ASSOCIATION OF CONSULTING STRUCTURAL ENGINEERS NSW

ENGINEERING IN THE PUB 2020

Finite Element Analysis Software

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Modelling Philosophy

- ✗ Series of instructions "cook-book"
  (training > skills)

- ✓ Understanding of the principles and underlying theory and awareness of the issues.
  (education > knowledge)

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Computer Modelling

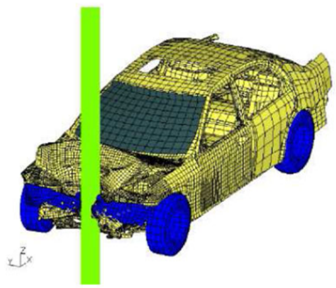
Figure: Crash test for automobiles

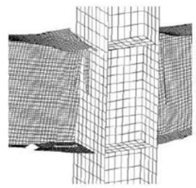
Figure: Fracture in steel connections

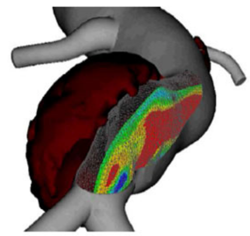
Figure: Human hearth

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Modelling: Definition

- Devise a representation, by an appropriate simplification of reality, of a phenomenon or system.
- Engineering Modelling – 2 Parts

  1) Physical / Empirical Modelling:
  - used to develop equations to describe the physical reality
  - e.g. laboratory tests, scale wind tunnel tests

  2) Theoretical Modelling:
  - using a mathematical model of the phenomenon or system based on relevant underlying assumptions to predict its behaviour before it occurs.
  - e.g. theory of elasticity, finite element computer analysis.

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Modelling: Definition

- **Mathematical Model:** description of a physical event using mathematical concepts by identifying the parameters that influence the physical reality and constructing relationships between these parameters.
    - **Analytical Model / Solution:** mathematical models that have a closed form solution (can be expressed as a mathematical analytical function).
    - **Numerical Model / Solution:** mathematical models that use numerical stepping procedure to obtain the phenomenon or system's behaviour at a point in space and time.
- **Computer Modelling:** simply modelling with the assistance of computer.

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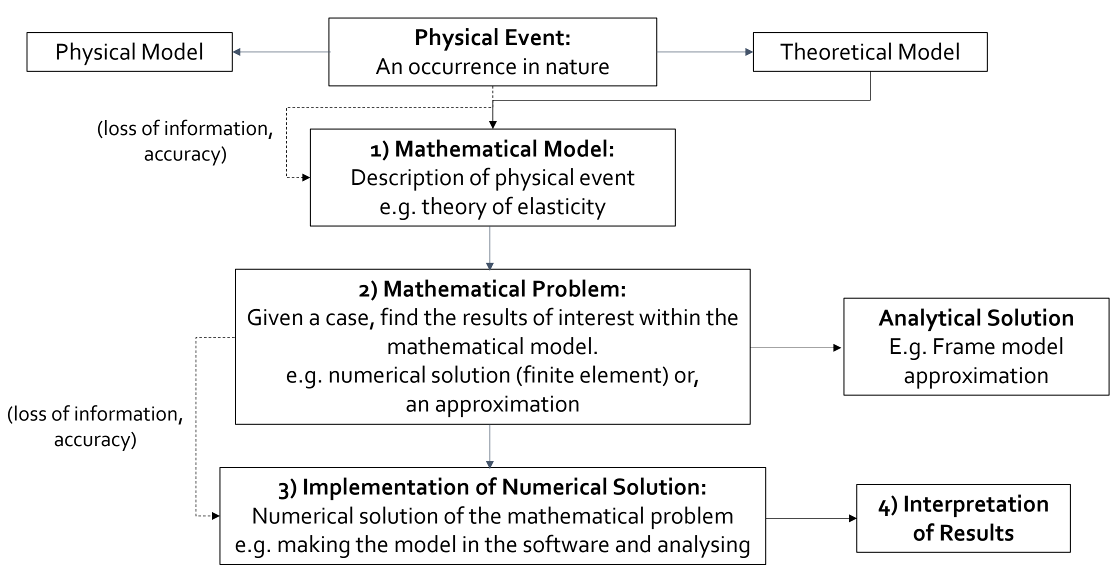
Modelling Procedure



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Structural Modelling: The Challenge

- Predict structural response of a non-existent structure.
- Response: behaviour under different loading conditions.
- Main Concerns:
  - Accuracy
  - Efficiency
- Computer model only as accurate as the mathematical model.

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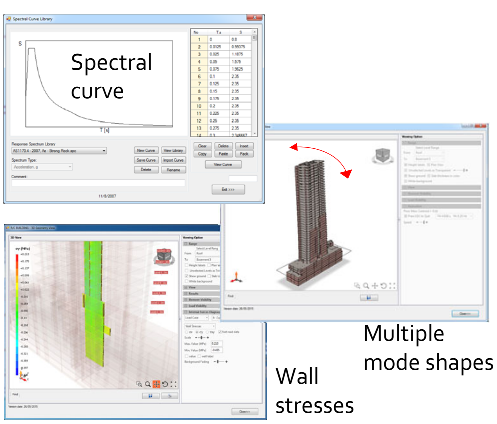
Mathematical Problem

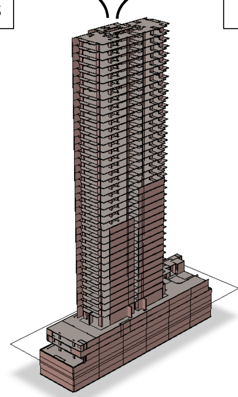
Building's Response Under Earthquake Loading

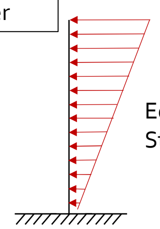
Numerical Solution:
3D Dynamic Spectral Analysis

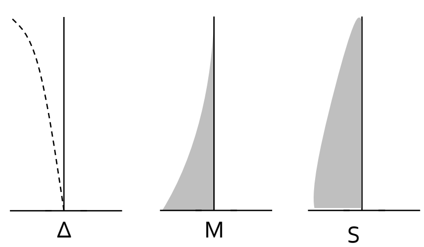
...or

Analytical Solution:
Stick 2D cantilever









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Structural Modelling Using Software

?? Input ?? → "Black Box" Computer Software → ?? Output ??

- FEA Theory
- Engineering Theory

?

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Why FEA Software is considered to be a "Black Box"

- FE Theory is complicated.
  - Numerical solution of higher order partial differential equations.
  - Results of complex structural systems can be difficult to rationalise.
- Implementation is complicated.
  - Must use computer programs.
  - Technology is still inaccessible to / avoided by some.
- Insufficient education.
  - Lack of knowledge of more complex engineering principles.
    - Plate Theory
    - Dynamic Analysis
- Hesitation to use / trust FEA.

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Design Codes - making things more confusing

- Insufficient and confusing instructions for some cases.
- Prone to interpretation.
- Too complicated.
- Incomplete
  - Many gaps
- Too old
  - Does not reflect current design practice and state of the art of science
- Not sufficient for buildings.

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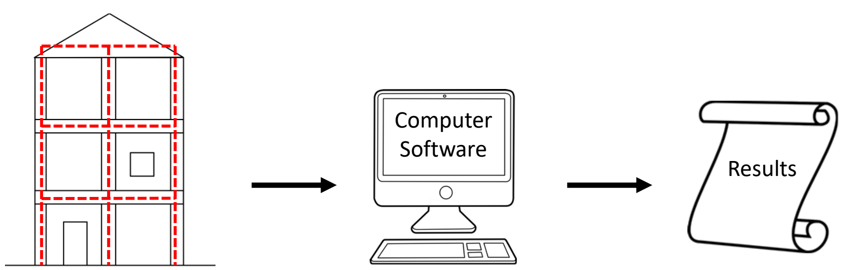
Modelling Process - How it is commonly perceived



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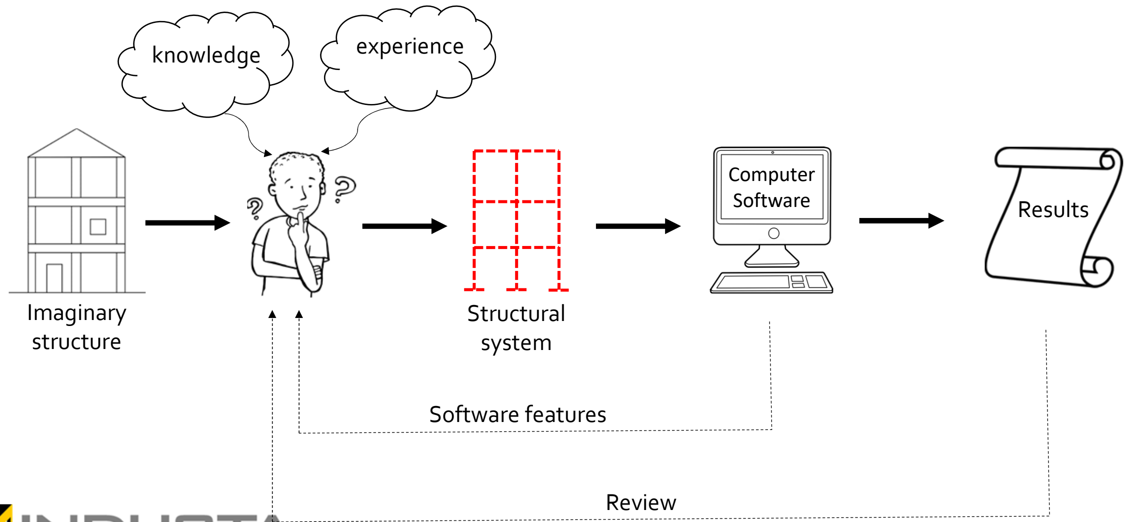
Modelling Process - Reality



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Two Major Aspects in Modelling

- Overall Philosophy / General Approach e.g.
  - stick model (1D) or 2D or 3D model
  - linear vs non-liner analysis
- Details e.g.:
  - column ends rigid link
  - how to model the header beam
  - how to model the soil
  - stiffness of elements
  - other items covered in "Modelling Specific" Section

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Finite Element Analysis

Overview

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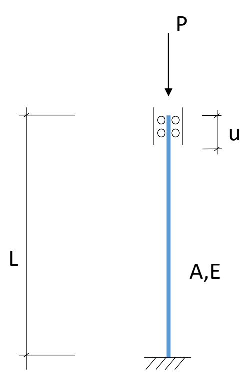
Basic Concept - Stiffness



$K \cdot u = P$

$K = A * E$

Solve for u (unknown)

$u = \frac{P}{K}$

Once u is known, calculate internal stresses:

$\varepsilon = \frac{u}{L}$

$\sigma = E\varepsilon$

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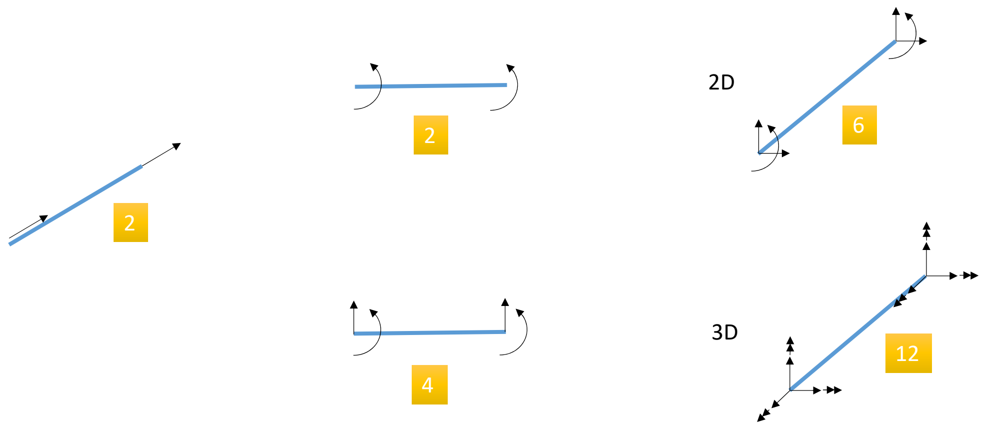
Degrees of Freedom
Frame Element (Beam and Column)



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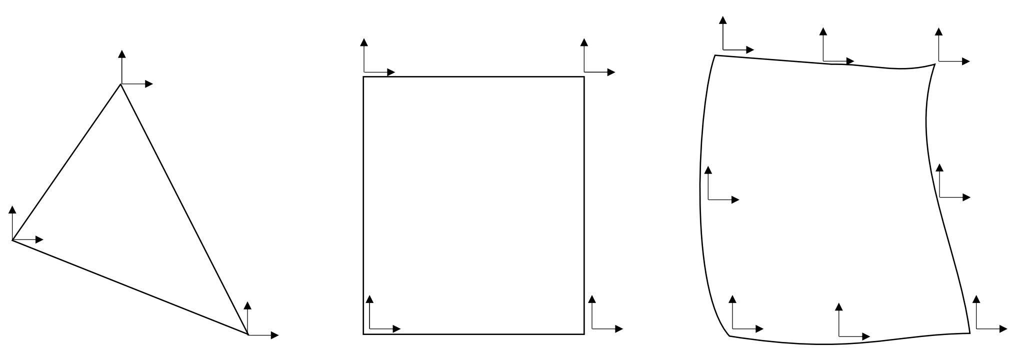
2D Stress Problems



In-plane stresses

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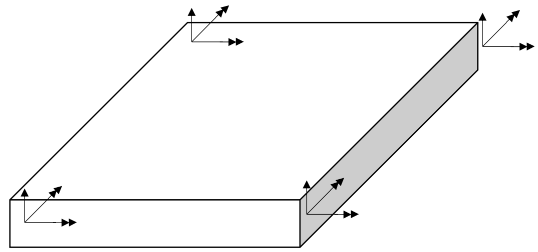
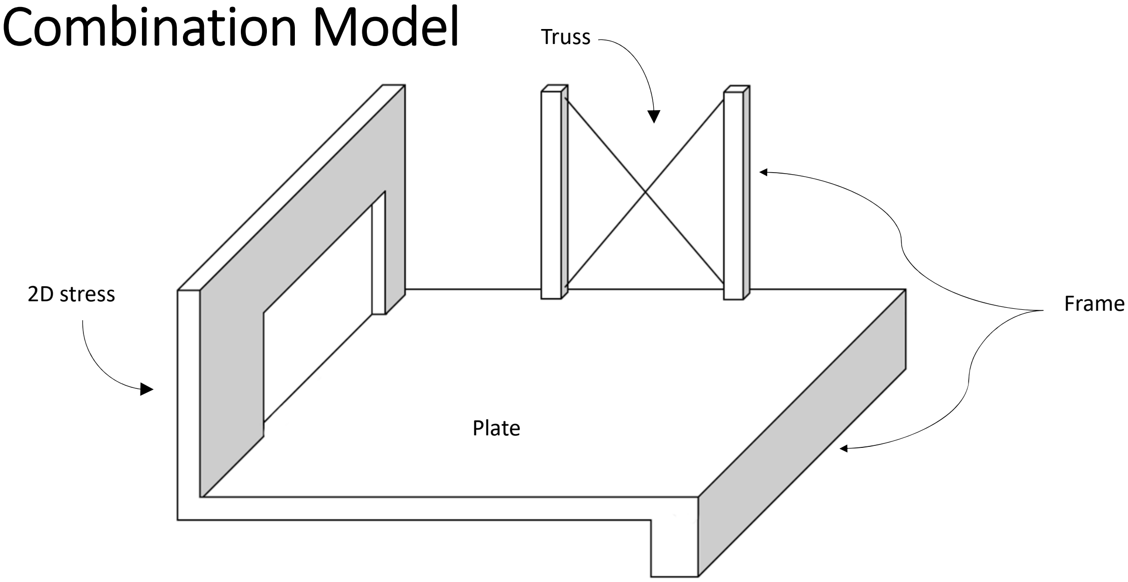
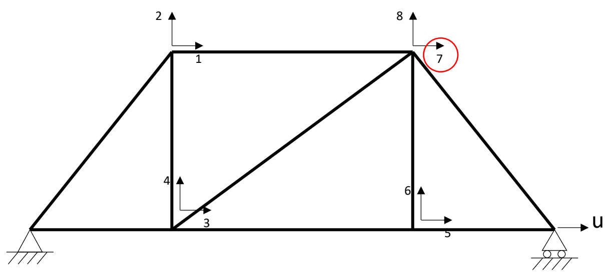
Plate Bending



Combination Model



FE Procedure – Structure D.O.F.



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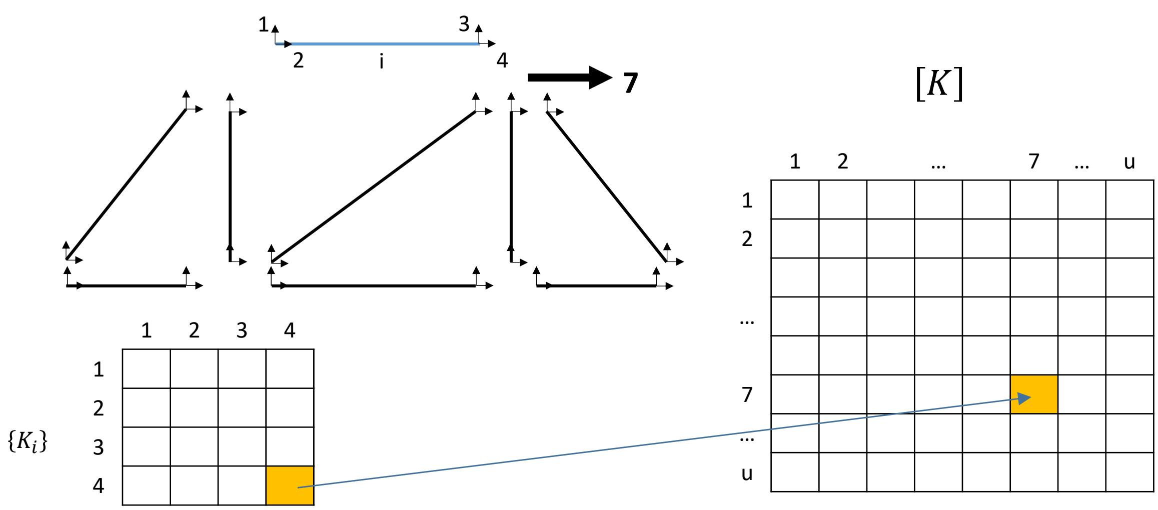
FE Solution – Stiffness Assemble



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FE Solution - … Unknowns

$$[K]\{u\} = \{P\}$$

Known:
- Structure (stiffness)
- Loading

$$\{u\} = \begin{matrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{matrix} \begin{Bmatrix} \dots \\ \dots \\ \dots \\ \dots \\ \dots \\ \dots \end{Bmatrix}$$

Solve: Deformations

$$\varepsilon = f(u)$$

$$\sigma = f(\varepsilon, u)$$

Derive: Internal Forces

Use σ for strength design

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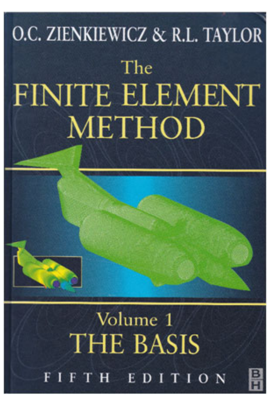
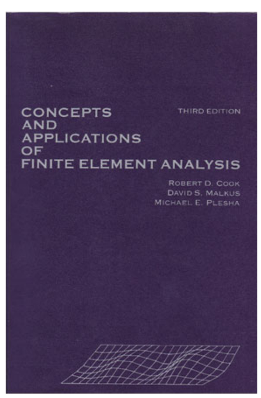
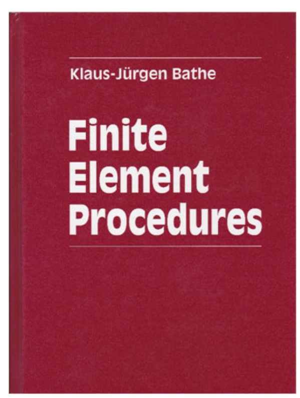
Reference Books







Finite Element – Fundamental Theory and Numerical Solutions

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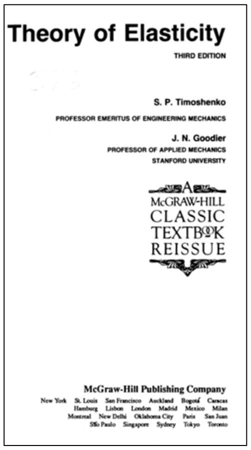
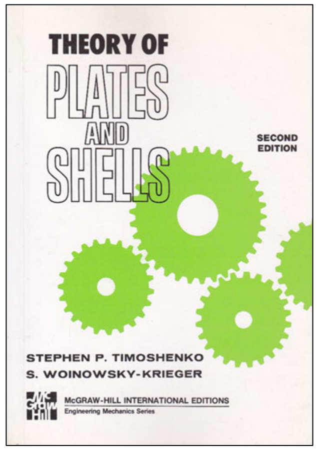
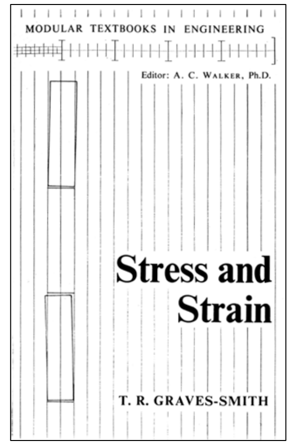
Reference Books







Theory of Elasticity and Plates and Simple Stress Analysis

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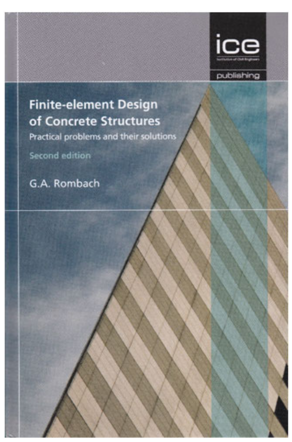
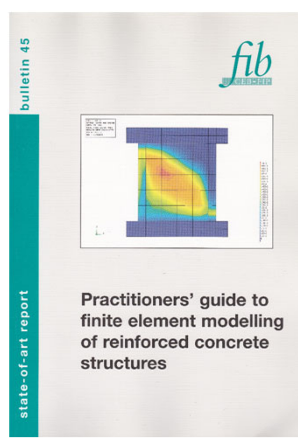
Reference Books





Practical guidelines for finite element modelling

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FEA Software

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Software for Structural Analysis and Design

General purpose or **problem specific?**

- Which software is better: ✗
- Which software is more accurate: ✗
- Which software is easy to use: ✗
- Modelling speed: ✓
- Complexity: ✓
- Familiarity: ✓
- Widely accepted: ✓
- Integrated design: ✓
- Do the design features reflect local practice: ✓

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Software Types

	Analysis	Integrated Design	Manual Design
General Purpose FEA	✓	✗	✓
Problem Specific (Buildings)	✓	✗	✓
	✓	✓	✗

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The Ideal Approach to Structural Modelling

Two models
Two different software
Two different engineers
...Compare results

- Expensive
- Time consuming
- Too hard to match
  - Difference in underlying assumptions:
    - Modelling assumptions of the engineer
    - Varying built-in settings of different software.
- Conflicts: which set of results to use/trust?

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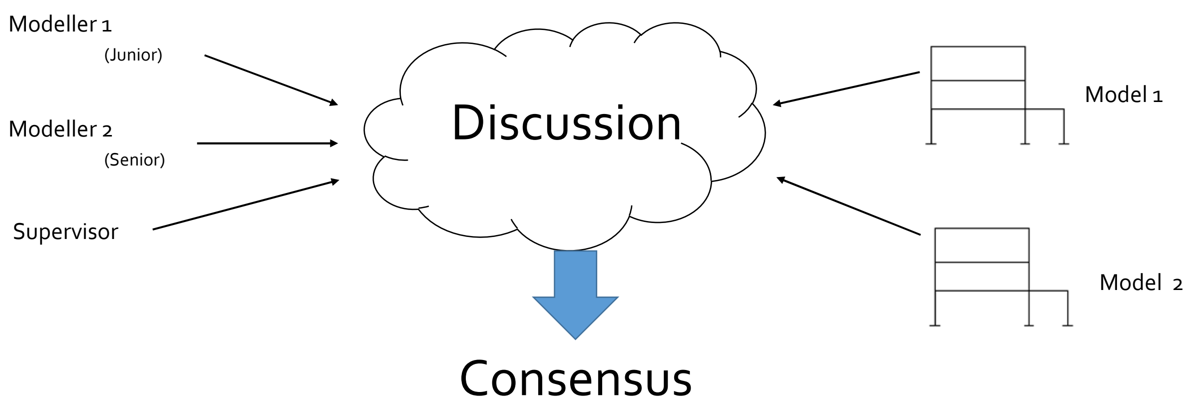
Modelling Review/Check

3 People:

2 Models / Different software:



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Structural Modelling: Approach

- **Several Models of increasing complexity**
- **Start with simple models (prelim design)**
  - **Quickly understand the general behaviour of the structure.**
  - **Hard to rationalise the results of complex models.**
    - **Seemingly simple structures can have complex load paths for example.**
- **Several iterations of the structural model as the design progresses.**

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How to check the results?

- Understand structural response (behaviour)
- Sensitivity analysis
  - Vary input parameter to determine overall effect on final results
- Simple hand calculation
  - Does not always match complex model (FEA vs stick cantilever)
- Start with simple, increase complexity
- Some results cannot be checked

The model has to be as simple as possible, but sufficient to capture the behaviour used in design.

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Modelling Specific Details

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Modelling Specifics

- Structural system
- Elements
- Connections
- Supports
- Stiffness

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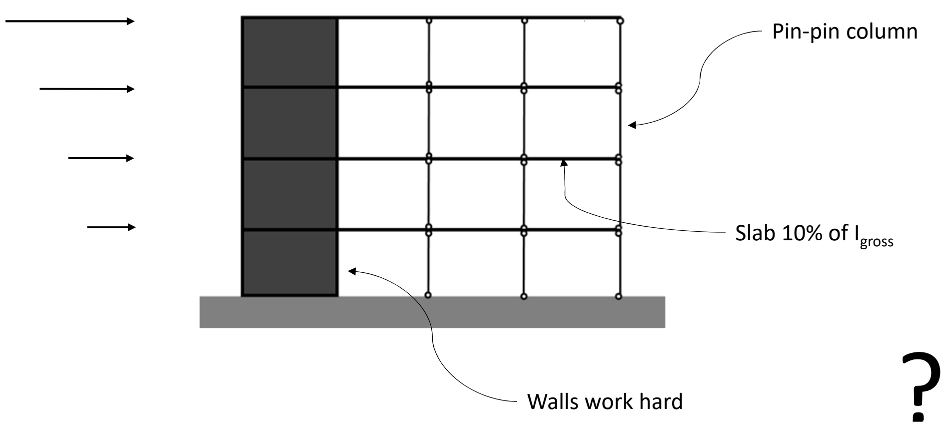
Stiffness Manipulation



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Stiffness manipulation can "hide" problems

- The model does not represent the structure
- Walls are over-designed
- Columns are under-designed:
  - No M in columns
  - Increased N due to overturning
- No clear understanding of the structural response

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Suggested Modelling Approach

- No stiffness manipulation
- Model to capture the structural response as closely as possible.
- Apply safety (conservatism) at the very end on the final results.

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Final Remarks on Structural Modelling

- Minimum complexity to capture structural response
- Do not "skew" the model (no stiffness manipulation)
- Understand structural response
- Apply conservatism at the end of modelling to the entire structure.

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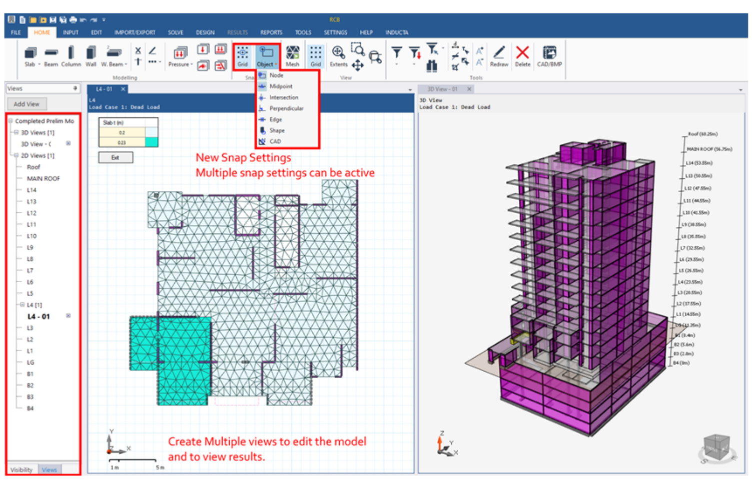
Version 2.0: Coming July / August 2020

- New Graphics Engine:
  - Improved CAD & Bitmap importing.
  - Displaying results, mesh and colouring is faster.
  - Editing features are faster and more intuitive to use.
  - Cleaner model can be created faster than ever before!
- Available for RCB, SLB and PTD.
- Version 2.0 update is free for all users with an active license.
- Contact info@inducta.com.au for a free trial.



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