INCREMENTAL DYNAMIC ANALYSIS &
Fragility Analysis

1. Approximate determination of dynamic response.
   Spectral Capacity Approach.
   \[ S_a^* = S_a \]
   \[ R = 1 \text{ (elastic spectrum)} \]
   \[ S_d = \left( S_d^* \cdot \frac{d_k}{R_k} \right) \]

1. Determine \( S_a^* \) from intersection of tangent of post-yielding range to the other (i) initial stiffness or (ii) secant stiffness \( \Rightarrow \) equal work.

2. Determine spectral elastic response \( S_a^* \).

3. Determine \( R \)-factor from \( R = \frac{S_a^*}{S_a} \)

4. Select an inelastic spectral curve for \( R \) (use computer program N.SPECTRA from HCER Users Network. (also: http://civil.eng.buffalo.edu/spectra)
Note 1: Need material spectra for:
(i) specified R factor or multiple R factors.
(ii) specified viscous damping ratio.

Note 2: Need "spectral capacity."

(i) Perform nonlinear static incremental analysis.
(Pushover*).

(ii) Transform axes to obtain spectral values:
\[ \phi_0 = \frac{\beta s}{\pi} \quad \xi_0 = \frac{\mu_0}{\nu_0} \]

Note 2: Spectral Capacity may be calculated through nonlinear dynamic incremental analysis.

(i) Select a ground motion (or an ensemble of
ground motions).

(ii) Perform nonlinear dynamic analysis for a base motion at low maximum amplitude, and record response maxima. Repeat analysis for same base motion scaled to a larger peak. Record response maxima. Repeat previous step each time necessary (usually acceleration of base motion and record motion. With sufficient motions obtain the capacity of structure.)
Uncertainties in response.

Uncertainties in structural behaviour:

- Spectral capacity valuations
- Load pattern
- Material properties
- Analytical method
- Construction issues

Uncertainties in ground motions:

Ground motions are never known or accurately predicted.

Range of response!!

Response for one case.

$S_a \rightarrow S_d$

$S_a^* \rightarrow S_d^*$

$S_a = S_d$

$S_a^* = S_d^*$
Fragility of structures.

Uncertain response.

\( \text{Fragility} = P(R \geq L \mid I = I) = \frac{\text{Area outside limit}}{\text{Total area}} \)

probability conditional of an earthquake with intensity \( I \).

always smaller than unit.

Limit of functionality (functionality).

Limit of resistance (safety).

Limit of usability (not ground motion).

\( R(S_a, S_d) \)

\( S_d \)

\( S_a \)

\( \text{Sa} \uparrow \)
**Fragility curves**

\[
P = P_1 \quad \text{or} \quad P_2
\]

Limit state = \(L_1\)

Limit state = \(L_2\)

\[\gamma_g = 0.2g\]

**L_2** - Probability = \(P_1\).

**L_1** - \(\gamma = P_2\)

(Which is more suitable?)

Another representation
Use of fragility curves:

(1) Post-analysis:

Cost of building 'a limit state' such as:
ability to "displacement capacity of 2"`

= $M/4$

Actual cost estimate =

\[ \hat{\#\text{Estimate}} = \#M_1 \cdot \frac{F(L_1 | I) - P(I)}{\sum_P(\#M_1 | F) \cdot P(\#L_1 | I) \cdot P(I)}. \]

(2) Direct comparison of alternatives:

based on "performance limit states"

responsive to "performance limit state" conditional on "seismological data".

Also known as "performance based" evaluation.
Indicator for retrofit or other action.

Original.