CCS323050

# Optimizing Steelwork Design and Detailing Workflows from Concept to Fabrication

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## Learning Objectives

- Learning Objective 1: Get familiar with various connection design workflows across the Autodesk AEC Collection
- Learning Objective 2: Find out about challenges in connection design from various real-life projects
- Learning Objective 3: Learn how to quickly deal with code-checking all types of connections to increase productivity
- Learning Objective 4: Get insight into CBFEM-based connection design and how it compares to traditional approaches

## Description

This class will investigate how much the connection design workflows have changed in recent years. Using several high profile design projects delivered by Mott MacDonald, we will demonstrate how to work with Autodesk Revit, Dynamo, Robot Structural Analysis, Advance Steel and IDEA StatiCa to slash designing time, optimize material and satisfy the code requirements at the same time.

Case studies from Jakarta Velodrome (Indonesia) and Waterloo Station (United Kingdom) will be presented with focus on how to handle data models across the Autodesk AEC collection and synchronize them with IDEA StatiCa Connection, a code-checking application from Autodesk industry partner IDEA StatiCa.

## Speakers

### Matt Pearce

Matt is a principal structural engineer and digital design leader at Mott MacDonald, with 12 years of experience in designing complex structures across the globe. He started with Mott MacDonald in 2007 and has since worked in UK, Hong Kong, Macau, China, Singapore and now Canada.

Matt has worked extensively in the steelwork design field, having worked on the structural designs for Waterloo Station, London 2012 Olympics Shooting Venue and Twickenham Stadium (East Stand Extension) in the UK, Jakarta Velodrome in Indonesia and Wynn Palace in Macau . He currently leads digital design for building structures at Mott MacDonald.  He was co-speaker at Autodesk University in 2018.

**Martin Rolný**

Martin is the Head of Product Team at IDEA StatiCa with over 10 years of experience across development, testing and supporting CAE applications for structural engineers. With his team of Product Engineers, Martin supports global community of engineers in delivering their projects effectively, on-time and with all the code-check requirements. He is a big enthusiast about new technologies and pushing limits of software tools for engineers.

## Introduction

This handout is intended to provide highlights and some additional background to our presentation on optimizing steelwork design workflows, together with useful links to further reading.

## Learning Objective 1: Get familiar with various connection design workflows across the Autodesk AEC Collection

### Definitions

- **Workflow** – Google definition: "the sequence of industrial, administrative, or other processes through which a piece of work passes from initiation to completion." In this context, the piece of work is a steelwork structure, initiation is the design brief and conceptual design, and completion is the erected frame. The processes are the design, detailing, fabrication and construction steps taken to complete the flow.

- **Concept Design** – the first stage in the development of the steel design. This typically includes initial visualizations of the design, based on design brief and design standards. Concept structural design proposals may include preferred frame system, structural grid, preliminary element sizes, expansion joints, major openings, schedules of design loads.

- **Steel Fabrication** – the process of manufacturing structural steel components to enable construction on site. This may include cutting, drilling, welding, assembly and painting.

- **Optimization** – the process of assessing and selecting preferred design solutions based on defined performance criteria. In the context of steel design and fabrication this could include minimizing steel weight, depth, cost, number of connections, number of elements, while satisfying strength, serviceability and functional requirements.

- **CBFEM Method :** component-based finite element method is a new method to analyze and design connections of steel structures. It models members, plates, welds and bolts as equivalent finite elements, with loads applied to the connected members

- **Component Method:** Traditional method of calculating the resistance of elements within a steel connection. It breaks down the connection into discrete components, the capacity of which is calculated using code-based equations.

## Software

- **Autodesk Revit** – BIM authoring software with following key features
  - Parametric components
  - Worksharing
  - Schedules
  - Interepoerability and IFC read/write function
  - Add-ins to 3rd Party software to extend Revit functionality
  - Parametric Steel Connections
  - Drawing Production

- **Autodesk Advance Steel** – 3D model authoring platform for steel frames with following key features
  - Parametric Steel Connections
  - Steel connection libraries and groups
  - Production of fabrication data
  - Code based connection design
  - Modelling of sheet metal and folded plate work
  - Modelling of stairs, railings and ladders

- **Autodesk Robot Structural Analysis** – Finite Element based structural analysis and design software with following key features
  - Multiple analysis types: Linear, geometrically non linear, non-linear materials, modal, time history
  - Wind load generator
  - Seismic load generator
  - Code-based element design
  - Integration with Revit, Advance Steel and IDEA Statica

- **Autodesk Dynamo** – graphical programming interface for a number of Autodesk products including Revit, Advance Steel and Civil 3D

- **IDEA Statica Connection** – Finite element-based steel connection design software with following key features
  - Automatic mesh generation
  - Elasto-plastic analysis of welds and plates
  - Non-linear analysis of bolts
  - Determination of connection stiffness

## Learning Objective 2: Find out about challenges in connection design from various real-life projects

### Jakarta Velodrome


#### Overview

- Project Name: Jakarta International Velodrome
- Design and Construction period: 2016-2018
- Client: ES Global Ltd.
- Key Features
    - 2000 seats
    - UCI standard timber track
    - Lightweight membrane roof

## Key Challenges

The key challenges relating to steelwork design were as follows;

1. Long span (120x90m) roof structure with relatively large forces
2. Seismically active region and together with the high occupancy put the building in a relative high risk category D building
3. Architecturally exposed steelwork
4. One of the unique features of the steelwork was that it comprised of approximately 75% re-used modular components, with bespoke connections facilitating rapid erection
5. Design to AISC codes with local Indonesia parameters
6. Modular design with sizes limited by shipping containers
7. Tight design programme Of 9 months
8. Tight construction programme of 18 months

## Connection Design Software Assessment

- Before commencing the detailed design, an appraisal of the available software programs for connection designs was carried out.

- Prioritized software over spreadsheets as this make checking easier.

- Categorized the connections into 4 main types:
  - Base Plates
  - End Plates
  - Welded Tubes
  - Fin Plates / Gusset Plates

| Connection Type | Autodesk Robot | Bentley Limcon | RISA-3D | IDEA Statica |
|---|---|---|---|---|
| Base Plates | N | Y | Y | Y |
| End Plates | N | Y | Y | Y |
| Welded Tubes | N | N | N | Y |
| Fin Plates / Gusset Plates | N | Y | Y | Y |

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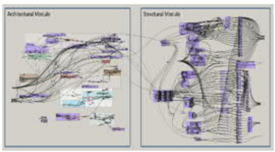
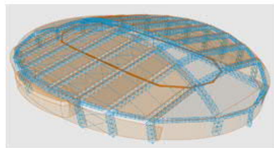
## Connection design process

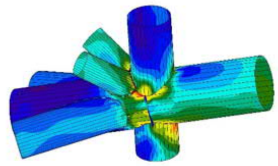
The connection design process is summarized as follows:



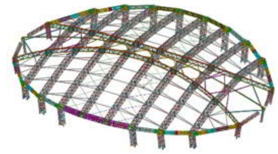
1. Integrated structural and architectural parametric models created



2. Wireframe Rhino / Robot model created



3. Connections designed in IDEA Statica 3D finite element design software

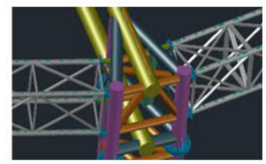


4. AutoCAD fabrication model produced directly from wire frame Rhino models

8. Steel erected in Indonesia

7. Steelwork stockpiled in UK, ready for shipping to Indonesia

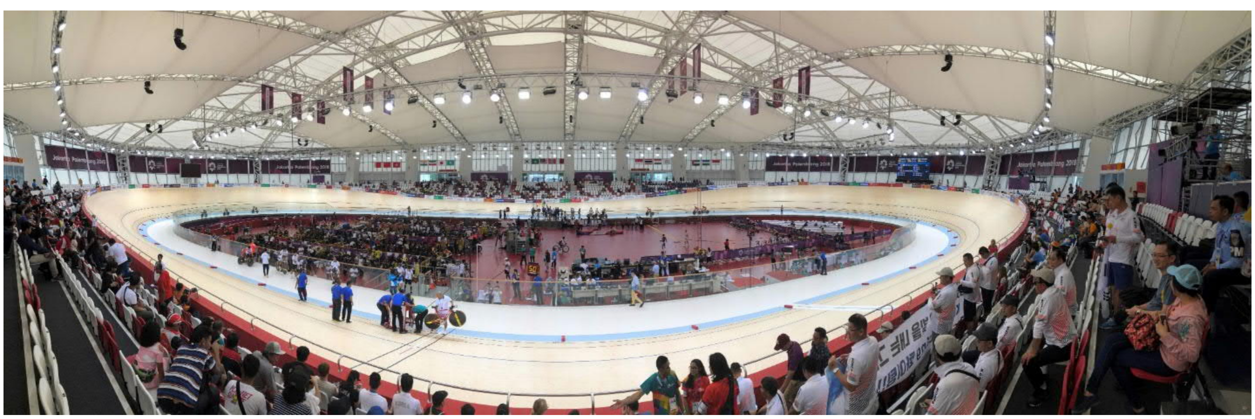
6. Steelwork fabricated with trial fit ups in UK



5. Connection details modelled in AutoCAD fabrication model by ES Global steelwork delivery team

## Outcomes

- Steelwork connection designs delivered in two months, compared to four months originally programmed.
- Design costs were approximately £30k less than equivalent traditional method
- Results showed good correlation with traditional hand methods of calculation.
- Still required  manual manipulation of output to provide sketches to contractor



## Waterloo Station

- Project Name: Waterloo Station Wessex Capacity Alliance
- Design and Construction period: 2015-2019
- Client: Network Rail / Bourne Engineering Ltd.
- Location: London, UK
- Key Features
  - c.52x17m roof span
  - MM design team were seconded to Bourne Engineer Ltd to assist coordinating the steelwork design with connection design.

### Key Challenges

The key challenges relating to steelwork design were as follows;

- Fully glazed structure with tight deflection limits
- Significant bomb blast resilience requirements
- Architecturally exposed steelwork
- Construction over live railway station
- Complex foundation / existing substructure interaction
- Complex load paths through steelwork

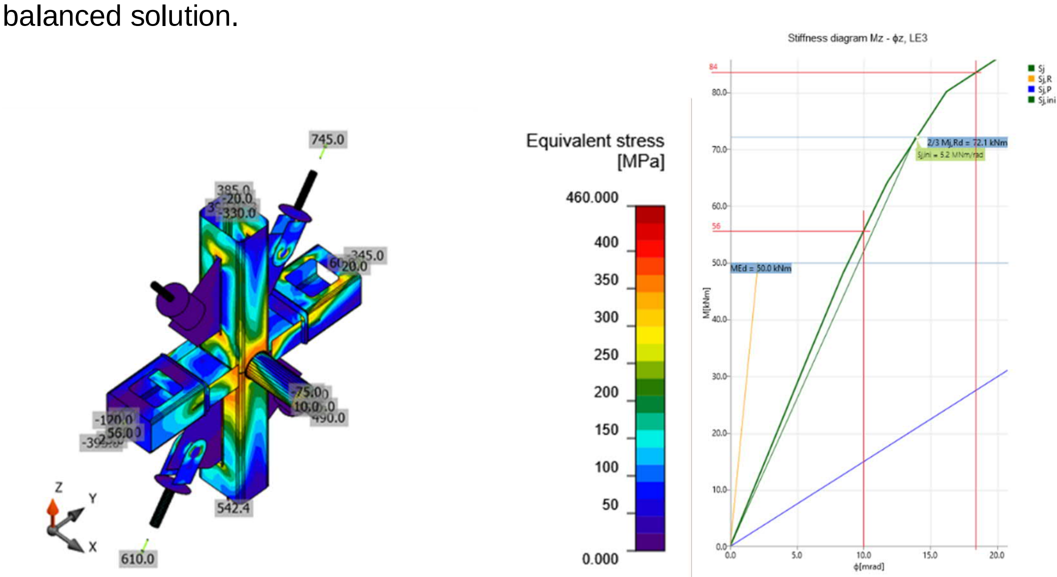
- Limited site access
- Tight programme

### Connection Requirements

- Architecturally exposed
- 120 year design life
- Tension only elements for MacAlloy bars
- Access holes for bolt tightening
- RHS Transoms fixed in major axis, pinned in minor axis, axially stiff
- 3 different sets of load combinations
    - ULS
    - ACC – Blast
    - ACC – Post Blast
- Non-slip connection at service for transoms
- Internal forces in upright element required to be modelled.

### Methodology

- Due to the number of combinations totalling more than 3000, the forces were enveloped into the 3 types: ULS, Blast and Post Blast
- Using IDEA Statica we able to assess the stiffness of these options to come up with a balanced solution.




### Outcomes

- Comprehensive calculation reports achieved approval from design team

- Stiffness properties could be fed back to design team and incorporated into frame design, and vice versa additional loads due to connection stiffness.
- Required work to envelope connection forces
- Required manipulation of output to provide sketches to contractor

## Learning Objective 3: Learn how to quickly deal with code-checking all types of connections to increase productivity

This will be demonstrated in a live class demonstration.

## Learning Objective 4: Get insight into CBFEM-based connection design and how it compares to traditional approaches

The method for design and code-check of steel connections and anchoring by finite elements. All checks according to the code (same as the Component method).

### Why was it created?

Structural engineers needed a tool for quick and efficient design and code-check of steel connections and anchoring.
The weak point of the standard Component method is limited topology. At the same time, everybody is using finite elements for global analysis. We merged both methods in one

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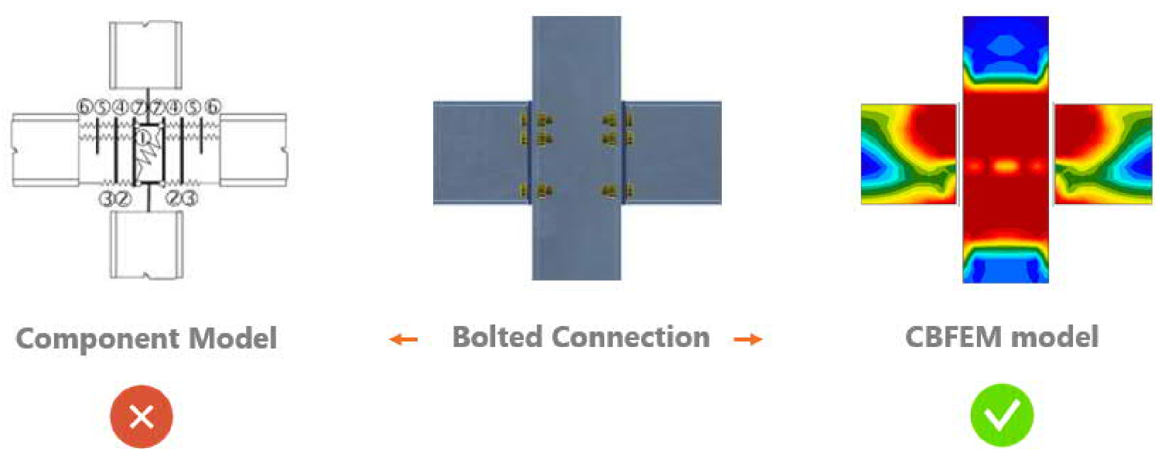



In the CBFEM, finite elements are created for each component:

- member
- plate
- weld
- anchor/bolt

### Plates

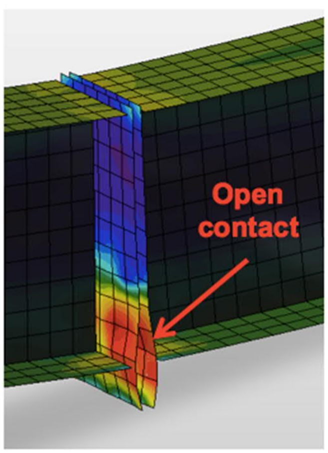
- Plates converted to 2D shell elements
- Elasto-plastic analysis allows redistribution of stresses
- Determine equivalent plastic strain

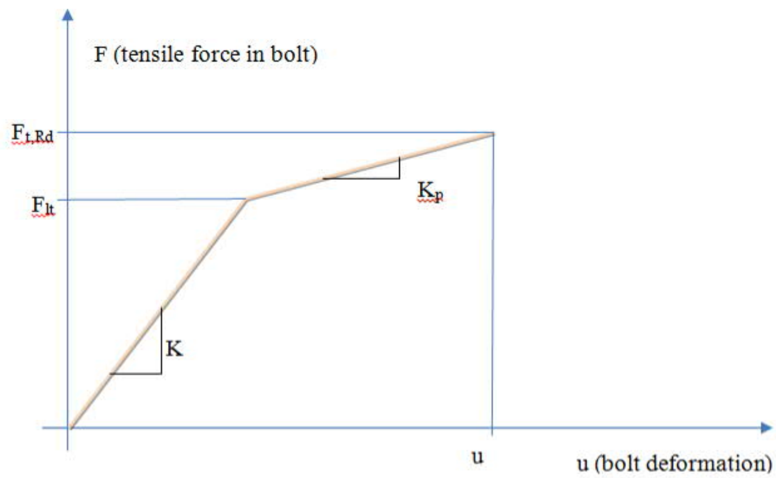
## Welds

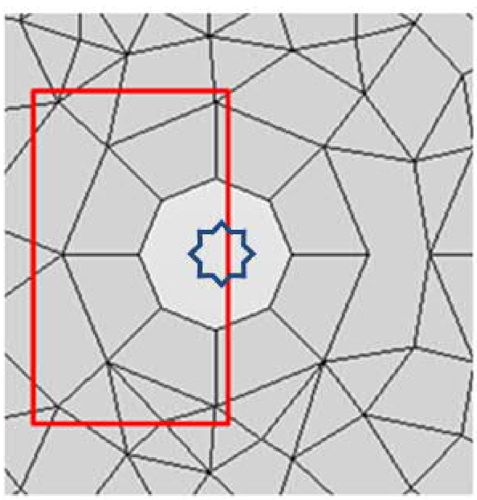
- Welds are modelled as solid elements
- Elasto-plastic analysis allows redistribution of the stress along the weld
- Also enables determination of the stiffness of the weld

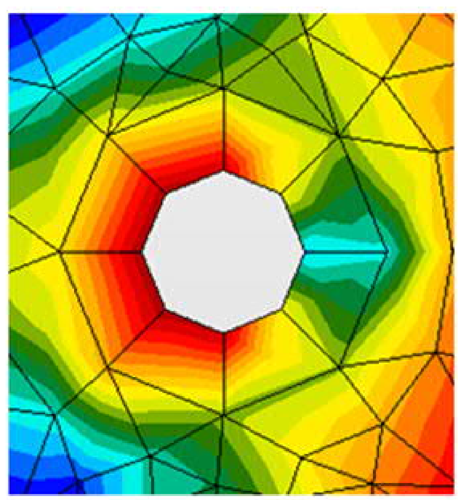
## Bolts

- Bolted connections are modelled as a combination of steel plates in contact and discrete bolt elements
- Bolts are modeled as nonlinear springs
- Heads and nuts are connected by force interpolation constrains
- Bolt shear modelled as a contact with steel plate



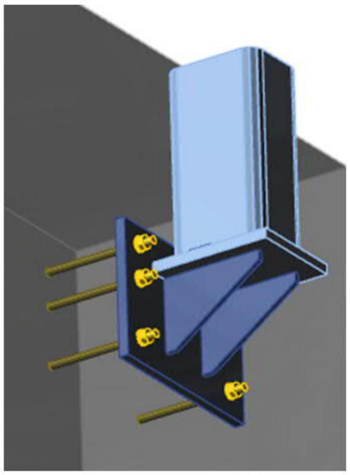
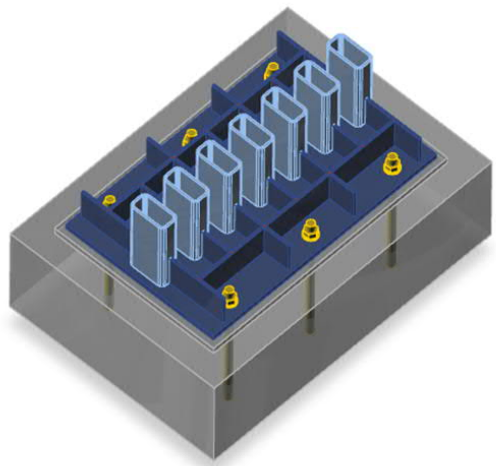





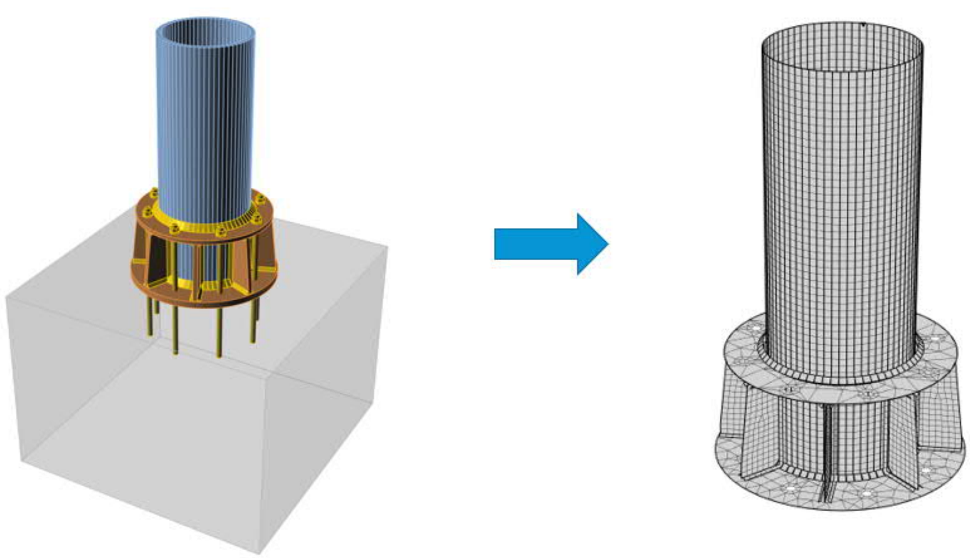
### Anchoring

- Steel to concrete connections modelled as a contact element between concrete and steel base plate
- Contact stress is evaluated, average stress from the effective area is checked
- Shear force is checked against friction, shear iron or bolts
- Code based check of concrete break out resistance

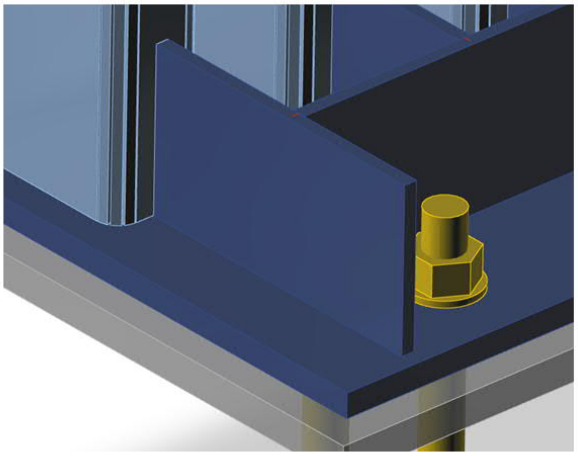



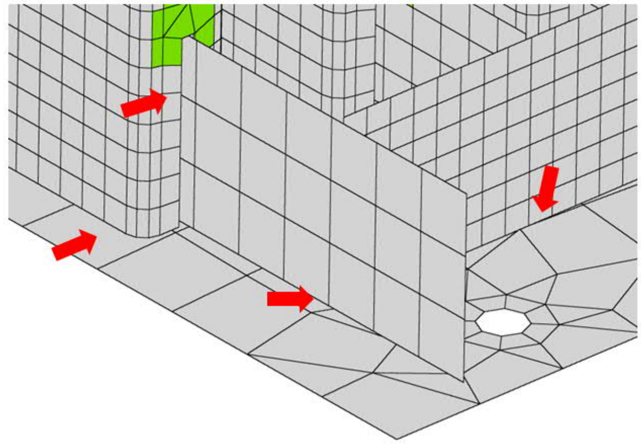
### FEM analysis

- Automatic generation of finite element model

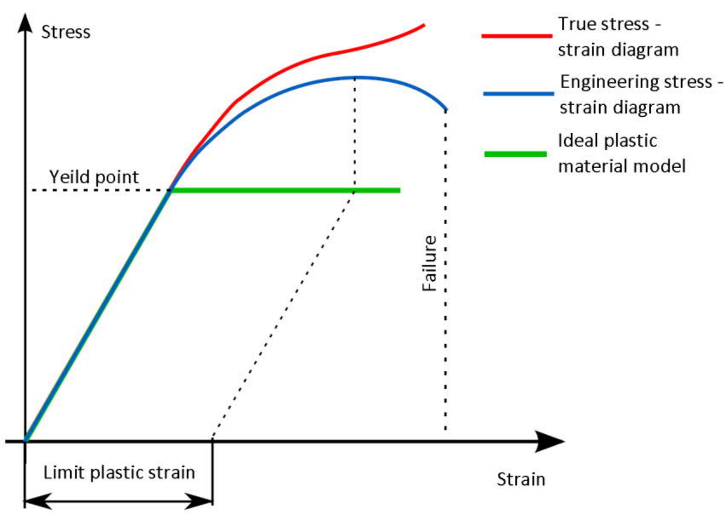


- Plates are connected by interpolation constrains and **weld finite elements**





- The analysis takes account of material non-linearity through idealised stress-strain curves




- The analysis also take account of geometrical non-linearity.

## Validation

- Live testing and calibration

- Benchmark case studies
- University research

## Further Reading

- Waterloo Case Study https://www.mottmac.com/article/37784/international-rescue
- Jakarta Case Study https://www.mottmac.com/article/40133/london-to-jakarta-in-half-the-time
- "Benchmark Cases for Advanced Design of Structual Steel Connections", by Wald F., Šabatka L., Bajer M., Barnat J., Gödrich L., Holomek J., Kabeláč J., Kočka M., Kolaja D., Král P., Kuříková M., Vild M.https://resources.ideastatica.com/Content/02_Steel/Verifications/Book/CBFEM-a_new_method.htm
- IDEA Statica Connection https://www.ideastatica.com/steel/
- Mott MacDonald https://www.mottmac.com/
- Autodesk Dynamo https://dynamobim.org/
- Autodesk Revit https://www.autodesk.com/products/revit/overview
- Autodesk Robot https://www.autodesk.com/products/robot-structural-analysis/overview
- Autodesk Advance Steel https://www.autodesk.com/products/advance-steel/overview

## About Mott MacDonald

We're a global engineering, management and development consultancy focused on guiding our clients through many of the planet's most intricate challenges.

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**Global engineering, management and development consultancy**

**2**

**Employee Owned**

**3**

**16,000 employees**

**180 Principal Offices**

**Based in 50 Countries**

**4**

**6 Key Sectors**

Built Environment

Energy

Education

Transportation

Environment

Water

**5**

**Digital consultancy services**

SMART Infrastructure

BIM Consultancy

## About IDEA Statica

We develop software for structural engineers, fabricators, consultants and all others who perform or use structural analysis. Our development team researches, tests and applies new methods of analyzing behavior of structures and their members. Based on this, we create IDEA StatiCa – software that enables engineers to work faster, evaluate requirements of the national code thoroughly and use optimal amount of material. For us, creating software is a way to contribute to making every new construction around the world safer and cheaper.