distribution factor

$w_i$ Weight of the structure located at level $i$

$w_x$ Weight of the structure located at level $x$

$h_i$ Height from the base to the level $i$

$h_x$ Height from the base to the level $x$

$k$ An exponent related to the structure period

$\rho$ Redundancy factor

$r_{max}$ Largest of the element-story shear ratios

$A_g$ Ground floor area of the structure in square feet

$S_a$ Spectral acceleration

$S_d$ Spectral displacement

$\alpha_1$ Modal mass coefficient for the 1st mode

$PF_1$ Modal participation factor for the 1st mode

$\Delta$ Roof displacement (chapter 4)

$g$ Acceleration due to gravity

$\phi_{i}$ Amplitude of mode 1 at level $i^{th}$

$C_A$ Site seismic coefficient

$C_V$ Site seismic coefficient

$SR_d$ Reduction factors for $C_A$
$SR_v$  Reduction factors for $C_v$

$\beta_{eff}$  Effective viscous damping

$\beta_o$  Equivalent viscous damping

$\kappa$  Damping modification factor

$a_{pi}$  Spectral acceleration coordinate of the trial performance point $i$

$d_{pi}$  Spectral displacement coordinate of the trial performance point $i$

$a^*$  Spectral acceleration coordinate of the point determined by the equal displacement rule

$d^*$  Spectral displacement coordinate of the point determined by the equal displacement rule

$a_y$  Spectral acceleration coordinate of the yielding point

$d_y$  Spectral displacement coordinate of the yielding point