Influence of semi-rigid joint characteristics on the behaviour of composite steel-framed structures under fire conditions

- Experimental Programme
- Numerical Modelling
- Component-based Approach
- Analysis of a typical sub-frame
- Conclusions

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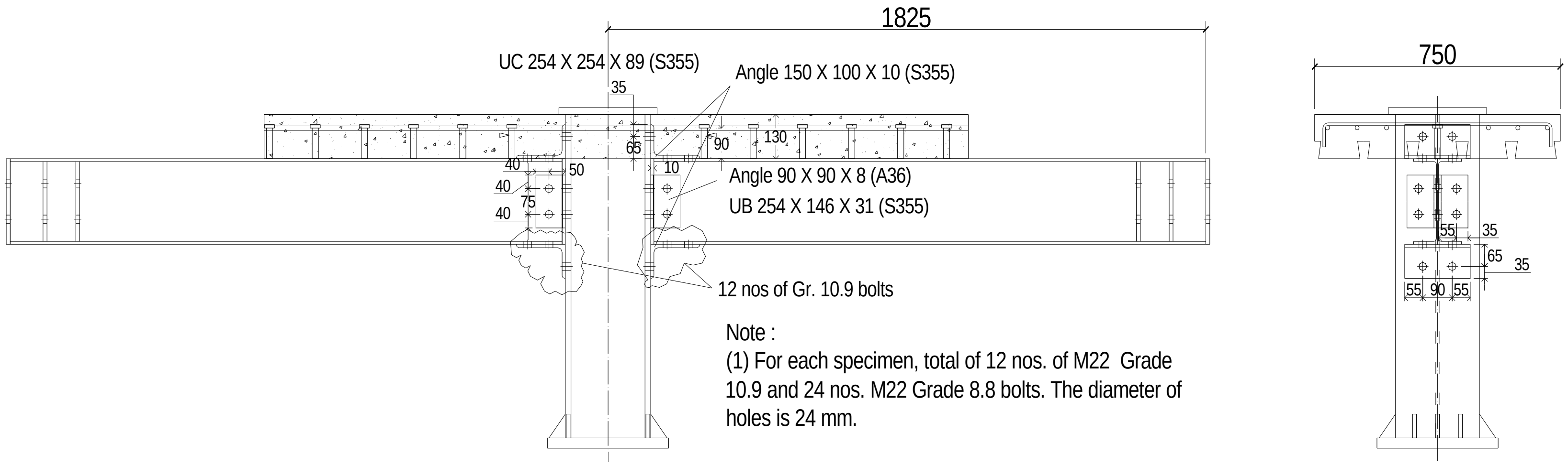
Experimental programme

Top-and-seat-and-web-angle joint



Column :	UC 254x254x89 kg/m (S355)
Beam :	UB 254x146x31 kg/m (S355)
Top & seat angle :	150x100x10 (S355)
Web angle :	90x90x8 (A36)
Bolts :	M22 bolts Gr 8.8 and Gr 10.9
Concrete slab :	2100 (L)x7509(W)x130(H) mm
Reinforcement :	6 nos. T13
Shear stud :	6 nos. 100mm Ø19 mm

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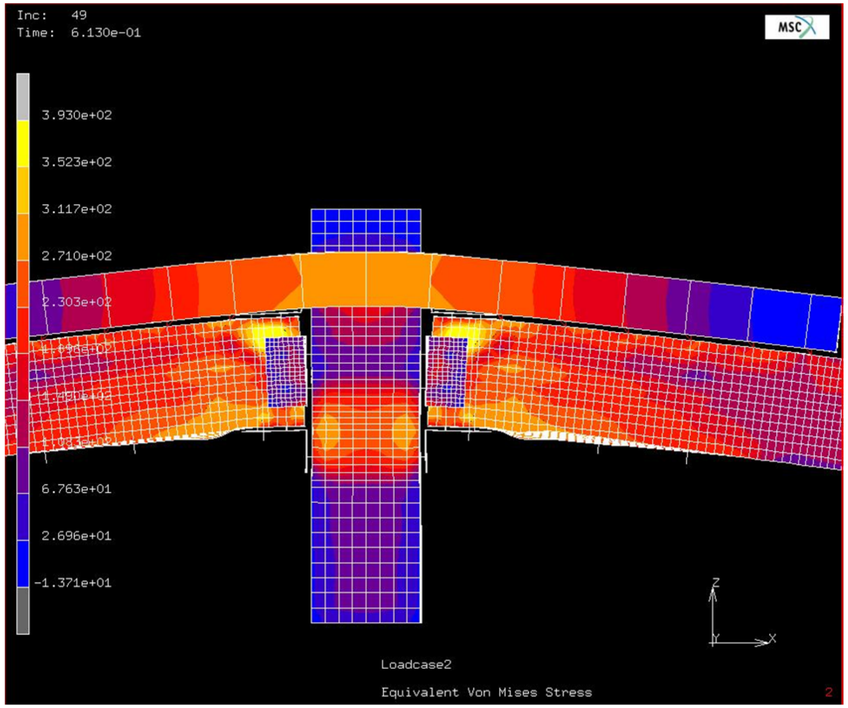
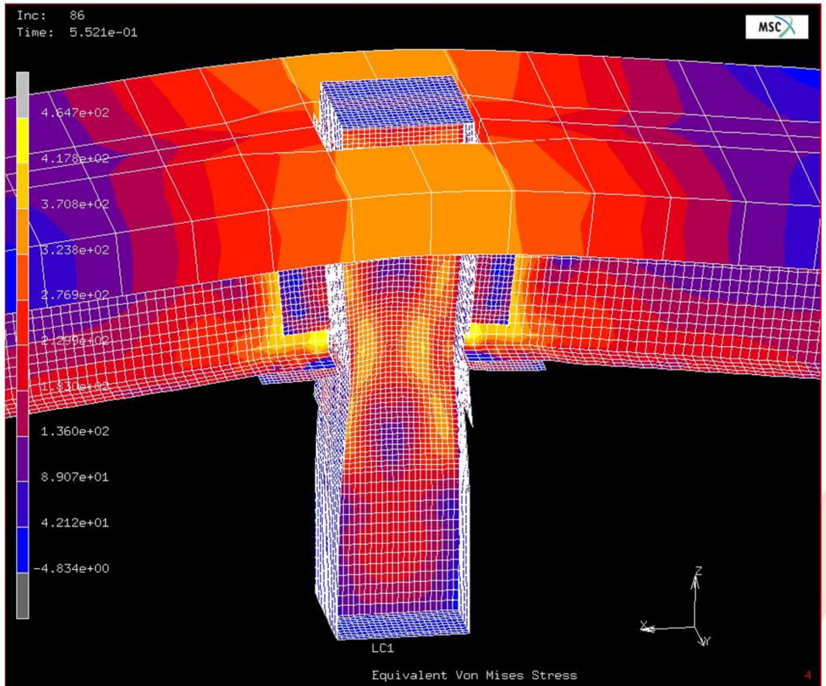
Numerical modelling

- Failure modes of joints



Beam flange buckling of Joint C1-T1

Column web buckling of Joint C3-T2



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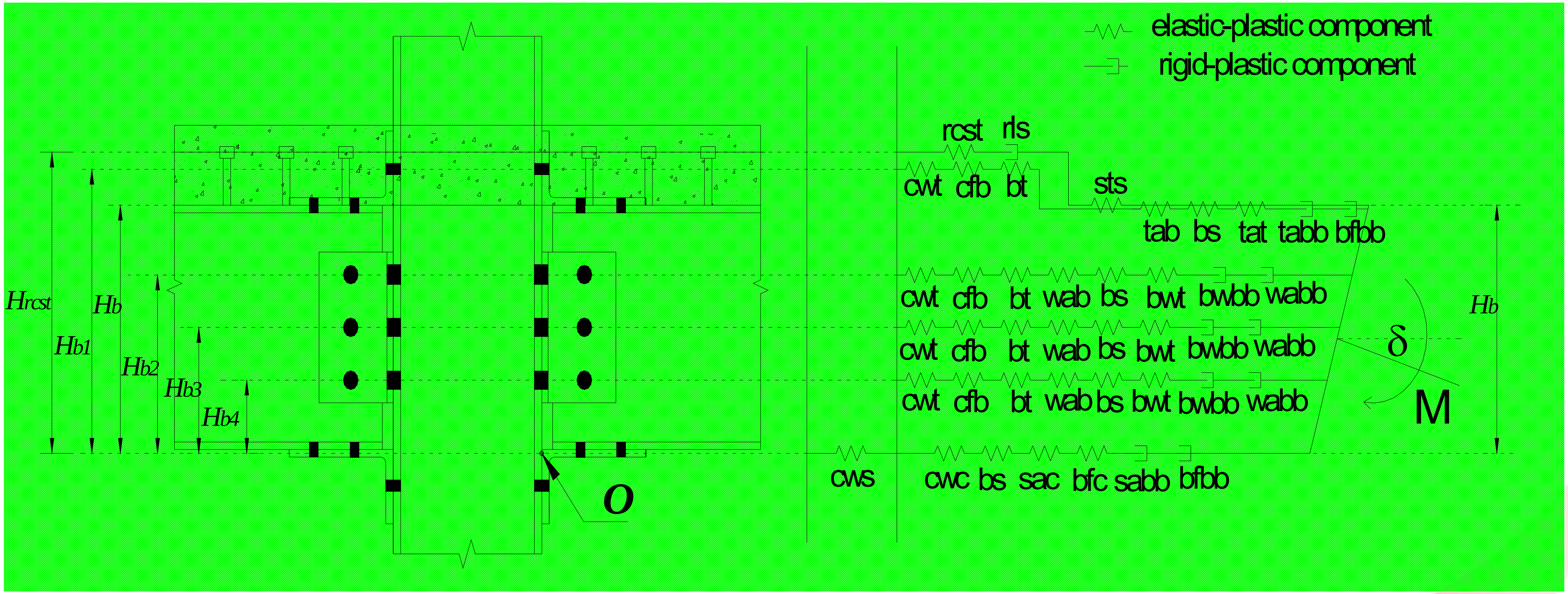
Component-based approach

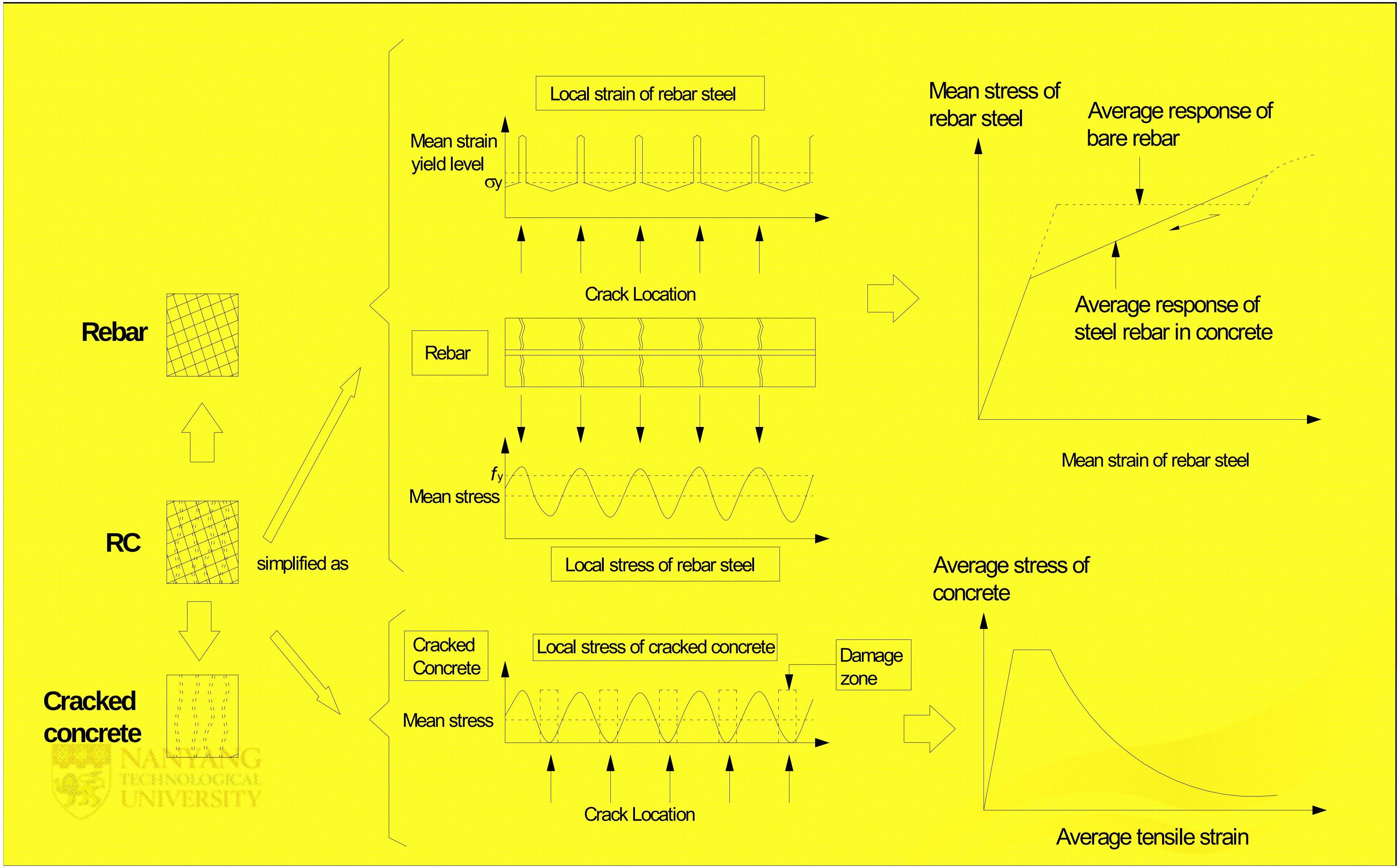
Top-and-seat-and-web-angles with composite slab

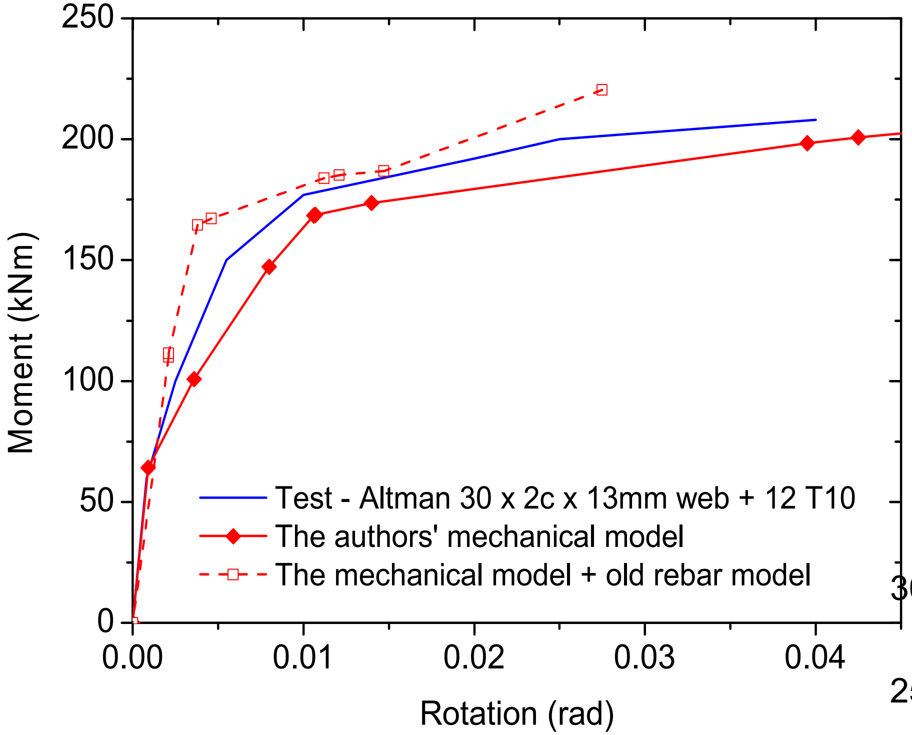
- Major innovative feature is the inclusion of a new joint component to represent the RC slab in tension.



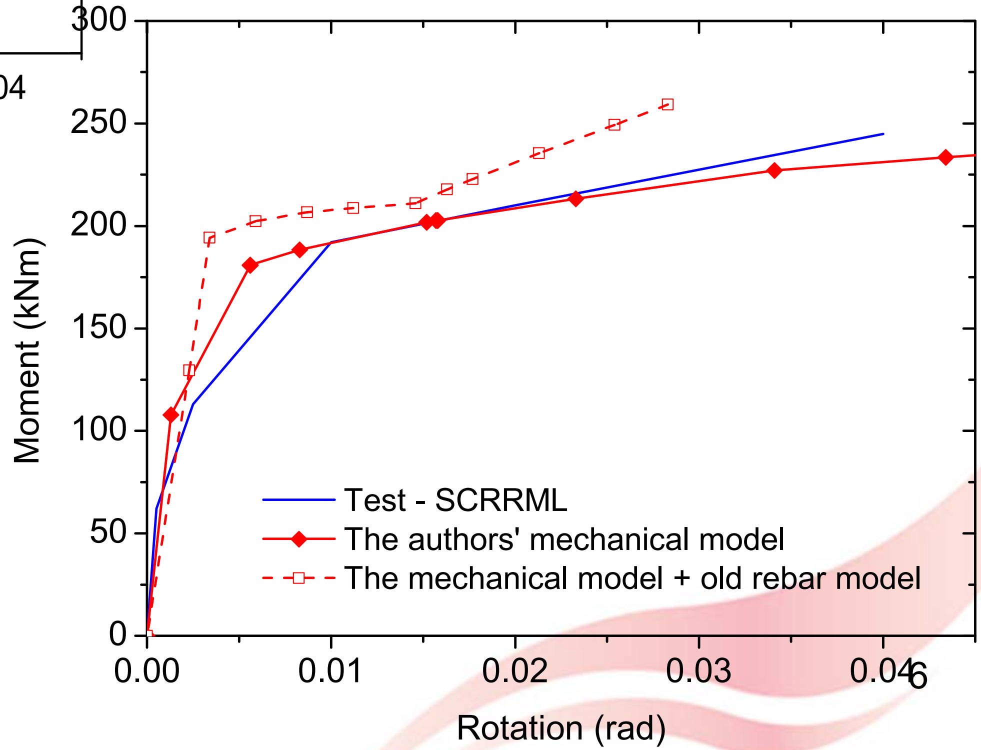
Component-based approach

Analytical model of Maekawa et al. (2003).





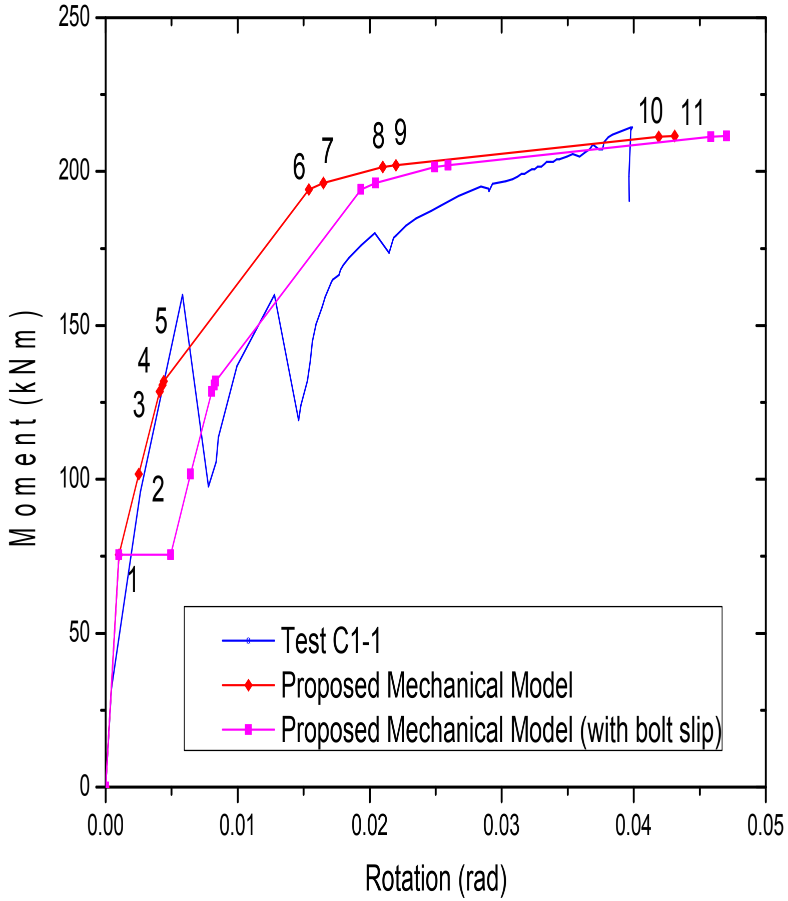
250
200
150
100
50
0
0.00
0.01
0.02
0.03
0.04
Moment (kNm)
Rotation (rad)
Test - Altman 30 x 2c x 13mm web + 12 T10
The authors' mechanical model
The mechanical model + old rebar model



300
250
200
150
100
50
0
0.00
0.01
0.02
0.03
0.04
Moment (kNm)
Rotation (rad)
Test - SCRRML
The authors' mechanical model
The mechanical model + old rebar model

Component-based approach

Top-and-seat-with-web-angles



Component failure sequence:

1.Reinforced slab reached elastic limit.

2.Shear studs reached elastic limit.

3. 2nd row of bolts reached elastic limit.

4. Beam flange (comp) reached elastic limit.

5. 1st row of bolts reached elastic limit.

6. Reinforced slab reached yield.

7. Beam flange in (comp) reached yield.

8. 1st row of bolts reached yield.

9. 2nd reached yield.

10. 3rd row of bolts reached elastic limit.

11. Beam flange (comp) reached ultimate.

12. The joint reached “failure”.

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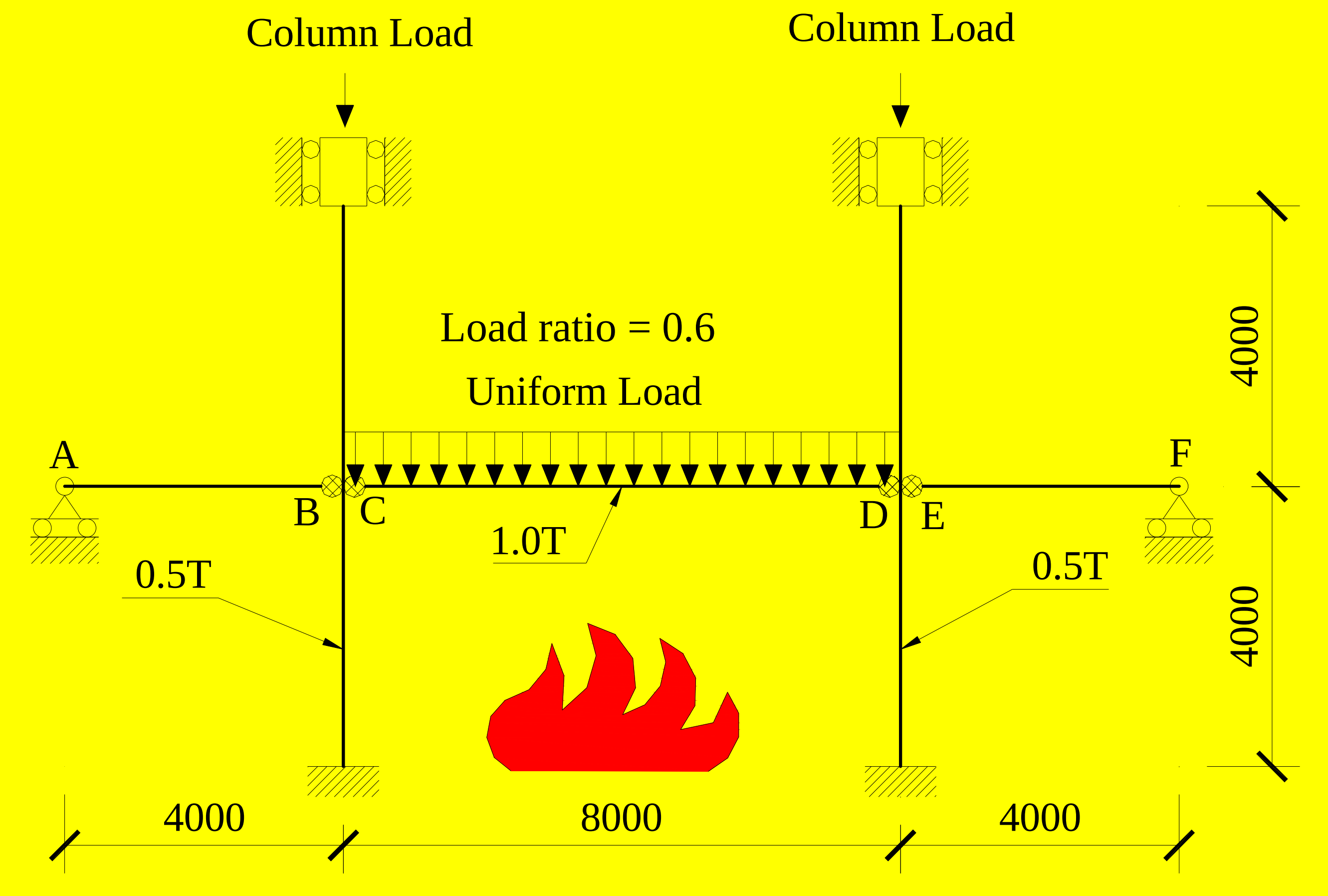
Component-based approach

Joint Specimen	BFC Temp. (°C)	$M_{u,test}$ (kNm)	$M_{u,pred}$ (kNm)	$M_{u,test}/M_{u,pred}$	Failure Mode: Test	Failure Mode: Predicted	$K_{i,test}$ (kNm/rad)	$K_{i,pred}$ (kNm/rad)	$K_{i,test}/K_{i,pred}$
Elevated Temperature Test									
C1-T1	434	201	202	0.995	A	A	141644	59606	2.376
C1-T2	569	138	133	1.038	B	B	25415	21073	1.206
C2-T1	633	165	150	1.100	B	B	21259	19632	1.083
C2-T2	646	150	139	1.079	B	B	17436	21098	0.826
C2-T3	491	211	208	1.014	B	B	85714	57163	1.499
C3-T1	651	207	214	0.967	C	C	43490	26866	1.619
C3-T2	551	278	263	1.057	C	C	53894	24039	2.242
C3-T3	424	338	326	1.037	D	D	86458	60262	1.435
Ambient Temperature Test									
C1-A1	26	215	225	0.956	D,A	D	37588	41690	0.902
C1-A2	26	154	133	1.155	B	B	40372	41708	0.968
C2-A1	26	269	256	1.051	B	B	104600	63591	1.645
C2-A2	26	279	253	1.103	B	B	61646	63591	0.969
C3-A1	26	286	273	1.048	B	B	81970	84025	0.976
C3-A2	26	278	275	1.011	B	B	65450	84154	0.778
			Mean	1.044				Mean	1.323
			SD	0.054				SD	0.508

Note: A = Local yielding/buckling of beam flange in compression; B =Longitudinal shear splitting of RC slab; C = Local buckling of column web in compression ; D = Yielding of main reinforcement bars; BFC = Beam flange in compression.

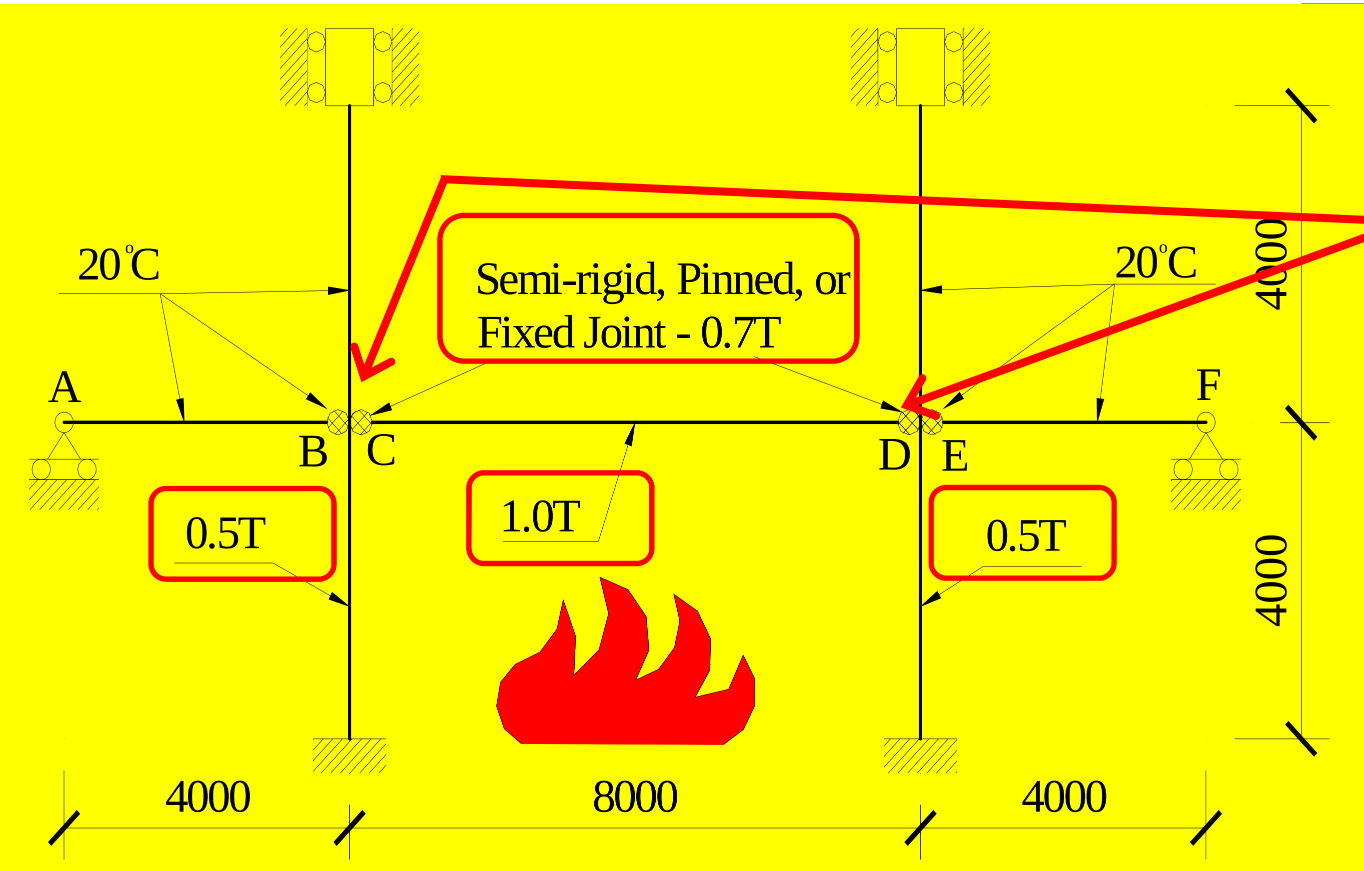
Analysis of a typical sub-frame



El-Rimawi (1989) concluded that the results of sub-frame analysis are reasonably representative of the full-scale frame tests under local fire conditions

Roller supports at A & F ---> no axial restraints
Fixed supports at A & F ---> with axial restraints

Analysis of a typical sub-frame



Temperature Distribution with the Sub-frame

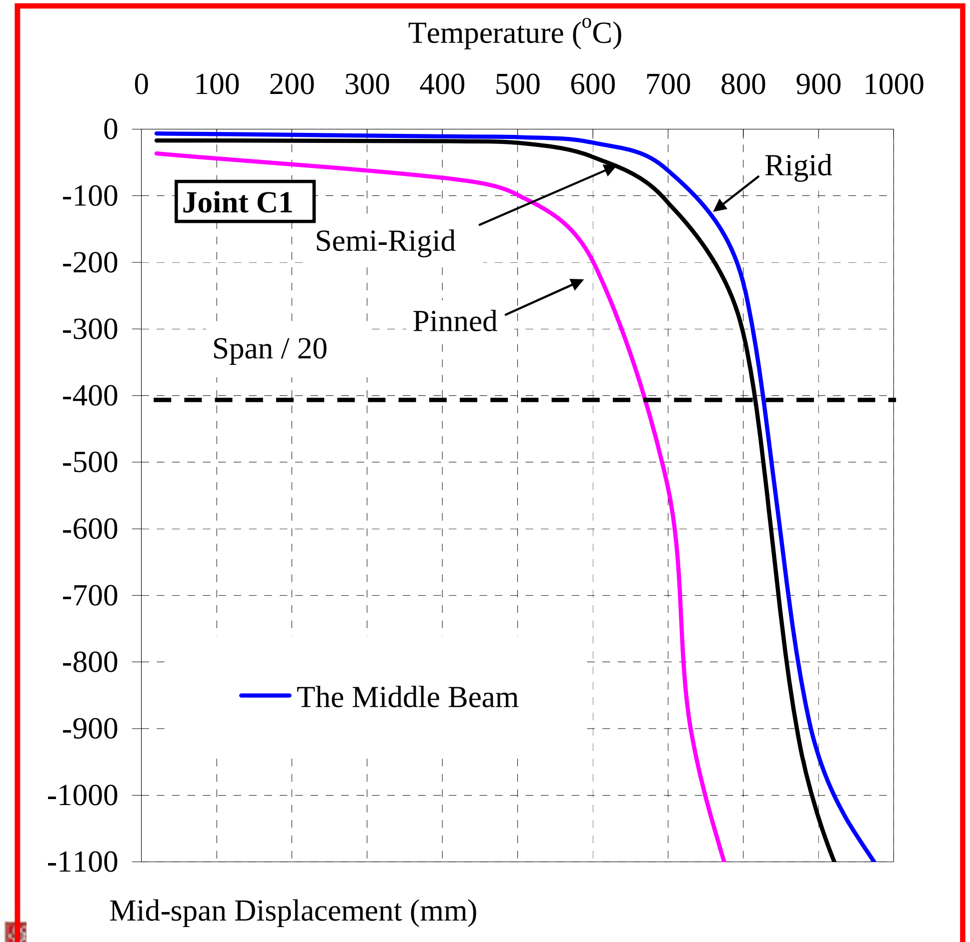
The elevated temperature profiles in the joints C & D follow the test measurements in Yuan's (2011) study

Middle beam temperature is assumed to be uniform1.0T along the length and across the section

Analysis of a typical sub-frame

Boundary Conditions

Middle beam behaviour incorporating joint C1 characteristics



- UDL = 25.9 kN/m.
- Failure temp.
  - 670°C for pinned joints
  - 830°C for fixed joints
  - 810°C for semi-rigid joint
- Semi-rigid joints greatly enhance the beam performance and increase the failure temp.

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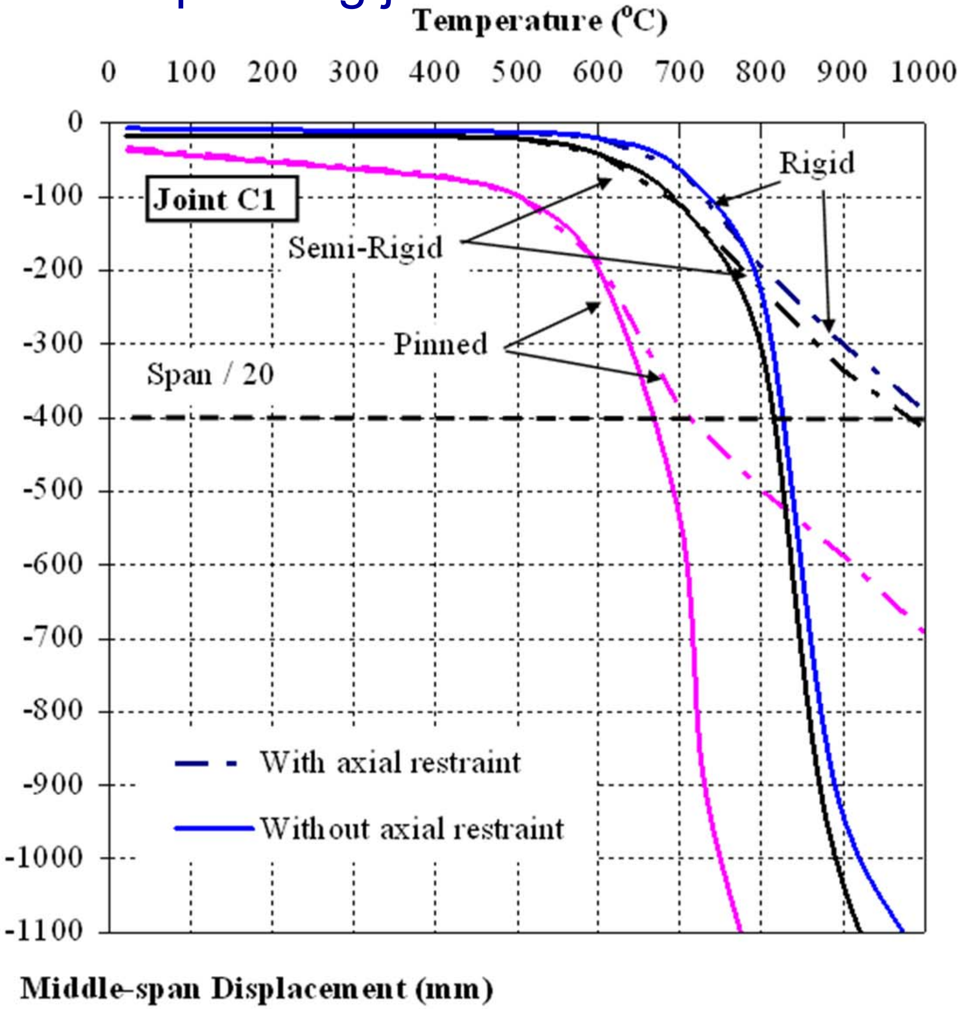
Analysis of a typical sub-frame

Axial Restraint

- Influence of axial restraint on the middle beam response incorporating joint C1 characteristics



- At L/40 deflection, the catenary action kicks in.
- At > L/40 deflection, the rate of deflection is reduced significantly with ↑ temp.
- Failure temp. is increased also.

Joint C1	Failure Temperature (°C)		
	Rigid	Pinned	Semi-rigid
No axial restraint	830	660	810
With axial restraint	1010	710	975

Conclusions

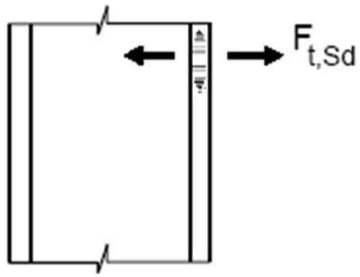
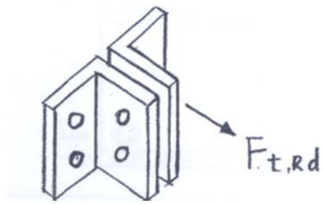
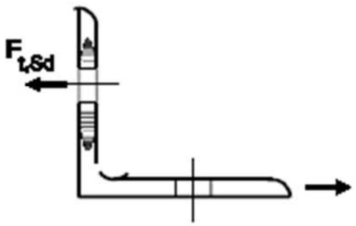
1. **Experimental programme and FE modelling to study the rotational behaviour of top-and-seat-with-web-angle joints.**
2. **Component-based approach provides reasonably accurate simulations of stiffness and strength compared with test results.**
3. **Composite semi-rigid joints greatly enhance the beam performance under fire conditions.**
4. **Axial restraint should be included in the numerical analysis for better behaviour of the middle beam.**

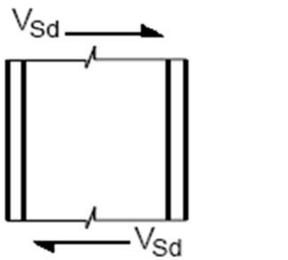
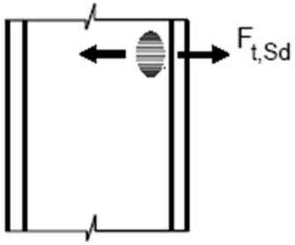
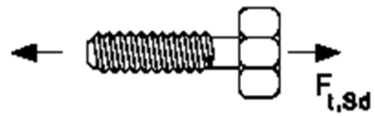
Thank you for your attention!

http://www.ntu.edu.sg/cee/research/Research_groups/Fireresearch/research.htm

Component-based approach

joint components in top-and-seat-and-web angle joint

1	Column flange in bending (**cfb**)	
2	Top angle in bending (**tab**)	
3	Web angle in bending (**wab**)	

4	Column web panel in shear (**cws**)	
5	Column web in tension (**cwt**)	
6	Bolts in tension (**bt**)	

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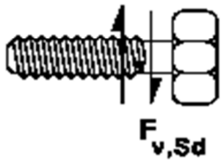
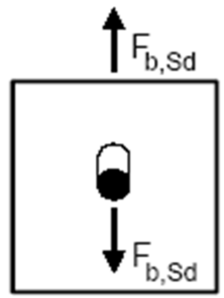
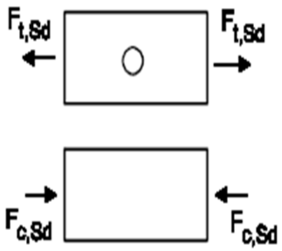
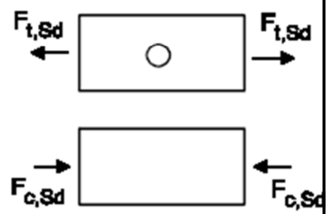
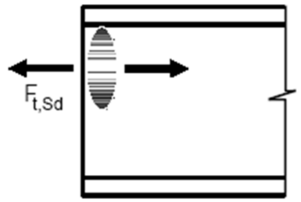
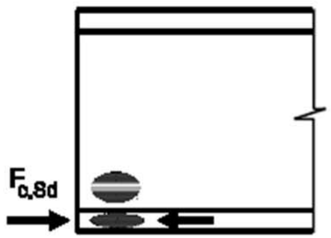
Component-based approach

joint components in top-and-seat-and-web angle joint

7	Bolts in shear (**bs**)	
8	Bolts in bearing (**bwbb**, **bfbb**, **wabb**, **tabb** & **sabb**)	
9	Plate in tension at top angle (**tat**)	

10	Plate in compression at the seat angle (**sac**)	
11	Beam web in tension (**bwt**)	
12	Beam flange and web in compression (**bfc**)	

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