The prevention of disproportionate collapse using catenary action

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1983 US Marine Corps HQ, Lebanon - 241 dead + 60 wounded
Catenary Action

Steel columns

Damage

Catenary Action

Redistribution of perimeter column loads through hat truss in WTC1
Tying Force Method

Accidental limit state load = 1.05 g_k + 0.33 q_k

UK approach
DAF = 1
Pinned joints
Full reliance on catenary action
Notes:
All columns – 356 x 406 x 235 UC
All main beams – 533 x 210 x 82 UB
All secondary beam – 457 x 191 x 67 UB
Steel grade – S355
Concrete grade – C35
Imposed load – 5 kN/m²
Partition load – 1 kN/m²
Design rotation capacity = 4°
The Best Guess Scenario, FoS = 0.12

- Full tensile strength of the slab included
- DAF = 1.5

Accidental limit state load = 1.05 \( g_k \) + 0.33 \( q_k \)

\[ \frac{528}{4569} = 0.12 \]
The Best Case Scenario, FoS = 0.19
   – Full tensile strength of the slab included
   – DAF = 1.0

The Worst Case Scenario, FoS = 0.08
   – Tensile strength of the slab ignored
   – DAF = 2.0 in accordance with US practice
What if we have unlimited ductility in the connections?

\[ DLF=1.5 \]

Slab strength included
Joint 'A' Joint 'C'

A

C

24°
3.84 m

DLF=1.5

Slab strength included

Joint ‘A’

Joint ‘C’
(b) Joint ‘A’

c) Joint ‘C’
Unsupported columns
1995 Federal Murrah Building
Typical Canary Wharf Tower –

- Flexible cladding
- No stiff internal partitions
- No columns between service cores and perimeter
- Number of columns minimised by use of transfer beams
- Low stiffness slab
- Low ductility “Pinned connections”
Rupture
**Figure 8a**

**Connection – Type 4**

**VBH Patent**

**Extreme Event Beam Link Connection**

- **Completed**
  - Retracted link bars (33) fitted in shop and lifted with previous beam
- **During Erection**
  - Slots through flanges (12), No stiffeners
  - Shop welded fin plate (11)
  - Shop welded fin plates (34)

**ERECPTION**

- **Stage 1** Fix beam to fin plate only
- **Stage 2** Link bars later and off critical path of construction programme
Available rotation capacity for industry standard semi-rigid composite connections limited to:

- $1.80^\circ$ for S355 beams
- $1.43^\circ$ for S275 beams
End plate (Detail 2)

533 x 210 x 82 UB

20mm stiffener

4T16 rebars

203 x 86 UC

6 No. holes 22φ for M20 bolts

Detail 2
Conclusions

• Tying capacity of “industry standard” connections is generally determined in the absence of beam rotations.

• Connections can develop a prying action that leads to rapid failure.

• Tying method will not prevent progressive collapse when used with low ductility connections.

• Semi-rigid (partial strength) connections have insufficient ductility to survive the demands of catenary action.