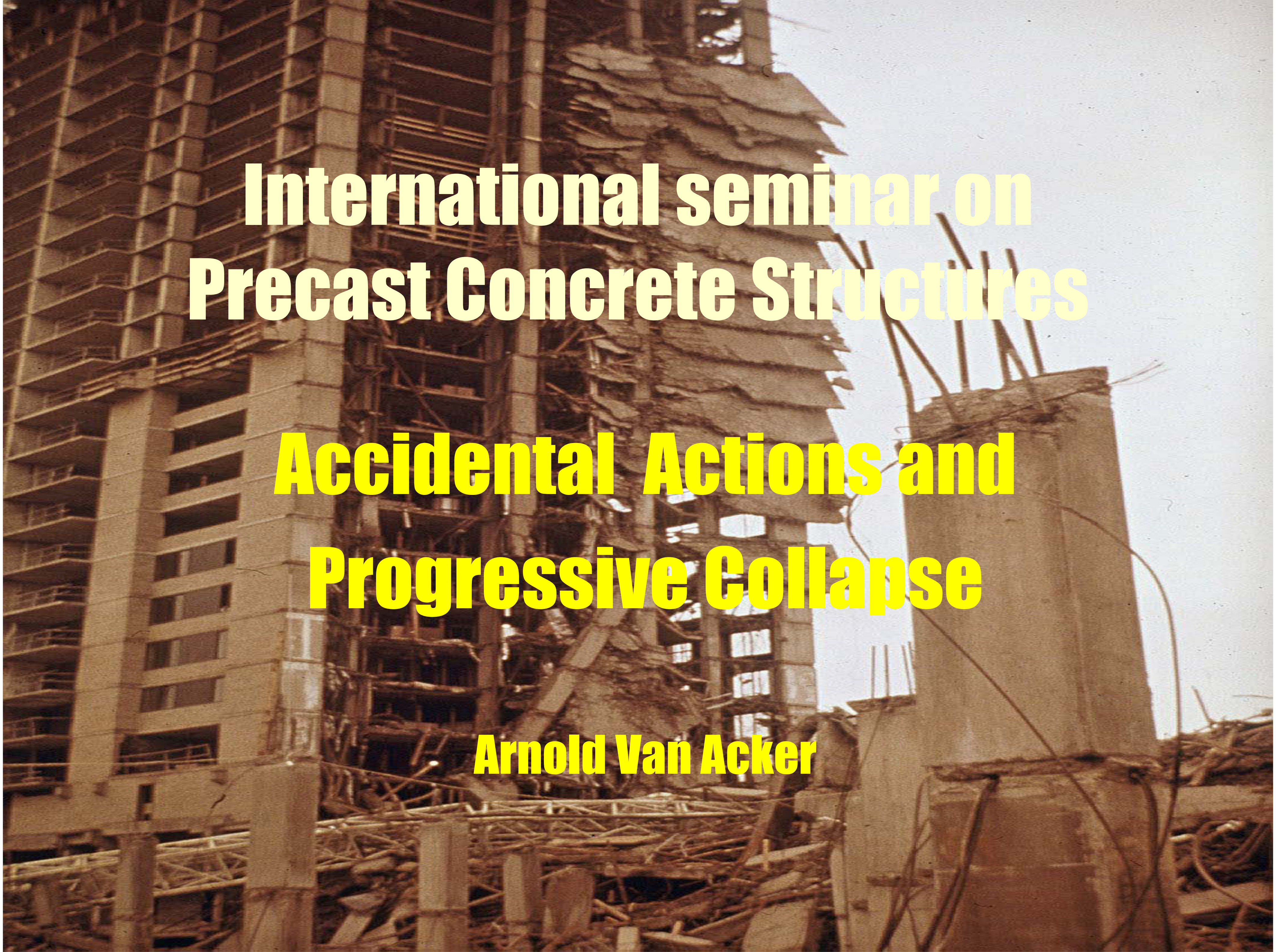


# International seminar on Precast Concrete Structures

# Accidental Actions and Progressive Collapse

Arnold Van Acker

# Progressive collapse

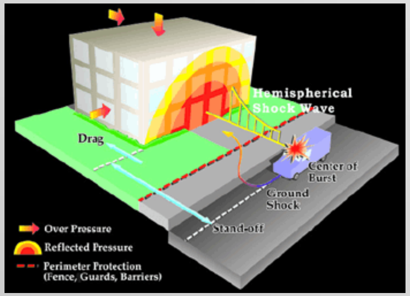
- Ronan Point, London 16 May 1968

Gas explosion

Progressive collapse of a part of an apartment building after a gas explosion at the 18th floor

# Modern threats and building design

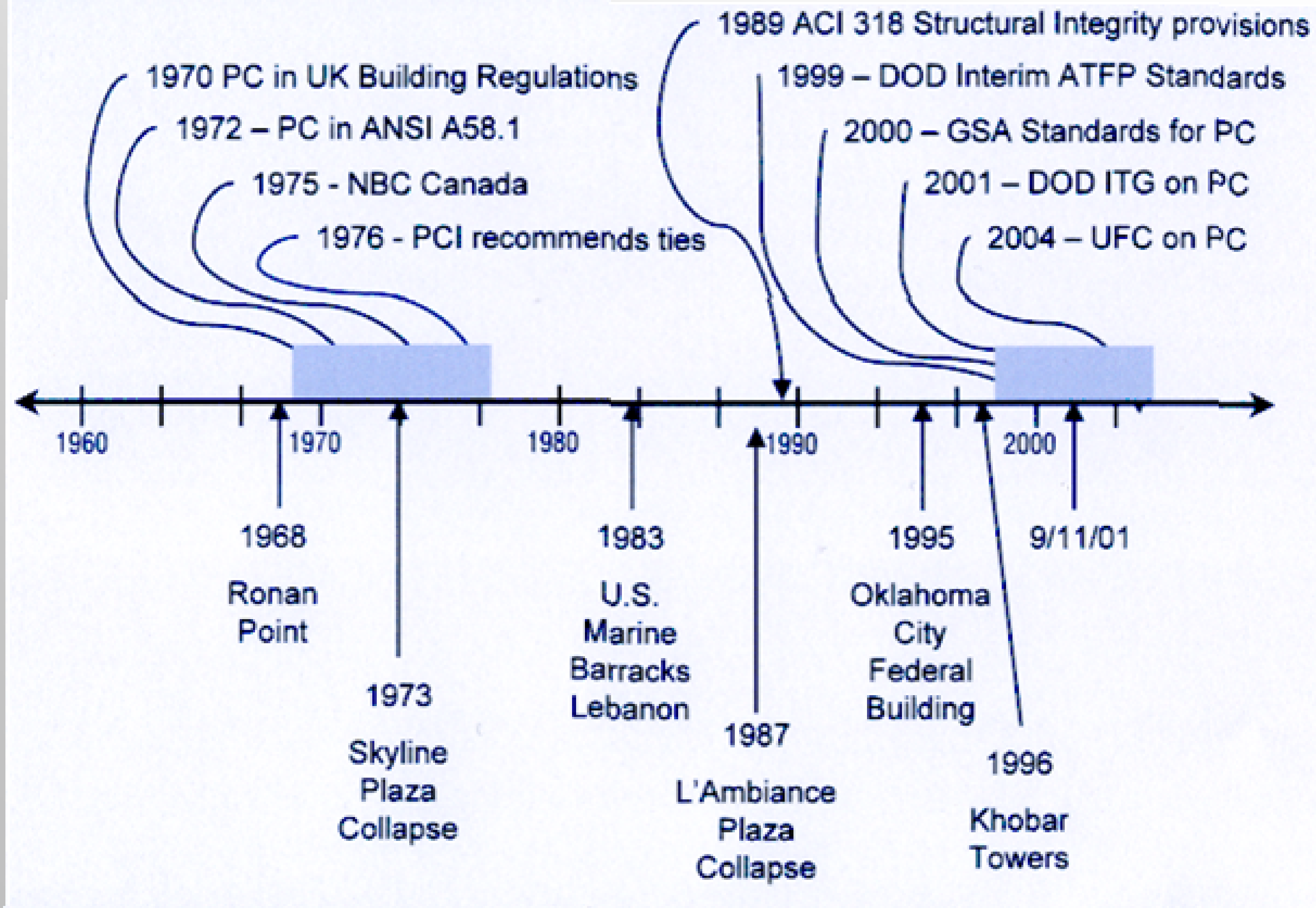

Dexia Tower Brussels, 37 storeys




Ellipse building Brussels, 26 storeys

**Steadily higher and more slender precast building structures**

# Progressive collapse - timeline

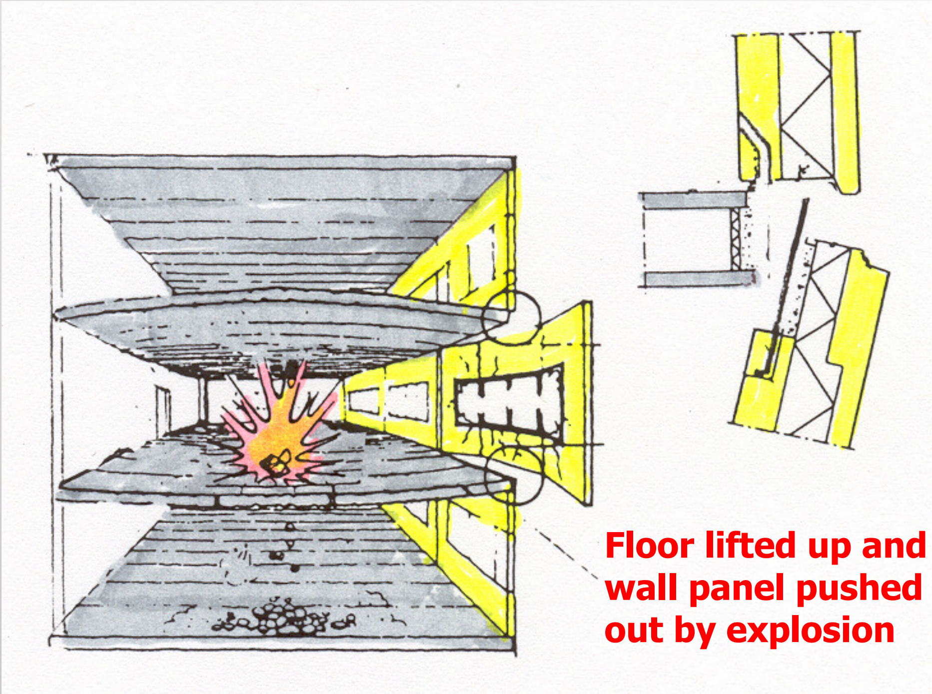


# Apartment building Maastricht

Progressive collapse of balconies after failure of balcony anchorage at fifth storey

# Phenomenon

- A local failure results in the collapse of the whole building or a large part of it.

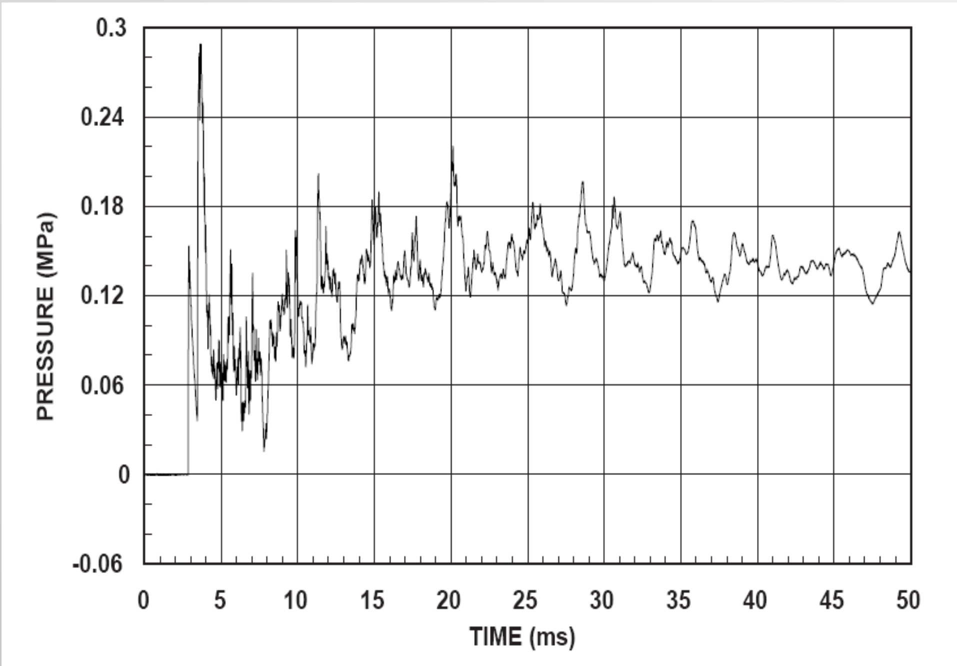


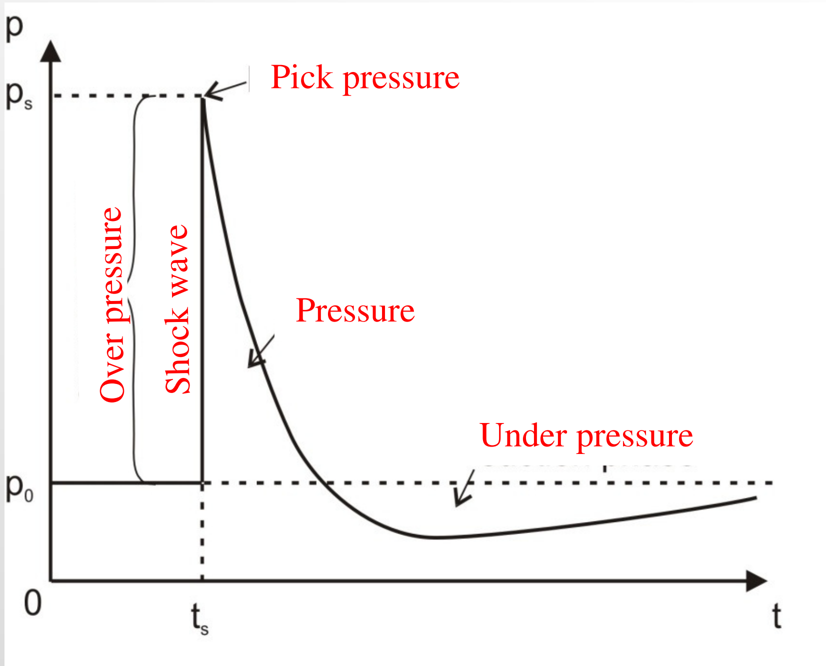

Scenario of possible effects caused by gas explosion

# Types of accidental actions

- **EN 1991-1-7:**
  - Impact by car collision
  - Impact by lift trucks
  - Impact by trains
  - Impact by ships
  - Hare landing od helicopters on roofs
- ***fib* study**
  - Impact by the  accidental action itself
  - Impact by falling debris
  - Impact by transition from the original structure to the alternative structure
- **UFC (USA):**
  - Explosives

# Acting forces

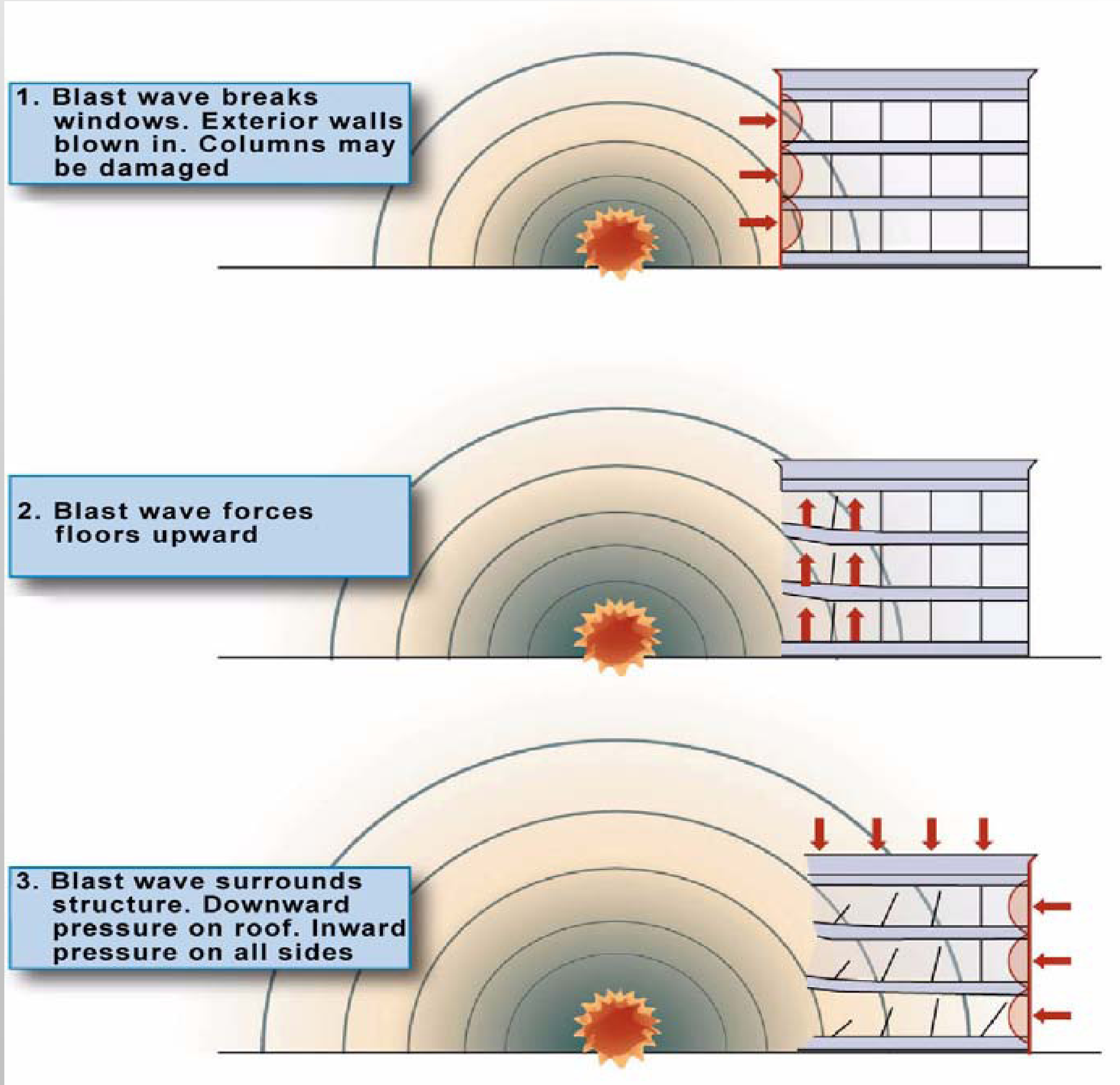



**Gas explosion**

**Explosives**

# Sequence of building damage



# Design strategies

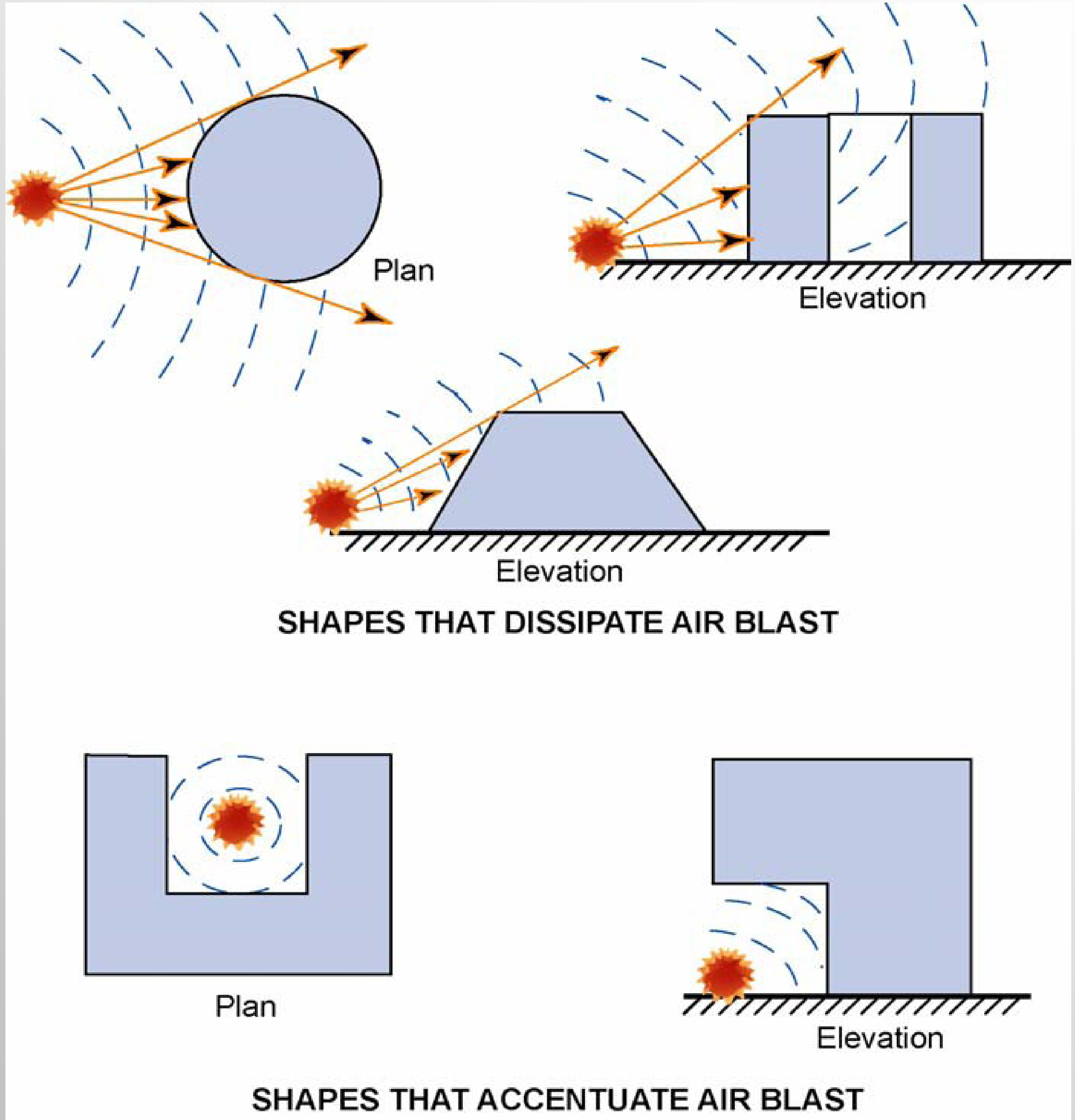
## The three basic physical protection strategies for buildings to cope with accidental actions are

1) prevention of accidental actions;
2) protective measures to eliminate accidental actions;
3) structural measures preventing progressive collapse.

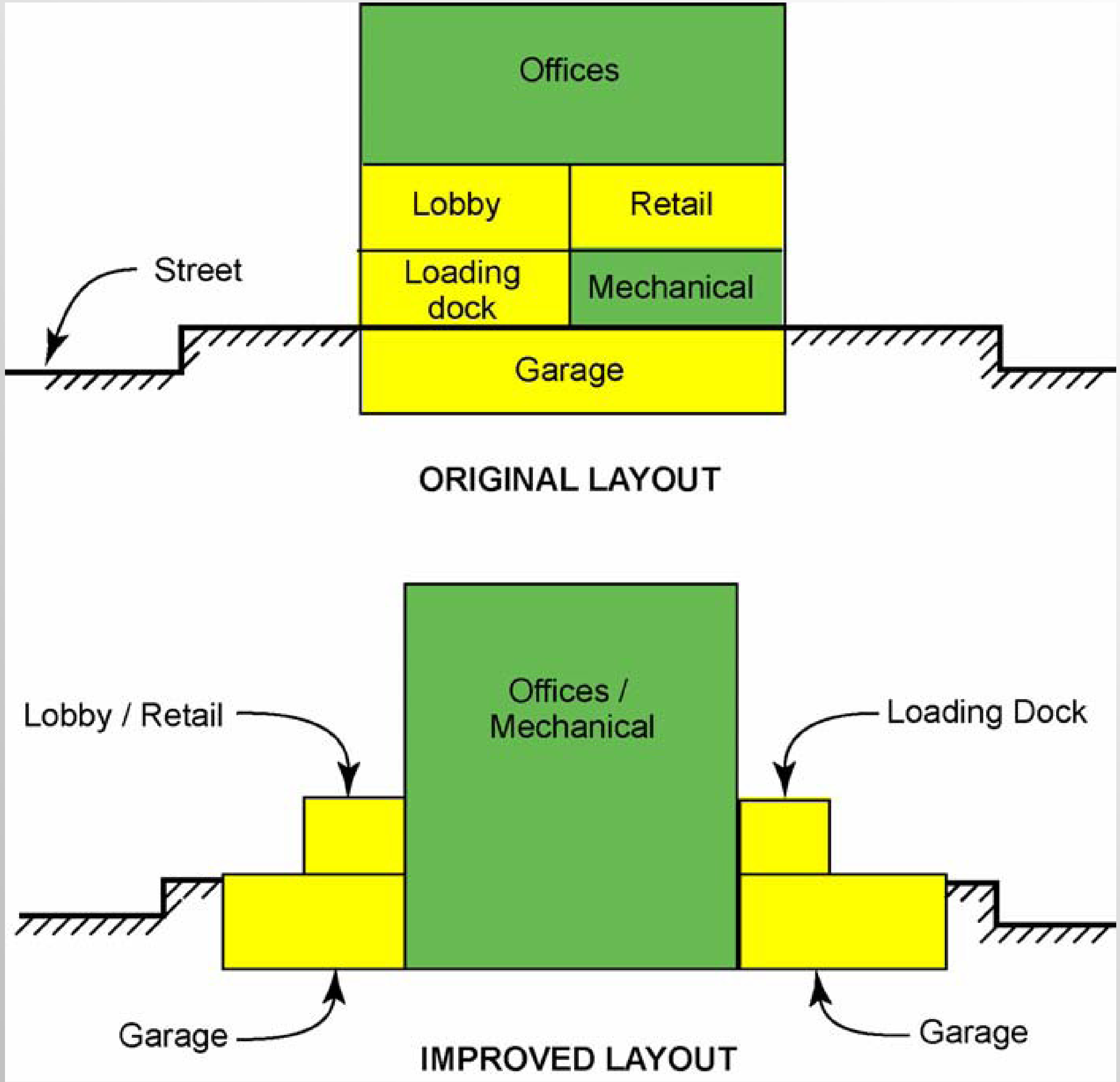
## Influencing factors

a. Type of loading (gas explosion, impact, blast, ...)
b. Magnitude  and location accidental loading
c. Structural system

# Effect of building shape on air blast impacts



# Example of lay-out to decrease the risk of progressive collapse



# Categorisation of buildings

## Eurocode 1 part 1-7

| Class | Building type and occupancy | Action required |
| --- | --- | --- |
| 1 | Houses not exceeding 4 storey's.<br>Agricultural buildings.<br>Buildings into which people rarely go, provided no part of the building is closer to another building, or area where people do go, than a distance of 1.5 times the building height. | No additional measures |
| 2A | 5 storey single occupancy houses.<br>Hotels not exceeding 4 storey's.<br>Flats, apartments and other residential buildings not exceeding 4 storeys.<br>Offices not exceeding 4 storey's.<br>Industrial buildings not exceeding 3 storey's.<br>Retailing premises not exceeding 3 storey's of less than 2000 $m^2$ floor area in each storey.Single storey Educational buildings.<br>All buildings not exceeding 2 storeys to which members of the public are admitted and which contain floor areas exceeding 2000 $m^2$ at each storey. | Horizontal ties to be provided or effective anchorage of floors to supports. |
| 2B | Hotels, flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storey's.<br>Educational buildings greater than 1 storey but not exceeding 15 storey's.<br>Retailing premises greater than 3 storey's but not exceeding 15 storey's.<br>Hospitals not exceeding 3 storey's.<br>Offices greater than 4 storey's but not exceeding 15 storeys.<br>All buildings to which members of the public are admitted and which contain floor areas exceeding 2000 $m^2$ but less than 5000 $m^2$ at each storey.<br>Car parking not exceeding 6 storey's. | Horizontal ties to be provided together with either vertical ties or allowance made for the notional removal of support |
| 3 | All buildings defined above as Class 2A and 2B that exceed the limits on area and/or number of storey's.<br>All buildings, containing hazardous substances and/or processes.<br>Grandstands accommodating more than 5000 spectators. | Specific consideration to take account of the likely hazards. |

# Design concepts

- Design for prevention of progressive collapse

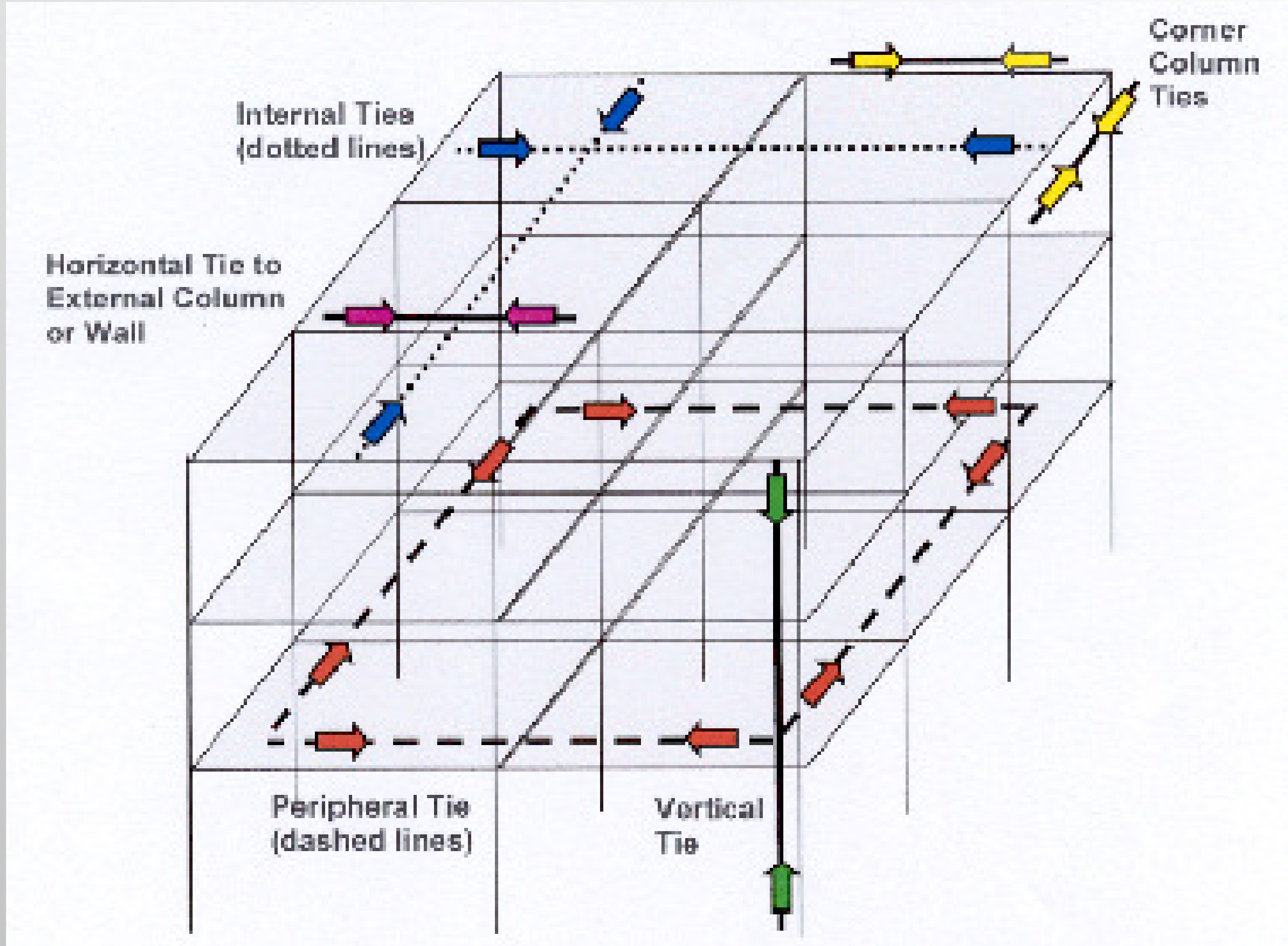
a. Indirect method
Minimum tie provisions

b. Alternative load path method
A critical element is removed from the structure, due to an accidental loading, and the structure is required to redistribute the gravity loads to the remaining undamaged structural elements.

c. Specific load resistance method
All critical gravity load-bearing members should be designed and detailed to be resistant to a postulated accidental loading

# a) Indirect method

- ## Tie force approach




**A weak point in the direct approach method is that the prescriptive tying force requirements neglect ductility issues and relies primarily on bending, cantilever action and compressive arching rather than tensile catenary action for enhanced structural robustness.**

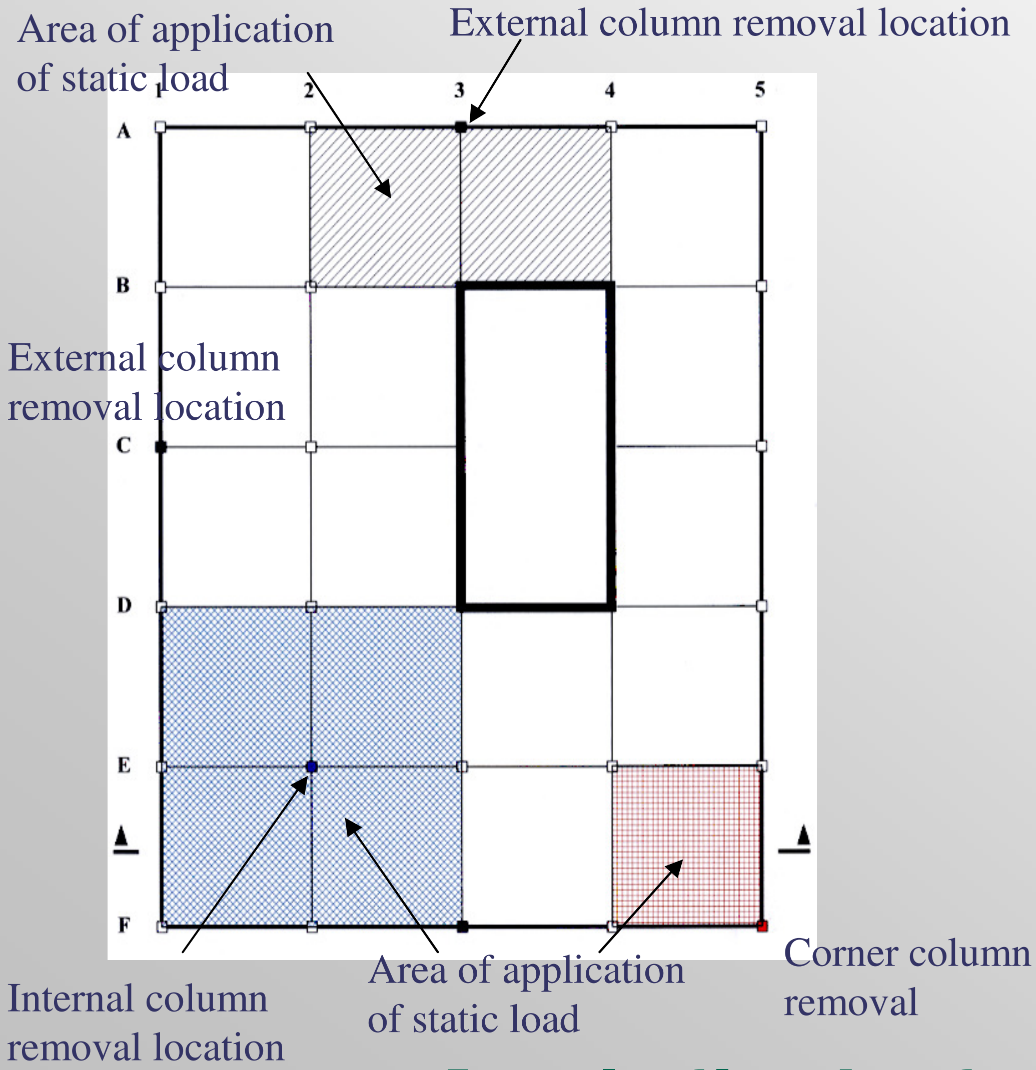
# b) Alternative load path method

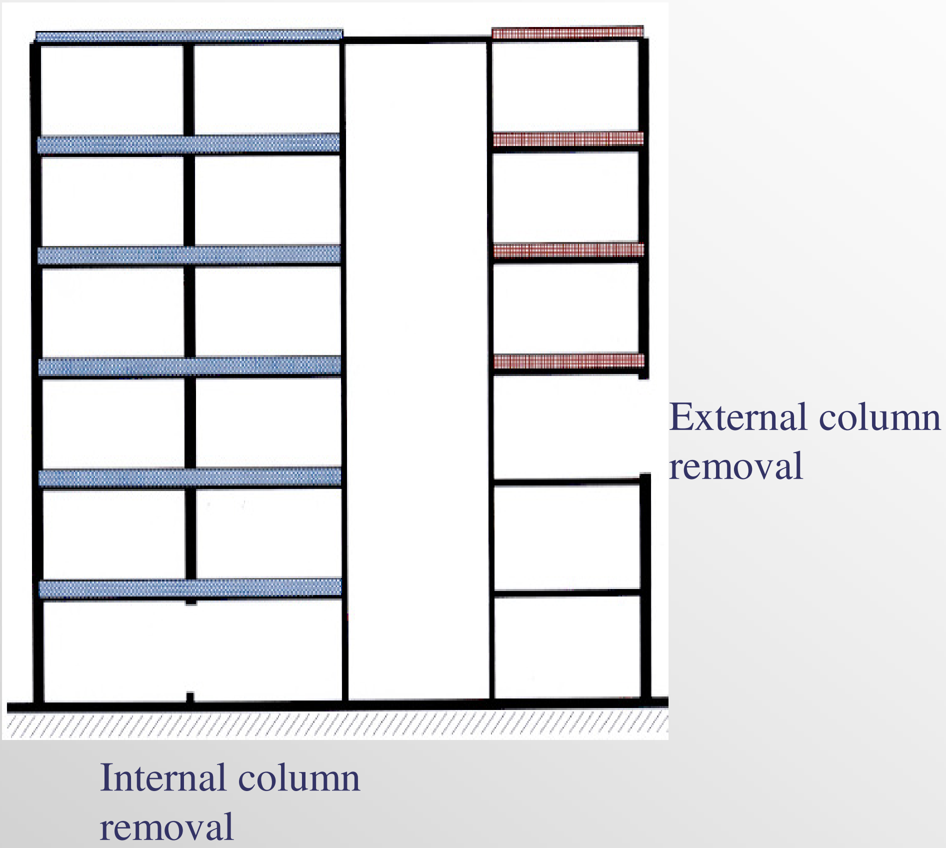
- **The alternative load path method implies that:**

  - the local damage must be bridged by an alternative load-bearing system: catenary action, cantilevering action, bridging action, suspension. The transition to this system is associated with dynamic effects that should be considered .
  - the structure in its whole must shown to be stable with the local damage under the relevant load combination

# Primary local damage

- **Skeletal structures**

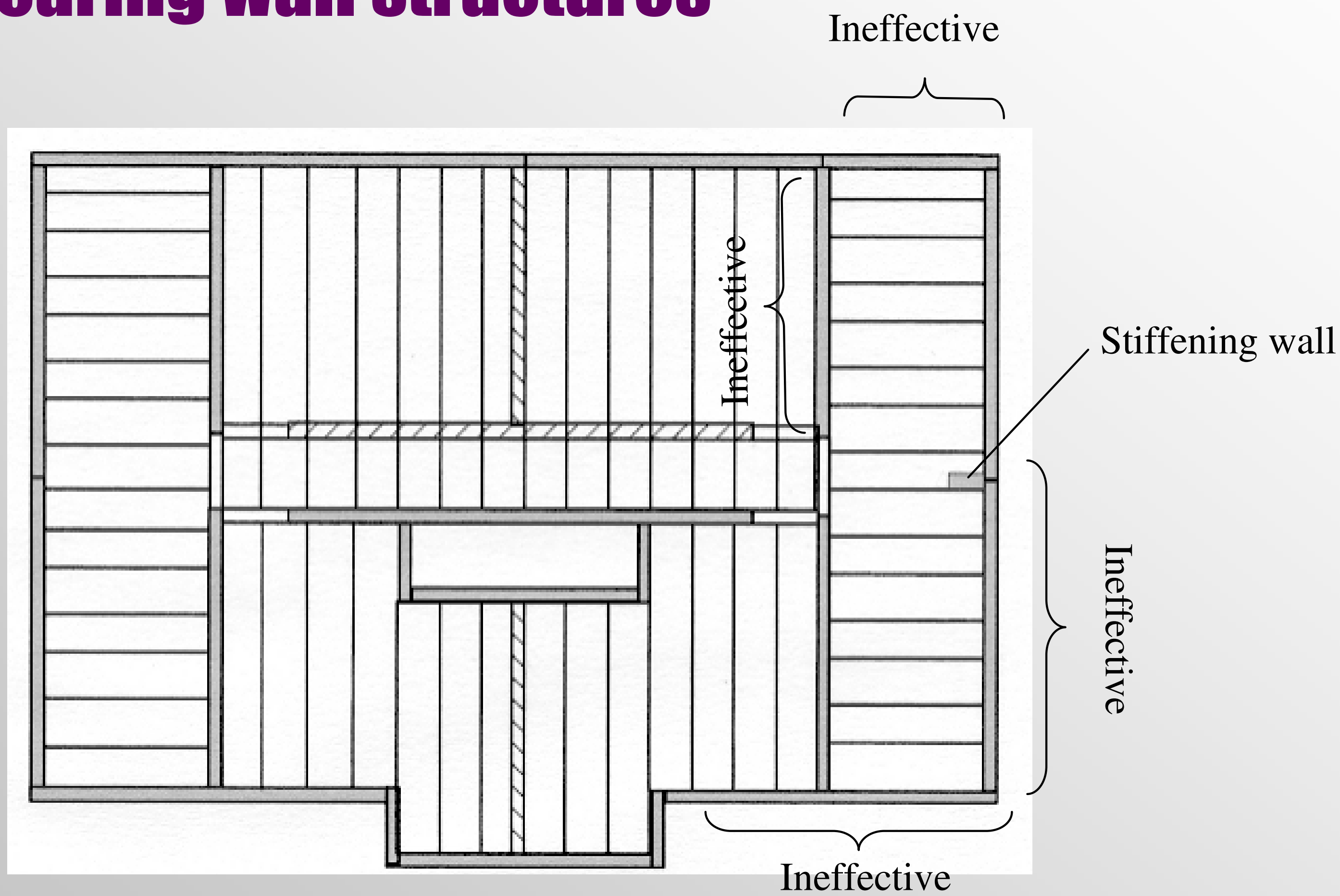



**Example of location of columns for design removal**

# Primary local damage

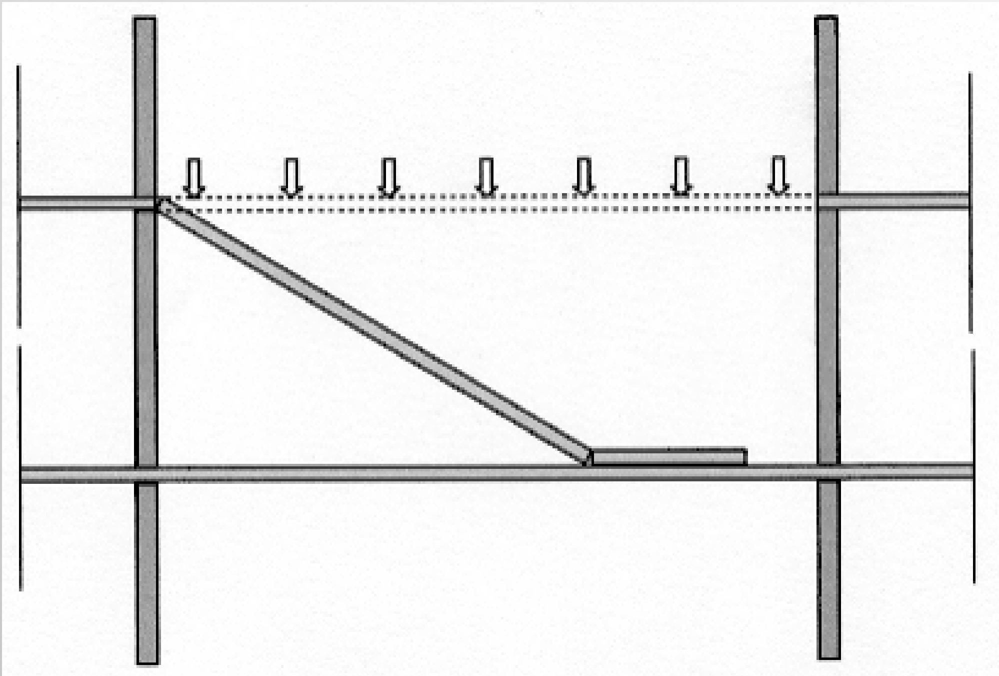
- **Load bearing wall structures**

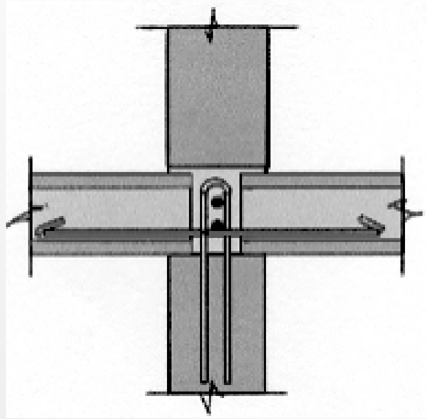


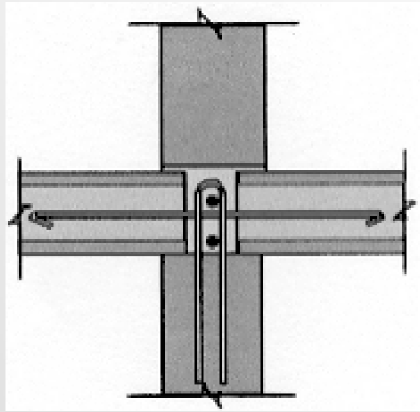

**Extent of assumed wall damage under accidental actions**

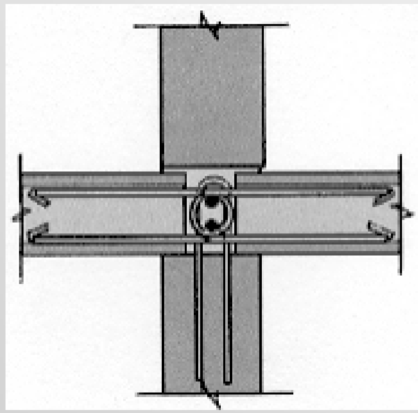
# Primary local damage

- Floors and roofs



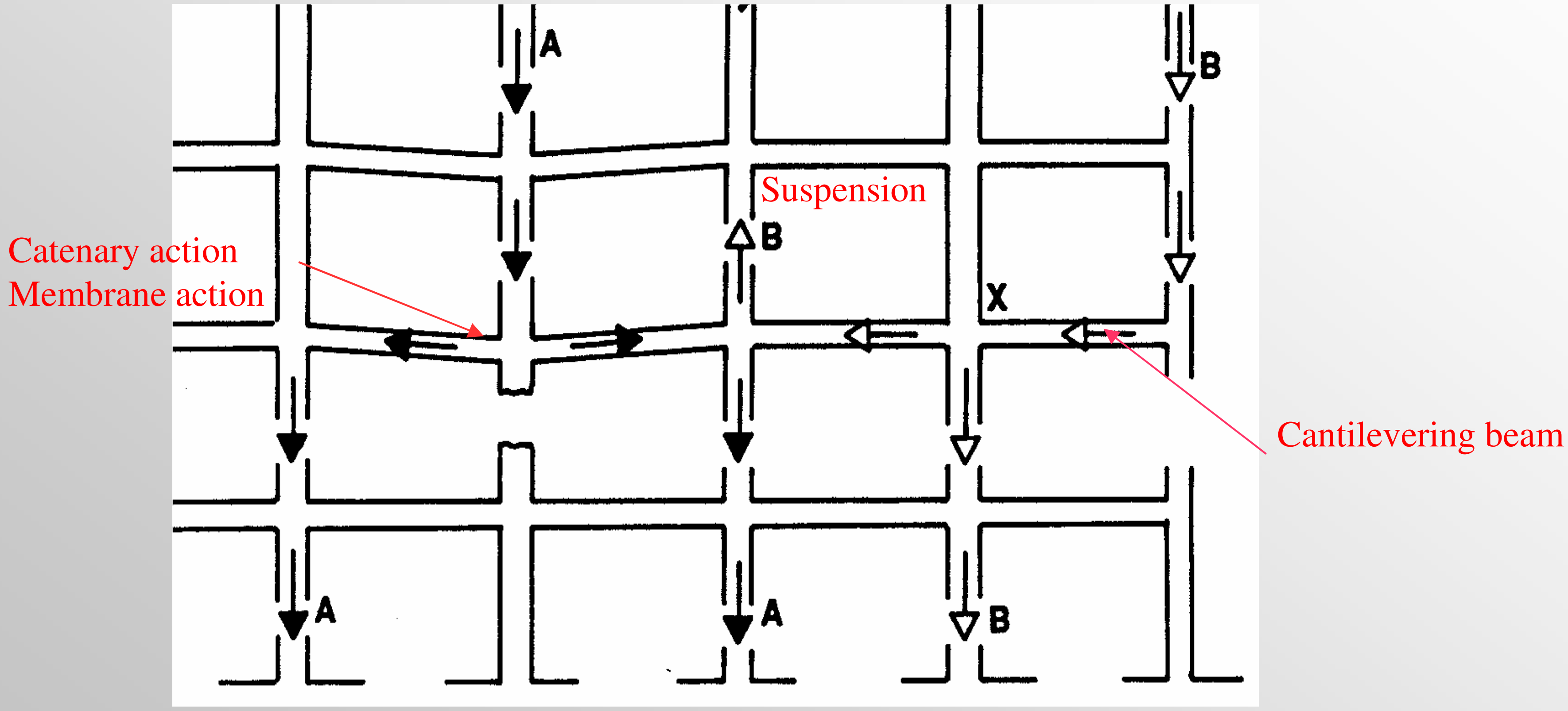






Detailing of hollow core floor support connections to avoid damaged floor falling from support

# Mechanisms for alternative load path




**Alternative means of protection against progressive collapse in skeletal structures**

# Catenary action

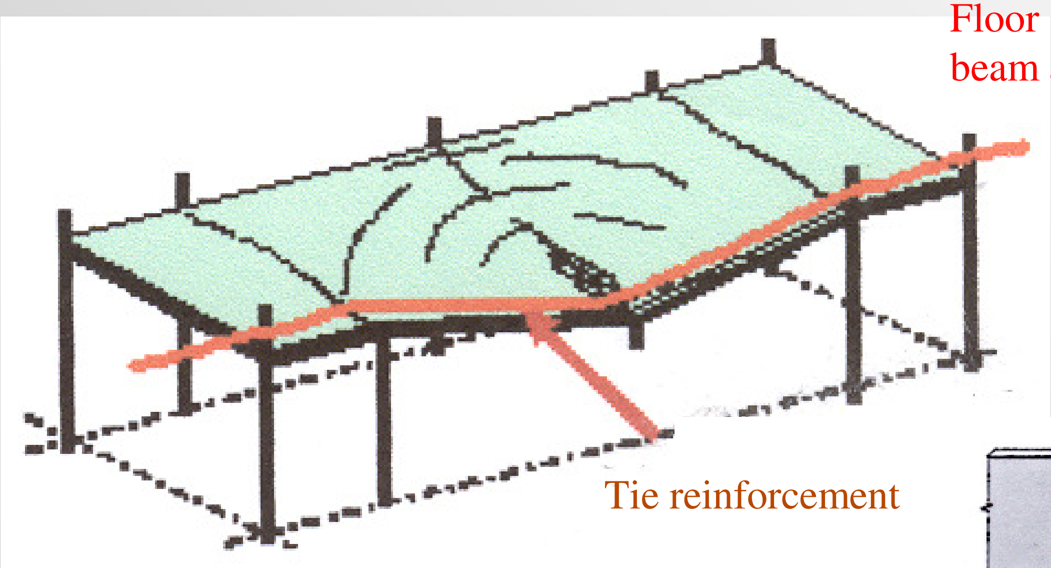
- Flooded box culvert near Bari, Italy

# Membrane action

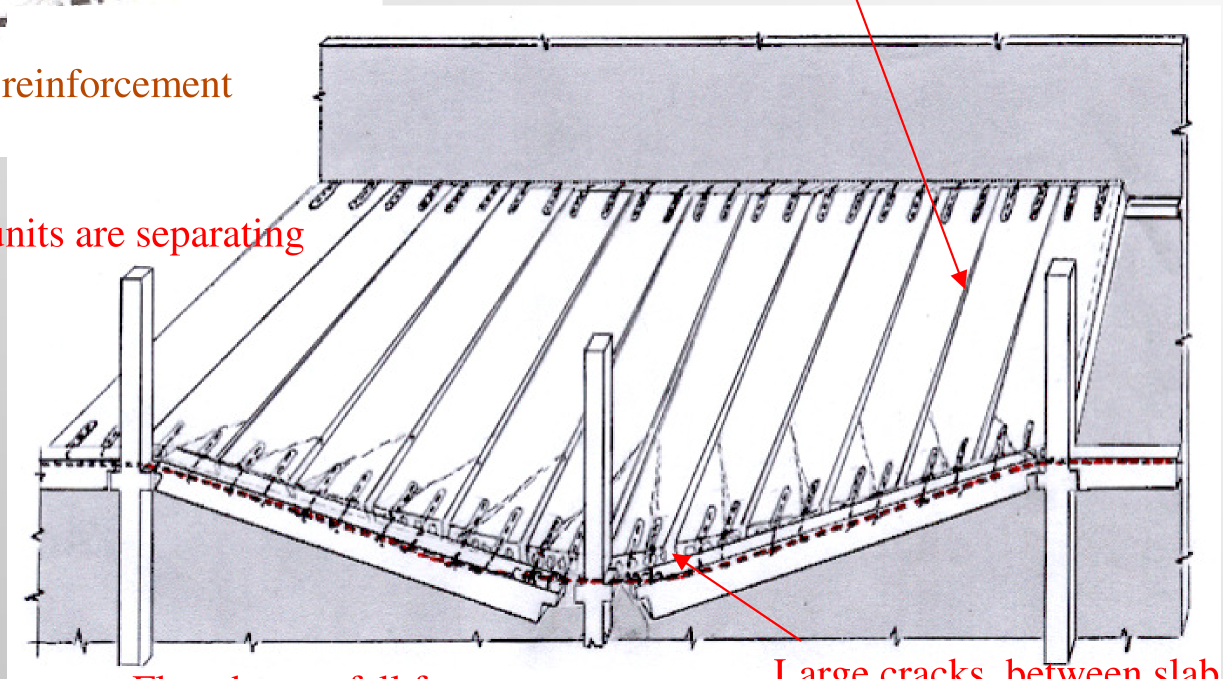
The by impact damaged roof beam remains in place through the membrane action of the steel deck and is still able to carry the roof structure through partial force transfer in the top and bottom flanges.

# Catenary action

## Difference between a monolithic and a precast structure




**Cast in-situ**

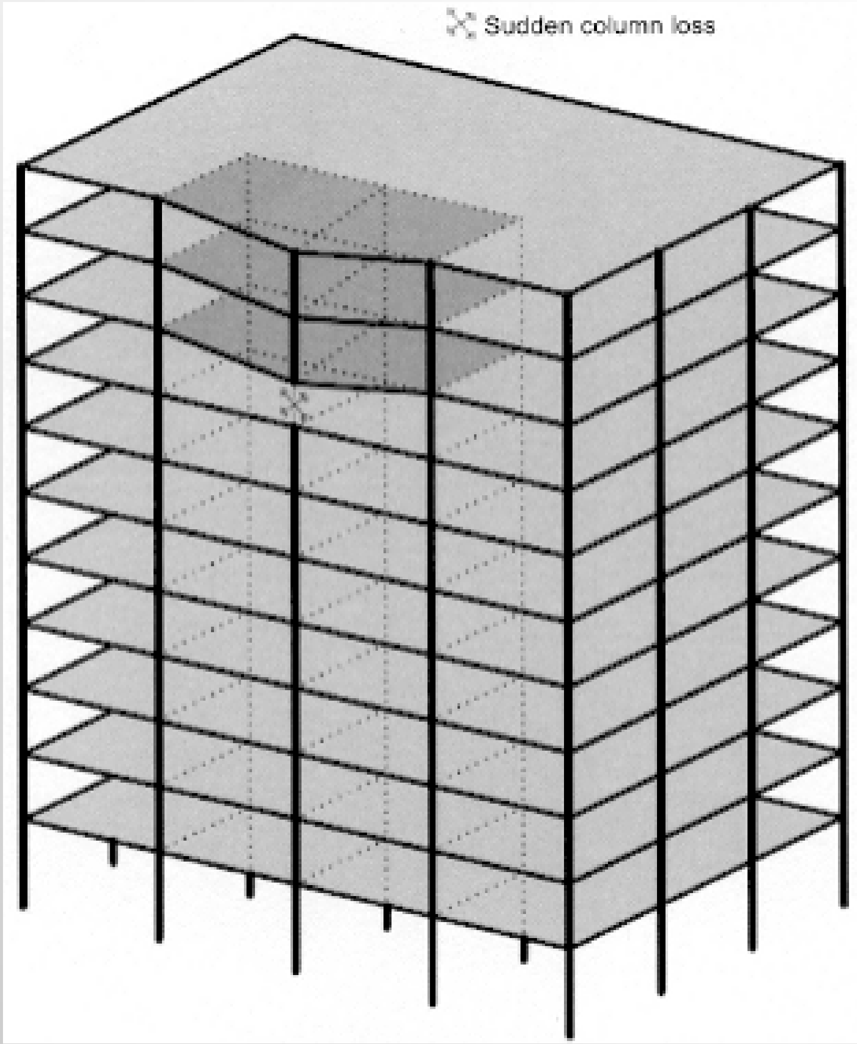



**Precast**

# Catenary action

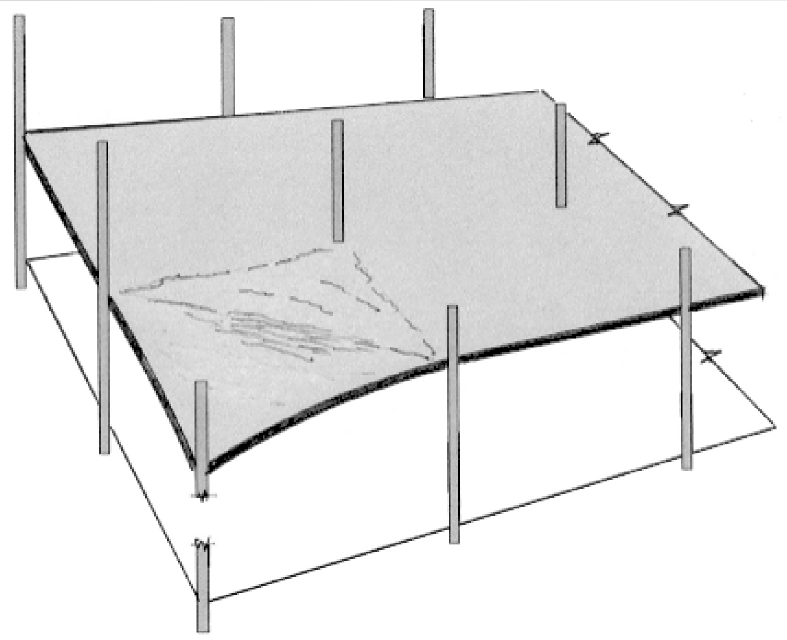
- **Suspension**

Depending on the rigidity of the frame structure above the lost column, a part of the column load could also be transferred by the vertical tie reinforcement in the columns above the removed column. When this is not the case, each one of the above floor structures will have to take up his part of the excessive load.

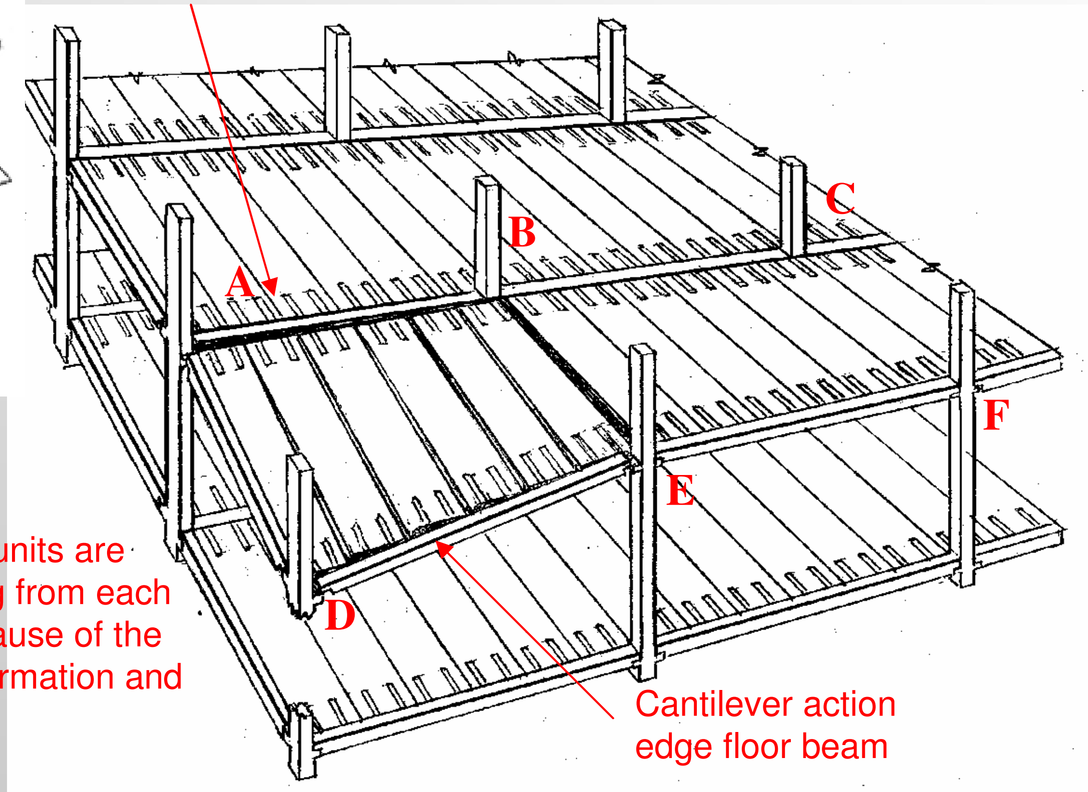


# Catenary action

## Loss of a corner column



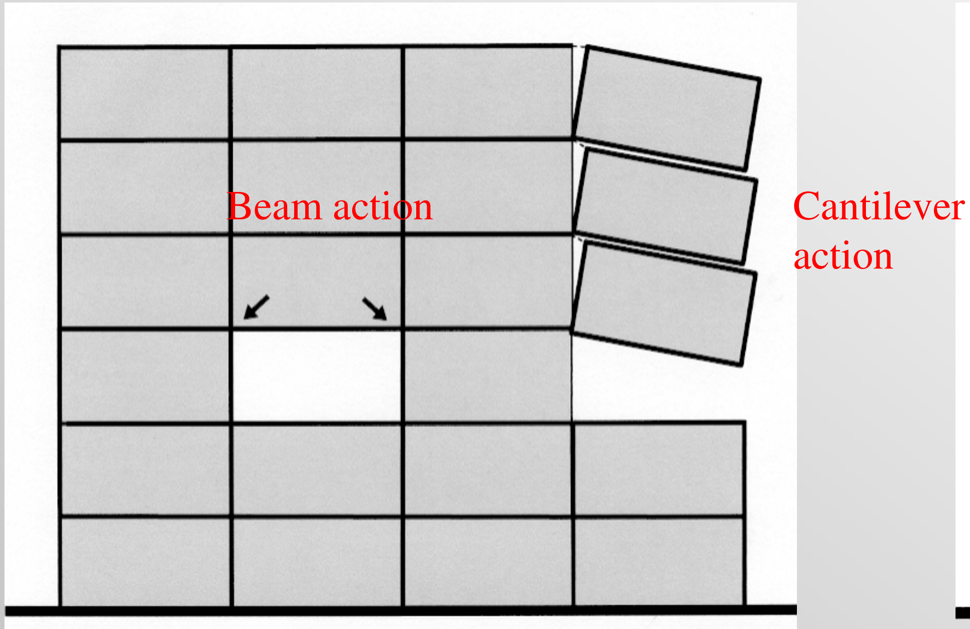
Cast in-situ



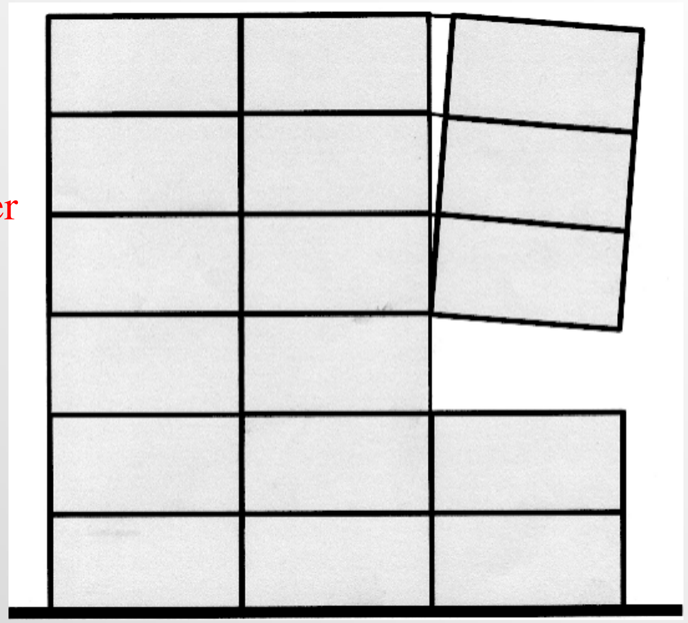

Precast

# Beam & cantilever action

- **Wall panel structures**




Individual cantilevers

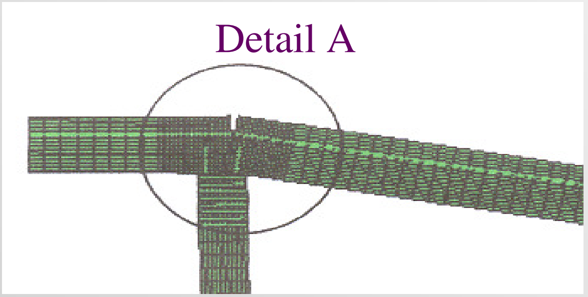


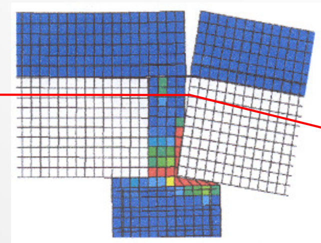
Composite cantilevers

**Alternative mechanisms for alternative load path in wall frame structures**

# Force transfer mechanisms

## 1. Cantilever action

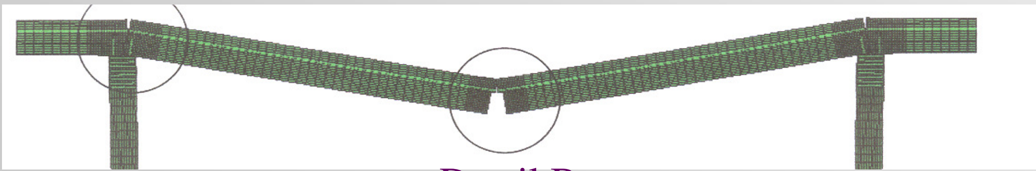


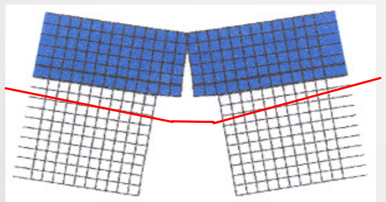
Detail A

## 2. Strut and tie action

Detail A

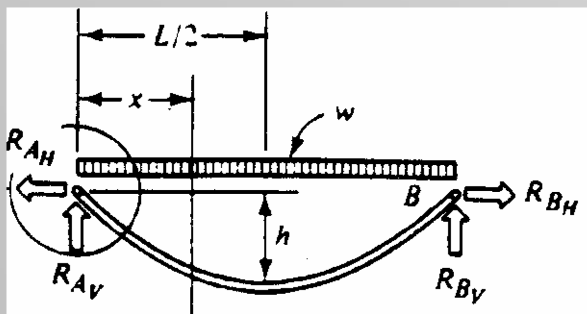


Detail B

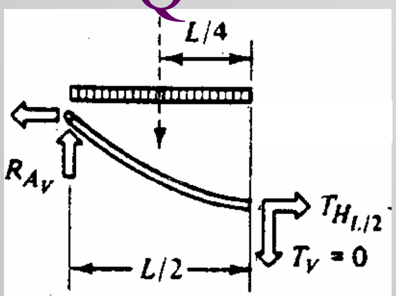


Detail B

## 3. Cable action



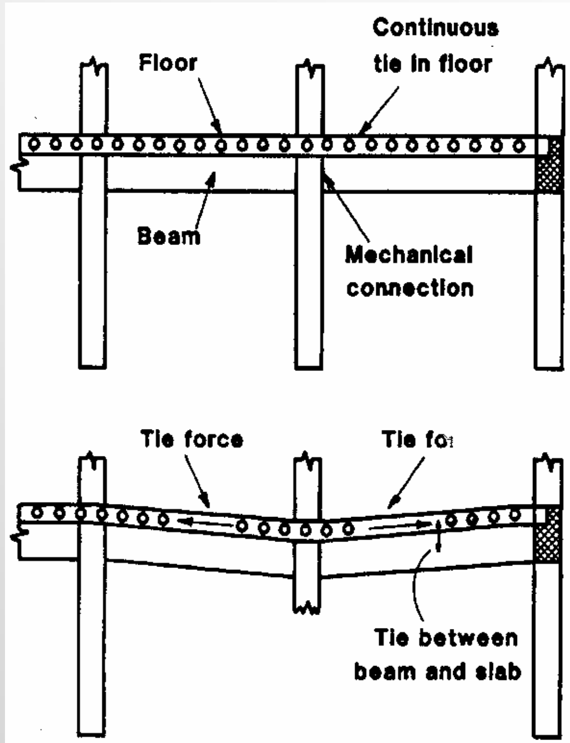

Q




$$R_{A_H} = \omega \left[ G \cdot \gamma_G + \psi_1 or \psi_2 \cdot Q \cdot \gamma_Q \right] \cdot \frac{L}{4u}$$

# Alternative load path method - example

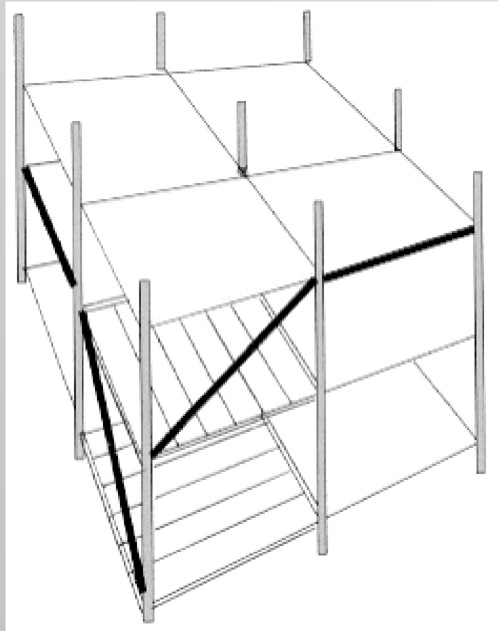
- Failure of intermediate façade column

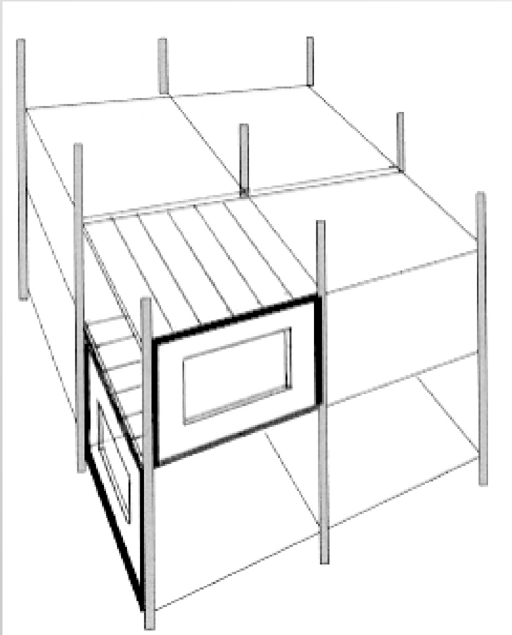
# Alternative solutions

Floor spans in opposite directions

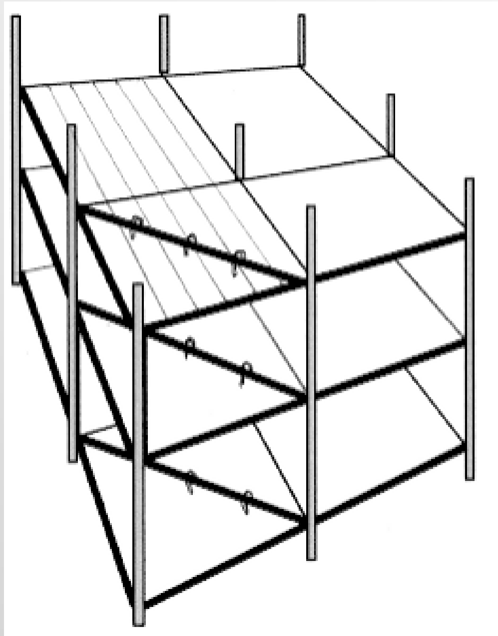
Floor spans in same direction



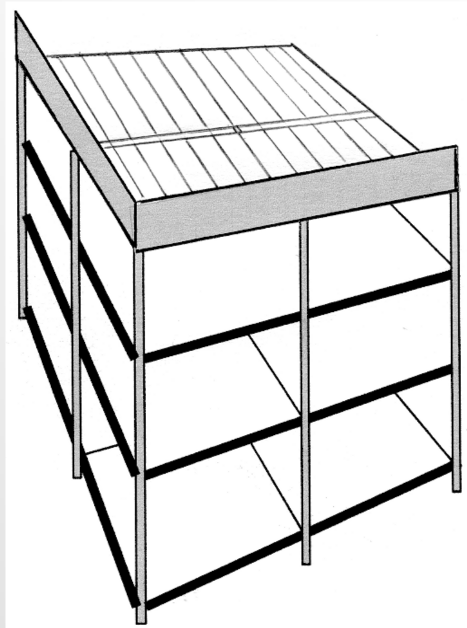
Diagonal restrainment



Wall panels



Diagonal ties



Rigid cornice

**Structural systems able to take up vertical loading**

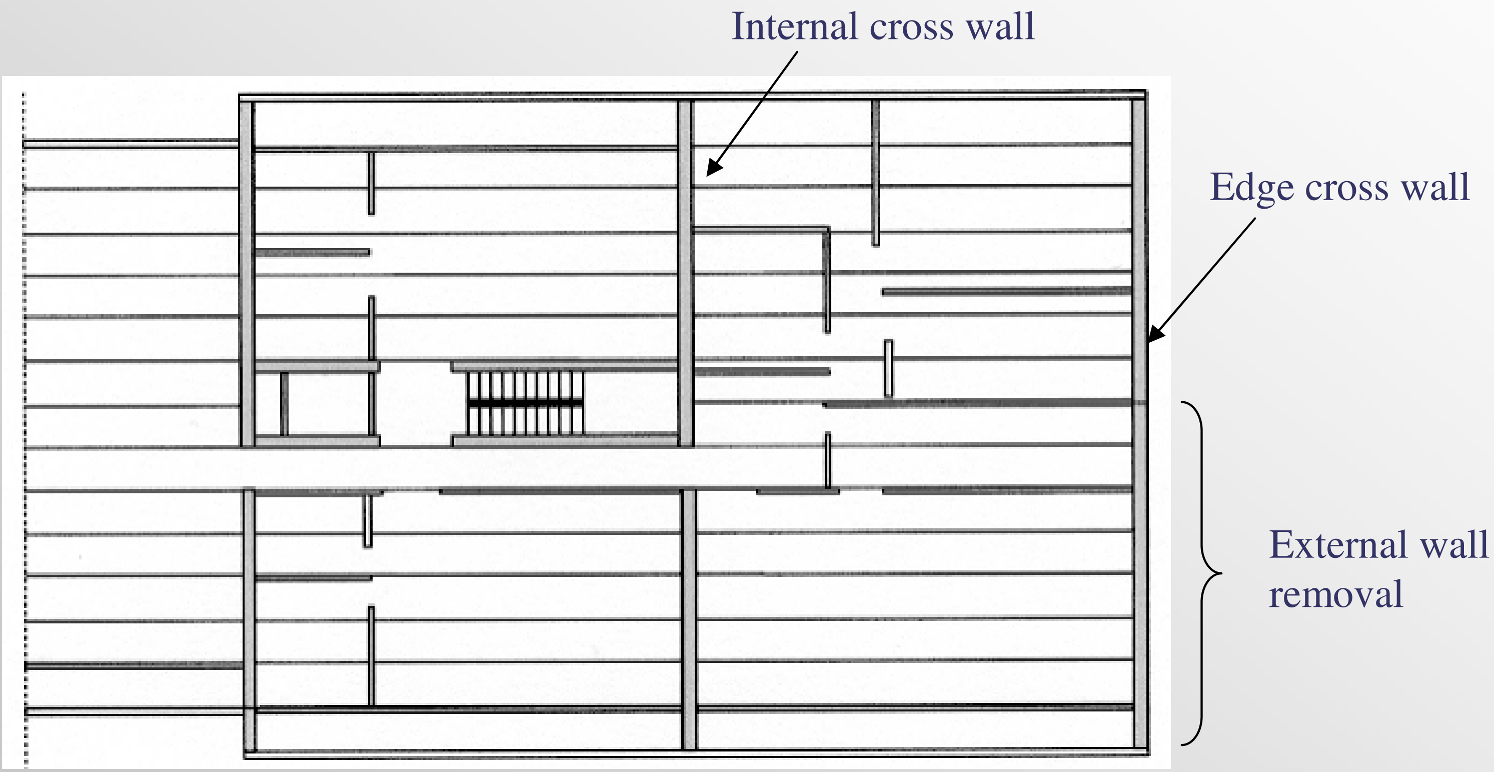
# Specific load resistance method

- **Design of key elements**

Where the effect of the removal of any single column or beam carrying a column would result in collapse of any area greater than 100 $m^2$ or 15% of the area of the storey, that member should be designed as a key element. Key elements should be designed for an accidental loading not less than 34 $kN/m^2$, or the notional load imposed by authorities. Any other member or other structural component which provides lateral restraint vital to the stability of a key element should itself also be designed as a key element for the same accidental loading.

# Specific load resistance method

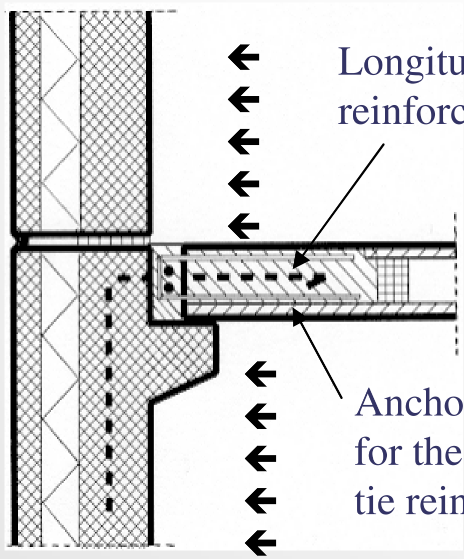
- **Practical example wall panel structure**

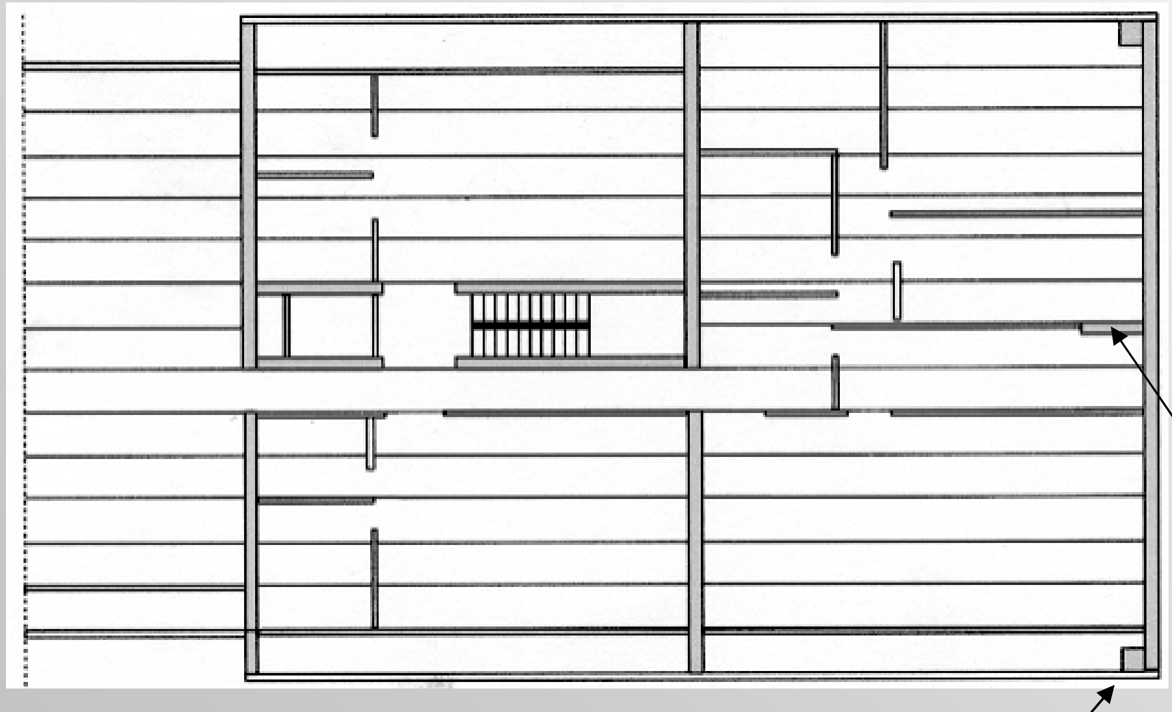



**Alternative (a): cross-wall system with key elements at the edge**

# Specific load resistance method

- **Practical example**

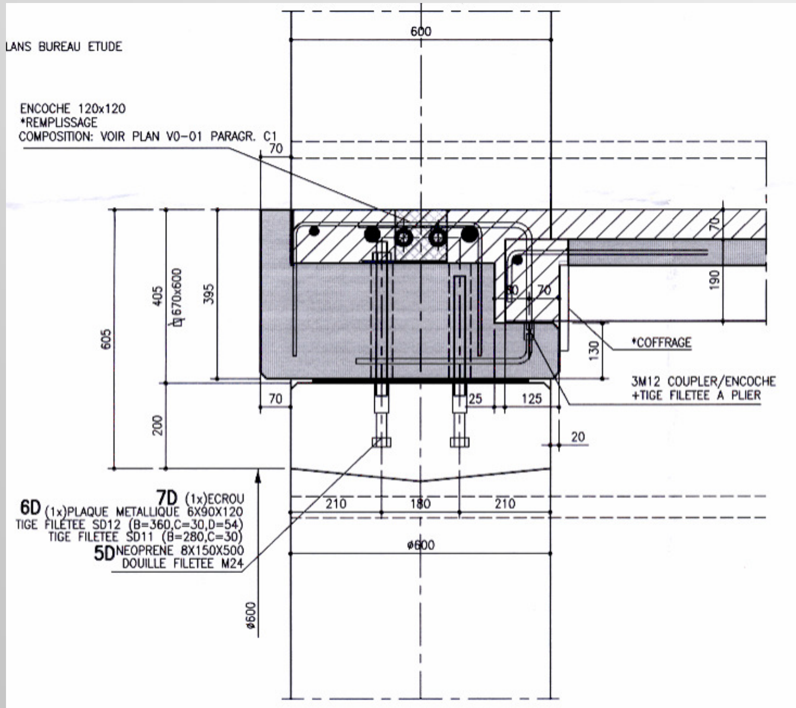


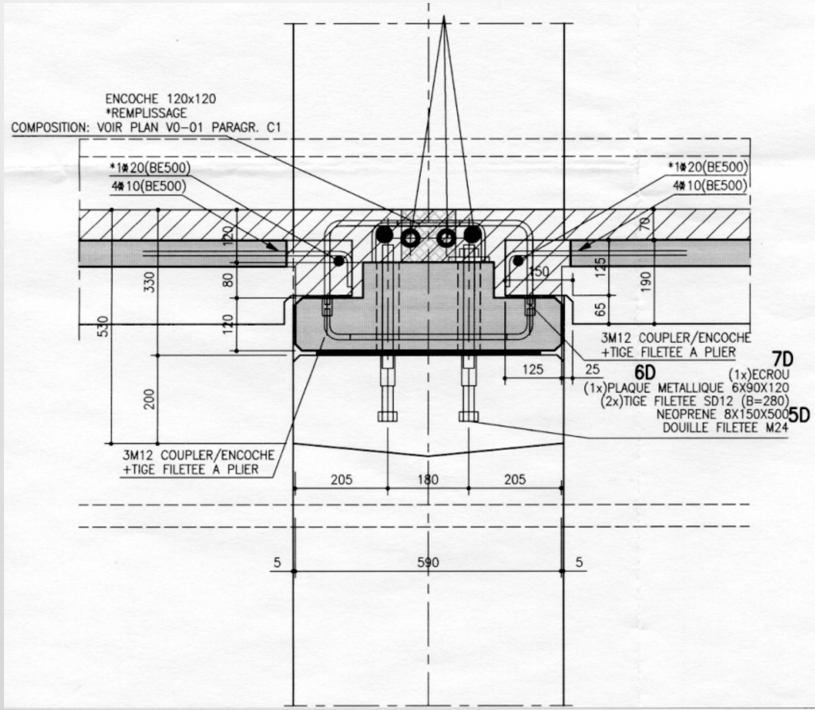

**Alternative (b): cross-wall system with stiffening columns and wall**

# Detailing

- **Ties for catenary action**




Edge beam




Intermediate beam

**Tie provisions in skeletal tower buildings**

# Detailing

- Realisation peripheral ties


Detail tie beam

Tie provisions in skeletal tower building 26 floors

# Detailing

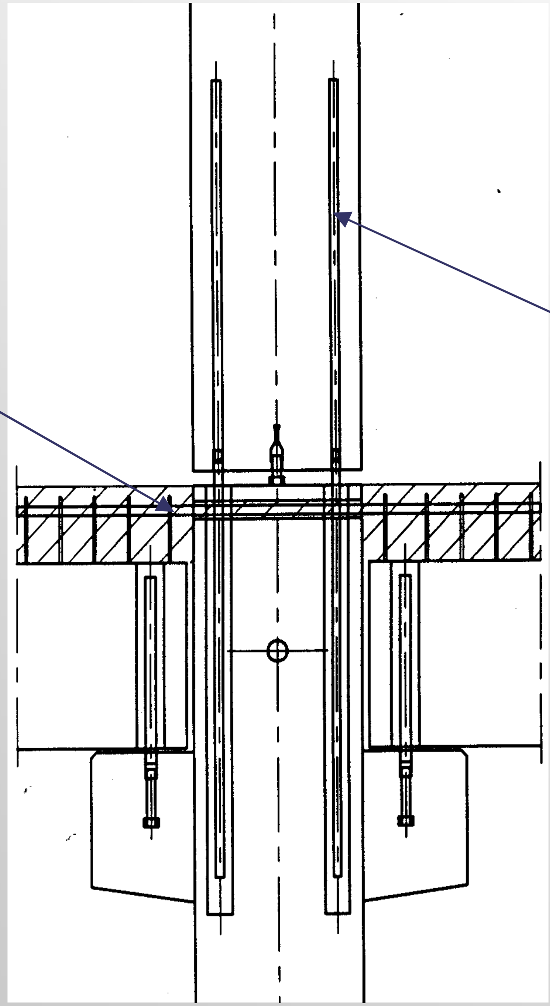
- Provisions for peripheral ties

Sleeves in columns for passage of ties

# Detailing

- **Column to column connections**

Hole through column for continuity of tie reinforcement

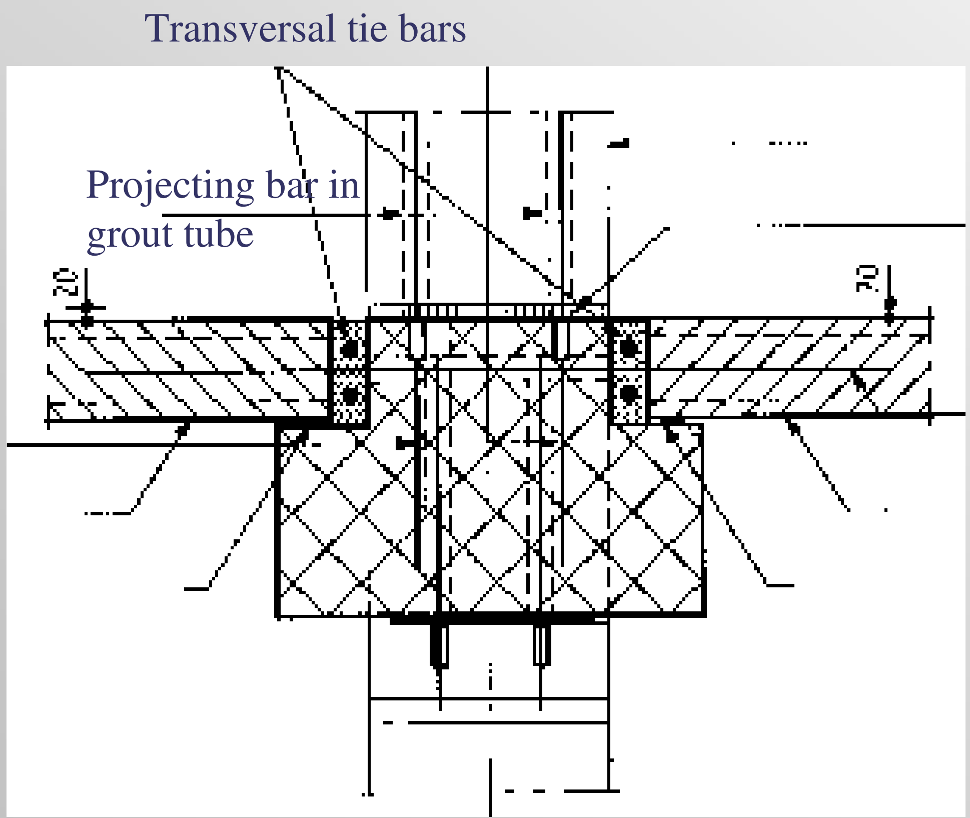


Projecting bars from lower column anchored in grout tubes in upper column

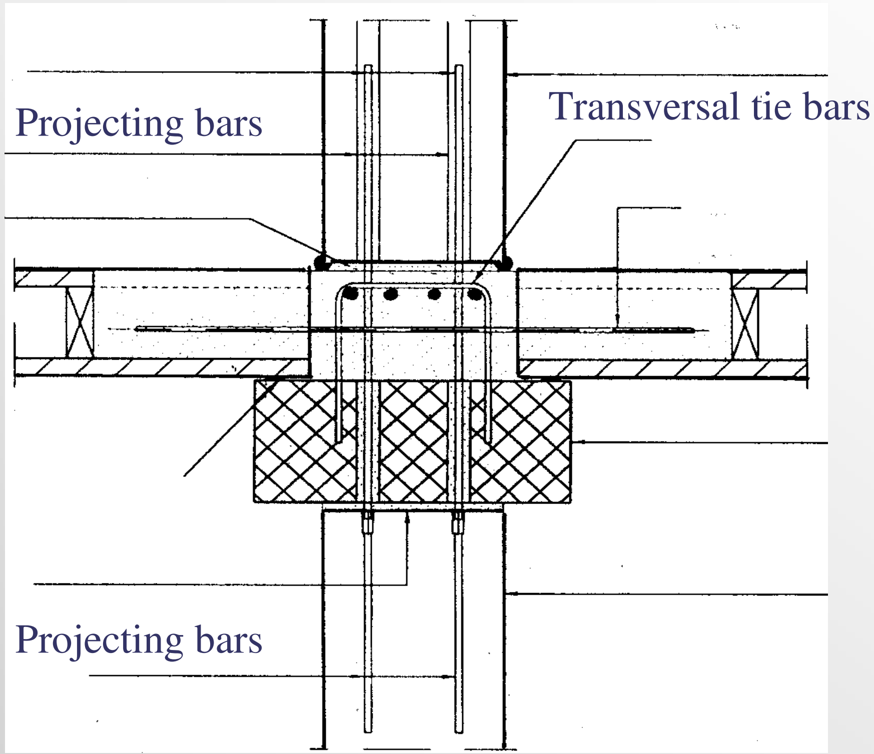
**Example of column-to-column connection with good strength, anchorage and ductility characteristics to withstand abnormal loads from accidental actions**

# Detailing

- **Beam to floor connections**




(a) less good solution

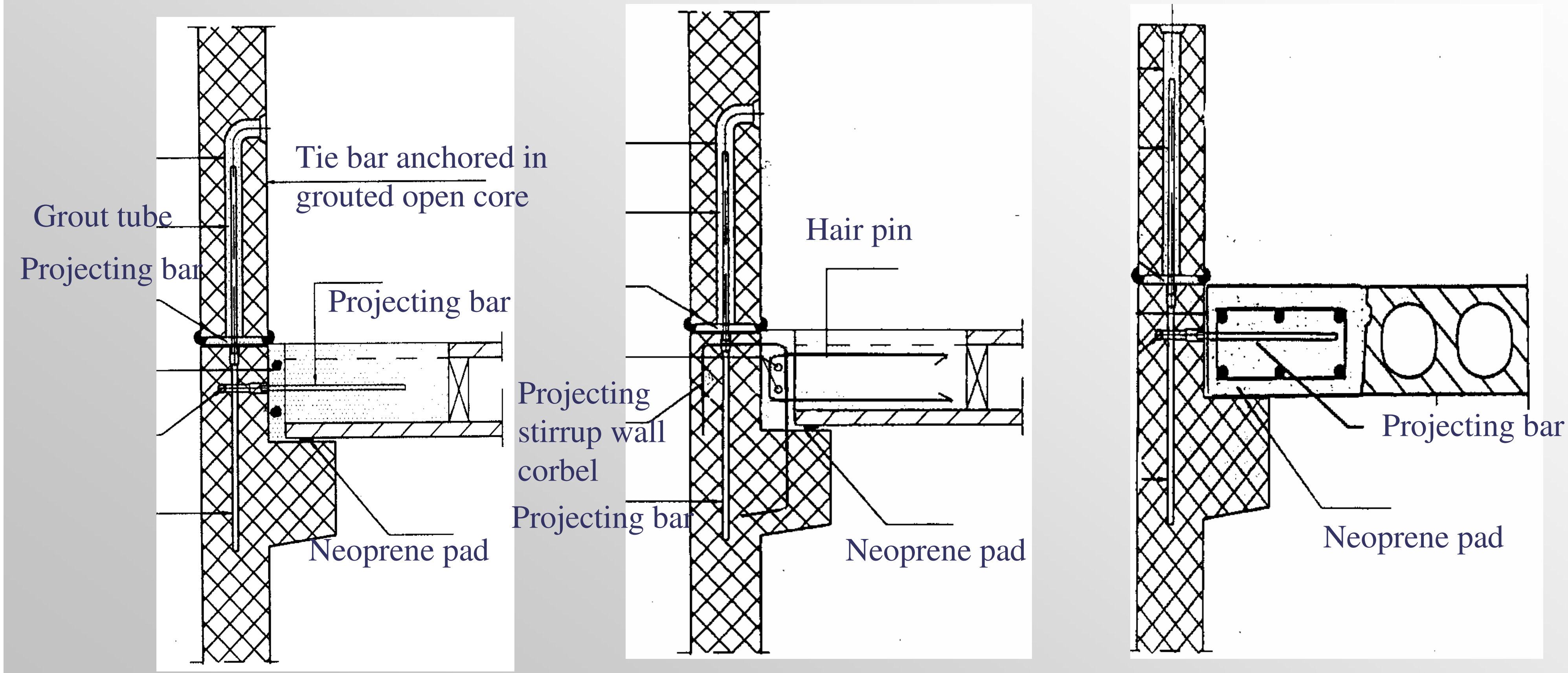



(b) good solution

**Examples of transversal tie reinforcements in floor-beam connections**

# Detailing

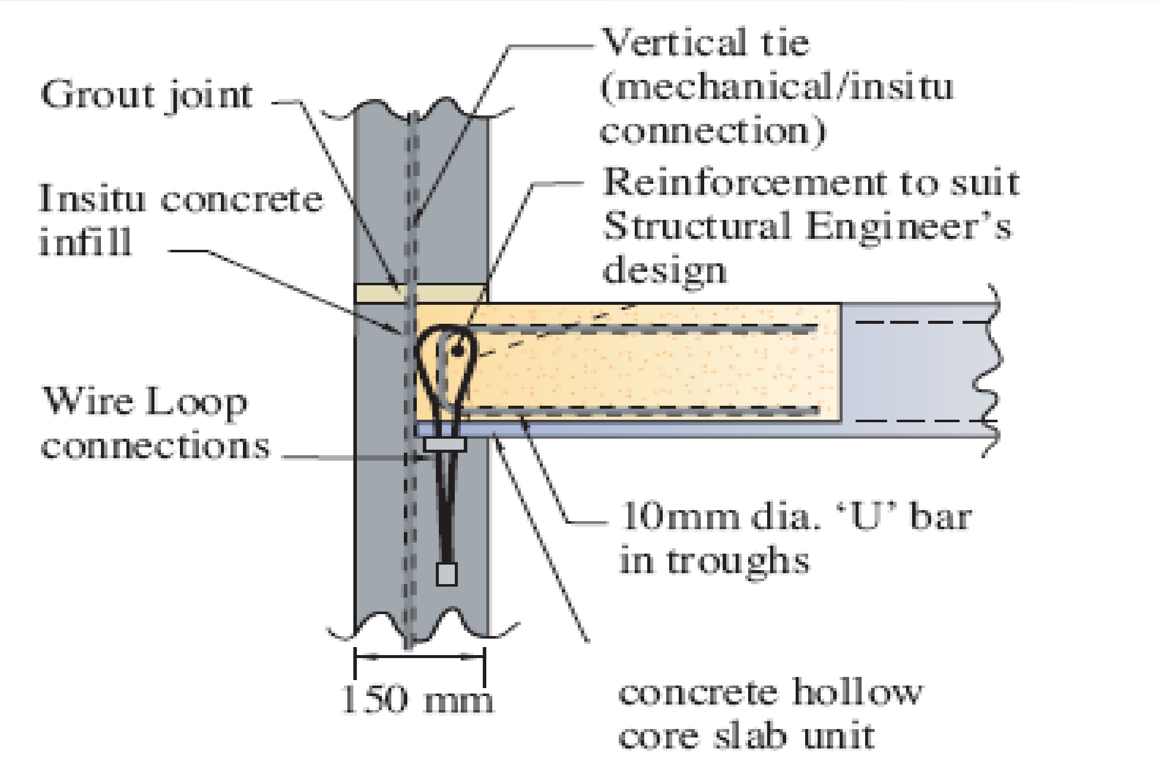
- **Wall to wall and wall to floor connections**




**Examples of wall-to-wall-to-floor connections**

# Detailing

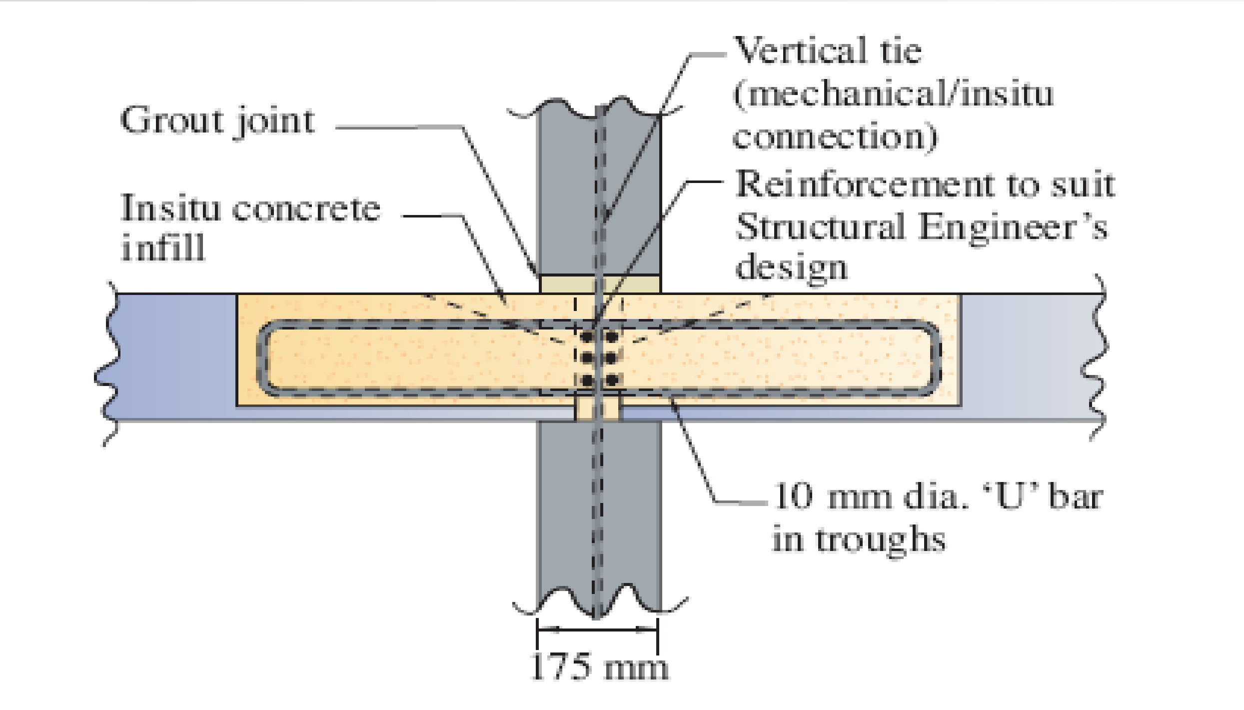
- **Wall to floor connections**




**Typical section through load bearing edge wall**

# Detailing

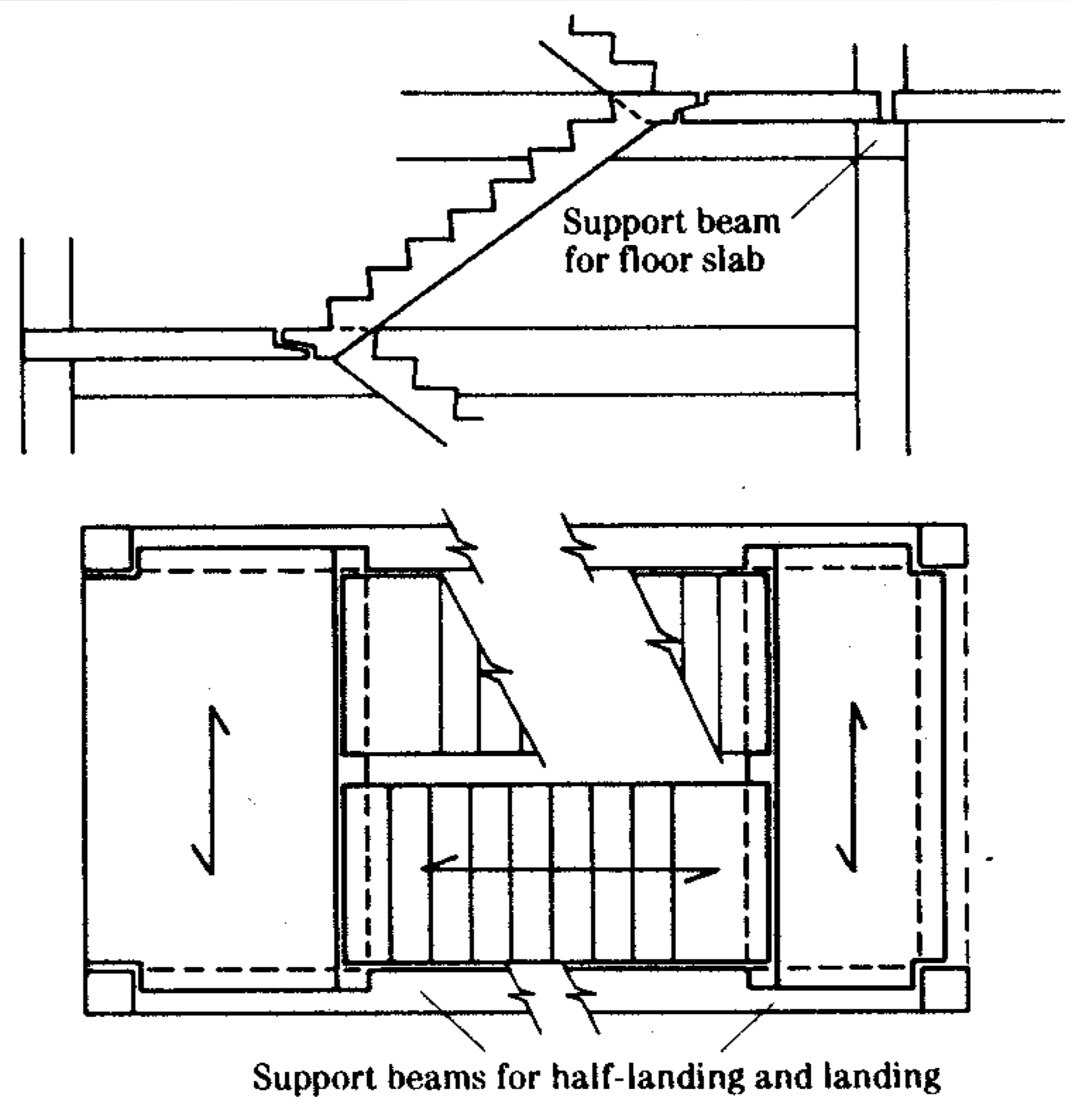
- **Wall to floor connection**

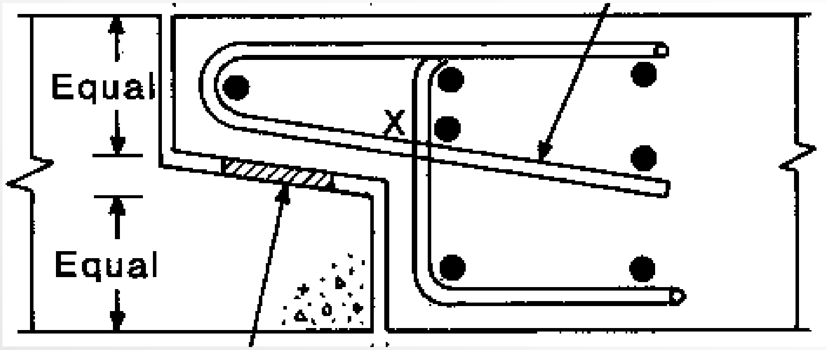



**Typical section through internal load bearing wall**

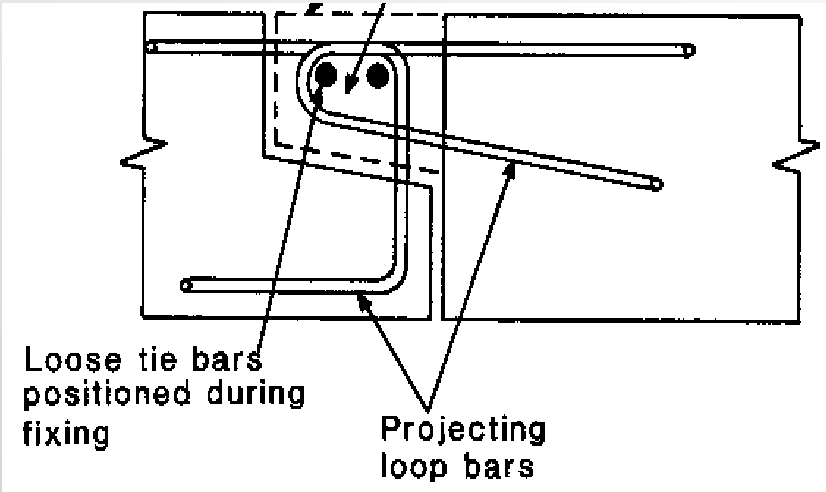
# Detailing

- **Stairs**




(a) Reinforcement in stair scarf joint




(b) intermittent scarf joint

**Staircase to landing joint details**

# Detailing

- **Ineffective positioning of tie bars**

# *fib* Guide to good practice

1. Terms and definitions
2. General
3. Actions and properties for good structural response
4. Strategies to cope with accidental actions
5. Design methods to prevent progressive collapse
6. Detailing
7. Calculation examples