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UNIVERSITY OF LEEDS

School of Civil Engineering

Optimisation of Column-Beam Connections Using Beam Web Perforation

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The Institution of Structural Engineers

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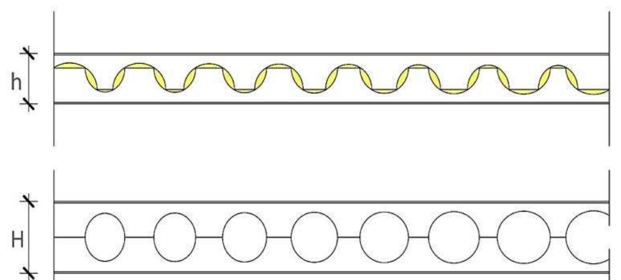
1 - Why Reduced Web Sections (RWS) ?

Brittle Connection Damage, 1994 Northridge

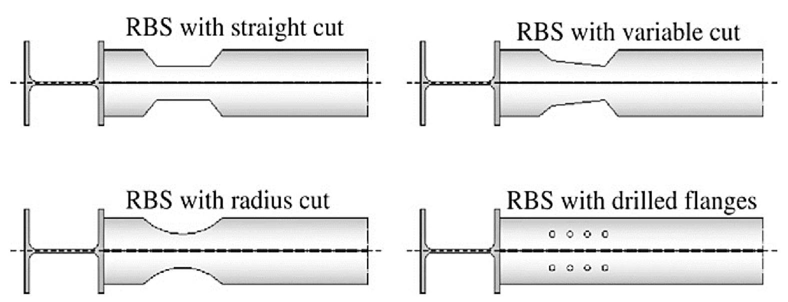
Following the 1994 Northridge and 1995 Kobe earthquakes, the previously used welded steel moment resisting frames in areas of high seismicity were proved unsatisfactory with unexpected brittle fractures confined to the vicinity of welds of the beam-to-column connections.

Concept of fuse to effectively dissipate the seismic energy and control the location of plastic hinges.



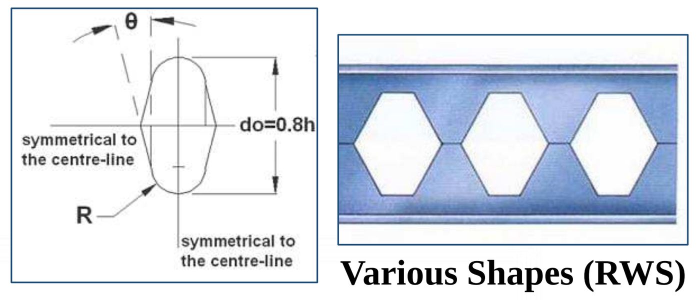
Fabrication Process (RWS)

- Reduce section of the beam by having flange cut-outs at a close distance from the face of the column (RBS).

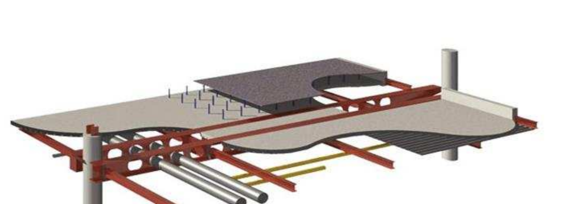


Established Concept (RBS)

- Better performance based design by reducing the web section of the beam (RWS).
  - Various shapes
  - Minimal waste from fabrication
  - Supports service integration
  - Lighter (reduction off frames)



Various Shapes (RWS)



Ongoing Concept (RWS)

Material and cost efficiency with reduction in cross sectional area

Ability to span longer distances (decrease in weight)

Possibility to incorporate services, reduction of the floor-to-ceiling zone overall depth

2 - Aims & Objectives

This research aims to study the behaviour of partially restrained bolted RWS beam-to-column connections under cyclic loading.

The effect of geometric parameters such as the distance from the face of the column, S, and web opening spacing, S_o, is variable while constant large circular web openings of 0.8h are used throughout with results scrutinised in order to propose an optimum structural design. The potential of adding periodical web openings along the length of the beam is also examined.

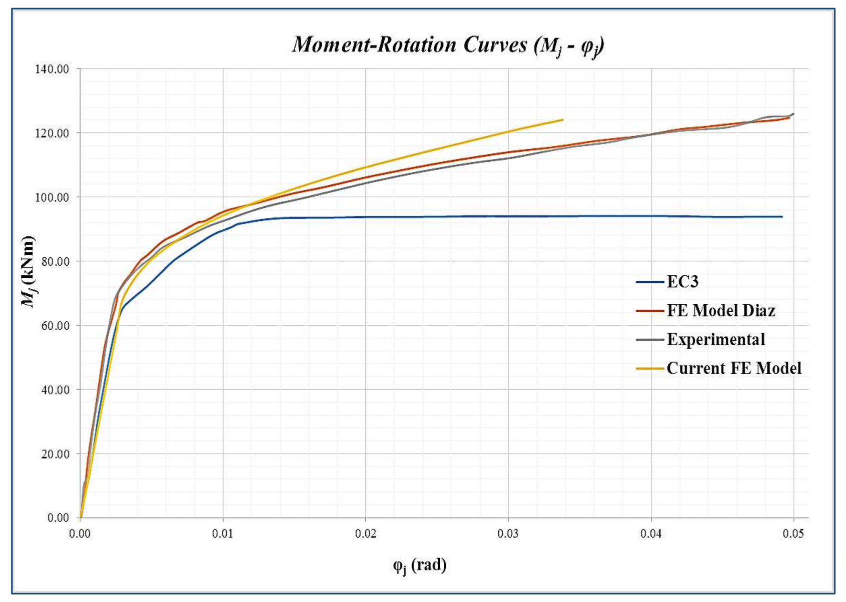
The main objectives to fulfil the project aim are as follows:

- Evaluate the seismic performance of RWS using Finite Element Analysis (FEA) by examining the dissipation of stresses and hysteretic curves.
- Propose suggestions to the current design guidelines to accommodate the practical use of perforated steel beams.

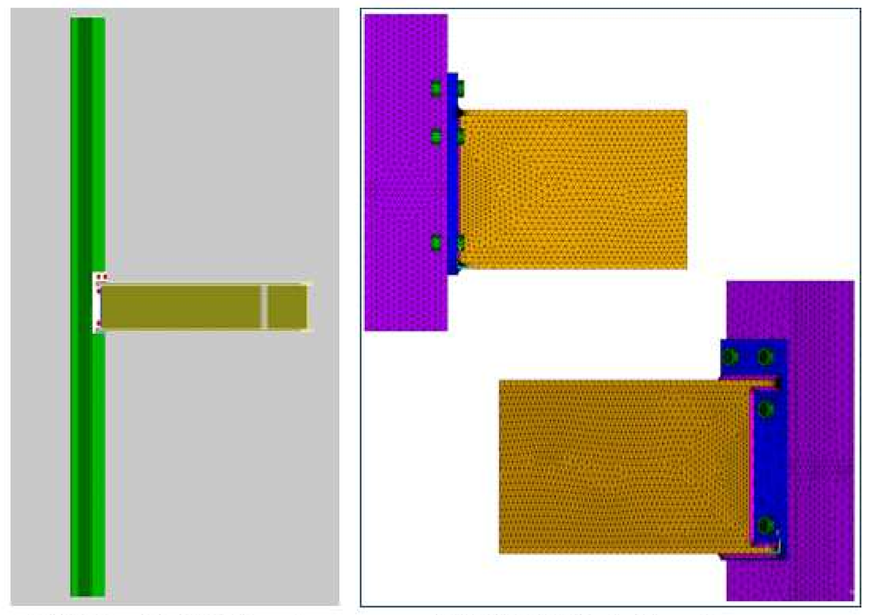
3 - Validation of FE model

Full 3D model developed similarly to FE model by Díaz et al. (2011) and experimental test conducted by Janss et al. (1987), including:

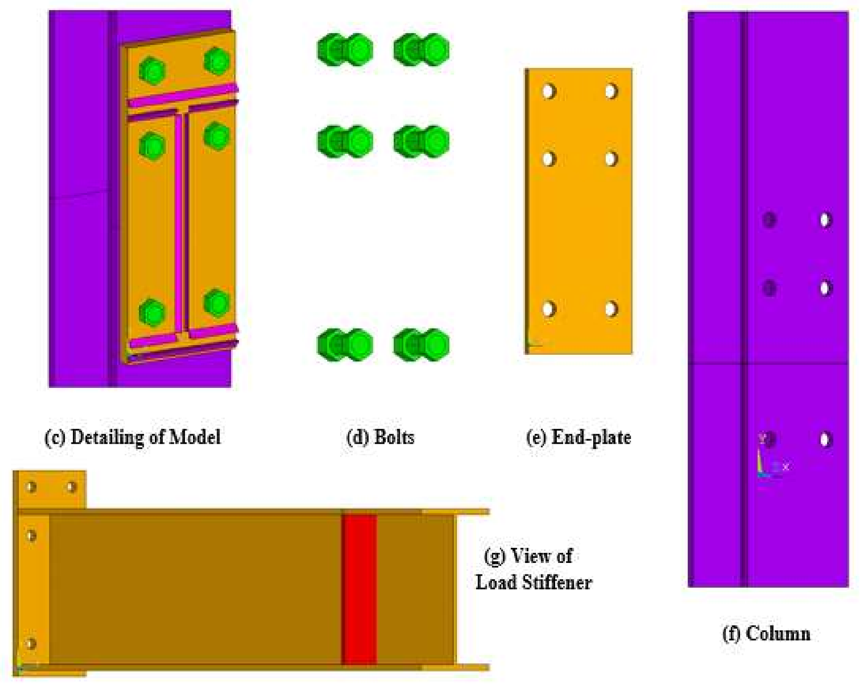
- Material nonlinearities.
- 8-node solid elements throughout (SOLID185).
- 6 contact regions to model semi-rigid connection.



Results showed good correlation, validating the FE model for further parametric studies.



(a) Full View of FE Model Geometry (b) 3D FE Mesh-Work of Connection



(c) Detailing of Model (d) Bolts (e) End-plate (f) Column (g) View of Load Stiffener

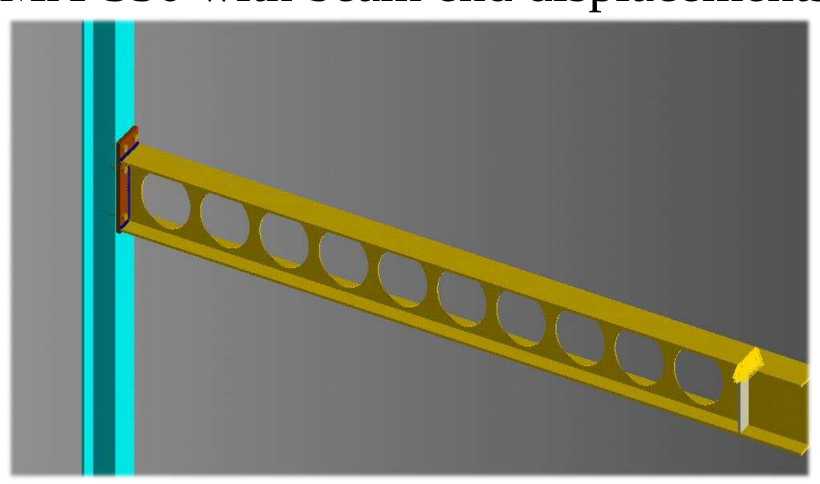
3D FE Model (Detailing of Individual Components)

4 - Parametric Studies

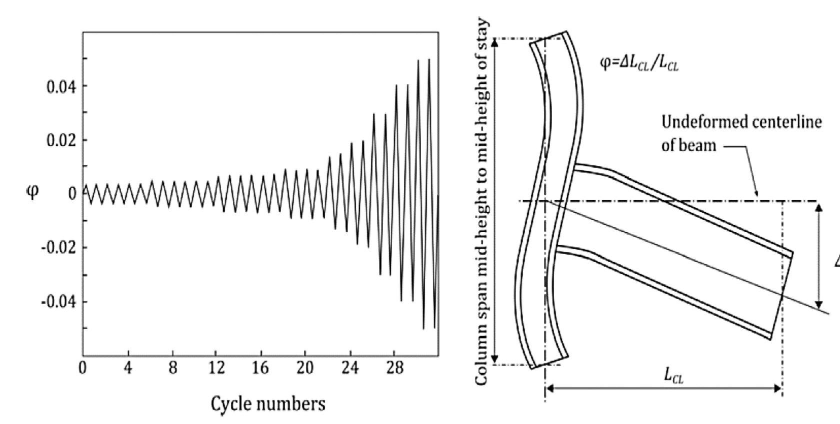
Summary Table:

Model	Number of holes	Column Face Distance, S	Web Opening Spacing, So	Second Web Opening Distance	Material Properties	Column Stiffeners	Flanges Restrained	
Solid	N/A	N/A	N/A	N/A	As experimental study	N/A	N/A	
1	1 hole	200	1.2	N/A	As experimental study	N/A	N/A	(a)
2	2 holes	200	1.2	1.2	As experimental study	N/A	N/A	(a)
3	full of holes	200	1.2	1.2	As experimental study	N/A	N/A	(a)
4	full of holes	200	1.2	1.2	All S355 but Class 10.9 Bolts	N/A	N/A	(b)
5	full of holes	200	1.2	1.2	All S355 but Class 10.9 Bolts	YES	N/A	(b)
6	full of holes	520	1.2	1.2	All S355 but Class 10.9 Bolts	YES	N/A	(b)
7	full of holes	350	1.6	1.2	As experimental study	N/A	N/A	(b)
8	full of holes	350	1.6	1.2	All S355 but Class 10.9 Bolts	YES	N/A	(b)
9	full of holes	200	1.2	1.2	All S355 but Class 10.9 Bolts	YES	YES	(c)
10	full of holes	350	1.2	1.2	All S355 but Class 10.9 Bolts	YES	YES	(c)
11	full of holes	520	1.2	1.2	All S355 but Class 10.9 Bolts	YES	YES	(c)

All specimens are loaded cyclically following the SAC loading protocol by FEMA-350 with beam end displacements applied at the location of the stiffener.

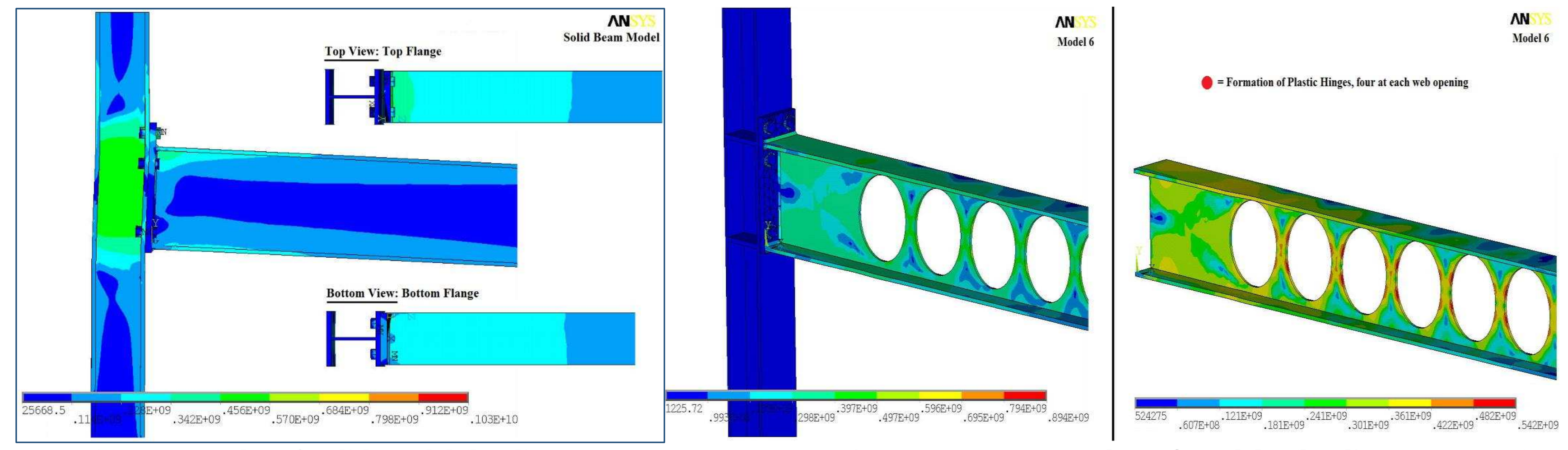


FEM Model (Location of Applied Displacements)

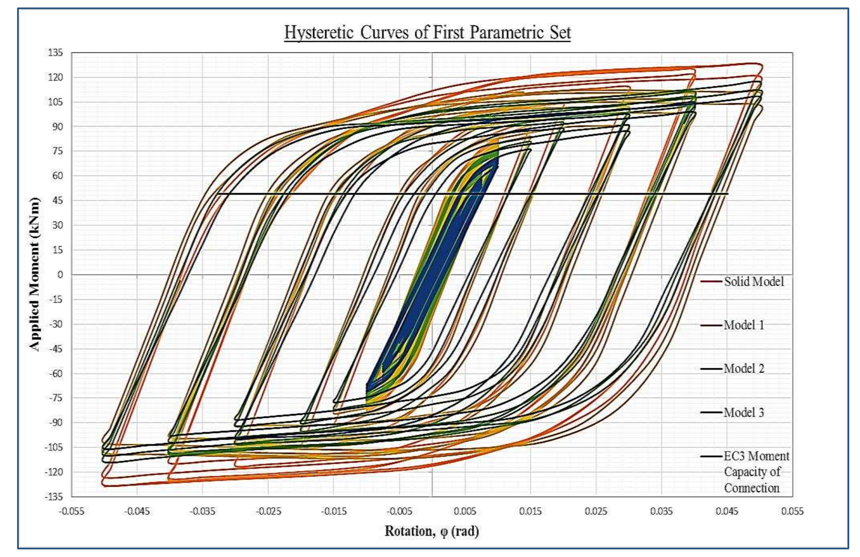


SAC Cyclic Loading Sequence

5 - Analysis of FE Results



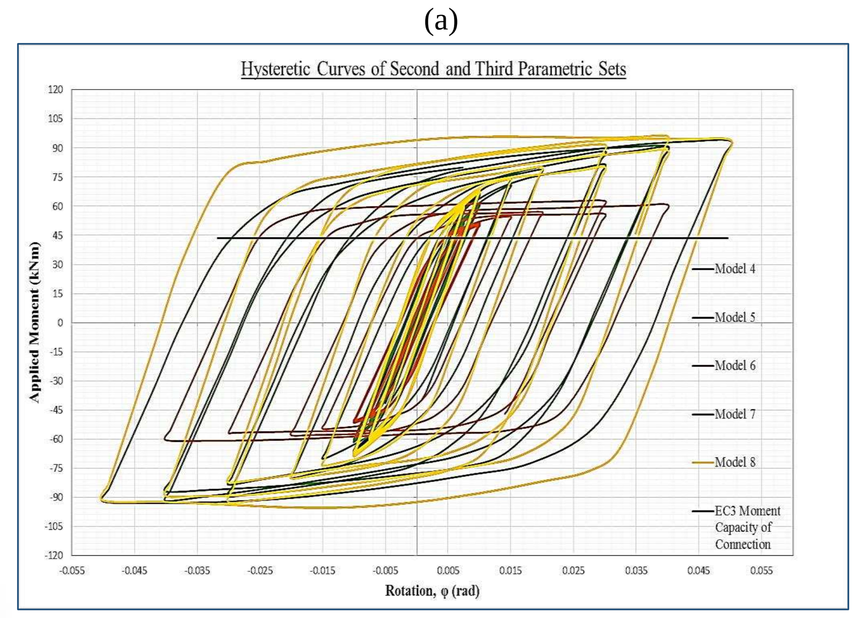
Von-Mises Stress Plot of Solid Model (loading at 155.1mm) Von-Mises Stress Contour Plots of Model 6 (loading at 93.1mm)



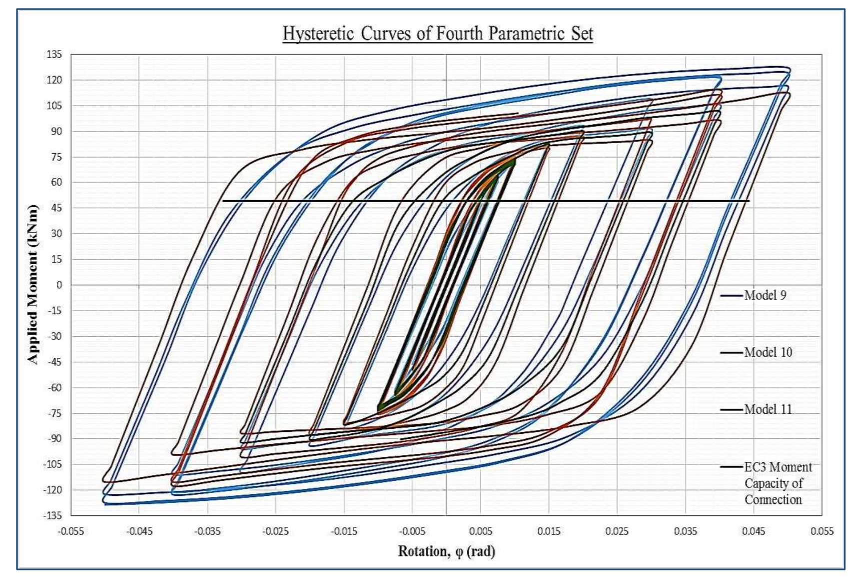
(a)

- Stress concentration away from connection, critical at corners around the beam web openings.
- Minimal stresses around bolts, end-plate and column with RWS.
- Expected reduction in ultimate moment with no decrease in ultimate rotational capacity.

Parametric Models Hysteretic Curves



(b)



(c)

6 - Conclusions and Future Work

- **Desirable weak beam-strong column mechanism achieved** by the introduction of web openings, with an enhanced overall response of the connection.
- **Potential of RWS to be used in seismic-resistant designs**.
- Better performances achieved for models where S355 were used for all materials but the bolts (Class 10.9), the initial difference in material properties of the experiment hindered the desired mechanism.
- Addition of column stiffeners helped analysis while having the flanges restrained created similar results and avoided local buckling issues.
- Both closely and widely spaced web openings showed good results, with the latter concentrating the critical stresses around the first web opening.
- A column face distance of 520mm decreased the ultimate rotational capacity from 0.05 to 0.04rad in both cases, while a distance of 200mm led to some critical stress concentration too close to the column face.
- **Ideal column face distance was therefore identified as being 350mm**.

- **Study is part of wider project** investigating different types of connections, the use of novel patented elliptically-based web openings, more geometric characteristics, the dynamic response of the entire frame aiming to establish comparison of seismic and progressive collapse codes and guidelines current provisions.
- Further potential is to introduce a fuse at design stage to replace the isolated damaged section that would arise due to the critical stress around the widely spaced web opening.