3.3 Common philosophy for design under extreme loadings

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Common philosophy for design under extreme loadings

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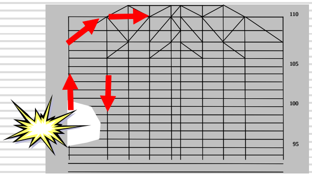
- Buildings should poses sufficient robustness to avoid progressive collapse Robust based design methodology may be generalised considering localised failures in models (e.g. scenarios) for specific of extreme events, like:
  - Fire
  - Earthquake
  - Blast, impacts
  - Fire after blast
  - Fire after earthquakes



Fire after blast, WTC structure

Fire after earthquake, Kobe 1995

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- Robustness can be defined as ability of structure to absorb local failure without widespread collapse.
- Robust structures may be achieved by providing, from the design phase, multiple routes for force transfer, secure plastic capacity in structural members and sufficient strength to structural members that cannot be allowed to collapse.
- Increasing cross-section of structural members (members' overstrength) is not always leading to an increased robustness. Instead of increasing the overall strength, the robustness may be enhanced through redundancy.
- Redundancy may be defined as the incorporation of redundant load paths in the vertical load carrying system to ensure that alternate load paths are available in the event of local failure of structural elements.
- Structures subjected to localised failure by extreme action effects may benefit of some aspects of seismic design, considering also that the actual seismic design practice is more advanced than blast design.

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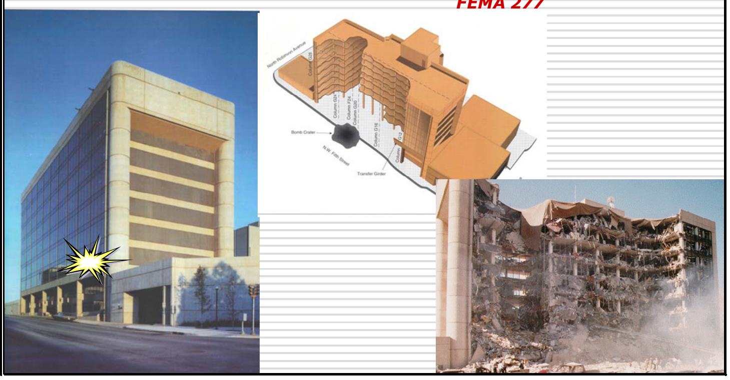
Alfred P. Murrah Building, Oklahoma City

The report suggested that if more recently developed conception and detailing, such as those present in special moment frames used in seismic regions had been in place, the collapsed area would have been reduced at least by 50 % and at most by 80 %.

FEMA 277



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Design strategies

- providing **specific local resistance** for the extreme load - such an approach provides resistance to only one hazard
- developing **alternate load paths** - focuses the attention of the designer on the global behavior of the structural system
- A two steps analysis approach can be developed combining the two models

The **alternate load path approach** provides structural systems with ductility, stress redistribution capacity and energy absorbing properties that are desirable in preventing progressive collapse.

This approach is consistent with the **seismic design approach:**

- The seismic codes promote regular structures of components well tied together.
- They also require ductile details so that plastic deformations can take place.

In order to develop a multilevel evaluation, different extension of damage (number of critical members that are lost) is considered, in relation with the blast and fire scenarios.

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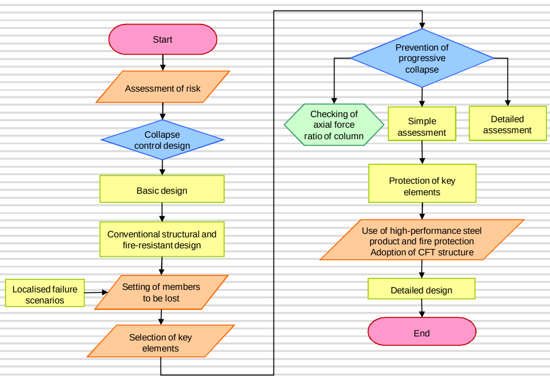
Recommendations for Collapse Control design (seismic, fire, blast) (JSSC & CTBUH, 2005)



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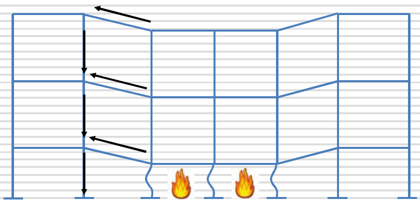
- The fire scenarios should consider the fire compartments in the building and the potential failure of individual members such as columns or beams.
- The fire load density may be calculated on the basis of previous ECSC researches, „Natural Fire Safety Concept" (implemented in EN1991-1-2, Annex E), considering the lack of active fire measures (water supply, automatic extinguishing system, prompt intervention of the fire brigade, access routes, etc.) and the danger of fire activation, which is higher than in a normal situation.
- Nonlinear and/or probability analysis will be used to obtain the localised failure models in fire compartments and further to simulate the global response of the structure.



Fire after earthquake/Fire after blast

- In order to develop a multilevel evaluation, different extension of damage is considered prior to fire analysis:
  - For fire after earthquake, the level of damage to structural elements ranges from minor to extensive (seismic hazard ranges from frequent earthquakes to very rare earthquakes)
  - For fire after blast, number of critical members that are lost is gradually increased, to consider different blast magnitudes
  - The single and coupled events can be characterized in terms of frequency of appearance and probability of occurrence

Overall Performance Criteria

Depending on the selected performance level, earthquake structural and non-structural damage are computed based on the overall performance of a structure *(VISION 2000):*

- Operational- Facilities continue in operation with neglectable damage
- Functional- Facilities continue in operation with minor damage and minor disruption to non essential services
- Life safety- Life safety is substantially protected, damage is moderate to extensive
- Near collapse- Life safety is at risk, damage is severe, structural collapse is prevented

Performance levels of PBSE for Buildings (SEAOL, 1995)

Model can be extended to all other type of hazards : blast, fire, impact

Earthquake design level	Recurrence (years)	Recommended drift (%)	Probability of excedence
Frequent – Operational	43	0.5	50% in 30 years
Occasional – Functional	72	1.5	50% in 50 years
Rare – Life Safety	475	2.5	10% in 50 years
Very rare – Near Collapse	970	3.8	10% in 100 years

Blast load/ explosions – The Risk Matrix

Recommended practice for the design of offshore facilities against fire and blast loading
API RP 2FB First Edition 2006

Probability of Occurrence (depends on facilities, product type, structure type, sources, operation, management)				
	High	MR	HR	HR
	Medium	LR	MR	HR
	Low	LR	LR	MR
		Low	Medium	High
		Consequence of occurrence (subjects to life, environmental, operator and public interest)		

Legends :

HR = High Risk
Consider blast as a load condition i.e. blast overpressure and blast drag loads, implement prevention and mitigation, may require change in layout or structural design.

MR = Medium Risk
Further risk assessment and mitigation measures.

LR = Low Risk
Insignificant risk and need not be considered for structural design purposes.

PERFORMANCE BASED DESIGN OF OFFSHORE STRUCTURES SUBJECTED TO BLAST LOADING
A thesis submitted to Imperial College London for the degree of Doctor of PhilosophybyRafee Makbol Mohamed Ali

The expected structural performance levels against blast load of topside structures

Performance	Primary structural members	Secondary structural members	Remarks
Functional	Neither damage nor deformation is allowed	Insignificant damage	All systems on topside are operable immediately. Repair is not required.
Operational	Insignificant damage (not exceeding yield) for main members and connections	Marginally to reach yield or just surpass yield level	Minor damage, all systems are operable and repair work can be executed at anytime.
Life safety	Deformation is allowed up to 50% loss of carrying capacity	Deformation is allowed up to 75% loss of carrying capacity	Significant damage, not safe, systems' failures and structural entities require major repair.
Failure/ Near Collapse	Deformation is allowed up to 75% loss of carrying capacity.	Deformation can reach 100% loss of carrying capacity	Loss of structural integrity and repair is totally impractical.

Performance levels are defined associated with probability or risk of occurrence of events, related to load intensity or period of occurrence.

Instead of Conclusions

- A performance based philosophy similar with the one applied in seismic engineering can be used for structural evaluation in case of other extreme events, fire included.
- Such an approach may be applied in two steps :
  1st . localised failure models are pre-defined or simulated
  2nd PBE is applied in order to evaluate the global performance of the structure.
- Different fragility scenarios associated with different accidental events, fire for instance, can be defined and investigated in order to evaluate the risk level and decide the performance objective for which a given structure has to be designed