Reliability-Based Design (for CE152)

by

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Reliability ?

- “BEST bus services are very reliable”
- “BMC water supply is not very reliable”
- “In Mumbai, Western Railway’s service is more reliable than that of the Central Railway”

➔ What is reliability, in technical terms?
➔ How do we measure it?
➔ Why is not a system fully reliable?

Civil Engineering Systems

- Structural (Buildings, Bridges, Dams, Fly-overs)
- Transportation (Road systems, Railways, Air traffic)
- Water (Water supply networks, Waste water networks)
- ……

Each system is designed differently, but there is a common philosophy

How To Design

Requirement	Provision
• Demand	• Capacity/Supply
• Load	• Resistance
➔ x million liter/day of water for IITB residents	✓ x million liter/day of water for IITB residents

Basic Design Philosophy

Capacity should be more than demand

$$C \geq D$$

Example: Provide at least x million liter/day of water to the IITB residents

How much more than the demand?

- Theoretically, just more
- However, designers provide a lot more
- Why?

→Because of uncertainty

Uncertainty

We are not certain about the values of the parameters that we use in design specifications

Sources/reasons of uncertainty:

- Errors/faults/discrepancies in measurement (for demand) or manufacturing (for capacity)
- Approximations/idealizations/assumptions in modeling
- Inherent uncertainty — “Aleatory”
- Lack of knowledge — “Epistemic”

Measurement and Manufacturing Errors

- Strength of concrete is not same at each part of a column or a beam in a building system
- The depth of a steel girder is not exactly same (and not as specified) at each section

(Errors in estimating demand/capacity?)

(*source*: SAC Steel Project)

Measurement and Manufacturing Errors

- Weight of concrete is not same at each part of a column or a beam in a building system

(Error in estimating demand/capacity?)

- Wheels of an aircraft hit the runway at different speeds for different flights

Moral of the story:

Repeat a measurement/estimate/experiment several times and we do **not** get exactly the same result each time

Idealizations in Modeling

- Every real system is analyzed through its "model"
- Idealizations/simplifications are used in achieving this model

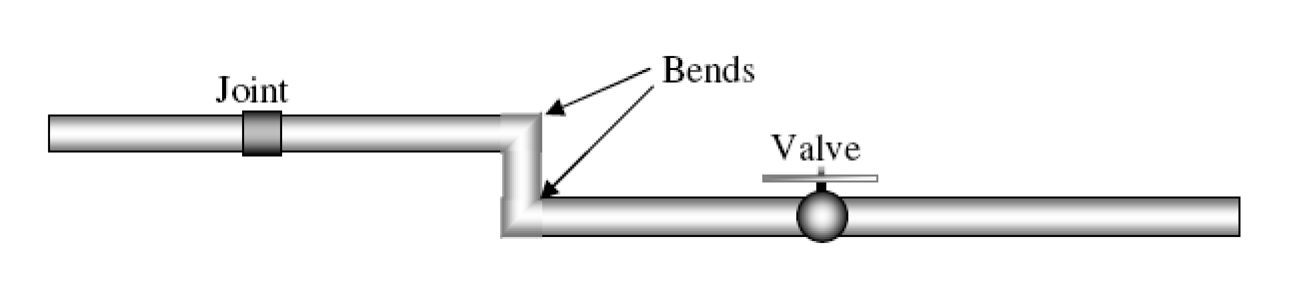
Example: (modeling live load on a classroom floor)

- Live loads are from non-permanent "occupants"; such as people, movable furnishers, etc.
- We assume live load to be uniform on a classroom (unit?)
- [We also assume the floor concrete to be "homogeneous" (that is, having same properties, such as strength, throughout)]
- Therefore our analysis results are different from the real situation

Idealizations in Modeling

Example: (modeling friction in water systems)

- Friction between water and inner surface of a pipeline reduces flow
- We assume a constant friction factor for a given pipe material
- In reality, the amount of friction changes if you have joints, bends and valves in a pipe
- If we need to consider these effects, the analysis procedure will be very complicated
- However, we should remember that there is difference between the behaviors of model and the real system



Epistemic and Aleatory Uncertainties

Epistemic

- Due to lack of understanding
- Not knowing how a system really works
- These uncertainties can be reduced over time (enhanced knowledge, more observation)

Aleatory

- Due to inherent variability of the parameter
- Unpredictability in estimating a future event
- These uncertainties can be reduced as well, with more observations

The Case of Earthquakes

- Structures have to be designed to withstand earthquake effects
- Earthquakes that a structure is going to face during its life-span are unpredictable
- We do not know when, how big (magnitude), how damaging (intensity) ....
- This is due to the unpredictability inherent in the physical nature of earthquakes

Aleatory uncertainty

How Earthquakes Occur

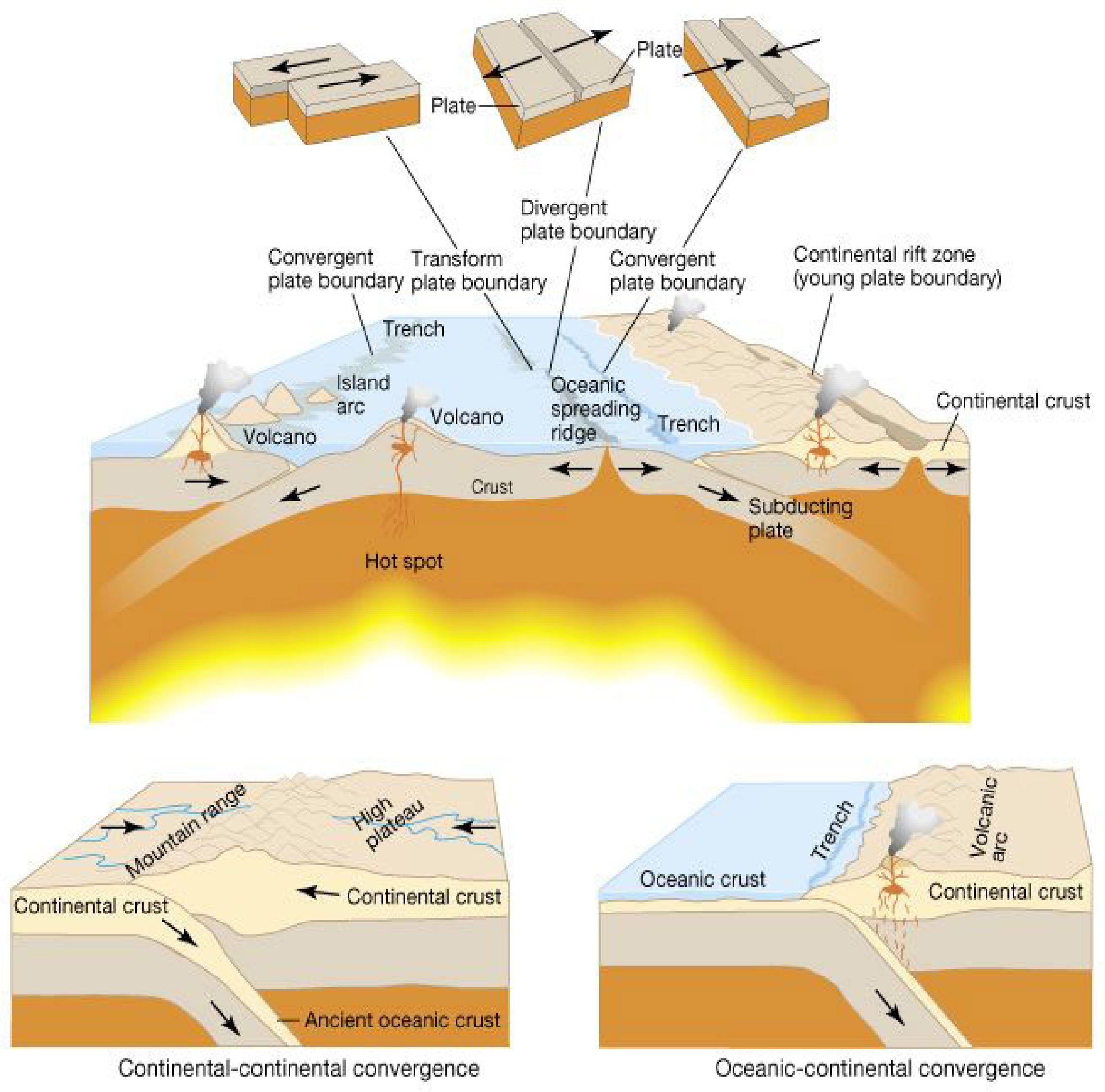
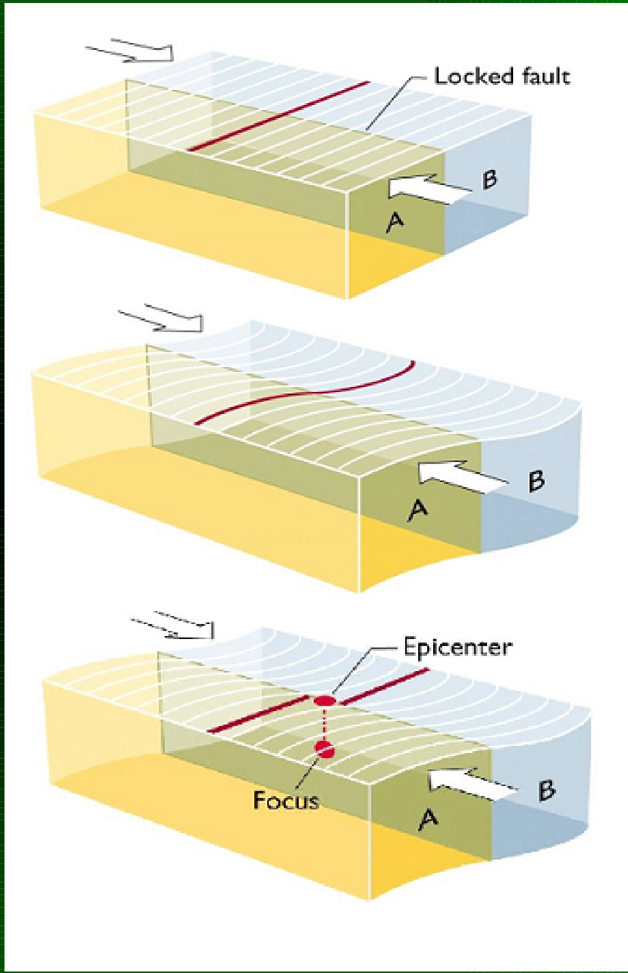
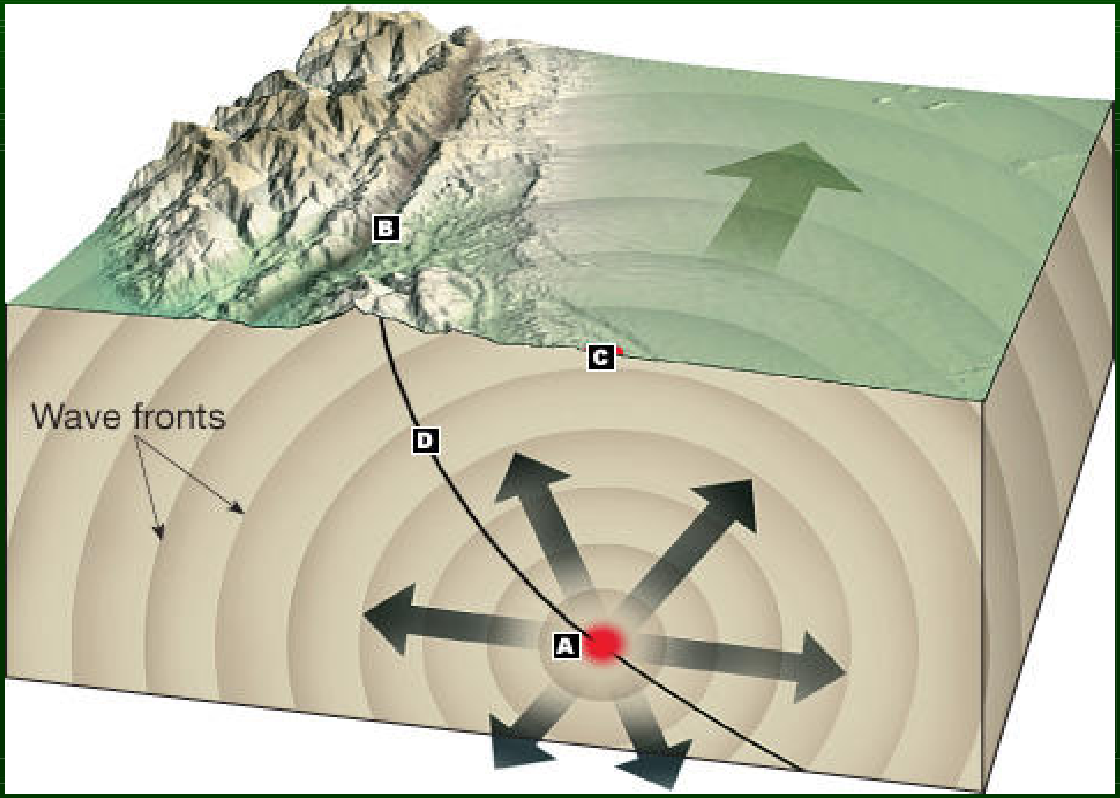


Plate Tectonics



Elastic Rebound Theory

How Earthquakes Occur



AD = Fault line (along which one side of earth slides with respect to the other)
A = Focus of the earthquake (where the slip occurs and energy is released)
C = Epicenter of the earthquake (point on earth surface directly above the focus)
B = Site (location for the structure)
Earthquake waves travel from A to B (body waves) and C to B (surface waves)

How Earthquakes Occur

- Earthquake waves travel from epicenter to the site (site = where the structure is located)
- The shock-wave characteristics are changed by the media it is traveling through
- The earthquake force that is coming to the base of a structure is also determined by the soil underneath
- We need to know accurately these processes by which the ground motion is affected
- Any lack of knowledge in these regards will lead to:

Epistemic uncertainty

Effects of Uncertainty

- Analysis results are not exactly accurate (that is, not same as in real life)
- Estimation of demand and capacity parameters is faulty
- We may not really satisfy the $C \geq D$ equation
- However, we will not know this
- Solution: apply a factor of safety (F)

$$C \geq FD \text{ or } C/F \geq D$$

- This factor takes care of the unforeseen errors due to uncertainty

If $C \geq 2.5D$, then even in real situation,
it should be $C \geq D$

Deterministic Design: Factor of Safety

- This is the traditional design philosophy
- A deterministic design procedure assumes that all parameters can be accurately measured (determined)
- Thus, there is no uncertainty in estimating either C or D
- So, if we satisfy a design equation, we make the system "100% safe". It cannot fail.
- In addition, we add a factor of safety to account for unforeseen errors
- This factor of safety is specified based on experience and engineering judgement
- The value of the safety factor varies for different cases

Deterministic Design: Factor of Safety

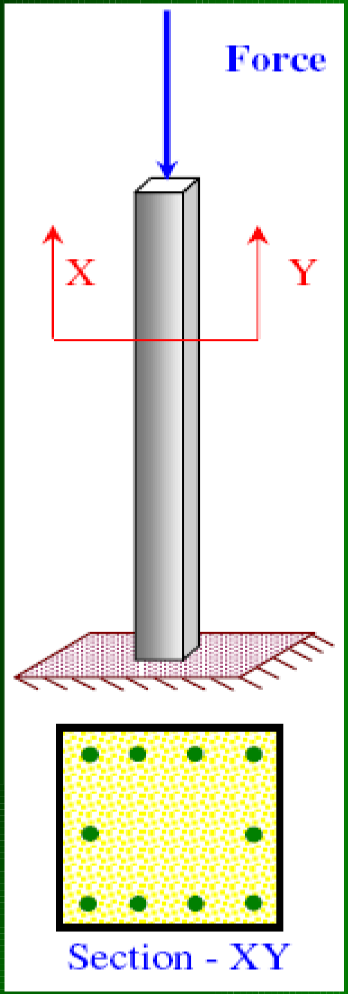
Example:

$$0.447\, f_c A_c + 0.8\, f_s A_s \geq P$$

- This is the design specification for a reinforced concrete column

  (RC = concrete reinforced with steel bars)

- f_c = strength of concrete, f_s = strength of steel
- A_c = area of concrete, A_s = area of steel bars
- 0.447 and 0.8 are for safety factors
- P = Force acting on the column (demand)



Reliability-Based Design

- This is the newly developed design philosophy
- Here, we accept the uncertainties in both demand and capacity parameters
- However, all these uncertainties are properly accounted for
- Uncertainty in estimating each parameter is quantified
- The C $\geq$ D equation does not provide a full-proof design
- The design guideline specifies a probability of failure due to those uncertainties
- Load and resistance factors are used in stead of a single factor of safety
- These factors are based on analysis, not on judgement

Old vs. New

<u>Deterministic</u>

- 100% safe
- No uncertainty
- Factor of safety is based on judgement
- Simple, but claims are not realistic

<u>Reliability-Based</u>

- Less than 100% safe
- Uncertainties are properly accounted for
- Factors are calculated from uncertainty
- More scientific in all aspects, but complex

Reliability-Based Design

- Reliability-based design equation:

$$\phi C \geq \gamma D$$

- ϕ = Resistance/Capacity Factor
- γ = Load/Demand Factor
- This equation assigns a probability of failure (P_f) for the design
- This P_f is based on the load and resistance factors (also known as "partial safety factors")
- Real systems always have some probability of failure (even though deterministic design does not recognize)

Concluding Remarks

- Uncertainties are unavoidable; it exists in natural systems and the way we measure and manufacture
- It is not wise to ignore them
- The best way to deal with uncertainties is to quantify them properly (using statistics and probability)
- Reliability-based design accounts for uncertainties scientifically (whereas, deterministic design does not)
- RBD assigns a specific reliability on a design through P_f (probability of failure)
- It is not bad for a system to have probability of failure, but bad not to know how much
- RBD tries to keep P_f within a target level

Thank you

Questions?