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Failures from Hazards, a Short Review

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Hazards

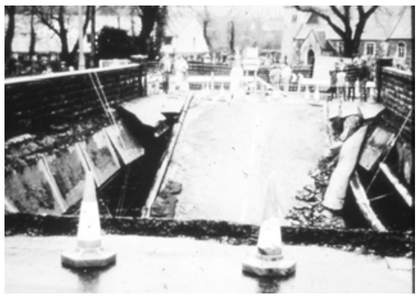
*"**hazard:** for the purpose of EN 1990 to EN 1999, an unusual and severe event, e.g. an abnormal action or environmental influence, insufficient strength or resistance, or excessive deviation from intended dimensions*"

Where are hazards coming from:

1. **BS8110 and EN 1900** do not have properly calibrated partial factors [1, 2, 3] and have simplifications which leave structures with widely varying reserves of strength, ductility and robustness.

2. **Risks** are progressively increasing because of "Progress" e.g.:
Refined analysis,
Innovative, economical, short life design,
Fast-build with simple non-robust connections,
Lowest tender contracts,
Fragmented supply chain.

3. **Robustness** of structures to resist hazards needs to be quantified.



4. **Deterioration,** which can destroy ductility or attack a weak link in a structure, is the most widespread hazard, so quantitative durability evaluation is an essential element in evaluating robustness.

Construction Industries Historic Response to Failures.

We need to broaden the view from the Twin Towers and terrorism to a wider range of hazard damaged and hazard resistant structures over the years.

Improving the resistance of structures to hazards following major catastrophes has been an intermittent process over hundreds of years. We should consider our debates as a small step in the long road of the evolution of structures and look back at old investigation reports and the responses as well as considering this decade's fashionable disasters.

In this short presentation one cannot do more than remind you of a few failures, which will be dealt with more fully elsewhere [4].

Traditionally dead bodies and/or massive economic consequences are required to trigger funding for research and developing improved design standards and construction practice (e.g. Dee Rail Bridge, Tay Rail Bridge, Ronan Point, Milford Haven Box Girder, Ramsgate, Heathrow NATM, Rail crashes).

Often overreaction to one type of failure has led to design going to the other extreme introducing the next hazard. For example:

- King St Bridge weld brittle failure of 1962 led to the use of site bolted connections, the eccentricities of which triggered buckling collapse of the fragile West Gate Yarra Bridge in 1970.

- Tacoma Bridge collapse led to Severn Bridge aerodynamic section, which crashes vehicles in high winds. Current preoccupation with behaviour of other bridges with low stiffness and damping is distracting design and research focus.

- Steel Box Girder failures in c1970 led to a preference for 'maintenance free' concrete construction, with associated durability problems.

Hazards are inherently unexpected and while we prepare for the previous one something entirely different occurs. To avoid this we need a longer term balanced historical perspective.

The enquiry into Ronan Point [5] looked in detail at the risks of gas explosions and their consequences and suggested the use of ties as a means of providing sufficient robustness to resist it in large panel construction. BS8110 has treated ties as 'generally sufficient' to prevent progressive collapse. While ties, with connections sufficiently strong for the whole to be ductile, do enhance robustness, lessons from the Oklahoma bomb [6] show that weak lapped connections are ineffective in extreme conditions. Rebar connectors, not laps, are necessary for the main reinforcement. Framed structures can easily form mechanisms despite ties.

It is interesting that The Times 2nd June 2004 reports on an al-Qaeda suspect in America who had planned to rent pairs of adjacent flats in high rise apartments to be carefully sealed, then filled with gas and then all simultaneously ignited to produce widespread catastrophe. Perhaps someone has been reading up on robustness. He abandoned this plot due to the difficulty in renting apartments, in favour of a radiological dirty bomb plot.

Earthquakes are beautifully efficient experiments in structural robustness. In Kobe after the earthquake, many old buildings stood with minor cracks, but the Hanshin Expressway sections collapsed over a long length from shear failures of columns subject to vertical accelerations with horizontal forces. The adoption of earthquake type connection requirements would be the simplest route to robust structures.

It does not take earthquakes or explosions or impacts to cause buildings to suddenly collapse. Ynys-y-gwas and Mandovi bridges both collapsed suddenly due to slow corrosion of key elements which weakened and embrittled them.

Piper's Row Car Park [7, 8] and Sampoong Superstore [9] both collapsed due to brittle punching shear failure. At Pipers Row, design and construction defects led to a weak structure which then lost strength from deterioration until it collapsed with no live load and just a tweak of temperature effects.

Structures which have **not** collapsed in extreme circumstances are of similar importance. Eg Twin Towers explosion in 1993 [10] , Pentagon on 9/11, Empire State Building aircraft crash c1946, gas explosions reviewed at the time of Ronan Point [11], IRA bombs including flyover at Staples Cross.

We need to identify lack of structural robustness as a hazard in itself. Structural weakness contributed more to the death toll at Oklahoma and the Twin Towers than the bomb or the aircraft impacts.

Deterioration needs to be considered a hazard as seriousness as bombs.

Robustness in other structures

Designers of a wide range of structures are looking for robustness. In the construction industry we tend to lag behind. Examining how aviation, automotive and train design is seeking to achieve robustness needs to be part of our approach.

Aircraft: Wellington Bomber

Train Crash Survival: "Undermatching of welds resulted in body shell fragmentation" [12].

Cars, crash testing and barrier design.

The common approaches in resisting hazards adopted in these industries, which we need to emulate in the construction industry, are:

- Integrated total structure design and analysis, as distinct from element by element design.
- Multiple load paths,
- Energy absorption, rather than strength, as the design criteria,
- Connections no weaker than connected parts.

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