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Vulnerability Analysis of Structures

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Objectives

- To consider the robustness of structures
  - Structural vulnerability analysis

- To present an approach to manage risks
  - Vulnerable failure scenarios

Robustness

- There is no theory of robustness
- Structural design based on a load model
- Loads change
  - climate change, structural usage
- Structures deteriorate
  - corrosion, carbonation
- New demands arise
  - terrorist threat

Robustness

- Common measures for protection
  - Strengthening schemes
  - Manage loads and usage

- Examine the form of the structure
  - identify *inherent* weakness in form
  - explore actions posing the threats
  - manage the associate risks

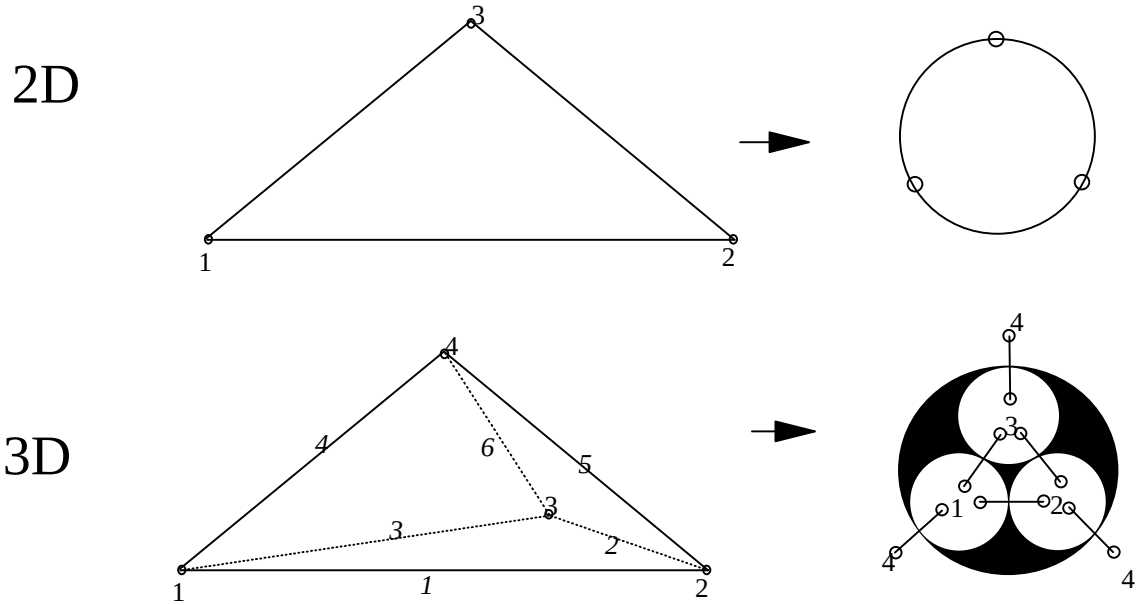
Structural Vulnerability Analysis

- An analysis of form and connectivity
- Uses characteristics of members and joints

- Enables identification of scenarios with disproportionate consequences to damage
- Damage may be due to any possible action

Structural Vulnerability Analysis

- 2D Rings and 3D Rounds
  - configuration capable of carrying a set of forces



Structural Vulnerability Analysis

- Well formedness of a ring/round

  - based on the properties of the members and their connectivity

$$q_i = det(K_{ii}) \qquad \textit{(product of eigenvalues)}$$

$$Q = \Sigma\, q_i / N$$

  - a measure that helps in ranking rings and clusters

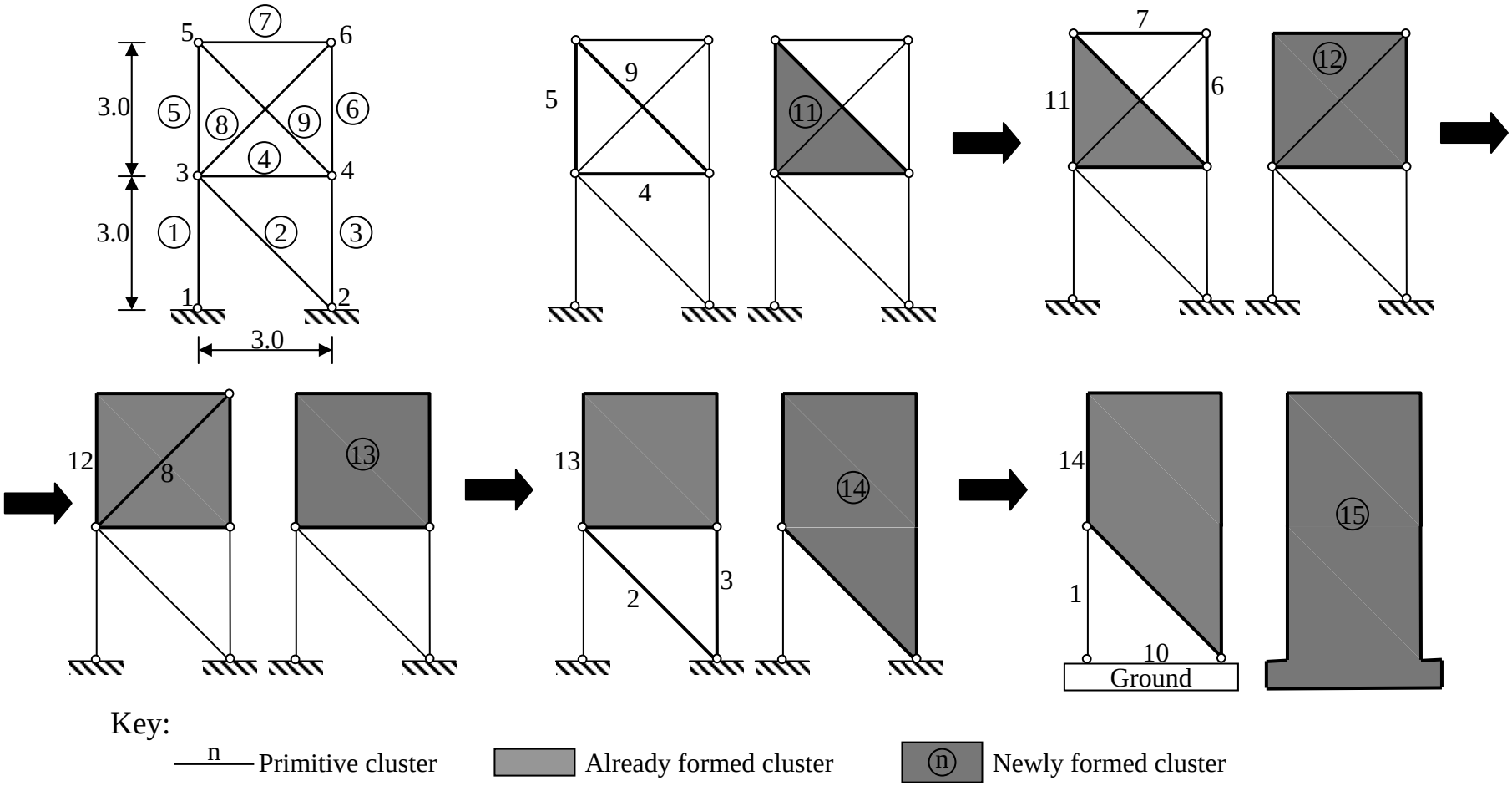
Structural Vulnerability Analysis

- Cluster
  - a set of tightly connected structural components

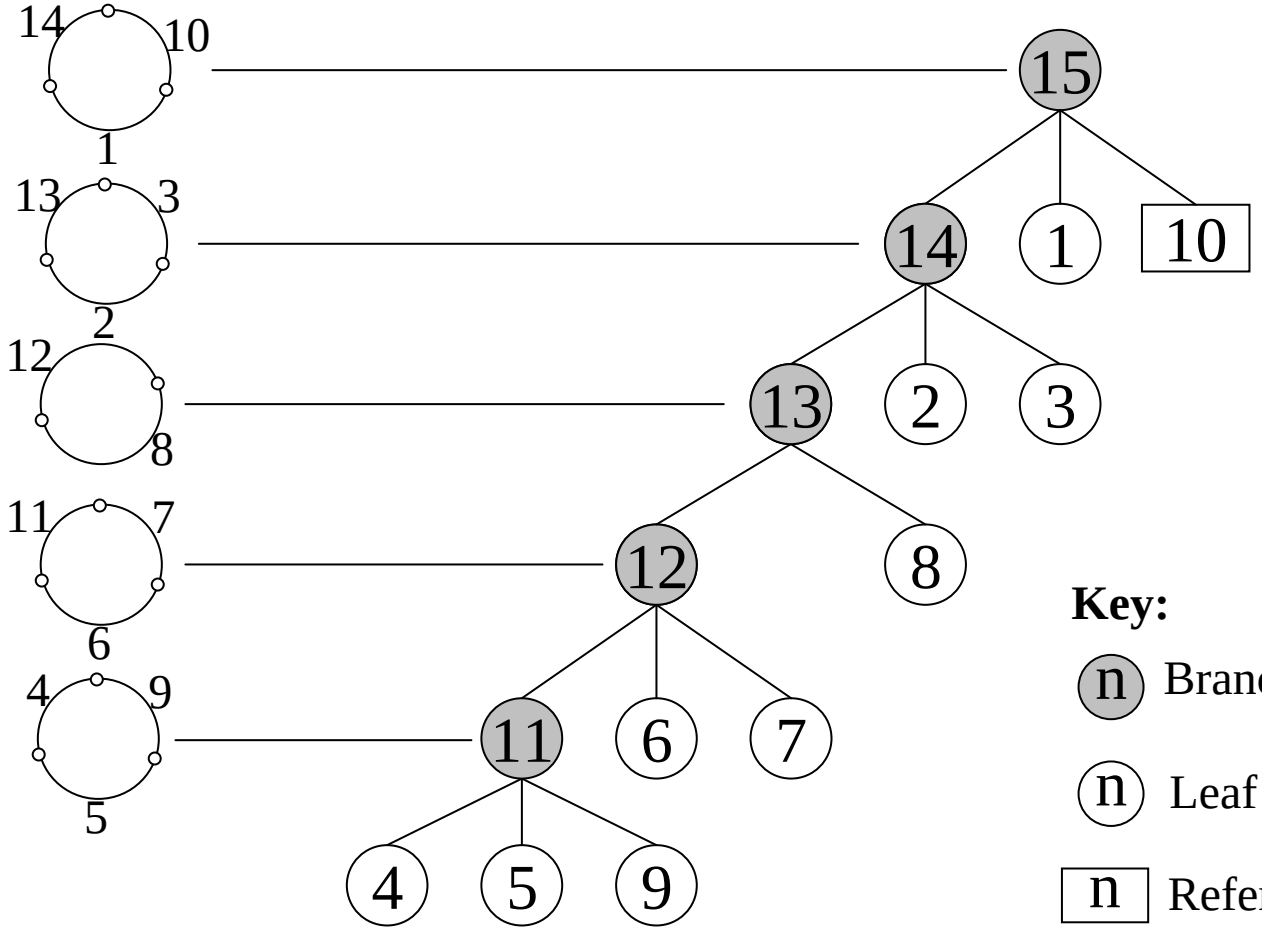
- Clustering criteria
  - Well-formedness
  - Minimum damage demand
  - Nodal connectivity
  - Distance from reference

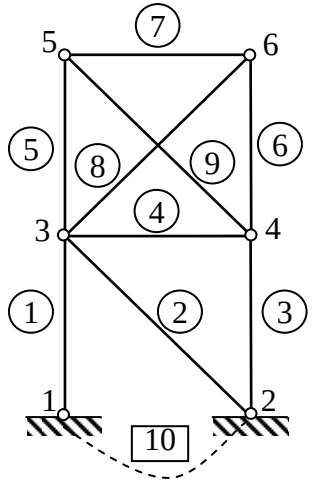
- Hierarchical representation of the system

Structural Vulnerability Analysis



Structural Vulnerability Analysis





Key:

n Branch cluster

n Leaf cluster

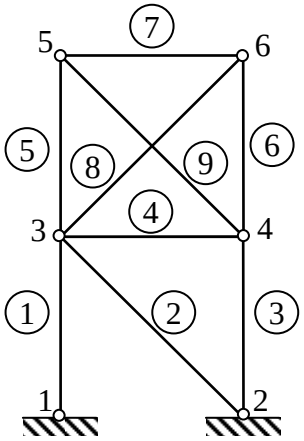
n Reference cluster

Structural Vulnerability Analysis

- Unzip the hierarchy in a specific way to find vulnerable failure
  - not a reference cluster
  - forms a ring with the reference cluster
  - connects directly to the reference cluster
  - a leaf cluster rather than a branch cluster
  - least well-formedness
  - least minimum damage demand
  - clustered the latest

Structural Vulnerability Analysis

- Maximum failure scenario (2)
  - large failure with least effort
- Minimum demand failure scenario (2)
  - easiest way to damage a structure
- Minimum failure scenario (8 or 9)
  - causes the least loss of form of the structure
- Total failure scenario (1 or 2)
- Specific failure scenario



Structural Vulnerability Analysis

- Damage demand
  - effort required to damage members
  - member properties
- Consequence
  - relative change in well-formedness
  - form of the structure
- Vulnerability index
  - consequence in proportion to damage demand

Managing Structural Risks

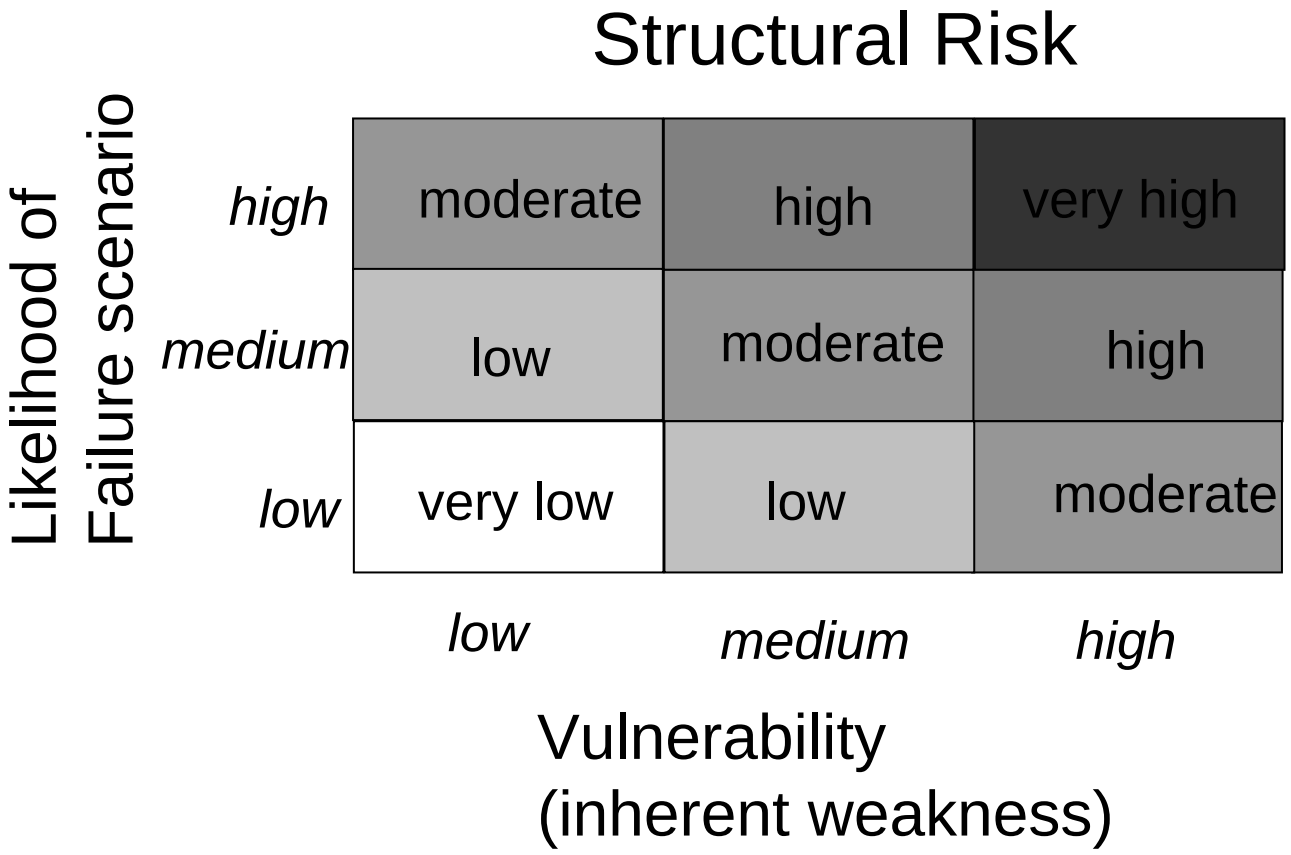
- Structural vulnerability
  - about the relative size of the consequences of damage to the effort in producing that damage
  - no matter the chance of it happening

- Vulnerability + Threat = Risk
- Chance of threat is equally important to manage the risks

Managing Structural Risks

- Threat may be due to one or more actions
  - Extreme natural hazards
  - Degradation of material
  - Accidental damage
  - Intentional damage
  - ….
- Identify actions for each failure scenario

Managing Structural Risks



Managing Structural Risks

- Modify or protect the vulnerable parts
- Monitor or remove the actions causing high risks

Conclusion

- Vulnerability analysis examines the form
- Vulnerable failure scenarios identified
- Risk can be managed by improving the form or controlling the actions
- Flexible and adoptive approach for *known* and *unknown* actions