Ministry of Economics
Republic of Latvia

Apmācību semināru cikls
«Datoraprēķini būvkonstrukciju projektēšanā»

ID Nr. EM 2020/46

Rīga, 2020

Ministry of Economics
Republic of Latvia

Training seminar / Apmācību seminārs

Good Practice in Finite Element Analysis (FEA)
Laba prakse aprēķinos ar galīgo elementu metodi (GEM)

October 5, 2020, Riga

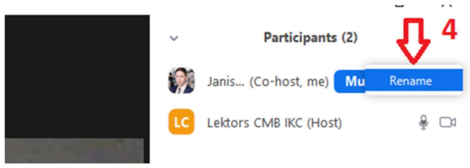
Peter Debney (United Kingdom)

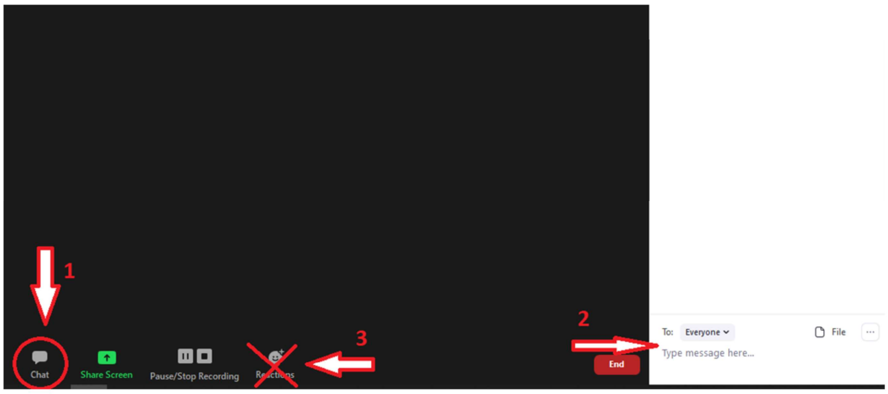
Agenda

09:00 – 10:00	**Registration**
10:00 – 11:30	Introduction Finite Element Analysis (FEA main principles, advantages, and disadvantages How to avoid common mistakes in FEA modelling Checking, validation, and interpretation of FEA results
11:30 – 12:00	Coffee break
12:00 – 13:30	Finding hidden modelling errors and inaccuracies in FEA results Making good structural analysis models – best practices and reducing errors
13:30 – 14:00	Lunch break
14:00 – 15:30	FEA specifics in reinforced concrete structures and design FEA specifics in timber, steel, and other nonlinear structures design Future of digital structural engineering
15:30 – 16:00	Question and answer session

Asking questions

1. For questions use the chat functionality
2. Enter your question at the chat window on the right side
3. Do not use the reactions
4. Write your full name





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Agenda / 10:00 - 11:30

Introduction

- Finite Element Analysis (FEA) main principles, advantages, and disadvantages
- How to avoid common mistakes in FEA modelling
- Checking, validation, and interpretation of FEA results

Coffee break / 11:30 - 12:00

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Agenda / 12:00 - 13:30

- Finding hidden modelling errors and inaccuracies in FEA results
- Making good structural analysis models – best practices and reducing errors

Lunch break / 13:30 - 14:00

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Agenda 14:00-15:30

- FEA specifics in reinforced concrete structures and design
- FEA specifics in timber, steel, and other nonlinear structures design
- Future of digital structural engineering

Agenda 15:30 -16:00

Question and answer session

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Training seminar / Apmācību seminārs

Introduction. Finite Element Analysis (FEA) main principles. How to avoid common mistakes in FEA modelling?

Ievads. Galīgo elementu metodes (GEM) galvenie principi. Kā izvairīties no ierastām kļūdām GEM modelēšanā?

Peter Debney (United Kingdom)

Introduction

Peter Debney
BEng(hons), CEng, FIStructE

The Institution of StructuralEngineers
Fellow

ARUP

Oasys

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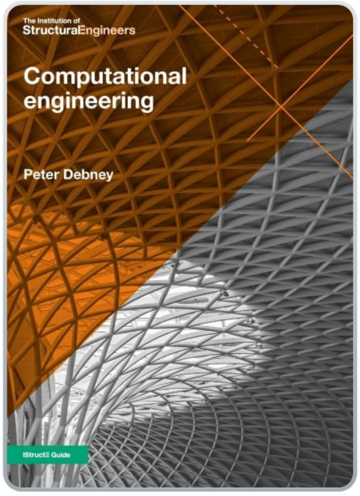
Computational Engineering

The Institution of Structural Engineers

https://bit.ly/IStructE_CE

"This is the best structural engineering book I've read, irrespective of computation."
Stephen Melville
Format Engineers



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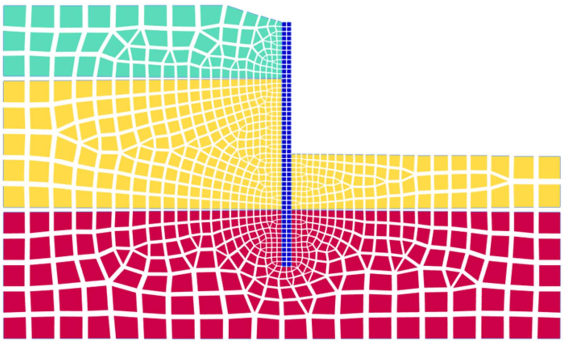
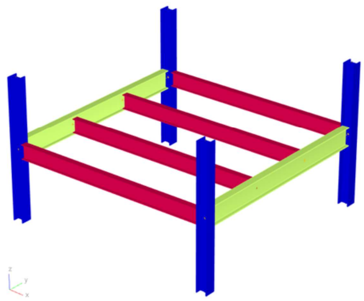
Finite Element Analysis

Main principles, advantages, and disadvantages

Universal Analysis

- Finite Element Analysis (FEA) / Finite Element Method (FEM)
  - Analyse any structure and any material (though some are more suitable than others)
  - Analyse static and dynamic, linear and nonlinear problems
  - Quality of results is dependant on the suitability and quality of the software, model, and analysis method chosen





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Universal Analysis

- Finite Element Analysis includes many methods
  - Static linear analysis (stiffness matrix)
  - P-delta analysis (stiffness matrix + geometric stiffness matrix)
  - Buckling analysis (eigenvectors | eigenvalues of stiffness + geometric stiffness matrices)
  - Modal analysis (eigenvectors | eigenvalues of stiffness + mass matrices)
  - Nonlinear analysis
    - Newton Raphson method (multi-step P-delta analysis)
    - Dynamic relaxation | Explicit solvers (no matrix but displace until equilibrium is found)
    - Meshless and particle methods (no elements)

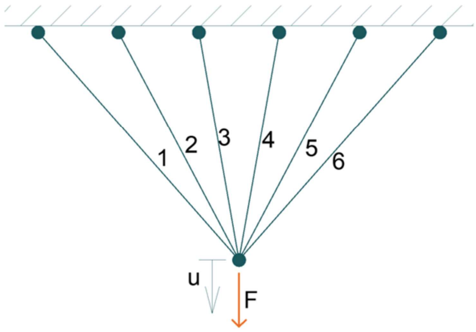
Stiffness Method

FEM basic concepts:

- The whole structure is in equilibrium
- Every node is in equilibrium
- Every element is in equilibrium
- The force (f) in an element equals the deflection (u) times stiffness (k)
  - $f = ku$
- The external forces and element stiffness are known – the deflection is unknown
  - $u = f/k$
- Write equations for every node, group in a matrix, and solve:
  - $\{f\} = [K]\{u\} \Rightarrow [K]^{-1}\{f\} = \{u\}$

Stiffness method

- We do not know how much the node will move, but we do know that it will move an amount u
- The distance moved will be a function of the force and the sum of the stiffnesses of all the elements
- The node is in equilibrium so the sum of the forces in elements 1-6 = F
- The strain of each element is a function of the element stiffness ($EA/L = K$) & the force (f)
- $F = \Sigma\left(\frac{AE}{L}\right)u \Rightarrow F = Ku$



Stiffness method

- Pre-processing (model creation)
  1. Define the model as nodes connected by elements (or elements connected at nodes)
  2. Apply properties to the elements
  3. Apply constraints to model (eg restraints on nodes)
  4. Apply actions to the model (forces, moments, thermal, etc)

Stiffness method

- Processing (solver)
  1. Calculate individual element stiffness matrices and assemble into global stiffness matrix
     - $[K]$
  2. Apply boundary conditions (remove lines and columns with zero movement) and invert
     - $[K_r] \rightarrow [K_r]^{-1}$
  3. Multiply inverted stiffness and forces matrices to get displacements
     - $\{u\} = [K_r]^{-1}\{f\}$
  4. Multiple full displacement matrix by element stiffness matrix to find reactions
     - $\{f\}=[K]\{u\}$
  5. Use the displacement matrix to find strains, stresses, moments, etc.
     - $\{u\} \rightarrow \varepsilon, \sigma$, BM…

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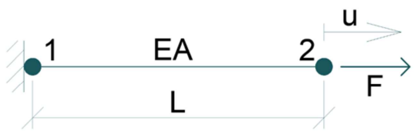
Stiffness method

- Post Processing (results)
  1. Multiple and combine results for serviceability and ultimate limit state results
     - Note: Linear analysis only
  2. Run design checks on elements
     - Calculate reinforcement or section size requirements
  3. Output results for records and reports

Matrix Maths

- Stress on bar equal to Young's modulus times strain
  - $\sigma = E\varepsilon$
- Stress is equal to the force divided by the bar's cross sectional area
  - $\sigma = \frac{F}{A}$
- Strain is extension over length
  - $\varepsilon = \frac{u}{L}$
- Substitute into first equation
  - $\frac{F}{A} = E\frac{u}{L}$
  - $F = \frac{AE}{L}u$
  - $F = ku$



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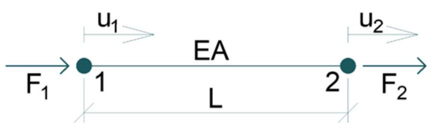
To keep things simple we will look only at Bar elements. Other element types use similar principles, but with more complexity.

Matrix Maths

- End forces:

$$F_1 = \frac{AE}{L}(u_1 - u_2)$$

$$F_2 = \frac{AE}{L}(u_2 - u_1)$$



- Write in matrix form:

$$\begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix} = \frac{AE}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix}$$

- Where the element stiffness matrix is

$$K_e = \frac{AE}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

Matrix maths - example

- Combined Stiffness matrix of structure:

$$\begin{bmatrix} k_{e1} & k_{e1} & 0 \\ k_{e1} & k_{e1}+k_{e2} & k_{e2} \\ 0 & k_{e2} & k_{e2} \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \end{Bmatrix}$$

$$\frac{AE}{L} \begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ P \end{Bmatrix}$$

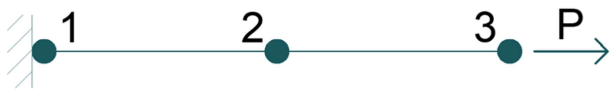
- Remove rows and matching columns where the displacement is constrained to be zero

$$\frac{AE}{L} \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} \begin{Bmatrix} u_2 \\ u_3 \end{Bmatrix} = \begin{Bmatrix} 0 \\ P \end{Bmatrix}$$

Matrix maths - example

- Inverse of a 2x2 matrix

$$\frac{1}{ad-bc}\begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$$



- Multiply by inverse of stiffness matrix

$$\frac{AE}{L}\begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}\begin{Bmatrix} u_2 \\ u_3 \end{Bmatrix} = \begin{Bmatrix} 0 \\ P \end{Bmatrix}$$

$$\begin{Bmatrix} u_2 \\ u_3 \end{Bmatrix} = \frac{L}{AE}\begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}\begin{Bmatrix} 0 \\ P \end{Bmatrix}$$

- Multiply out to find displacements

$$u_2 = \frac{PL}{AE} \qquad u_3 = \frac{2PL}{AE}$$

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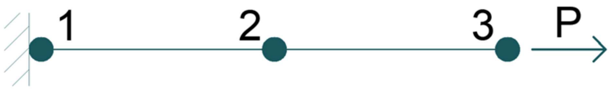
Matrix maths - example

- Substitute displacements into original matrix

$$\frac{AE}{L}\begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{Bmatrix} 0 \\ PL/AE \\ 2PL/AE \end{Bmatrix}=\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \end{Bmatrix}$$

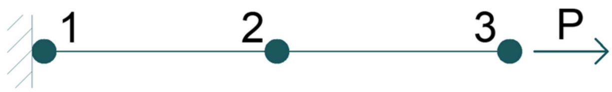


- Cancel out $\frac{AE}{L}$

$$\begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{Bmatrix} 0 \\ P \\ 2P \end{Bmatrix}=\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \end{Bmatrix}$$

- Calculate forces at nodes
  - Node 1 $F_1=(1\times 0)+(-1\times P)+(0\times 2P)=-P$
  - Node 2 $F_2=(0\times 0)+(2\times P)+(-1\times 2P)=0$
  - Node 3 $F_3=(0\times 0)+(-1\times P)+(1\times 2P)=P$

Matrix maths - example



- Calculate forces in elements from nodal displacement
- Strain in first element is

$$\varepsilon_1 = \frac{u_2 - u_1}{L}$$

$$\varepsilon_1 = \frac{PL/AE - 0}{L} = \frac{P}{AE}$$

- Force in element is:

$$F = A\sigma = AE\varepsilon$$

- Force in first element is:

$$F_1 = AE\frac{P}{AE} = P$$

- Force in second element is the same

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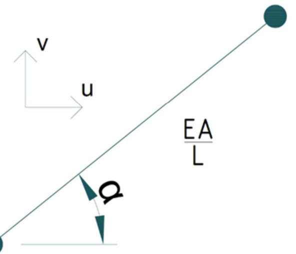
Matrix maths

- Bar element in two dimensions

$$[K_e]\{u_e\} = \frac{AE}{L}\begin{bmatrix} \cos^2\alpha & \cos\alpha\sin\alpha & -\cos^2\alpha & -\cos\alpha\sin\alpha \\ \cos\alpha\sin\alpha & \sin^2\alpha & -\cos\alpha\sin\alpha & -\sin^2\alpha \\ -\cos^2\alpha & -\cos\alpha\sin\alpha & \cos^2\alpha & \cos\alpha\sin\alpha \\ -\cos\alpha\sin\alpha & -\sin^2\alpha & \cos\alpha\sin\alpha & \sin^2\alpha \end{bmatrix}\begin{Bmatrix} u_{1x} \\ u_{1y} \\ u_{2x} \\ u_{2y} \end{Bmatrix}$$

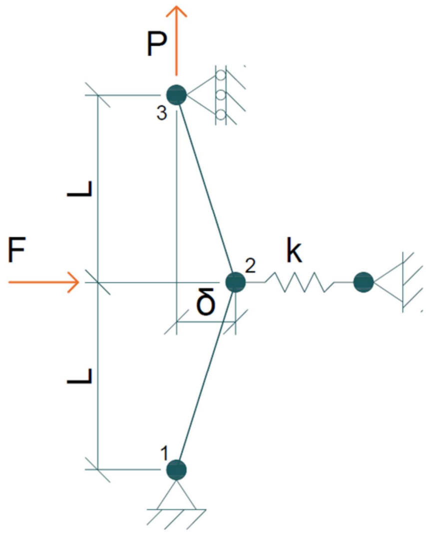
- Shortened form of stiffness matrix
  - $\cos\alpha = c \qquad \sin\alpha = s$

$$[K_e] = \frac{AE}{L}\begin{bmatrix} c^2 & cs & -c^2 & -cs \\ cs & s^2 & -cs & -s^2 \\ -c^2 & -cs & c^2 & cs \\ -cs & -s^2 & cs & s^2 \end{bmatrix}$$



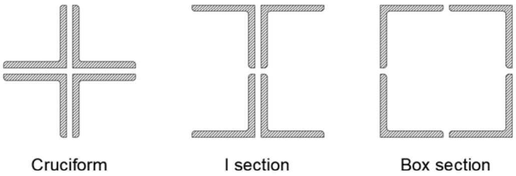
Linear vs Nonlinear – Analysis Assumptions and Simplifications

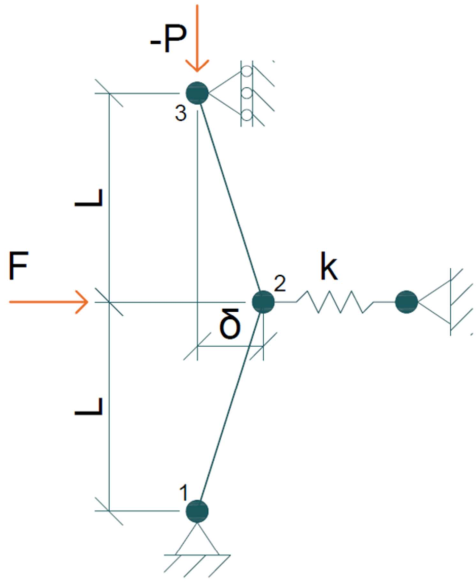
- Linear
  - Static analysis assumes deflections are small
  - Equilibrium is found at undeflected position
  - Linear relationship between loads, deflections, stresses and strains
  - Factored combinations are multiples of original results
- Nonlinear
  - Deflections can be large
  - Equilibrium is found at deflected position
  - Nonlinear relationship between loads, deflections, stresses and strains
  - Analyses must use factored load combinations



Linear vs Buckling – Analysis Assumptions and Simplifications

- Static linear analysis can produce forces that the structure cannot carry
  - Buckling
  - Yielding
  - Breaking
- Separate checks are required for structural capacity





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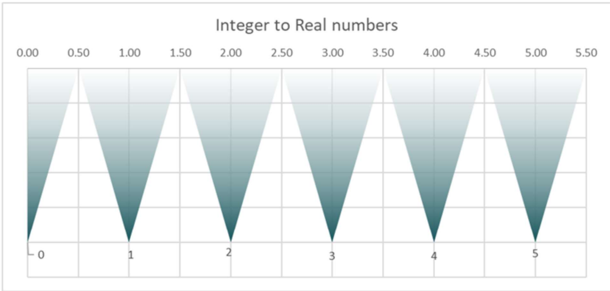
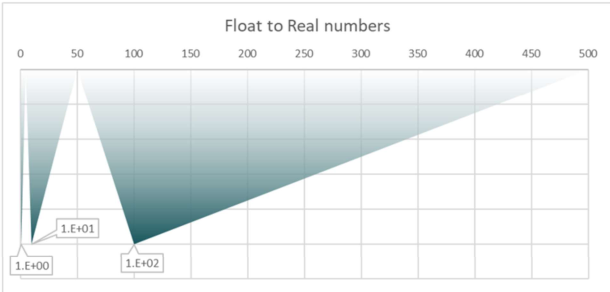
Analysis Assumptions and Simplifications

- Rounding:
  All numbers in a computer are approximate and represent a range of real numbers





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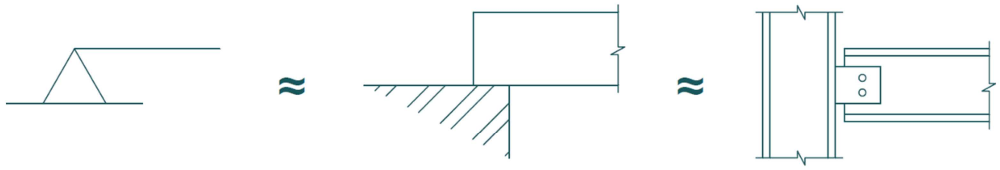
Analysis Assumptions and Simplifications

- No model can totally represent reality
  - Structural dimensions are approximate and probable
  - Material properties are approximate and probable
  - Loading is approximate and probable
  - All models are simplifications
- An art of engineering is to make suitable simplifications



Analysis Assumptions and Simplifications

The Stool Paradox

- How much load is in the leg of a stool?
  - If the stool has three legs the load is $^1/_3$
  - If the stool has four legs the load is not $^1/_4$ but $\sim {^1/_2}$
    - The floor is not perfectly flat
    - The stool is not perfectly even
    - One leg will be off the floor unless the chair is flexible enough to redistribute the load

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Short Question and Answer session

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How to avoid common mistakes in FEA modelling

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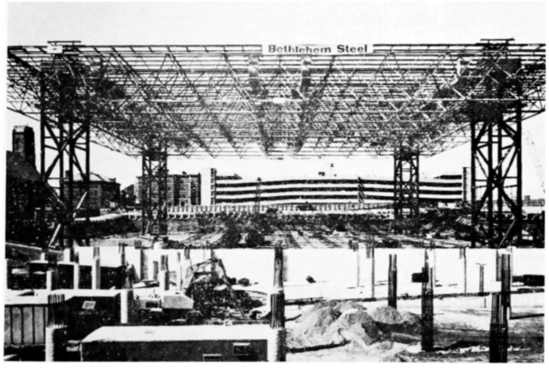
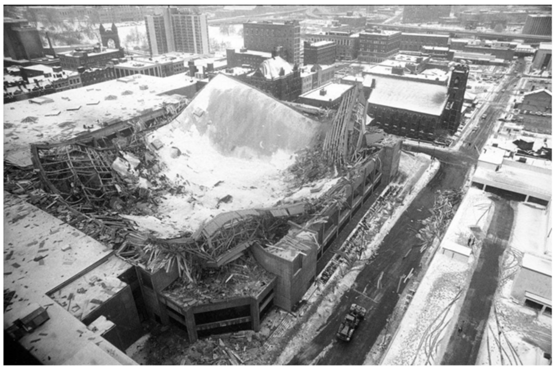
Models may be stable in 2D but not 3D

Hartford Civic Center – 1978

- On a snow night, a few hours after 14,000 sports fans had left the stadium, the Hartford Civic Center collapsed
- The cause: torsional buckling of the roof members





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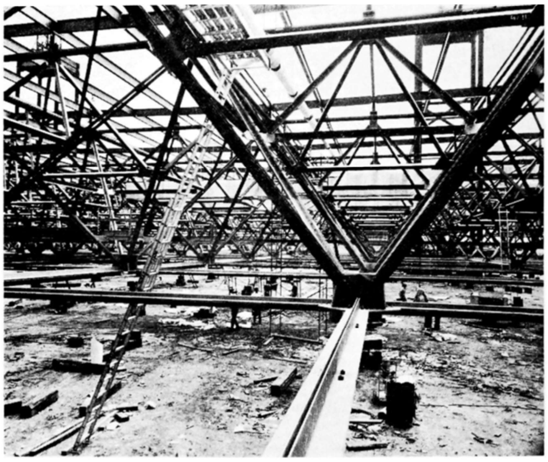
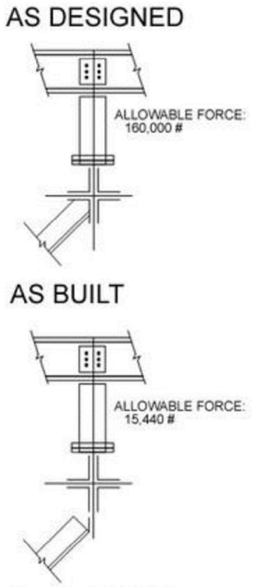
Hartford Civic Center collapse – no torsional capacity

- The sections had little torsional capacity
- The design did not expect torsion
- The construction added torsion





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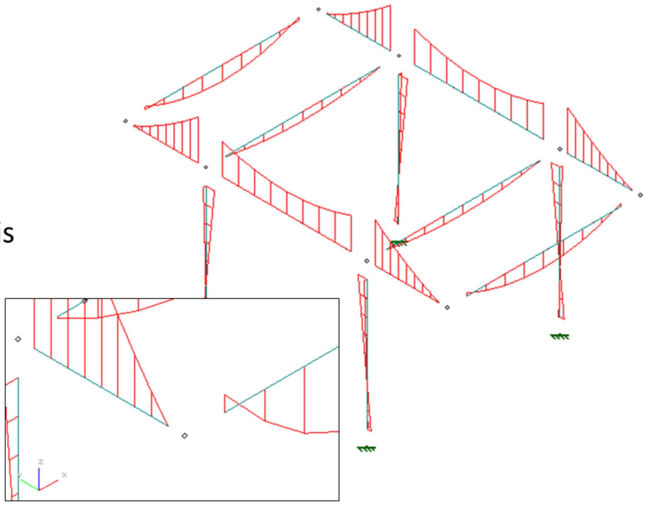
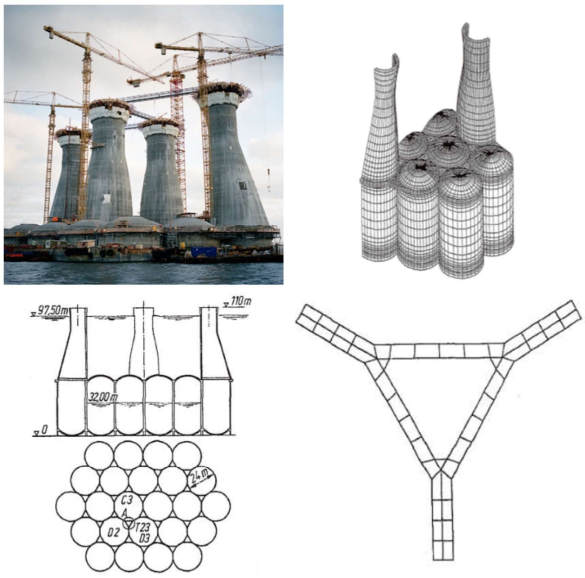
Torsion

- Some structures generate torsion on the member
- You must check for and design for this torsion

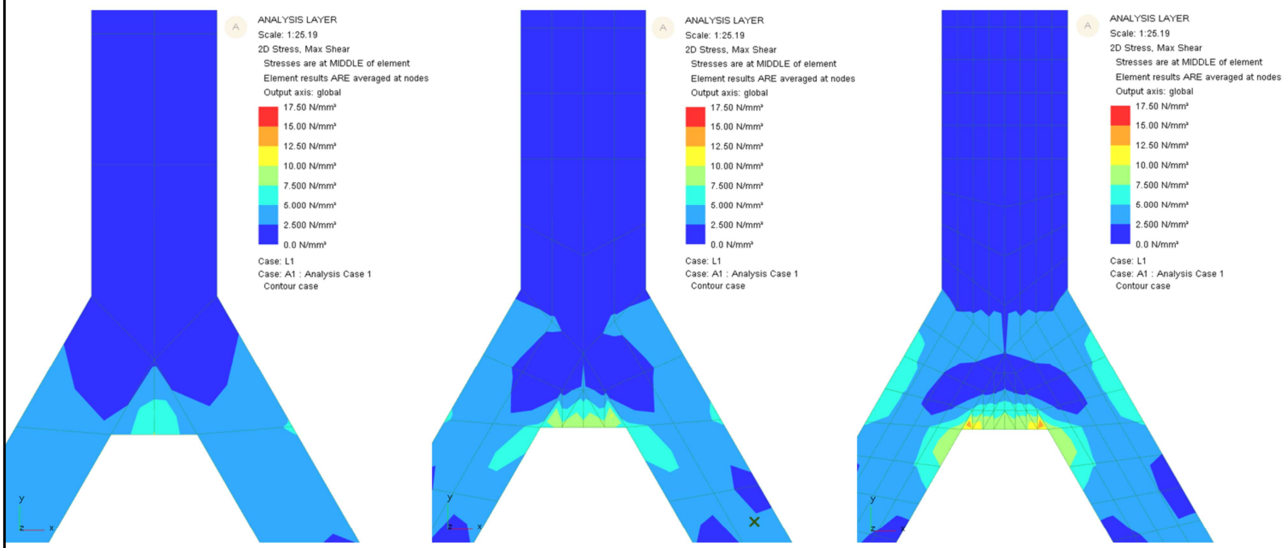


Meshing – Sleipner A collapse

- The quality of the results can depend on the element size
  - Too large and too small can be bad
- Sleipner A oil rig gravity base model was
  - Good for calculating overall behaviour
  - Bad for calculating detailed behaviour
  - Calculated shear stresses 50% of actual stresses
- A hand calculation would have saved $180,000,000 (1991 prices)

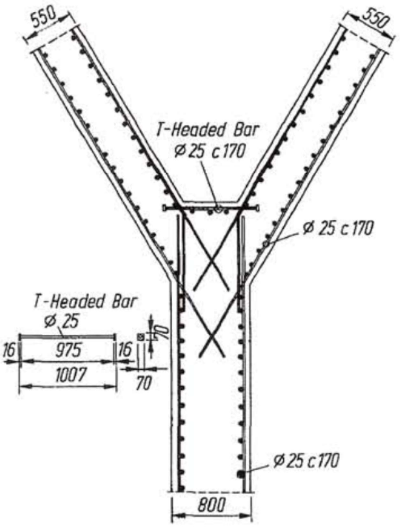


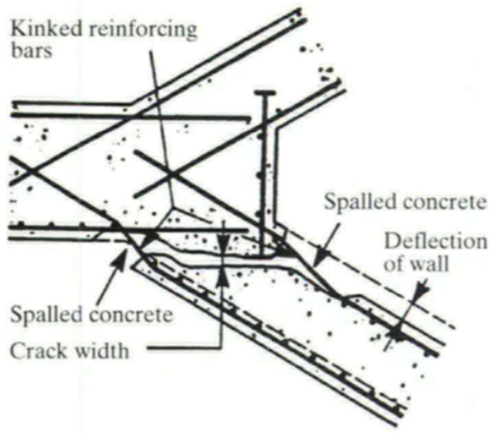
Meshing – Sleipner A collapse



Meshing – Sleipner A collapse

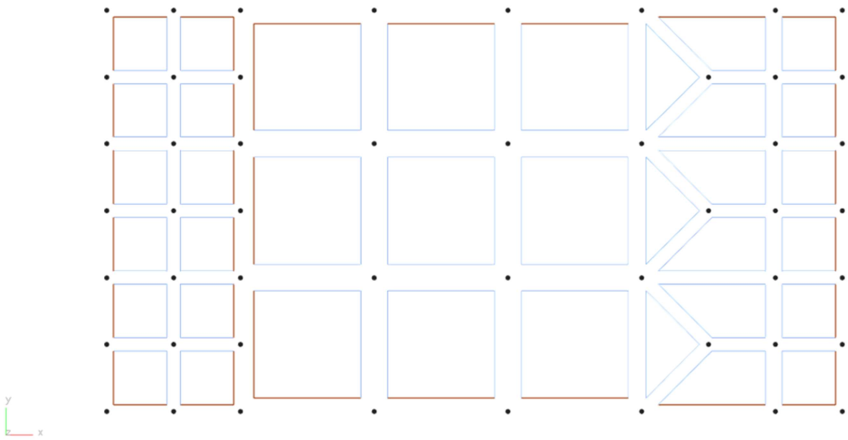
- The reinforcement detailing was also terrible…





Meshing errors - discontinuities

- Every node within a mesh must be connected to the surrounding elements



Meshing errors - discontinuities

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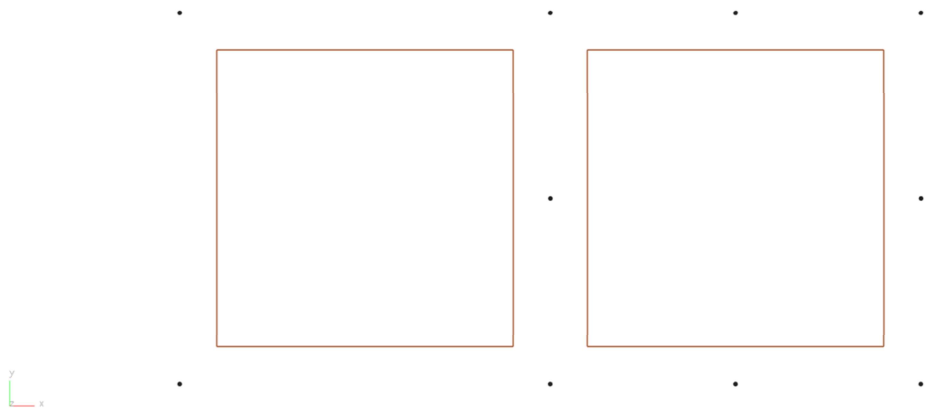
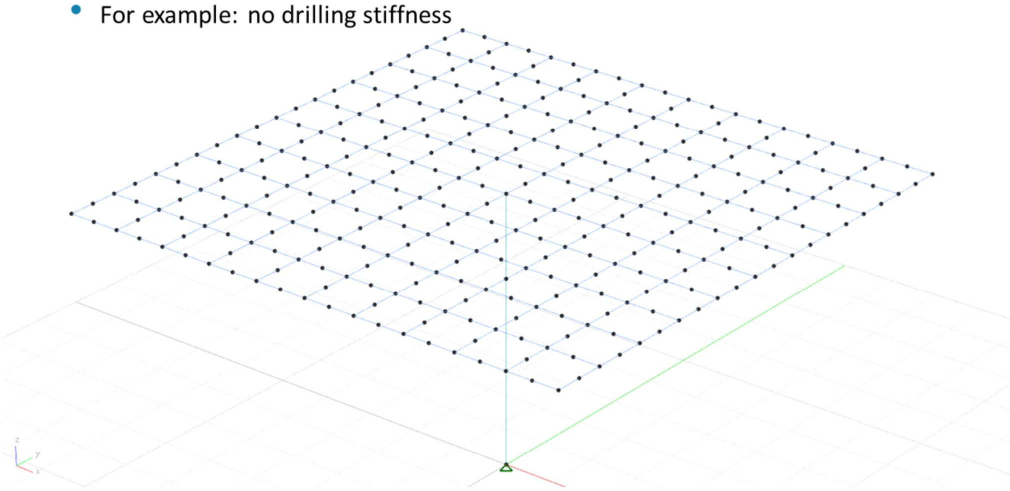


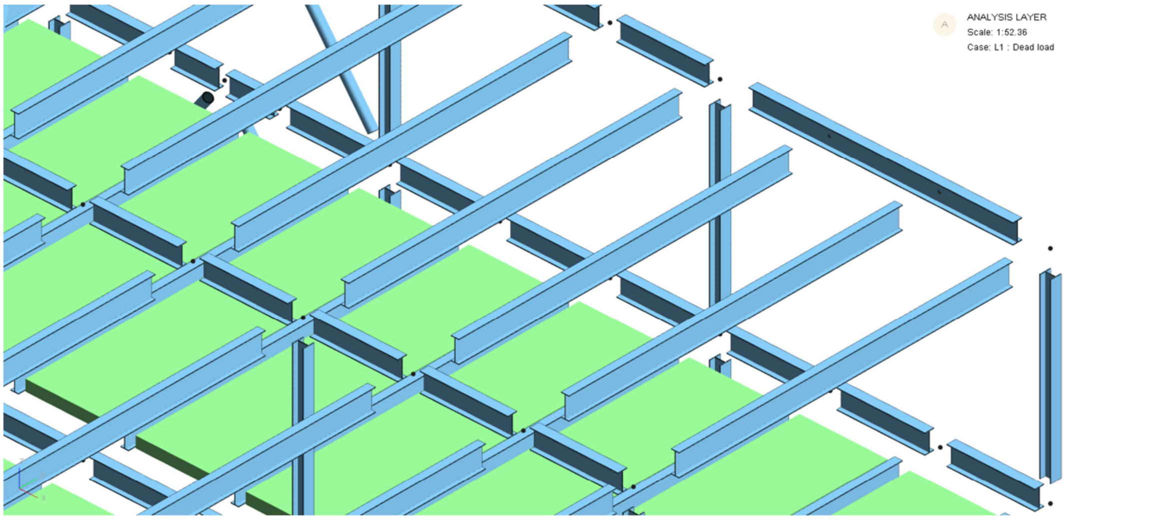
Meshing errors – single point connection instability

- Watch out for 1D / 2D connections where the 2D elements have less than 6 degrees of freedom
  - For example: no drilling stiffness



Connected or not?

- Ensure that everything that **should be** connected **is** connected

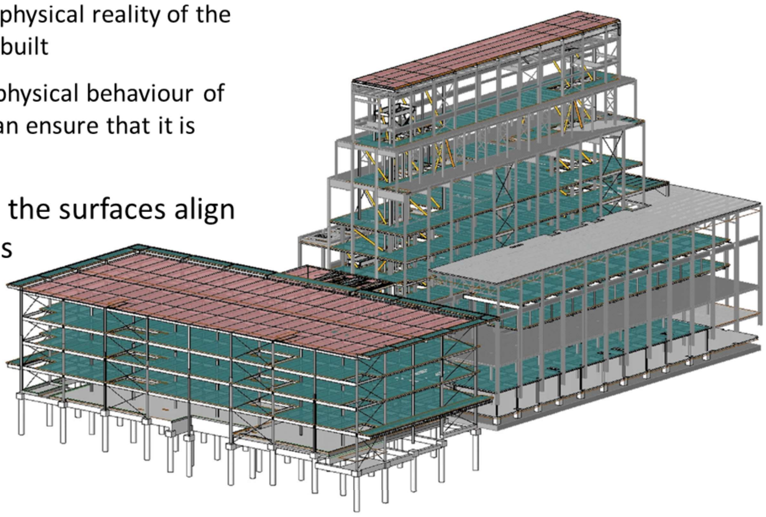


Units

- It is easy to use the wrong units
  - mm or m?
  - N or kN?
- Check deflections
- Check solid display
- Check total loads

Offsets

- FEA is not CAD
  - CAD should represent the physical reality of the structure so that it can be built
  - FEA should represent the physical behaviour of the structure so that we can ensure that it is strong and stiff enough
- Offsetting beams to make the surfaces align can add unexpected forces into the model



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Offsets

Two simply supported beams
One that is offset

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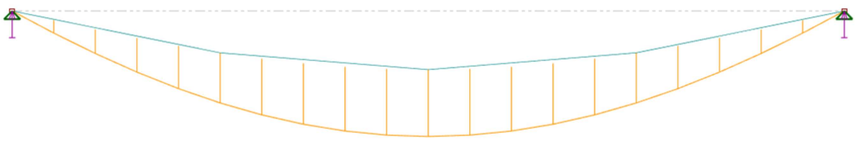
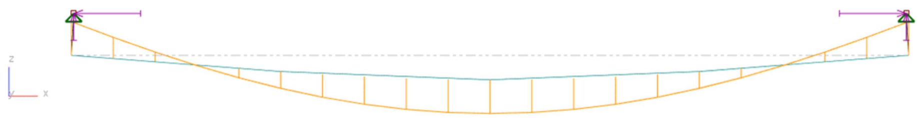
Offsets

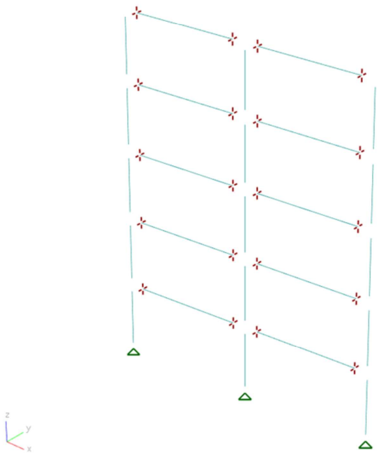


The offset beam has end moments and an axial force

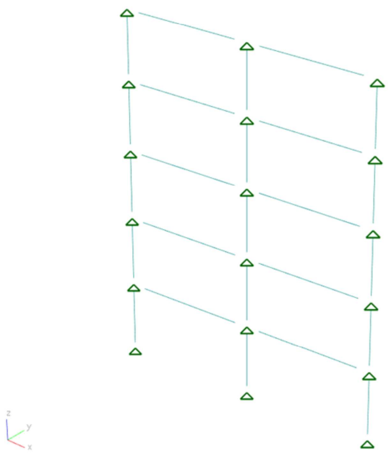


Do not confuse Releases and Restraints

Pinned releases



Pinned restraints



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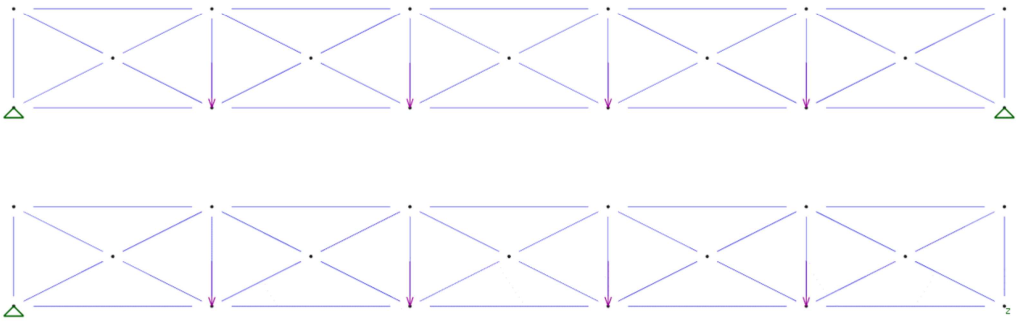
Boundary conditions – choose the right restraints

- These two trusses are identical apart from the supports



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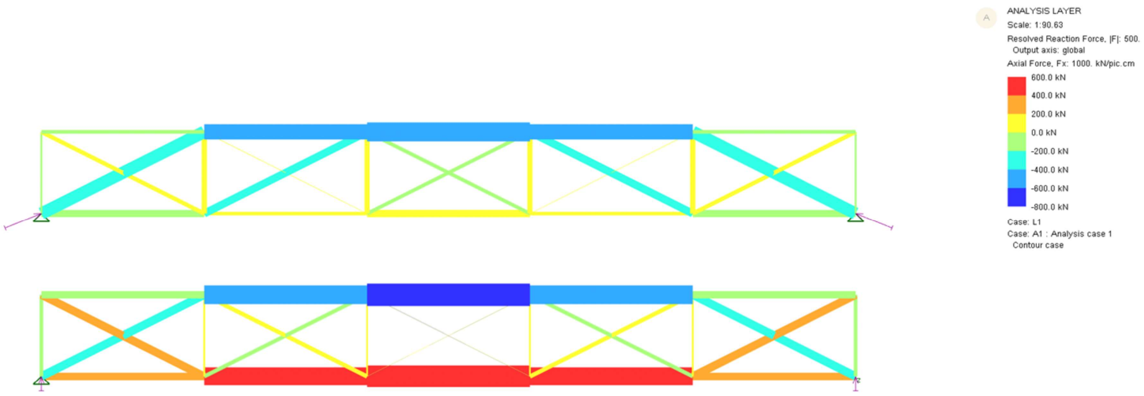
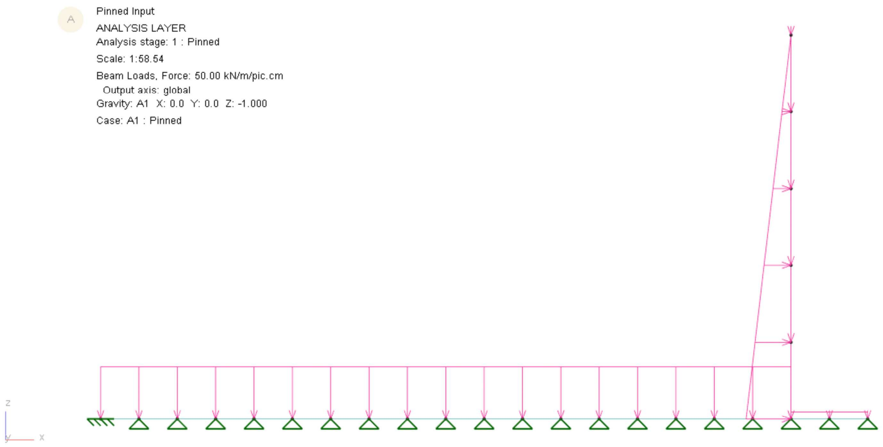
Boundary conditions – choose the right restraints

- These two trusses are identical apart from the supports
- Using a horizontal reaction at both ends gives a very different structural behaviour



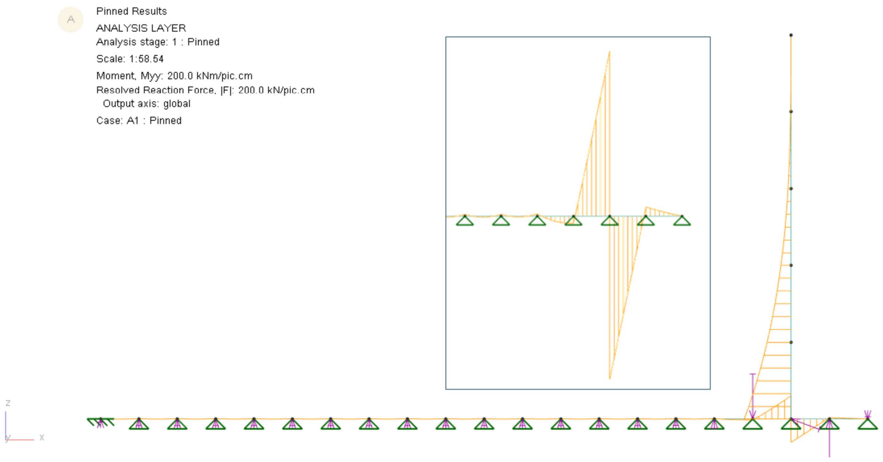
Using restraint stiffness

- Using pinned supports can give wrong results for continuous structures



Using restraint stiffness

- Using pinned supports can give wrong results for continuous structures



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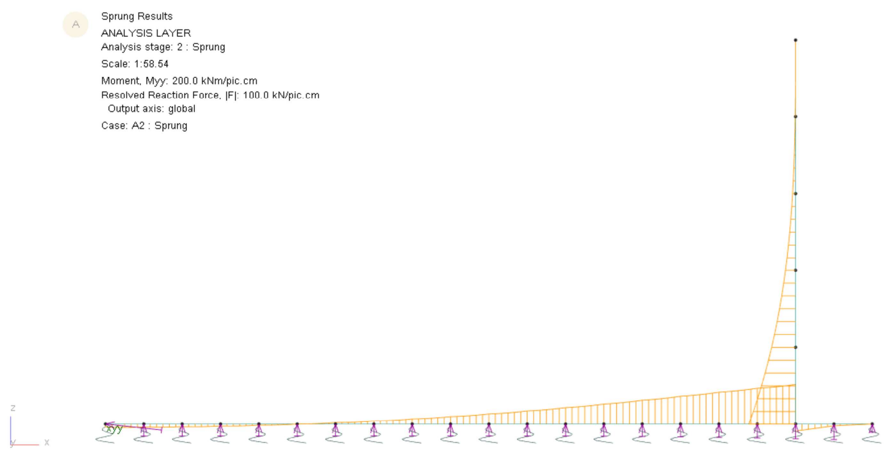
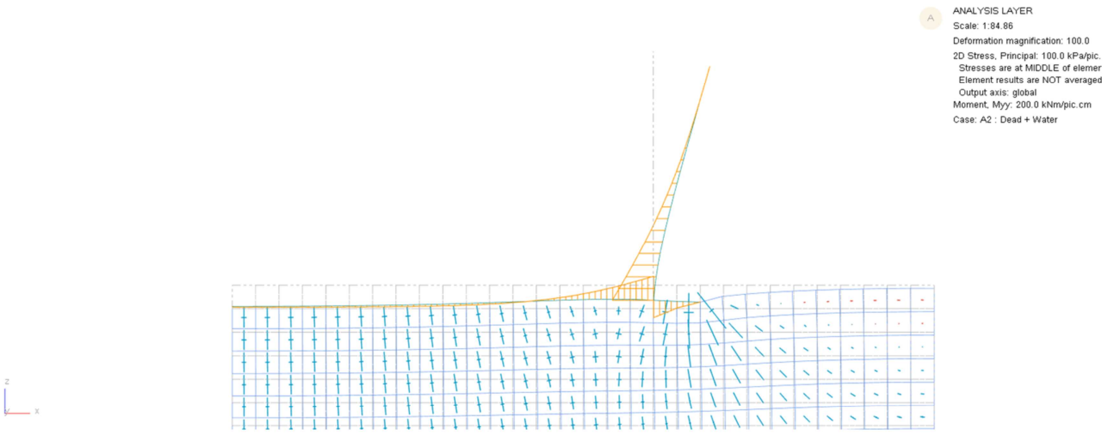
Using restraint stiffness

- Using spring supports can give good results for continuous structures



Using restraint stiffness

- Explicit modelling of the soil can also give good results
  - But is it worth the effort?



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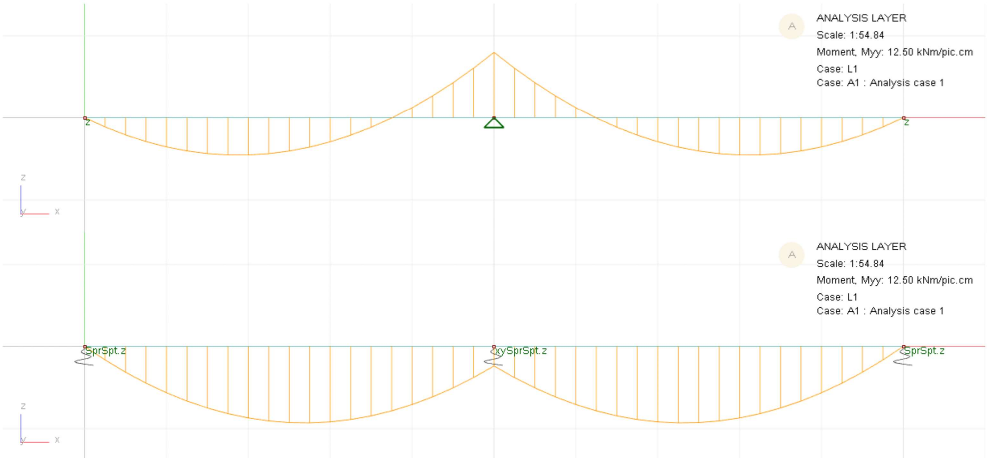
Using restraint stiffness

- Changing the support stiffness can change the moment distribution



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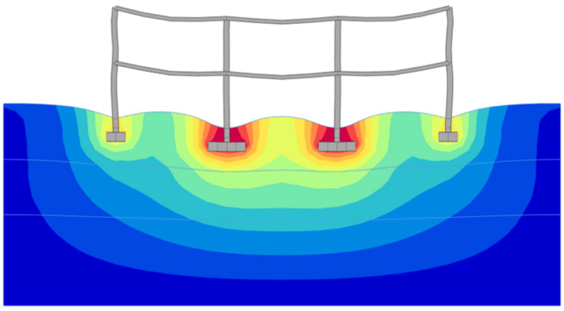
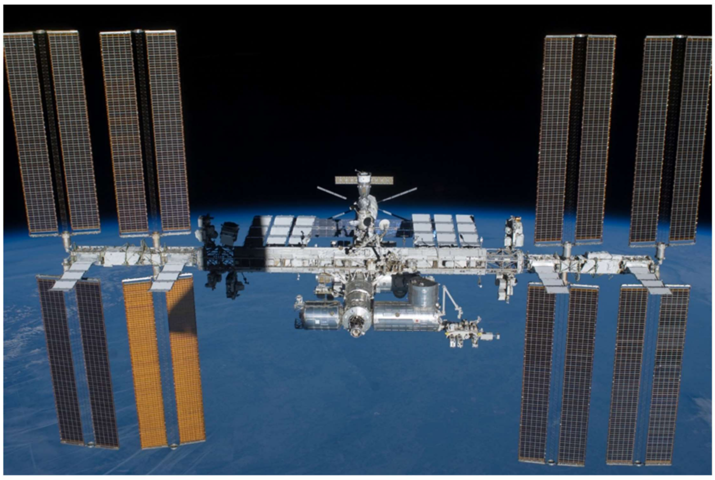
Soil Structure Interaction

- The ground is effectively less stiff under the centre of a building than at the edges
- This will redistribute moments and shears



Lack of restraints

- Models must be restrained in all 6 directions
  - 3 translation + 3 rotation
- Nodes must be restrained in all 6 directions
- Some analysis types add restraints



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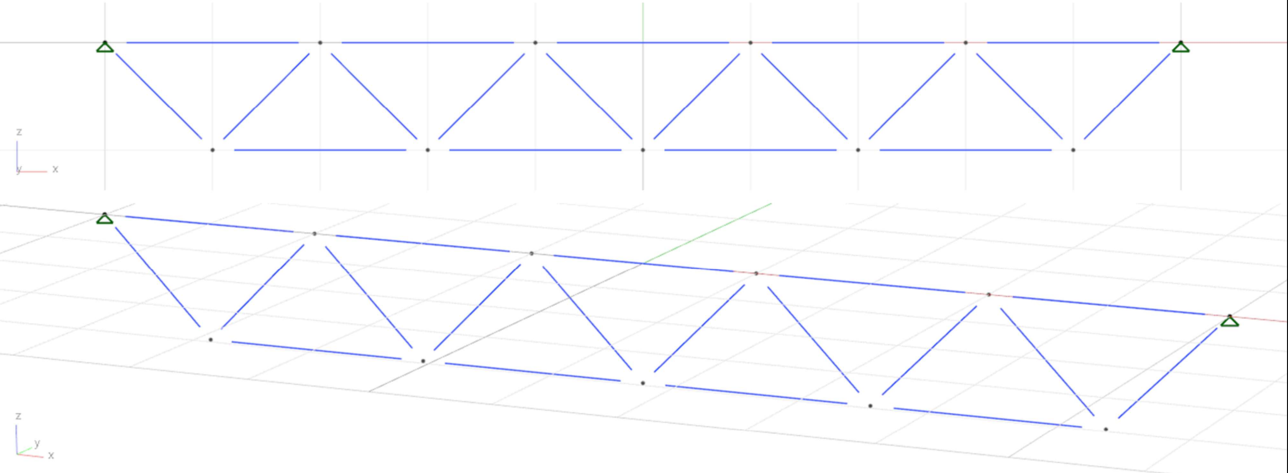
Lack of restraints

- Trusses with Bar elements can be stable in 2D and unstable in 3D



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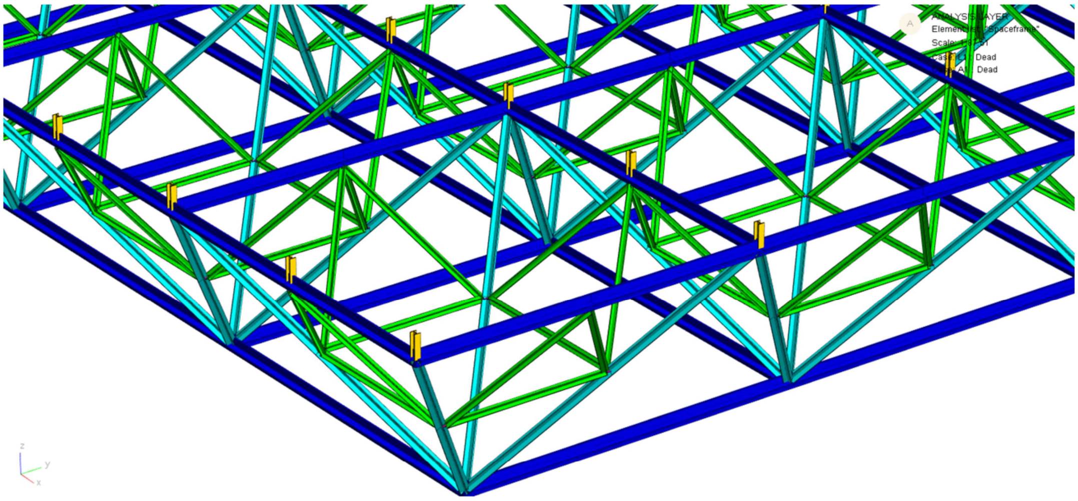
Hartford Civic Center

- Unstable Bar elements – were there warnings?



Short Question and Answer session

Coffee break / 11:30 - 12:00

65

Ministry of Economics
Republic of Latvia

Training seminar / Apmācību seminārs

Finding hidden modelling errors and inaccuracies in FEA results.
Making good structural analysis models – best practices & reducing errors.

Slēpto modelēšanas kļūdu un neprecizitāšu konstatēšana GEM rezultātos.
Labu konstruktīvo analīzes modeļu veidošana – labā prakse & kļūdu samazināšana.

Peter Debney (United Kingdom)

Checking, validation, and interpretation of FEA results

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Model Validation

"the process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method." (ISO 16730)

In other words: **is the model realistic, is it valid?**

Design the analysis – analyse the design

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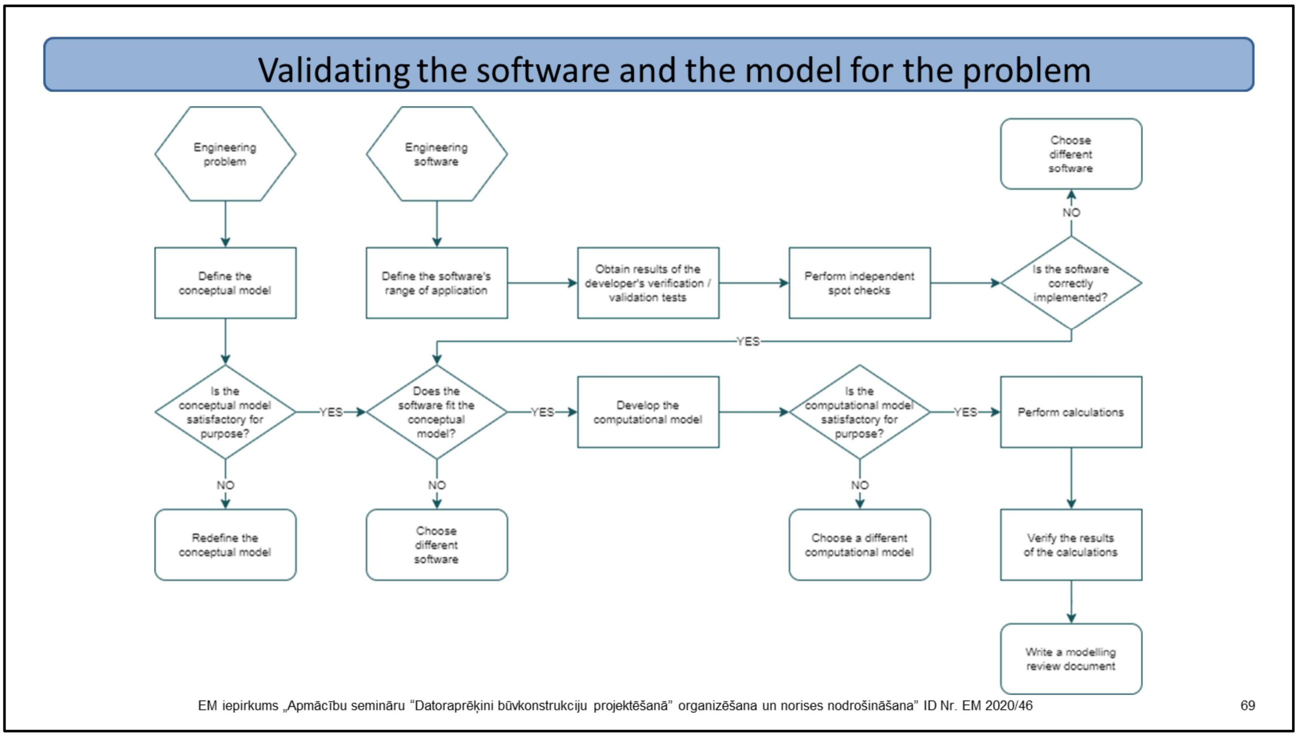
Validating the software and the model for the problem
Engineering problem
Engineering software
Choose different software
NO
Define the conceptual model
Define the software's range of application
Obtain results of the developer's verification / validation tests
Perform independent spot checks
Is the software correctly implemented?
YES
Is the conceptual model satisfactory for purpose?
YES
Does the software fit the conceptual model?
YES
Develop the computational model
Is the computational model satisfactory for purpose?
YES
Perform calculations
NO
NO
NO
Redefine the conceptual model
Choose different software
Choose a different computational model
Verify the results of the calculations
Write a modelling review document
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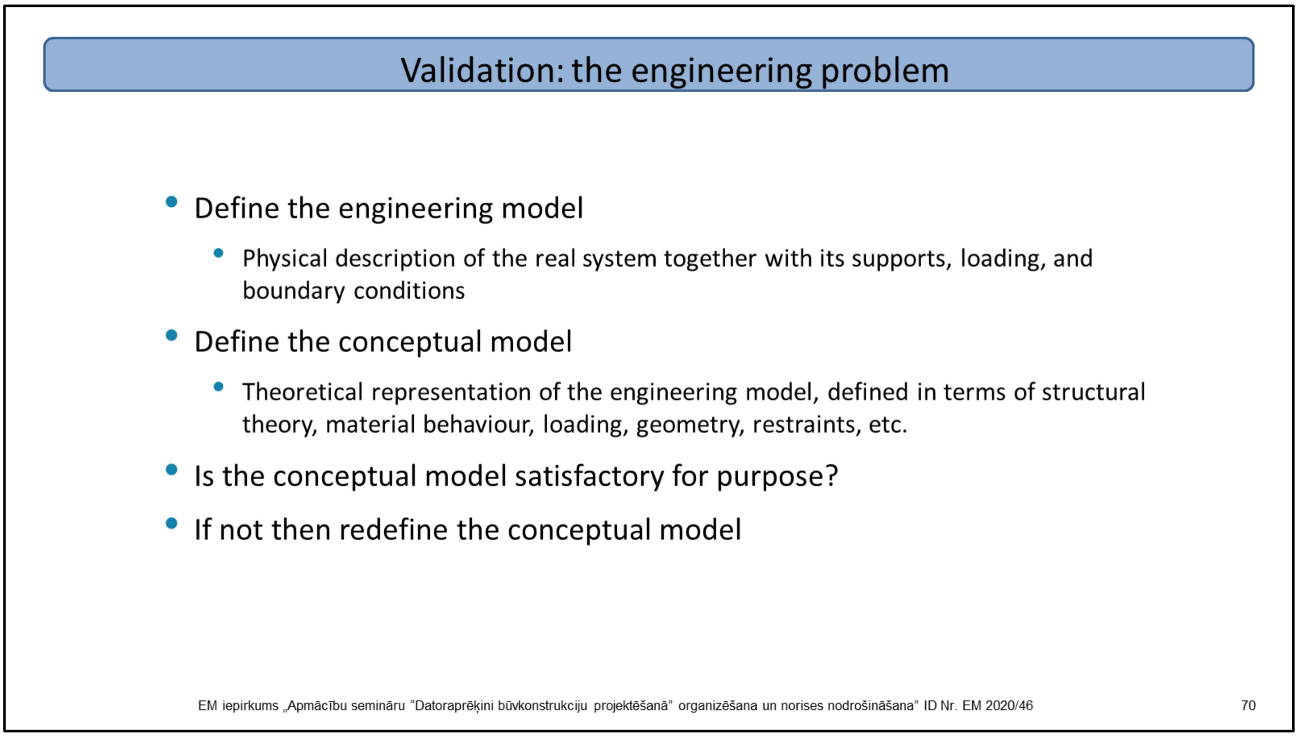


C:\Users\Peter.Debney\OneDrive - Arup\Documents\References\IStructE\The use of computers for engineering calculations.pdf
Structural theory: beam, deep beam, shear panel, shell, etc

Validation: the engineering software

- Define the software's range of application
- Obtain results of the developers verification / validation tests
- Perform independent spot checks
- Is the software correctly implemented
    - If no then choose different software
- Does the software fit the conceptual model?
    - If no then choose different software

Validation: the computational model

- Develop the computational model
  - The finite element analysis model or similar
- Is the computational model satisfactory for purpose?
  - If no then choose a different computational model
- Perform calculations
- Verify the results of the calculations
- Write a modelling review document

Validation – inclusion and exclusion

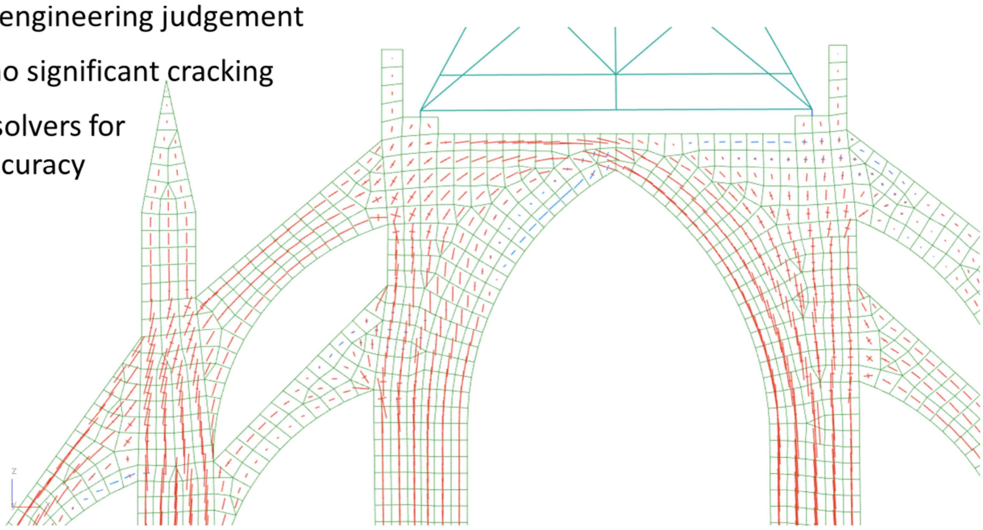
- What does the automated design include and what does it exclude?
- For example:
  - Does it calculate punching shear?
  - Are the seismic storey drifts at just the centre or also at the corners?

Validation – does the diaphragm include voids?

- If the horizontal load transfer is a concrete floor in the real structure and a rigid diaphragm in the model, and there are significant openings close to the stability members (such as the core) then is the diaphragm valid?

Validation - Masonry

- Modelling masonry is possible, but with a lot of engineering judgement
- Linear ok if no significant cracking
- Use Explicit solvers for maximum accuracy



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Validation: compression-only & tension-only

- If structural members can take only tension, or only compression, do you need to model them as such?
- If so, have they been modelled as such?
- And have they been analysed appropriately?

Millau Viaduct, France (Michel Virlogux)

Validation: elastic and plastic

- Are any parts of the structure yielding?
- What difference does this make to your analysis?
- What difference should this make?

Short Question and Answer session

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Finding hidden modelling errors and inaccuracies in FEA results

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Verification

“the process of determining that a calculation method implementation accurately represents the developer’s conceptual description of the calculation method and the solution of the calculation method.” (ISO 16730)

In other words: **is the model correct?**

Verification ≈ V.error.fication

Finding Errors

- Verification – know that there are errors
  - If you do not know that there are errors, will you look for them?
  - If you do not look for errors then how you will find them?

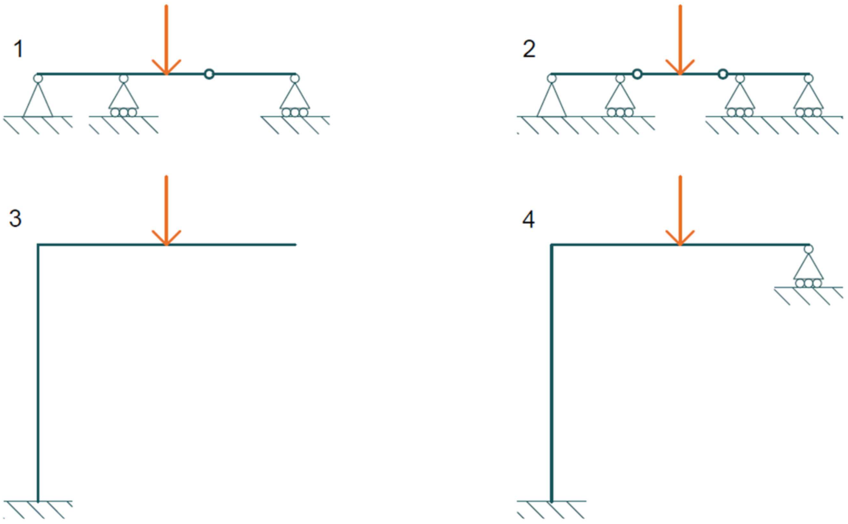
Verification

- Results ≠ Expectations
  1. Your model is wrong
  2. Your expectations are wrong
  3. The software is wrong

It is not normally #3…

Qualitative Analysis – Does it look right?

- Sketch the bending moments and deflected shapes
- If the FEA model looks different, which is wrong?
- Might they both be wrong?



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Comparing Apples with Apples

If two similar models give very different results then they are significantly different, but why?

- The usual reason for different results is that the models are different, but determining the difference can be difficult

It seems obvious but…

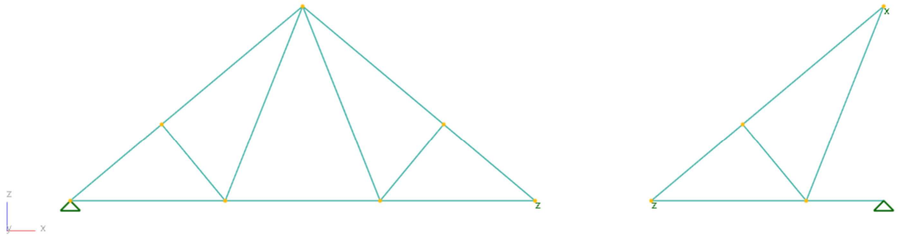
Warnings and Errors

- Read the warnings that the software gives
- Decide if they are ok or not
  - Engineering judgement
- Deal with all errors

Divide and Conquer

You know that there is a problem somewhere, but where?

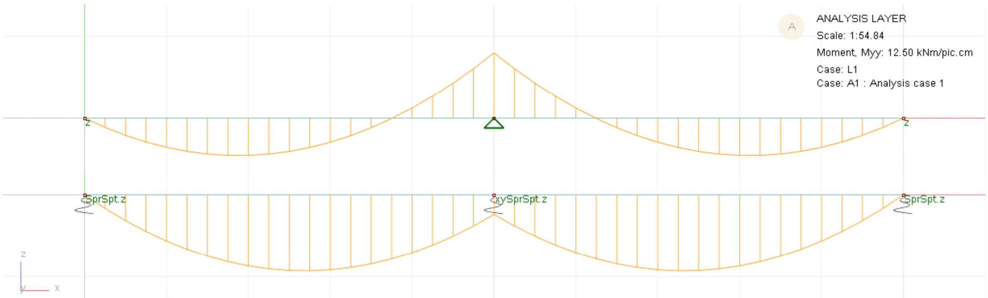
- Cut the model in half and see which half it might be in
- Add restraints into the model to prevent that area from moving



Sensitivity checks

What happens to the results if you change something?

- Change the support stiffness
- Change the section size
- Change the load magnitude
- Change the load direction



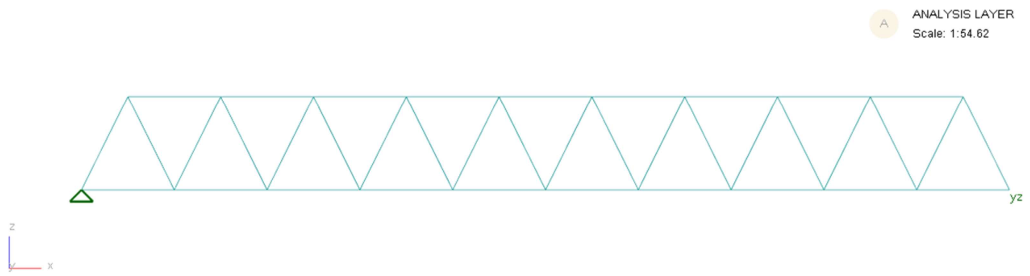
Verification – quick calculations

Bending moment ➔ chord axial force = $wl^2/8h$

Shear force ➔ diagonal axial force = $wl/2\sin\theta$

Deflection = $(5/384).(wl^4/EI)$

$$I_Z = I_x + Ah^2$$



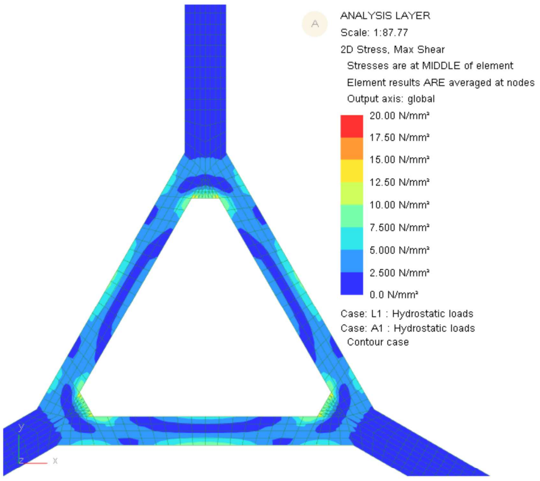
Verification – quick calculations

Bending moment

Ends $M = wl^2/12$

Centre $M = wl^2/24$

Shear force $S = wl/2$



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Static | Dynamic checks

Bridge frequency ~1 Hz

Floor Frequency ~4-8 Hz

Floor frequency $f = 18/\sqrt{\delta}$

δ = deflection

Building frequency $f = 10/N$

N = number of storeys

Millennium Bridge, London (Arup)

Ill conditioning

- Excessive differences in stiffnesses will reduce accuracy
  - Matrix solutions
  - Nonlinear convergence problems

- Check total loads and reactions

Limits to Accuracy

- Sum total loads and reactions
- Check mesh shapes are not too stretched
- Check for very short or long elements
- Remember variations on site:
  - Dimension
  - Materials
  - Verticality
  - loading

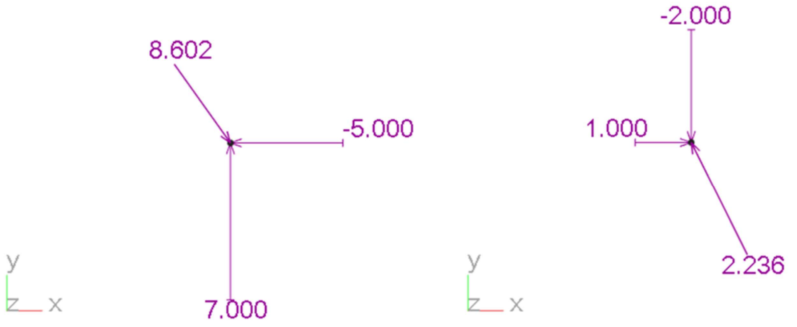
Verification – Enveloping

- Enveloped values:
  - Are they the biggest positive and the biggest negative?
  - Or are the biggest absolute values?

Case	Fx	Fy	|F|
P1	5	-7	8.602
P2	-1	2	2.236

Bad Envelope			
Max	5	2	5.385
Min	-1	-7	7.071

Good Envelope			
Max	5	2	8.602
Min	-1	-7	2.236

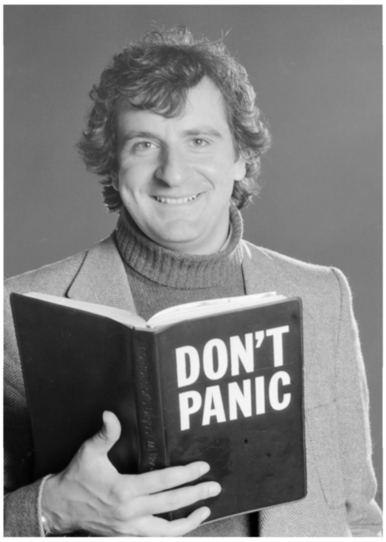


Verification – Software Errors

"A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools."
Douglas Adams

Commercial software producers are professional and there will be lots of checks, but mistakes can still happen.

Professional engineers likewise check but can make mistakes.



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Independent Checks

Design check category	BS 5975 description Temporary works	BD2 description Bridges	Checks
Category 0	Standard solutions	Single span less than 5 m	The check may be carried out by another member of the site or design team
Category 1	Simple designs	Single, simply supported span < 20 m and skew < 20°	The check may be carried out by another member of the design team
Category 2	Complex or involved designs	Not categories 0, 1, or 3	The check should be carried out by someone not involved in the design and not consulted by the designer
Category 3	Complex or innovative designs	Complex structures, sophisticated analysis, high redundancy, span > 50 m, skew > 45°, movable, suspended, grouted tendons	The check should be carried out by another organisation and should include an overall check to assure coordination of the whole design

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https://www.ihsti.com/tempimg/484A91A-CIS888614800326221.pdf
https://www.ihsti.com/tempimg/484A91A-CIS888614800284660.pdf

Checklist for Checking

- Stage 1 – look and think
  - Is the displaced shape correct?
  - Does the bending moments or stress distribution look sensible?
  - Are there any discontinuities in the results?
- Stage 2 – see if the answers are sensible
  - Do a separate hand calculation
  - Build a simplified FEA model of the structure
- Stage 3 – check really carefully
  - Build the model again in another program, or get someone else to do it

Checklist for Checking

- Check output for obvious errors
- Check input
- Use checking calculations
- Check overall equilibrium
- Check support conditions – forces and deflections of supports
- Check symmetry
- Check overall form of results – deflected shape, bending moments, etc
- Compare results with other programs

Comparing a conceptual model and a checking model

- Four possible results:

1. Results are similar and correct – the desired result
2. Results are significantly different – why? The reasons might reveal problems in conceptual or checking model
3. Results are similar but both wrong – possibly for different reasons
4. Results are similar, conceptual model is correct, computational model wrong but with compensating errors

Here be errors:

Ill conditioning - excessively long or short elements

Wrong units in dimensions, loads, or materials

Meshing that is too large or too small

Too many or not enough restraints

Over or under releasing elements

Inappropriate offsets

Forgetting torsion

2^{nd} order effects

Combining nonlinear results

Not validating and verifying the model

Short Question and Answer session

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Making good structural analysis models

Best practice and reducing errors

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Accurate – as necessary

- *"It is better to be vaguely right than exactly wrong"* Carveth Read
- Ultimate Limit State:
  - The structure must be strong enough
- Serviceability limit State:
  - The structure should perform well in typical conditions

Stopped vs slow clock
There are many unknowns
ULS - failure is not allowed
SLS – it should be generally ok but might occasionally exceed the limits
All models break down at some point – you need to know when that it

Realistic – as appropriate

- *"Models are simplified reproductions of portions of reality that, if validated, are still able to capture a few of its essential properties."*
  Guido Fioretti
- Our models are unrealistic, but are they close enough?
- When do we need to model the reinforcement in the beams and columns?
- What is the chance of a 1 in 50 year load occurring in the 50 years?

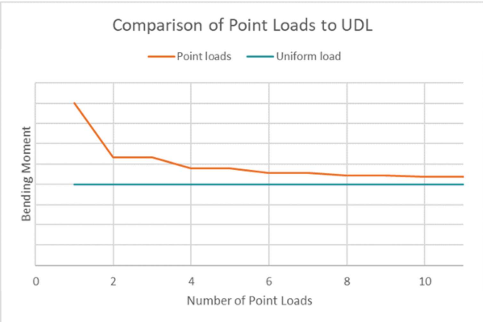
We can model entire concrete frames without modelling the reinforcement so that we can determine the reinforcement.
But if we model a frame to understand why it fell down, then we will need to model every bar.
Realistic loading: what might happen over 50 years
1 in 50 year event has a 2% chance of happening in any year, and a 64% chance of happening in 50 years

Simple – as possible

- *"Perfection is achieved not when there is nothing more to add, but when there is nothing left to take away."*
  Antoine de Saint-Exupery
- Do you need the beams and columns in a stability model?
- Do you need to model the floor slab?
- Do you need to model the entire frame or just one floor or wall?

Simple as possible

- When do point loads become a uniformly distributed load?



Useful

- *"The purpose of computing is insight not numbers"*
  Richard Hamming
- What question are you trying to answer with your model?
  If you ask the right question then you might get the right answer.
  - Are you checking ultimate or serviceability limit states?
  - Do you need a nonlinear analysis or is linear ok?
  - Are you modelling static or dynamic loads?

Checking

- Have you included what you need to include?
- Have you removed what you can remove?
- Is the model sensible and appropriate?

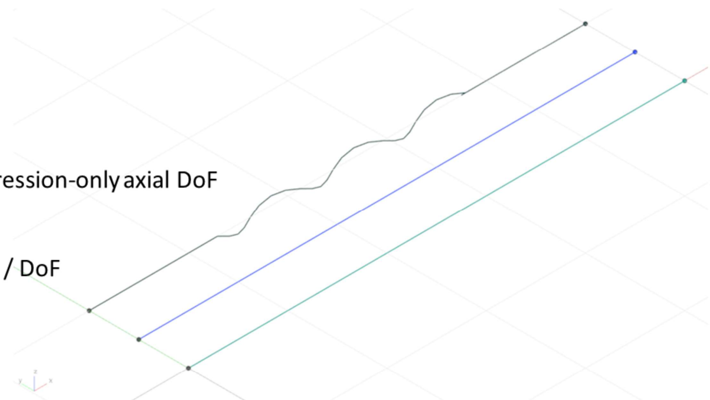
Structural Types

- Three principle forms:
  - Stick
  - Shell
  - Mass

Stick – 1 dimension is much **larger** than the other 2 – 1 dimensional
Shell – 1 dimension is much **smaller** than the other 2 – 2 dimensional
Mass – the 3 dimensions are all similar – 3 dimensional

1D Structural Types

- Beams
  - Section and material
  - Axial, major and minor axis shear, torsion, major and minor axis bending DoF
- Bars
  - Section and material
  - Axial DoF
- Ties and Struts
  - Section and material
  - Tension-only and Compression-only axial DoF
- Springs
  - User-defined stiffnesses / DoF
- Links
  - Infinite stiffness



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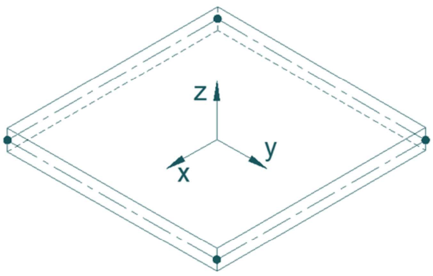
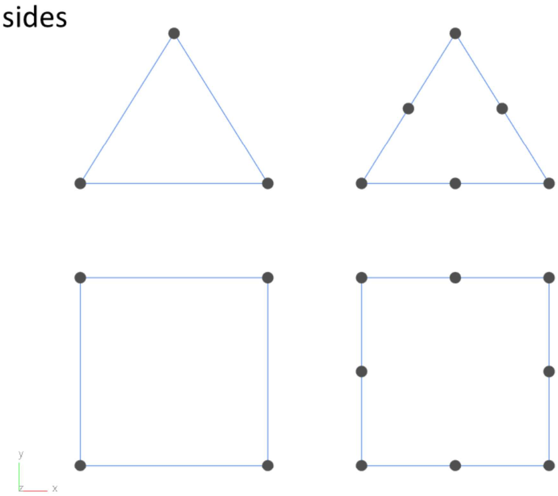
2D Element Types

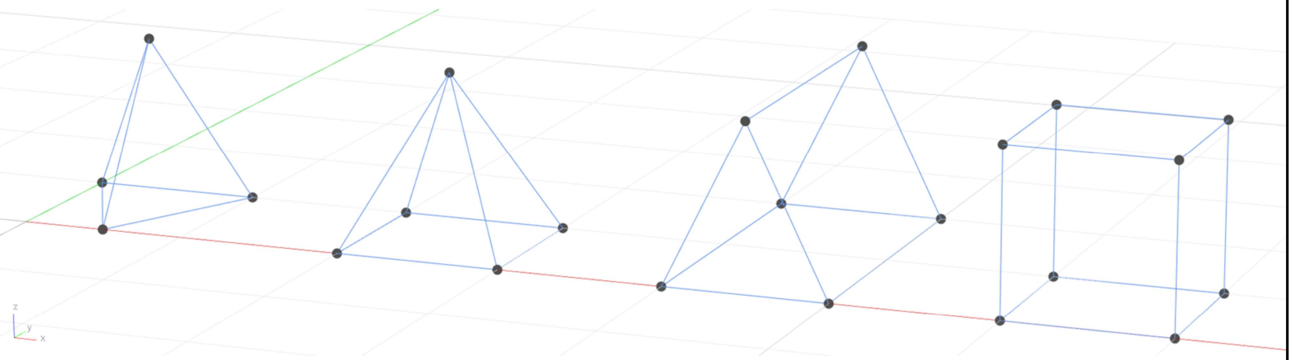
- 2D elements are triangles or quads
- Node at each corner plus sometimes on sides
- Properties: thickness and material
- Shell – 5 or 6 DoF
- Plan Stress, Plane Strain – in-plane DoF





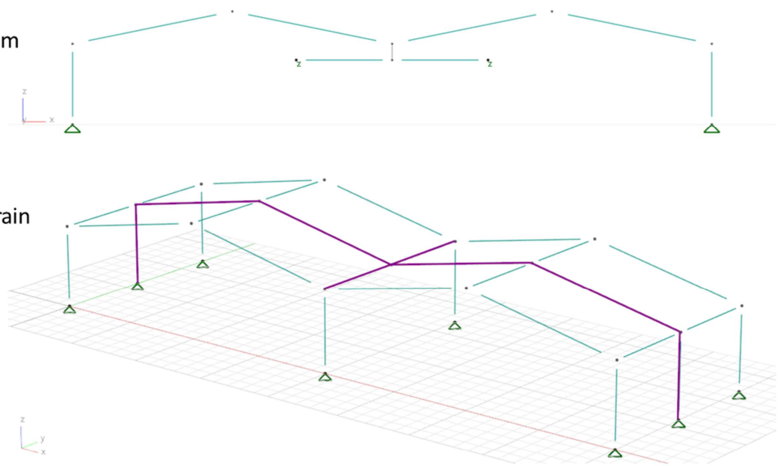
3D Element Types

- 3D element sides are triangles or quads
- Node at each corner plus sometimes on edges
- Properties: only material
- Output: only stresses and strains



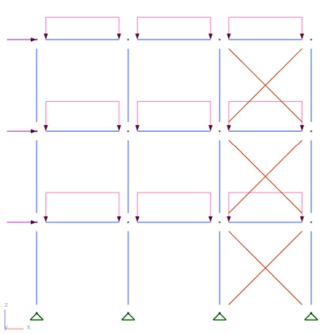
1D / 2D / 3D Models

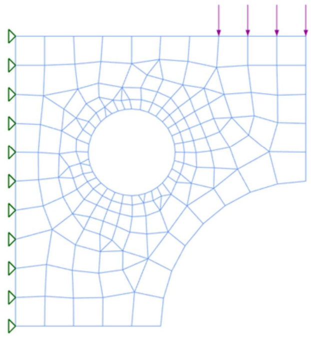
- Models can be
  - 1D
    - Single (multi) span beam
  - 2D
    - Plane frames
    - Floors
    - Plane Stress / Plane Strain
  - 3D
    - Anything...



Meshing

- Include nodes at the crucial locations:
  - Where members join
  - Where there is a significant change in geometry
  - Where there is a significant change in loading
  - Where stresses etc need calculating
  - The problem boundaries





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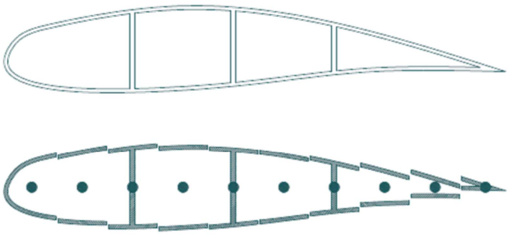
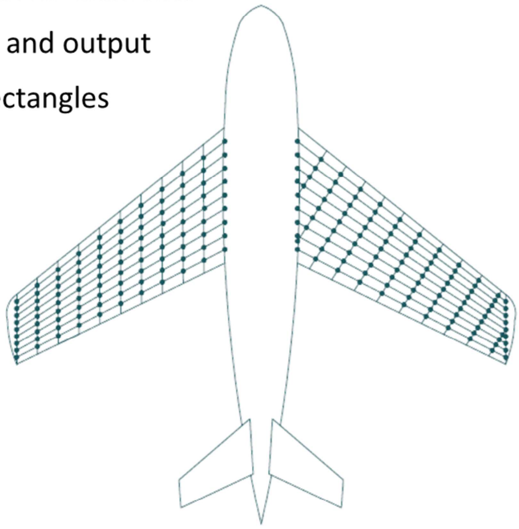
Good element size and shape

- 1D elements:
  - Beam length must be more than twice the depth
  - If very short then replace with Link
- 2D elements:
  - Plan dimensions must be more than twice the thickness
  - Mesh so that there are 8-10 nodes in span between main supports
  - The closer to square or equilateral the better the result
  - Quads are better than Triangles, unless the surface is double-curved
- 3D elements:
  - As 2D elements but 3D should be as close to cubes or tetrahedrans (etc) as possible.

1D Grillage or 2D Mesh?

- Grillage: representing 2D structures with 1D elements
- Advantage: direct control of properties and output
- Disadvantage: difficult to model non-rectangles





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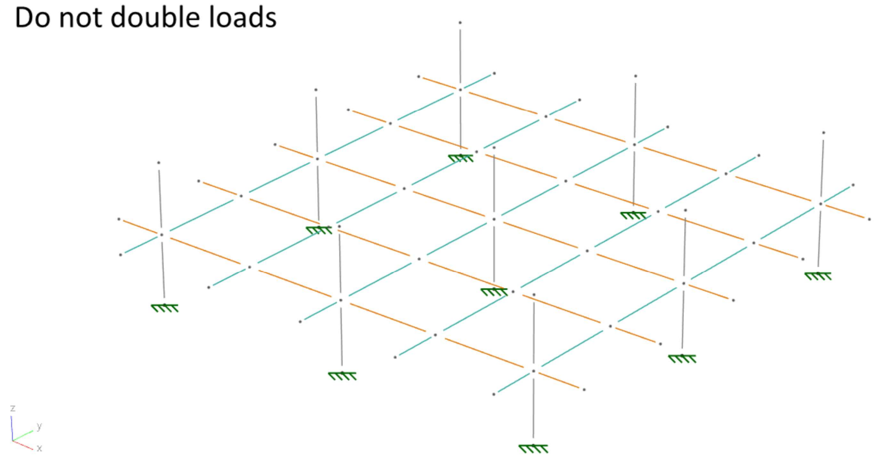
1D Grillage or 2D Mesh?

- Grillage: representing 2D structures with 1D elements
- Good for modelling beam strips
- Do not double loads



Model for the analysis

- Each of these requires a different model:
  - Linear static
  - Nonlinear static
  - Buckling
  - Dynamic
- Similarly, these need different models
  - Overall behaviour
  - Local / detailed behaviour
- Keep the models simple
- Subdivide the structure into smaller models where appropriate
- Do not try to make one model do too much

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Stability models
Very stiff + very flexible structures

Model for the analysis

- 1D elements – linear analysis
  - Node at every connection and change of direction or section
- 2D elements – linear analysis
  - 8-10 nodes per major span
  - Remember minimum size
  - Keep elements square
- 1D buckling analysis
  - Min 1 node at mid-span
- 2D buckling analysis
  - Keep subdividing until no significant change in result
- 1D & 2D – Dynamic analysis
  - ~8 nodes to a span
  - Fix connections?

Personnel and procedures

- Decide in advance what question the model is to answer.
- Record your assumptions.
- Make sure that you know what the model does, and does not, do.
- Those building the analysis models must have sufficient structural knowledge. They should be trained on the software.
- The model and modeller must be supervised and reviewed by an experienced, qualified engineer.
- Remember that everyone makes mistakes. Just because the answer comes from a computer does not mean that it is correct.

Example model purposes

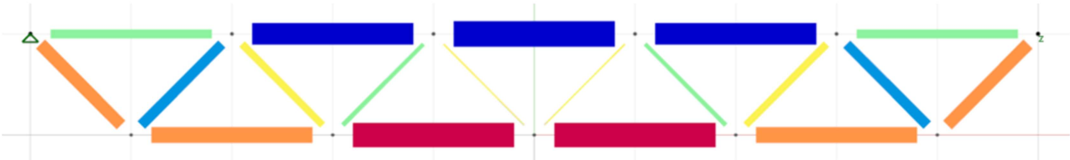
- Decide the size of beams and columns
- Decide if the design meets requirements of code of practice
- Decide if footing has adequate factor of safety (nonlinear)
- Investigate force distributions at concept stage
- Predict short and long term deformations
- Study possible collapse mechanisms
- Study dynamic behaviour
- Investigate effect of structural damage
- Inform the structural optimisation

Load combinations

- Linear analysis:
  - Linear relationship between loads, moments & forces, stresses & strains, and deflections
  - It is ok to analyse each load case separately, then multiple and combine the results afterwards
- Nonlinear elements / models / analysis:
  - Nonlinear relationship between loads and results
  - Reversing or changing load combination can change load paths, contact areas, or material yield
  - It is NOT ok to analyse each load case separately
  - Analyse the combinations together
- Do not forget self-weight

Trusses

- Trusses rely only on axial forces
  - But moments can exist
- Stage 1 – determining axial forces and section sizes
  - Model with Bar elements
  - Statically determinate so section size does not affect results
- Stage 2 – determining local moments
  - Model with beam elements + releases where appropriate
  - Model eccentricity at connections
  - Statically indeterminate so section sizes do affect results



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Modelling process

1. Plan
    - What behaviour needs predicting?
    - What actions need resisting?
    - What criteria must it meet?
    - Is the software suitable?
2. Do
    - Build the model
    - Could it have been built better?
    - Run the analyses
3. Check
    - Do the results look right?
    - Are they like the predictions?
    - What do the results tell you about the model and the design?
4. Act
    - Does the design need updating?
    - Does the model need changing?
    - Do the models need replacing?

Short Question and Answer session

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Lunch break / 13:30 - 14:00

125

Ministry of Economics
Republic of Latvia

Training seminar / Apmācību seminārs

Finding FEA Specifics in Reinforced Concrete Structures and Design.
FEA Specifics in Timber, Steel, and Other Nonlinear Structures Design.
Future of Digital Structural Engineering.

GEM specifika dzelzsbetona konstrukcijās un projektēšanā.
GEM specifika koka, tērauda un citu nelineāru konstrukciju projektēšanā.
Digitālās strukturālās inženierijas nākotne.

Peter Debney (United Kingdom)

FEA specifics in reinforced concrete structures

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Beams and Slabs

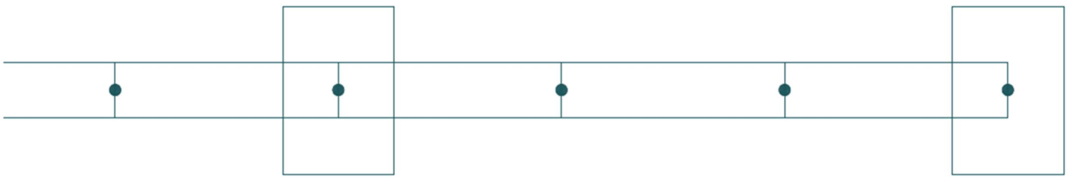
- Q: What is the best way to model beams and slabs?
- A: It depends on what you want to model…

Beams and Slabs

- Option 1: model just the beams
  - Calculate beam loads or use area loads
  - Slabs have no effect on beams

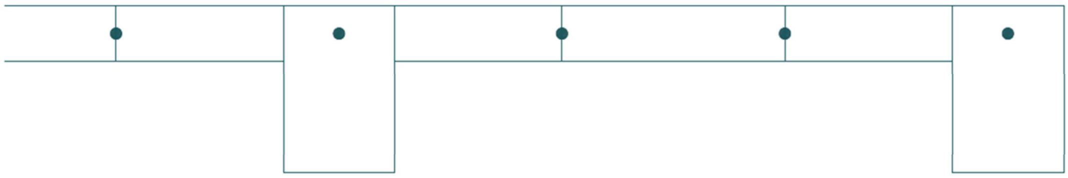
Beams and Slabs

- Option 2: model the beams and slabs on the centroid
  - Load the 2D elements
  - Slab stiffness small in comparison to beams – act independently
  - Design beams as rectangles



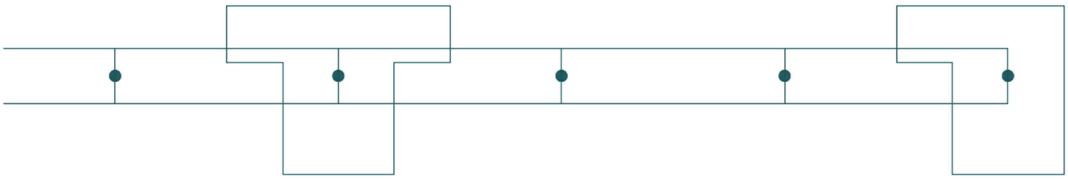
Beams and Slabs

- Option 3: model the beams and slabs offset
  - Load the 2D elements
  - Beams and slabs work together
  - Design beams as tee



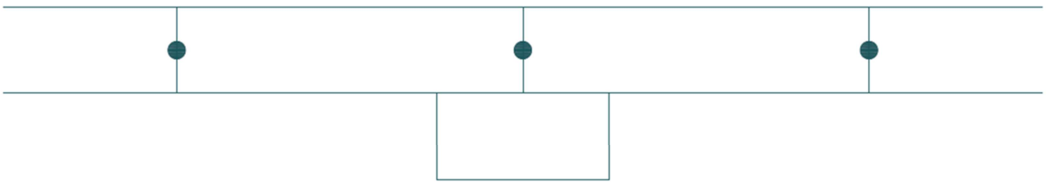
Beams and Slabs

- Option 4: model the beams and slabs on centroid
  - Load the 2D elements
  - Slab stiffness small in comparison to beams – act independently
  - Design beams as Tee



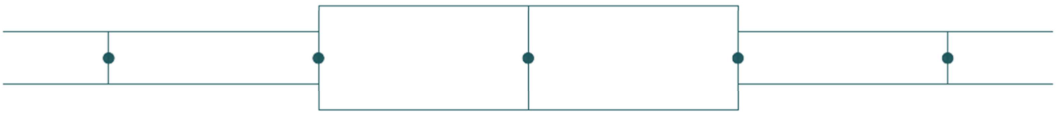
Beams and Slabs

- Option 5: model the beams as downstands on slab
  - Load the 2D elements
  - Beams and slabs work together
  - Design beams as stiffener to slab



Beams and Slabs

- Option 6: model the beams with 2D elements
  - Good for ribbon beams
  - Load the 2D elements



Ribbed slabs

- Modelling ribbed slabs with orthotropic materials
  - Model slab as shell, thickness t

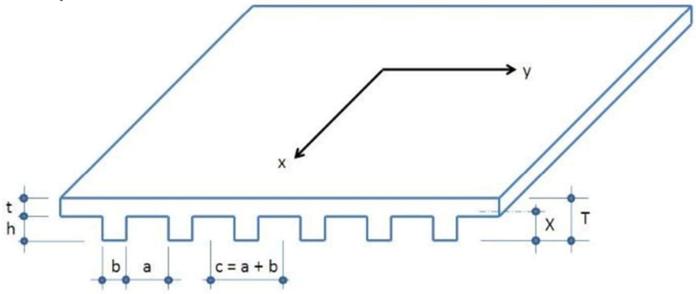
$$E_y = E,\ I_y = \frac{ct^3}{12}$$

$$A = tc + bh$$

$$y_c = T - X = \frac{ct^2 + bh(2t+h)}{2(tc+bh)}$$

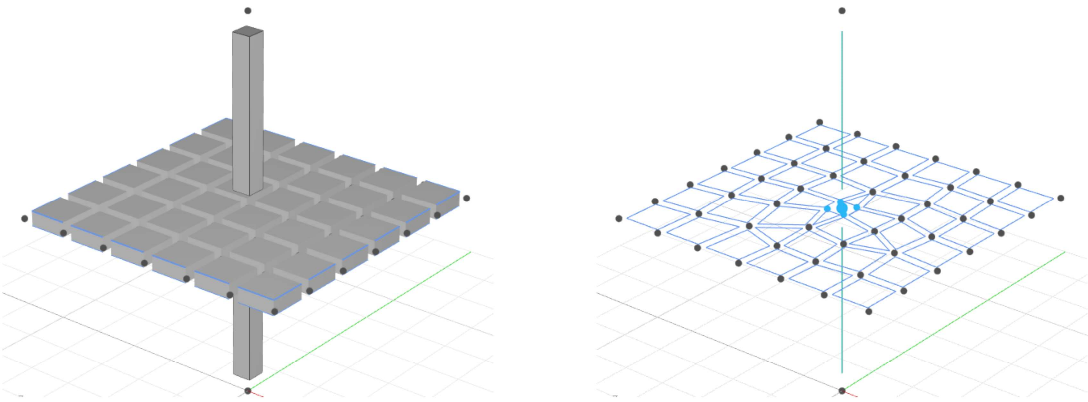
$$I_x = \frac{c}{3}(h+t)^3 - \frac{h^3}{3}(c-b) - A(h+t-y_c)^2$$

$$E_x = E_y \frac{I_x}{I_y}$$



Flat Slabs

- Flat slab to column connections create unrealistic moments
  - The smaller the mesh the higher the moment
  - Minimum element size >= thickness*2



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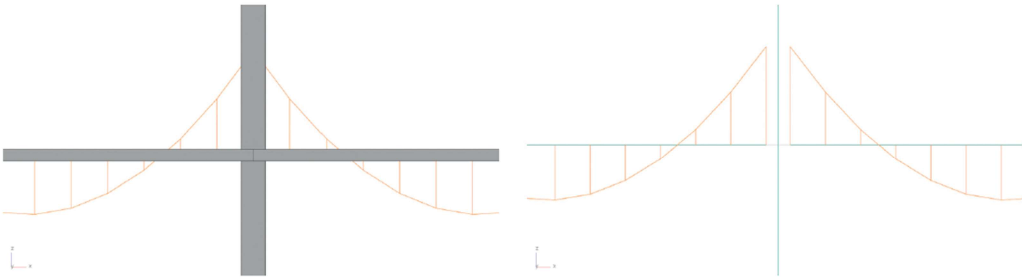
Flat slabs

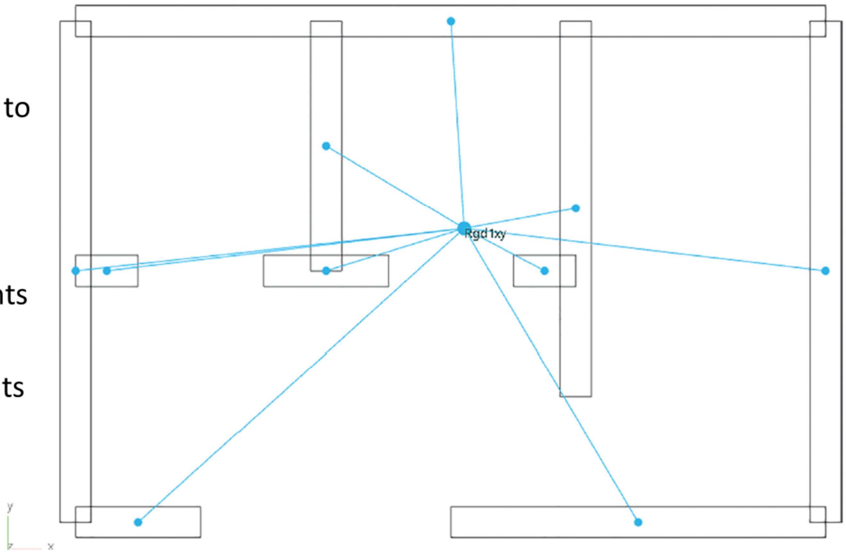
- Options:
  - Add rigid constraint between column and column face
  - Ignore the moments



Walls and Cores

- Three principle ways to model cores:

1. Single 1D element (whole core)
2. Multiple 1D elements (walls)
3. Mesh of 2D elements



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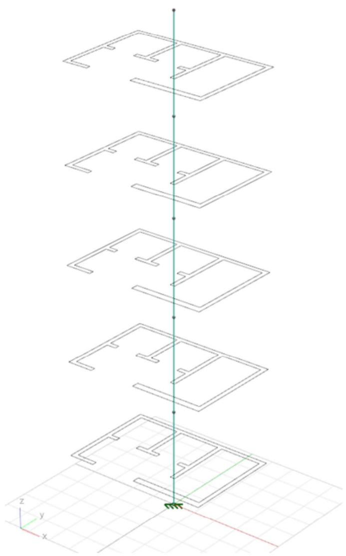
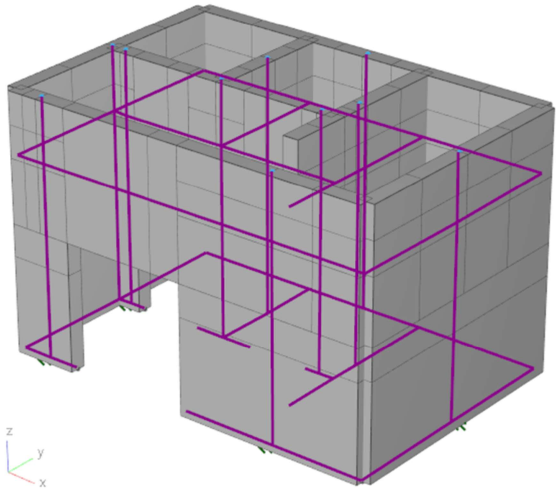
1D cores

- Use 1D cores where the detail is not important, only the overall stiffness
- Good for:
  - Stability checks (use rigid diaphragm for floor
  - Seismic check / natural frequency
- Advantage:
  - Very simple – good for checking more complex models
- Problems:
  - Difficult to account for stiffness reduction from openings
  - Difficult to connect to beams and slabs



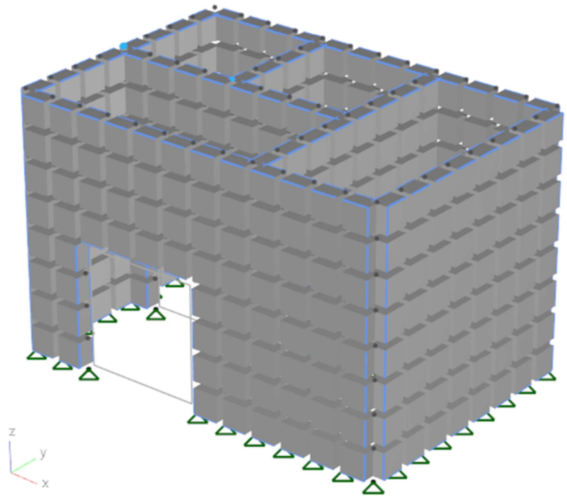
Stick cores

- 3D cores made of 1D elements
- Join at floor levels with rigid constraints
- Or join at lintel levels with beam elements
- Good for
  - Wall overall forces
- Advantages
  - No meshing required
  - Simple results
- Disadvantages
  - Easy to get confused
  - Openings difficult to address



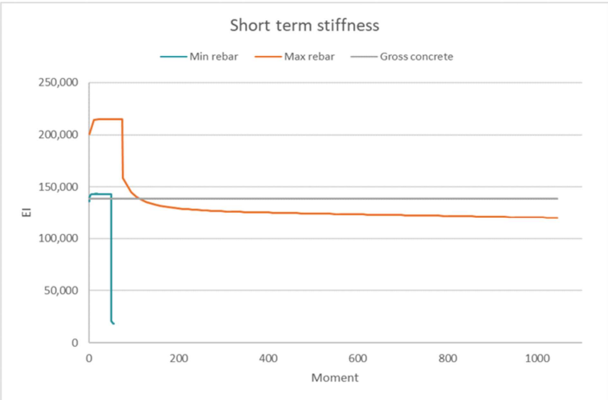
2D cores

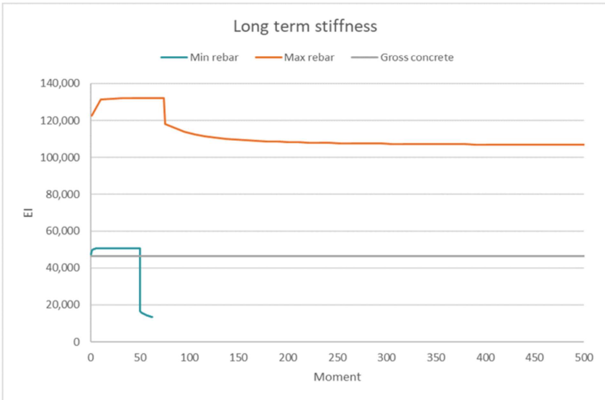
- 3D cores made of 2D elements
- Good for detailed analysis of forces, moments, and principle stresses in a core
- Advantages:
  - Easy to model with a good meshing engine
  - Direct control of openings
  - No limitations on geometry
- Disadvantages
  - Lots of elements – slow analysis
  - No abstraction of results



Stiffness and deflections

- Reinforced concrete stiffness is dependant on a number of factors:
  - Concrete grade
  - Reinforcement quantity
  - Duration of load
  - Axial load and Bending moment





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Short Question and Answer session

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FEA specifics in timber, steel, and nonlinear structures

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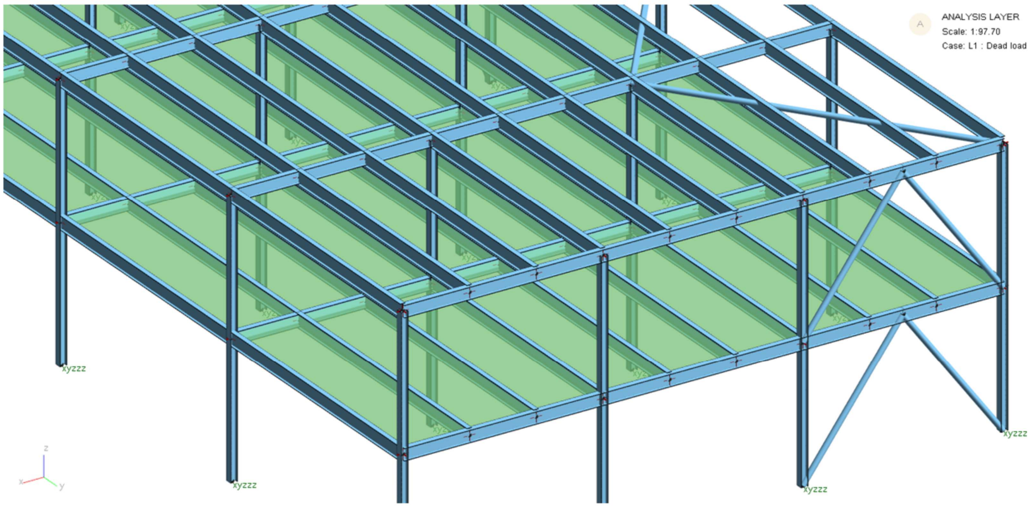
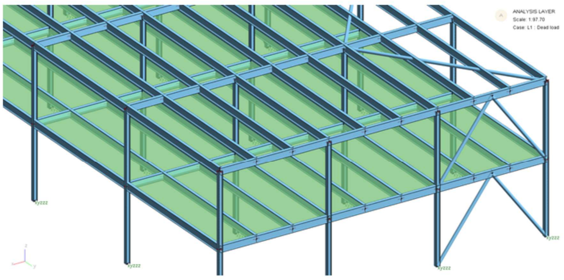
Stability



Diaphragms - advantages

- Steel frames with simple bolted connections rely on the floor diaphragms to give stability
  - Transfers loads horizontally
- Modelling floors with shell elements adds vertical stiffness
  - Risk of under-designing the beams
- Rigid diaphragms give a faster analysis than 2D elements
- Other structure can be left out
  - If you are checking just the stability system, do you need all the beams and columns?



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Diaphragms - disadvantages

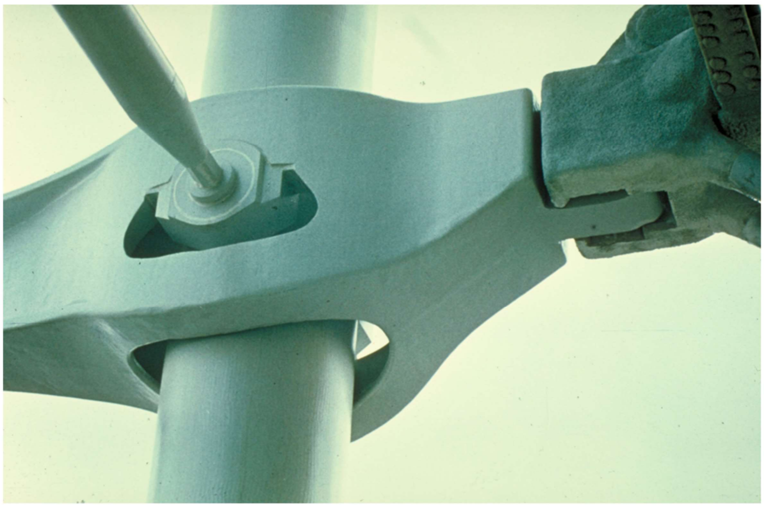
- Rigid diaphragms stop **all** differential movement in the constrained direction
  - Beams, braces, and truss elements in the rigid diaphragm plane will report **zero** force
- The default for many rigid diaphragms is in **all** directions
  - Including the vertical direction in a floor diaphragm will stop the beams deflecting under gravity

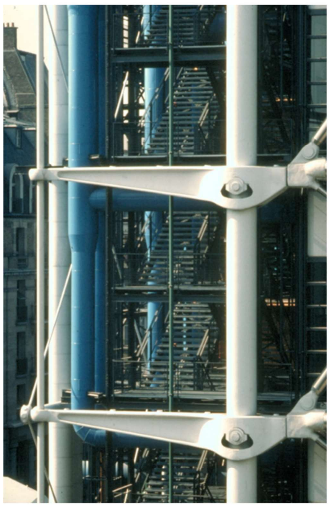
Offsets – end connections

- Connections can induce moments into members

Offsets – end connections

- End connections can also prevent moments in supports





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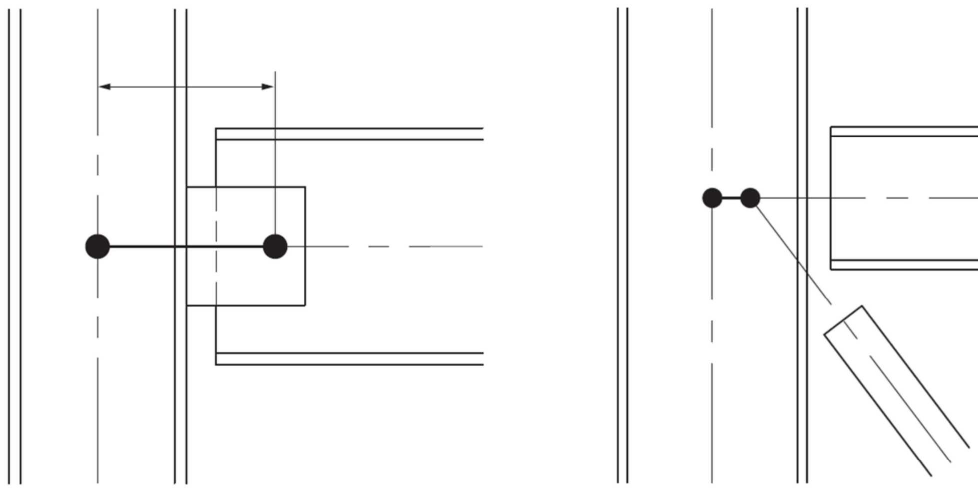
Pompidou Centre, Paris, France (Arup)

Offsets – end connections

- Use end offsets or rigid links to generate connection moments

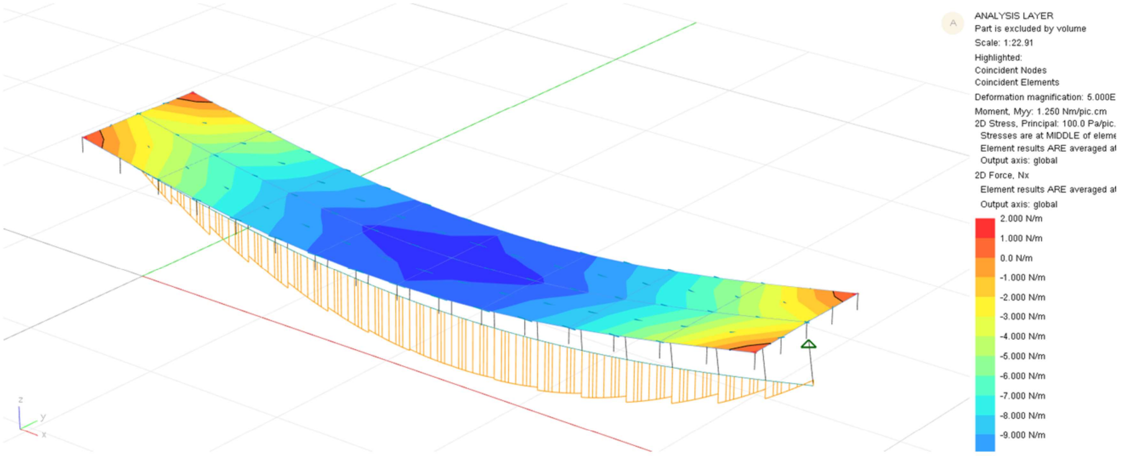


Offsets – bracing connections

- Use Link elements to induce eccentric connection moments

Offsets for composite structures

- Adding offsets can simulate composite action between the beam and slab



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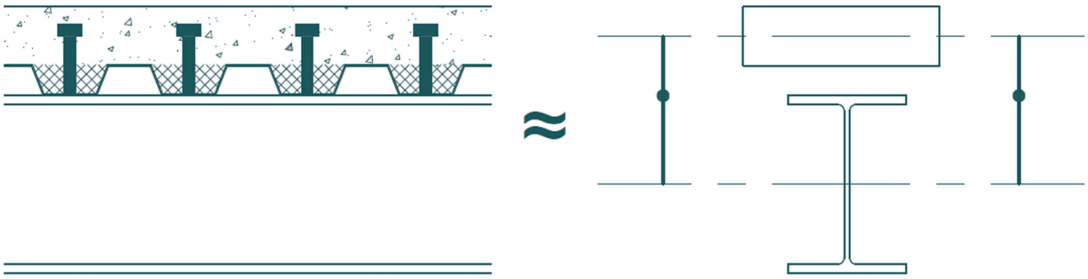
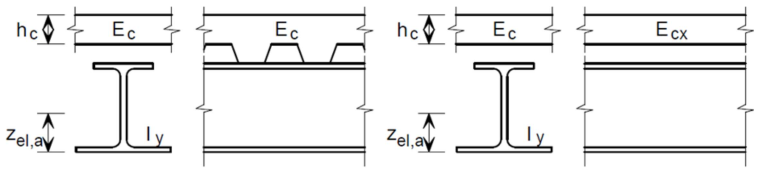
Offsets – parallel – composite

- Adding offsets can simulate composite action between the beam and slab



Orthotropic materials and structures



Parameter	Unit	Value
Ex Young's Modulus	[N/mm²]	295723
Ey Young's Modulus	[N/mm²]	38000
Ez Young's Modulus	[N/mm²]	38000
nuxy Poisson's Ratio		0.2
nuyz Poisson's Ratio		0.2
nuzx Poisson's Ratio		0.2
Density	[t/m³]	2.4
alphax Temperature Coefficient	[/°C]	1e-005
alphay Temperature Coefficient	[/°C]	1e-005
alphaz Temperature Coefficient	[/°C]	1e-005
Gxy Shear Modulus	[N/mm²]	11666.67
Gyz Shear Modulus	[N/mm²]	11666.67
Gzx Shear Modulus	[N/mm²]	11666.67
Damping Ratio		5

$$E_{cx} = E_c \frac{12}{{h_c}^3} I_{c,x}$$

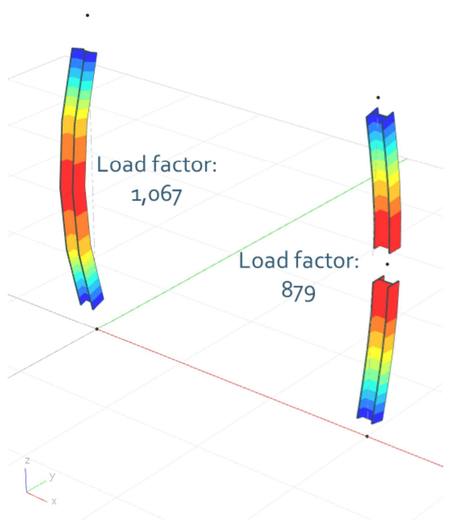
$I_{c,x}$ 2nd moment of area of profiled slab/m in spanning direction

h_c depth of concrete above profile

E_c dynamic elastic modulus of concrete

2nd order effects – buckling analysis

- Meshing affects buckling results
- Ensure that you have at least one node mid height



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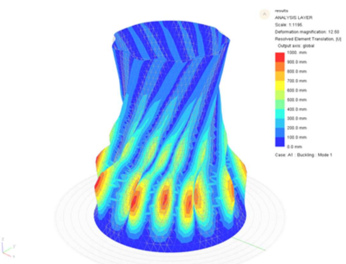
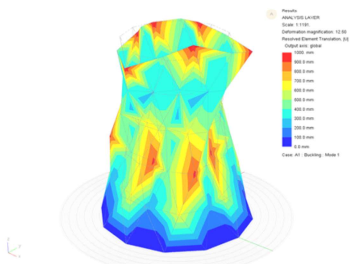
2nd order effects – shell buckling analysis

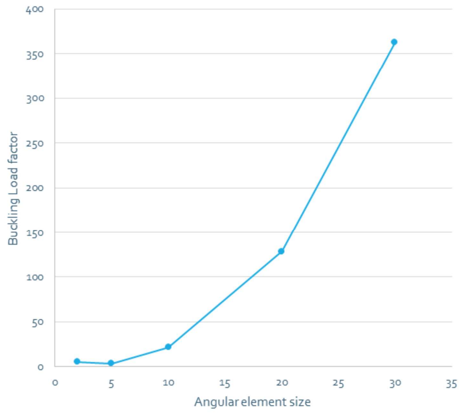
- Meshing affects buckling results
- Keep subdividing until results do not change significantly



2.5 degree element size



30 degree element size



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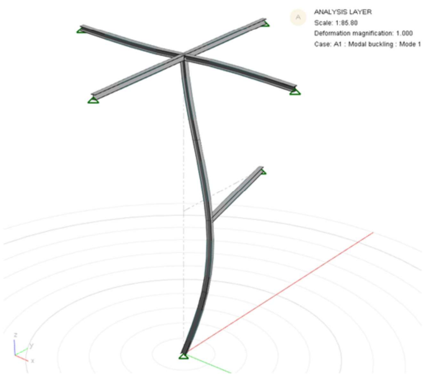
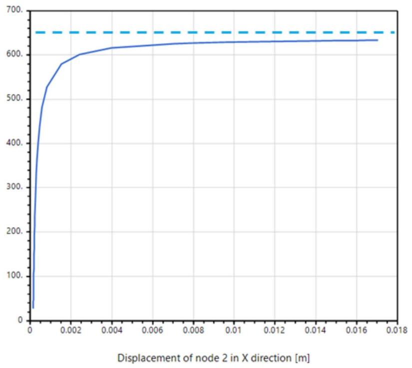
Linear and nonlinear buckling

- Linear buckling will usually give a higher capacity than nonlinear buckling
- Nonlinear buckling with nonlinear materials will give an even lower capacity

Linear buckling



Nonlinear buckling



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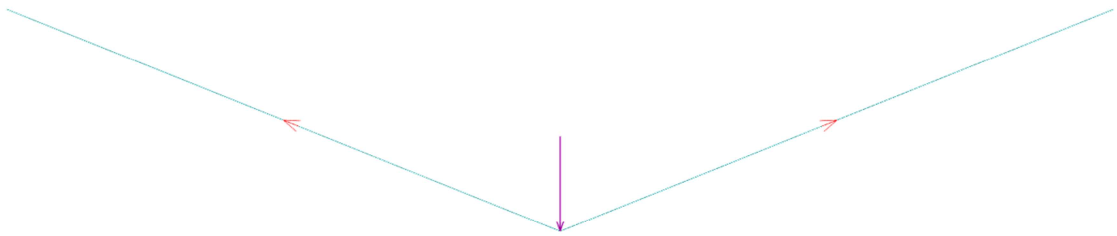
Nonlinear structures

- With nonlinear structures the equilibrium is found at the deformed geometry

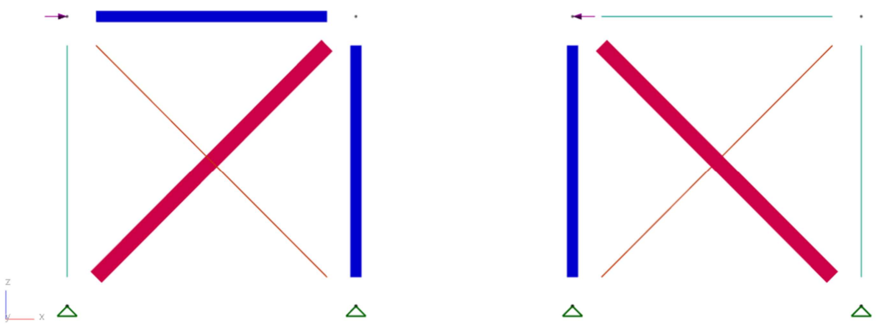
Factors affecting final deflection	
Load	Span
Cross sectional area	Young's modulus
Pretension	Stress (yielded or not)
Support stiffness	Initial sag

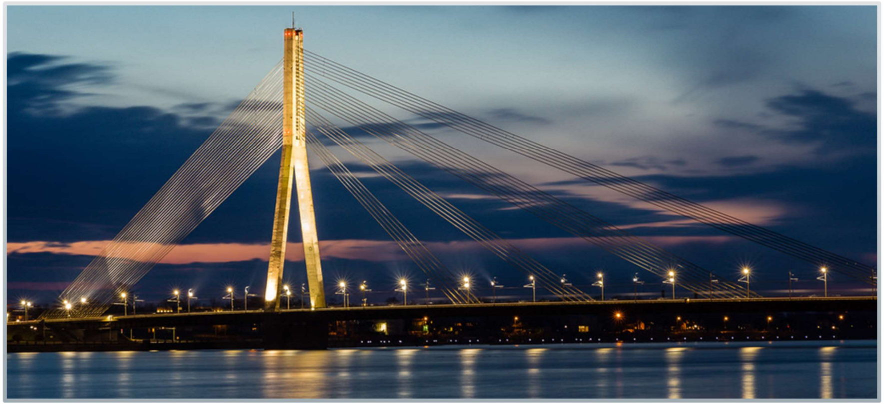


It is hard to find the deflection, but it is easier to decide on the deflection and work back

Nonlinear elements

- Nonlinear elements: changing load can change load path



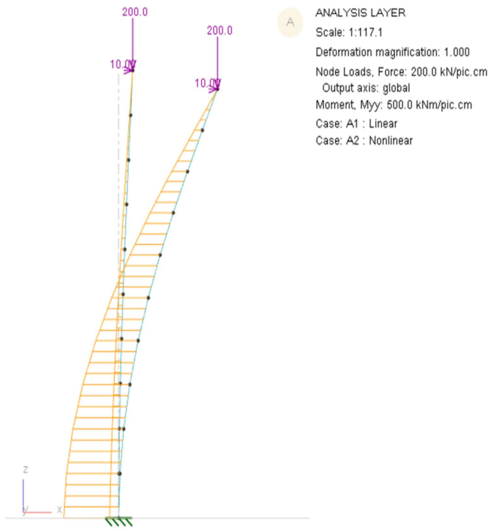


Vanšu Bridge

Vanšu Bridge (George Fuchs or Fukss)

2nd order effects – linear vs. nonlinear (p-delta)

- When the axial load is high, linear and nonlinear or p-delta analyses can give very different results



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2^{nd} order effects – linear vs. nonlinear (p-delta)

- Linear

Equilibrium is established at the undeformed configuration

$F = P$

$V = Q$

$M = Qh$

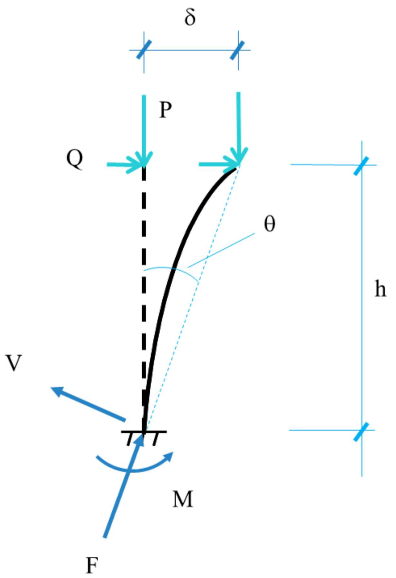
- Nonlinear

Equilibrium is established at the deformed configuration

$F = P\cos\theta - Q\sin\theta$

$V = Q\cos\theta + P\sin\theta$

$M = Qh + P\delta$



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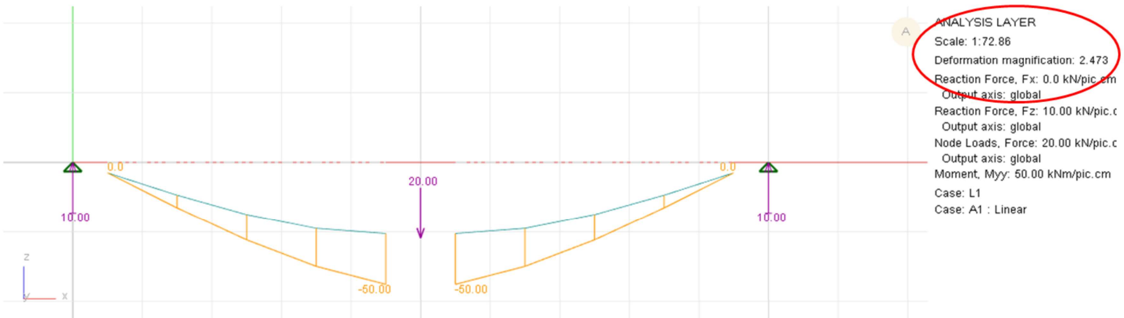
2nd order effects – linear analysis

- Beam subject to a point load – linear analysis:



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2nd order effects – linear analysis

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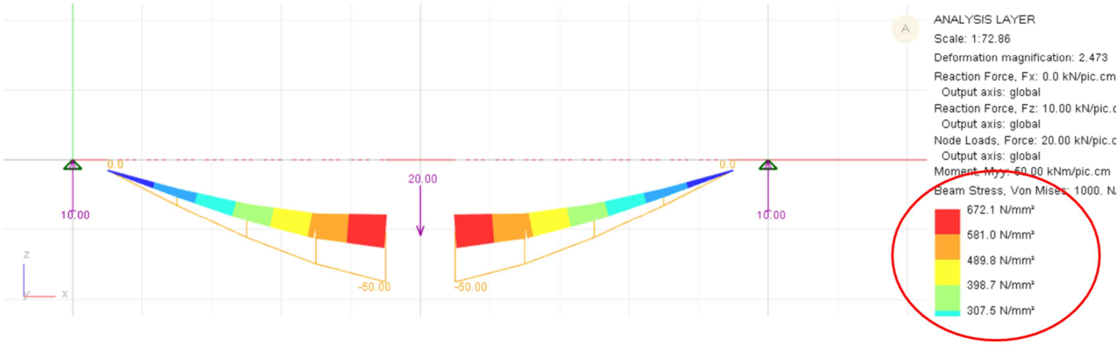

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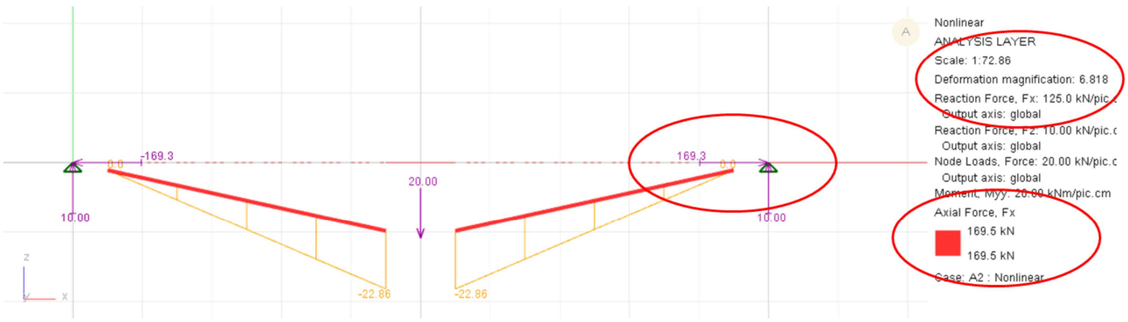
2^{nd} order effects – nonlinear analysis

- Beam subject to a point load – nonlinear analysis:



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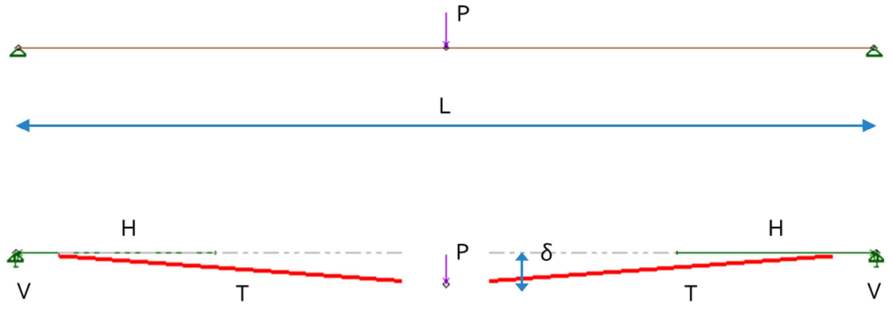
2^{nd} order effects – nonlinear analysis



$$T = \sqrt{\left((P/2)^2 + H^2\right)}$$

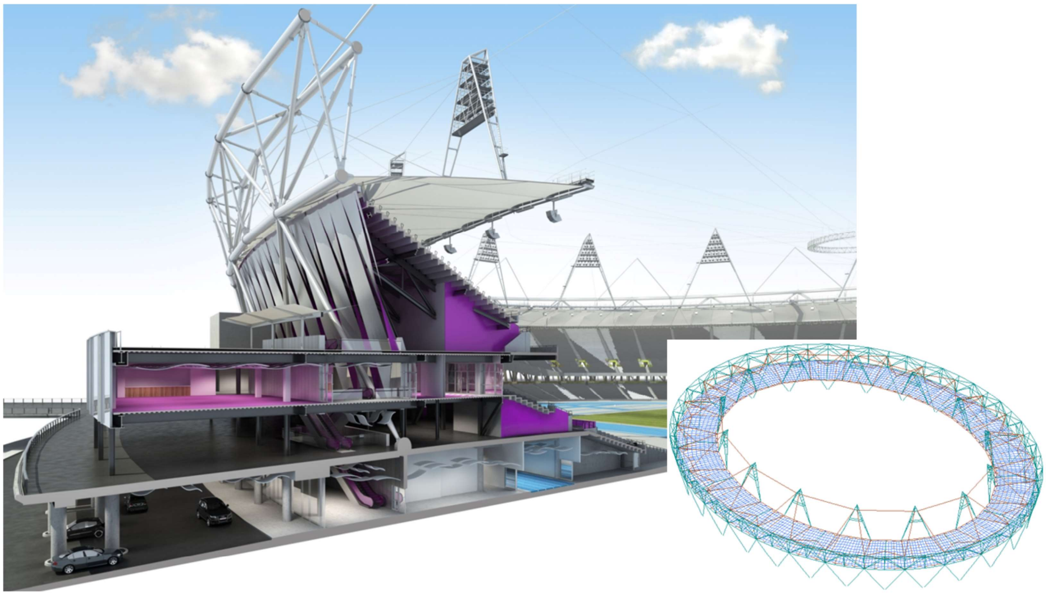
$$H = L.P/4\delta$$

Force → Deflection → Strain → Stress → Reaction

Humber bridge

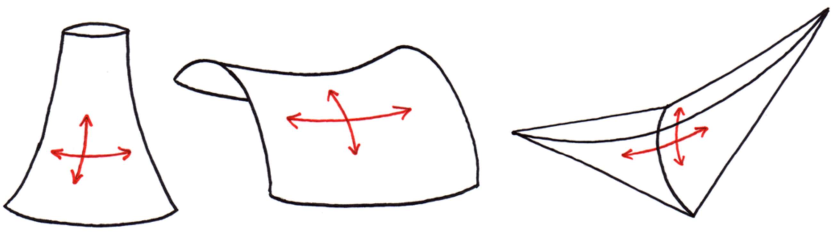
Humber bridge (Freeman Fox)

Tension structures for stadia



London 2012 main stadium (Buro Happold)

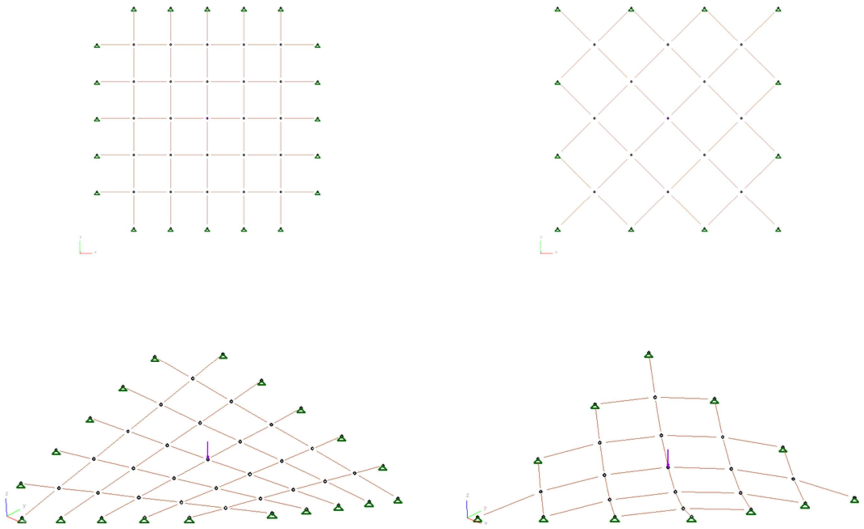
Double-curvature for tension-only structures



(a) Conic (b) Barrel vault (c) Hypar

With cable nets and fabrics the geometry is crucial
Surfaces must be double curved for stiffness
There are three basic shapes…
The importance of form finding – force equilibrium

Cable nets



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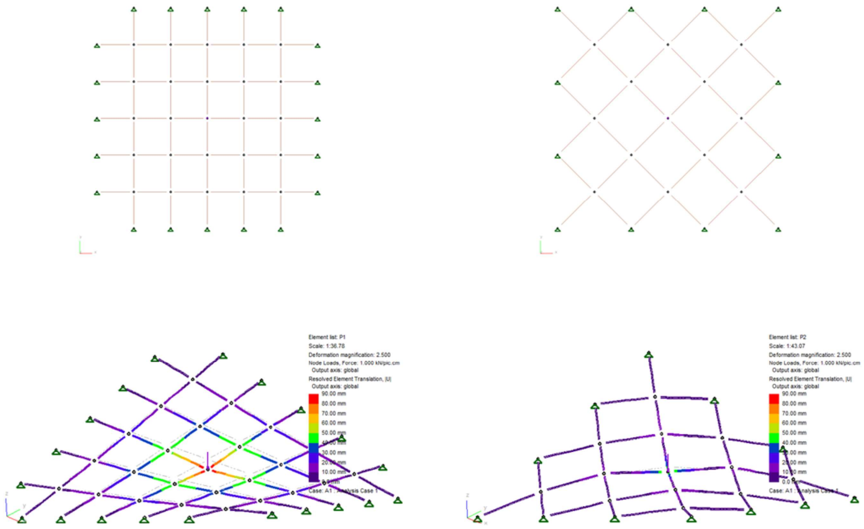
Lets look at two very similar cable nets, though they differ from the spider's web because I have added a third dimension to them:

- both are warped into hyperboloid surface by twisting the support points
- Both are about the same weight
- Both have the same section and prestress (none in this case)
- Both carry the same load

But do they both behave about the same?

Cable nets



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No: you can see that the left-hand (and slightly heavier) cable net deflects about twice as much as the net on the right, even through it is sharing the load better

The difference is down to their geometry: that on the right is more efficient than the one on the left

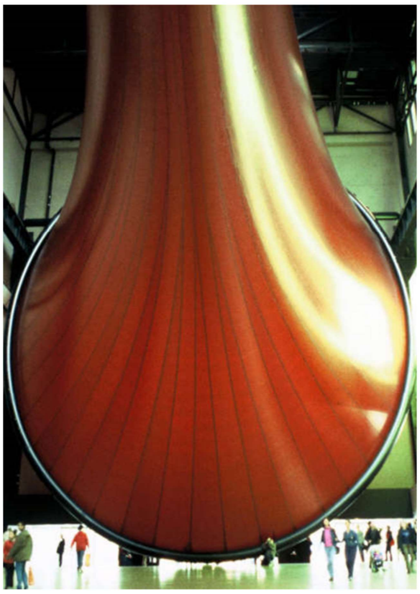
The curvature gives stiffness to the structure

Consider the humble spider's web: a **site fabricated cable** net stretching across a gap with a span to depth ration virtually infinite, and subject to imposed loads many times the self weight, especially impact loads

Why is it flat?

Interestingly, its **flexibility** is the key to its impact resistance: when hit by a fly it gives to absorb the kinetic energy rather than trying to directly resist it

Necessity of Pretension



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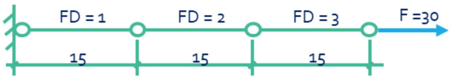
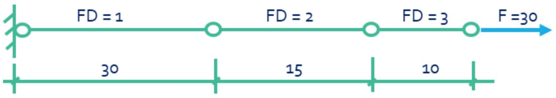
This image shows the importance of correct form finding. Before tensioning the fabric is wrinkled; if it is cut correctly then it will become smooth when under load. Out of balance tensions will result in Heugens tension fields: waves in the fabric.
"Marsyas" –Anish Kapoor, Tate Modern (Arup)

Form finding for tension structures

- Tension-only (and Compression-only) structures need
  - The right geometry
  - The right prestress
- Form finding is needed to find both
- **Force Density**
  - Set element length proportional to load

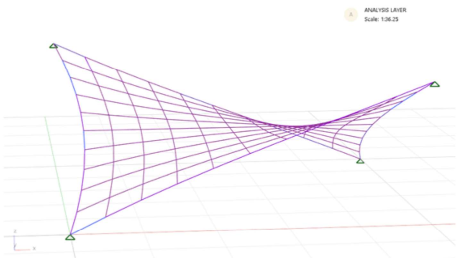


The Model



The Result

- **Soap film**
  - Find geometry where pretensions are in equilibrium



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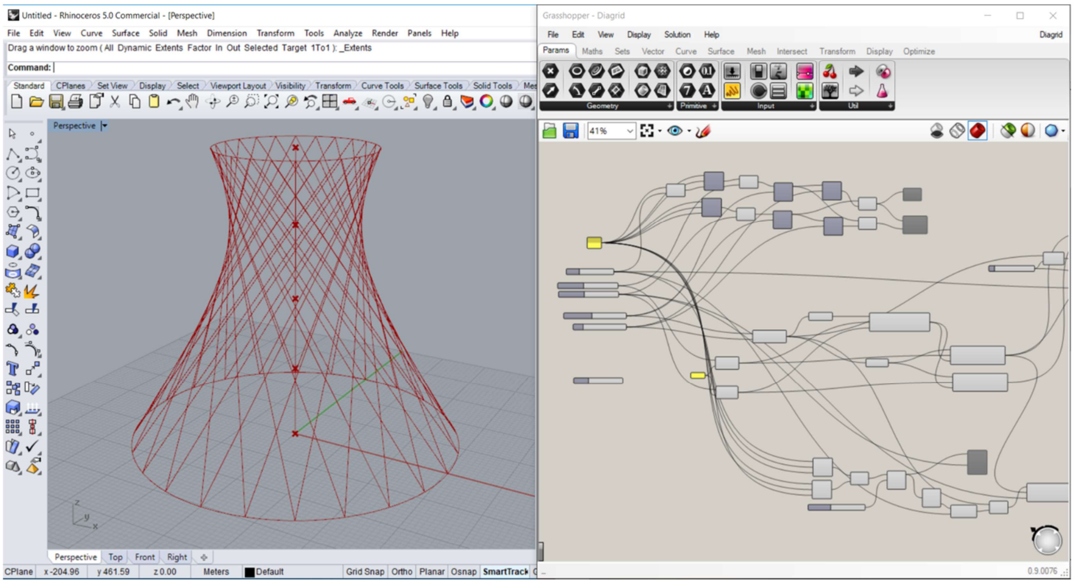
Short Question and Answer session

Future of digital structural engineering

Parametric Design



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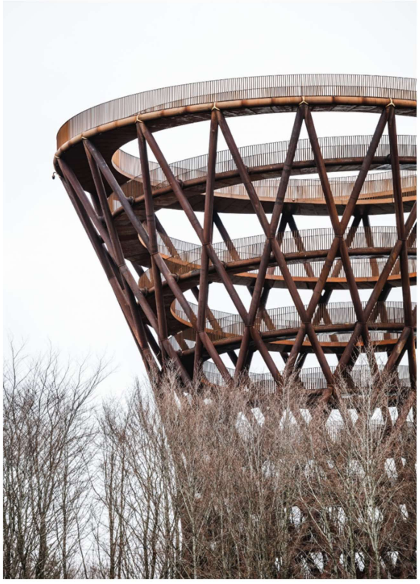
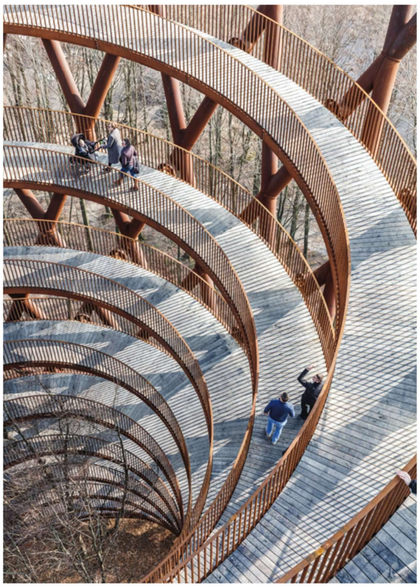
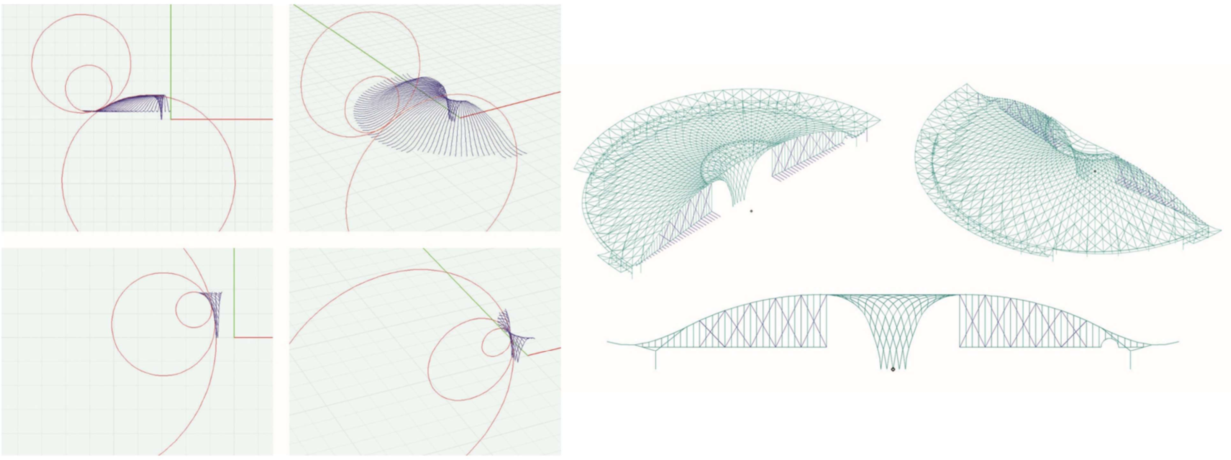
Parametric Design





Camp Adventure Tower, Denmark (Arup)

Parametric Design



London Kings Cross Station, UK (Arup)

Parametric Design

London Kings Cross Station, UK (Arup)

Timber and Carbon Net Zero

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Temple Galaxia (Format Engineers)

Artificial Intelligence and Machine Learning

EM iepirkums „Apmācību semināru "Datoraprēķini būvkonstrukciju projektēšanā" organizēšana un norises nodrošināšana" ID Nr. EM 2020/46 182

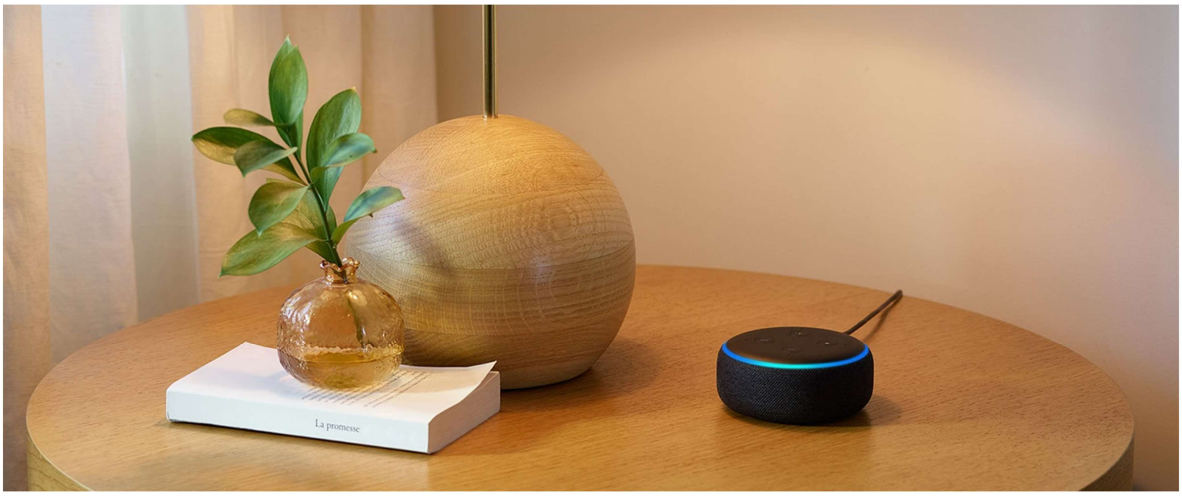
AI was initially a quest to model human intelligence in computers. Started in 1950s
Focused initially on symbolic manipulation to emulate thought processes: words and numbers are symbols.
Symbolic AI mostly struggled to live up to its hype, but has created some highly successful applications that are often not now recognised as AI

What is AI? Automated search

It is not possible to directly solve the question: "what is the shortest route between two points". Instead AI research produced algorithms such as A* to intelligently search for the shortest route with a mixture of estimates, calculation, and data storage.

Searching through unsorted databases is also an AI application, the most famous of which has become a verb: To Google. Google's search rankings were initially based on keywords and webpage connectedness to predict what the best order was to present the results, but has subsequently added machine learning to record and use what links people actually click on.

What is AI? Natural language processing



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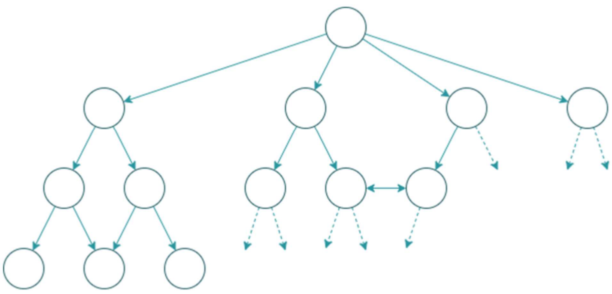
Natural Language Processing is found in many homes and pockets. After machine learning parses speech sounds into words, NLP groups the words into sentences, work out which parts are nouns, verbs, and adjectives from grammatical rules, then determine the instruction or question.
It then either tries to find the answer from the internet or play the music of choice.

What is AI? Automated decision making



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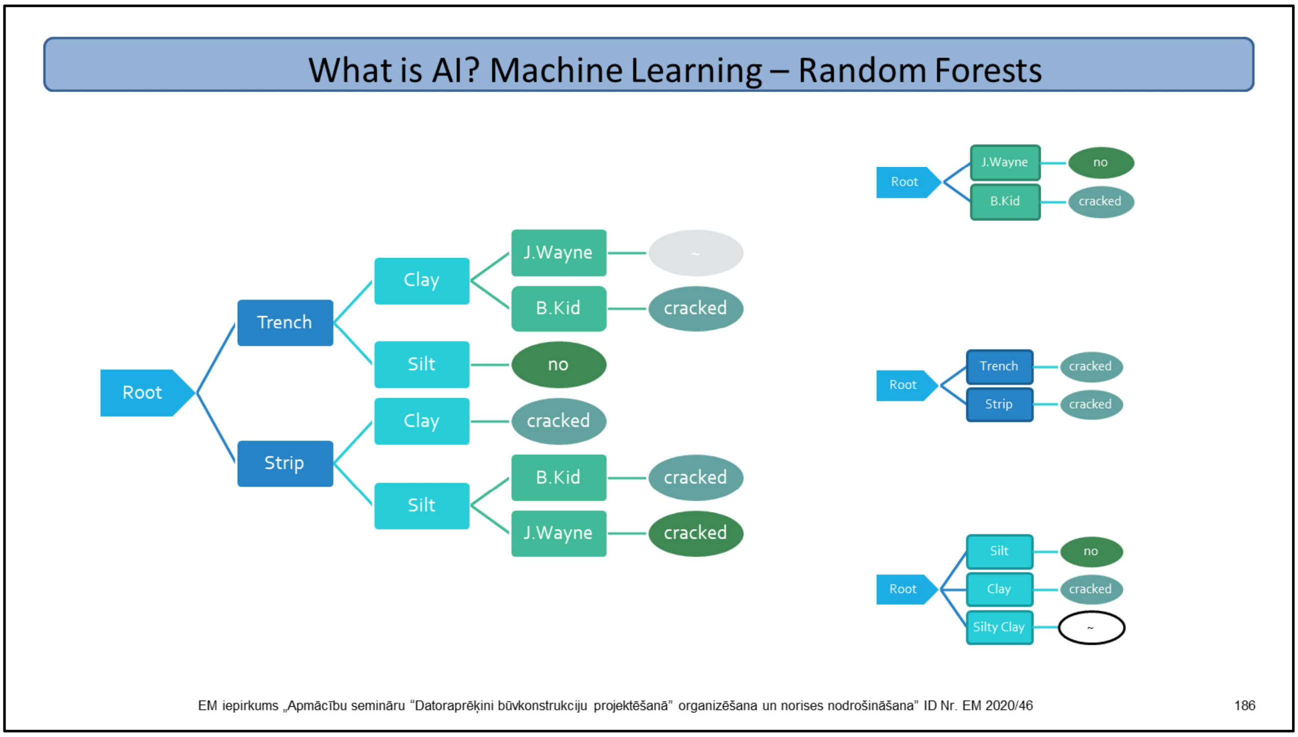
Another aim of AI is to encapsulate knowledge and enable automatic decision making. This came in the form of

Expert Systems – encode both an expert's knowledge and the way that they solve problems. This has proved difficult as most people cannot articulate how they solve any problem, only specific problems, and they are difficult to generalise. Also experts' knowledge is founded on general knowledge, which we all have but is to trivial and extensive to record (though some are trying to).

State Search builds a tree of possible decisions and then navigates it to find the best answer, or at least the most promising route to the answer. These have proved successful in games, which are formal (have set rules) and bounded. Chess has about 16 billion possible moves in the first four turns, and about 10^{120} possible moves over a typical game: it is just not possible to check them all.

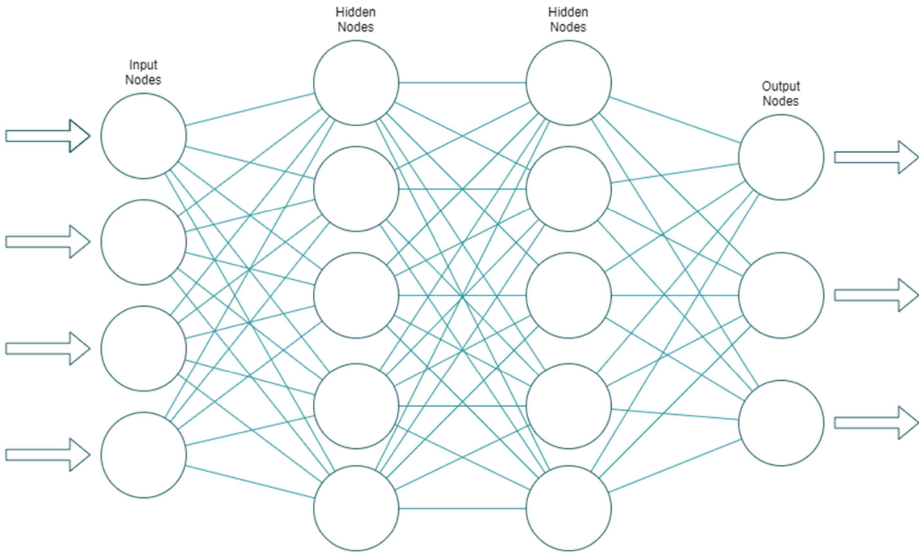
When IBM's Deep Blue beat Kasperov, the world chess champion in 1997 using state search to check all the possible moves over the next few turns, giving maximum points to the computer and minimum to the human. Kasperov, on the other hand, said that he considered on one move: "the right one".



While state search extrapolates a tree of options, we can also build the trees from existing data, finding correlations between different events and incidents. The idea is that we can then propose a new condition and the state tree will say what the underlying causes are.

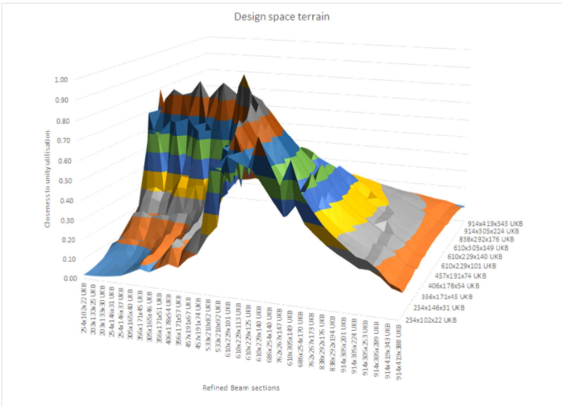
The problem is that the tree only works for particular cases and struggles to generalise. To overcome this we create large numbers of pruned copies of the trees: a forest! When presented with the new data, each tree votes on what it thinks is the likely cause. Random forests have proved very successful in a number of technical applications such as medical diagnosis.

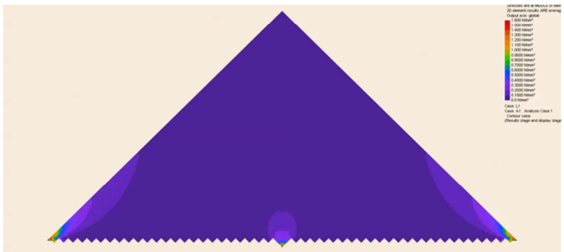
What is AI? Machine learning – Deep learning

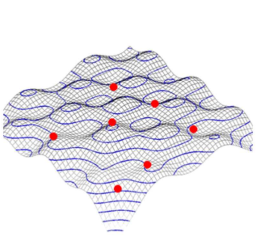


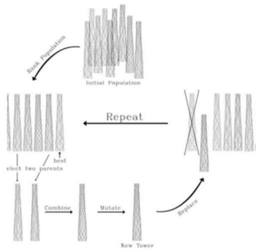
While neural networks have been around since the 1960s, they were initially so unsuccessful that in the 1970s papers on the subject were banned from AI conferences. Now with fast processors and powerful training algorithms they are the dominant machine learning method.
Neural networks are inspired by how the neurons in the brain connect together, collating data to enable pattern recognition.
They work by taking numerical data in by a number of inputs, multiplying and adding these together multiple times, until an output indicates which is the answer. If they are right then the options that gave this are strengthened, if wrong they are weakened. The neural network is thus trained over thousands of iterations until it consistently, or at least generally, gives the right answers.
The game of Go has 10^{360} possible moves and it is extremely difficult to measure the quality of any particular move. AlphaGo beat the world champion using deep earning to predict the best moves, having trained on existing games and against itself.

What is AI? Optimisation









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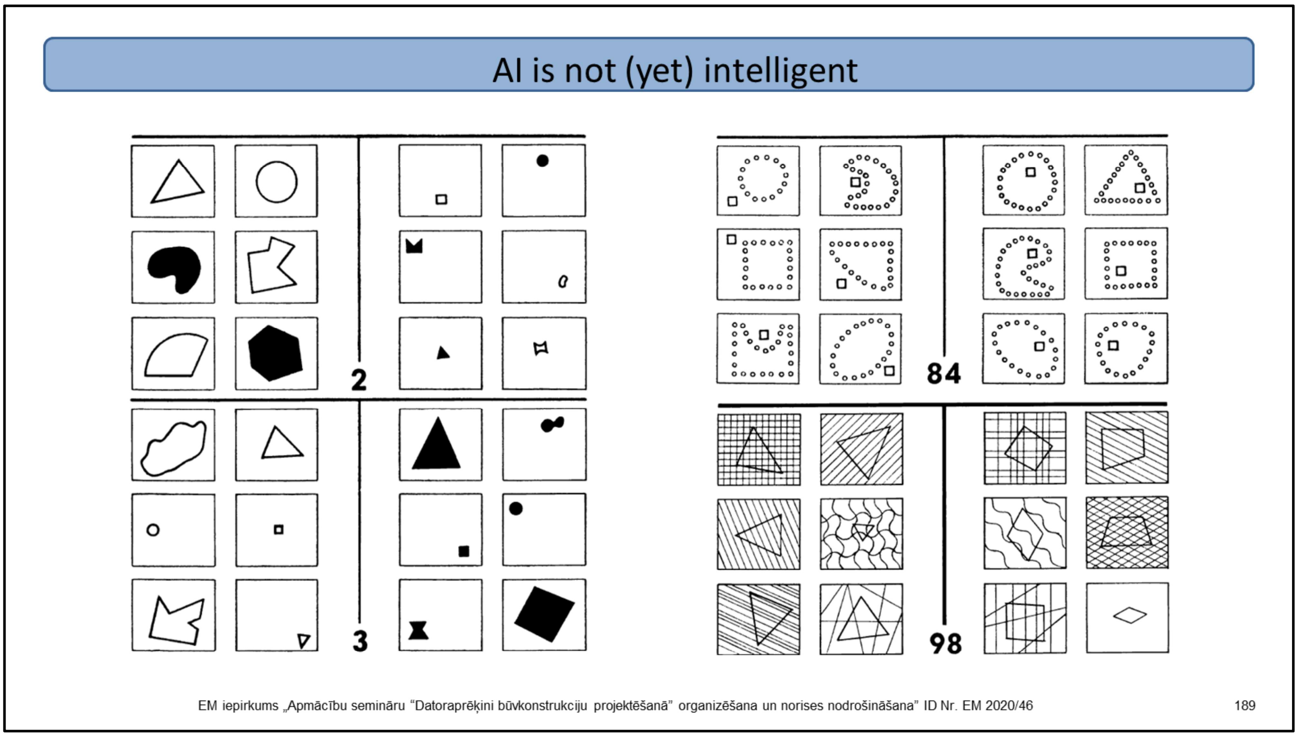
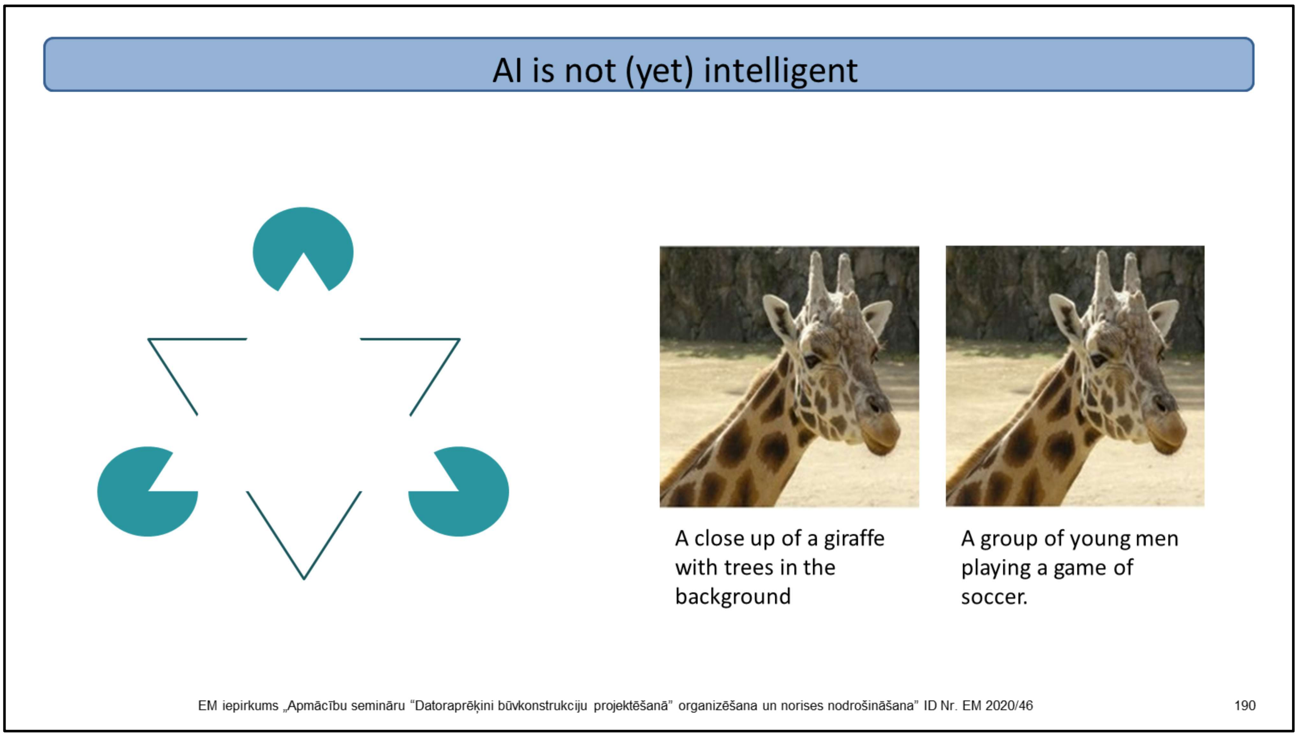
It is often forgotten that optimisation is a form of artificial intelligence, search for and choosing the best answers from a myriad of options. Optimisation uses a large number of methods (see my Structural Engineer paper from a few years ago on the subject), many of which are inspired by nature: the evolution of life, how that life works together to find food, how bones react when they are exercised, or what happens when metal cools.



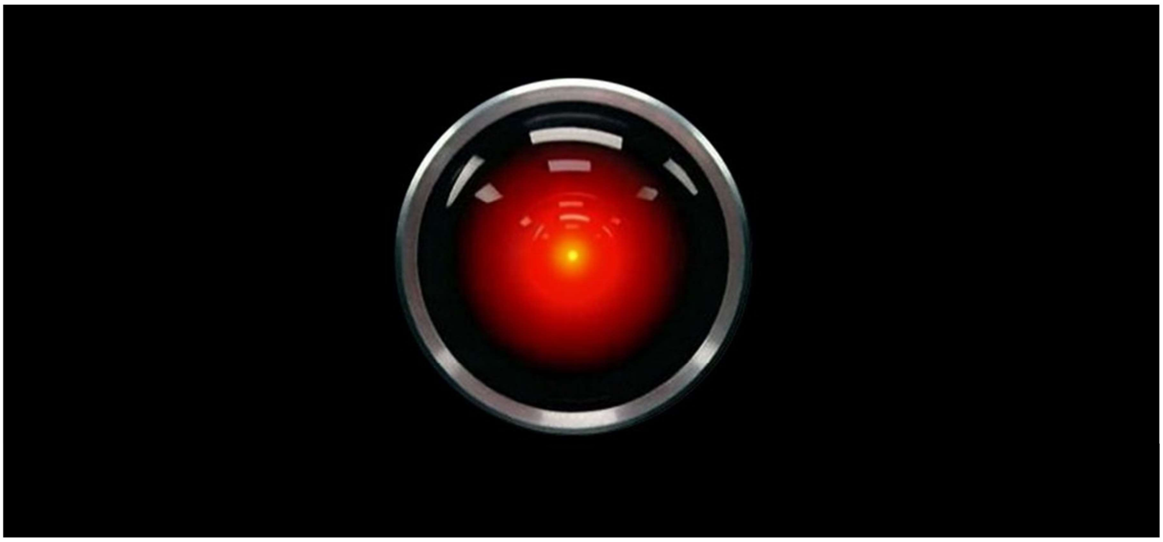
There is a lot hype around AI, but then this has been a characteristic of AI since its invention. Let us temper that with a look at what AI is not.
Artificial Intelligence is not intelligent. Humans can generalisation of solutions from just a handful of examples.
We can look at these four pattern recognition tests, each with six examples of one concept and six of another, and quickly work out what the categories are.
On the left they are reasonably easy; those on the right are very difficult for AI to categorise, especially 98, which requires the AI to ignore the background hatching. Even after tens of thousands of training examples, the best machine learning systems manage only a little better than random guessing.



Human intelligence can see what is not there but only suggested
Can you see the white-bordered Kanizsa triangle in the left image? AI cannot.

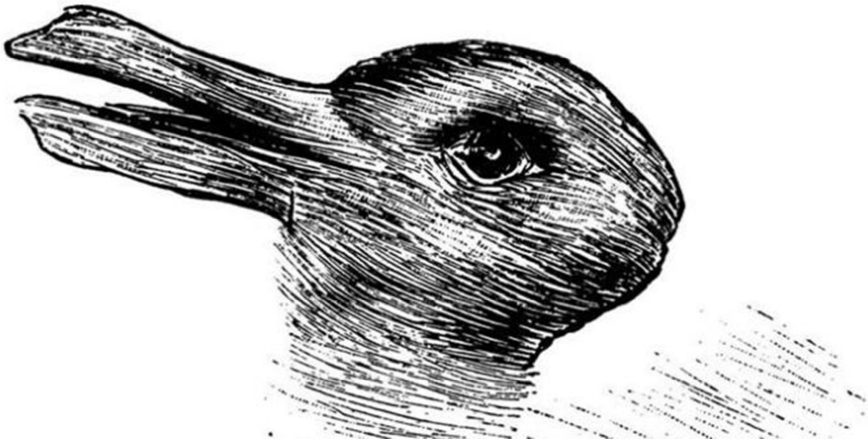
Human intelligence is also not easily fooled.
Can you see the difference between the two giraffes? AI thinks they are completely different because a few significant pixels have been changed. AL does not recognise things in the same way that we do.
Even if we initially think that we see something strange, we know that is strange and look closer until we understand.

AI is not (yet) aware or conscious



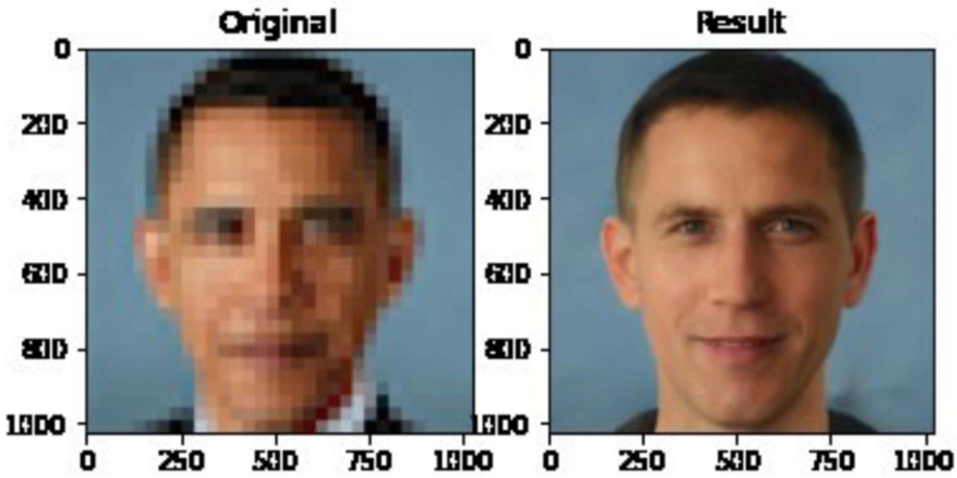
Deep Blue and AlphaGo beat world champions but neither knew that they or their opponent existed.
I occasionally hear talk about giving AI rights, but this is extremely premature, as they have no self awareness or consciousness.
We do not even understand how consciousness arises in our brains, so we have no way of knowing how to create it artificially.
Self aware artificial intelligence is still science fiction

AI is not (yet) robust



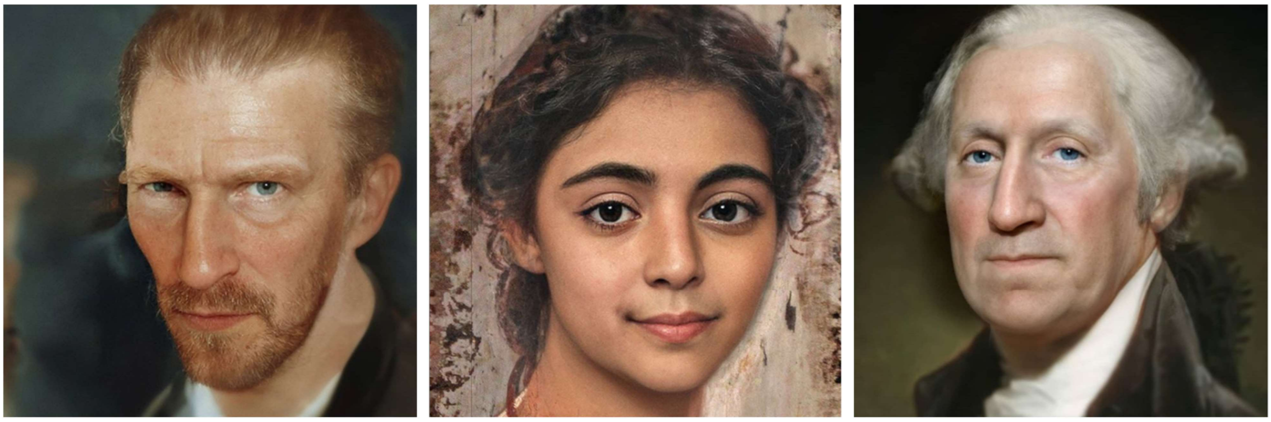
Is this a duck or a rabbit?
Humans can recognise ambiguous data, but AI accepts all and gives the result regardless.
We can be fooled but we often know that that is happening.
Like humans, AI is vulnerable to bias. Ours comes from our upbringing and education or lack of it; AI's bias comes from poor training data. Providing training data that is free of bias is a major problem for machine learning systems.
We need AI that can function well when the inputs are not certain.

What AI is not (yet) robust



Like humans, AI is vulnerable to bias. Ours comes from our upbringing and education or lack of it; AI's bias comes from poor training data. Providing training data that is free of bias is a major problem for machine learning systems.
In this case a data set that was all white faces

AI is not (yet) robust



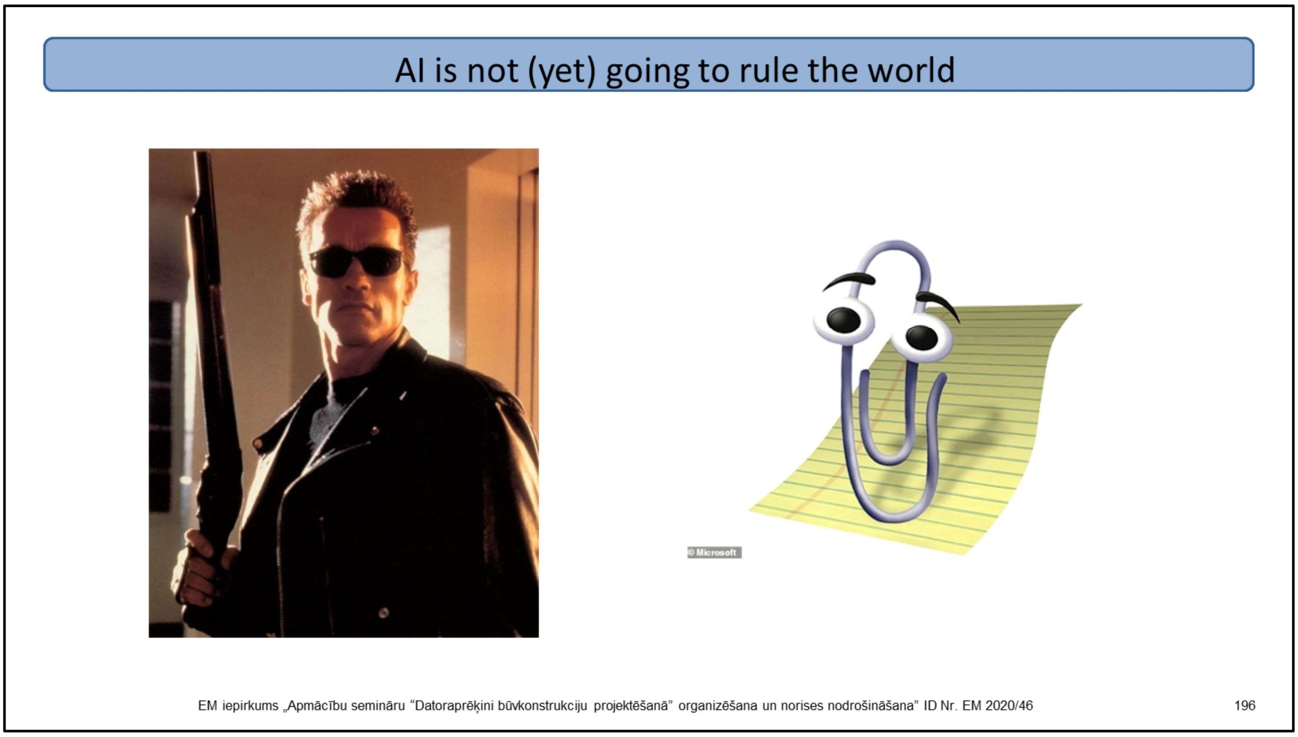
When properly trained the results can be impressive
https://www.instagram.com/ganbrood/?hl=en
https://thispersondoesnotexist.com/

AI is not (yet) possessing common sense

- Sentence 1: “I poured water from the bottle into the cup until it was empty”.
- Question: What was empty?

- Sentence 2: “I poured water from the bottle into the cup until it was full”.
- Question: What was full?

Common sense is knowledge about the world that is learned from being in the world but difficult to quantify in advance.
To understand these questions, you need to have some knowledge of the world. In each pair the sentences differ by just one word, but they completely and ambiguously change the subject of the sentence.
We understand who might fear or advocate violence, because we watch the news and understand the role of the city council and what might demonstrators do.
Likewise we understand the concepts of Full and Empty, and therefore which container will be which after the pouring.
An AI might be able to recognise the words and how they connect grammatically, but it does not understand meaning.
The Google routines can find you a picture of a cup or a bottle, but it has no idea what a cup or a bottle is; it can only match up the word symbol with a pixel pattern.



Stories of the created rebelling against the creator have been with us for thousands of years. From the Garden of Eden to The Terminator or The Matrix. Humans have never liked feeling controlled and assume that any AI would feel the same way.

This idea conflates intelligence with emotions, not realising that emotions are something intrinsic to most, possibly all, animals. Emotions have developed to reward helpful behaviour (breeding or feeding for example) and protect against danger (fleeing from or fighting threats).

These emotions would have to be explicitly added to any AI, and then only if they would boost performance.

The world is more at risk from Artificial Stupidity than Artificial Intelligence.

- Self driving cars that cannot recognise a white truck against a bright sky.
- Automated stock market programs that all buy or all sell in response to the same stimulus, causing economic chaos.
- Engineers who blindly accept a computer design without checking that it has covered all the special cases.

How might structural engineers use AI?

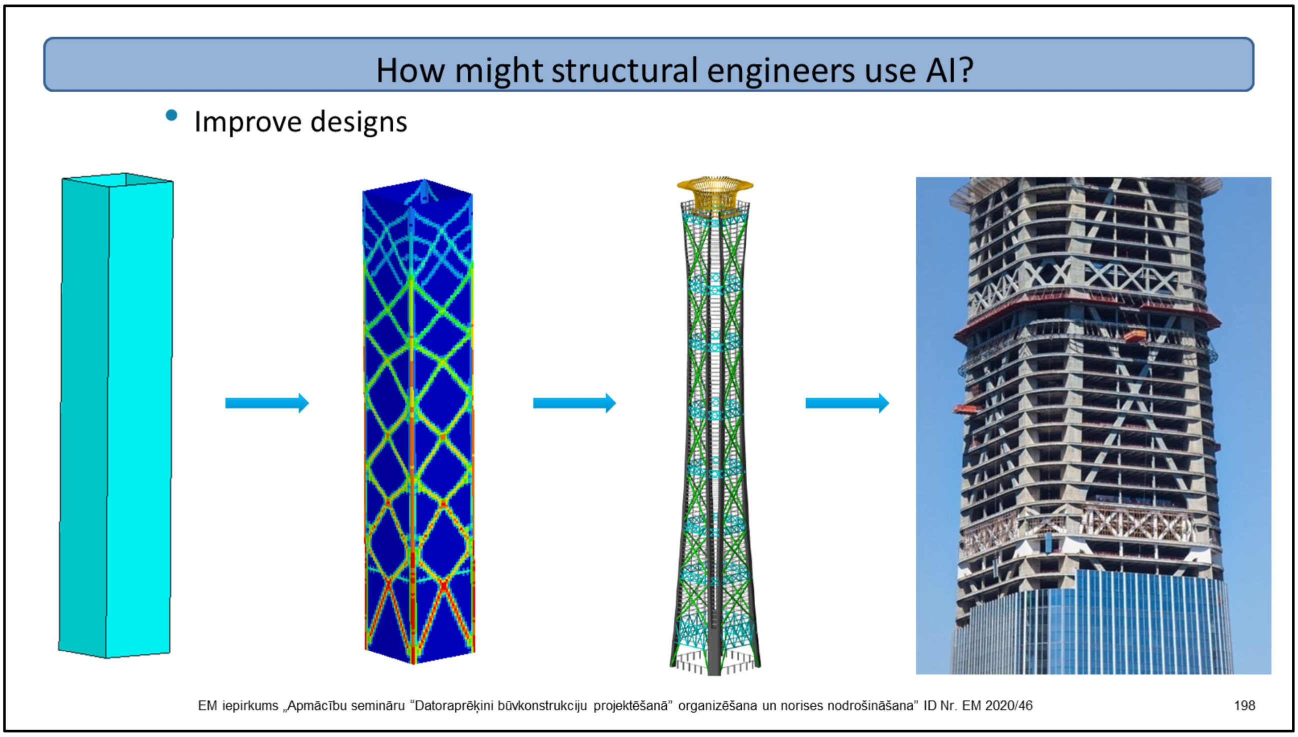
- Zero carbon

So how might we use artificial intelligence for design and on site?

AI is going to supply key tools in achieving zero carbon in construction. We cannot achieve zero net carbon by just planting more trees, but by causing less damage to the environment in the first place.

Machine Learning can use existing and ideal projects to recommend design approaches that improve efficiency.

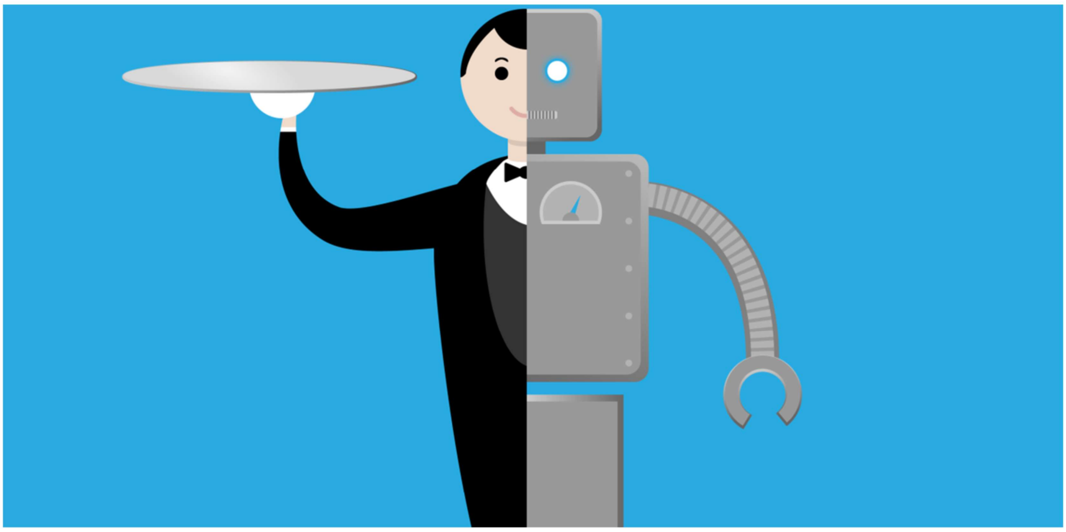
AI in the form of optimisation can allow us to explore many more design options than we would have the time or patience to do manually. While efficient use of materials will not solve all the problems, it will be a major contributor to minimising the amount of carbon that our designs need to offset.



Here we can see an Arup project from China, where first an optimisation is used to find the best bracing arrangement.
Then the building perimeter is automatically adjusted to give the best overall form.
This would involve hundreds or thousands of analysis and design iterations until the final result is found.
But that is not the end of the design but only the start. We must then go through all the detailed checks, to ensure that it is economic, robust, safe, buildable, and meets all the client requirements.

How might structural engineers use AI?

- Administrative assistant



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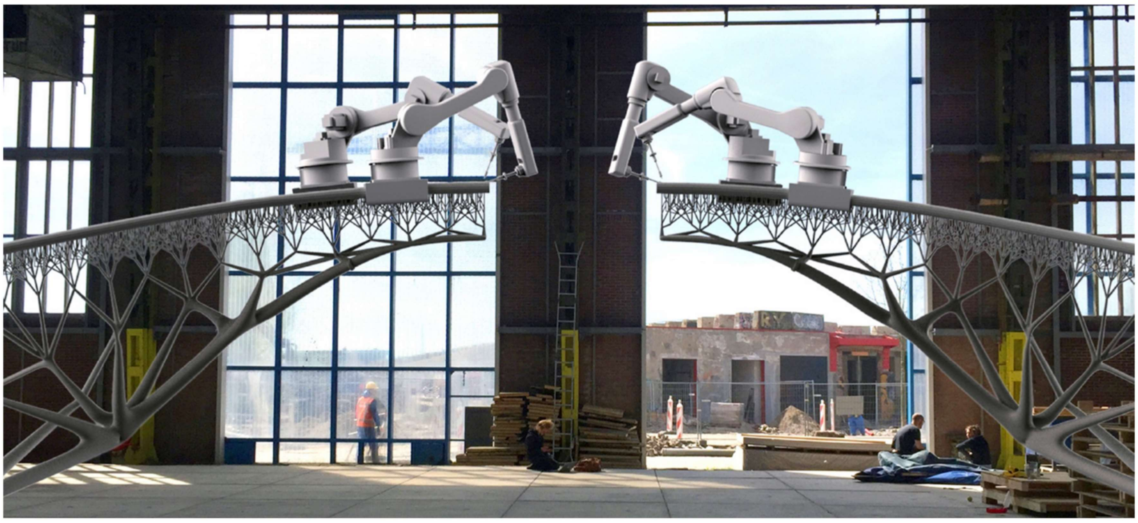
The area that I am most looking forward to is the automated administrative assistant. There are already some AI bots that can arrange meetings with clients; other that can field questions on websites until it gets one that it cannot answer.
I use Outlook to remember all my appointments and phone numbers for me. But I want it to help prioritise which emails need responding to first and give some suggestions as to what the reply should be.

How might structural engineers use AI?

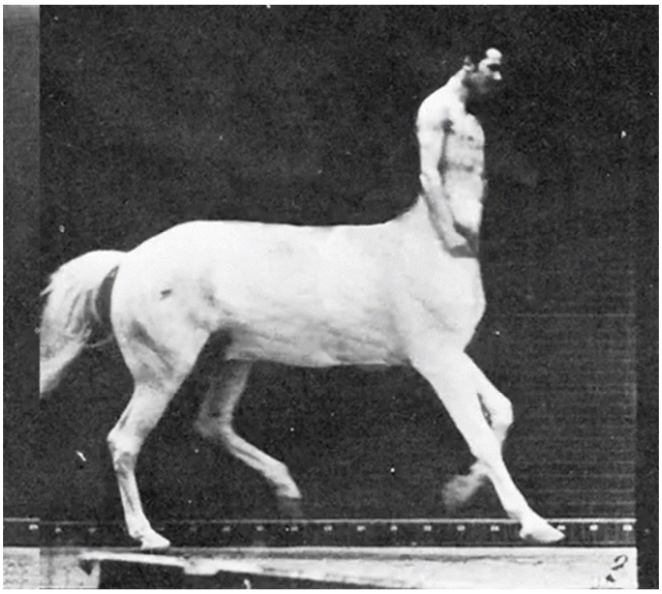
- Engineering assistant

Engineering assistants on site are already starting to be used.
For example you can request regular site surveys by drone + point cloud + AI conversion of point cloud into 3D model to check progress and accuracy.
Concrete batching plants might have AI monitoring the materials going into the mix and the concrete coming out for instant quality control.
Eventually I see AI becoming like a smart but inexperienced graduate engineer: fresh from college with the latest ideas but lacking in common sense and practical experience; trusted to come up with good ideas and suggestions, and to do calculations and designs. But these should only be issued and built after careful checks to see what it has missed or misunderstood.
I would also not send it to a client meeting.

Digital Fabrication and Construction



The engineer of the future is a centaur



So how should structural engineers use AI?
As we have seen, there is a lot of hype around AI and it is not without its problems, but there are also a lot of successes and useful applications available to us. The important thing is that we make the most of these powerful tools but with our eyes open.
Deep Blue did not stop people from playing chess. On the contrary, the top players both train against AI and work with them to play the best games.
We engineers should take the same approach: work with the computers, as we do at the moment, using our own strengths of creativity, common sense, and understanding, with the AI’s ability to explore options and automate tasks, even those that are too complex for classically programmed computers to resolve.
The engineer of the future, as is now, is a centaur.

Question and Answer session

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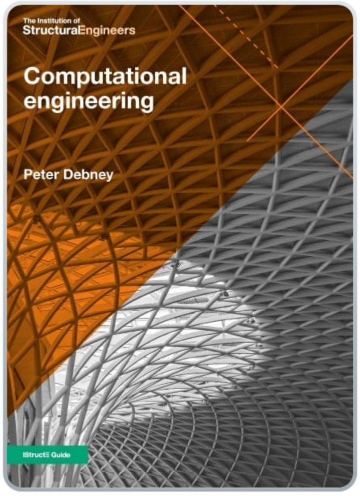


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