PERFORMANCE LIMITS FOR REINFORCED CONCRETE COLUMNS UNDER SEVERE DISPLACEMENT CYCLES

Bora ACUN  Haluk SUCUOĞLU
OBJECTIVES

• Investigation of the **effect of displacement history** on the deformation response of concrete columns controlled by flexure.

• Comparative evaluation of the **limit states** proposed by:

  - ASCE/SEI 41-Update (2007),
  - Eurocode 8 (2005),
  - Turkish Earthquake Code, TDY (2007)

• Assessment of the **modeling criteria** in ASCE/SEI 41-Update
EXPERIMENTAL STUDIES
**Experimental Studies - GENERAL**

- **Six “non conforming” column specimens (Type-1)**
  - => Plain bars,
  - => Low strength concrete (∼13 MPa)
  - => Inadequate detailing (poor confinement)

- **Six “code conforming” column specimens (Type-2)**
  - => Deformed bars,
  - => Normal strength concrete (∼25 MPa)
  - => Ductile detailing (plastic hinging zone)
## Experimental Studies—TEST SPECIMENS

### Material properties and reinforcement ratios of test specimens

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>Concrete</th>
<th>Longitudinal Reinforcement</th>
<th>Transverse Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compressive Strength $f'_c$</td>
<td>Yield Strength $f_y$</td>
<td>Ultimate Strength $f_u$</td>
</tr>
<tr>
<td></td>
<td>(Mpa)</td>
<td>(Mpa)</td>
<td>(Mpa)</td>
</tr>
<tr>
<td>Type 1</td>
<td>13</td>
<td>315</td>
<td>448</td>
</tr>
<tr>
<td>Type 2</td>
<td>25</td>
<td>454</td>
<td>604</td>
</tr>
</tbody>
</table>
**Experimental Studies— TEST SPECIMENS**

**Type - 1**

- Plan view: 14 mm bars, 8 mm bars
- Elevation: 2φ/165, φ/165, 2φ/70
- Longitudinal Reinforcement: φ/14
- Transverse Reinforcement: 2φ/165, φ/165
- All dimensions are in mm

**Type - 2**

- Plan view: 14 mm bars, 8 mm bars
- Elevation: 2φ/70, φ/70
- Longitudinal Reinforcement: φ/14
- Transverse Reinforcement: 2φ/70, φ/70
- All dimensions are in mm

Dimensions and details of test specimens
Experimental Studies— TEST SPECIMENS

Reinforcing cage of Type-2 test specimens
Experimental Studies— TEST SETUP

**TEST SETUP**

- Reaction Wall
- Hinges
- Steel Loading Beam
- Load Cells
- Steel Head
- Post tensioning bars
- Fixing bars
- Steel Support beam
- Mat Foundation
- Counter Weights
- Strong Floor
- I-Beams supporting the lateral loading system

**Equation:**
\[ \Delta = \frac{L_{meas} - L}{L} \]
Experimental Studies— INSTRUMENTATION

Nominal locations of instruments

Longitudinal Reinforcement (Corner bars)

2 LVDT's @ 2800mm level

Load Cell

Longitudinal Reinforcement

8@14

Transverse Reinforcement

1 LVDT @ 2550mm level

2 LVDT's @ 2800mm level

Load Cell

1 LVDT @ 1800mm level

315 mm

2 strain gages at stirrups

2 strain gages at each level

4 Dial gages @1150 level

2 LVDT's @ 1150mm level

4 Dial gages @1150 level

1 LVDT @ 750mm level

1 LVDT @ 1150mm level

1 Dial Gage @ 350mm level

1 LVDT @ 750mm level

Strong Floor 0 Level

Not to scale

Dial gages

LVDT's

4 strain gages at each level
A ready-to-test specimen instrumented and connected to real time data acquisition system
Displacement protocols imposed on the test specimens

<table>
<thead>
<tr>
<th>Cycle No</th>
<th>Type 1</th>
<th>Type 2</th>
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<tbody>
<tr>
<td>1</td>
<td>1P2</td>
<td>1D2</td>
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<tr>
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<td>2P3</td>
<td>2D3</td>
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<tr>
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<td>4P4</td>
<td>4D5</td>
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<tr>
<td></td>
<td>5P5</td>
<td>5DV1</td>
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<tr>
<td></td>
<td>6PV1</td>
<td>6DV2</td>
</tr>
<tr>
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<table>
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<tr>
<th>Cycle No</th>
<th>Top Displacement Amp. (mm)</th>
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</tbody>
</table>
Imposed top displacement protocols
(Constant Amp.)

Imposed top displacement protocols
(Variable Amp.)
EVALUATION OF TEST RESULTS

“Limit States and Modelling Parameters”
MOMENT - CHORD ROTATION RELATIONS - *Experiments*

Chord rot. = Drift ratio = $\frac{\text{Top Disp.}}{\text{Specimen Height}}$
**DEFORMATION LIMIT STATES - Codes**

**ASCE / SEI 41-Update (2007)**

- Column Type
- Condition (i)

**Eurocode 8 (2005)**

- Column Type
- No Classification

**LIMIT STATES (Rotations)**

- **Yield**
- **Life Safety**
- **Collapse Prevention**
- **Effective stiffness**

Table 6-8 of ASCE/SEI 41-Update

\[ \theta_y = \phi_y \cdot \frac{L_s}{3} + 0.0013 \left( 1 + 1.5 \frac{h}{L_s} \right) + 0.13 \phi_y \cdot d_{bl} \cdot f_{y} \sqrt{f_c} \]

\[ \theta = \frac{3}{4} \theta_{um} \]

\[ \theta_{um} = \frac{1}{\gamma_{el}} \cdot 0.016 \cdot 0.3^\omega \left[ \frac{\max(0.01; \omega)}{\max(0.01; \omega)} \right]^{0.225} \left( \frac{L_s}{h} \right)^{0.35} \left( \frac{f_{yw}}{f_c} \right) \left( 1.25^{(100\rho_f)} \right) \]
DEFORMATION LIMIT STATES - Codes

TDY (2007)

Column Type

No Classification

LIMIT STATES
(Strains)

• Min. Damage

\( (\varepsilon_{\text{cu}})_{\text{MN}} = 0.0035 \quad ; \quad (\varepsilon_s)_{\text{MN}} = 0.010 \)

• Safety Limit

\( (\varepsilon_{\text{cg}})_{\text{GV}} = 0.0035 + 0.01 (\rho_s / \rho_{\text{sm}}) \leq 0.0135 \quad ; \quad (\varepsilon_s)_{\text{GV}} = 0.040 \)

• Collapse Limit

\( (\varepsilon_{\text{cg}})_{\text{GC}} = 0.004 + 0.014 (\rho_s / \rho_{\text{sm}}) \leq 0.018 \quad ; \quad (\varepsilon_s)_{\text{GC}} = 0.060 \)
DEFORMATION LIMIT STATES: **Type-1**

**Yield/Minimum damage**

Specimen 2P3

Specimen 6PV1
DEFORMATION LIMIT STATES: Type-1

Life safety/Significant damage

Specimen 2P3  Specimen 6PV1
DEFORMATION LIMIT STATES: Type-1

Collapse prevention/Collapse limit

Specimen 2P3

Specimen 6PV1
DEFORMATION LIMIT STATES: Type-2

Yield/Minimum damage

Specimen 3D4

Specimen 5DV1
DEFORMATION LIMIT STATES: Type-2

Life safety/Significant damage

Specimen 3D4

Specimen 5DV1
DEFORMATION LIMIT STATES: Type-2

Collapse prevention/Collapse limit

Specimen 3D4

Specimen 5DV1
ASCE/SEI 41-Update
Modelling Parameters

- plastic rotation at significant loss of plastic rotation capacity, \(a\)
- plastic rotation at axial load failure, \(b\)

Generalized Load-Deformation relationship
**Analytical Studies – MODELLING PARAMETERS**

**ASCE/SEI 41-Update**

**Modelling Parameters**

**Type-1 Columns**

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**Specimen 2P3**

**Specimen 6PV1**
Analytical Studies – MODELLING PARAMETERS

ASCE/SEI 41-Update

Modelling Parameters

Type-2 Columns

Specimen 3D4

Specimen 5DV1
**Analytical Studies – EFFECT OF LOADING HISTORY**

Envelope curves

**Type-1**

**Type-2**
SUMMARY and CONCLUSIONS

• Limit state predictions of all Codes for the “non-conforming” columns controlled by flexure tested in this study are conservative with respect to the experimental performance of these columns.

• Limit state predictions of TDY 2007 and Eurocode 8 are consistent with the experimental performance of “code conforming” reinforced concrete columns controlled by flexure, meanwhile ASCE/SEI 41 limit state definitions are conservative for such columns.

• The modeling parameter \( a \) of ASCE/SEI 41 seems to be conservative for defining the rotation capacity of column plastic hinges under the axial load ratio of 0.2.
Reference:

THANK YOU FOR YOUR ATTENTION