Disproportionate Collapse of Steel Frame Buildings

Andrew Way

Steel Knowledge

Design for Avoidance of

Disproportionate Collapse ~~of Steel Frame Buildings~~

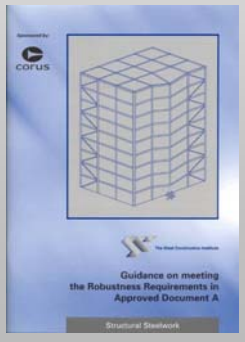
for all buildings

Andrew Way

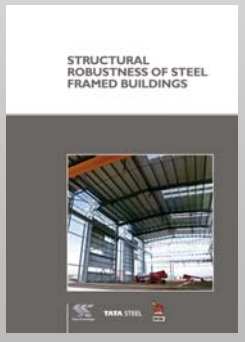
Steel Knowledge

Introduction

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



P341, 2004



P391, 2011

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

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

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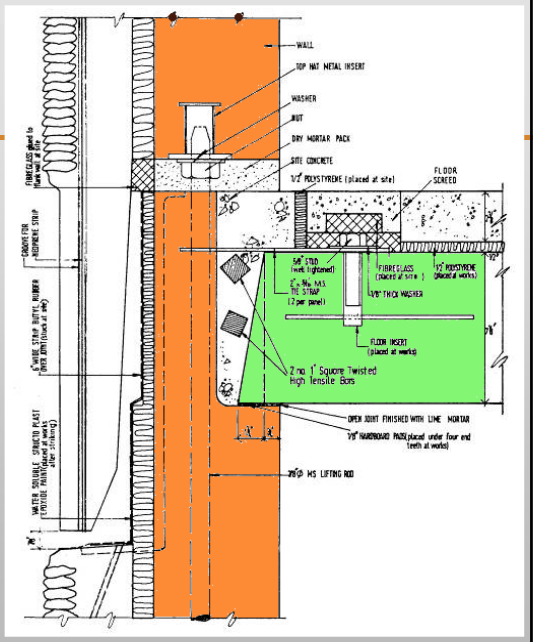

Ronan Point

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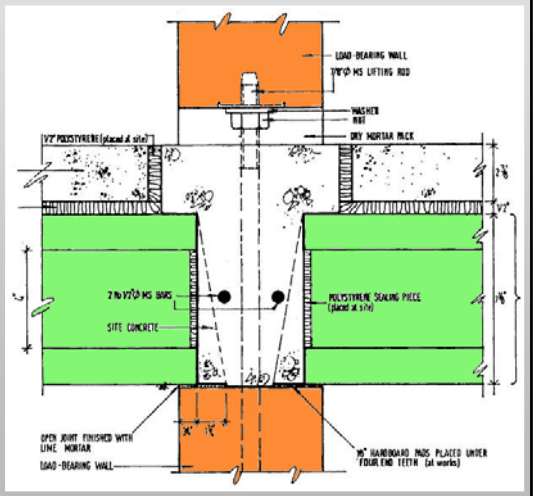


Disproportionate Collapse

- 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

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 …

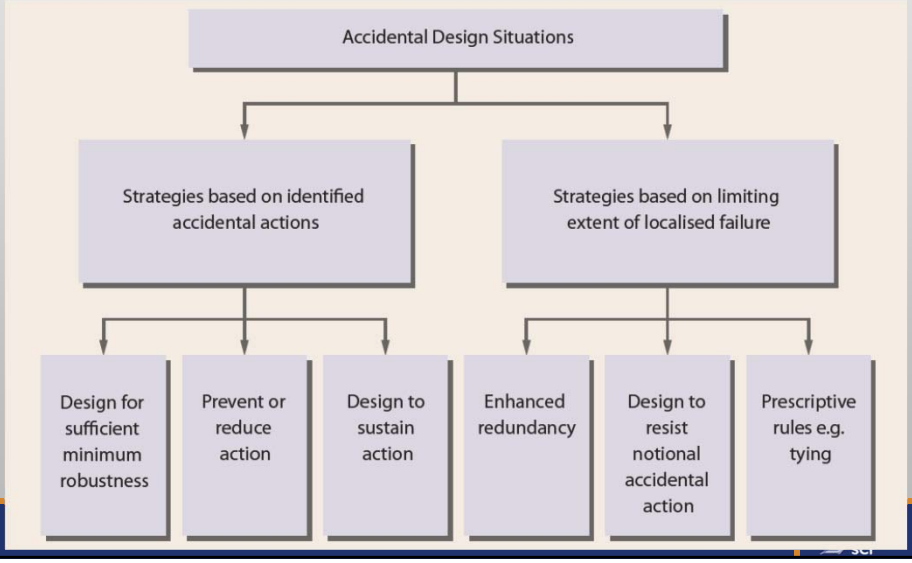
- Structural requirement, frame and floors
- Not façade, finishes etc

- 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

Eurocode Strategy



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

Industrial ≤ 3 storeys

Public ≤ 2 storeys & ≤ 2000m^2

Class 2A

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

Class 2B

Hotels ≤ 15 storeys

Office ≤ 15 storeys

Class 2B

Car park ≤ 6 storeys

Hospital ≤ 3 storeys

Class 2B

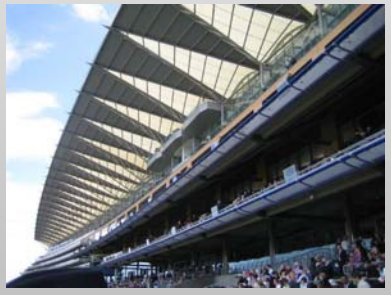
- Hotels, residential ≤ 15 storeys
- Educational, retail, offices ≤ 15 storeys
- Car parks ≤ 6 storeys
- Hospitals ≤ 3 storeys
- Open to public, 2000m^2 < area ≤ 5000m^2

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

$T_i = 0.8(g_k + \psi q_k) sL$ or 75 kN, whichever is the greater

$T_p = 0.4(g_k + \psi q_k) sL$ 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

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

- BS 5950: Notional Removal
  - Limited collapse area
  - 15% or 70 m^2
- Eurocode: Notional Removal
  - Limited collapse area
  - 15% or 100 m^2
- 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/m^2
  - 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

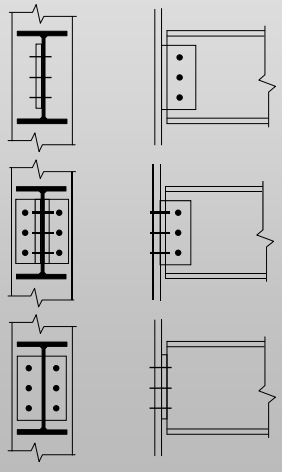
Horizontal Tying

- Generally ~ end shear
- Nominally pinned connections

- Capacities SCI-P212
- Eurocode version soon

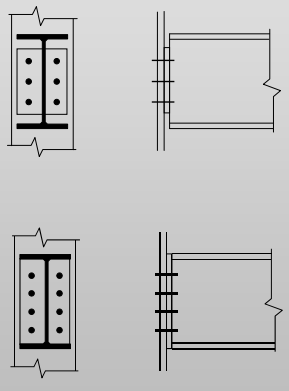
Horizontal Tying (BS 5950)

- 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



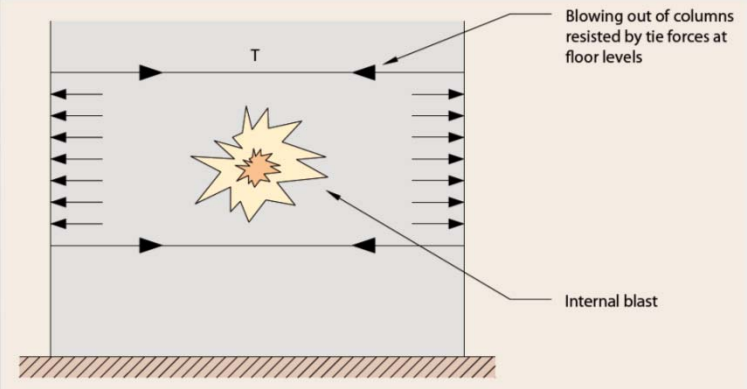
Enhanced Tying Capacities (Euro)

- Flexible End Plate
  - Partial depth
  - Tying : Shear = 0.3 – 0.9
- Flexible End Plate
  - Full depth
  - Tying : Shear = 0.7 – 1.4



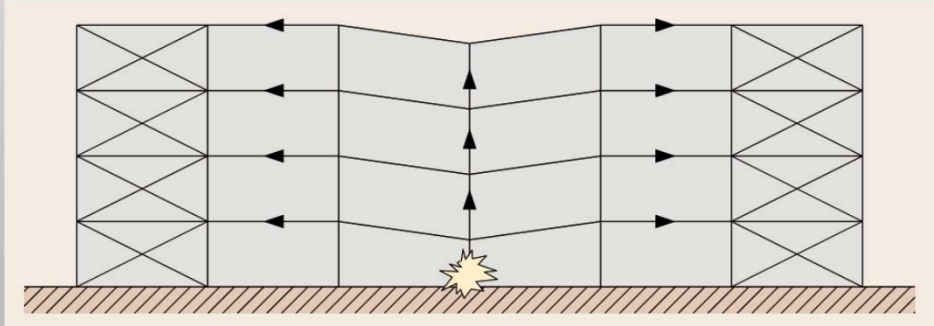
Horizontal ties

- Hold columns in place



Ties & Bracing

- Catenary action, redistribution of loads

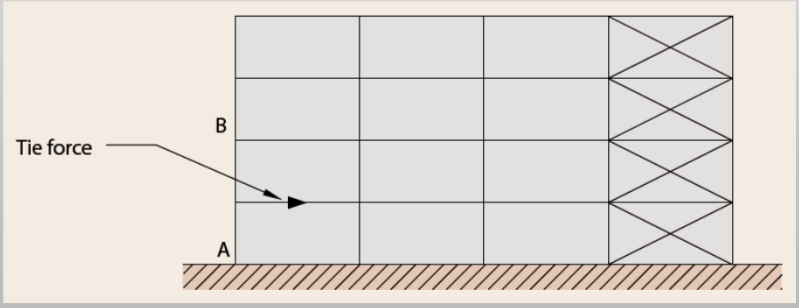


Guidance vs Reality

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

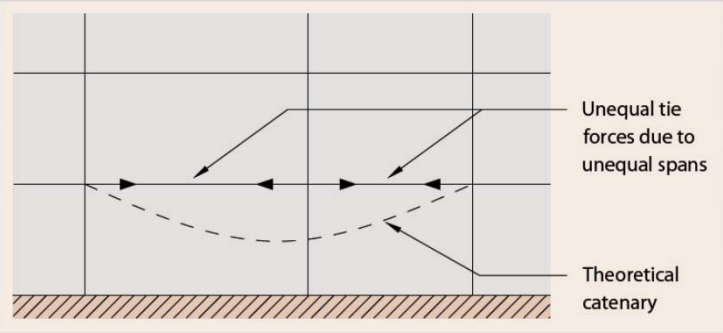
Application in Practice

- Tie force
  - Don't chase loads



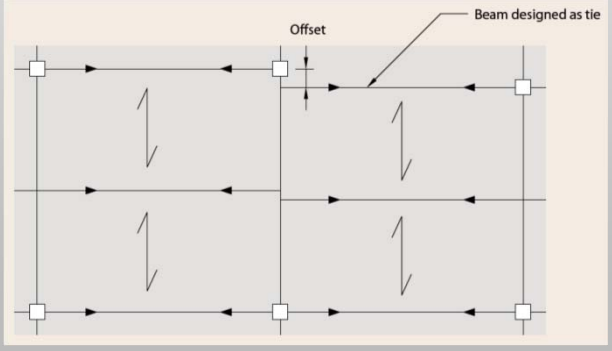
Application in Practice

- Unequal spans
  - Theoretical inconsistency



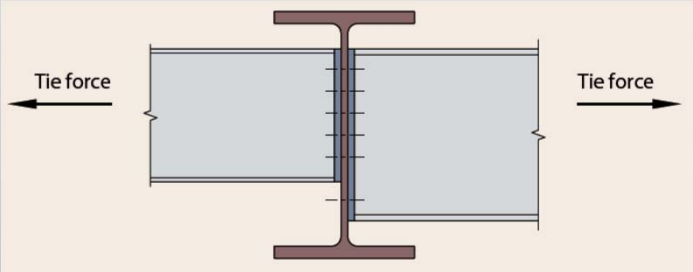
Application in Practice

- 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

Exchequer Court

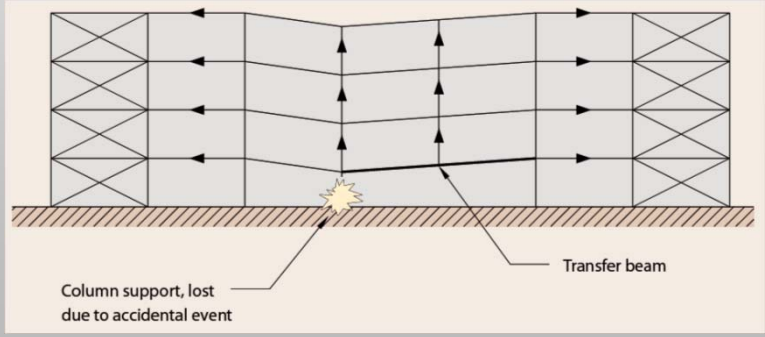
Docklands

- 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

Docklands

Transfer beams

- Tying method, or
- Key Element method



Transfer beams

- Tying method
  - Modified tie force expressions in SCI-P391
  - Include column loads
  - Column bases fixed to transfer beam

$$T_i = 0.8(g_k + \psi q_k)sL + 0.5V_c$$

Transfer beams

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

How?

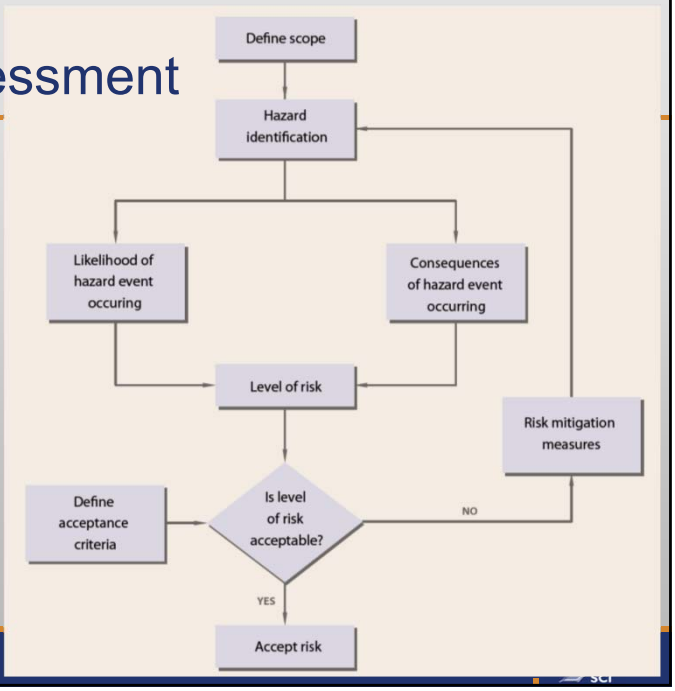
- Class 3 buildings
  - Systematic risk assessment
  - First apply rules for Class 2B
  - Consider possible hazards
  - Not resist all actions (hazards)
  - Avoid disproportionate collapse

How?

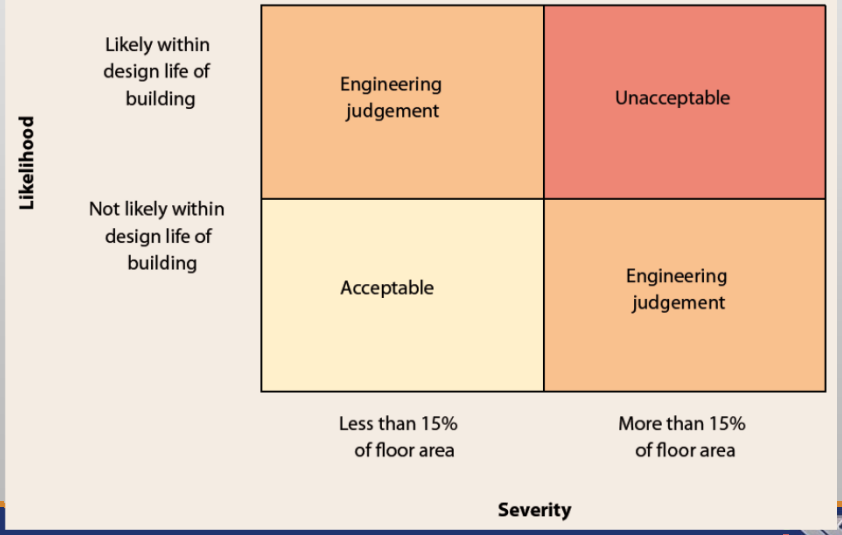
- Class 3 buildings
  - What hazards to include?
  - What is likelihood of hazard occurring?
  - How much risk is acceptable?

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

Risk Assessment



Simplified Risk Matrix



Class 3 Guidance

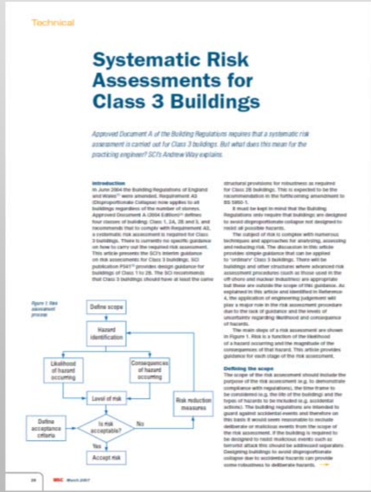
- Paper by G.Harding & J.Carpenter
- Structural Engineer, August 2009


Paper

Disproportionate collapse of 'Class 3' buildings: the use of risk assessment

Class 3 Guidance

- New Steel Construction (NSC)
- March 2007



Technical

Systematic Risk Assessments for Class 3 Buildings

Class 3 Guidance

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

viewpoint building regulations

New approach to disproportionate collapse

Stuart Alexander (F), Group Technical Co-ordinator WSP Group, explains the new Building Regs regime and proposes a way of responding to it which is appropriate without being too complex or difficult

General Guidance

- On 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