Introduction

- The Steel Construction Institute (SCI)
  - Dissemination of design guidance

Disproportionate Collapse

- Why bother?
  - Legal requirement
  - Regulation A3 of Building Regulations (E&W)
    “The building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause.”
  - Similar in Scotland, N. Ireland and Ireland
Disproportionate Collapse

- Why bother?
  - Legal requirements
    - Not just Building Regulations!
  - Construction (Design & Management) Regulations
  - Workplace (Health, Safety and Welfare) Regulations
  - Health and Safety at Work Act

Disproportionate Collapse

- Why bother?
  - BS 5950 Part 1 and Part 5
    - Structural Integrity
  - EN 1990, EN 1991 and EN 1993
    - Robustness
  - Reasonable level of safety in accidental loading situations

(c) The Steel Construction Institute
Robustness

- EN 1991-1-7: General Actions – Accidental Actions
  - Definition:
    “Robustness is the ability of a structure to withstand events like fire, explosions, impact or the consequences of human error, without being damaged to an extent disproportionate to the original cause.”

Ronan Point

- 23 storey precast panel construction
- Newham, London
- 1968
- Gas explosion on 18th floor
- Disproportionate collapse
Ronan Point

- Poor construction details
- Quick and easy to build
- Minimal tying
- Minimal robustness
Ronan Point

- Poor construction details
- Quick and easy to build
- Minimal tying
- Minimal robustness

Disproportionate Collapse

- What is it?
  - Collapse >> Cause
  - How much is too much?
    - Quantity of collapse
    - Magnitude of original event
  - Spread of damage – progressive collapse – disproportionate collapse
  - In some cases total collapse may be acceptable

(c) The Steel Construction Institute
After the event …

- Accidental event (unknown)
- Some collapse
- Limited spread of collapse
- Large distortion of structure
- Stability not serviceability
- Survival condition, evacuate people
- Demolition may well be required

After the event …

- Structural requirement, frame and floors
- Not façade, finishes etc

- Simple Aim:
  - Not required to resist all actions
  - Just avoid a disproportionate amount of collapse
Avoidance of Disproportionate Collapse

- **How?**
  - Generically:
    - Tying
    - Redundancy
    - Alternative load paths
    - Reserves of strength
  - Specifically:
    - Since 2004 depends on Building Classification
    - Previously only applied to 5 or more storeys

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Eurocode Strategy

- Accidental Design Situations
  - Strategies based on identified accidental actions
    - Design for sufficient minimum robustness
    - Prevent or reduce action
    - Design to sustain action
  - Strategies based on limiting extent of localised failure
    - Enhanced redundancy
    - Design to resist notional accidental action
    - Prescriptive rules e.g. tying
Avoidance of Disproportionate Collapse

- How?
  - Building Classification (size and use)
  - Same for Approved Document A, BS 5950 and EN 1991 (Eurocode 1)
    - Class 1
    - Class 2A (Lower risk group)
    - Class 2B (Upper risk group)
    - Class 3

Class 1

Houses ≤ 4 storeys
Agricultural buildings
Class 1

- Houses ≤ 4 storeys
- Agricultural buildings
- Buildings which people rarely enter
  - If not too close to other buildings

Class 2A

- Hotels ≤ 4 storeys
- Offices ≤ 4 storeys
Class 2A

- Single occupancy houses = 5 storeys
- Hotels, residential, offices ≤ 4 storeys
- Retail ≤ 2000m² & ≤ 3 storeys
- Industrial ≤ 3 storeys
- Open to public ≤ 2 storeys and ≤ 2000m²
- Educational = 1 storey
Class 2B

Hotels ≤ 15 storeys
Office ≤ 15 storeys

Class 2B

Car park ≤ 6 storeys
Hospital ≤ 3 storeys
Class 2B

- Hotels, residential $\leq$ 15 storeys
- Educational, retail, offices $\leq$ 15 storeys
- Car parks $\leq$ 6 storeys
- Hospitals $\leq$ 3 storeys
- Open to public, 2000m$^2$ < area $\leq$ 5000m$^2$

Class 3

- Offices > 15 storeys
- Public > 5000 m$^2$
Class 3

- Grandstands > 5,000
- Hazardous process / substance

Class 3

- Buildings exceeding limits of Class 2A and 2B
- Grandstands with > 5000 spectators
- Buildings containing hazardous substance/process
Classification

- Not so simple in practice
- Some common issues:
  - Mezzanine floors
  - Habitable roof spaces
  - Mixed use
  - Basements
  - Conversions and extensions
  - Mixture of structural materials

Design Strategies

- BS – Material Specific
  - BS 5950-1 etc
- Eurocode – Non Material Specific
  - EN 1990 – “damage not disproportionate to cause” and accidental load cases
  - EN 1991-1-7 – Design strategies for classes
  - EN 1993 (Steel design) – No guidance on achieving robustness
### How? Class 1

- **BS 5950-1**
  - Horizontal tying, 75 kN

- **Eurocode**
  - No specific consideration

- **SCI Recommendation**
  - Horizontal tying, 75 kN

| 2 x M16 tension = 90.4 kN | 1 x M20 shear = 94.1 kN |

### How? Class 2A

- **BS 5950-1**
  - Horizontal tying, 75 kN

- **Eurocode**
  - Horizontal tying, 75 kN
  - But could be more
  - Use formula

\[
T_i = 0.8(g_k + q_k) s L \quad \text{or 75 kN, whichever is the greater}
\]
\[
T_p = 0.4(g_k + q_k) s L \quad \text{or 75 kN, whichever is the greater}
\]
How? Class 2B

- **BS 5950 Options:**
  - Tying
  - Notional Removal
  - Key Element

- **Eurocode Options:**
  - Tying
  - Notional Removal
  - Key Element

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How? Class 2B

- **BS 5950:** Tying
  - Horizontal ties
  - Vertical ties
  - Bracing systems
  - Heavy floor units

- **Eurocode:** Tying
  - Horizontal ties
  - Vertical ties

- **SCI Recommendation to also include:**
  - Bracing systems
  - Heavy floor units
### How? Class 2B

<table>
<thead>
<tr>
<th>BS 5950: Notional Removal</th>
<th>Eurocode: Notional Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited collapse area</td>
<td>Limited collapse area</td>
</tr>
<tr>
<td>15% or 70 m²</td>
<td>15% or 100 m²</td>
</tr>
</tbody>
</table>

- Not commonly used for hot-rolled steel frame
- Recommended to always provide horizontal tying

### How? Class 2B

- **Key Element**
- Same for BS 5950 and Eurocode
  - 34 kN/m²
  - All directions but one at a time
  - Regard for strength of connected components

- Recommended to always provide horizontal tying
How? Class 2B

- Tying route
  - Most common and simplest to apply
    - Horizontal ties
    - Vertical ties
    - Bracing systems
    - Heavy floor units

Horizontal Tying

- Generally ~ end shear
- Nominally pinned connections
- Capacities SCI-P212
- Eurocode version soon
Horizontal Tying (BS 5950)

- **Fin Plate**
  - Tying: Shear = 0.7 – 1.7

- **Double Angle Cleat**
  - Tying: Shear = 1.1 – 1.8

- **Flexible End Plate**
  - Tying: Shear = 0.3 – 0.9

Enhanced Tying Capacities (Euro)

- **Flexible End Plate**
  - Partial depth
  - Tying: Shear = 0.3 – 0.9

- **Flexible End Plate**
  - Full depth
  - Tying: Shear = 0.7 – 1.4
Horizontal ties

- Hold columns in place

Ties & Bracing

- Catenary action, redistribution of loads
Guidance vs Reality

- Questionable theory
- Tie forces for catenary action
  - No connection rotation capacity
  - No connection ductility
  - Magnitude of tie forces

Application in Practice

- Tie force
  - Don’t chase loads
Application in Practice

- Unequal spans
  - Theoretical inconsistency

Application in Practice

- Continuous lines
  - Transfer the force
Application in Practice

- Connection design
  - Not considered simultaneously

Application in Practice

- For most cases
- Apply tying route
  - Follow code rules
  - Don’t consider “what if ?”
  - Forget theory
    - e.g. Don’t chase loads
Does it work?

- Apply rules to get good levels of robustness
- Balance of accuracy and efficiency
  - Semi-empirical rules
  - Theoretical inconsistencies
- No disproportionate collapse incidents
- Regulators are satisfied

Real events

- Exchequer Court, 1992
- Docklands, 1996
Exchequer Court

- St. Mary’s Axe, London, 1992
- Steel frame with composite floors
- Semtex explosion 6m from front
- Significant damage to 2 columns, beams deformed, bolts sheared, slab separated from beams
- **But no structural collapse**
Docklands

- London, 1996
- Lorry bomb under DLR bridge
- Two buildings required complete refurbishment
- One building beyond economic repair was demolished
- DLR station and the bridge only required cosmetic repairs despite proximity
- Minor structural collapse
Transfer beams

- Tying method, or
- Key Element method

\[ T_i = 0.8 (g_k + \psi q_k) sL + 0.5V_c \]
Transfer beams

- Key Element method
  - Design beam as key element and
  - Design supporting columns as key elements

How?

- Class 3 buildings
  - Systematic risk assessment
  - First apply rules for Class 2B
  - Consider possible hazards
  - Not resist all actions (hazards)
  - Avoid disproportionate collapse
How?

- **Class 3 buildings**
  - What hazards to include?
  - What is likelihood of hazard occurring?
  - How much risk is acceptable?

- Wide scope of Class 3
- Each case is different
- Limited guidance available

**Risk Assessment**
Simplified Risk Matrix

Likelihood

- Likely within design life of building
- Not likely within design life of building

Severity

- Engineering judgement
- Unacceptable
- Acceptable
- Engineering judgement

Less than 15% of floor area

More than 15% of floor area

Class 3 Guidance

- Paper by G.Harding & J.Carpenter
- Structural Engineer, August 2009
Class 3 Guidance

- New Steel Construction (NSC)
- March 2007

Class 3 Guidance

- Viewpoint by S. Alexander
- Structural Engineer, December 2004
General Guidance

- On [www.steelbiz.org](http://www.steelbiz.org)
  - SCI-P341: Guidance on Robustness requirements in Approved Doc A
  - SCI-RT1215: Robustness rules for Slimdek
  - SCI-P391: Structural Robustness of Steel Framed Buildings

Thank you for listening
SCI is the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector. We work in partnership with clients, members and industry peers to help build businesses and provide competitive advantage through the commercial application of our knowledge. We are committed to offering and promoting sustainable and environmentally responsible solutions.