Tri-Service Infrastructure Systems Conference & Exposition
St. Louis, MO - August 2005

# GSA Progressive Collapse Design Guidelines Applied to Concrete Moment-Resisting Frame Buildings

David N. Bilow, P.E., S.E. and
Mahmoud E. Kamara, PhD
Portland Cement Association

# Topics

- Definition
- Comparison of DOD & GSA requirements
- Purpose of PCA study
- Study procedure
- Results

# Ronan Point (1968)

- Explosion on 18th floor
- Wall panel blown out
- 22 floors collapse

# Ronan Point

# Prevent Progressive Collapse

- Explosion at ground floor
- Local damage only

# GSA and DOD Criteria Comparison

| Requirement | GSA | DOD |
|---|---|---|
| Level of Protection (LOP) | Exempt or nonexempt | Very Low, Low, Medium, and High |
| Tie Requirements | Redundancy, ductility & continuity | Vertical and/or horizontal tie forces, and ductility |
| Alternate Path Analysis | Required for nonexempt | Req'd for Low LOP w/o vertical tie, Medium LOP, & High LOP |
| Column Removal | Middle of long side, middle of short side, & corner column, at ground level only | Middle of long side, middle of short side, & corner column, at each floor one at a time |

# Comparison

| Requirement | GSA | DOD |
|---|---|---|
| Loads for Static Analysis | 2(DL +0.25LL) all bays and floors | 2.0(1.2DL + 0.5LL) + 0.2W Adjacent bays & floor above<br><br>1.2 DL + 0.5LL for rest of structure |
| Loads for Dynamic Analysis | DL + 0.25LL | 1.2DL + 0.5LL + 0.2W |
| Upward Loads on Floor Slabs | Recommended | 1.0DL + 0.5LL |
| Method of Analysis | Linear static preferred | Linear static, nonlinear static, or nonlinear dynamic |

# Comparison

| Requirement | GSA | DOD |
|---|---|---|
| Material Strength Increase Factor | 1.25 | 1.25 |
| Strength Reduction Factor, $\phi$ | 1 | $\phi$ specified in ACI 318 |
| Acceptance Criteria | DCR $\leq$ 2.0 for typical structures | Allow plastic hinges & moment redistribution |
| Maximum Extent of Floor Collapse | Exterior: 1800 $ft^2$<br>Interior: 3600 $ft^2$ | Exterior: 1500 $ft^2$ or 15%<br>Interior: 3000 $ft^2$ or 30% |

# PCA Study Objectives

1. Determine how to apply the GSA progressive collapse guidelines.
2. Determine additional reinforcement needed to meet requirements for reinforced concrete frame buildings.

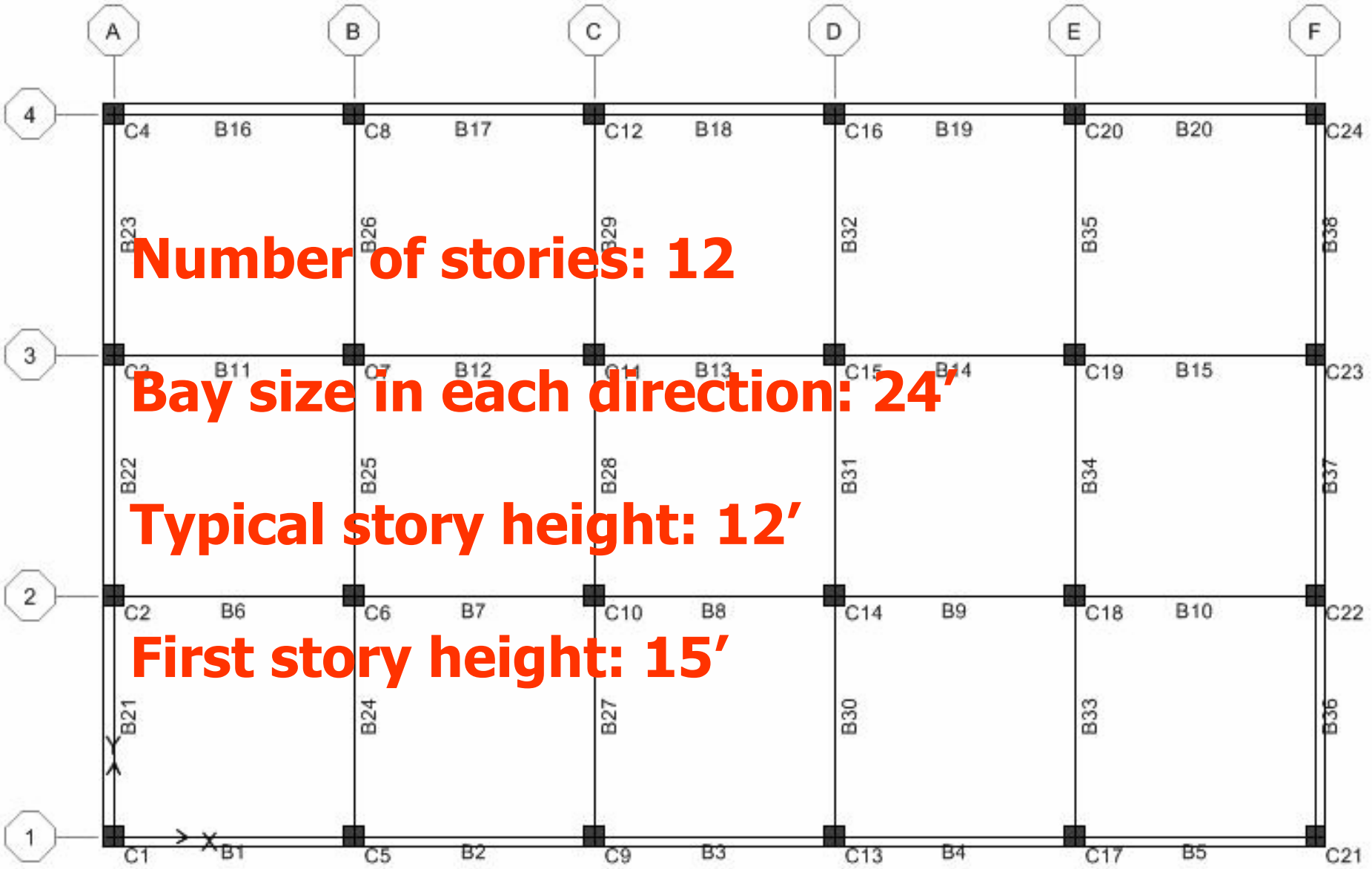
# References

- General Services Administration
  Progressive Collapse
  Analysis and Design Guidelines for
  New Federal Office Buildings and
  Major Modernization Projects
  June 2003
- 2000 International Building Code
- ACI 318-99 Building Code Requirements for Structural Concrete

# Study Procedure

1. Design 3 building structures for live, dead, wind, and seismic loads
2. Instantaneously remove selected first floor columns
3. Calculate the alternate path loads per GSA criteria
4. Apply the GSA loads to the structure
5. Determine moments and forces
6. Determine ultimate unfactored member capacity
7. Calculate Demand Capacity Ratios
8. Calculate additional reinforcement

# Building Plan



# Loads

- Floor Live Load = 50 psf
- Superimposed Dead Load = 30 psf
- Dead Load
- Wind Load for 70 MPH
- Seismic Load - 3 Locations

# Three Reinforced Cast-in-Place Concrete Moment Frame Buildings

| Seismic Design Class | Short Period Acceleration | Type of Detailing |
|---|---|---|
| A | .024g | Ordinary moment frame |
| C | .094g | Intermediate moment frame |
| D | .61g | Special moment frame |

# Load Combinations

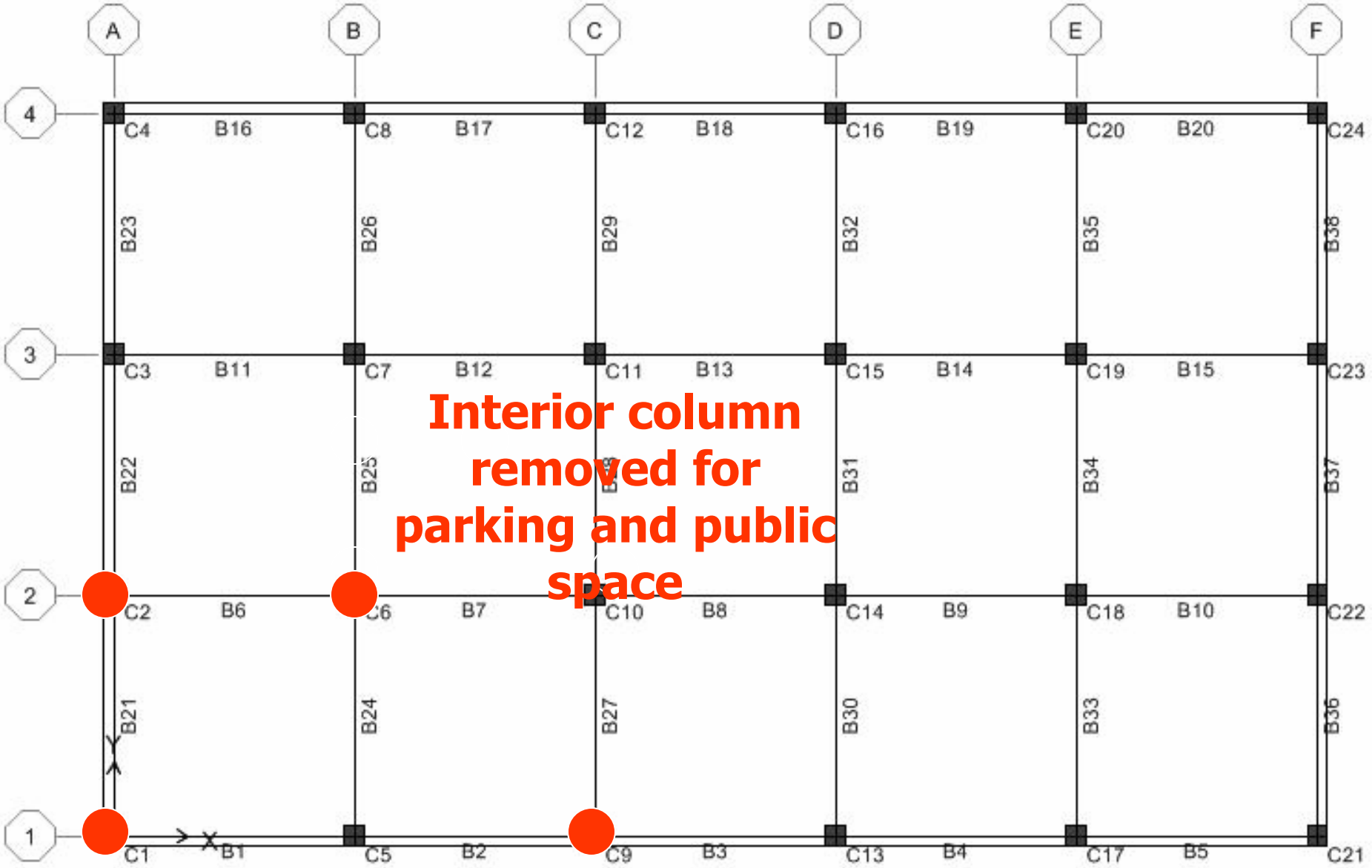
Normal Loading

- U = 1.4D + 1.7L
- U = 0.75(1.4D + 1.7L+ 1.7W)
- U = 0.75(1.4D +1.7L +1.1 E)

# Analysis and Design

- Select preliminary member sizes
- Model in 3 dimensions
- Static linear elastic analysis
- Beam and column reinforcement calculated
- ETABS software version 8.11

# Remove 1st Story Columns



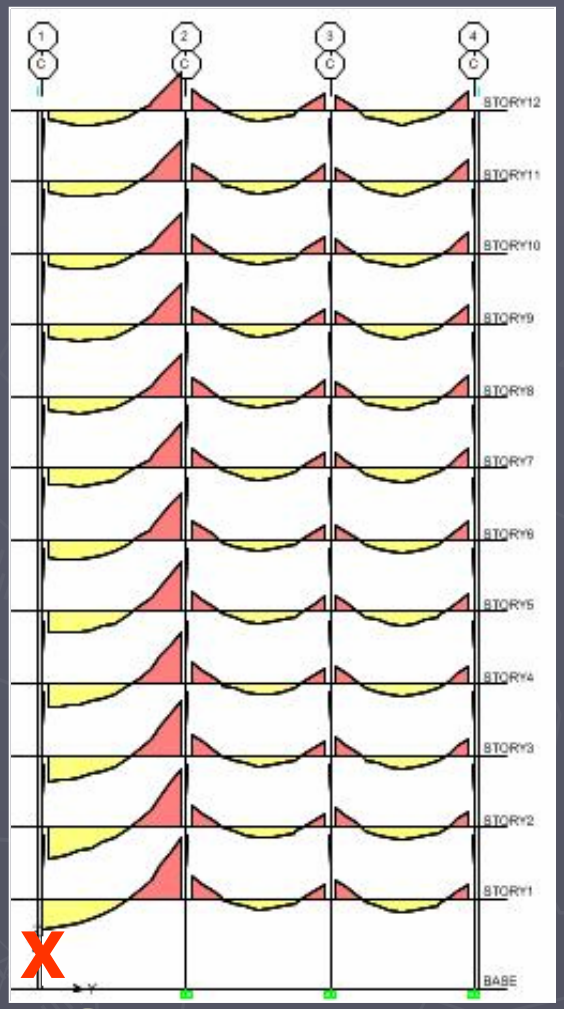
# Alternate Load Path Analysis

- Four new models of each of 3 buildings
- First story columns removed

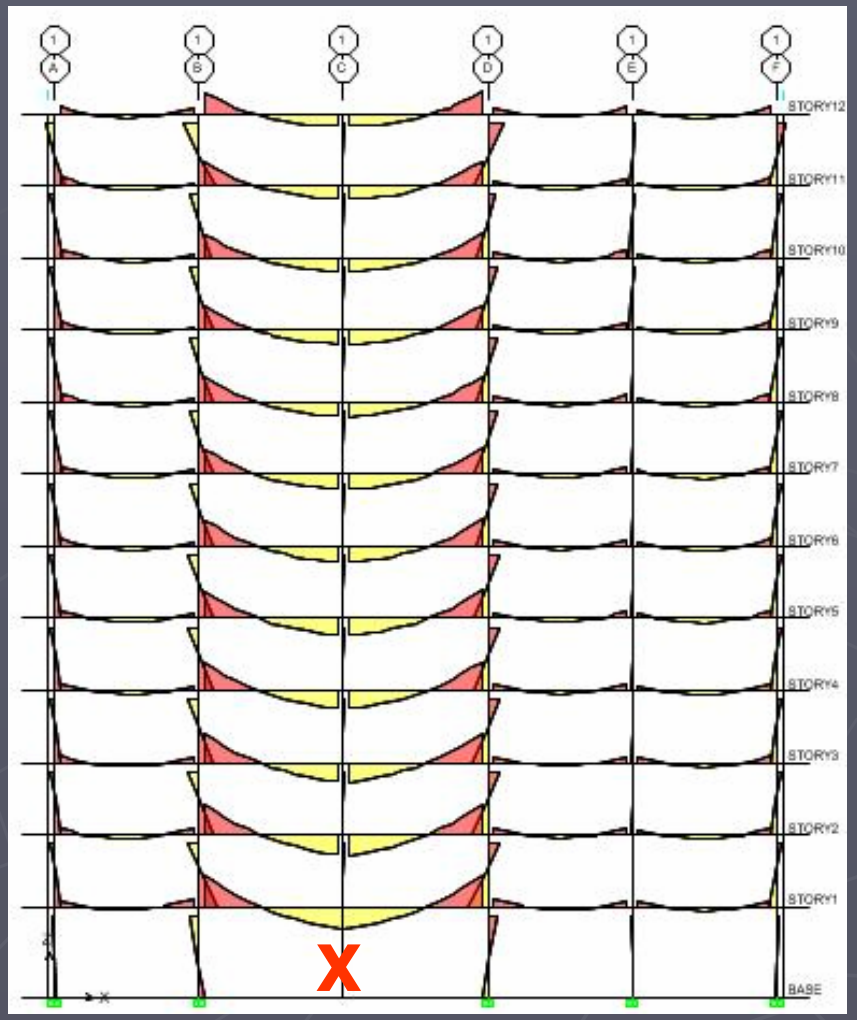
Progressive Collapse Alternate Load Path

- Gravity Load = 2(DL+0.25LL)
- Determine forces and moments (ETABS)

# Bending Moments



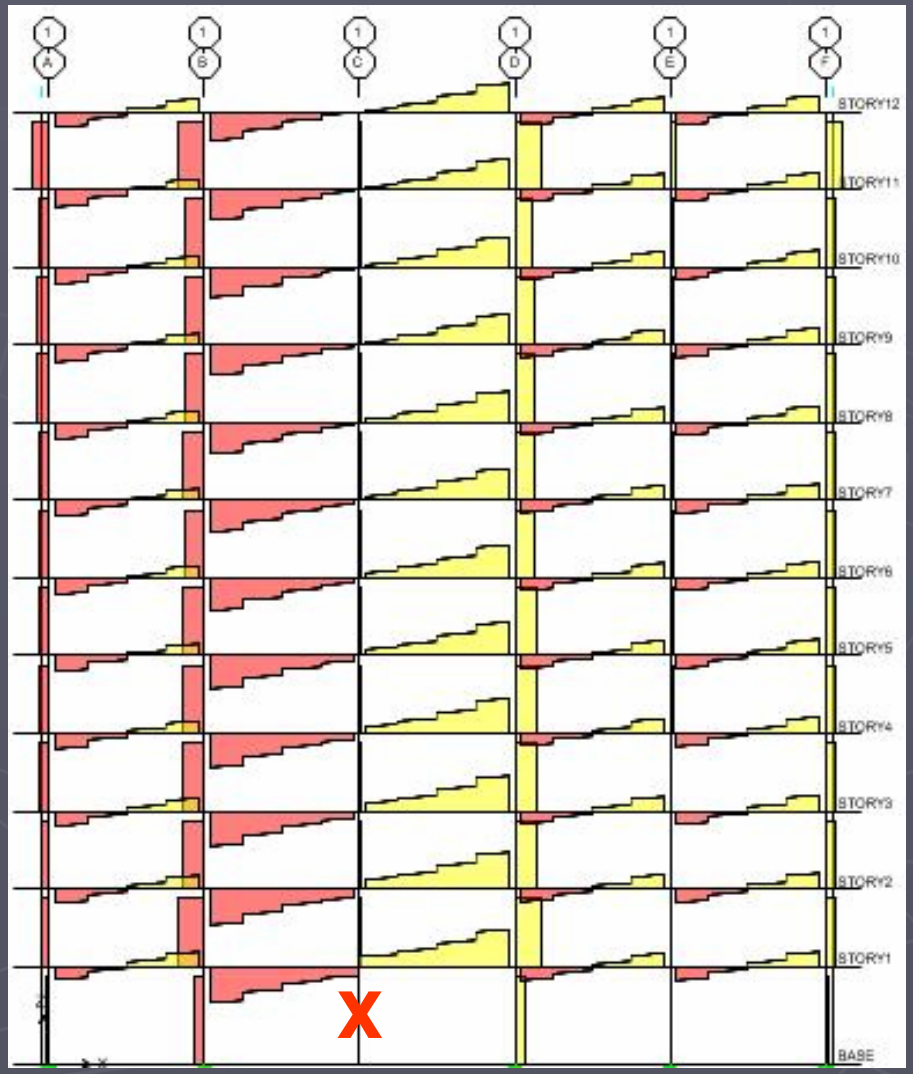

**After Removing Corner Column**




**After Removing Long Side Center Column**

# Shear Forces

**After Removing Long Side Center Column**



# Calculate Demand Capacity Ratios

**$DCR = Q_{UD}/Q_{CE}$**

**$Q_{UD}$**: Acting force from alternate load path

**$Q_{CE}$**: Ultimate unfactored component capacity with strength increased 25%

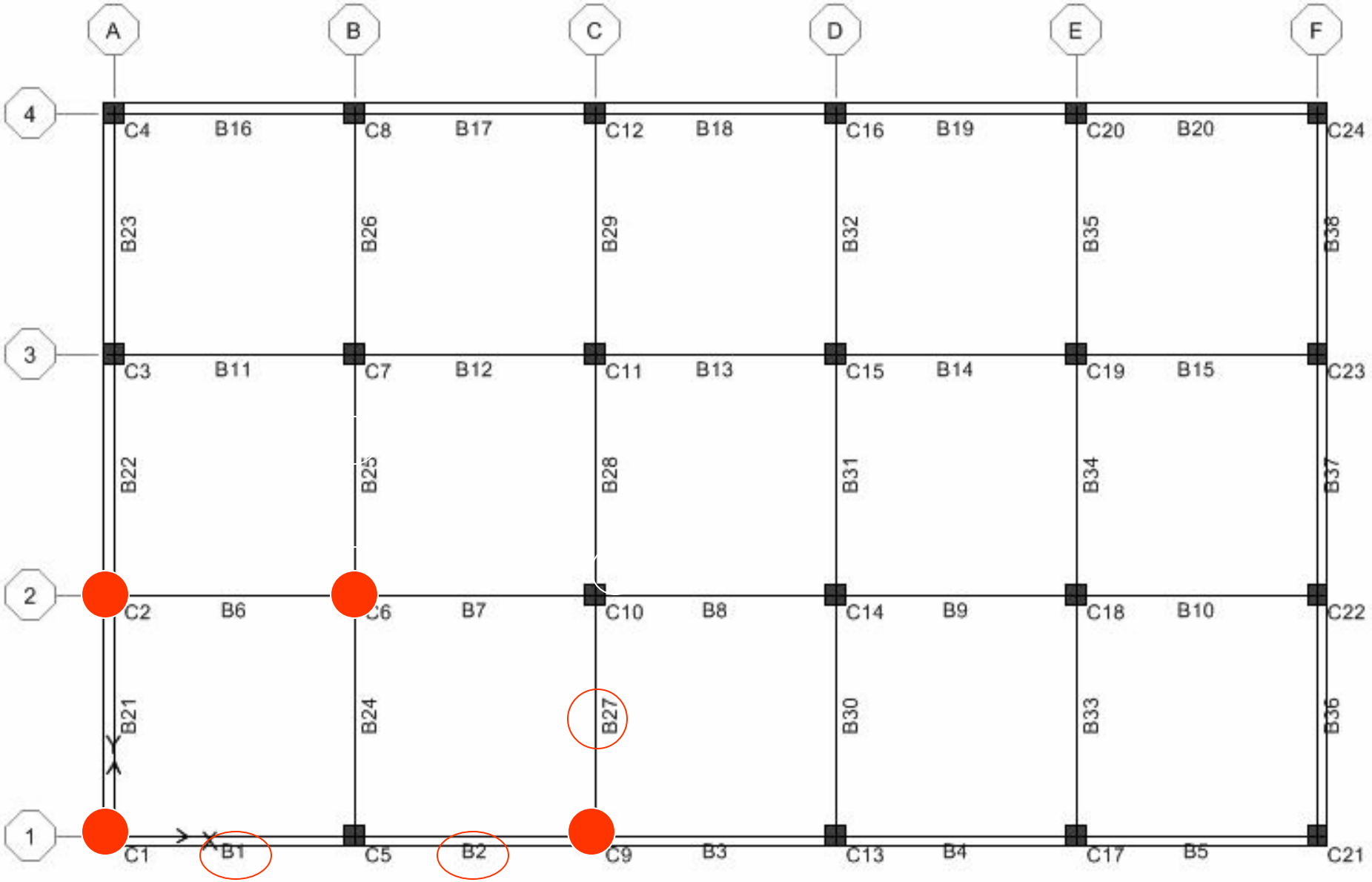
Limits:

DCR < 2.0 for typical structures

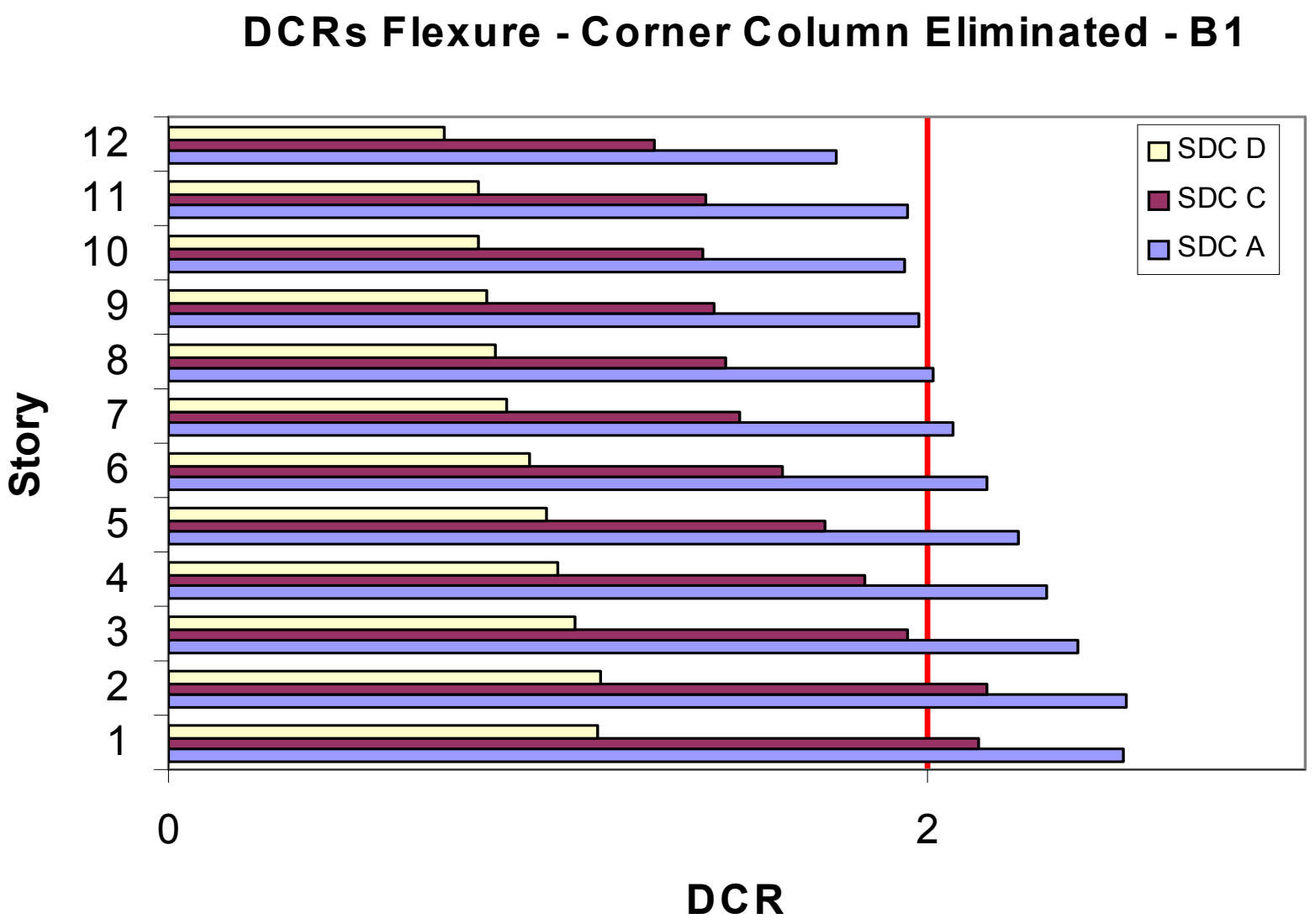
DCR < 1.5 for atypical structures

NEHRP Guidelines for Seismic Rehabilitation of Buildings- FEMA 1997

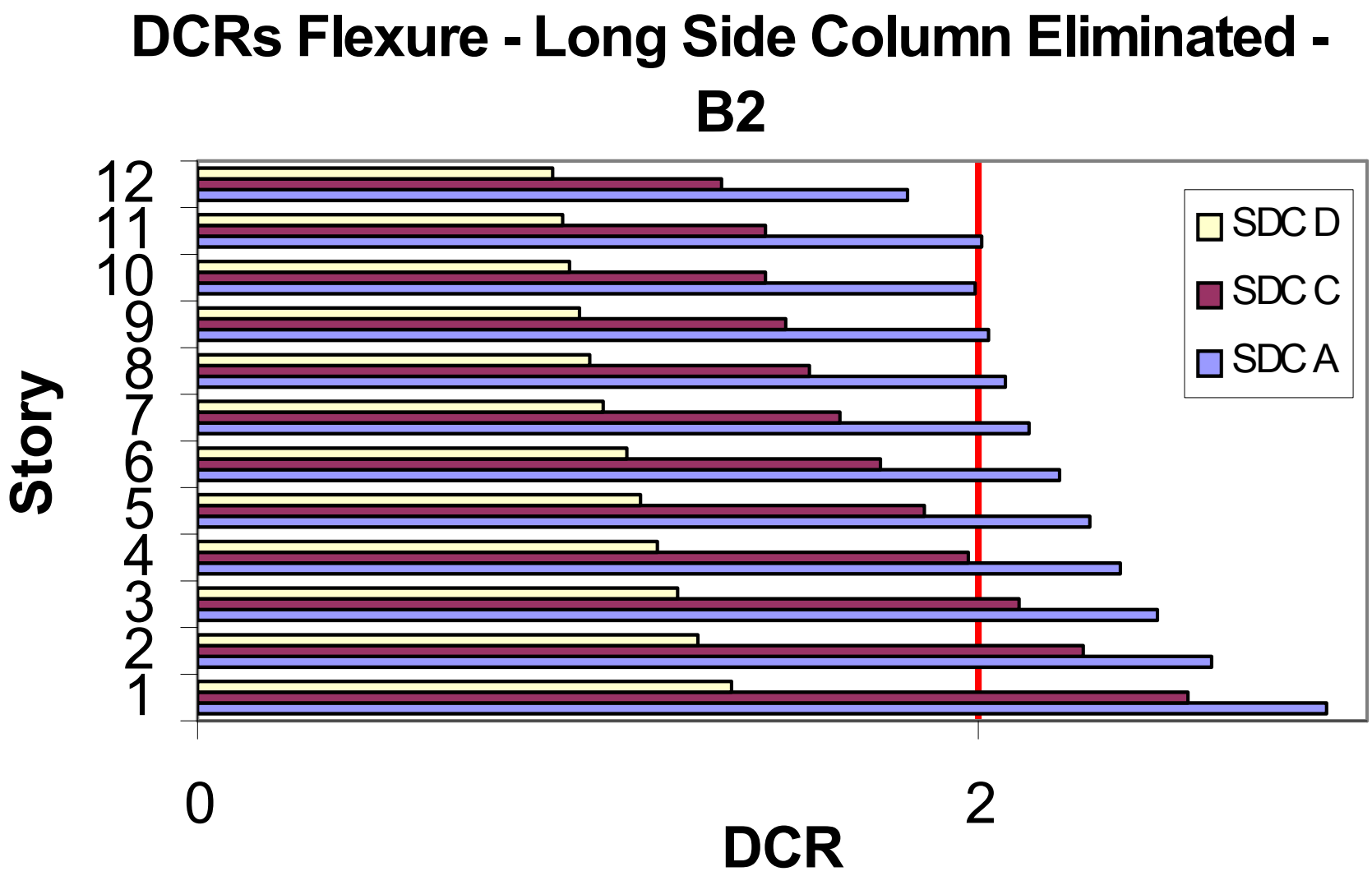
# Remove 1st Story Columns



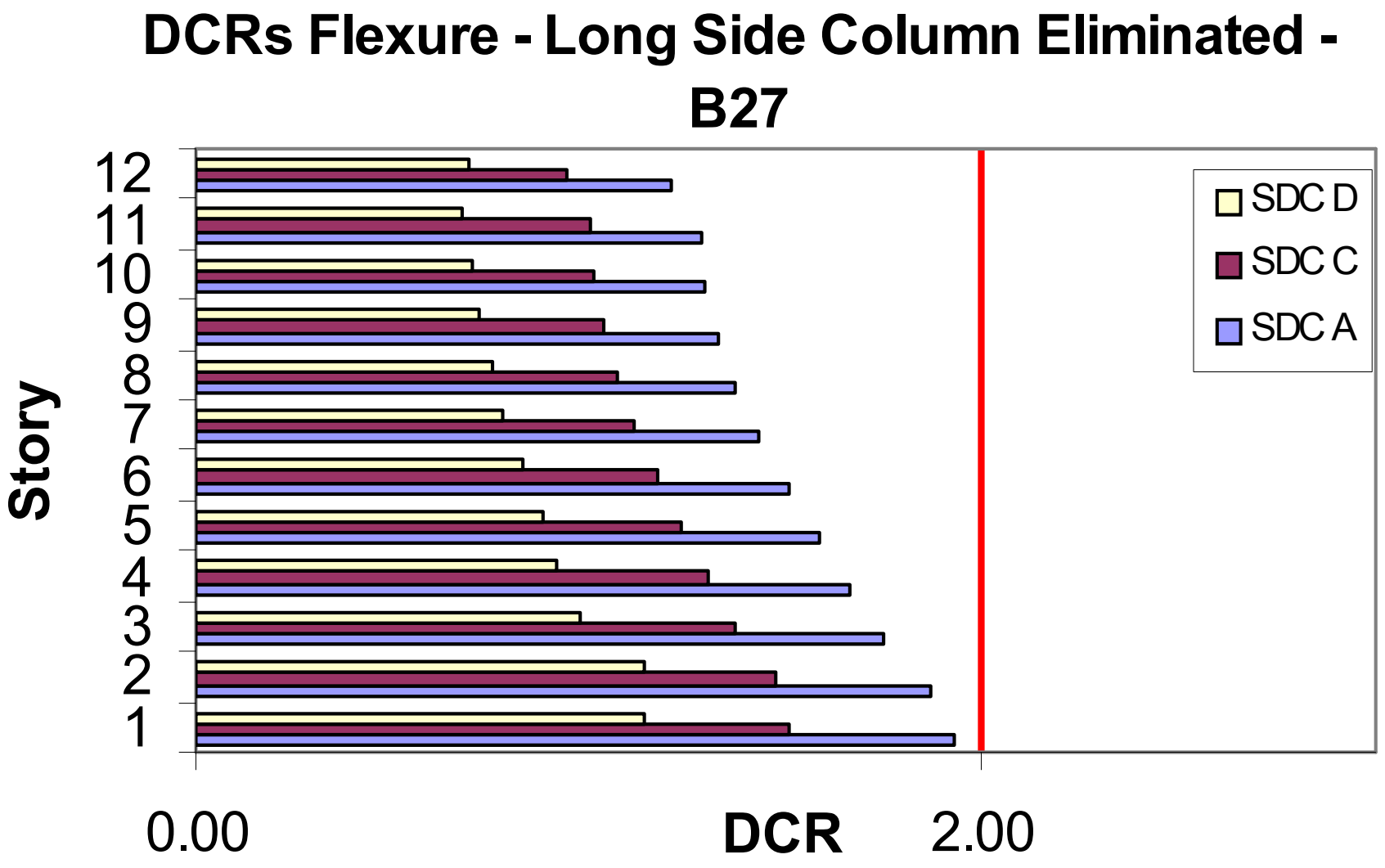
# Study Results



# Results


DCRs Flexure - Long Side Column Eliminated - B2
Story
12
11
10
9
8
7
6
5
4
3
2
1
0
2
DCR
SDC D
SDC C
SDC A

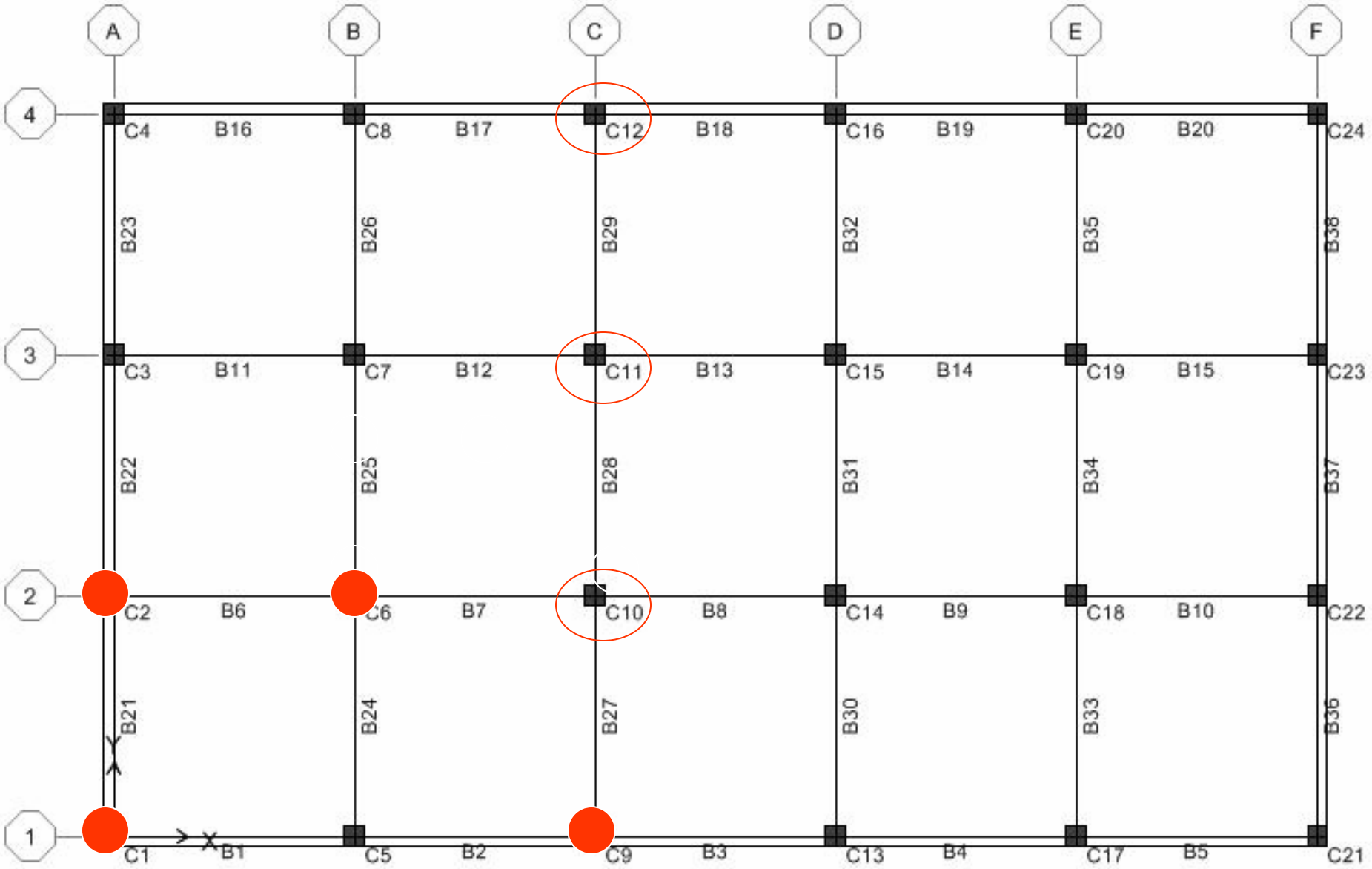
# Results


DCRs Flexure - Long Side Column Eliminated - B27
Story
12
11
10
9
8
7
6
5
4
3
2
1
SDC D
SDC C
SDC A
0.00
DCR
2.00

# DCR for Shear in Beams

| Story | B2 | B27 |
|---|---|---|
| 11 | 1.17 | .79 |
| 9 | 1.19 | .81 |
| 7 | 1.23 | .86 |
| 5 | 1.32 | .94 |
| 3 | 1.39 | 1.01 |
| 1 | 1.46 | 1.04 |

# Remove 1st Story Columns



# DCR for 1st Story Columns

| Column | Seismic Class A | Seismic Class C | Seismic Class D |
|---|---|---|---|
| C9 | X | X | X |
| C10 | 1.23 | .88 | .73 |
| C11 | 1.02 | .76 | .59 |
| C12 | .84 | .65 | .44 |

# Summary of Results

| Item | Number | DCR Value | Action |
|---|---|---|---|
| Shear | All | < 2.0 | None |
| Columns | All | < 2.0 | None |
| Beams, Class D | All | < 2.0 | None |
| Beams, Class C | 55 of 456 | > 2.0 | Add Rebar |
| Beams, Class A | 235 of 456 | > 2.0 | Add Rebar |

Additional rebar for "A" Structures

Cost = $12,000

# Conclusion

Applying the GSA criteria to prevent progressive collapse for concrete buildings can be accomplished by the structural engineer using readily available software and for little additional construction cost.

# Contact Information

David N. Bilow, P.E., S.E.
Portland Cement Association
dbilow@cement.org
847-972-9064
847-972-9065 Fax
5420 Old Orchard Road
Skokie, IL 60077