NORTHRIDGE 20 SYMPOSIUM

ATC 78-2*

Seismic Evaluation for Collapse Potential of Older Concrete Frame Buildings

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Project Management Committee: Jack Moehle, Abbie Liel, Mike Mehrain, Peter Somers

* Supported by FEMA Seismic and Multi-Hazard Technical Guidance Development and Support Contract (HSFEHQ-08-D-0726) Task Order 11, 1111, and 1211.

Intent

- Partly inspired by the Concrete Coalition
- Primary objective was to provide more robust information about the specific characteristics of older nonductile concrete buildings by identifying certain subclasses with inherent seismic deficiencies suspected to be most significant. Previous study (NIST GCR 10-917-6 thru BSSC) found no way to identify "collapse-prone" based on model building type level information.
- Initially, the Collapse Indicator methodology suggested in NIST GCR 10-917-7 appeared promising, but eventually proved too complex to cover all buildings.
- Objective now narrowed to development of rapid or efficient evaluation method to identify collapse prone concrete buildings.

History

- Year 1: Study Collapse Indicator Method suggested in NIST GCR 10-917-7 for application to simplified evaluation method
  - Use of FEMA P 695 methodology (Incremental Dynamic Analysis) to test affect of various seismic deficiencies
  - Interim Report

Concept of Collapse Indicators

from

NIST GCR 10-917-7

Program Plan

NIST GCR 10-917-7

Program Plan for the Development of Collapse Assessment and Mitigation Strategies for Existing Reinforced Concrete Buildings

NEHRP Consultants Joint Venture

A partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering

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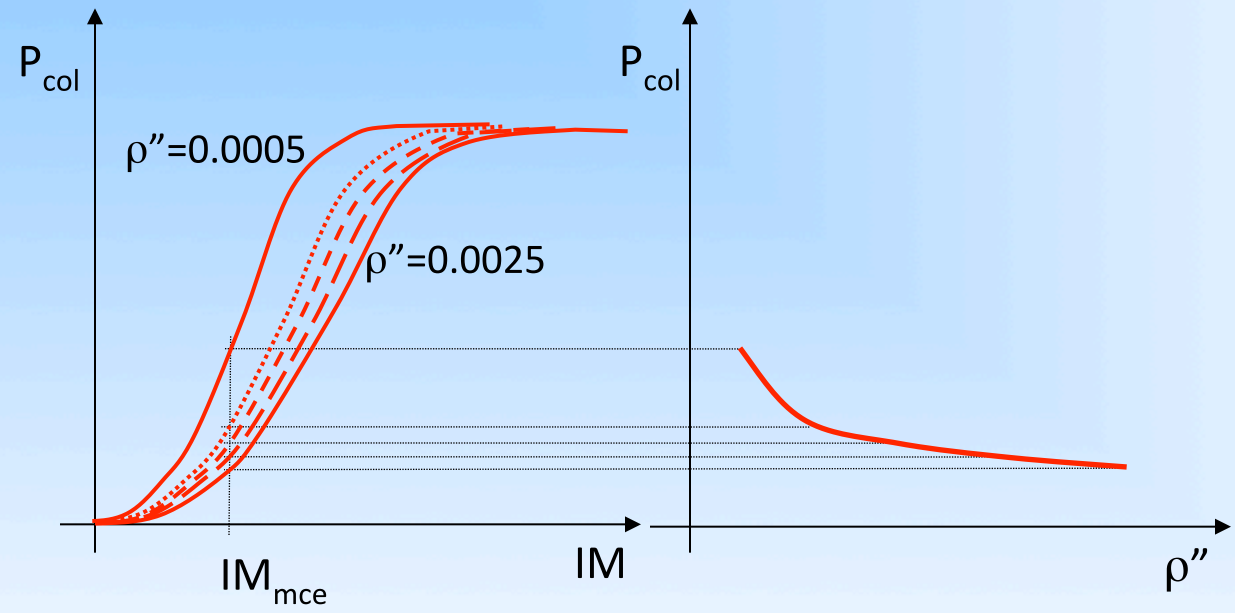
NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Evaluation of Collapse Indicators

- Methodology
  - ✓ Determine collapse fragility for a prototype building using Incremental Dynamic Analysis (FEMA P695)
  - ✓ Develop collapse fragilities for range of selected collapse indicator
  - ✓ For a given Intensity Measure,determine relationship between Probability of Collapse and value of Collapse Indicator



Potential generic presentation of collapse risk—Risk Matrix

R		3	4	5	6	7	10
$\Sigma M_c/\Sigma M_b$	0.7	0.32	0.59	0.77	0.88	0.94	0.99
	0.8	0.32	0.59	0.78	0.89	0.94	0.99
	0.9	0.30	0.56	0.75	0.87	0.93	0.99
	1.1	0.24	0.48	0.67	0.80	0.89	0.98
	1.2	0.15	0.35	0.54	0.70	0.81	0.95
	1.3	0.08	0.24	0.43	0.59	0.73	0.92
	1.5	0.04	0.13	0.28	0.44	0.59	0.86

A structure shaken with a spectral intensity 3x its "strength" and a col/beam M strength ratio of 0.9 will have a 30% chance of collapse.

Or, if you don't like this precision, the risk is 0.3 relative to all the other numbers in the table.

History

- Year 1: Study Collapse Indicator Method suggested in NIST GCR 10-917-7 for application to simplified evaluation method
  - Use of FEMA P 695 methodology (Incremental Dynamic Analysis) to test affect of various seismic deficiencies
  - Interim Report
- Year 2: Completion of CI study as pilot study for NIST Program Plan
  - ATC-78-1 Report, *Evaluation of the Methodology to Select and Prioritize Collapse Indicators in Older Concrete Buildings*.

ATC **78-1**

Evaluation of the methodology to select and prioritize collapse indicators in older concrete buildings

ATC Applied Technology Council

Funded by
Federal Emergency Management Agency

History

- Year 1: Study Collapse Indicator Method suggested in NIST GCR 10-917-7 for application to simplified evaluation method
  - Interim Report
- Year 2: Completion of CI study as pilot study for NIST Program Plan
  - ATC-78-1 Report, *Evaluation of the Methodology to Select and Prioritize Collapse Indicators in Older Concrete Buildings*.
- Year 3: Continuation of development of simplified method to identify high collapse risk buildings
  - March, 2013: Converted from use of CI to drift as primary EDP
    - Develop method for estimating critical drifts
    - Develop drift limits for predicting collapse
  - Develop methodology for frame structures

Features of Evaluation Procedure

- Collapse is taken as global loss of gravity support at a story. Significant deficiencies considered:
  - Weak stories
  - Torsion
  - Axial load, drift demand and shear capacity of columns
- Probabilistic characterization
  - Demand—as story drift at each column
  - Capacity—column collapse as predicted by test database
  - Combination enables probability of column collapse—at least relatively
- Story collapse taken as combined probability of 25% columns failing in one story

Features of Evaluation Procedure

- Engineering resources estimated to be equal or less than ASCE/SEI 31 evaluation ($10-15k)
- Methodology is essentially plug and chug.
- The worst story rating (probability) taken as the building score (probability)
- Use of results:
  - Buildings in a given inventory can be ranked
  - Or an absolute cut-off score set for "acceptable risk" or "temporarily acceptable risk."
- Currently limited to frame buildings

Summary of evaluation method (1)

- Obtain as-built data
  - Configuration and reinforcing required
  - Consistent with concept, general requirements are on the minimal side of ASCE 41 (or FEMA 273)
- Each direction considered independently
- Estimate the plastic story shear demand capacity ratio at each story using an inverted triangular demand
  - Identifies potential critical stories
  - Enables estimation of Vy for calculation of fundamental period

Period calculation

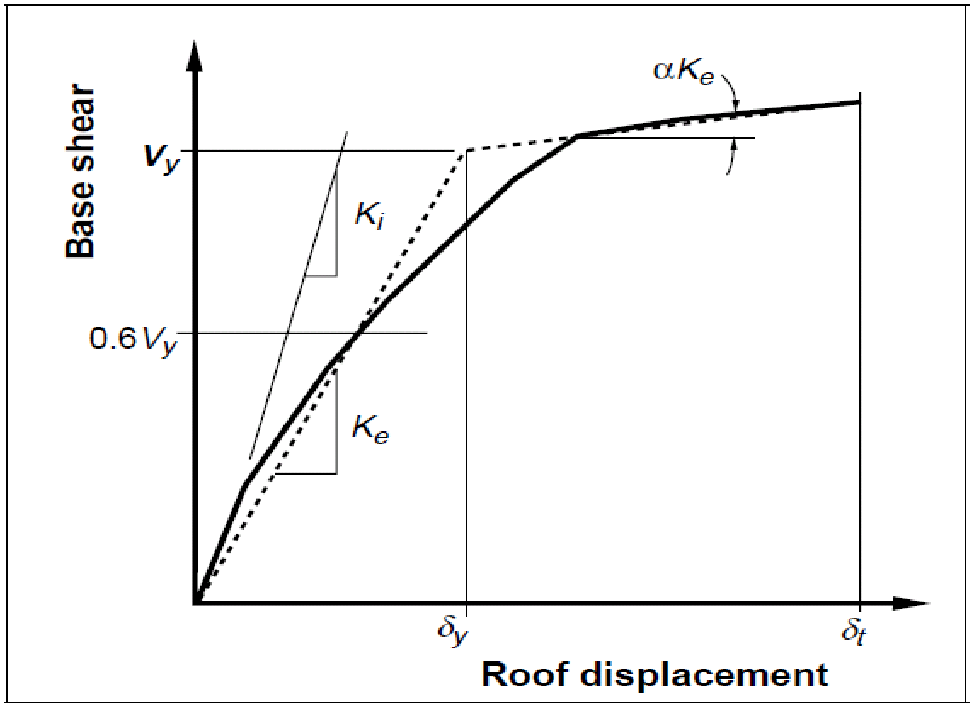


Figure 3-1 Calculation of Effective Stiffness, K_e

V_y from plastic story shear capacities

δ_y from assumed structural yield drift

Summary of evaluation method (2)

- Using the coefficient method of ASCE/SEI 41-13, calculate the spectral displacement
- Using rules developed in this project, calculate the story drift demand--and dispersion--at critical stories
- Using torsional amplification rules developed in this project, calculate drift demand at each column

Summary of evaluation method (3)

- Based on column test data (also used for acceptance criteria in ASCE 41), use loading and physical characteristics of column to calculate drift capacity (for collapse) and dispersion.
- Combine probabilities of drift demand and drift capacity to calculate probability of column failure (loss of gravity load carrying ability).
  - Currently, column "rating" is a single digit number representing a rounded probability of failure. i.e. 0.3 indicates 30% probability of loss of vertical capacity for the demand ground motion.

Summary of evaluation method (4)

- Based on the probabilities of failure of all columns, calculate the probability of failure of story.
  - Use correlation rules to consider failure of adjacent columns
  - Currently using 25% column failures to set story collapse.
- Highest probability of failure (rating) of a story is building score/rating
  - All “ratings” are a single digit number representing a rounded probability of failure (or collapse)

Potential Uses *(when completed)*

1. All older (pre 1980—pre 1976 UBC) concrete buildings considered ***High Seismic Risk Buildings***, unless shown to be acceptable by conventional methods (ASCE/SEI 41-13)
   A. Use evaluation method to rank buildings in inventory according to score/rating (f(probability of collapse))
      a) Select a proportion of highest probability (15%-25%?) to designate as ***Exceptionally High Seismic Risk Buildings***, to be mandated for mitigation.
   B. Alternately, select cut-off score/rating to designate Exceptionally High Risk (50% probability of collapse? Higher?)
      a) Project has not yet recommended such a number
2. Use method to rank all buildings to schedule mitigation (unless they can be shown to meet life safety guidelines).

Future Completion Tasks

- Expand to include buildings with walls
- Test and calibrate method
- Prepare example evaluations
- Estimate engineering level of effort for use of method for various buildings

Questions

Estimate of Fundamental Period

Estimate V_y and δ_y to get Ke

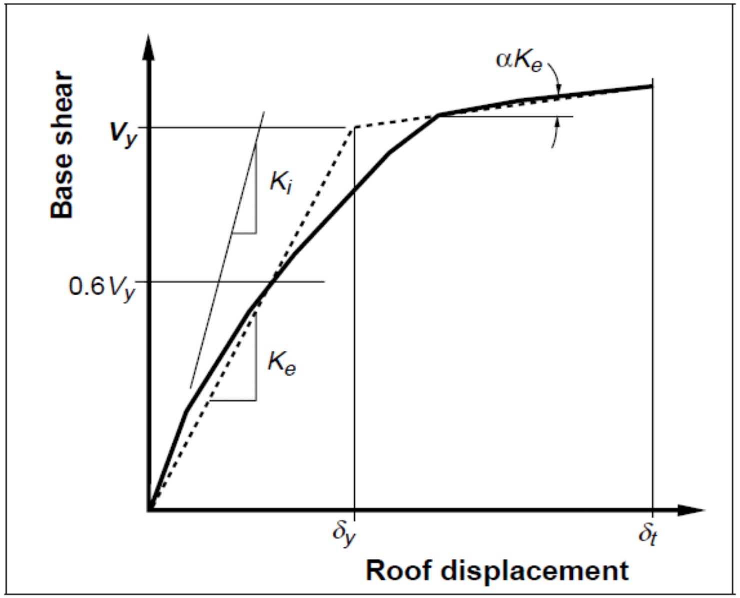
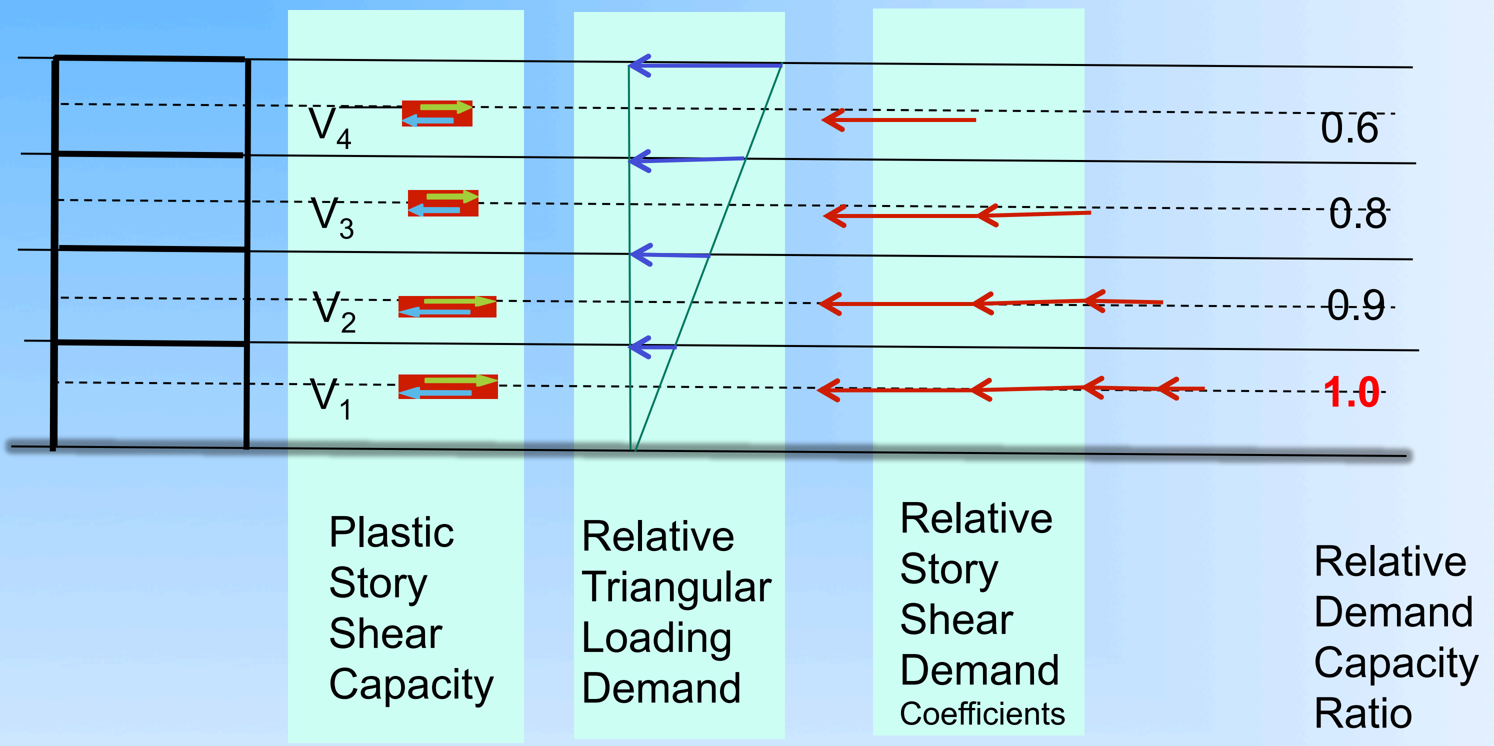


Figure 3-1 Calculation of Effective Stiffness, K_e

K_i would be unconservative for our method

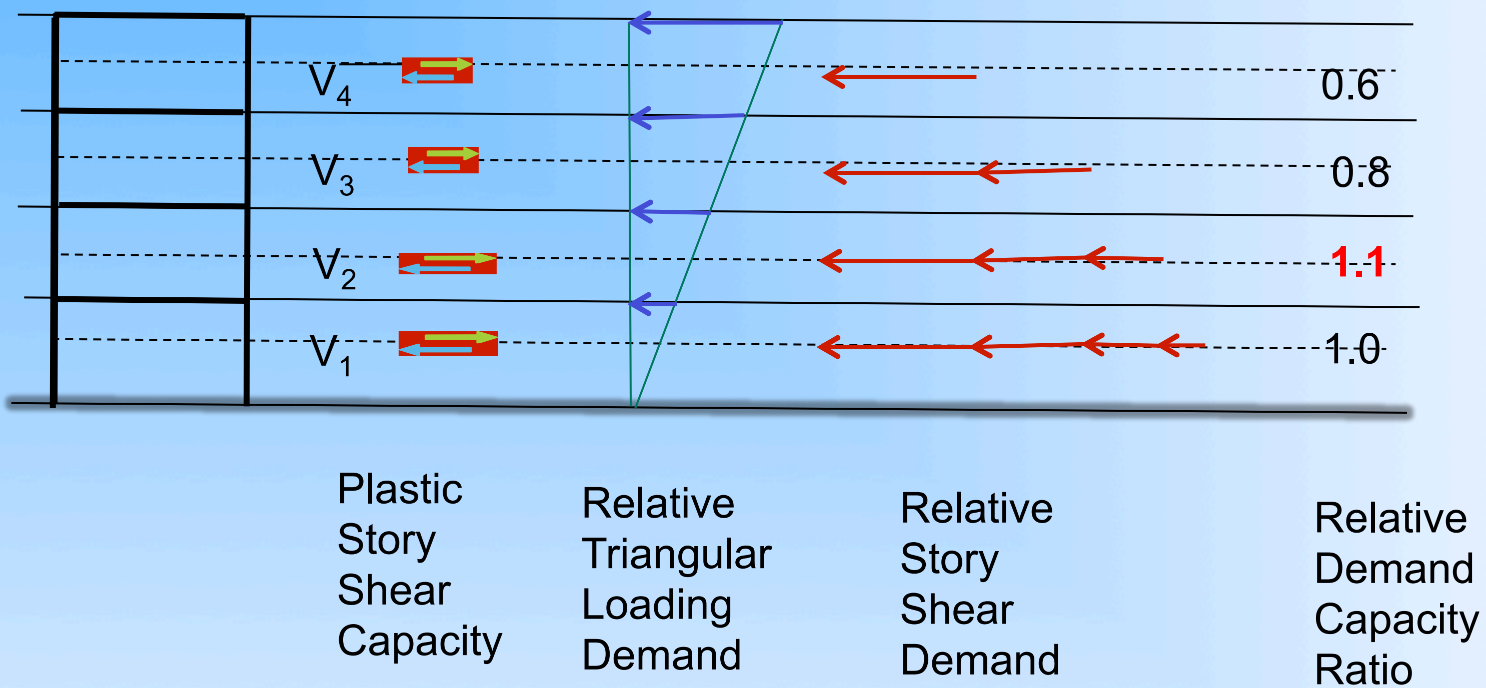
Mehrain Method



V_y controlled by weakest story relative to story demand

$V_y = V_1$ (most common)

Mehrain Method

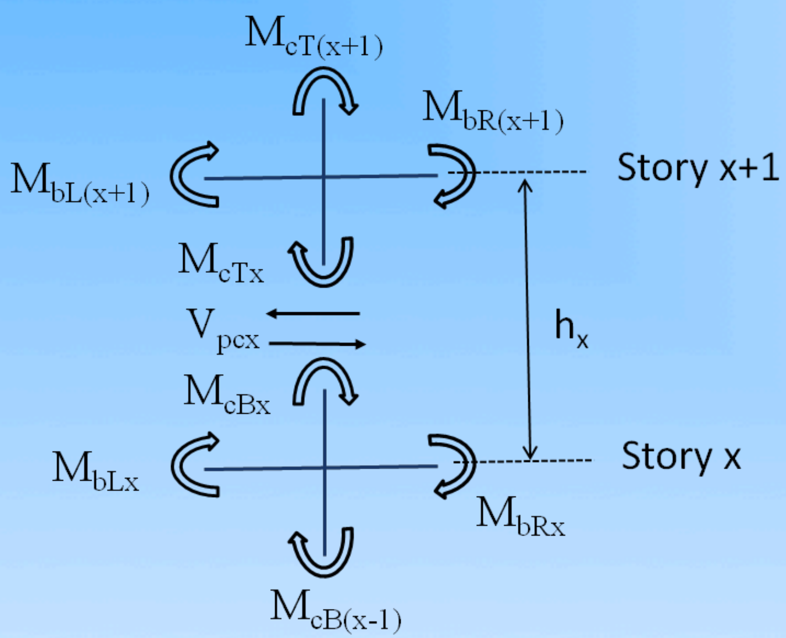


V_y controlled by weakest story relative to story demand

$V_y = V_1 \times 1/1.1$

Code type language for Story Shears

Section 2.5



Individual Column, Vpcx is the lesser of

- Column Shear Strength
- Plastic Moment Capacity governed by Column Moments
- or Plastic Moment Capacity governed by Beam Moments

Note: Formula for Plastic Moment Capacity governed by beam is incorrect in draft: Should be: $(M_{bLx} + M_{bRx})h_x/(h_x + h_{(x-1)})$

Code type language for Story DCRs

Section 2.5

$$DCR_{rx} = \frac{V_{rvx}}{V_{px}}$$

where:

V_{px} is the sum of individual column plastic shear capacities, V_{pcx} at story x.

V_{pcx} shall be the lesser of V_{nx} or V_{pMx}
(governed by shear capacity or moment capacity)

and V_{rvx} is the relative story shear at the x^{th} story

$$V_{rvx} = \sum_{i=x}^{n} C_{vx}\,(V_{p1})$$

$$C_{vx} = \frac{w_x h_x}{\sum_{i=1}^{n} w_i h_i}$$

Coefficient representing inverted triangle lateral loading

Where H is the height of the building in feet and $C = V_y/W$

Formula for Vy and Te

$$V_y = \frac{DCR_{r1}}{DCR_{rx}(max)} V_{p1}$$

Assuming the yield drift is 0.75% , the effective fundamental period may be taken as:

$$Te = 0.078 \sqrt{\frac{H}{C}}$$

Where H is the height of the building in feet and $C = V_y/W$
Derivation in Section 3.3.4

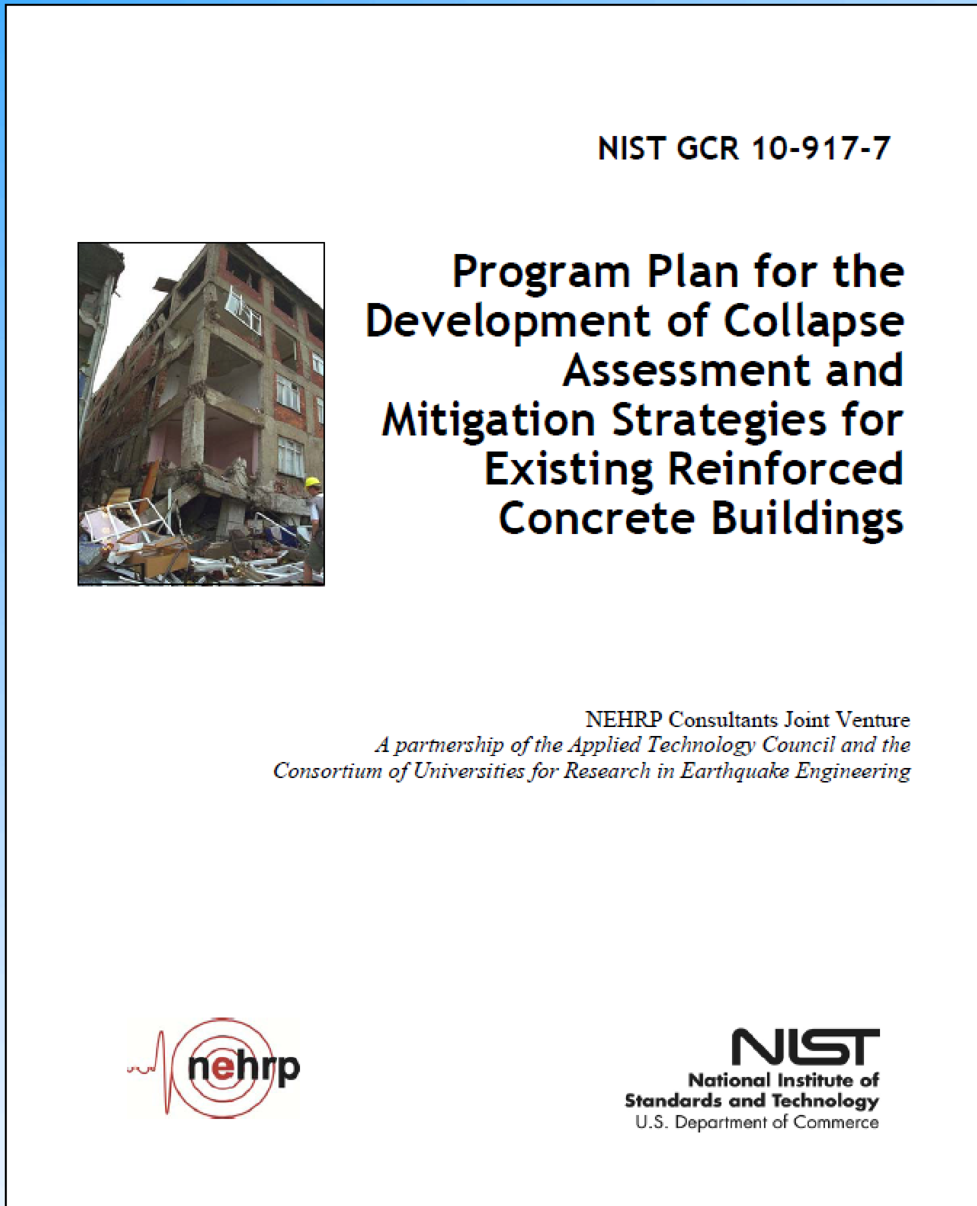
Discussion

Use of Results

Ranking of Buildings

- All older (pre 1980—pre 1976 UBC) concrete buildings considered *High Seismic Risk Buildings,* unless shown to be acceptable by conventional methods (ASCE/SEI 31-41)
- Using proposed evaluation method, rank buildings according to score/rating (f(probability of collapse))
  - Select a proportion of highest probability (15%-25%?) to designate as *Exceptionally High Seismic Risk Buildings*, to be mandated for mitigation.
- Alternately, select cut-off score/rating to designate Exceptionally High Risk (50% probability of collapse? Higher?)
  - PMC has not included such a cut-off

Concept of Collapse Indicators


NIST GCR 10-917-7

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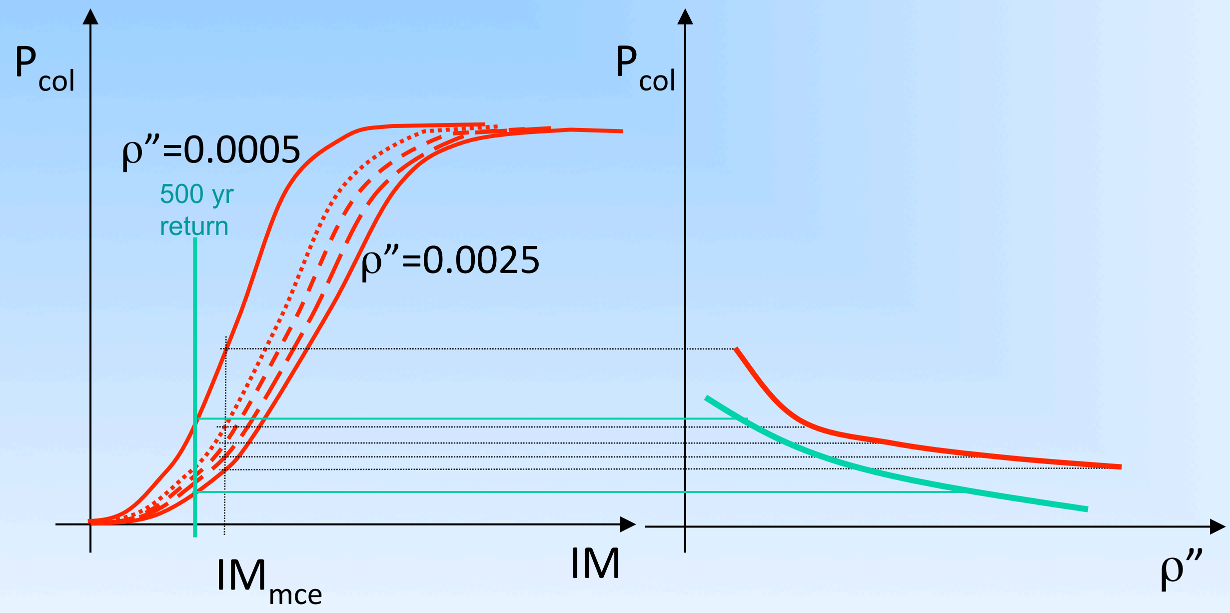
Program Plan

Evaluation of Collapse Indicators

- Methodology
  - ✓ Determine collapse fragility for a prototype building
  - ✓ Develop collapse fragilities for range of selected collapse indicator

▪ What if the evaluator wants to use a different IM?

▪ Different portion of the fragility yields different sensitivity relationship



Evaluation of Collapse Indicators

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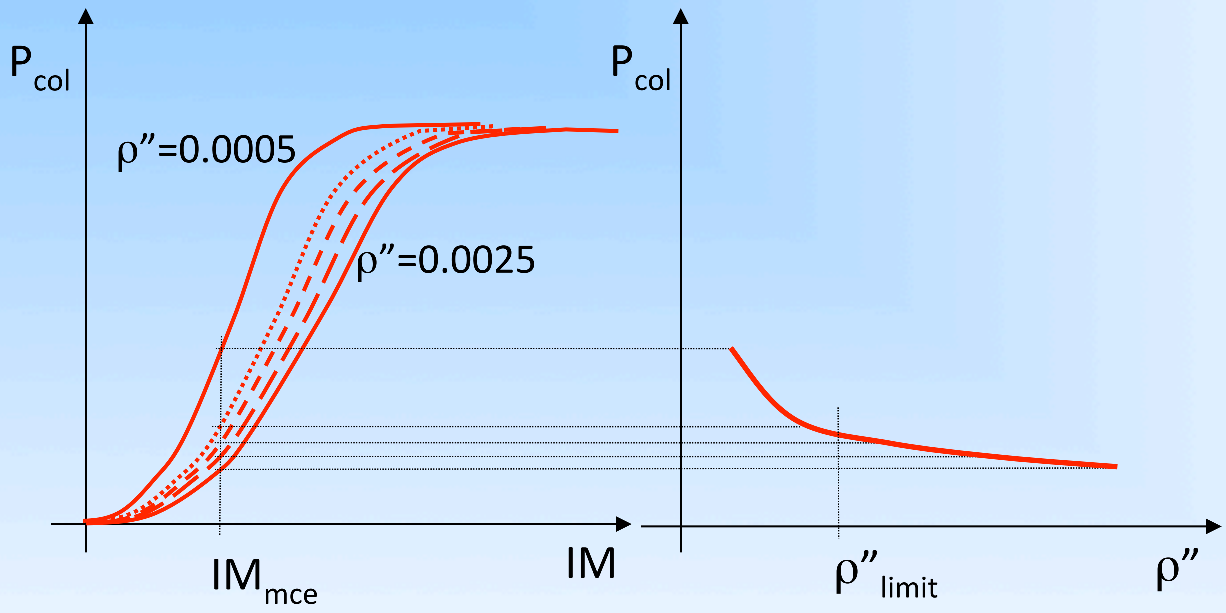
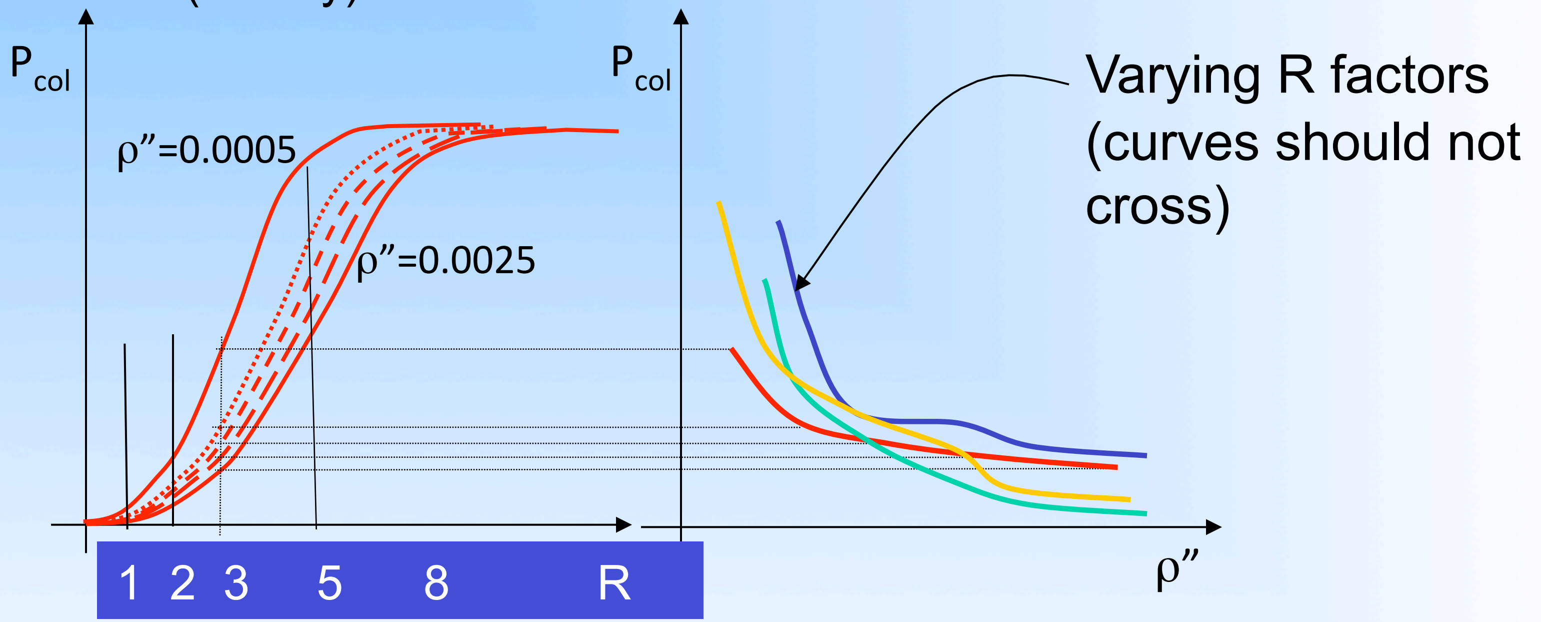
▪Similarly, a prototype with a different strength will yield a different initial fragility which will lead to a different sensitivity relationship



Evaluation of Collapse Indicators

- Methodology
  - ✓ Determine collapse fragility for a prototype building
  - ✓ Develop collapse fragilities for range of selected collapse indicator
    - ▪Propose to normalize IM with a strength measure of the structure (yield strength?)
      Call **"R"** (initially)



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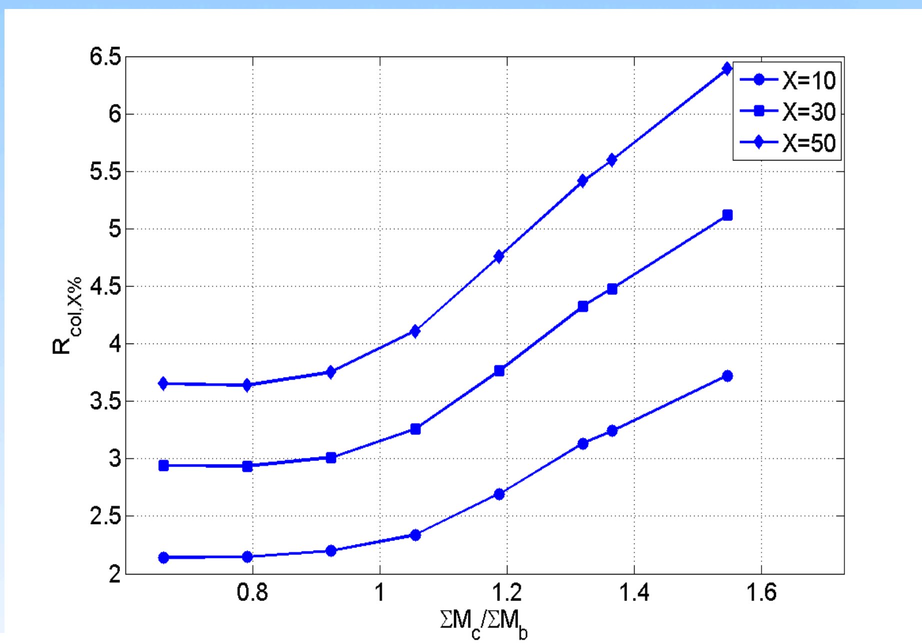
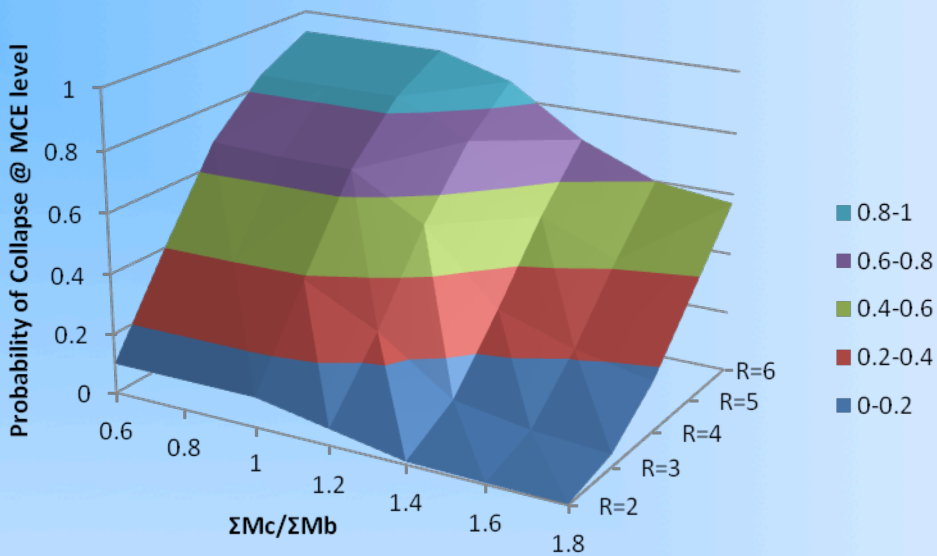


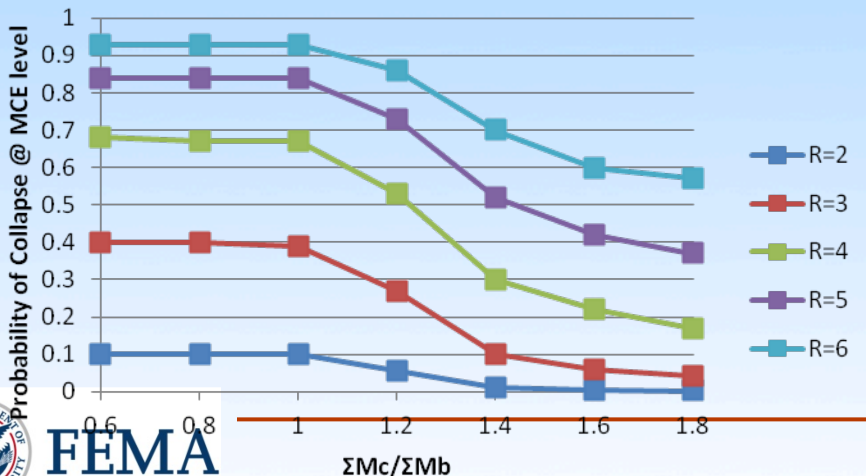
Also suggestion within the team to present in terms of equal risk curves.

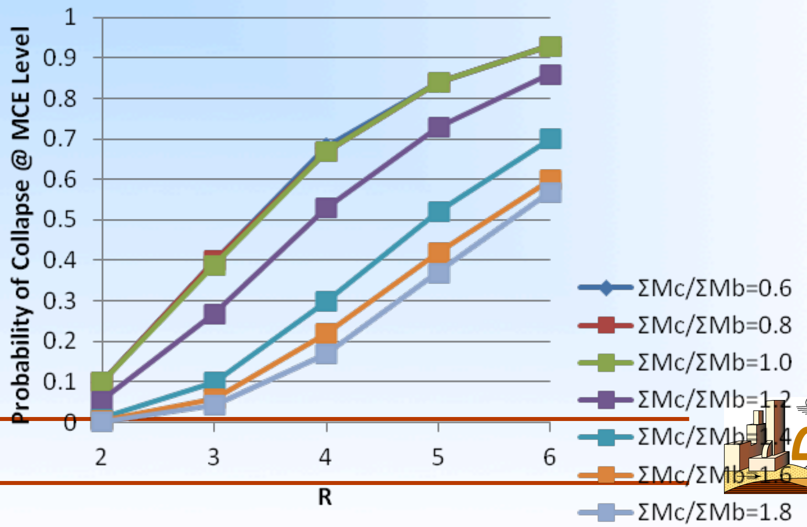
This format would be convenient to find the required strength to obtain a 30% chance of collapse (or a 0.3 relative risk factor) given a value of the CI

Combination of CIs

Vp/Vn=0.6

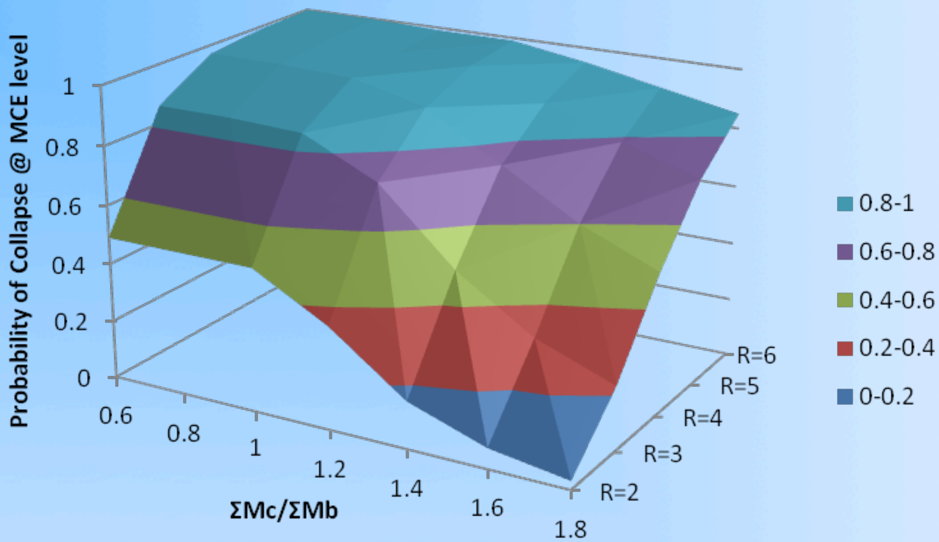


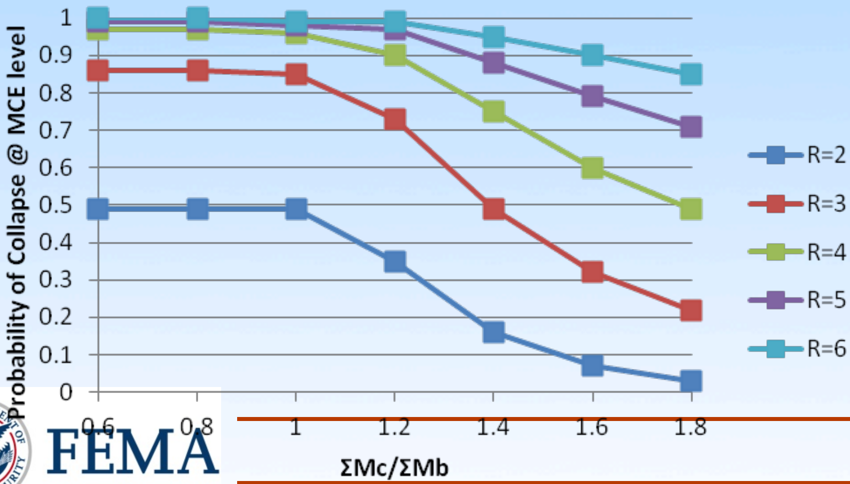


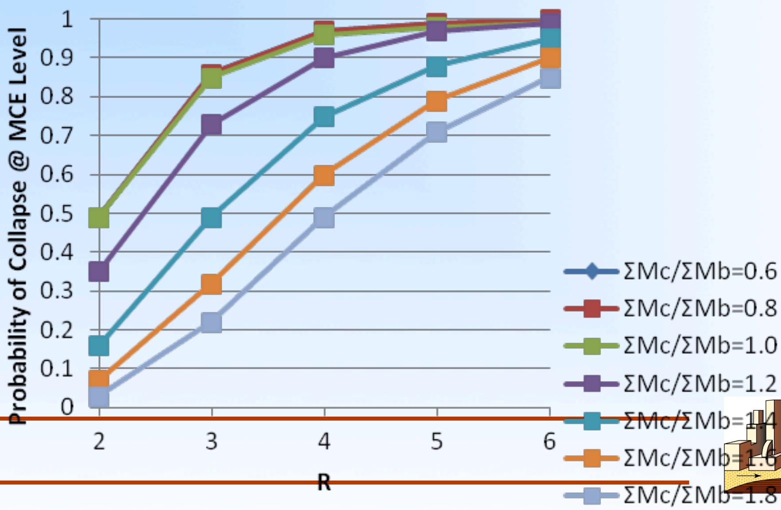


Combination of CIs

Vp/Vn=0.8

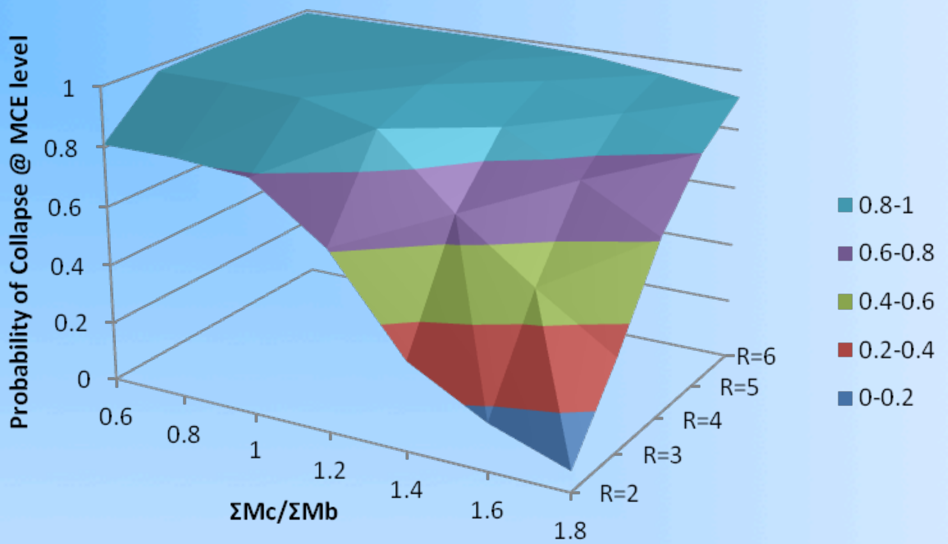


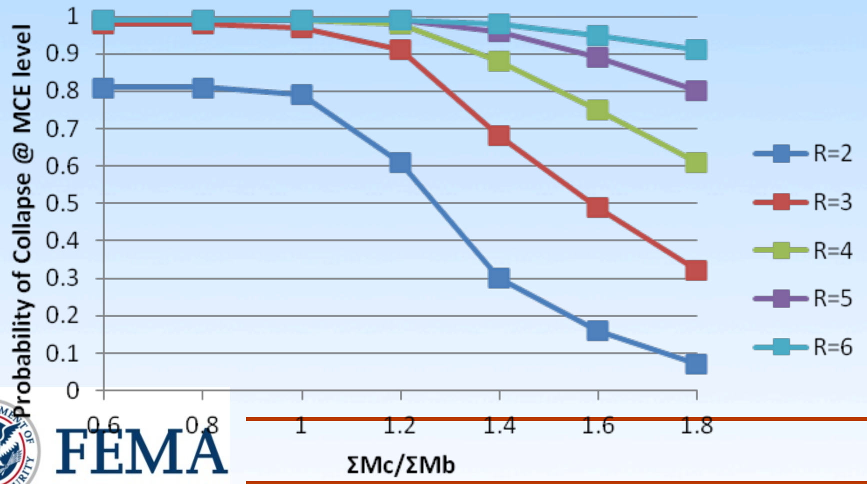


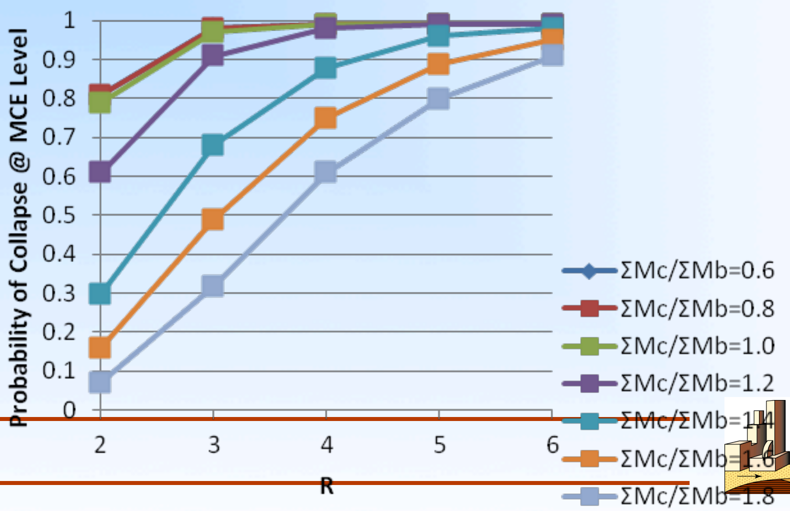


Combination of CIs

Vp/Vn=1.0







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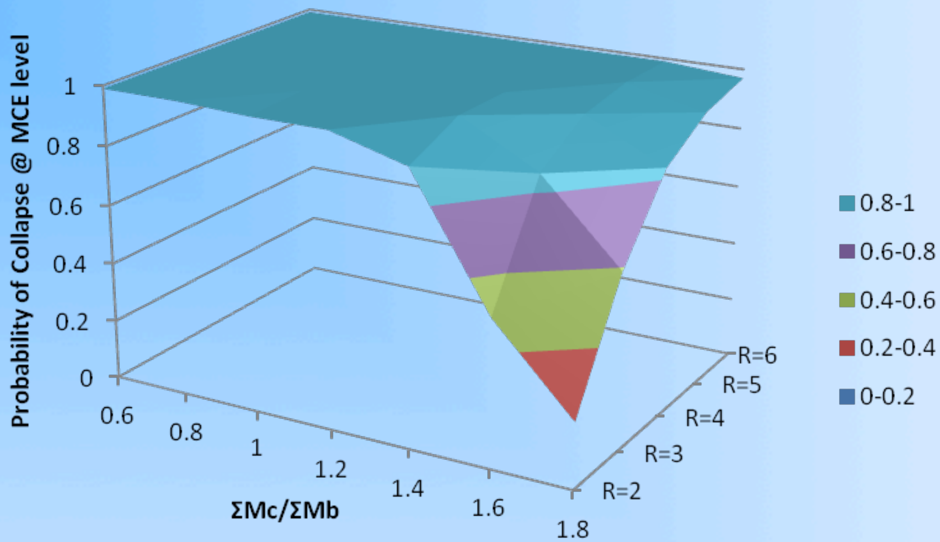
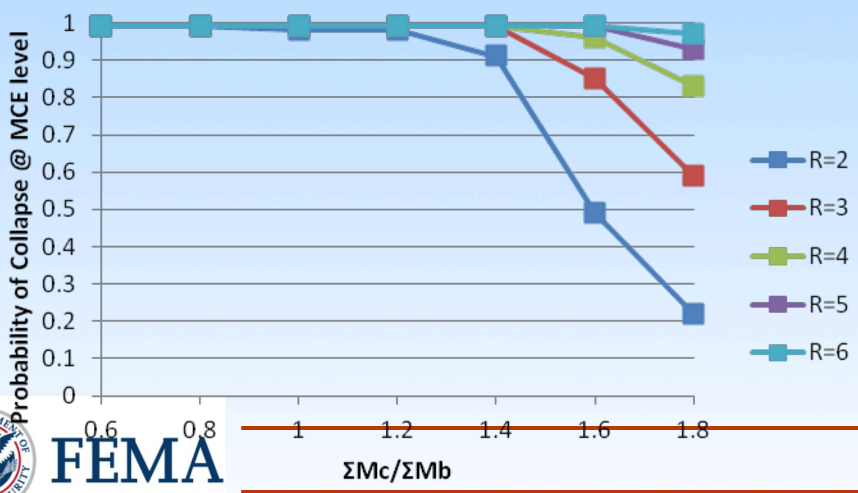
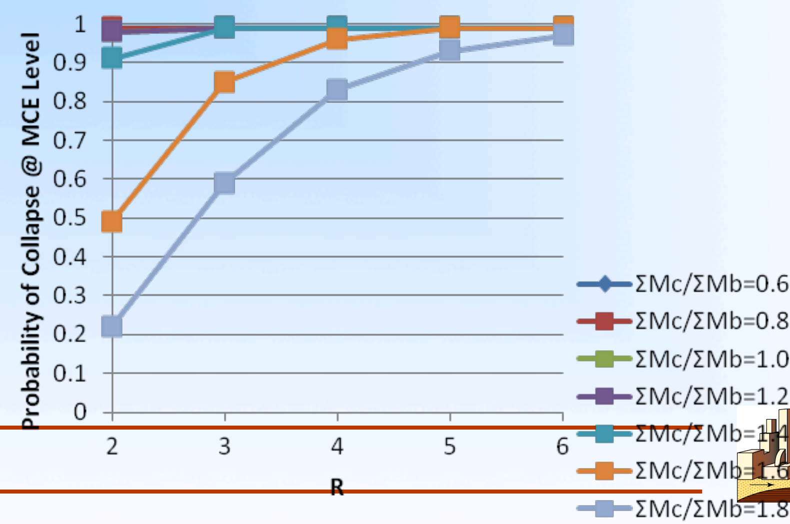
Combination of CIs

Vp/Vn=1.2







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Conclusions for use of CIs

- Calculation intensive
- Interesting relationships can be developed
- However,
  - Difficult to keep base structure "the same" while varying collapse indicator variables
  - There was often no distinct value of the CI that indicated significant worse behavior
  - Collapse indicator often not the same throughout the structure
    - Creates many combinations
  - Combination of CIs creates many combinations
  - The PMC found no clear path to develop an evaluation method based solely on CI relationships.
- In March, 2013, the PMC recommended development of a more generally applicable evaluation method using drift as primary engineering demand parameter rather than continuing with calculation of CI relationships