11/29/2019

AIMS & OBJECTIVES

Individual Research Project – CIVE 3750

Simplified Connection Design

[redacted]

University of Leeds

Civil & Structural Engineering

Supervisor – Mr David Richardson

Contents

1. Introduction

Connections between elements are implemented in all steel structures; simple connections and moment connections are both common. Simple connections transfer no moment from a supported beam to the supporting column (except for moments associated with the eccentricity of the beam), whereas moment connections do transfer a portion of the bending moment within the beam to the column. One of the most common types of simple connections is an end plate. There are currently 14 checks set out by BS EN 1993-1-8 to design a simple end plate connection; this study will determine, through the use of finite element modelling, whether any of these checks can be simplified or removed completely.

2. Literature Review

A short literature review has been performed to gain understanding of connection design.

2.1 Connection Classification

Simple connections are commonly referred to as nominally pinned; BS EN 1993-1-8 details multiple criteria that must be met in order to classify a joint as nominally pinned (SCI, 2014). Firstly, nominally pinned joints should be "capable of transmitting the internal forces, without developing significant moments which might adversely affect the members or the structure as a whole" as well as being "capable of accepting the resulting rotations under design loads" (BS EN1993-1-8, 2005). Furthermore, the joints must "provide the directional restraint to members which has been assumed in the member design".

Simple joints are also classified by stiffness (suitable for elastic analysis), by strength (suitable for plastic analysis) or by both (suitable for elastic-plastic analysis); only beam-column connections can be classified by stiffness (Jaspart, J; Demoonceau, J; n.d.).

To classify a joint by stiffness, the initial rotational stiffness of the joint ($S_{j,ini}$) must be calculated and compared to classification boundaries. The boundaries are shown in Figure 1, they can be calculated by the following equations:

$$\text{Nominally pinned} - S_{j,ini} \leq 0.5 \times \frac{EI_b}{L_b}$$

$$\text{Rigid} - S_{j,ini} \geq k_b \times \frac{EI_b}{L_b}$$

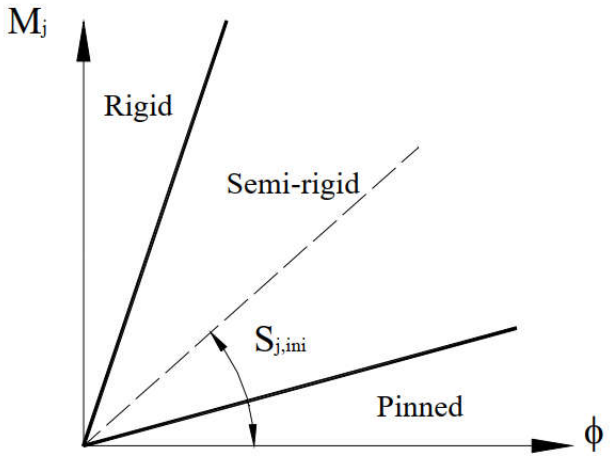


Figure 1 - $S_{j,ini}$ boundaries

A connection can also be classified based on the following strength criteria: “the design resistance of the connection does not exceed 25% of the design moment resistance required for a full-strength joint” and “the joint should be capable of accepting the rotations resulting from the design loads”. These statements are represented in Figure 2 as well as by the equations below.

Nominally pinned – $M_{j,Rd} \leq 0.25M_{full\text{-}stregnth}$

Full stregnth – $M_{j,Rd} \geq M_{full\text{-}stregnth}$

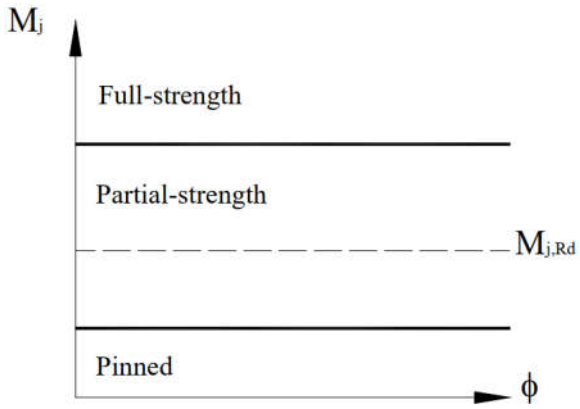


Figure 2 - $M_{j,Rd}$ boundaries

2.2 End Plate Connections

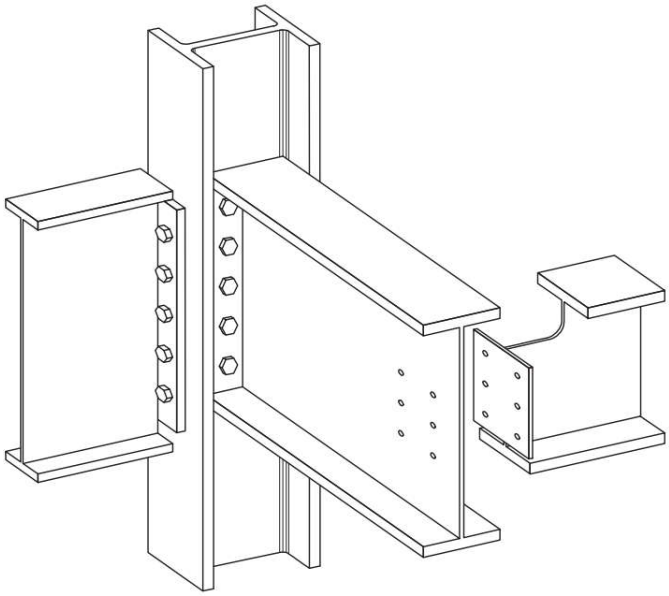


Figure 3 - End plate connections

One of the most common types of simple connections are end plates (as shown in Figure 3), either full depth or partial depth. End plate connections consist of a plate welded to the end of the supported beam, this plate is then bolted to the supporting member. Full depth end plates provide increased tying resistance as well as increased vertical resistance; despite enhanced stiffness compared to partial depth end plates, full depth plates can still be considered nominally pinned when detailed correctly (SCI, 2014).

End plates are also one of the most common types of moment connections, however the plates used in simple connections are much thinner (10 or 12mm) than in moment connections, the increased flexibility of the plates allows for the joint to be classified as simple.

All connections are required to resist a tying force to ensure robustness of the structure, this force is calculated from an equation given in BS EN1991-1-7 as shown below (BS EN1991-1-7, 2006):

$$T_i = 0.8(g_k + \psi q_k)sL \text{ or } 75kN \text{ whichever is greater}$$

The critical failure mode for partial depth end plates is the failure of the end plate or bolts due to this tying force (SCI, 2014); there are 3 possible failure modes in this case: yielding of the plate, failure of the bolts and yielding of the plate, and failure of the bolts. The 3 failure modes are shown in Figure 4 on page 3 (Hegyi, D; et al; 2017).

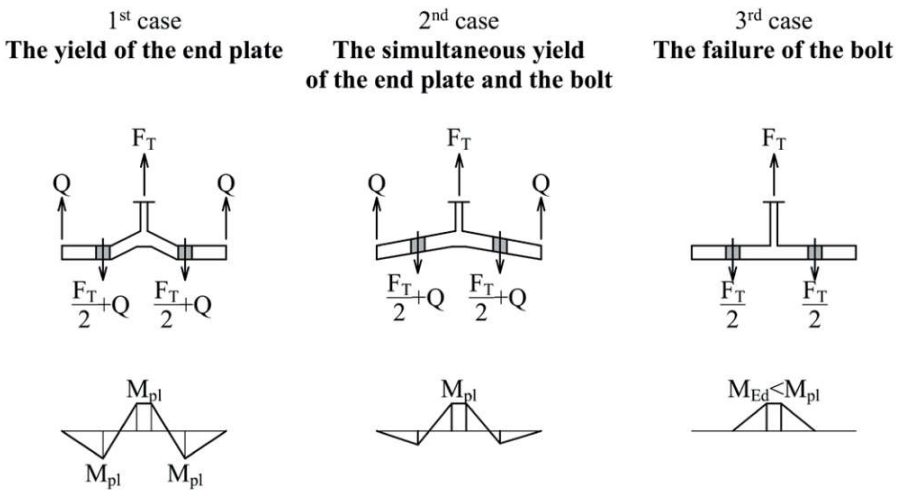


Figure 4 - Failure modes - tying force

The other failure modes detailed in Eurocode 3 include both brittle and ductile failures; brittle failures include the bolts both in shear and tension as well as the welds, ductile failure modes include the end plate in bending and the column web in shear and tension (Moore, E; Wald, F; 2003).

There are currently 14 checks (shown in Table 1) detailed in BS EN1993-1-8 to design a simple end plate connection, these are based on failure of the bolts, welds, end plate, supporting beam and supporting member. The stability of notched beams is also considered.

Table 1 – Design checks

Check	Description	Element	Failure Mode
1	Recommended detailing practice	-	-
2	Welds	Supported beam	Shear
3	Web in shear	Supported beam	Shear
4	Resistance at notch	Supported beam	Shear/Bending
5	Local stability of notched beam	Supported beam	-
6	Overall stability of notched beam	Supported beam	-
7	Bolt group	Bolts	Shear/Bearing
8	End plate in shear	End plate	Shear
9	Supporting beam/column	Supporting beam/column	Shear/Bearing
10	Tying Resistance	Plate and bolts	Tension
11	Tying Resistance	Supported beam web	Tension
12	Tying Resistance	Welds	Tension
13	Tying Resistance	Supporting column web	Tension
14	Tying Resistance	Supporting column wall	Tension

2.3 Abaqus Software

A finite element modelling software called Abaqus will be used to model various simple end plate connections to determine their actual behaviour under load; Abaqus is a software developed by Dassault Systemes and is not specific to structural engineering applications (Dassault Systemes, 2018). Figures 5-7 show an initial model for a partial depth beam to column end plate connection. As shown in the model, the flexibility of the end plate allows substantial rotations of the beam at the joint, this is the main reason the joint is simple; however, this flexibility results in considerable stresses in the plate especially where it is welded to the beam web. The model also shows that some stress is developed within the supporting column flange and web due to the bearing of the bolts, these forces are much lower than in moment connections. The detail in the propagation of the stresses within the connection shows that Abaqus is capable of accurately modelling a steel connection, it will therefore be effective in this study.

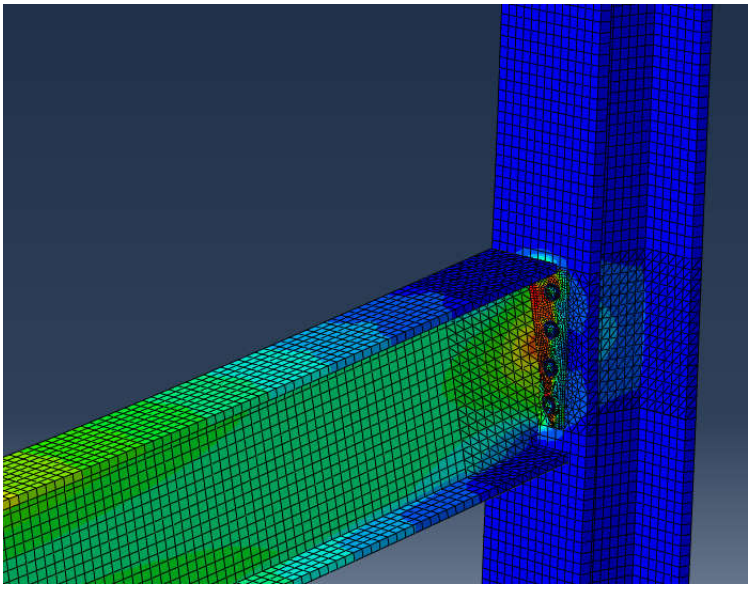


Figure 5 - Initial model 1 – connection

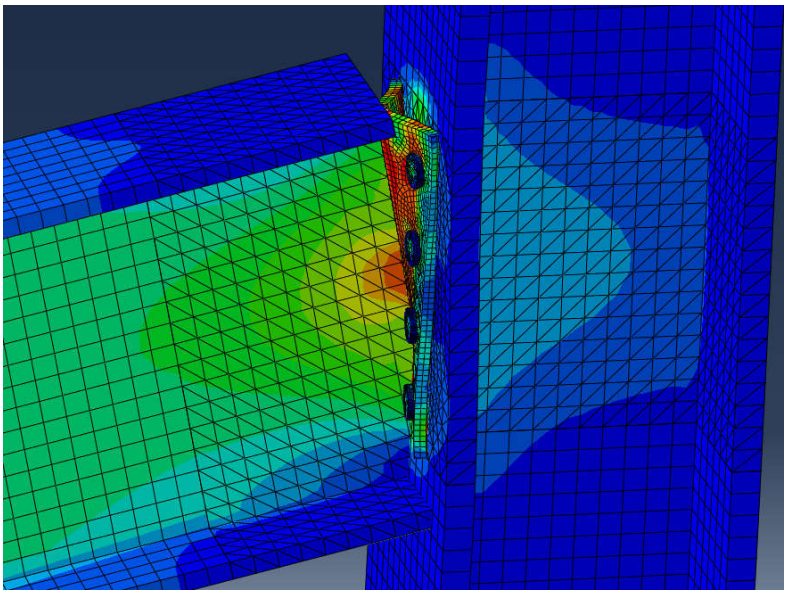


Figure 6 - Initial model 1 – end plate deformation

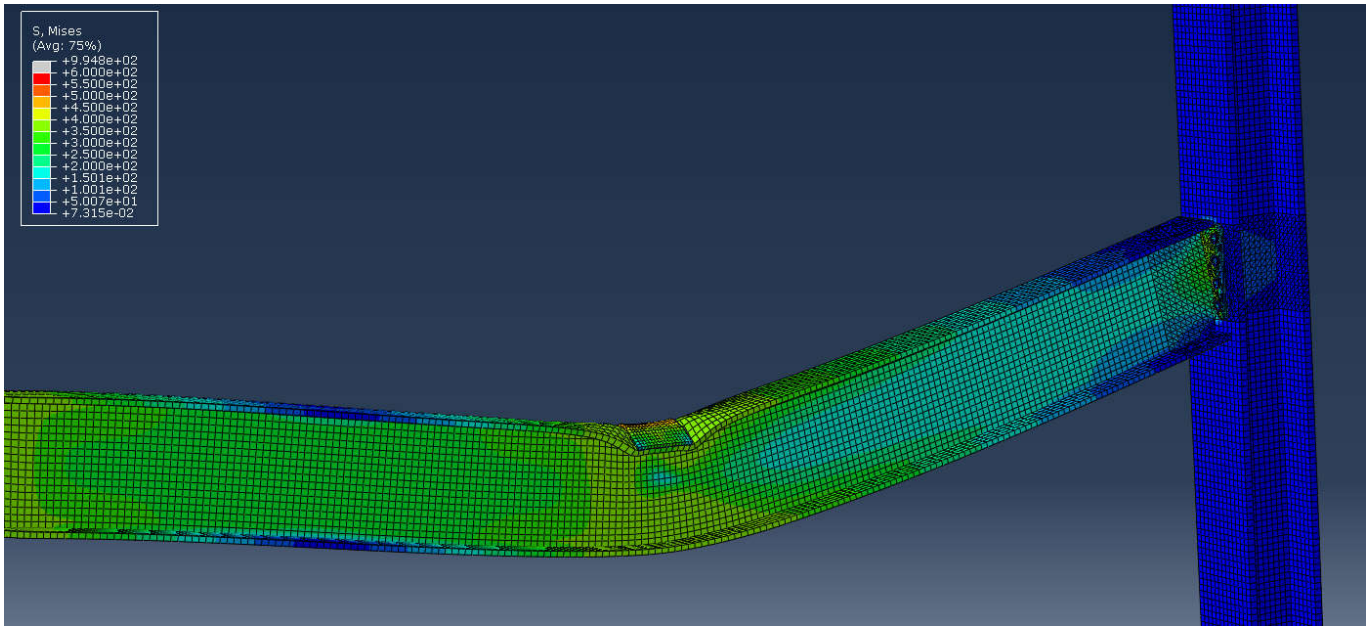


Figure 7 - Initial model 1 – full beam

2.4 Existing Research

Existing research into simplifying the design of steel connections is limited, this may be due to the fairly recent development of the Eurocode component method.

Research involving modelling macro-elements for simple beam to column joints has been carried out; the modelling of the connections was done through both Abaqus and an open source software called OpenSees. The results of the paper determined that modelling a connection in this way can "reduce modelling time" and "provide a more rigorous modelling of the beam to column joints" when compared to the component method detailed in BS EN1993-1-8 (Costa, R; et al; 2015).

A study into simplifying connection design used a method to simplify the individual checks set out in the component method. The study assumed standard ratios between the dimensions of the connections, such as between beam and column height and width, as well as flange and web thickness; this allowed equations to be simplified by cancelling geometric terms. The results of this allowed equations such as that for the column web in shear to be simplified as shown below:

$$V_{wp,Rd} = \frac{0.9 f_y A_{vc}}{\gamma_{m0}\sqrt{3}} \qquad \text{where } A_{vc} = (h_c + 4t_{fc})t_{wc}$$

can be simplified to

$$V_{wp,Rd} = 5.5 t_{fc}^2 f_y$$

The results of this study were somewhat accurate when compared to the component method with an error of -27% to +11%, further research into this method may therefore produce more accurate results (Kozlowski, A; et al; 2012). Figure 8 shows a graphical representation of the accuracy of the results.

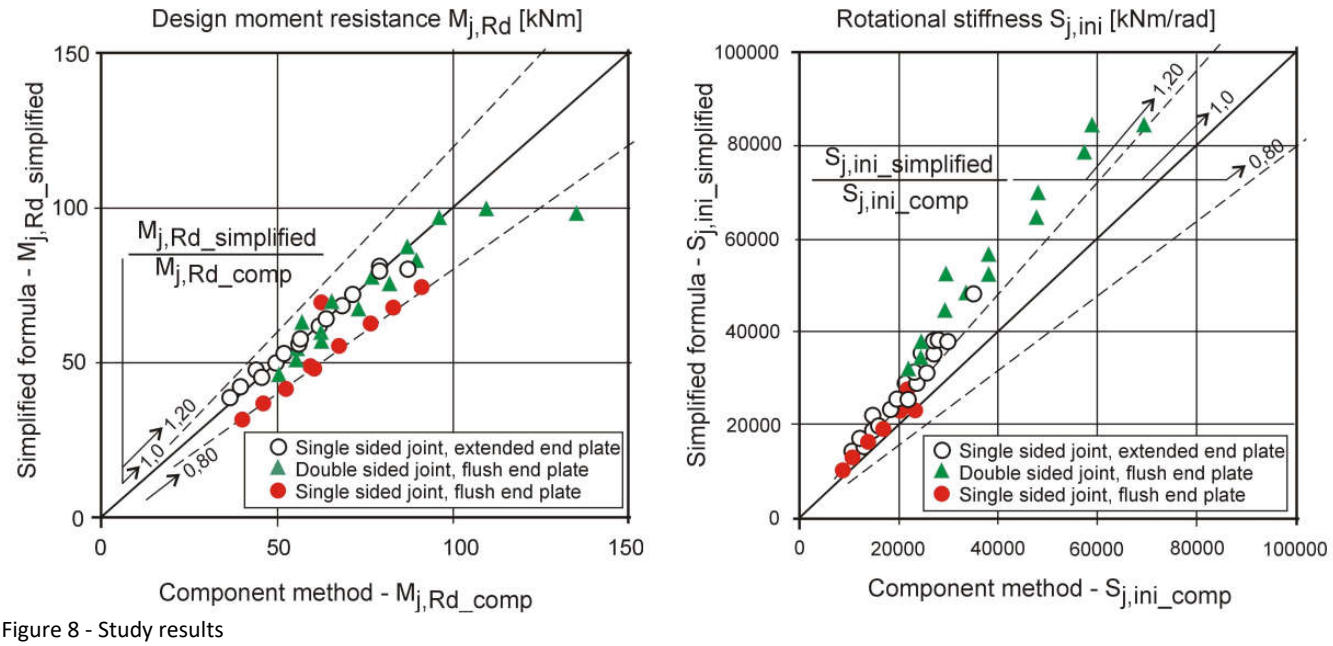


Figure 8 - Study results

3. Finite Element Models

The following section of this report details the initial finite element models that will be produced, however it is likely that further models will be built in the future.

1. Partial depth end plate UKB to UKC connection.
2. Full depth end plate UKB to UKC connection.
3. Partial depth end plate UKB to SHS/RHS connection.
4. Full depth end plate UKB to SHS/RHS connection.
5. Partial depth end plate UKB to UKB connection.
6. Full depth end plate UKB to UKB connection.

4. Aim

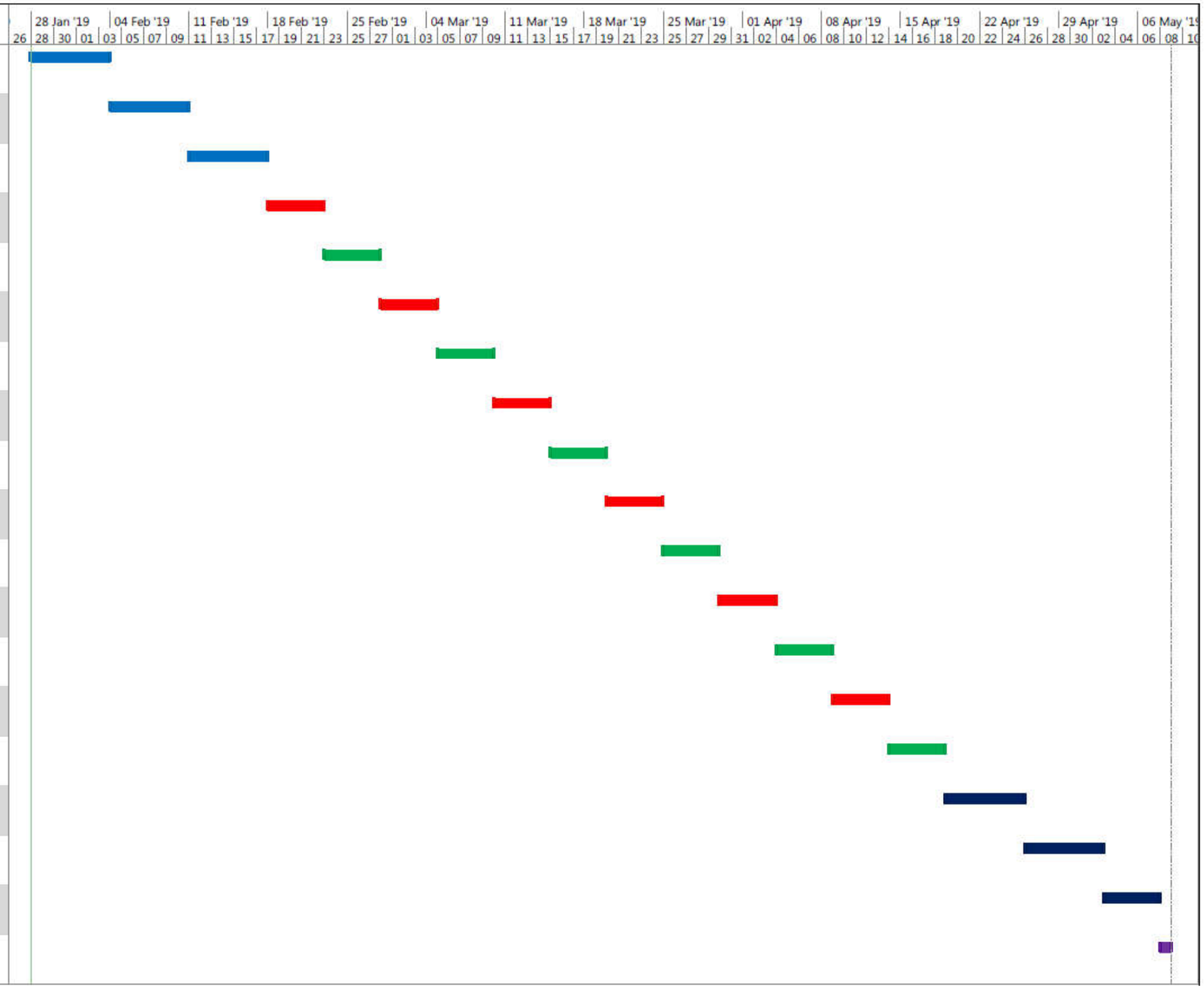
To simplify the procedure detailed in BS EN1993-1-8 for the design of a simple end plate connection using finite element modelling.

5. Objectives

- Perform an initial literature review to determine the current design procedure for simple connection design in BS EN1993-1-8.
- Determine the basic principles behind connection design, including design procedures laid out in other design standards, this should result in a more accurate and detailed analysis of future results.
- Carry out a literature review to determine the results of any previous research into simplifying the design procedure for both moment and simple connections.
- Build and test various simple end connection finite element models using Abaqus FEM software, these models are detailed in section 3.
- Critically analyse the results of the finite element models to determine the areas with the highest stress and therefore the critical failure mechanisms.
- Simplify the existing design procedure by removing checks that are not required to ensure the connection does not fail.
- Design various end plate connections using the initial and simplified procedures, compare the results to ensure they both indicate the same critical failure mechanism.
- Draw conclusions to determine whether the simplification of the design procedures were effective, and if so whether they should be implemented.

6. Work Plan

ID	Task Name	Duration	Start
1	Determine current design procedure	7 days	Mon 28/01/19
2	Determine connection design principles	7 days	Mon 04/02/19
3	Determine existing research	7 days	Mon 11/02/19
4	Build and test model 1	5 days	Mon 18/02/19
5	Critically analyse model 1 results	5 days	Sat 23/02/19
6	Build and test model 2	5 days	Thu 28/02/19
7	Critically analyse model 2 results	5 days	Tue 05/03/19
8	Build and test model 3	5 days	Sun 10/03/19
9	Critically analyse model 3 results	5 days	Fri 15/03/19
10	Build and test model 4	5 days	Wed 20/03/19
11	Critically analyse model 4 results	5 days	Mon 25/03/19
12	Build and test model 5	5 days	Sat 30/03/19
13	Critically analyse model 5 results	5 days	Thu 04/04/19
14	Build and test model 6	5 days	Tue 09/04/19
15	Critically analyse model 6 results	5 days	Sun 14/04/19
16	Simplify existing design procedure	7 days	Fri 19/04/19
17	Compare initial and simplified design procedure	7 days	Fri 26/04/19
18	Draw conclusions	5 days	Fri 03/05/19
19	Deadline	1 day	Wed 08/05/19



Literature review
Finite element modelling
Deadline
Analysis of results
Design simplification/conclusions

Project Start Date: 28/01/19 Project End Date: 08/05/19

7. References

1. BS EN1991-1-7. (2006). 'Eurocode 1: Actions on structures – Part 1-7: General actions- Accidental actions'. Available from: http://www.ihsti.com/CIS/document/307242?PreviousPage=search%3ff%3dAll%26t%3dbs%2ben1991-1-7%26sqm%3dAllTerms. [Accessed 16/01/2018].

2. BS EN1993-1-8. (2005). 'Eurocode 3: Design of steel structures – Part 1-8: Design of joints'. Available from: http://www.ihsti.com/CIS/document/295063. [Accessed 29/11/2018].

3. Costa, R; et al. (2015). 'Simplified model for connections of steel structures in OpenSees'. Available from: https://www.researchgate.net/publication/283009454_Simplified_model_for_connections_of_steel_structures_in_OpenSees. [Accessed 29/01/2019].

4. Dassault Systemes. (2018). '3DS Academy' Available from: https://academy.3ds.com/en/software/abaqus-student-edition. [Accessed 11/01/2019].

5. Hegyi, D; et al. (2017). 'A Simplified Method for the Design of Steel Beam-to-column Connections' Available from: https://pp.bme.hu/ar/article/download/11089/7864/. [Accessed 09/01/2019].

6. Jaspart, J; Demoonceau, J. (n.d.). 'European Design Recommendations for Simple Joints in Steel Structures' Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.845.8792&rep=rep1&type=pdf. [Accessed 05/01/2019].

7. Kozlowski, A; et al. (2012). 'Simplified Formulas for Assessment of Steel Joint Flexibility Characteristics' Available from: https://www.researchgate.net/profile/Aleksander_Kozlowski/publication/269100776_Simplified_formulas_for_assessment_of_steel_joint_flexibility_characteristics/links/554c97bf0cf29f836c9944fa/Simplified-formulas-for-assessment-of-steel-joint-flexibility-characteristics.pdf. [Accessed 29/01/2019].

8. Moore, E; Wald, F. (2003). 'Design of Structural Connections to Eurocode 3 – Frequently Asked Questions' Available from: http://people.fsv.cvut.cz/~wald/CESTRUCO/CESTRUCO_Engl_2003.pdf. [Accessed 29/01/2019].

9. SCI. (2014). 'Joints in Steel Construction: Simple Joints to Eurocode 3'. Available from: https://www.steelconstruction.info/index.php?title=Special:ImagePage&t=SCI+P358.pdf. [Accessed 29/11/2018].

8. Appendices

FACULTY OF ENGINEERING – RISK ASSESSMENT		UNIVERSITY OF LEEDS
To simplify the procedure detailed in BS EN1997-1-8 for the design of a simple end plate connection using finite element modelling.	**Assessment N°**	
N/A		

Preliminary notes
● Risk assessment must be conducted by Principal Investigator/Manager.
● Other team members and/or people involved or affected by the activities must be consulted in the construction of the risk assessment.
● PIs/Managers and other team members must ensure that the control arrangements and safe systems of work are followed.
● PIs/Managers must review this risk assessment at least annually, or in the event of incident, accident or changes to operating/maintenance procedures/personnel.
● Review of risk assessment must be conducted by the PI/Manager and initialled and dated in the space provided.

Reference information
● Health and Safety at Work etc Act 1974
● Management of Health and Safety at Work Regulations 1999

Copies
● Original signed risk assessment must be retained by the PI/Manager in their office.
● A copy (and any appendices) must be retained in the health and safety file in the workplace.
● A digital copy must be forwarded by email to the Faculty Safety Team before work begins.
● PIs/Managers may wish to keep a reference copy in their office.

RA review [to be dated initialled by PI/MANAGER]							
Date of next review due:							
Date review completed:							
Initials:							

Countersignatures (other members of risk assessment team) [Only if applicable – see Faculty RA Procedures]				
ROLE	**PRINT NAME**	**SIGNATURE**	**EMAIL/TELEPHONE**	**DATE**
-	-	-	-	-

IDENTIFICATION OF RISKS,CONTROLS & ACTIONS

HAZARD TYPE	WHO MAY BE HARMED?	CURRENT CONTROL MEASURES (IF ANY)	CURRENT RISK RATING Cx L/S = E,H,M,L,T	ADDITIONAL CONTROL MEASURES IDENTIFIED	NEW RISK RATING Cx L/S = E,H,M,L,T	ACTION BY (& DEADLINE)
N/A	N/A	N/A	N/A	N/A	N/A	N/A

Consequence/Severity of Harm (C)	Likelihood of a consequence/severity of harm being realised (L/S)				
	Remote Possibility	Possible	Likely	Highly probable	Virtual Certainty
Minor injury or illness	Trivial	Trivial	Low	Low	Low
Injury/illness requiring medical attention	Trivial	Low	Medium	Medium	High
Injury/illness involving more than 3 days off work	Low	Medium	Medium	High	High
Major injury or long term illness	Low	Medium	High	Extreme	Extreme
Fatal injury/illness	Low	High	High	Extreme	Extreme

RISK RATING		ACTION & TIMESCALES
Extreme	E	Work must not be started or continued until the risk level has been reduced. While the control measures should be cost-effective, the legal duty to reduce the risk is absolute. This means that if it is not possible to reduce the risk, even with unlimited resources, then the work must not be started or must remain prohibited.
High	H	Work must not be started until the risk has been reduced. Considerable resources may have to be allocated to reduce the risk. Where the risk involves work in progress, the problem should be remedied as quickly as possible. (Action within 1 Week)
Medium	M	Efforts should be made to reduce the risk, but the costs of prevention should be carefully measured and limited. Depending on the number of people exposed to the hazard risk reduction measures should normally be implemented (Action within 1 Month)
Low	L	Consideration should be given to cost-effective solutions, or improvements that impose minimal operating standards which will maintain Low level of risk. Monitoring is required to ensure that the controls are maintained. (Review Assessment Annually)
Trivial	T	No action is required to deal with trivial risks, and no documentary records need be kept (insignificant risk)(Review Assessment Annually)

Ethics Approval Form - Students

This form should be completed by the student and passed to the supervisor prior to a review of the possible ethical implications of the proposed dissertation or project.

No primary data collection can be undertaken before the supervisor has approved the plan.

If, following review of this form, amendments to the proposals are agreed to be necessary, the student should provide the supervisor with an amended version for endorsement.

The final signed and dated version of this form must be handed in with the dissertation. Failure to provide a signed and dated form on hand-in will be treated as if the dissertation itself was not submitted.

1. What are the objectives of the dissertation / research project?

   To simplify and/or reduce the number of checks required to design a simple end plate connection.

2. Does the research involve *NHS patients, resources or staff*? YES /(NO)(please circle).

   If YES, it is likely that full ethical review must be obtained from the NHS process before the research can start.

3. Do you intend to collect *primary data* from human subjects or data that are identifiable with individuals? (This includes, for example, questionnaires and interviews.) YES /(NO)(please circle)

   If you do not intend to collect such primary data then please go to question 14.

   If you do intend to collect such primary data then please respond to ALL the questions 4 through 13. If you feel a question does not apply then please respond with n/a (for not applicable).

4. What is the *purpose* of the primary data in the dissertation / research project?

5. What is/are the *survey population(s)*?

6. How big is the *sample* for each of the survey populations and how was this sample arrived at?

7. How will respondents be *selected and recruited*?

8. What steps are proposed to ensure that the requirements of *informed consent* will be met for those taking part in the research? If an Information Sheet for participants is to be used, please attach it to this form. If not, please explain how you will be able to demonstrate that informed consent has been gained from participants.

9. How will *data* be *collected* from each of the sample groups?

10. How will *data* be *stored* and what will happen to the data at the end of the research?

11. How will *confidentiality* be assured for respondents?

12. What steps are proposed to safeguard the *anonymity* of the respondents?

13. Are there any *risks* (physical or other, including reputational) *to respondents* that may result from taking part in this research? YES / NO (please circle).

    If YES, please specify and state what measures are proposed to deal with these risks.

14. Are there any *risks* (physical or other, including reputational) *to the researcher or to the University* that may result from conducting this research? YES / (NO) (please circle).

    If YES, please specify and state what measures are proposed to manage these risks.

15. Will any *data* be *obtained from a company or* other *organisation*. YES / (NO) (please circle) For example, information provided by an employer or its employees.

    If NO, then please go to question 18.

16. What steps are proposed to ensure that the requirements of *informed consent* will be met for that organisation? How will *confidentiality* be assured for the organisation?

17. Does the organisation have its own ethics procedure relating to the research you intend to carry out? YES / NO (please circle).

    If YES, the University will require written evidence from the organisation that they have approved the research.

18. Will the proposed research involve any of the following (please put a √ next to 'yes' or 'no'; consult your supervisor if you are unsure):

• Vulnerable groups (e.g. children) ?	YES		NO	√
• Particularly sensitive topics ?	YES		NO	√
• Access to respondents via 'gatekeepers' ?	YES		NO	√
• Use of deception ?	YES		NO	√
• Access to confidential personal data ?	YES		NO	√
• Psychological stress, anxiety etc ?	YES		NO	√
• Intrusive interventions ?	YES		NO	√

19. Are there any other ethical issues that may arise from the proposed research?

    No

Please print the name of: I/We grant Ethical Approval

student Joseph Sykes supervisor David Richardson

Signed:

(student) _____ (supervisor) _____

Date _____ Date _____

AMENDMENTS

If you need to make changes, please ensure you have permission before the primary data collection. If there are major changes, fill in a new form if that will make it easier for everyone. If there are minor changes then fill in the amendments (next page) and get them signed before the primary data collection begins.

CHANGES TO ETHICS PERMISSION

VERSION: ____

Please describe the nature of the change and impact on ethics:

Please print the name of: I/We grant Ethical Approval

student _____ supervisor _____

Signed:

(student) _____ (supervisor) _____

Date _____ Date _____