Optimizing Steelwork Design and Detailing Workflows from Concept to Fabrication

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CONNECT & CONSTRUCT SUMMIT

AUTODESK UNIVERSITY
Class objectives

1. Get familiar with various connection design workflows across the Autodesk AEC Collection

2. Find out about challenges in connection design from various real-life projects

3. Learn how to quickly deal with code-checking all types of connections to increase productivity

4. Get insight into CBFEM-based connection design and how it compares to traditional approaches
About the speaker

Matt Pearce
Principal Engineer at Mott MacDonald
Started with Mott MacDonald in 2007
Worked in UK, Hong Kong, Macau, China and Singapore
Key Projects: Waterloo, Twickenham Stadium Jakarta Velodrome, Wynn Palace, Macau
London 2012 Olympics Shooting Venue
Digital design leader for Building Structures
About the speaker

Martin Rolny

Head of Product Team at IDEA StatiCa with over 10 years of experience across development, testing and supporting CAE applications for structural engineers.
Overview

THE CHALLENGE
- Priorities of fabricators
- Priorities of engineers

THE SOLUTIONS
- Technology Solutions
- Concept Design
- Detailed Design
- IDEA Statica

PRACTICAL APPLICATIONS:
- Waterloo Station
- Jakarta Velodrome

THE OUTCOMES
- Lessons Learnt
- Conclusions
Challenges in Steel Fabrication
What are the priorities for fabricators?

TIME
Meet design and construction schedule
Minimize time on site
Minimize fabrication time
Minimize changes and rework
What are the priorities for fabricators?

**COST**

Time is money!
Minimize materials
Minimize temporary works
What are the priorities for fabricators?

QUALITY
Quality control during fabrication
Construction defects minimized
SAFETY

Safe access
Stability during construction

© Bettmann/CORBIS, courtesy First Run Features
What are the priorities for engineers?

SAFETY

Safe design under all load cases
Safe construction / dismantling
What are the priorities for engineers?

QUALITY
Fulfills functional and aesthetic requirements
Construction defects minimized
What are the priorities for engineers?

**TIME AND COST**
- Meet design and construction schedule
- Control design changes
- Time is still money
- Minimize materials
Some Common Ground?

CONTRACTOR

TIME

COST

QUALITY

SAFETY

ENGINEER
Technology Solutions
Structural Analysis and Design
Fabrication Modelling
CNC Machining and Robotics
Concept Design
Concept Design Objectives

Define an outline design that meets the requirements of the design brief

- Establish basis of Design
- Present conceptual design
- Create design brief for subsequent design stages
Establish Basis of Design

Identify Potential Solutions

Analyze Potential Solutions

Preferred Solution

Concept Design - Process
Concept Design - Process

Establish Basis of Design

- Functional Requirements
- Site Constraints
- Ground Conditions
- Design Codes
- External Loads
- Internal Loads
- Material Availability
- Design Interfaces
- Construction Constraints
Concept Design - Process

Identify Potential Solutions

- Construction Types
- Column Grids
- Building Massing
- Stability Systems
- Identify Key Components
Concept Design - Process

Analyze Potential Solutions

- Costing Data
- Foundation Loading
- Embodied Carbon
- Geometrical complexity
- Number and Type of Connections
- Specialist vs. General Contractors
- Integration with wider system design
- Structural Weight
Detailed Design
Objectives

Produce detailed design information to enable fabricator to produce fabrication information:

- Confirming design assumptions made at concept design
- Detailed coordination with other design disciplines
- Finalize structural arrangement and sizes
- Design of connections
Connection Design
Benefits, approach, theory, model, verification, validation.
IDEA StatiCa FOR STRUCTURAL ENGINEERING

Development team with 30 years of experience of making innovative software for structural engineers in more than 70 countries.
Engineering software dedicated to structural design and code-check of joints, cross sections, beams and other details.

Thousands of licenses around the world
Software results validated by universities
Linked to major CAE/CAD programs
THE CHALLENGE
STANDARD
Easy joint

NON-STANDARD
Difficult joint
STANDARD
Easy joint

Design books

NON-STANDARD
Difficult joint

Advanced scientific model

Excel spreadsheet

Estimation

Avoid using the joint
<table>
<thead>
<tr>
<th>NUMBER OF JOINTS</th>
<th>TIME SPENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% Difficult joint</td>
<td>30% Easy joint</td>
</tr>
<tr>
<td>70% Easy joint</td>
<td>70% Difficult joint</td>
</tr>
</tbody>
</table>
SOLUTION
ALL TYPES OF JOINTS

2D Frames & Trusses

Footing & Anchoring

3D Frames & Trusses
DESIGN WITH IDEA StatiCa CONNECTION

- Stress/strain analysis
- Buckling analysis
- Stiffness analysis
- Capacity design
- Design joint resistance
- Overall check
WORKFLOW
CAD BIM import

Export a connection from Revit

Code-check in IDEA StatiCa

Optimize in Revit

Recalculate in IDEA StatiCa

Report

Synchronize the models
Live Demonstration
Case Study - Waterloo
2018: Waterloo Station Wessex Capacity Alliance

- Project
  - Waterloo Station Wessex Capacity Alliance (2015-2018)
- Client
  - Network Rail / Bourne Engineering Ltd.
- Location
  - London UK
- Key Features
  - Reinstatement of the old Eurostar terminal (5 Platforms)
  - Additional pedestrian access to platforms, LU and Waterloo station (Stairs, lifts and escalators)
  - New infill roof and bridge to connect WIT to Waterloo station
Concept Design - Key Challenges

6
TRAIN LINES BENEATH STRUCTURE

100M
PASSENGERS PER YEAR

150Y
AGE OF WATERLOO STATION

1
ACCESS ROAD TO SITE
Concept Design

- Existing conditions modelling
  - Point cloud of adjacent structures
Threading a needle....
Why Steel?

- Minimize weight on existing structures
- Minimize number of support points
- Connection to existing steel structures
- Maximize open space for glazing and louvres
- Maximize off-site construction
Construction Modelling

Combining the construction schedule with design models
Construction Modelling
Detailed Design - Key Challenges

10+ DISCIPLINES TO COORDINATE

45m SPAN OF NORTH TRUSS

1/1000 SWAY ALLOWANCE

12 SUPPORT POINTS
Detailed Analysis

- Several analysis models developed
  - ULS
  - SLS
  - Blast
  - Post Blast
  - Foundation Sensitivity
- Robot Structural Analysis used for analysis and design
- Results compiled into data base for connection design
Model Hand Over

• Robot model converted to IFC via. Revit to be shared with fabricator
Detailed Coordination

Weekly coordination review meetings with key design team members
All disciplines used BIM to assist with coordination
Detailed Coordination

- As-Built data used to coordinate ancillary structures
Connection Design

- 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.
Connection Design
Outcomes

- 2,000 Elements in Steelwork Model
- 150+ Connection Types
- 18 Months to Design Steelwork
- 6 Months to Erect Steelwork
Outcomes
Lessons Learnt

**KEEP IT SIMPLE**
Simplify structural design as far as possible

**STRENGTH vs STIFFNESS**
Connection stiffness can impact on assumptions in global design model
Check sensitivity at early stage

**CLASH AVOIDANCE NOT DETECTION**
Use BIM as a tool not the solution
Case Study – Jakarta Velodrome
2016: Jakarta Velodrome

- Project
  - Jakarta International Velodrome (2016-2018)
- Client
  - ES Global Ltd.
- Location
  - Jakarta, Indonesia
- Key Features
  - 2000 seats
  - UCI standard timber track
  - Lightweight membrane roof
Key Challenges

- 400x300ft SPAN OF ROOF
- D SEISMIC RISK CATEGORY
- 75% RE-USED STEELWORK COMPONENTS
- 40ft SIZE OF CONTAINER TO SHIP STEELWORK
Key Challenges

- 3 DESIGN CODES TO RECONCILE
- 3 CONTINENTS WHERE DESIGN TOOK PLACE
- 9 MONTHS DESIGN PROGRAMME
- 18 MONTHS TO CONSTRUCT
Fabrication – Led Design
Design Workflow

Right click on the chart for an Excel spreadsheet to populate your figures and automatically update this chart.
Connection Design Workflow

Lorem ipsum dolor sit amet, consectetur adipiscing elit.
Cras lacinia interdum odio, at cursus elit sagittis lobortis.
Proin eu nisl molestie, dignissim ante ut, dictum ex. In nisi
erat, tristique ut mauris id, egestas convallis enim.
Construction Engineering

Outcomes

- **ELEMENTS IN STEELWORK MODEL**: 6,000
  - Right click on the chart for an excel spreadsheet to populate your figures and automatically update this chart

- **CONNECTION TYPES**: 90
  - Right click on the chart for an excel spreadsheet to populate your figures and automatically update this chart

- **MONTHS TO DESIGN STEELWORK**: 6
  - Right click on the chart for an excel spreadsheet to populate your figures and automatically update this chart

- **WEEKS TO ERECT STEELWORK**: 6
  - Right click on the chart for an excel spreadsheet to populate your figures and automatically update this chart
Outcomes


Photo credit goes here
Lessons Learnt

**DESIGN FOR FABRICATION**

- Modular sizes
- Agree connection principles with contractor
- Consider construction staging throughout

**DUCTILITY VS. STRENGTH**

Balance of minimizing size of structural elements vs. connection detailing

**DEVIL IN THE DETAIL**

- Clear the “too difficult” pile before fabrication starts
- Fully detailing Prefabricated elements led to fewer clashes on site

**FUTURE = DATA SHARING**

- Sharing parametric scripts much more efficient than sharing models
- Will need new type of quality control and change management.
CBFEM – The Background
CBFEM – introduction

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 it was created?

Structural engineers needed a tool for quick and efficient design and code-check of steel connections and anchoring.
How did we invent it?

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.
The Basis

Design-oriented FEA is optimized to deliver results relevant for code-check rather than exact simulations of behavior in extreme case.
Key features of CBFEM

- FE model created for each component:
  - Member
  - Plate
  - Weld
  - Bolt/Anchor
- Analysis model created automatically from each component
  - No user input needed
- Analysis performed:
  - Material nonlinearity
  - Geometrical nonlinearity
Members and Plates (CBFEM)

Member, plate = Shell element
Welds (CBFEM)

**Weld element**

- Real behavior of weld – special FE element
- Redistribution of the stress along the weld
- Stiffness of the weld
- Ductility
Bolts/Anchors in tension (CBFEM)

- Bolted connection = steel plates in contact + bolts
- Bolts are modeled as nonlinear springs
- Heads and nuts are connected by force interpolation constrains
Bolts/Anchors in shear (CBFEM)

Bolts

- nonlinear springs
- in contact with steel plate
Anchoring (CBFEM)

- 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
Analysis model (CBFEM)

Automatic generation of the analysis model - no user input needed
Dedicated FEM solver (CBFEM)

- Majority of CAE/FEA programs have FEM solvers from early ‘90s
- Other industries moved faster - **aircraft industry**
- **Mesh** - no intersection between plates
- Plates are connected by **interpolation constraints and weld finite elements**
Credibility and Verification of CBFEM

- Tailor-made design models created in various software (Midas FEA, Atena, Abaqus)
- Live testing
- All studies published
- Three years of studies produced by two university teams
CA25  Which university? it would be great to show a little more depth to these two studies. What did they find? What were results?
Clark, Alexis, 23-Oct-19

DK5  there are a lot of studies, evrything is summarised in our Verification book and artices on our WEB (web is mentioned further)
David Kucera, 25-Oct-19

OF1  Ondřej Fridrich, 29-Oct-19
Cooperation with Universities = Verified Solution
What Makes CBFEM Unique?

• CBFEM method is robust and generally **without limits** in topology, design or structure loading.

**CBFEM powers multiple SW tools:**

• IDEA StatiCa

• HILTI PROFIS Engineering

• Advance Design Connection

• Voestalpine Profilform
Where can I learn everything about CBFEM?

www.cbfem.com
Design Workflows

1. Use concept design stage to establish design parameters and assess potential solutions

2. BIM and parametric design can be used to quickly assess different options

3. Use detailed design to refine design and flush out the awkward details

4. Multiple tools – BIM, parametric design, FE analysis, clash detection, fabrication modelling
Challenges in Real Life Projects

1. Constructability should be central to design

2. Seek early contractor involvement – cannot design connections in isolation

3. All parties need to be on board with using digital design – only as good as the weakest link

4. Keep it simple – the most lightweight design may not be the best design
Use of IDEA Statica

1. Enables complex connections to be modelled quickly

2. Works best when fully integrated into the digital design process

3. Enables checks on stiffness as well as strength
CBFEM

1. Based on finite element analysis – natural extension of global finite element analysis

2. Ability to model elastic and plastic behavior

3. Enables designer to visualize interaction between components and determine “weakest link” in connection
Thank you for listening
Any Questions?