The ATC-58 Project
Development Of Next-Generation Performance-Based Seismic Design Criteria For Buildings

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Performance-based Design the New Design Paradigm

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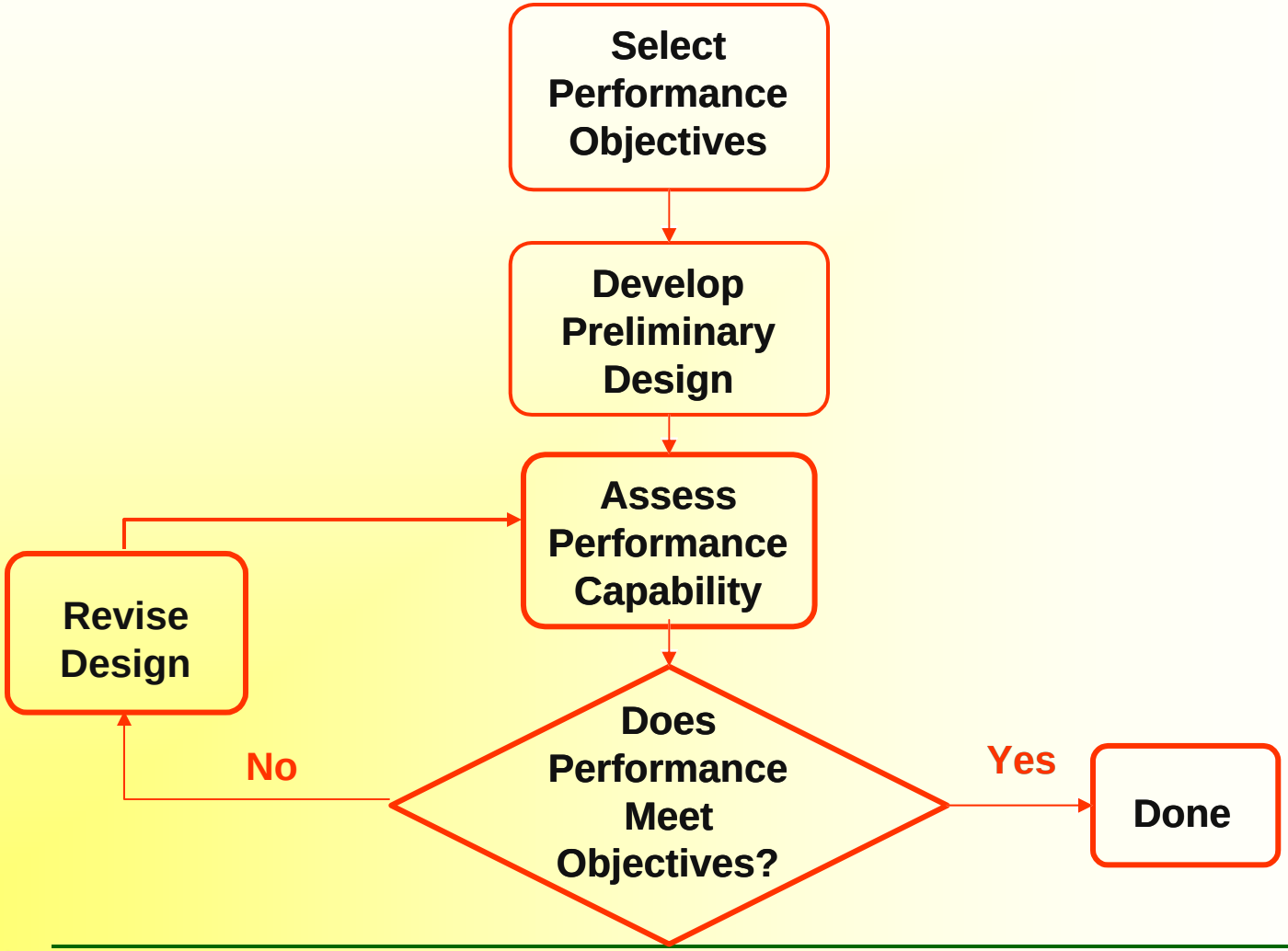
- Performance-based design approaches are routinely being used for:
  - Structural / Seismic Design of New Buildings
  - Seismic evaluation and upgrade of existing buildings

Performance-based Design What is It?

- An alternative to the prescriptive procedures contained in the building code
- Structures designed using performance-based approaches may or may not meet the literal requirements of the building code, but-
- Should be capable of performing as well as or better than code-designed structures

The Performance-based Design Process



Applications of PBD

- Design for better performance
  - “important” facilities
- Design for equivalent performance but at lower cost
  - “sharp” developers
- Design for equivalent performance, but using new systems and methods
  - “alternate means & methods”
- Design with higher confidence of performance
  - Institutional and corporate owner/occupants
- Improve prescriptive code requirements
  - All buildings and stakeholders

Acceptance of Performance-based Design

- Section 104-

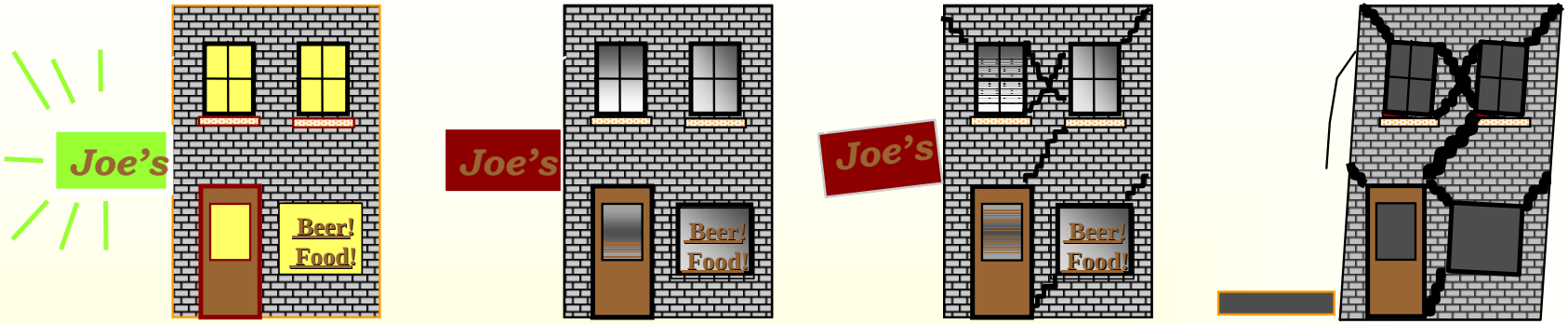
"The provisions of this code are not intended to prevent . . . or to prohibit any design or method of construction. . . provided that any such alternative has been approved.

An alternative. . . design shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code."

The Present Generation

- Based on technology developed in the mid-1990s for existing buildings
- Documented in ASCE-41, ATC-40, FEMA-440 and related publications
- Uses nonlinear analysis to:
  - Predict strength and deformation demands on individual components and elements
  - Compare demands against acceptable values for different performance levels

1st Generation Performance



Operational *Immediate Occupancy* *Life Safety* *Collapse Prevention*

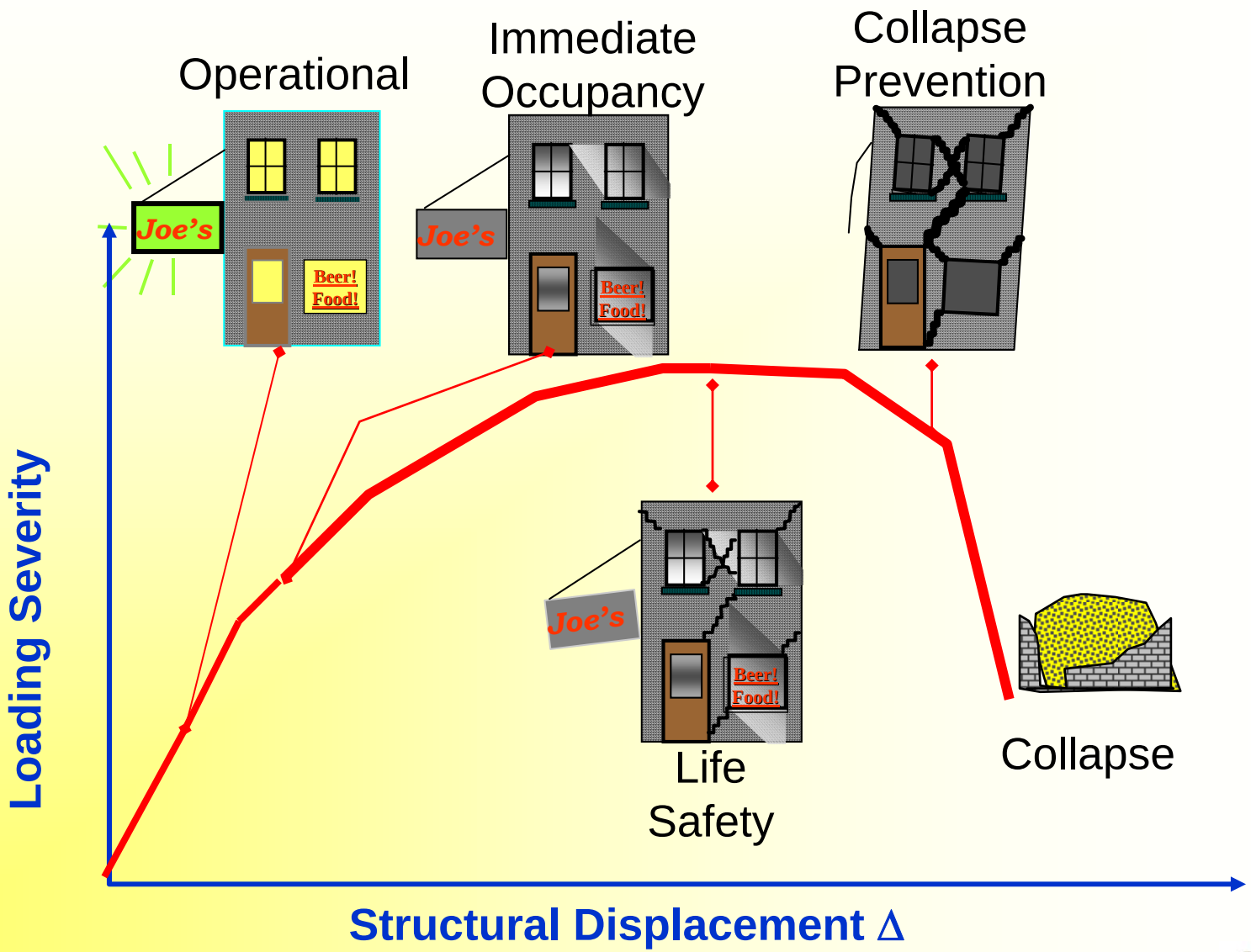
Operational – negligible impact on building

Immediate Occupancy – building is safe to occupy but possibly not useful until cleanup and repair has occurred

Life Safe – building is safe during event but possibly not afterward

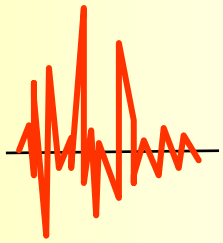
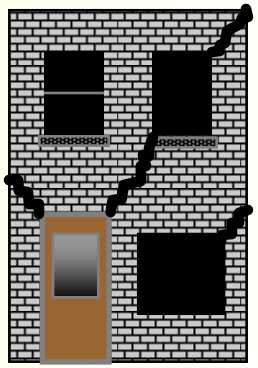
Collapse Prevention – building is on verge of collapse, probable total loss

1st Generation Performance



Selecting Performance 1st Generation

- Specification of :
  - ***Design Hazard (earthquake ground shaking)***
  - ***Acceptable Performance Level (maximum acceptable damage, given that shaking occurs***

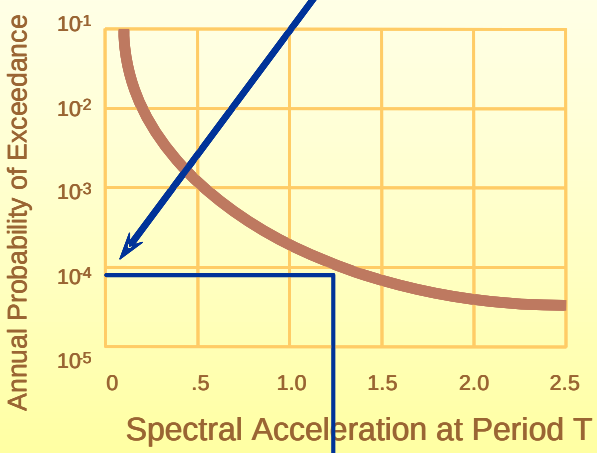
Performance Objective =  + 

Ground Motion x% - 50 years

Performance Level

Verifying Performance

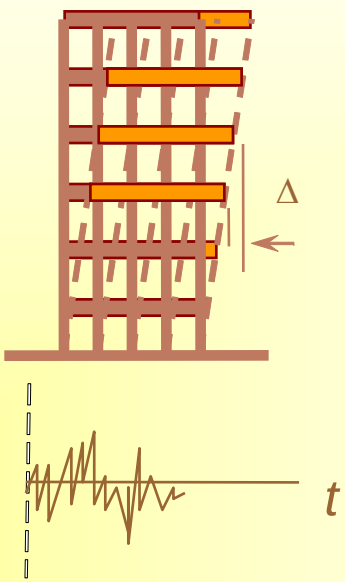
1- Select Hazard Level



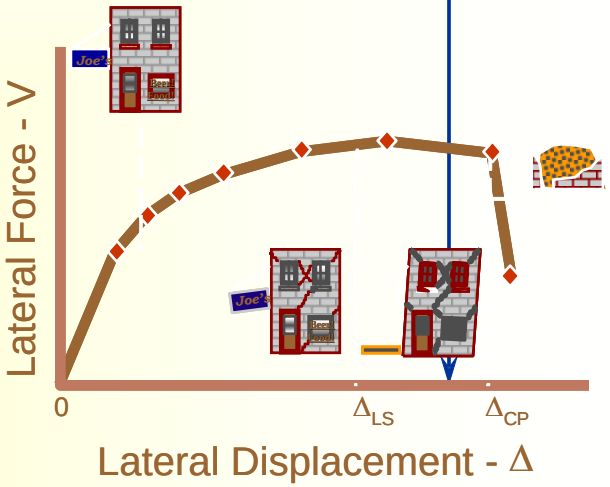
2- Determine ground Motion Sa

3- Run Analysis

4- Determine Drift & Component Demands



5- Determine Performance



6- Pass or Fail Criterion evaluated on component by component or global structural basis

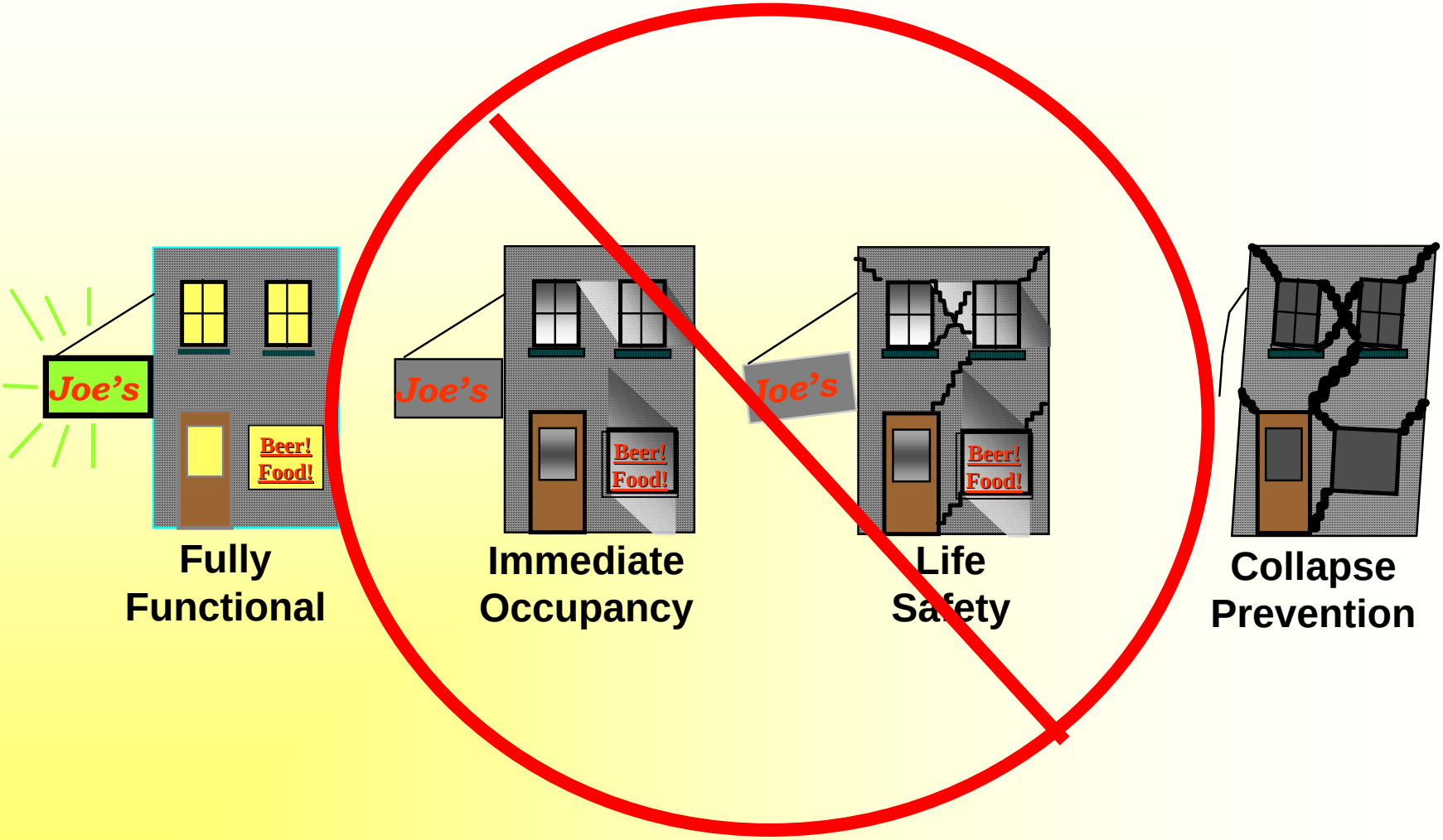
Limitations of Present Generation

- Performance is judged on an element, rather than system basis
- Performance levels, though qualitatively attractive do not directly relate to important decision parameters
- Reliability of performance and potential or adverse performance is not directly considered

The ATC-58 Project

- 10-Year Program to develop next-generation performance-based seismic design criteria:
  - Applicable to:
    - New Buildings & Existing Buildings
  - Compatible with parallel efforts in:
    - Blast Engineering
    - Fire Engineering
    - Extreme Wind Engineering
- Conducted by Applied Technology Council under funding by FEMA/DHS

Performance
The Next Generation

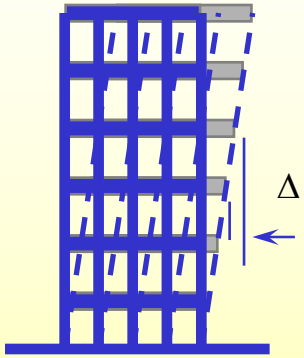


Performance
Next-Generation PBD

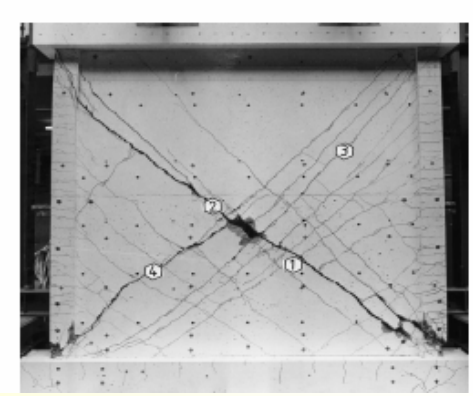
- The potential consequences of building response to earthquakes, including:
  - Casualties
    (Life loss and severe injury)
  - Direct economic loss
    (repair and replacement costs)
  - Downtime
    (loss of use of damaged or destroyed facilities)

Verifying Performance Capability

Ground Motion



Structural Response



Damage

Performance Metrics:
Casualties, Cash & Closure

All Steps Represented On A Probabilistic Framework Considering Uncertainty

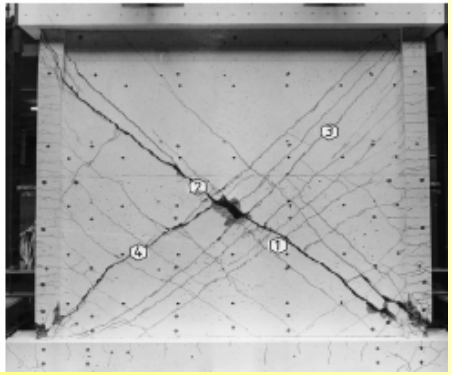
Expression of Performance

- Intensity-based
  - Probable losses given a specific intensity of ground shaking (response spectrum)
- Scenario-based
  - Probable losses given a specific earthquake (magnitude and distance)
- Time-based
  - Probable losses over a period of time

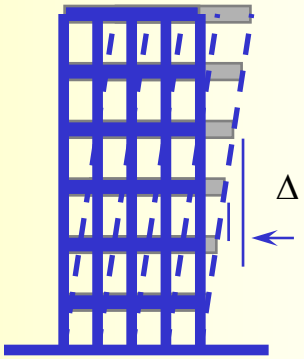
Performance Integral

$$P(Loss \geq x) = \sum_{DS_i} \iint P(Loss \geq x \mid D = DS_i)\, P\left(D = DS_i \mid F, \delta, a\right) P\left(F, \delta, a \mid S_a\right) P\left(Sa\right) dz$$

$



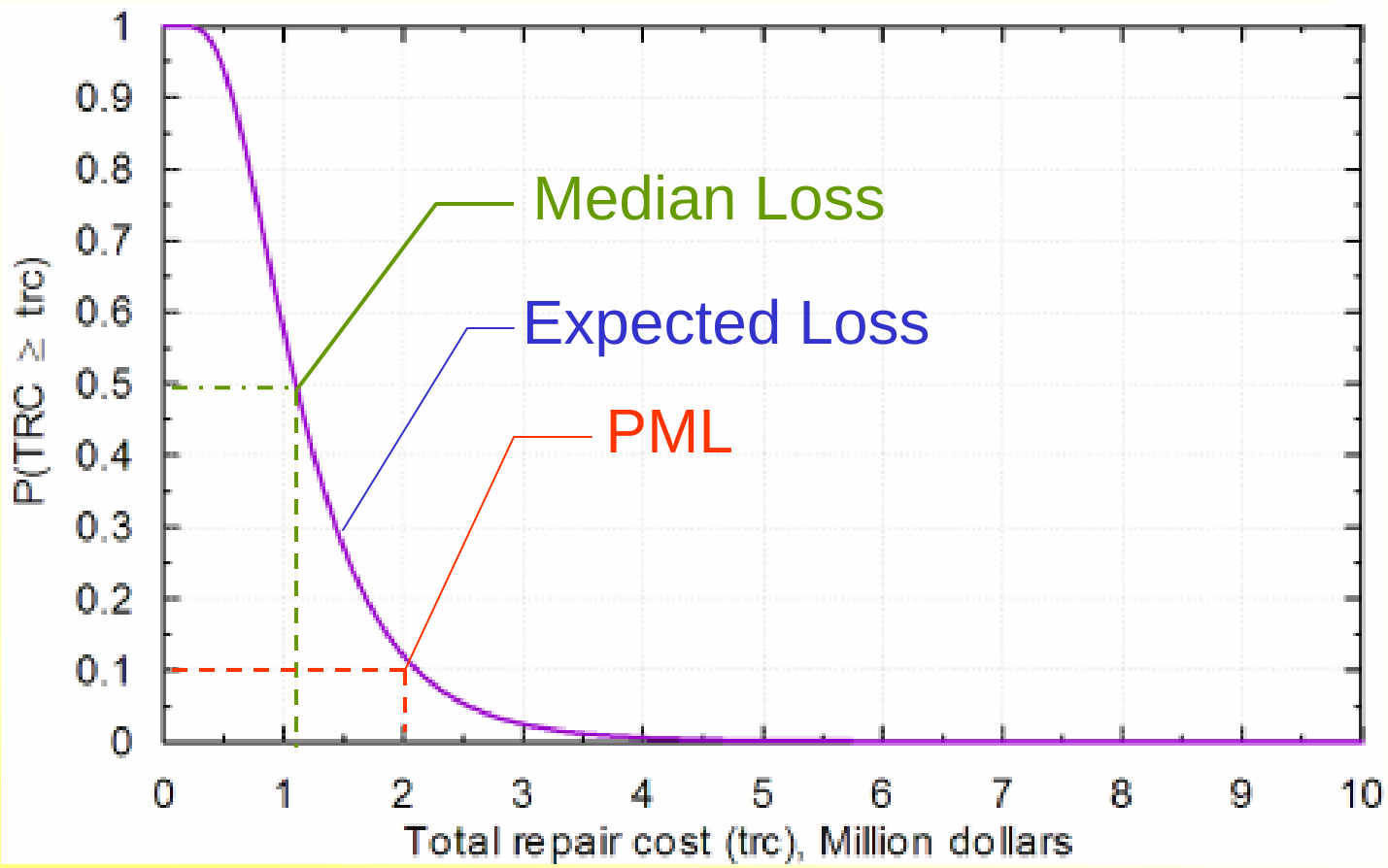
Damage



Structural Response

Ground Motion

Expressions of Performance



Sources of Uncertainty

- Ground motion
  - could be more or less intense than assumed
- Response
  - Record to record variability
  - Uncertainty in stiffness, damping, and strength of elements
- Damage
  - Dependent on number of cycles, quality of construction
- Loss
  - Number of persons present, efficiency of contractors, etc., etc.

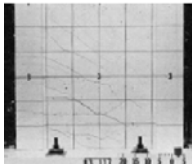
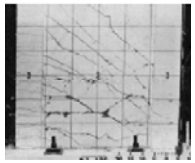
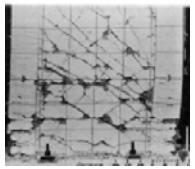
Process

- Define the building including:
  - Occupancy
  - Locations and types of components present
  - Damageabiltiy (fragility) of components and systems
  - Consequences of each damage state
- Analyze structure to predict (demands) accelerations and drifts at ground motion of interest
- Assess damage given demands
- Assess loss given damage

Performance Assessment Calculation Tool

- PACT - A simple software package that performs the complex and tedious calculations necessary to assess performance
  - Input
    - Building size and occupancy
    - Element types, fragility and consequence functions
    - Response data
  - Output- loss curves

Fragility Specifications

Fragility Specification **B1044.000 Reinforced Concrete Shearwalls**			
BASIC COMPOSITION	Reinforced concrete and finishes both sides		
Units for basic quantities	Square feet of wall area		
DAMAGES STATES, FRAGILIITES, AND CONSEQUENCE FUNCTIONS			
	DS1	**DS2**	**DS3**
DESCRIPTION	Flexural cracks < 3/16" Shear (diagonal) cracks < 1/16"	Flexural cracks > 1/4" Shear (diagonal) cracks > 1/8"	Max. crack widths >3/8" Significant spalling/ loose cover
ILLUSTRATION (example photo or drawing)			
MEDIAN DEMAND	1.5%	3.0%	5.0%
BETA	0.2	0.3	0.4
CORRELATION (%)	70%		
DAMAGE FUNCTIONS	Patch cracks each side with caulk Paint each side	Remove loose concrete Patch spalls with NS grout Patch cracks each side with caulk Paint each side	Shore Demo existing wall Replace Patch and paint
CONSEQUENCE FUNCTION			
Max. consequence up to lower quantity	$4.00 per sq ft up to 800 sq ft	$10.00 per sq ft up to 800 sq ft	$50.00 per sq ft up to 200 sq ft
Min consequence over upper quantity	$2.00 per sq ft over 4000 sq ft	$5.00 per sq ft over to 4000 sq ft	$30.00 per sq ft over 2000 sq ft
Beta (consequence)	0.2	0.3	0.3
TIMEFRAME TO ADDRESS CONSEQUENCES	days	weeks	months

Response Prediction (analysis)

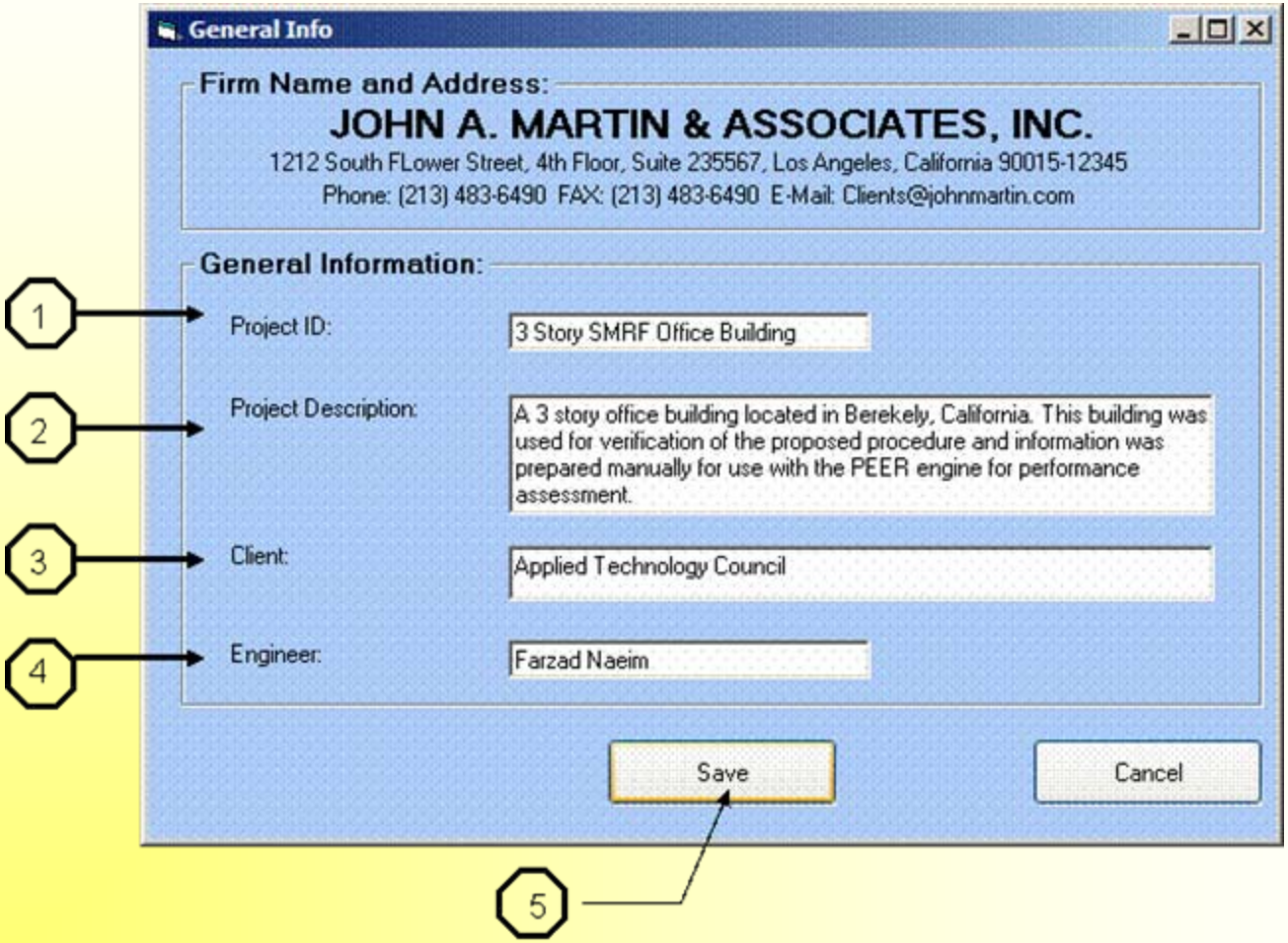
- Simplified
  - Linear analysis
  - Pushover to determine yield strength and “R”
  - Median drifts computed based on R and T
  - Default dispersions assigned based on R and T
- Nonlinear Dynamic
  - Ground motions selected and scaled and variability obtained directly from analysis results

What the Engineer Does

- Analyze the building
  - Nonlinear dynamic analysis
    - Numerous ground motions

No. of stories =	3									
No. of records =	12									
	du1-01	du1-12	du1-23	du2-01	du2-12	du2-23	ag	a1	a2	a3
eq1	1.399	1.83	1.793	1.399	1.83	1.793	0.5146	1.021	0.6538	0.6436
eq2	1.31	1.469	1.625	1.31	1.469	1.625	0.4642	0.9395	0.9868	0.6374
eq3	1.53	2.564	3.101	1.53	2.564	3.101	0.8101	0.9659	1.007	0.8481
eq4	1.842	1.889	2.789	1.842	1.889	2.789	1.114	1.644	1.449	1.042
eq5	2.138	2.629	2.938	2.138	2.629	2.938	0.6628	0.7715	0.7386	0.7202
eq6	1.262	1.903	1.887	1.262	1.903	1.887	0.2133	0.3575	0.3968	0.478
eq7	0.7691	1.688	2.294	0.7691	1.688	2.294	0.4245	0.761	0.7248	0.6393
eq8	1.382	1.759	2.065	1.382	1.759	2.065	0.5934	0.6885	0.5805	0.6065
eq9	1.382	1.759	2.065	1.382	1.759	2.065	0.5934	0.6885	0.5805	0.6065
eq10	1.382	1.759	2.065	1.382	1.759	2.065	0.5934	0.6885	0.5805	0.6065
eq11	1.382	1.759	2.065	1.382	1.759	2.065	0.5934	0.6885	0.5805	0.6065
eq12	1.382	1.759	2.065	1.382	1.759	2.065	0.5934	0.6885	0.5805	0.6065

Input to PACT



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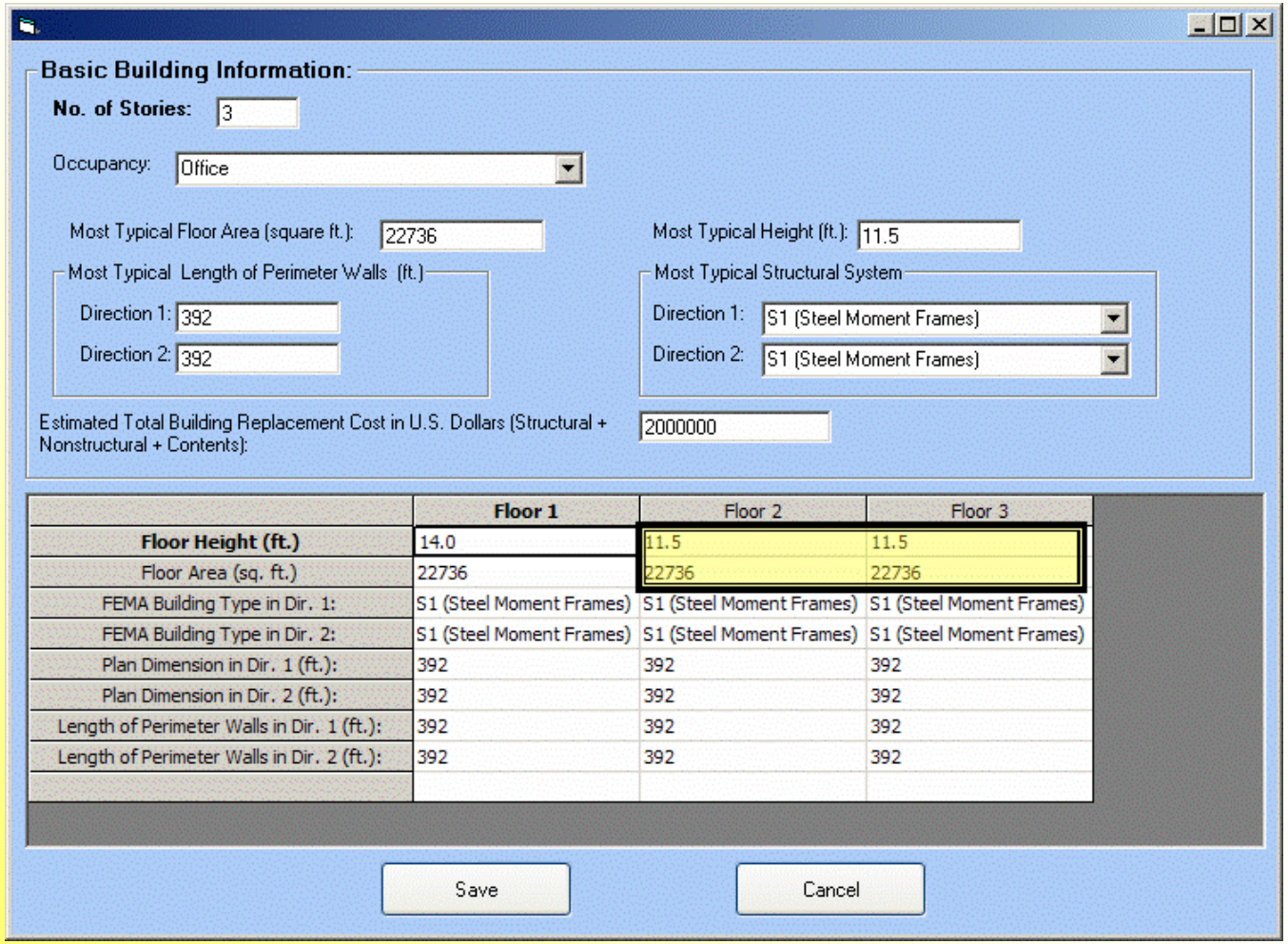
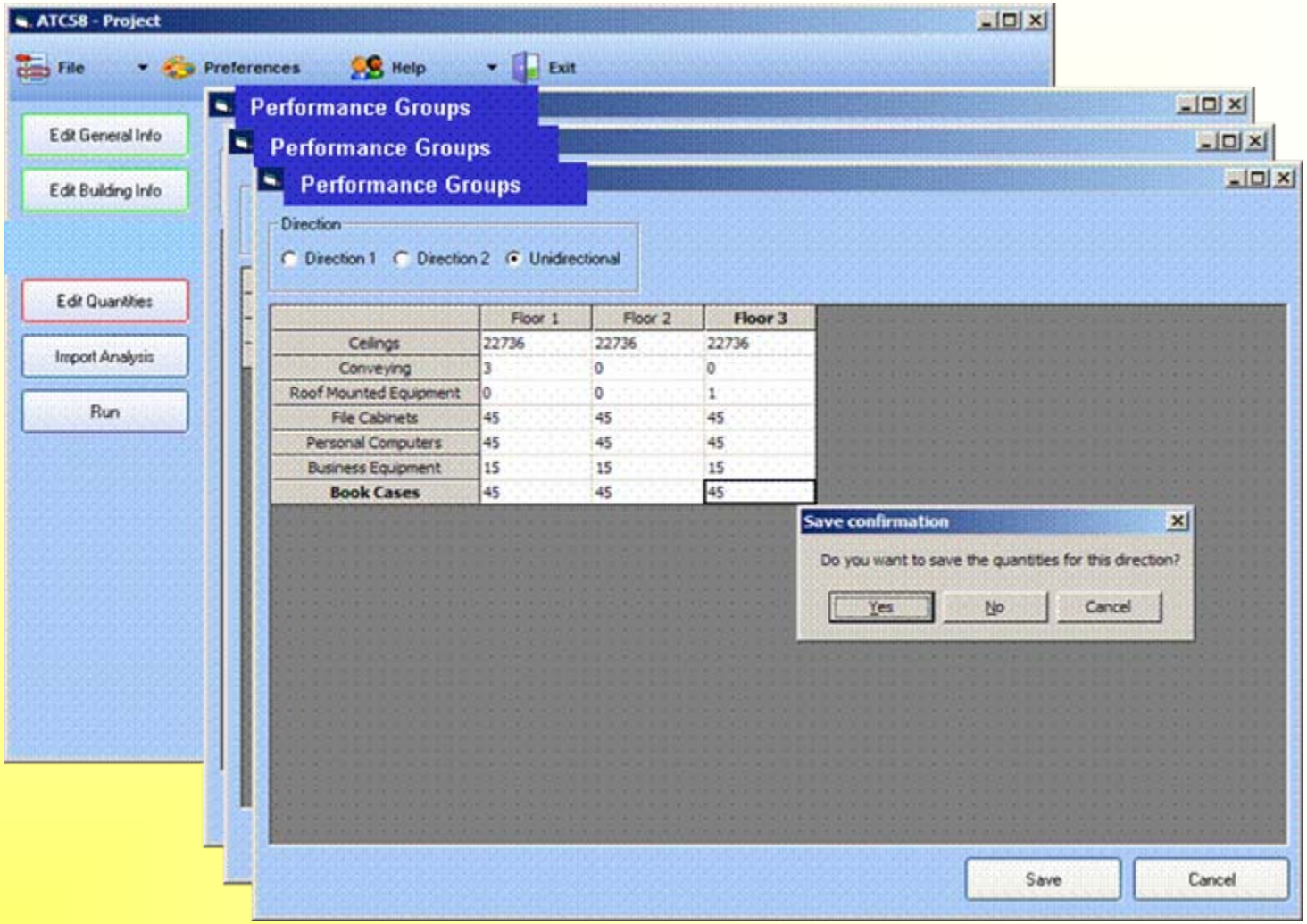


	Floor 1	Floor 2	Floor 3
Floor Height (ft.)	14.0	11.5	11.5
Floor Area (sq. ft.)	22736	22736	22736
FEMA Building Type in Dir. 1:	S1 (Steel Moment Frames)	S1 (Steel Moment Frames)	S1 (Steel Moment Frames)
FEMA Building Type in Dir. 2:	S1 (Steel Moment Frames)	S1 (Steel Moment Frames)	S1 (Steel Moment Frames)
Plan Dimension in Dir. 1 (ft.):	392	392	392
Plan Dimension in Dir. 2 (ft.):	392	392	392
Length of Perimeter Walls in Dir. 1 (ft.):	392	392	392
Length of Perimeter Walls in Dir. 2 (ft.):	392	392	392

Input to PACT



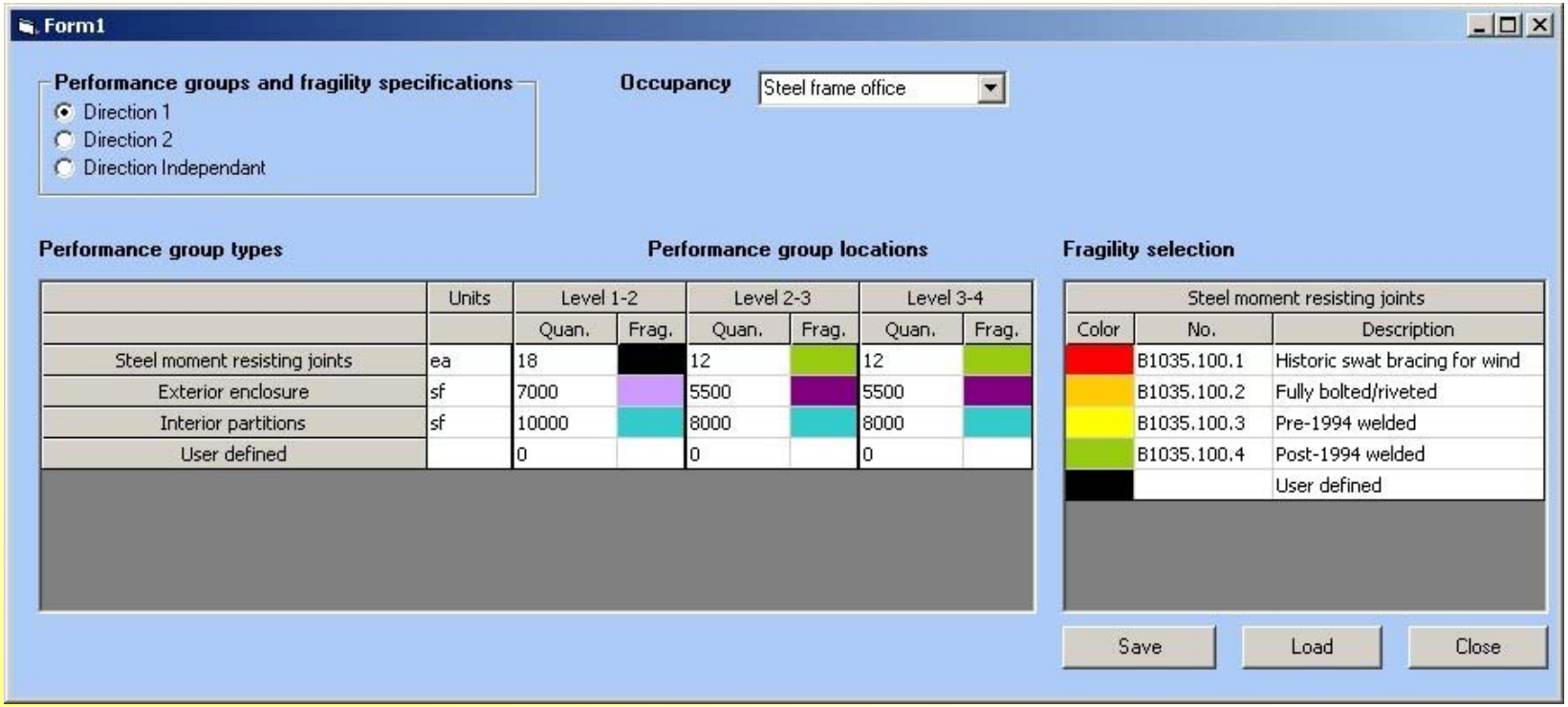
Input to PACT

Fragility Specifications

No.	Description
B1035.000	Steel Connections, post 1994 moment resisting
B2011.003a	Exterior shearwall, 7/16 OSB, 2x4, 16" OC, 7/8" stucco ext, GWB interior side
B2022.001	Highrise curtain-wall systems with annealed glass
B3011.002	Concrete, clay, and slate roofing tiles that are individually fastened to the roof sheathing
C1011.001a	GWB partition, no structural sheathing, 1/2" GWB two sides, 2x4, 16" OC
C1011.009a	Drywall finish, 5/8-in., 2 sides, on 3-5/8-in metal stud, screws
C3032.001	Lightweight acoustical ceiling 4'-x-2' aluminum tee-bar grid
C3033.001	GWB on wood joists
D1011.002	Hydraulic passenger elevators
D3063.000	Heating/Cooling Air Handling Units, all
E2022.000	Furniture & Accessories, all
E2022.004	Household entertainment equipment
E2022.011	Desktop computer system unit and CRT monitor
E2022.011a	Computer system servers and network equipment
E2022.026a	Tall file cabinets
E2022.029	Unanchored bookcases

Review or revise to add | Add new | Close

Input to PACT



Input to PACT

Fragility Specification

No.	Description
B1035.000	Steel Connections, post 1994 moment resisting

Correlation: 1

Consequence functions

DS-1 Limit State ID: Cracking or fracture of weldments [Edit]

DS-2 Limit State ID: Buckling or fracture of beam flanges and/or [Edit]

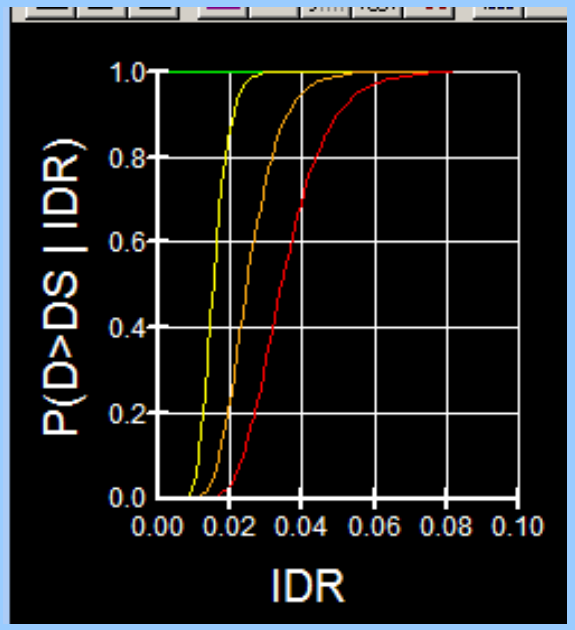
DS-3 Limit State ID: Fracture of column flanges and/or web [Edit]

Directional
- (•) Directional
- ( ) Not Directional

Engineering Demand Parameter:
- (•) Interstory Drift (IDR)
- ( ) Acceleration

Damage State: [Redraw]

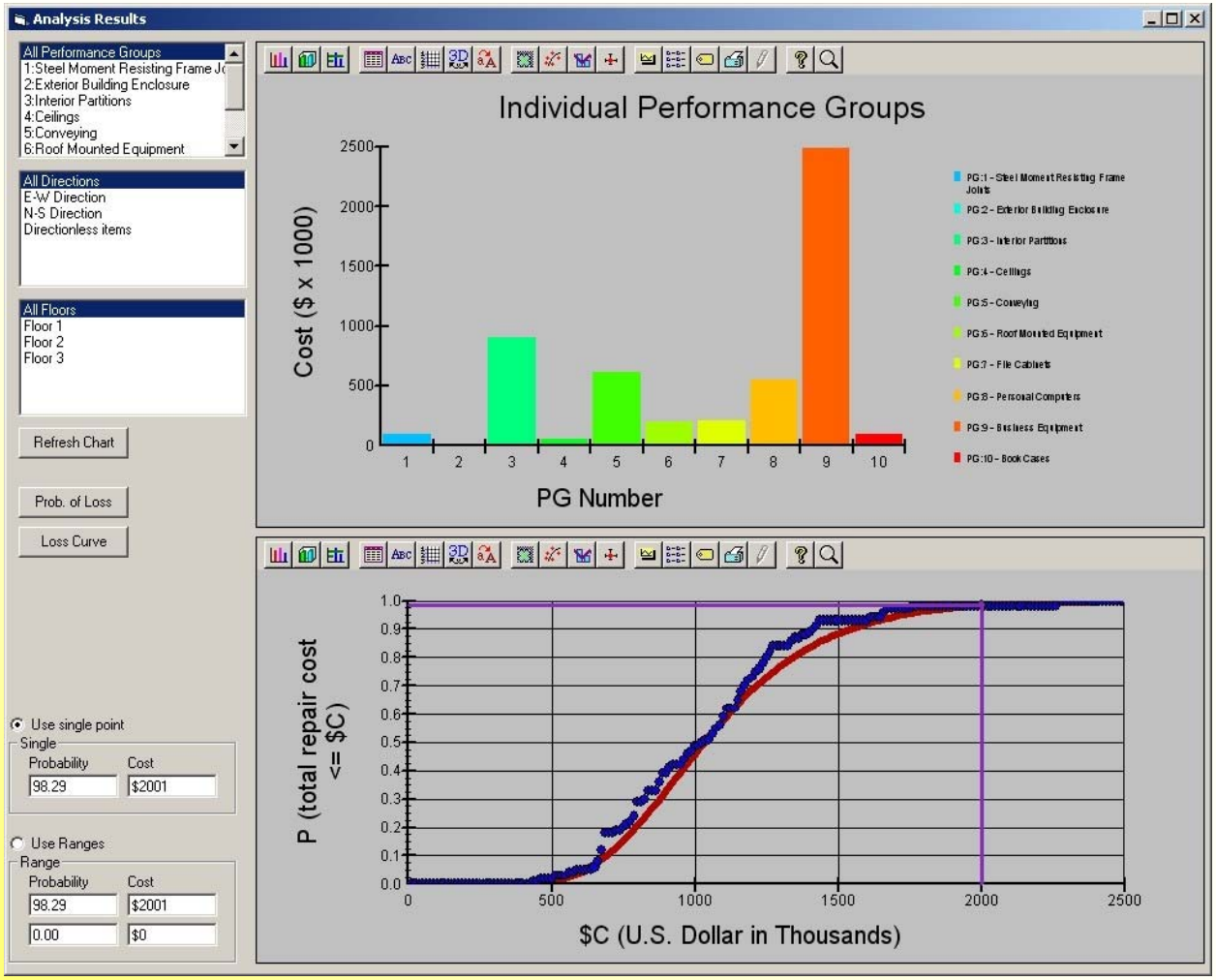
	DS-1	DS-2	DS-3
med.	0.015	0.025	0.035
beta	0.25	0.3	0.3



Close

Save as

What the Results Look Like



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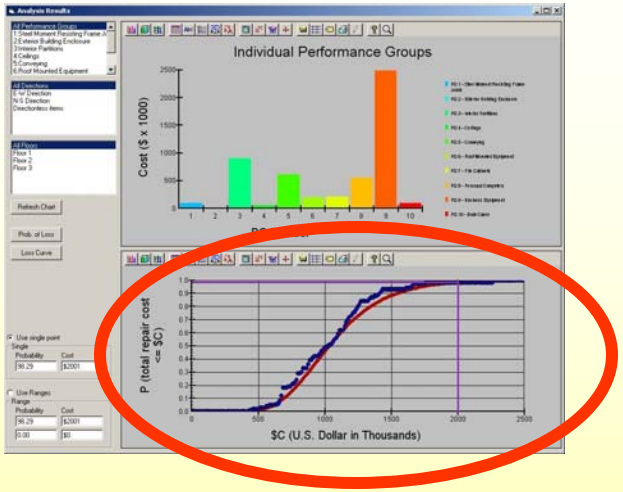

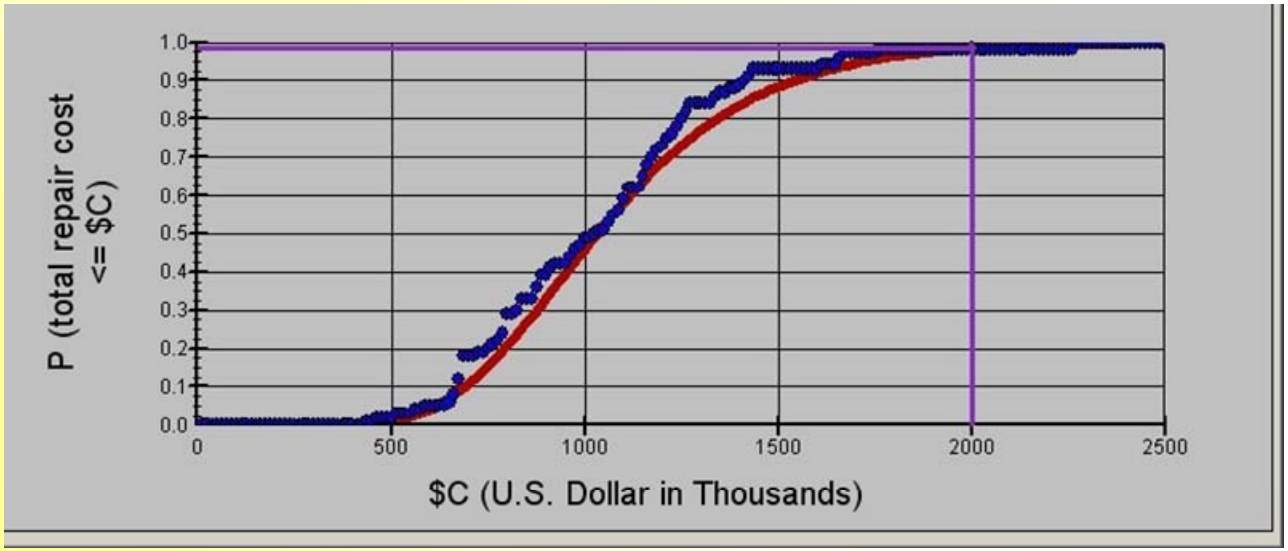

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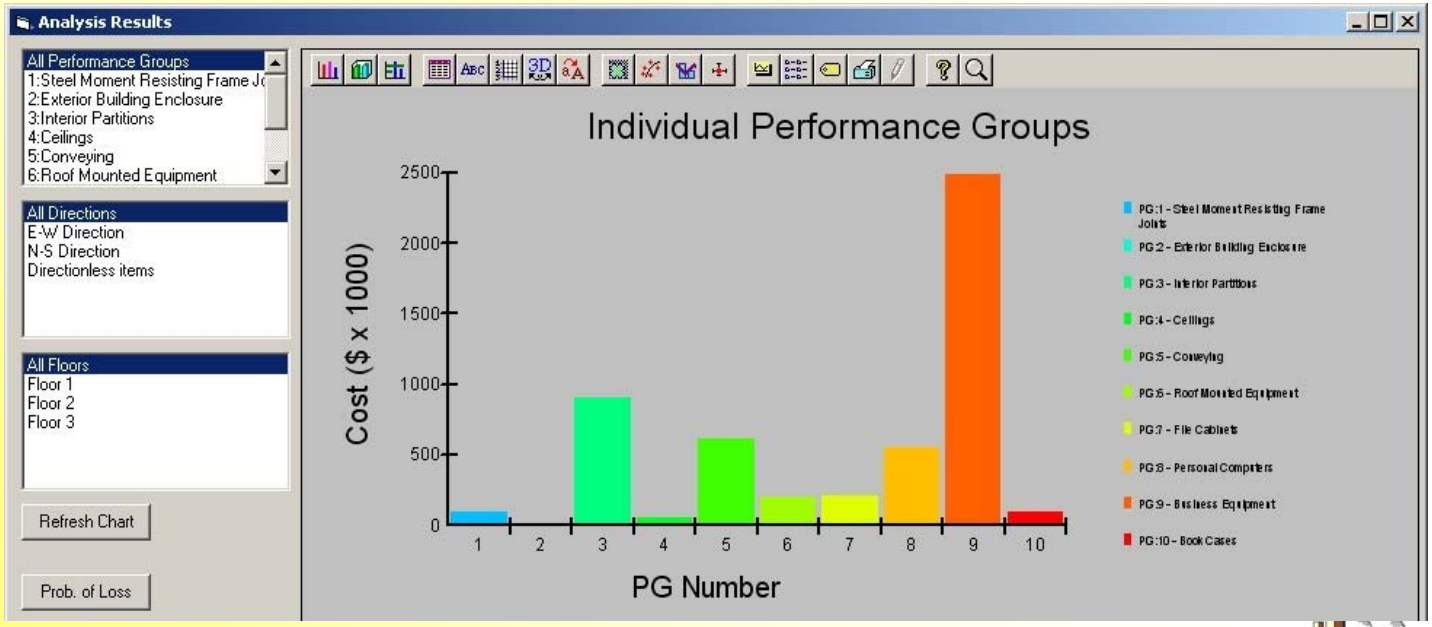


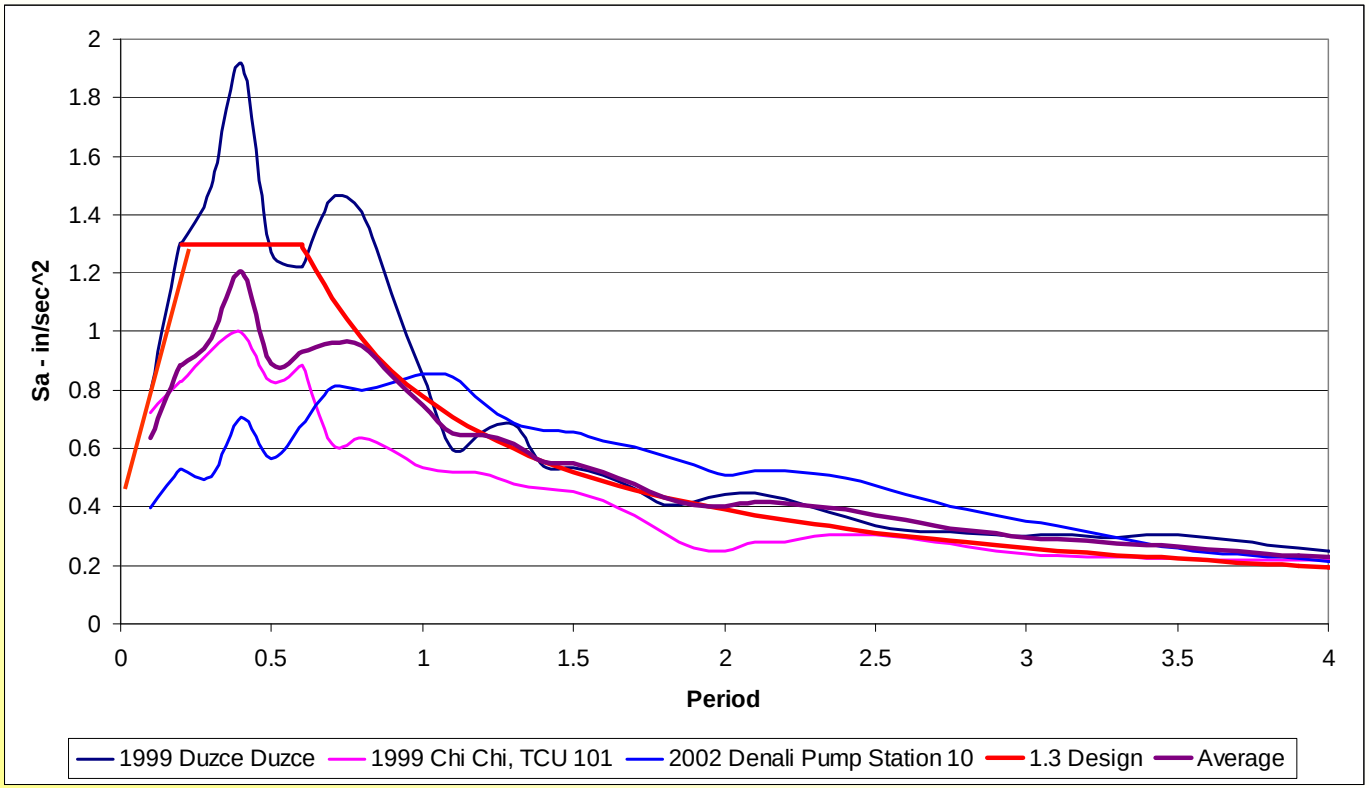
Uses

- Rapid evaluation of design alternatives
  - How is the building performance changed if we:
    - Use another system
    - Make the structure stronger
    - Add damping
    - Change the type of cladding details
- Probable Maximum Loss
- Comparison with code-conforming alternatives

3 Types of Performance Assessments

- Intensity based –
  - Probability of incurring loss > X, given that certain intensity is experienced
- Scenario based-
  - Probability of incurring loss> X, given that an earthquake of given size at given distance occurs
- Time based –
  - Probability of incurring loss> X, considering all earthquakes that may occur in time t, and the likelihood of each

Record to Record Variability

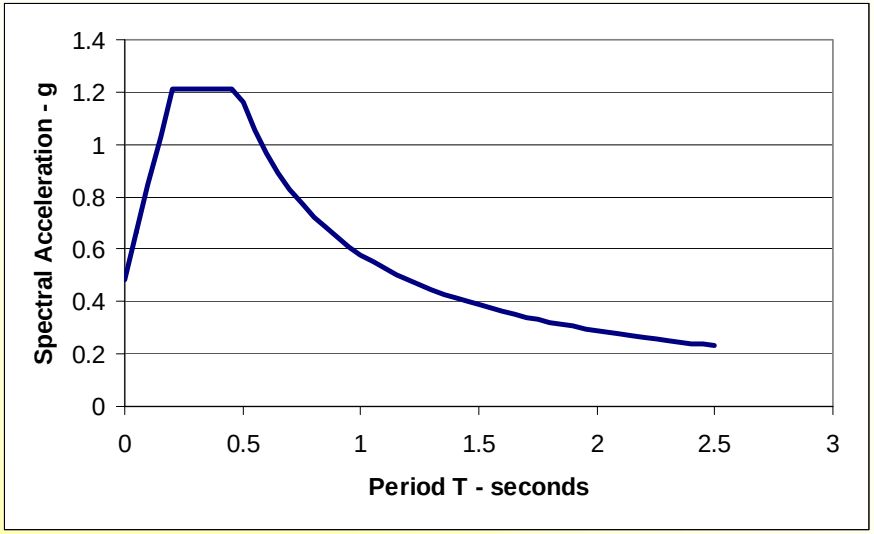


- Building Code, ASCE 41
  - Take maximum of 3 records
  - Take average of 7 records

Goal of ATC58 Scaling Rules

- Find median (50th percentile) response
  - 75% confident
  - Predicted median within +/- 20% of actual median

Intensity-based Assessment

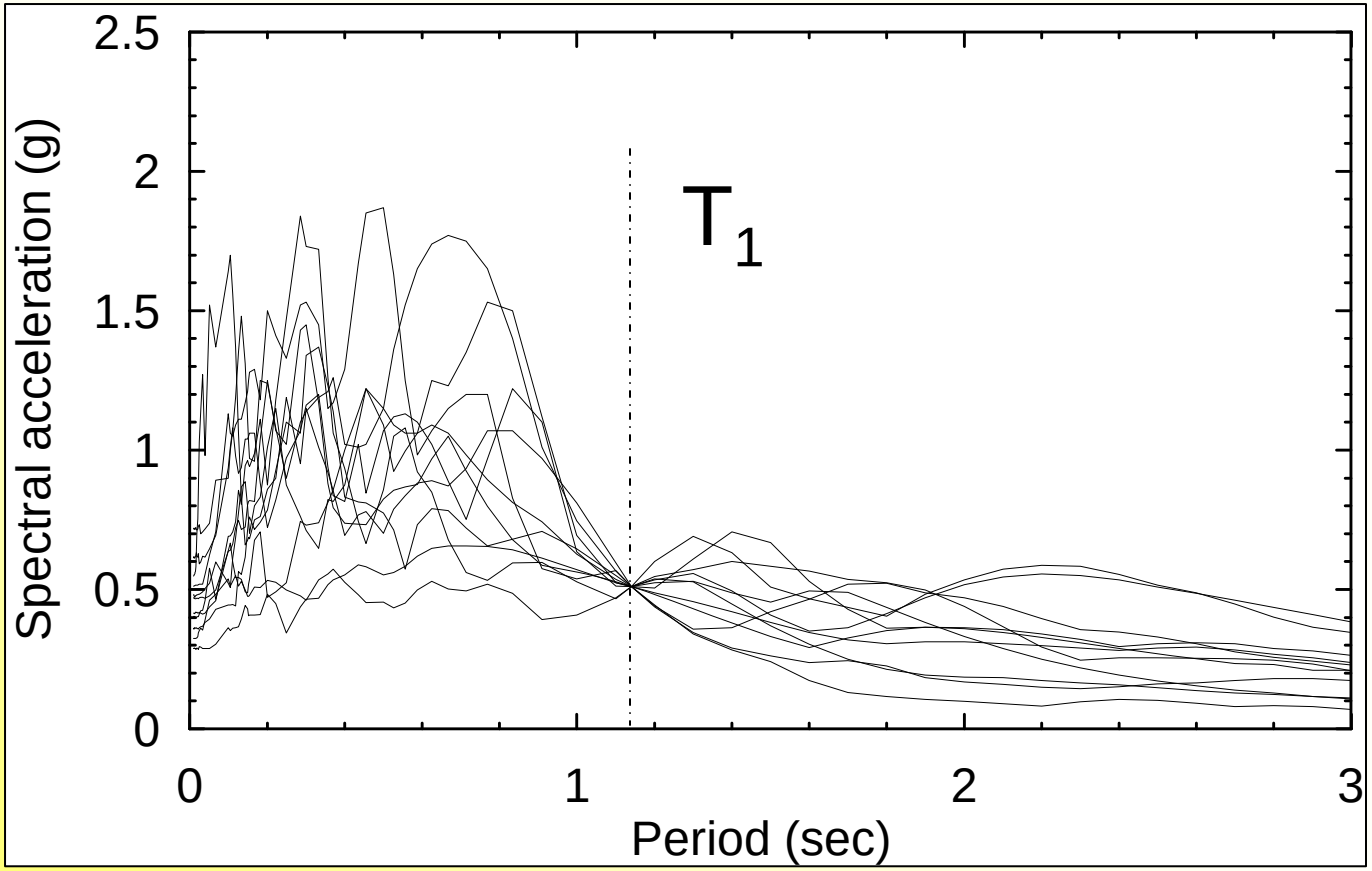


- Intensity represented by a single response spectrum
- Predict the median response and variability for records represented by this spectrum

Procedure: Intensity-Based

- Select response spectrum representing intensity of interest
- Determine fundamental period of structure, T_1
- Randomly select at least 11 ground motions from Near-fault or Far-field bin as appropriate
- Scale each motion such that $S_a(T_1)$ equals target spectrum

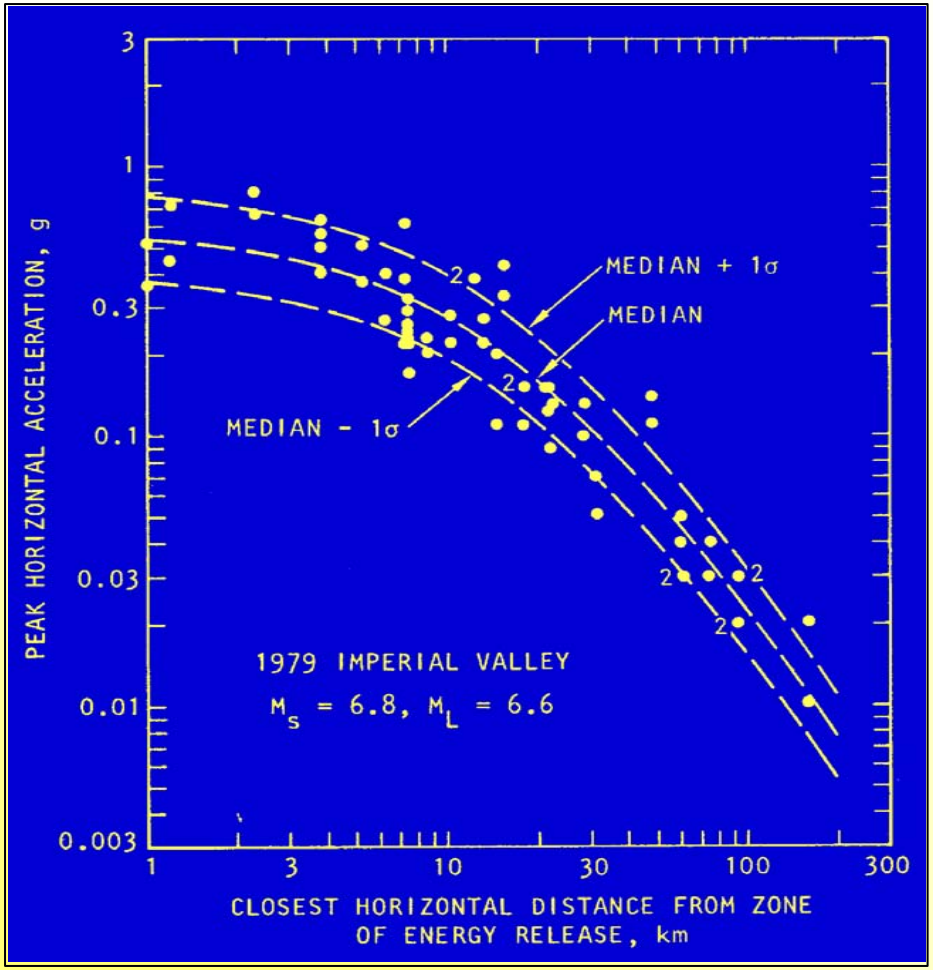
Motions scaled to Intensity



Why 11 motions?

- Nonlinear analysis of suite of SDOF buildings using 50 far field and 50 near field records
- Median displacement response for each structure determined
- Randomly selected bins of analyses consisting of:
  - Different numbers of records, (N)
  - Different records
- 11 motions required to be 75% confident of being within 20% of median displacement response

Scenario-based Assessment

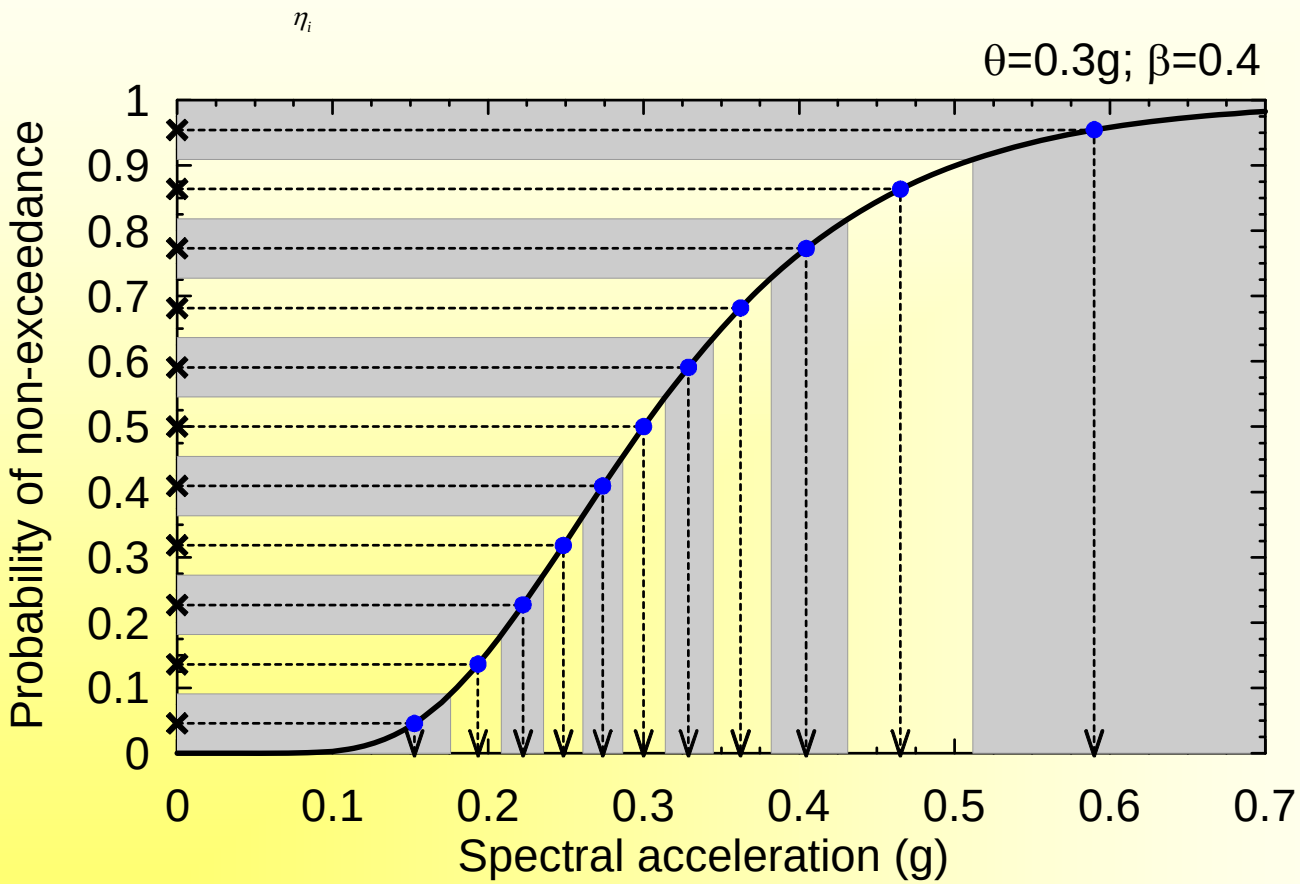


- Although earthquake is certain-
  - Magnitude & distance assumed
- Intensity is uncertain

Procedure: Scenario-based

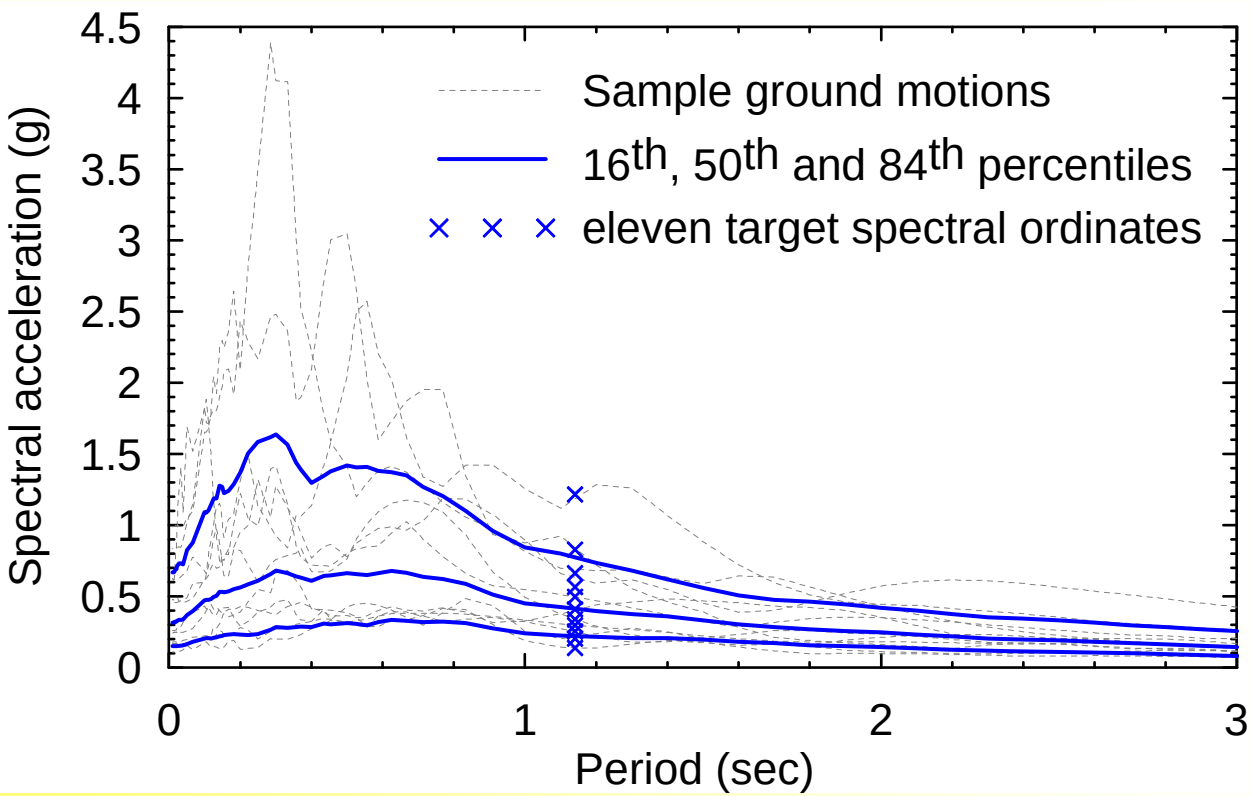
- Select scenario (M,r)
- Select attenuation relationship
- Determine median $S_a(T_1)$ and β
- Select 11 ground motions from appropriate bin
- Amplitude scale each of the 11 motions to match $S_a(T_1)$ at:
  - 11 equally spaced confidence levels (each with 9.99% probability of occurrence)

Scaling to Confidence Levels



I	n
1	-1.69
2	-1.10
3	-0.75
4	-0.47
5	-0.23
6	0
7	0.23
8	0.47
9	0.75
10	1.10
11	1.69

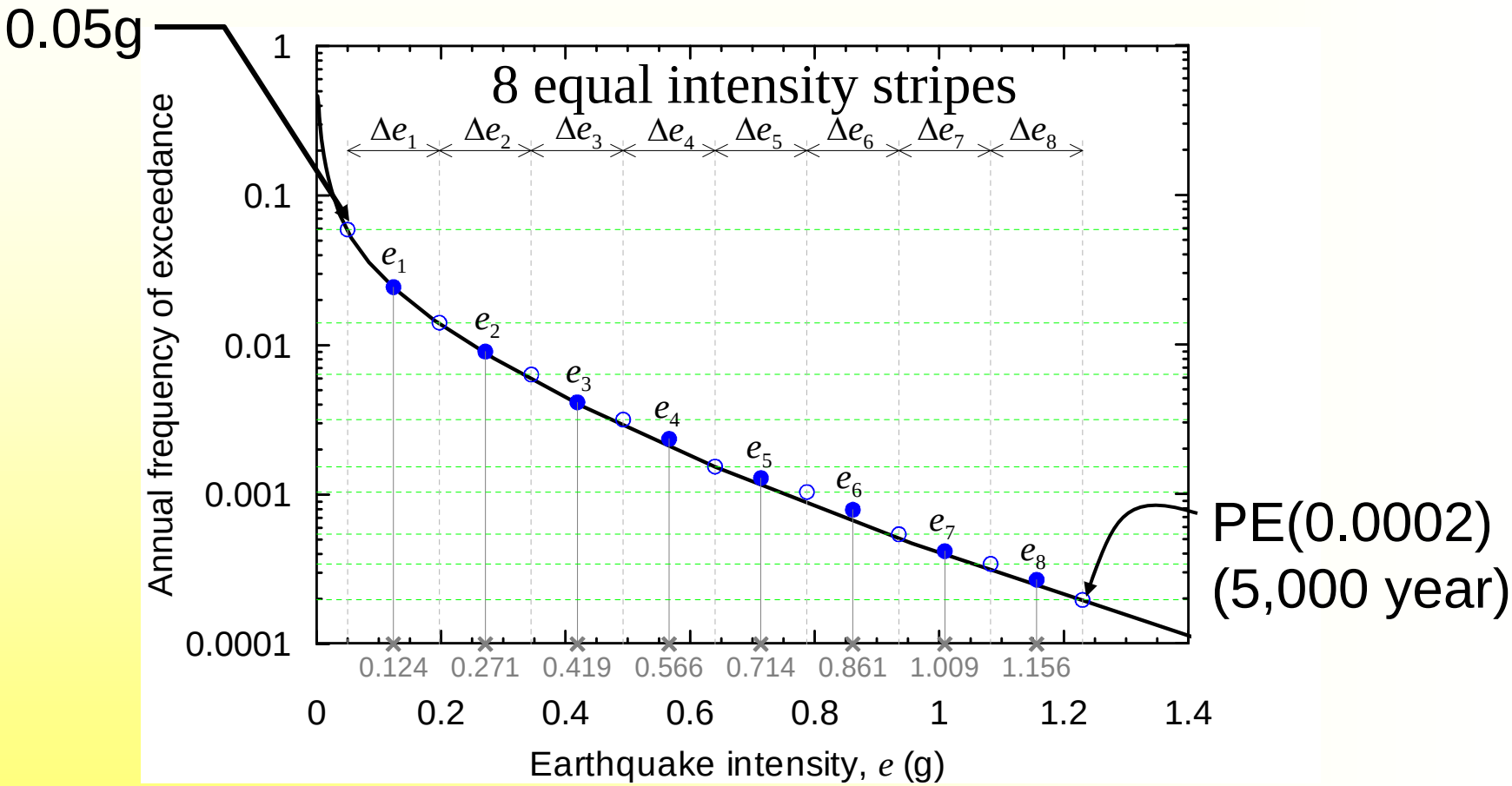
Scenario-based Scaling



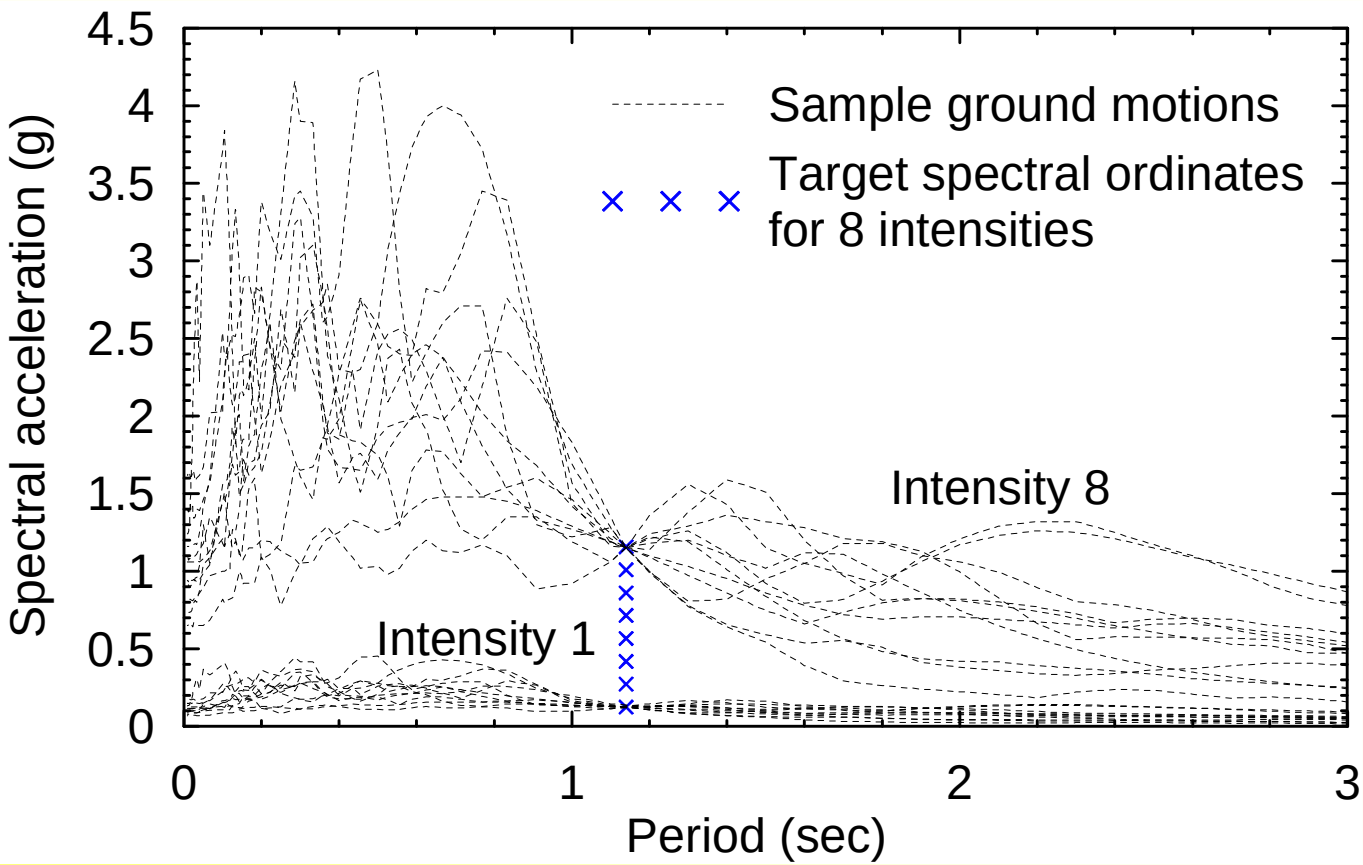
Time-based Assessment

- Neither the magnitude nor location of earthquakes that may affect the site are known
- Probabilistic seismic hazard curves used to represent probability of shaking
- 8 Stripes of equal ground motion intensity
- 11 motions scaled to $S_a(T_1)$ at central point of each stripe
  - 11 intensity assessments

Striping of Hazard Curve



Time-based Ground Motions



Summary

- Intent is to select and scale motions such that
  - Statistics obtained from analyses accurately represent the median and true record to record variabiilty in response
  - Minimize number of records required to achieve this

Summary

- 11 motions appropriately selected motions can be used to produce a 75% confidence that median will not be missed by more than 20%
- Procedures have been presented to scale motions to represent:
  - A single intensity
  - A single earthquake scenario
  - The entire probabilistic hazard