Henderson Colloquium 2004

Designing for the consequences of hazards

Is risk assessment the right answer?

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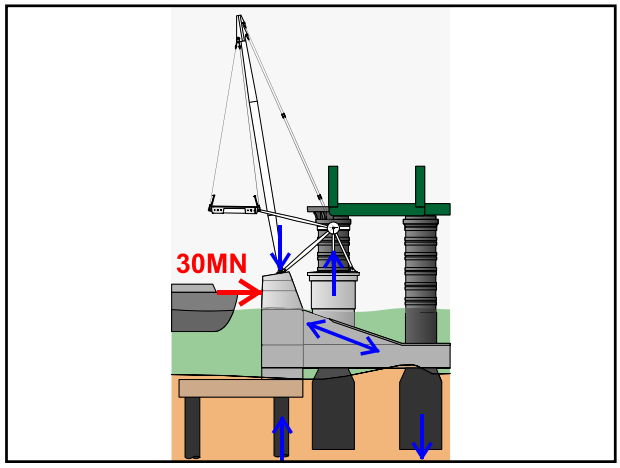
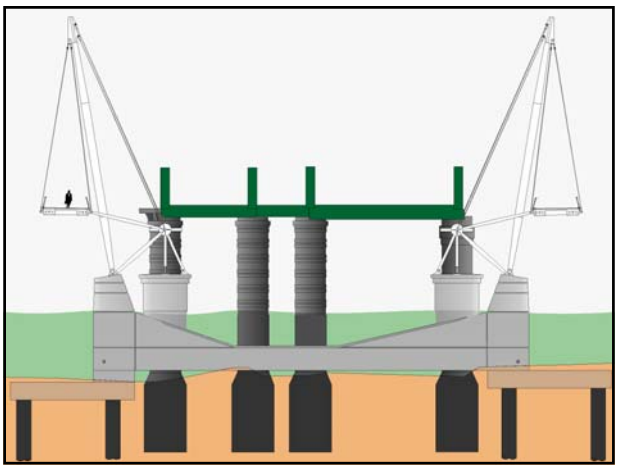




Risk assessment

- Aircraft impact
- Avalanche
- Cladding failure
- Construction error
- Crane load swinging or dropped
- Deflagration (gas explosion)
- Demolition error (eg adjacent site)
- Design error
- Detonation ('blast' from high explosive)
- Fire (cellulosic/hydrocarbon)
- Flood debris
- Floor load (excessive)
- Gale, hurricane or tornado
- Hailstones
- H-bomb, N-bomb
- Helicopter heavy landing
- Icebergs or ice floes
- Icicle fall
- Material faulty
- Meteorite
- Mud slide
- Ponding
- Rock fall
- Scour
- Ship impact
- Snow fall (eg from roof onto lower roof)
- Suicide jump
- Train impact
- Vehicle impact
- Wave, tsunami

\+ *combinations of the above*

Targets for hazard protection

- Avoid progressive collapse?
- Avoid disproportionate collapse?
- Define disproportionate?
- Define collapse?

Alternative approaches

- Good practice
- Prescriptive rules
- Standard events
- Performance design
- Risk assessment

EN 1991-1-7

Consequences classification:

CC 1 Single family to max 4 storeys

CC 2L Most to max 4 storeys, industrial and retail to max 3 and 1000 m^2, education 1 (UK: + others up to 2 storeys, 2000 m^2)

CC 2U Most to 15 storeys (*c 50 m*), parking to 6, hospitals to 3, public admission to 1000 m^2 per storey, leisure centres to 2000 m^2 (UK: 5000 m^2)

CC 3 All >2L & 2U, stadia >5000 people

Judgment: acceptable

Good practice

- Relies on judgment by each engineer
- Will vary by building or structure type and use
- Impossible to validate (eg by control body)
- Will lead to codification!

Performance design

- Means design for actual risk, eg Hungerford bridge
- Will be needed for some buildings, eg obvious terrorist targets and vulnerable contents, but additional to other criteria
- Probable specification will be largest credible detonation at closest credible location
- Feasible
- Meaningful? Overdesign likely, ie excessive cost v real risk

Prescriptive rules – EN 1991-1-7

- Redundancy or alternative load paths – defined by eg removal of one column
- Local resistance ('key element') – defined by eg 34 kN/m^2
- Interconnection or continuity – defined by specified tie force

Other prescriptive rules – not in EN 1991-1-7

- Strong storeys (probably storey height structure) to catch say 10 above
- Each floor to catch the one above
- Moment frames on perimeters (not necessarily at each level)

Redundancy

- How is column removed? Reasonable to assume no adverse effect of removal
- What about many closely-spaced columns? Could include all columns within a zone eg 6m diameter on plan
- Static or dynamic analysis? Static OK for small-medium deflections
- Methods with non-linear geometry and non-linear materials available (and calibrated?)
- Continuous moment-resisting frames preferred, especially on perimeter (helps to limit deflections for cladding)

Barclays Bank HQ, Canary Wharf

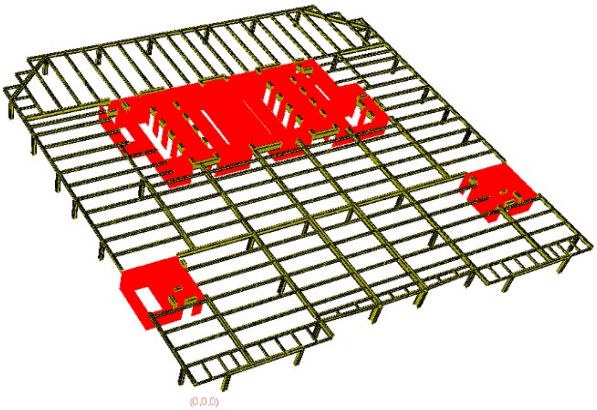
36 storeys

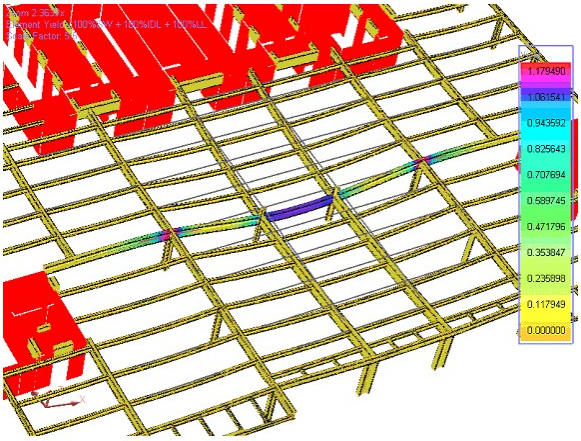
Six-storey atria

Concrete core

Composite steel frame

Three concrete cores





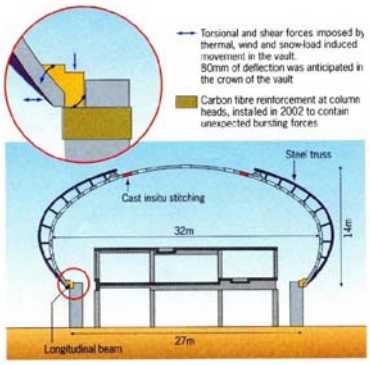
Key elements

- Includes columns, hangers, transfer beams
- Difficult to define suitable force or resistance – force preferred to pressure for narrow elements
- Static or dynamic?
- Different at (say) ground level?

Tying

- Rules have dubious origin
- No requirement for ductility
- Not needed if redundancy or key element satisfied?
- Can drag down extra extent – cf Paris (which didn't)

Paris CDG airport collapse



Public admitted, area 15,000 m² per storey *= class CC 3*

Appropriate tests?
- Tying: not meaningful
- Column removal: easy!
- Standard gas explosion: would not cope?
-Blast: probably could cope
- Impact: could cope (hopefully already)

Conclusion: gas explosion would give robustness

Standard events

Possible events:
- Gas explosion
- Detonation (blast)
- Impact

Standard gas explosion

- Good model: simultaneous upward, downward and outward pressures
- Could be calculated in domestic buildings from volume, venting etc
- Better to agree standard equivalent static pressure – how much? 15-20 kN/m²?
- Good for walls and slabs, not for narrow elements

Standard blast

- Define as equivalent mass of TNT at a specified distance from the structure at ground level
- Emphasises need for greater protection at ground level
- Significant uplift on first floor slab
- Probably shows how many columns to be removed, so correlates with other approaches

Standard impact

- Used in design of bridges and structures adjacent to roads and railways
- Equivalent static force used
  (34 x 2.25 x $2.6^2/2$ = 250 kN)
- Easy to apply
- Definition of ‘adjacent’ can be arbitrary (4.5 m on railway)

EN 1991-1-7 strategy

- CC 1: good practice
- CC 2L: horizontal ties
- CC 2U: horizontal and vertical ties, or column removal/key element
- CC 3: ‘systematic risk assessment’, taking into account ‘all the normal hazards that may reasonably be foreseen, together with any abnormal hazards’

Judgment: CC 3 meaningless

Summary

- CC 2: Reservations over emphasis on tying
- CC 3: Test vulnerability by standard gas explosion, blast and impact
- Paris structure vulnerable to gas explosion?
- ‘Vulnerability assessment’ preferred to risk assessment