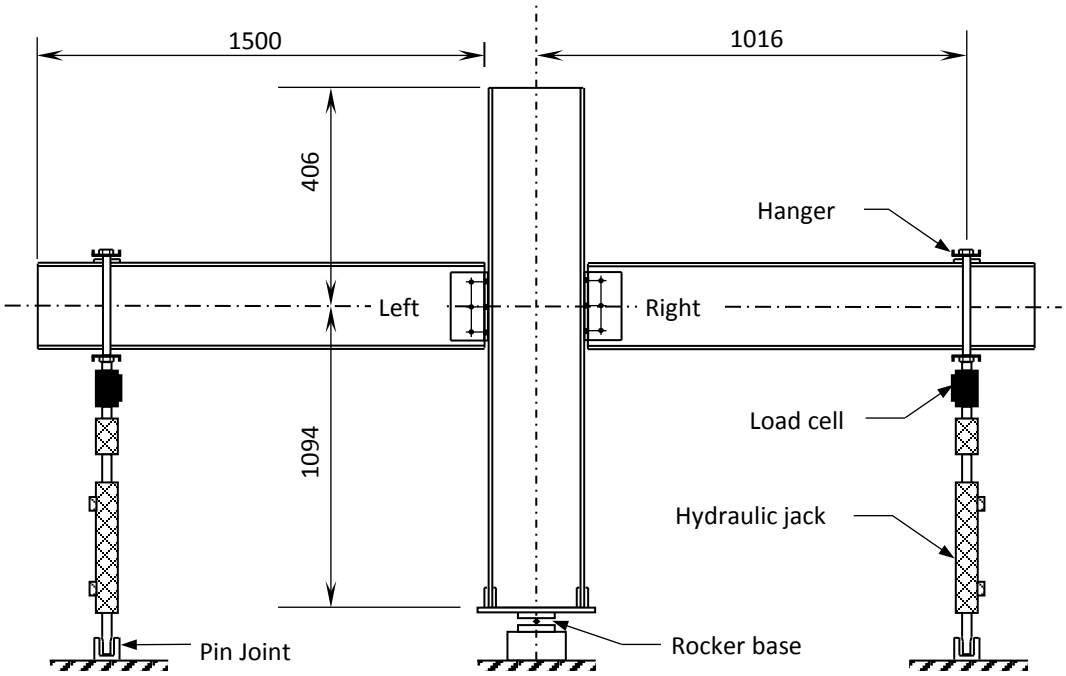



Fig. 1. Cruciform test configuration and loading arrangement (all dimensions are in mm).

Fig. 2. General test arrangement for major-axis beam-to-column joint Wmj254_2M16_ST1-3.

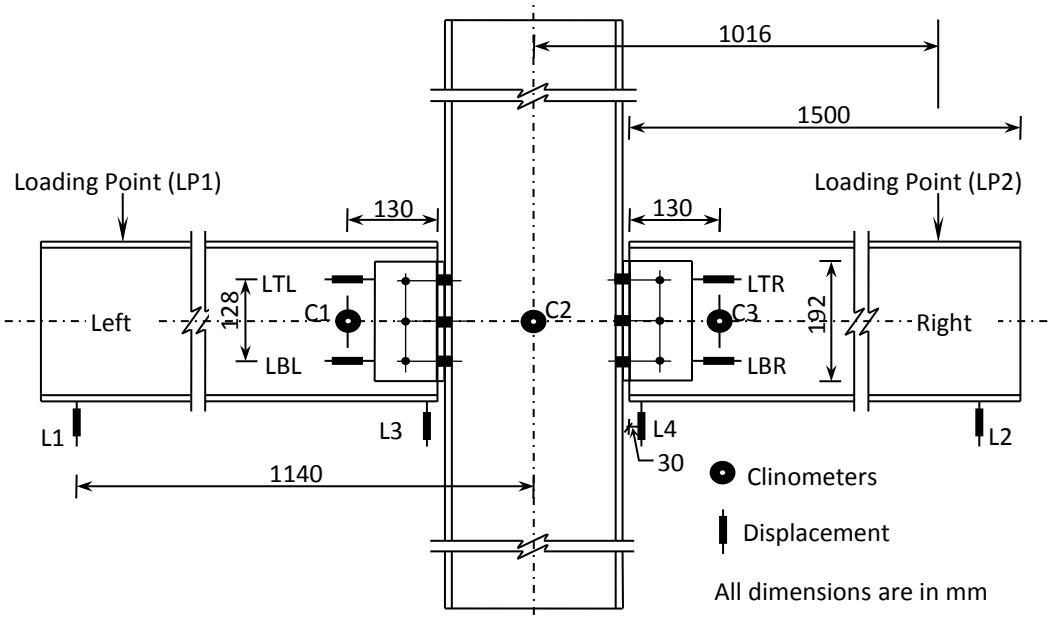



Fig. 3. Location of instrumentation in nominally pinned beam-to-column joint tests (all dimensions are in mm).

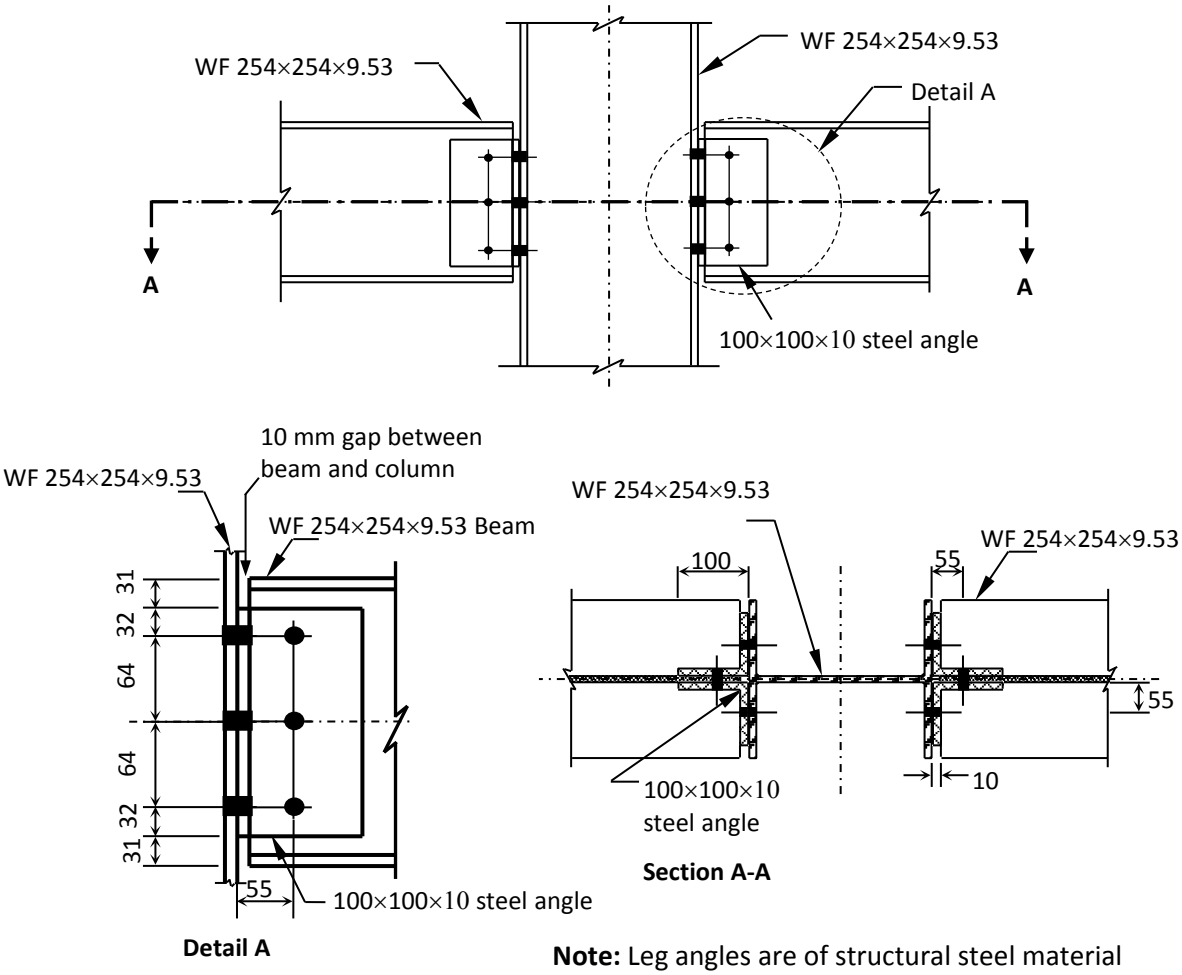



Fig. 4. Connection details for beam-to-column joint tests with structural steel cleats (All dimensions are in mm), adapted from [Fig. 1].

Fig. 5. Details of nominally pinned beam-to-column joint test Wmj254_2M16_ST1-3.

Test Ref: Wmj254_2M16_ST1-3 Test date: 8th December 2011

Moment arm = 1.016 m

| | | LEFT SIDE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Incr | Centre rotation, C2 (CH18) | Load Point, LP1 (CH 21) | Rotation, C1 (CH 17) | Moment =LP1 x moment arm | Joint rotation, (4)-(2) | Slip compensated joint rotation, (6)-(12) | End beam deflection on L1, (CH11) | Slip top, LTL (CH1) | Slip bot, LBL (CH3) | Beam deflection near column end, L3 (CH13) | Rotation due to horizontal slip, arctan ((LBL-LTL)/L) |
| | mrad | kN | mrad | kN.m | mrad | mrad | mm | mm | mm | mm | mrad |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | | | | | | | | | | | |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | -0.68 | 0.12 | -0.83 | 0.12 | 0.15 | 0.06 | 1.02 | -0.05 | -0.04 | 0.00 | 0.09 |
| | -0.31 | 0.37 | -0.82 | 0.37 | 0.51 | 0.35 | 1.11 | -0.06 | -0.03 | 0.01 | 0.16 |
| | -0.50 | 0.39 | -1.04 | 0.40 | 0.54 | 0.37 | 1.31 | -0.06 | -0.04 | 0.01 | 0.17 |
| | -0.61 | 0.85 | -2.19 | 0.86 | 1.59 | 1.31 | 2.38 | -0.07 | -0.03 | 0.04 | 0.28 |
| | -0.57 | 0.85 | -2.20 | **0.86** | **1.64** | **1.33** | 2.37 | -0.08 | -0.04 | 0.04 | 0.30 |
| | -1.34 | 1.35 | -4.76 | 1.37 | 3.42 | 3.04 | 4.63 | -0.08 | -0.03 | 0.08 | 0.37 |
| | -1.37 | 1.33 | -4.89 | 1.35 | 3.52 | 3.09 | 4.74 | -0.09 | -0.04 | 0.08 | 0.42 |
| | 0.45 | 1.82 | -5.89 | 1.85 | 6.34 | 5.84 | 5.48 | -0.09 | -0.03 | 0.14 | 0.49 |
| | 0.55 | 1.76 | -6.07 | 1.79 | 6.62 | 6.15 | 5.61 | -0.10 | -0.04 | 0.14 | 0.48 |
| | 0.09 | 2.36 | -11.84 | 2.39 | 11.93 | 11.37 | 10.53 | -0.11 | -0.03 | 0.26 | 0.56 |
| | 0.06 | 2.24 | -12.19 | 2.28 | 12.25 | 11.65 | 10.78 | -0.12 | -0.04 | 0.27 | 0.60 |
| | 0.98 | 2.58 | -15.84 | 2.62 | 16.82 | 16.18 | 13.75 | -0.12 | -0.04 | 0.37 | 0.63 |
| | 0.85 | 2.43 | -16.18 | 2.47 | 17.03 | 16.38 | 14.00 | -0.12 | -0.04 | 0.38 | 0.65 |
| | 0.01 | 2.73 | -21.14 | 2.77 | 21.15 | 20.48 | 18.21 | -0.13 | -0.04 | 0.47 | 0.66 |
| | -0.29 | 2.53 | -21.53 | 2.57 | 21.24 | 20.59 | 18.50 | -0.13 | -0.04 | 0.48 | 0.66 |
| | -4.79 | 0.11 | -9.97 | 0.11 | 5.17 | 4.97 | 8.87 | -0.13 | -0.10 | 0.11 | 0.20 |
| | -4.83 | 0.12 | -9.88 | 0.13 | 5.05 | 4.81 | 8.81 | -0.13 | -0.10 | 0.11 | 0.24 |
| | 0.46 | 2.74 | -24.12 | 2.78 | 24.58 | 23.83 | 20.57 | -0.16 | -0.06 | 0.56 | 0.76 |
| | 0.86 | 2.94 | -28.02 | 2.99 | 28.89 | 28.11 | 23.76 | -0.16 | -0.06 | 0.66 | 0.78 |
| | 0.81 | 2.76 | -28.68 | 2.81 | 29.49 | 28.67 | 24.25 | -0.17 | -0.06 | 0.67 | 0.81 |
| | -5.00 | 0.09 | -12.56 | 0.09 | 7.55 | 7.30 | 10.96 | -0.15 | -0.11 | 0.17 | 0.26 |
| | -4.46 | 0.09 | -11.43 | 0.10 | 6.97 | 6.66 | 10.00 | -0.16 | -0.12 | 0.15 | 0.31 |
| | 0.18 | 2.87 | -30.06 | 2.92 | 30.23 | 29.43 | 25.39 | -0.18 | -0.08 | 0.69 | 0.80 |
| | 1.03 | 3.08 | -34.16 | 3.13 | 35.19 | 34.31 | 28.69 | -0.18 | -0.07 | 0.80 | 0.88 |
| | 1.49 | 2.85 | -34.60 | 2.90 | 36.08 | 35.28 | 28.96 | -0.19 | -0.08 | 0.82 | 0.80 |
| | -1.68 | 3.28 | -52.57 | 3.33 | 50.89 | 49.85 | 43.76 | -0.22 | -0.08 | 1.18 | 1.04 |
| | -2.38 | 3.35 | -54.53 | 3.40 | 52.16 | 51.12 | 45.41 | -0.21 | -0.08 | 1.21 | 1.04 |
| | -3.59 | 3.06 | -54.88 | 3.11 | 51.29 | 50.25 | 45.69 | -0.22 | -0.09 | 1.19 | 1.04 |
| | -2.08 | 3.36 | -56.54 | 3.41 | 54.46 | 53.36 | 46.97 | -0.23 | -0.09 | 1.26 | 1.09 |
| | -0.12 | 3.48 | -56.72 | 3.53 | 56.60 | 55.50 | 47.07 | -0.23 | -0.09 | 1.31 | 1.10 |
| | -0.28 | 3.63 | -59.85 | 3.68 | 59.58 | 58.37 | 49.70 | -0.23 | -0.08 | 1.38 | 1.20 |
| | -0.27 | 3.68 | -63.76 | **3.74** | **63.49** | **62.27** | 52.86 | -0.24 | -0.08 | 1.48 | 1.23 |
| | -0.11 | 3.28 | -64.42 | 3.33 | 64.31 | 63.07 | 53.29 | -0.25 | -0.09 | 1.50 | 1.24 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.91 | 0.12 | -19.11 | 0.12 | 20.02 | 19.61 | 15.84 | -0.21 | -0.15 | 0.45 | 0.41 |
| | 4.17 | 0.03 | -12.91 | 0.03 | 17.08 | 16.77 | 10.43 | -0.20 | -0.16 | 0.37 | 0.31 |

**Note: L is vertical separation between two horizontal displacement transducers on the web cleat = 128 mm**

**Green:** **indicates linear elastic joint properties**
**Red:** **shows joint properties at damage onset***
**Blue:** **indicates joint properties at maximum moment**

***Damage Onset** **is defined in following two ways:**

1. When audiable loud cracking noise is first heard.
2. When width of column near centreline of top bolt increases by 1% of its width before loading. (refer worksheet **col data**)

In col data worksheet, width of column near top bolt increases by 1% when load is 2 kN.
From moment rotation curves, the joint properties at damage onset are as under:

| M | $\phi$ (with slip) | $\phi$ (Compensated for slip) |
|---|---|---|
| **2.03** | **8.50** | **8.00** |

Test Ref: Wmj254_2M16_ST1-3 Test date: 8th December 2011

Moment arm = 1.016 m

| RIGHT SIDE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Load Point, LP2 (CH 22) | Rotation C3 (CH 19) | Moment =LP2 x moment arm | Joint rotation, (14)-(2) | Slip compensated joint rotation, (16)-(22) | End beam deflection L2, (CH9) | Slip top, LTR (CH5) | Slip bot, LBR (CH7) | Beam deflection near column end, L4 (CH15) | Rotation due to horizontal slip, arctan ((LBL-LTL)/L) |
| kN | mrad | kN.m | mrad | mrad | mm | mm | mm | mm | mrad |
| 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.14 | -0.46 | 0.14 | 0.23 | 0.19 | -0.27 | -0.03 | -0.04 | 0.00 | 0.04 |
| 0.39 | 0.50 | 0.39 | 0.81 | 0.77 | 0.68 | -0.04 | -0.05 | 0.01 | 0.05 |
| 0.41 | 0.42 | 0.42 | 0.92 | 0.91 | 0.59 | -0.05 | -0.05 | 0.01 | 0.01 |
| 0.87 | 1.69 | 0.88 | 2.30 | 2.24 | 1.77 | -0.06 | -0.05 | 0.04 | 0.05 |
| 0.86 | 1.76 | **0.87** | **2.33** | **2.22** | 1.83 | -0.07 | -0.06 | 0.04 | 0.10 |
| 1.37 | 3.31 | 1.39 | 4.65 | 4.45 | 3.16 | -0.08 | -0.06 | 0.08 | 0.20 |
| 1.34 | 3.38 | 1.36 | 4.75 | 4.60 | 3.19 | -0.09 | -0.07 | 0.08 | 0.16 |
| 1.84 | 8.16 | 1.87 | 7.72 | 7.46 | 7.42 | -0.09 | -0.06 | 0.14 | 0.26 |
| 1.78 | 8.26 | 1.80 | 7.71 | 7.43 | 7.49 | -0.10 | -0.07 | 0.14 | 0.28 |
| 2.37 | 12.13 | 2.40 | 12.04 | 11.68 | 10.70 | -0.11 | -0.07 | 0.22 | 0.37 |
| 2.25 | 12.21 | 2.29 | 12.15 | 11.79 | 10.74 | -0.12 | -0.07 | 0.22 | 0.36 |
| 2.58 | 16.22 | 2.62 | 15.24 | 14.79 | 14.18 | -0.13 | -0.07 | 0.28 | 0.45 |
| 2.44 | 16.33 | 2.48 | 15.48 | 15.04 | 14.25 | -0.14 | -0.08 | 0.29 | 0.44 |
| 2.73 | 22.12 | 2.77 | 22.11 | 21.64 | 19.03 | -0.14 | -0.08 | 0.43 | 0.48 |
| 2.54 | 22.40 | 2.58 | 22.69 | 22.23 | 19.17 | -0.14 | -0.08 | 0.44 | 0.46 |
| 0.14 | 1.16 | 0.14 | 5.95 | 5.86 | 0.71 | -0.11 | -0.12 | 0.11 | 0.09 |
| 0.15 | 1.06 | 0.16 | 5.90 | 5.84 | 0.65 | -0.11 | -0.12 | 0.11 | 0.06 |
| 2.76 | 26.15 | 2.80 | 25.69 | 25.28 | 22.13 | -0.16 | -0.11 | 0.49 | 0.41 |
| 2.96 | 31.09 | 3.00 | 30.23 | 29.78 | 26.11 | -0.17 | -0.11 | 0.59 | 0.45 |
| 2.77 | 31.61 | 2.82 | 30.81 | 30.39 | 26.45 | -0.17 | -0.11 | 0.60 | 0.41 |
| 0.12 | 3.15 | 0.12 | 8.16 | 8.14 | 2.34 | -0.14 | -0.14 | 0.16 | 0.02 |
| 0.12 | 3.13 | 0.12 | 7.59 | 7.49 | 2.39 | -0.14 | -0.15 | 0.15 | 0.09 |
| 2.88 | 31.72 | 2.93 | 31.54 | 31.11 | 26.49 | -0.18 | -0.13 | 0.61 | 0.43 |
| 3.09 | 36.49 | 3.14 | 35.46 | 35.05 | 30.40 | -0.18 | -0.13 | 0.70 | 0.41 |
| 2.87 | 36.65 | 2.91 | 35.16 | 34.76 | 30.53 | -0.19 | -0.13 | 0.69 | 0.40 |
| 3.28 | 45.04 | 3.33 | 46.72 | 46.18 | 37.22 | -0.21 | -0.14 | 0.94 | 0.54 |
| 3.35 | 47.67 | 3.40 | 50.05 | 49.56 | 39.29 | -0.21 | -0.15 | 1.01 | 0.49 |
| 3.07 | 48.13 | 3.12 | 51.72 | 51.25 | 39.52 | -0.21 | -0.15 | 1.04 | 0.47 |
| 3.37 | 56.52 | 3.43 | 58.60 | 58.07 | 46.60 | -0.22 | -0.16 | 1.20 | 0.53 |
| 3.50 | 62.50 | 3.55 | 62.62 | 61.97 | 51.53 | -0.23 | -0.15 | 1.28 | 0.65 |
| 3.64 | 66.72 | 3.70 | 66.99 | 66.34 | 54.99 | -0.23 | -0.15 | 1.37 | 0.66 |
| 3.68 | 69.60 | **3.74** | **69.87** | **69.17** | 57.68 | -0.24 | -0.15 | 1.44 | 0.70 |
| 3.29 | 69.85 | 3.34 | 69.96 | 69.29 | 57.83 | -0.25 | -0.16 | 1.44 | 0.67 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.14 | 23.65 | 0.15 | 22.74 | 22.71 | 19.51 | -0.18 | -0.19 | 0.46 | 0.03 |
| 0.04 | 23.32 | 0.04 | 19.15 | 19.05 | 19.33 | -0.18 | -0.19 | 0.39 | 0.10 |

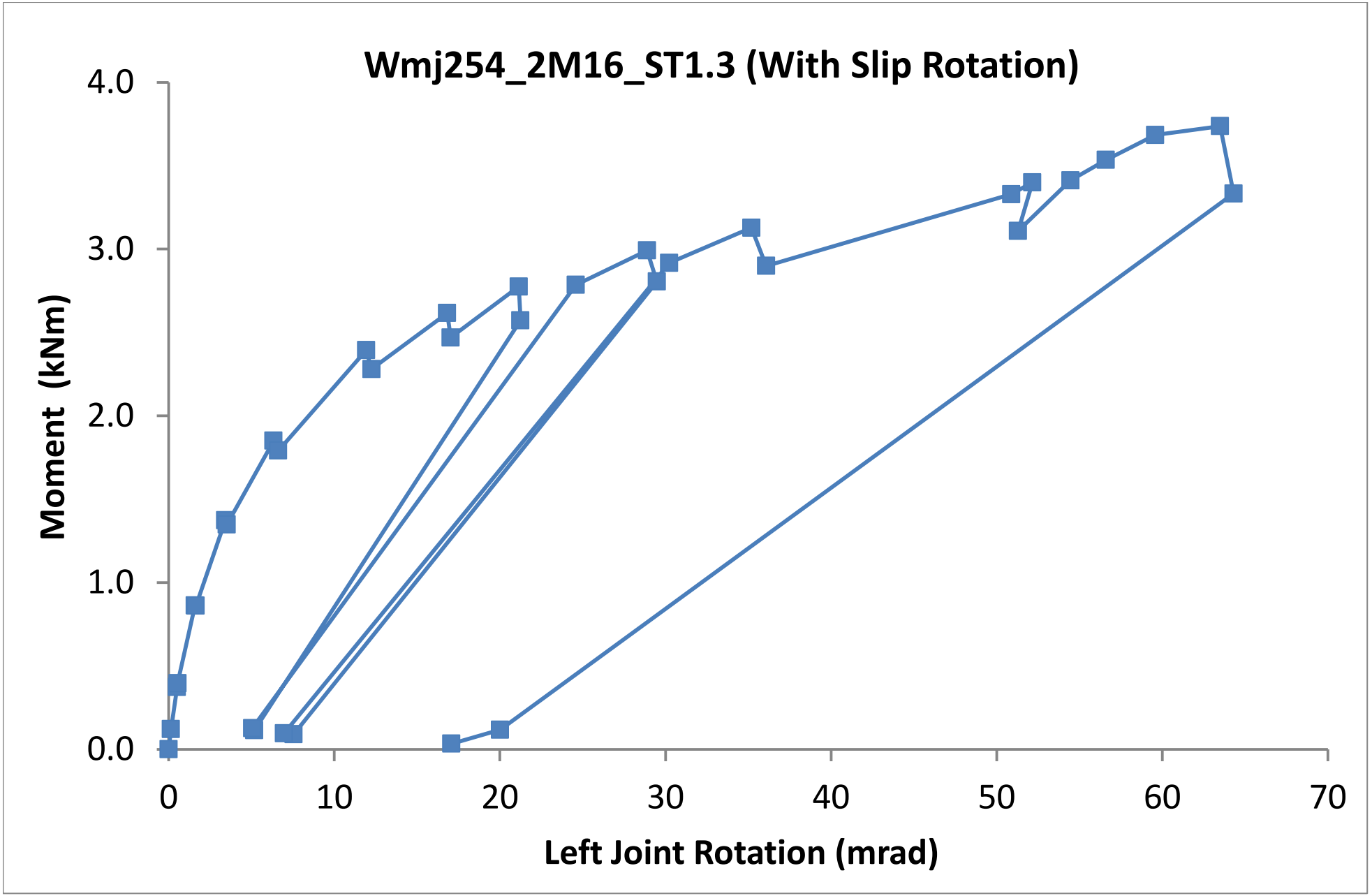
***Damage Onset** is defined in following two ways:**

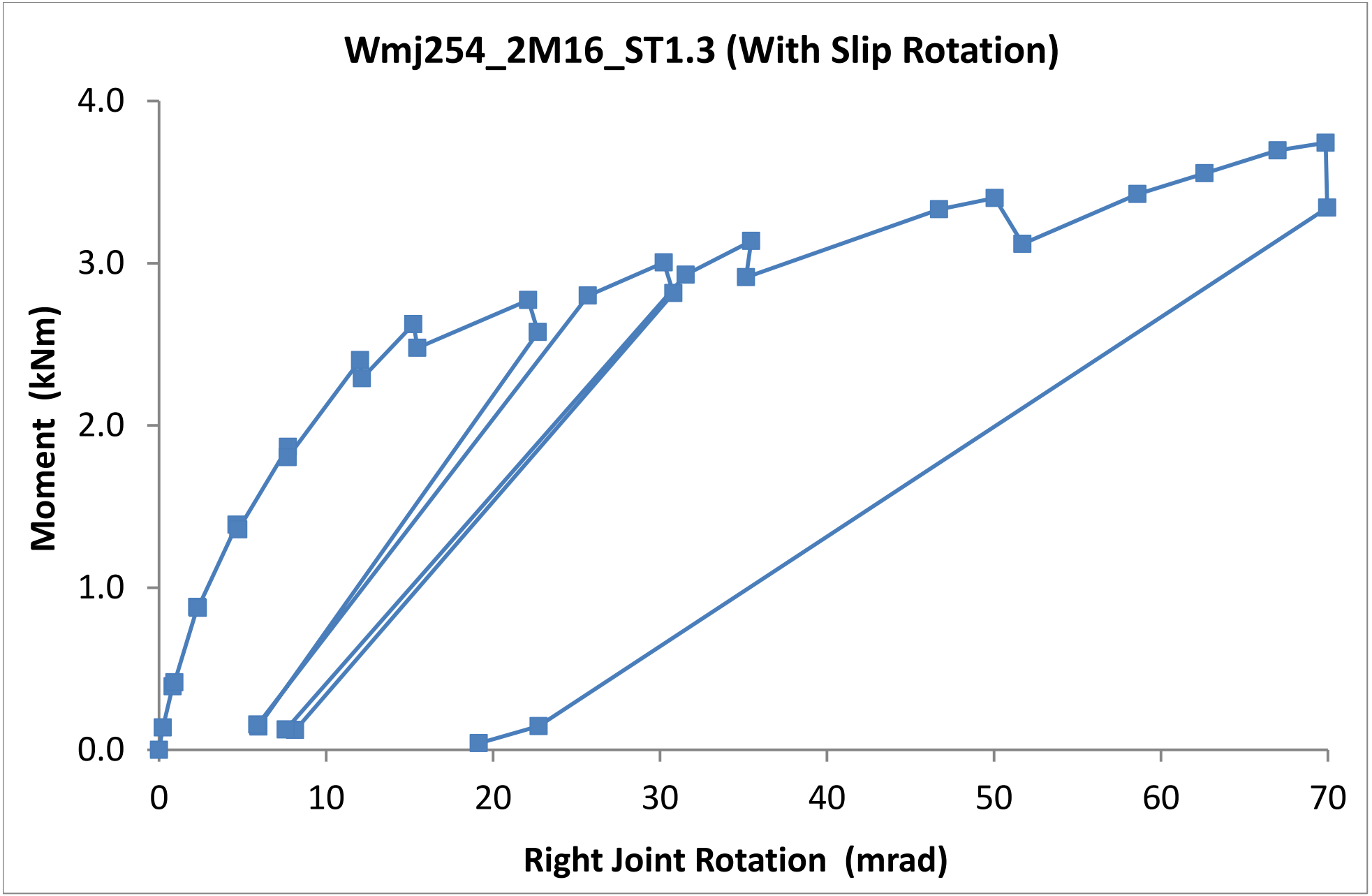
1. When audiable loud cracking noise is first heard.
2. When width of column near centreline of top bolt increases by 1% of its width before loading.
   (refer worksheet **col data**)

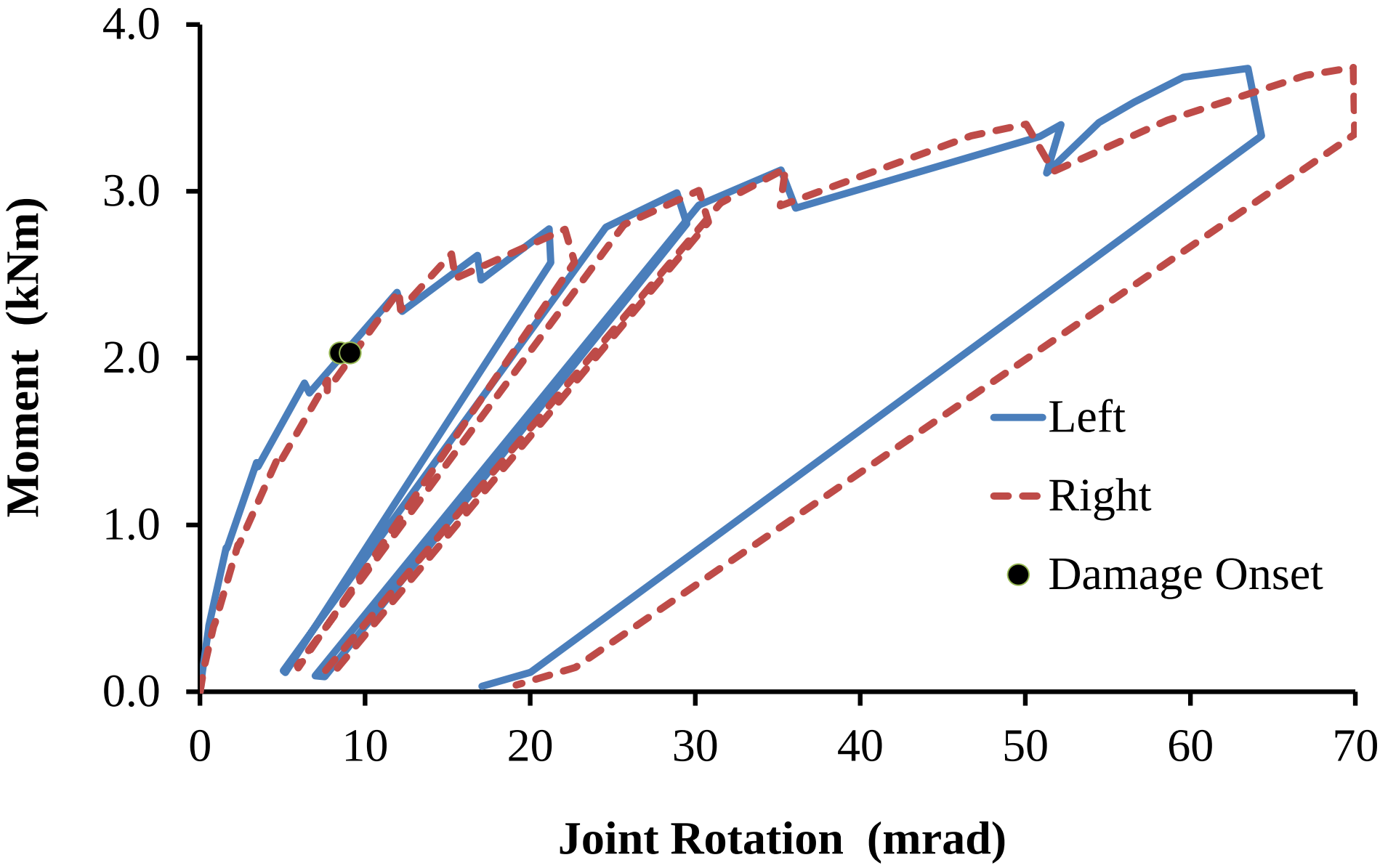
In col data worksheet, width of column near top bolt increases by 1% when load is 2 kN.

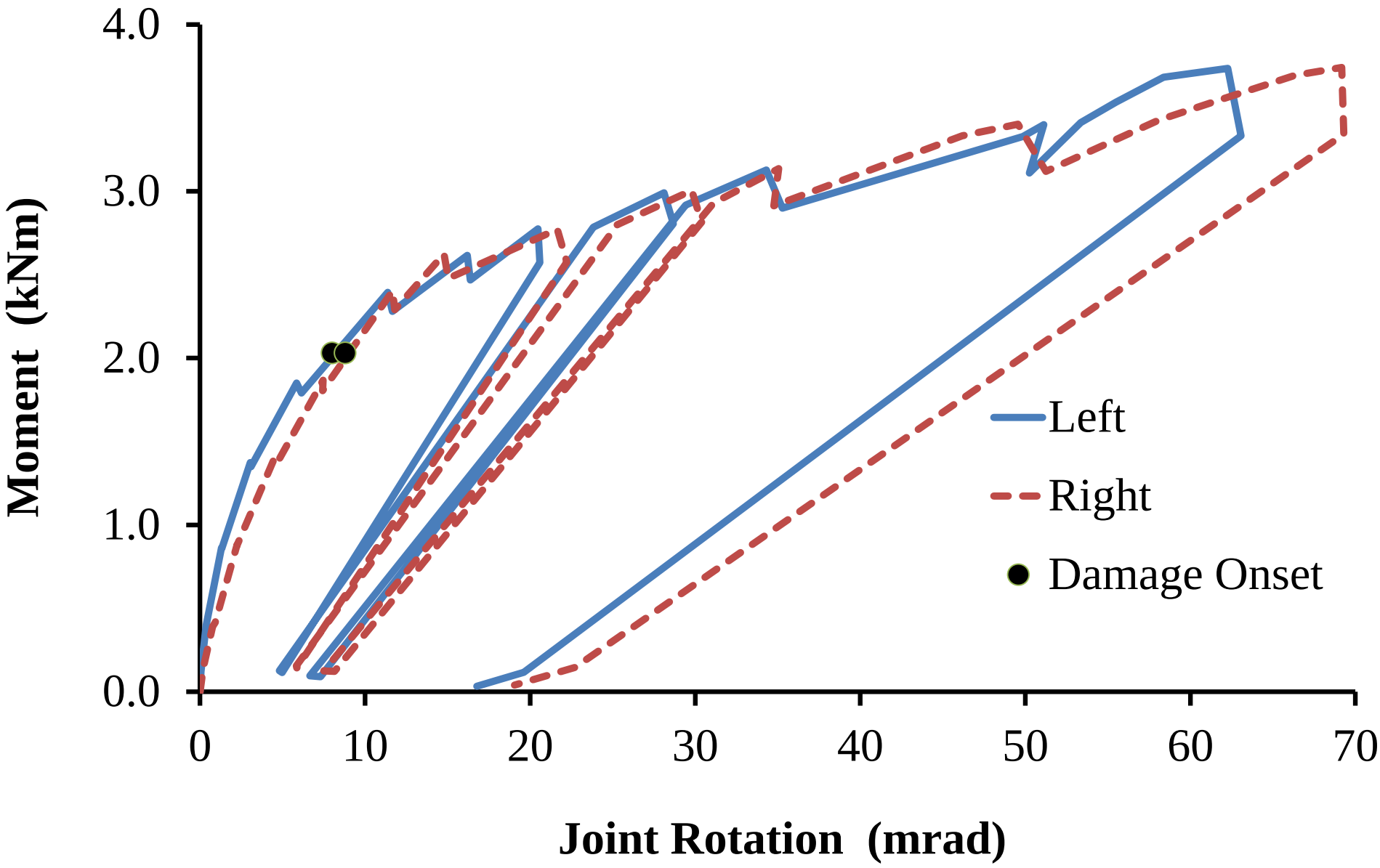
From moment rotation curves, the joint properties at damage onset are as under:

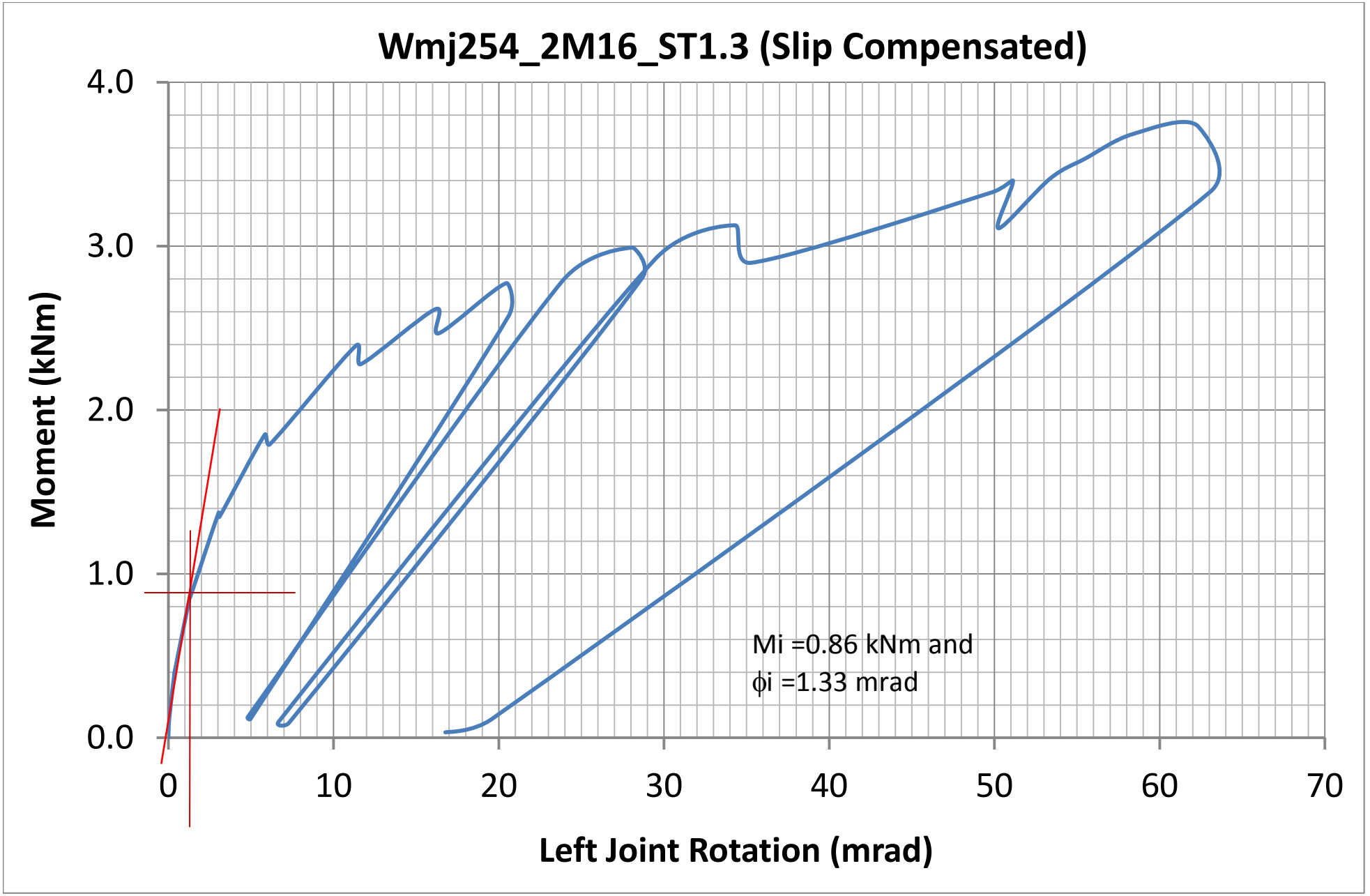
| M | $\phi$ (with slip) | $\phi$ (Compensated for slip) |
|---|---|---|
| **2.03** | **9.10** | **8.80** |

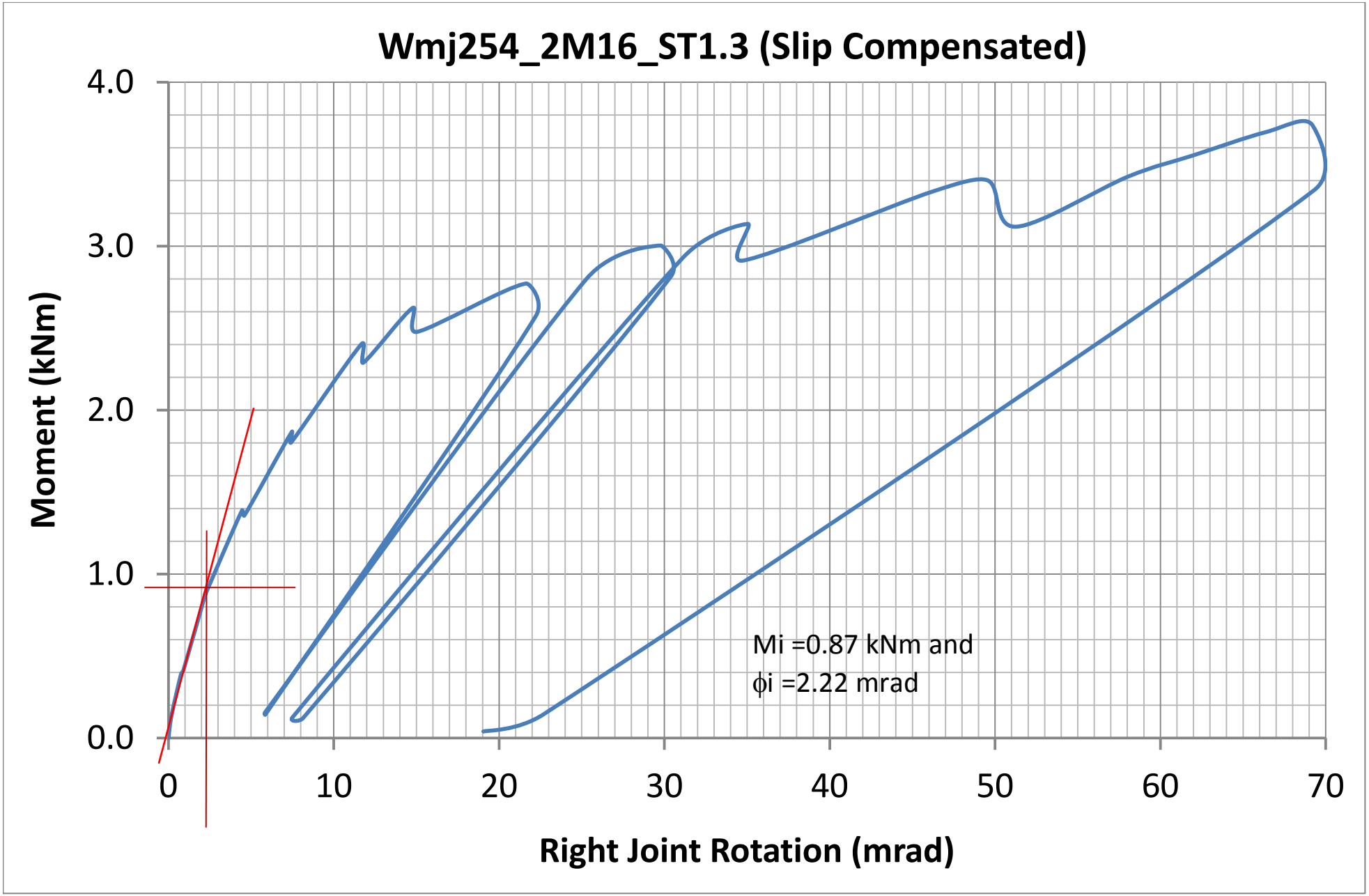

Wmj254_2M16_ST1.3 (With Slip Rotation)
Moment (kNm)
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
Left Joint Rotation (mrad)


Wmj254_2M16_ST1.3 (With Slip Rotation)
Moment (kNm)
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
Right Joint Rotation (mrad)


4.0
3.0
2.0
1.0
0.0
Moment (kNm)
0
10
20
30
40
50
60
70
Joint Rotation (mrad)
Left
Right
Damage Onset


4.0
3.0
2.0
1.0
0.0
Moment (kNm)
0
10
20
30
40
50
60
70
Joint Rotation (mrad)
Left
Right
Damage Onset

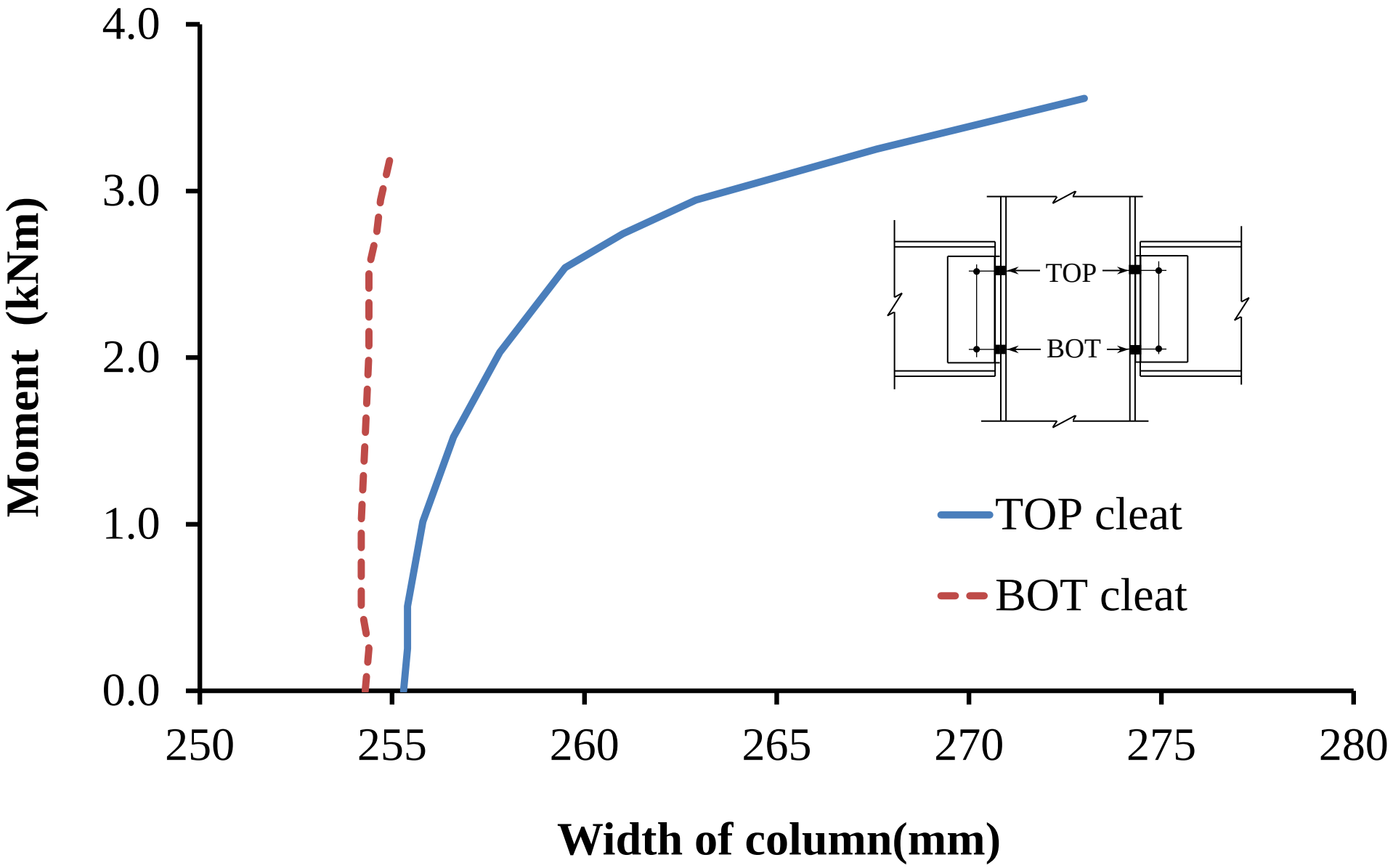

Wmj254_2M16_ST1.3 (Slip Compensated)
Moment (kNm)
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
Left Joint Rotation (mrad)
Mi =0.86 kNm and
ϕi =1.33 mrad


Wmj254_2M16_ST1.3 (Slip Compensated)
Moment (kNm)
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
Right Joint Rotation (mrad)
Mi =0.87 kNm and
ϕi =2.22 mrad

Moment = Applied Load × Moment Arm
Moment Arm = 1.016 m

Width of the column at TOP web cleat = TOP
Width of the column at BOTTOM web cleat = BOT

| | Load (kN) | Moment (kNm) | TOP (mm) | BOT (mm) | | % increase TOP | % increase BOT | |
|---|---|---|---|---|---|---|---|---|
| Before start of test | 0.00 | 0.00 | 255.3 | 254.3 | | | | |
| | 0.25 | 0.25 | 255.4 | 254.4 | | 0.0% | 0.0% | |
| | 0.50 | 0.51 | 255.4 | 254.2 | | 0.0% | 0.0% | |
| | 1.00 | 1.02 | 255.8 | 254.2 | | 0.2% | 0.0% | |
| | 1.50 | 1.52 | 256.6 | 254.3 | low acoustic emission | 0.5% | 0.0% | |
| | **2.00** | **2.03** | **257.8** | **254.4** | **loud cracking noise** | **1.0%** | **0.0%** | **damage onset** |
| | 2.50 | 2.54 | 259.5 | 254.4 | | 1.6% | 0.0% | |
| | 2.70 | 2.74 | 261.0 | 254.6 | | 2.2% | 0.1% | |
| | 2.90 | 2.95 | 262.9 | 254.7 | | 3.0% | 0.2% | |
| | 3.20 | 3.25 | 267.6 | 255.0 | loud continous cracking noise | 4.8% | 0.3% | |
| | 3.50 | 3.56 | 273.0 | 255.0 | | 6.9% | 0.3% | |
| After unloading | | | | | | | | |


4.0
3.0
2.0
1.0
0.0
Moment (kNm)
250
255
260
265
270
275
280
Width of column(mm)
TOP
BOT
TOP cleat
BOT cleat