New *fib*-handbook

Planning and design of precast concrete building structures

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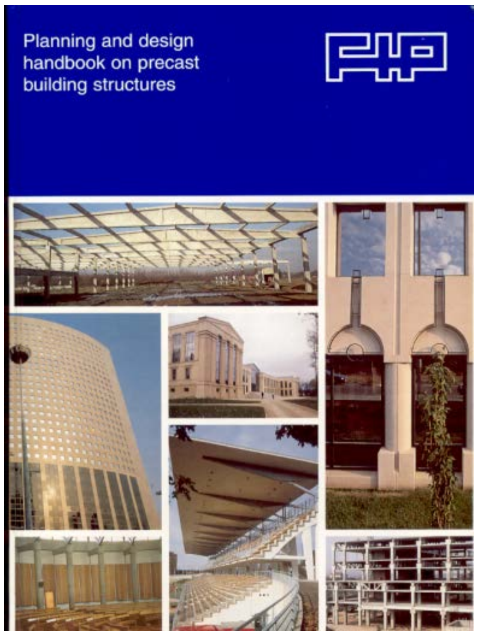
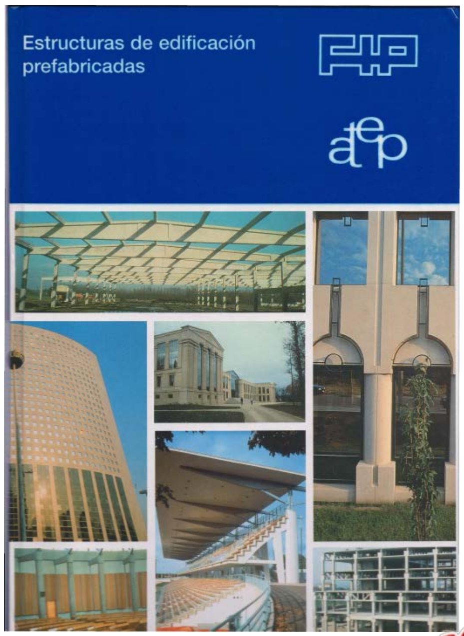
First edition in 1994





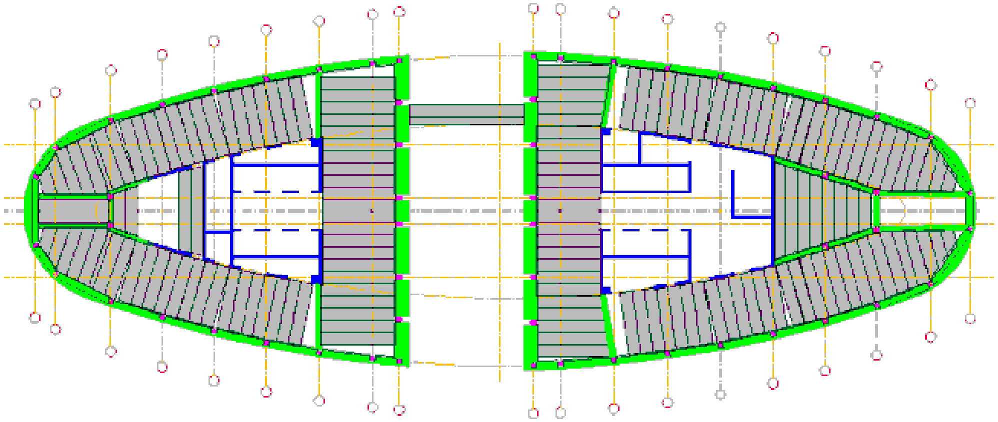
45000 books printed

Scope

- Precast building systems
- Specific design philosophy precast construction
- No general concrete calculations but specific aspects related to prefabrication
- Principles and detailing of connections
- Specific construction detailing

Content of the handbook

- Chapter 1 Suitability for precast construction
- Chapter 2 Preliminary design considerations
- Chapter 3 Precast building concepts
- Chapter 4 Structural stability precast buildings
- Chapter 5 Structural connections
- Chapter 6 Portal and skeletal structures
- Chapter 7 Wall frame structures
- Chapter 8 Precast floors and roofs
- Chapter 9 Architectural concrete façades
- Chapter 10 Constructional detailing and dimensional tolerances
- Chapter 11 Fire resistance



Chapter 1

SUITABILITY
PRECAST CONSTRUCTION

Suitability precast construction

- Advantages and limitations
- Differences between precast and cast in-situ construction
- Opportunities with prefabrication
- Quality assurance and product certification
- Best practices with precast concrete

Differences with cast in-situ

Cast in-situ

- Traditional
- High labour
- Long construction delays
- Much waste
- Large finishing work
- Weather conditions

3D

Precast

- Modern technology
- Limited labour
- Fast construction
- Limited waste
- Finished surfaces
- No adverse weather conditions
- Easy
- Large design flexibility
- **Modern technology and organisation**

Opportunities

Forerunner in development of construction

Construction delay **Quality** **Efficiency**

Concrete technology

SCC

Environment **Economy**

Best practices with precast concrete

- Overview typical realisations in market segments

Tower buildings

Chapter 2

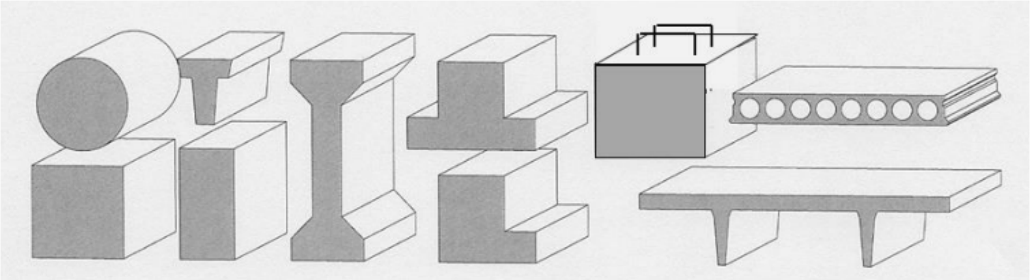
PRELIMINARY DESIGN CONSIDERATIONS

Preliminary design considerations

- Basic design principles
- Conceptual design principles in earthquake regions
- Design stages
- Selection of structural precast system

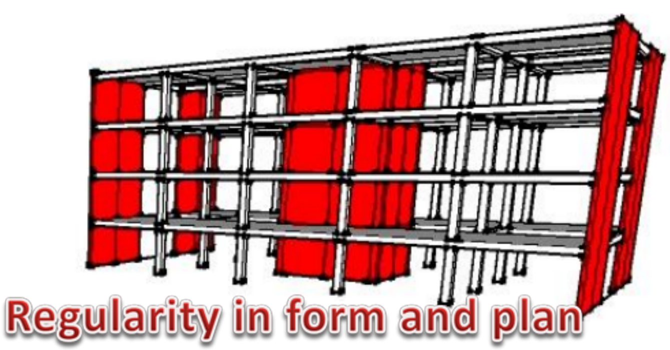
Basic design principles

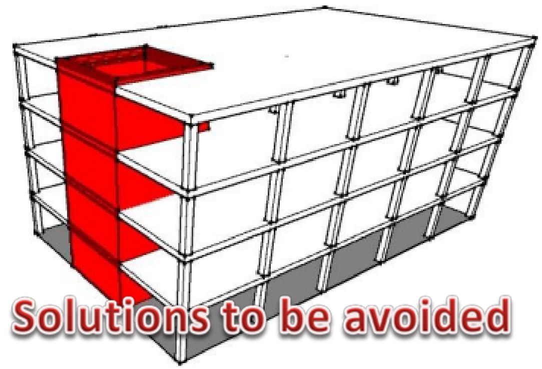
- Respect the specific precast design systems
- Use standard solutions whenever possible
- Details should be simple
- Take account of dimensional tolerances
- Take advantage of industrialisation
- Modulation is recommendable
- Standardisation of products and processes



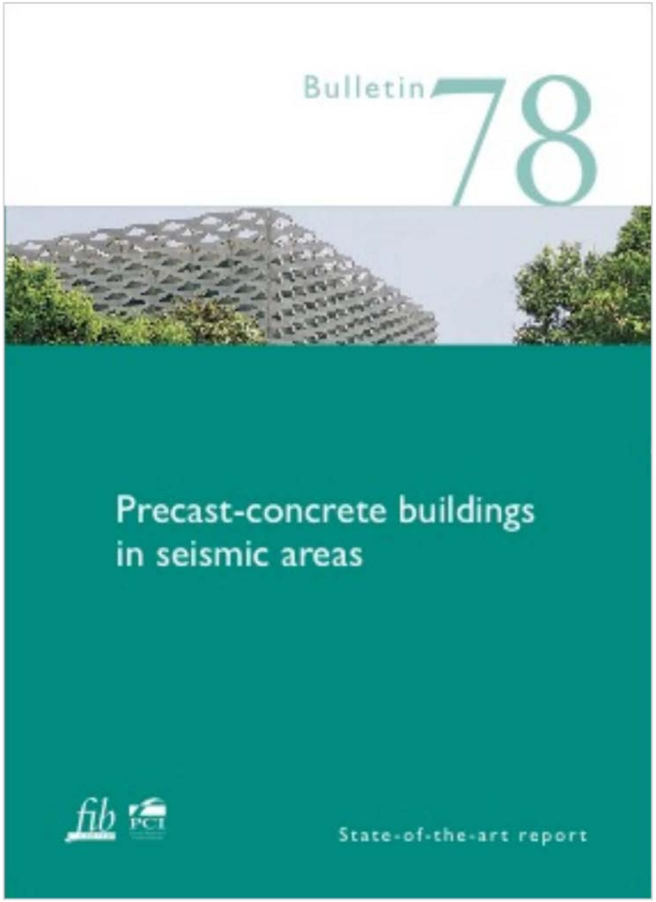
Conceptual earthquake design principles

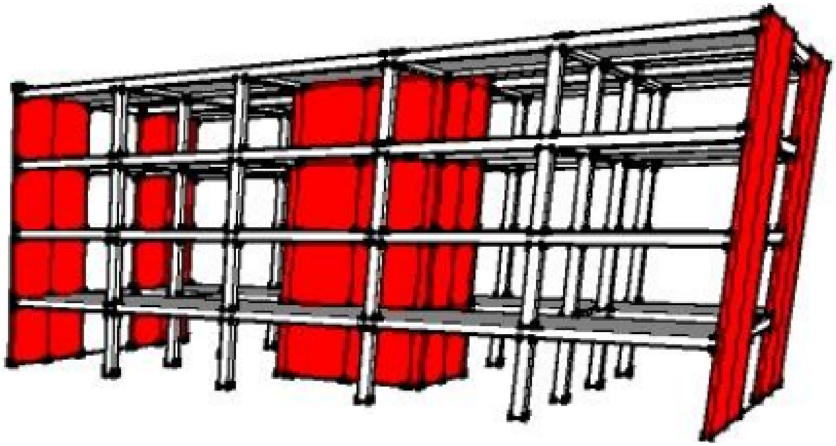
- Structural simplicity
- Regularity and uniformity in plan
- Regularity and uniformity in height
- Bi-directional resistance, torsional resistance and stiffness
- Adequate and secure connections in precast buildings
- Adequate foundation
- Effects of the contribution of infills, partitions, and claddings

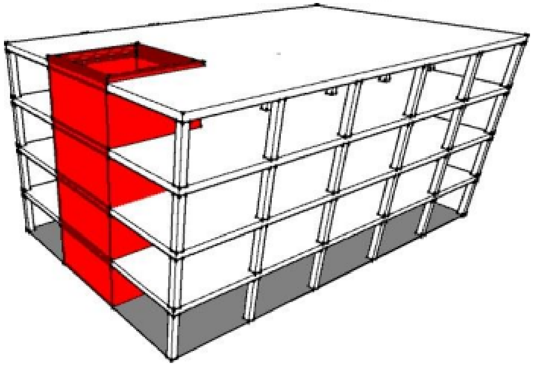




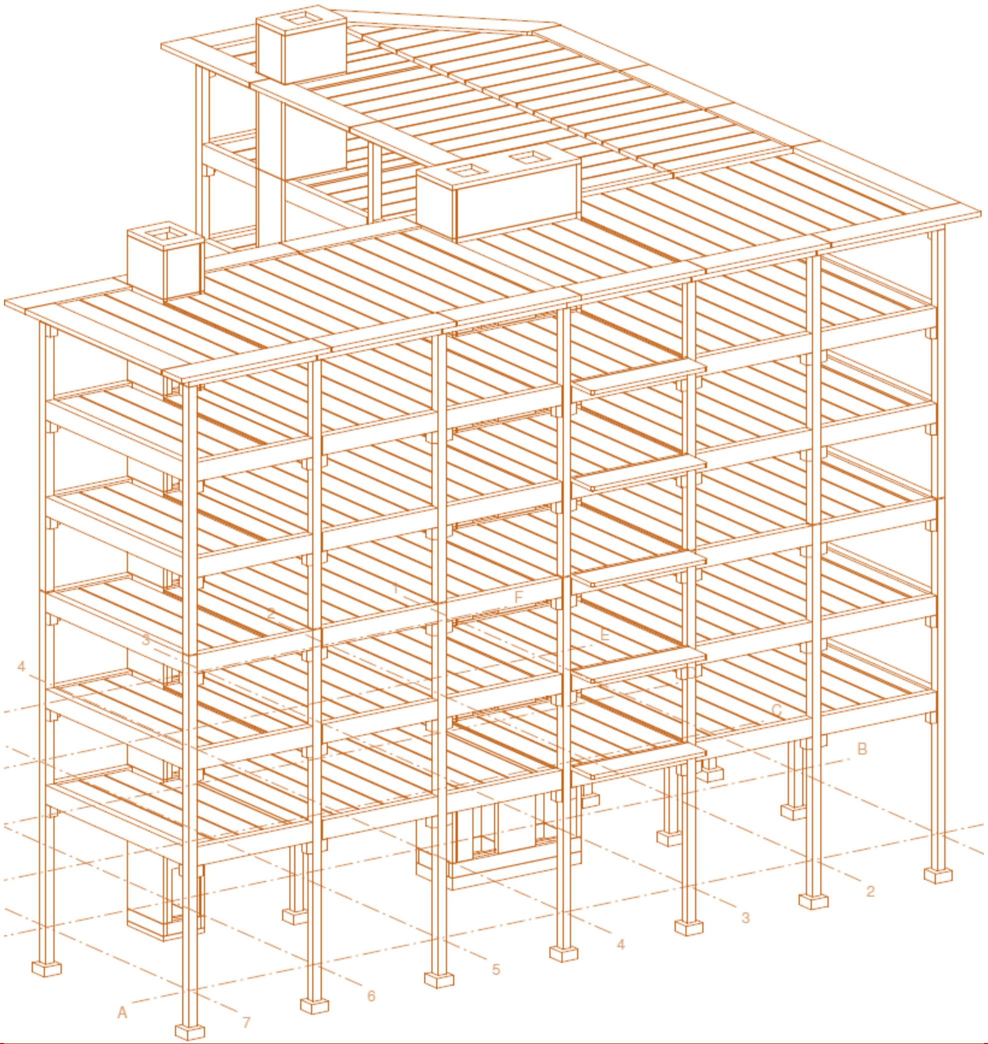
Conceptual earthquake design principles







Design stages



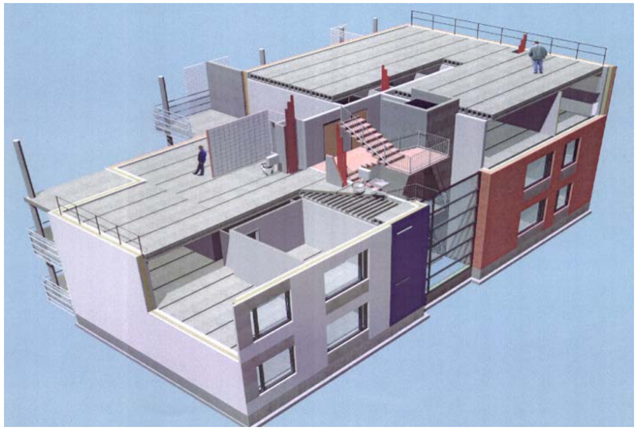
- First step: general layout of the floor plan and vertical and horizontal circulation
- Second step: selection of the precast structural system
- Third step: choice of the column grid and floor span
- Fourth step: choice and implantation of the stabilising components
- Fifth step: choice and preliminary dimensioning of the precast beam and floor units
- Sixth step: choice of the façade cladding

Selection of precast system

Portal structures

Skeletal structures

Bearing wall structures



Floors and roofs

Façade systems

Cell structures

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Chapter 3

PRECAST BUILDING SYSTEMS

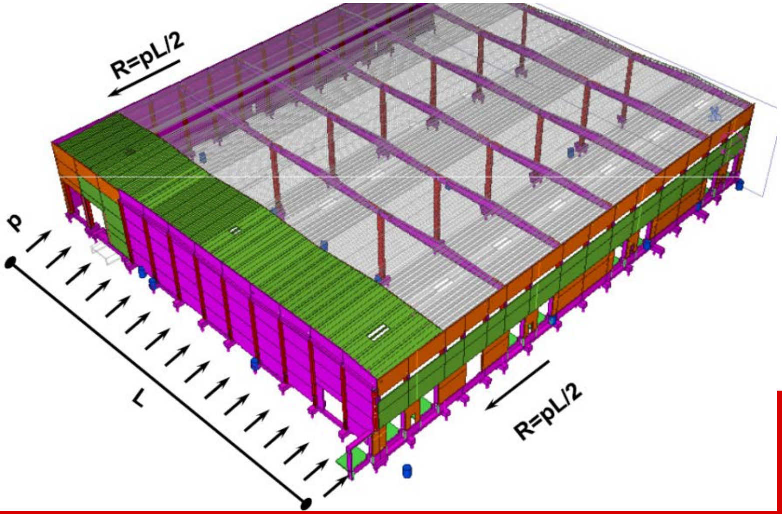
Precast building systems

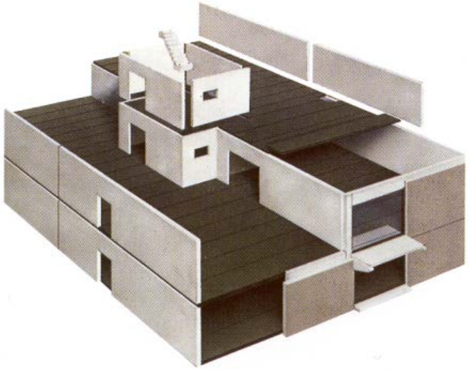
- Structural systems
  - Portal and skeletal structures
  - Wall frame structures
  - Floor and roof structures
  - Precast façades
- Applications
  - Housing and apartments
  - Offices and administrative buildings
  - Hotels, hospitals
  - Educational buildings
  - Commercial buildings
  - Car parks
  - Sport facilities

Constructional systems

load bearing systems

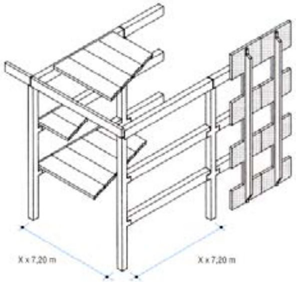
Portal structures





Wall frame structures

Skeletal structures



Constructional systems

Complementary systems

Stairs

Floors

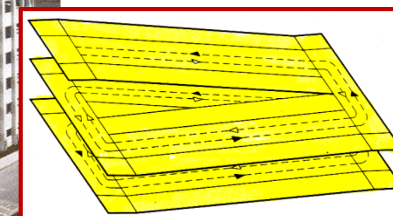
Façades in precast concrete

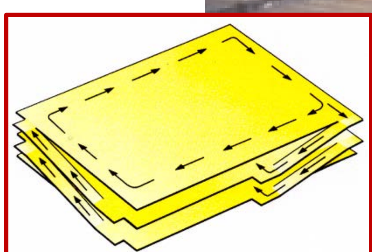
Examples of applications

Car parks

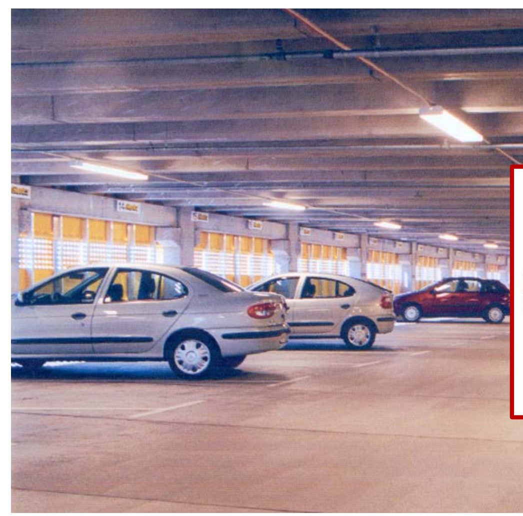
Underground park

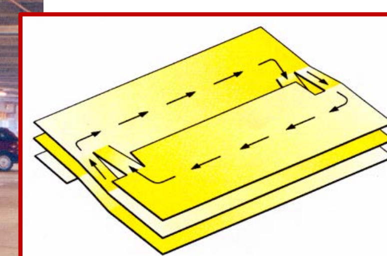
Slooping floor system



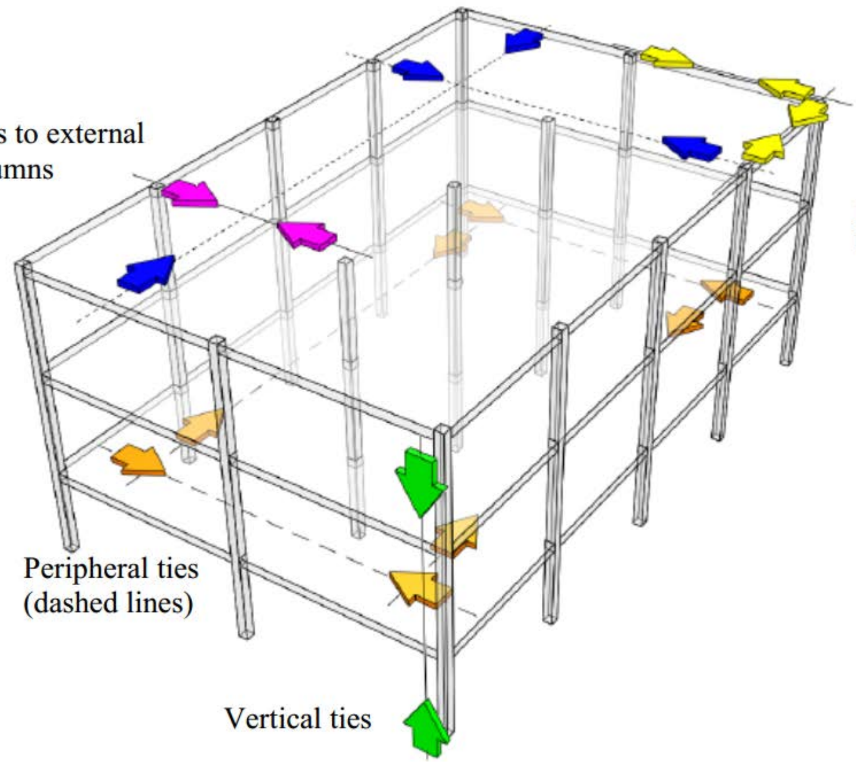


Flat parking deck





Split level system



Chapter 4

STRUCTURAL STABILITY

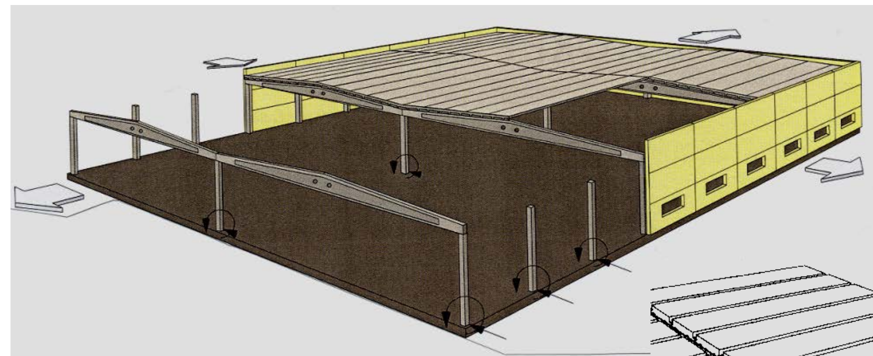
Structural stability

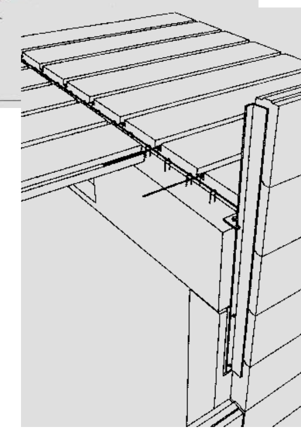
- Prefabrication shall be designed according to a specific philosophy which is different from in-situ construction
- Stability concepts
  - Unbraced structures
  - Braced structures
- Floor diaphragm action
- Expansion joints
- Structural integrity
- Design with regard to accidental actions

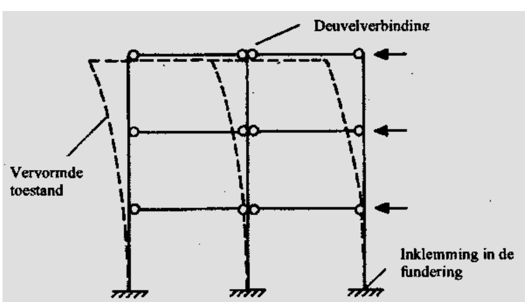
Unbraced structures

- Columns restrained into foundations
- Diaphragm action floors and roofs
- Diagonal bracing

Interaction between columns by diaphragm action of the roof







Schematic deflection of unbraced skeletal structure

Steel diagonal cross bracing

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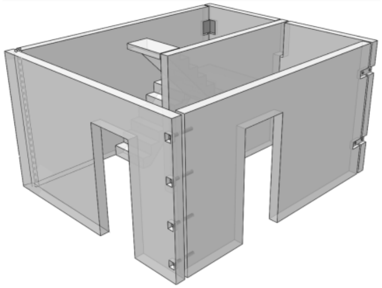
Braced structures

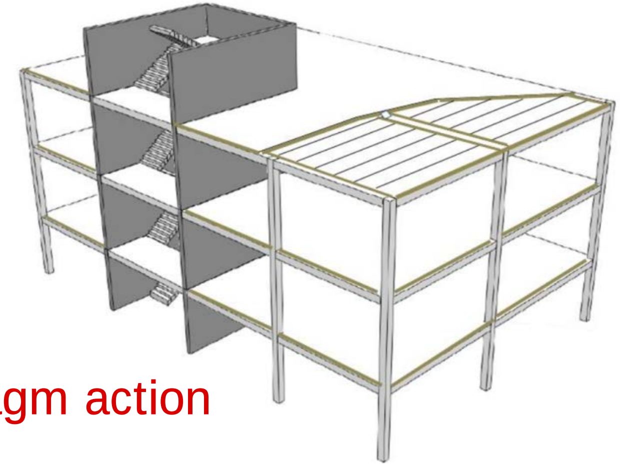
- Principle
- Cross wall action
- Central core and lift shafts
- Diaphragm action floors
- Structural integrity
- Tying systems

Stability through central cores



Precast central core

Stability through cross wall action



Floor diaphragm action

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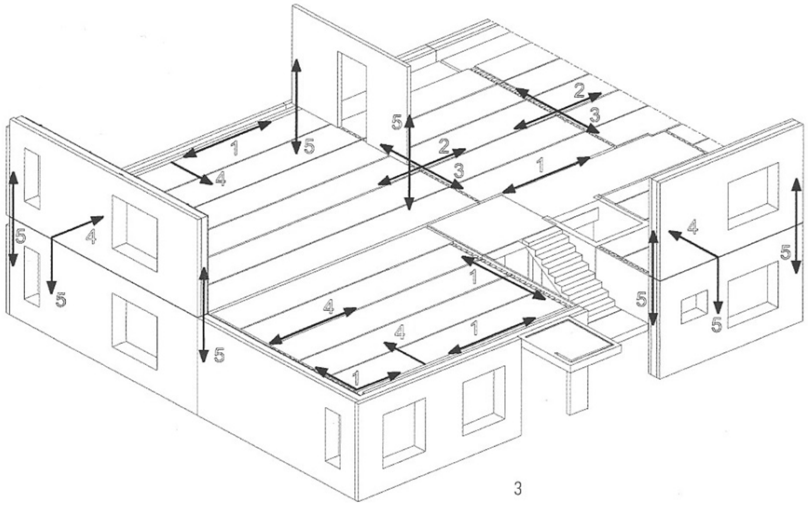
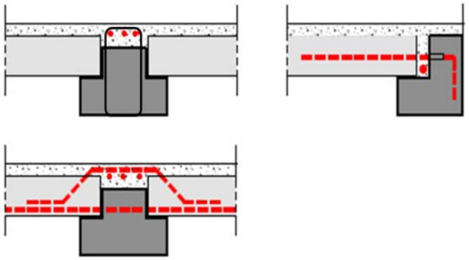
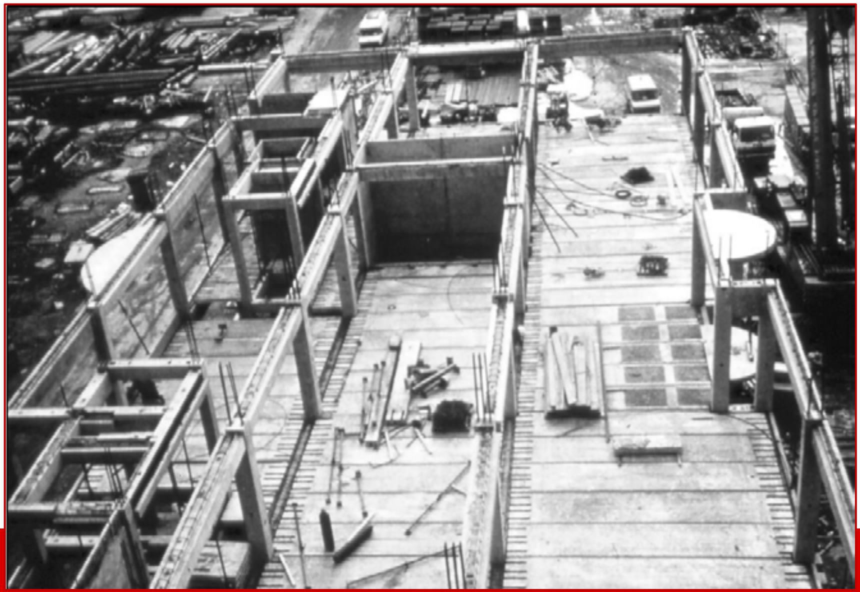
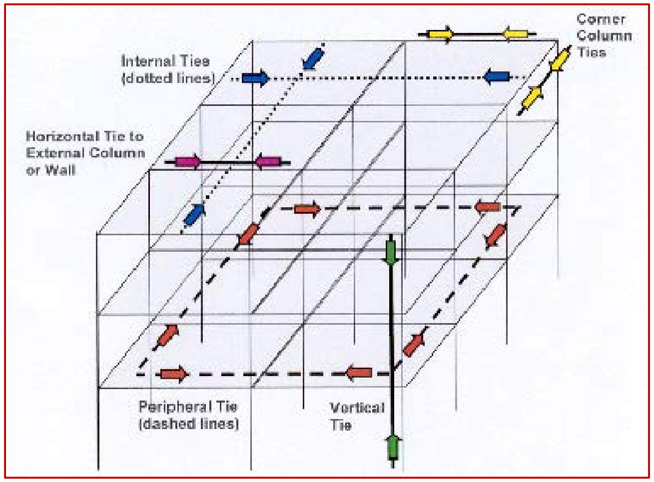
Structural integrity



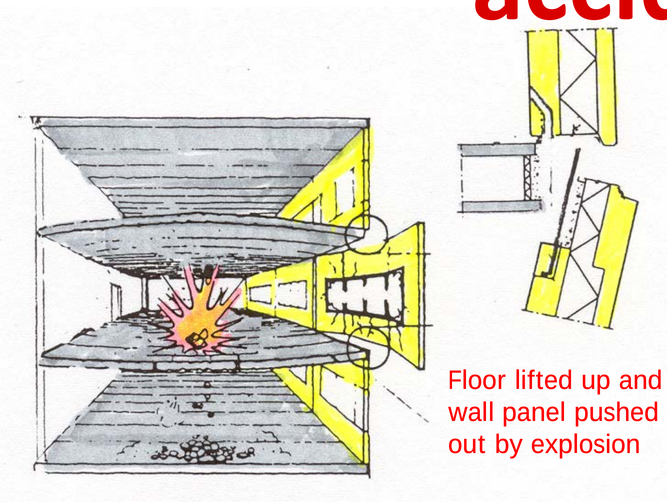
1. Peripheral floor ties
2. Longitudinal internal ties
3. Transversal internal ties
4. Floor to wall ties
5. Vertical ties



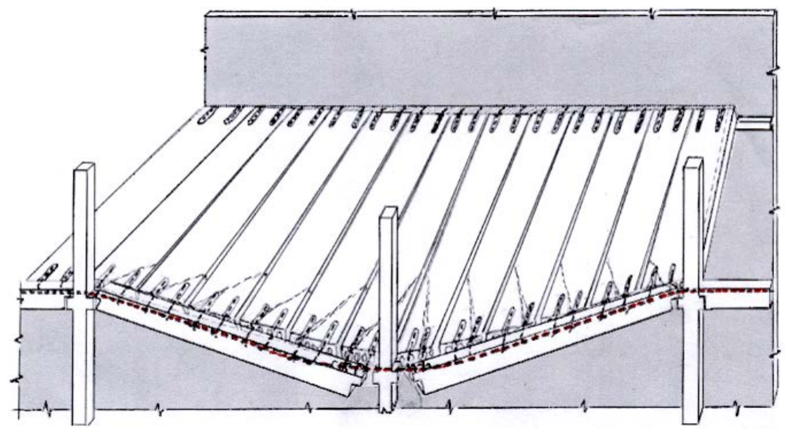




Design with regard to accidental actions

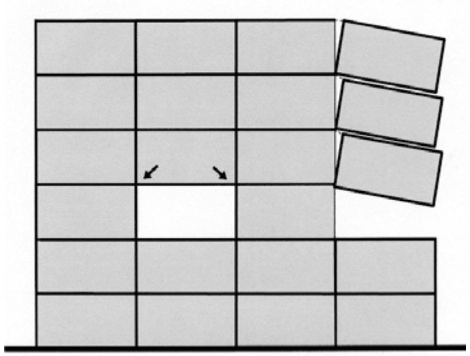


Phenomenon

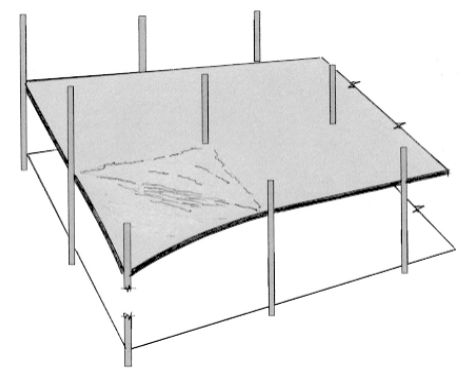


Catenary action

- Design strategies
- Tie force method
- Alternative load path method
- Specific load resistance method



Beam or arch action   Cantilever action



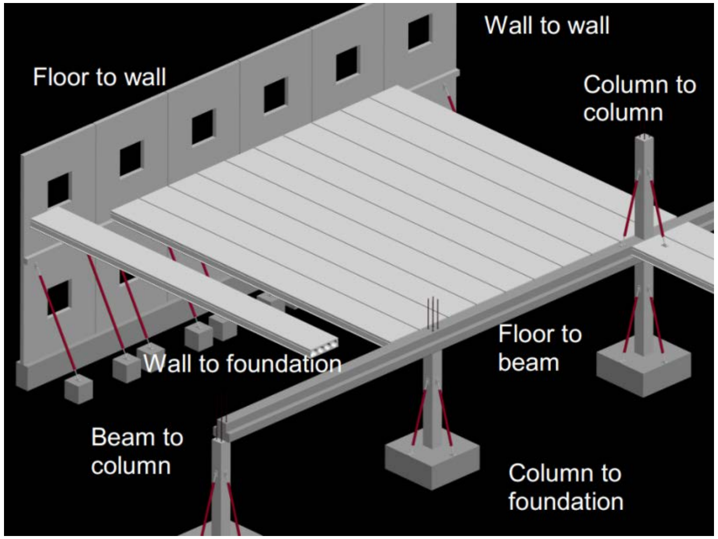
Membrane action

Chapter 5

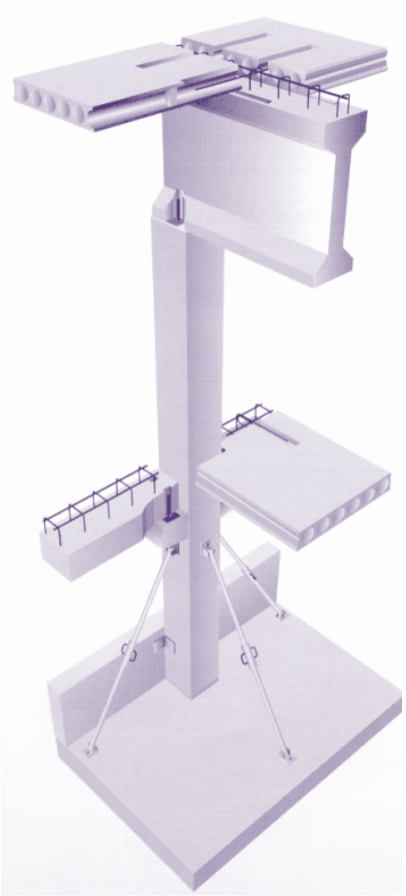
STRUCTURAL CONNECTIONS

Structural connections

- Objectives
- Design criteria
- Basic force transfer mechanisms
- Design of structural connections
- Other design criteria

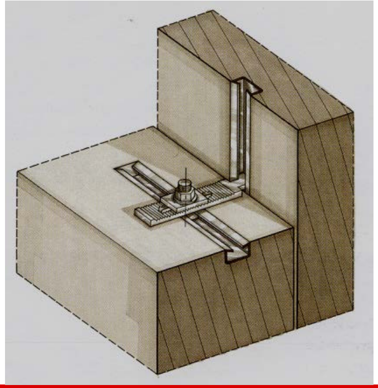


The purpose is to realise a coherent and robust structure out of individual units

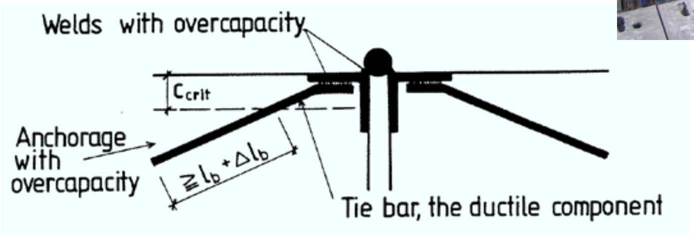


Design criteria

- Structural behaviour
  - Strength: resist forces during whole lifetime. Consider also the possibility of accidental actions
  - Absorb possible volume changes :shrinkage, creep, temperature
  - Allow movements
  - Ductility
  - Durability
- Dimensional tolerances
  - Possibilities for adjustment during erection
- Fire resistance



3-dimensional adjustemt

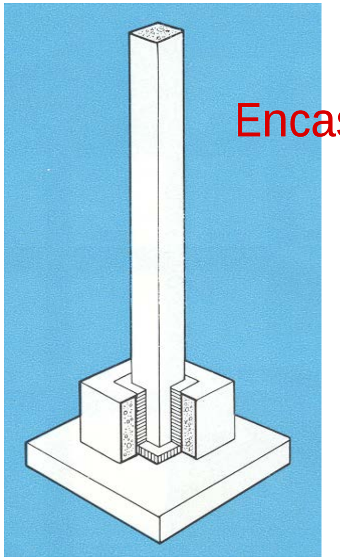


Ductility

Coherent and robust structure

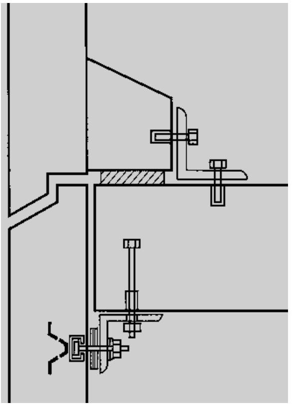
Basic force transfer mechanisms

- Encasing
- Lapping of reinforcing bars
- Dowel action
- Bond
- Friction + shear interlock
- Shear keys
- Staggered joints
- Bolting
- Bars in grout ducts
- Welding
- Post tensioning

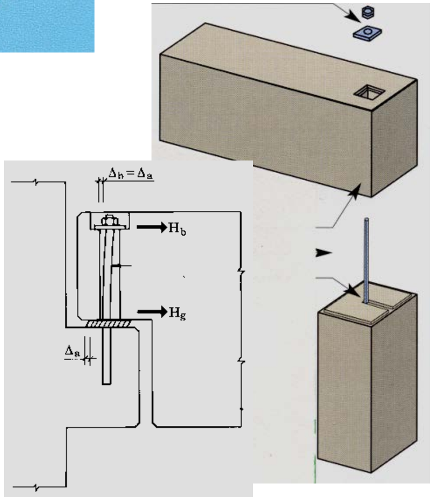


Encasing

Lapping



Bolting or welding



Dowel action

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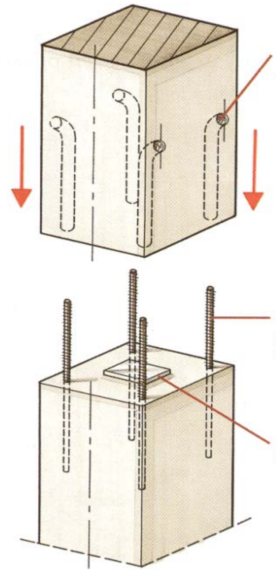
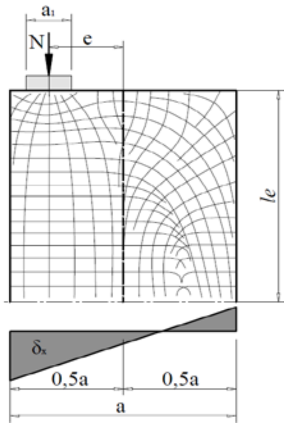
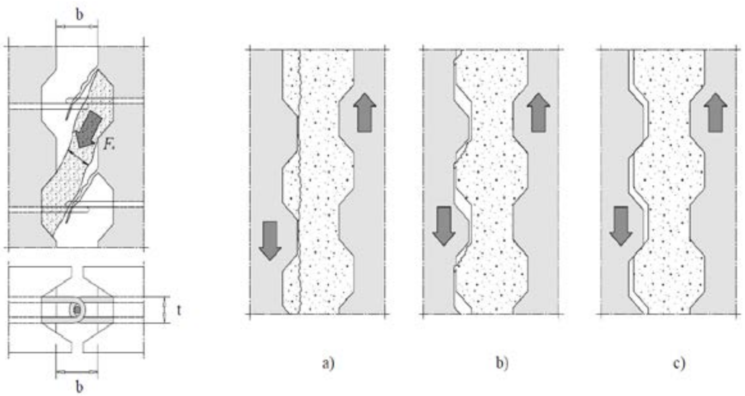
Design of structural connections

- Transfer of compressive forces
- Transfer of tensile forces
- Transfer of shear forces
- Transfer of bending and torsion



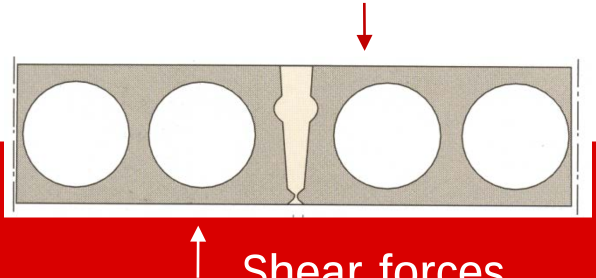


Compressive forces



Force transfer and failure modes

Torsion



Shear forces

Chapter 6

PORTAL & SKELETAL STRUCTURES

Portal & skeletal structures

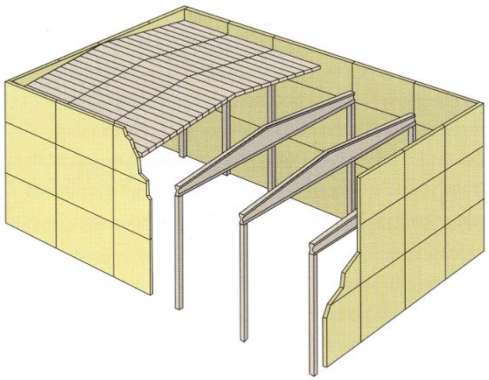
- Types of linear precast structures
- Lay-out and modulation
- Stability
- Elements
- Typical connections

Skeletal structures

Portal structures

Existing systems

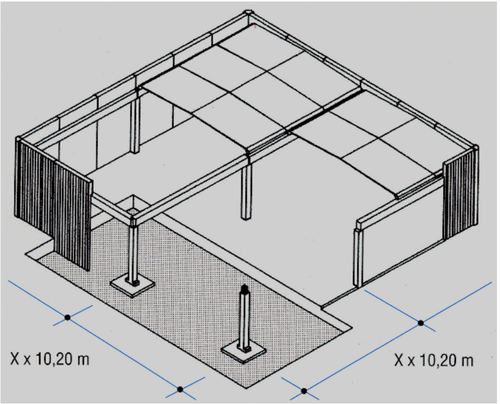
Portal structures (idem for skeletal)



Simple portal frames

Portal frames with purlins

Portal frames with intermediate floor



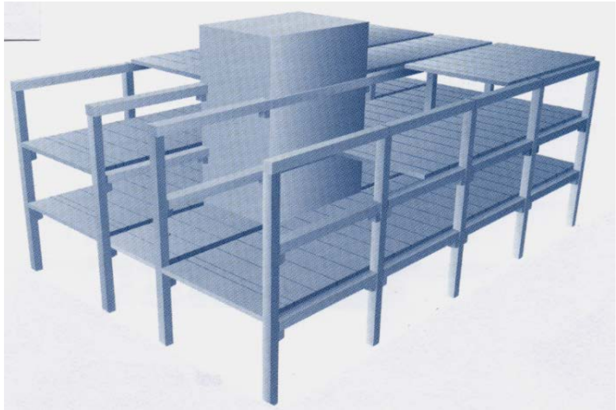
Portal frames with saddle roof units

Structural stability

- Cantilevering columns from the foundation
- Cores and shear walls

~ 3 storeys

> 3 storeys



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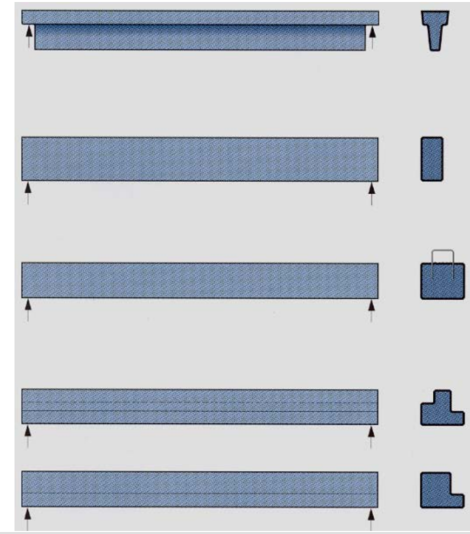
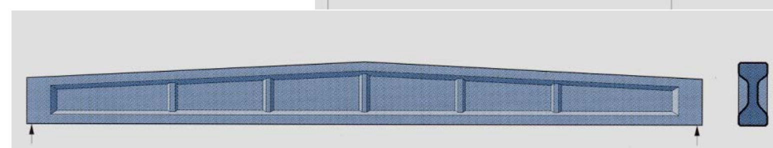
Elements

- Columns
- Roof beams
- Purlins
- Floor beams


Columns

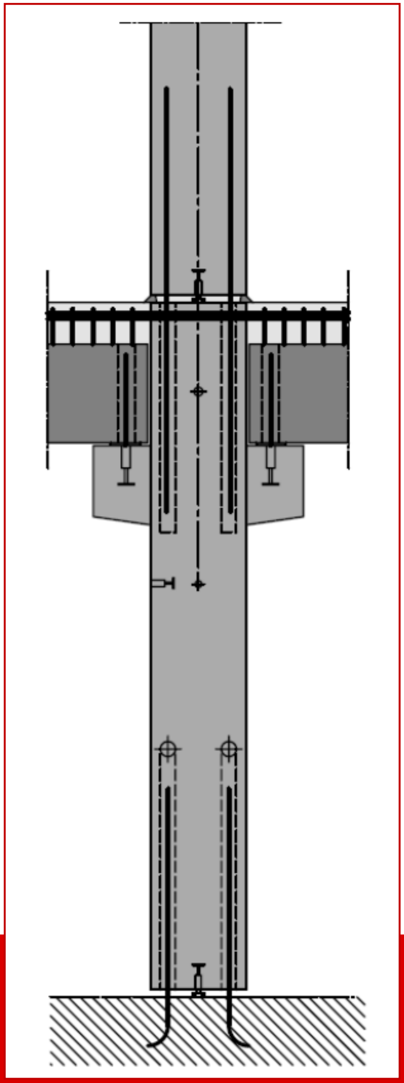

Floor beams

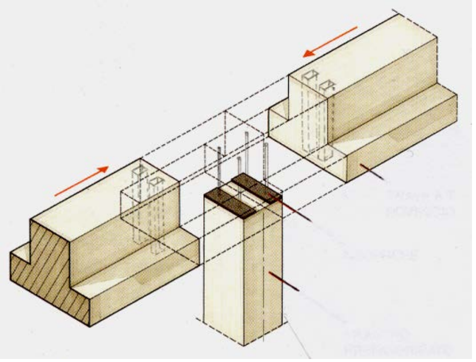
Spandrel beams


Roof beams

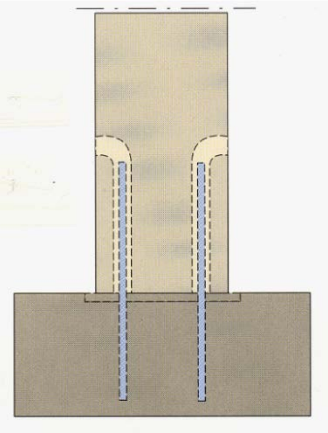
Typical connections

Examples of connections in portal and skeletal structures





Floor beams to columns



Projecting bars from
the foundation

Chapter 7

WALL FRAME STRUCTURES

Wall frame structures

- Structural wall frame systems
- Modulation
- Structural stability
- Elements
- Examples of connections

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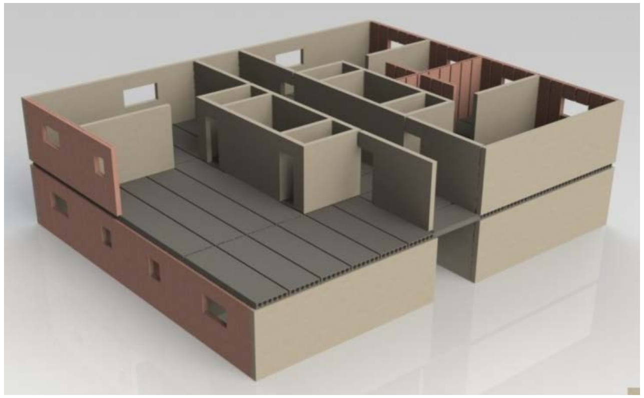
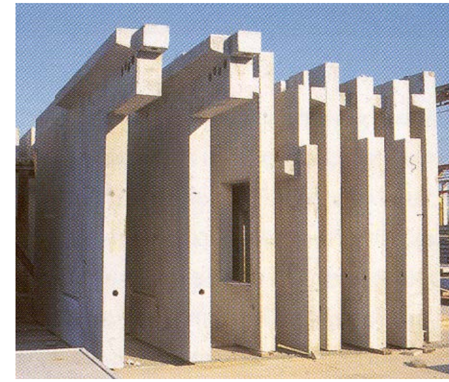
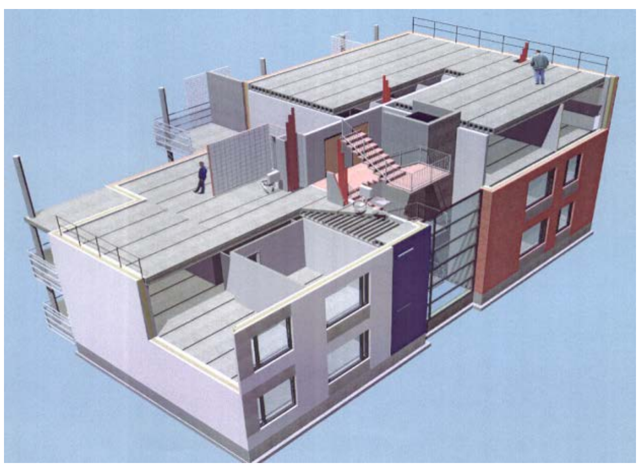
Structural wall frame systems

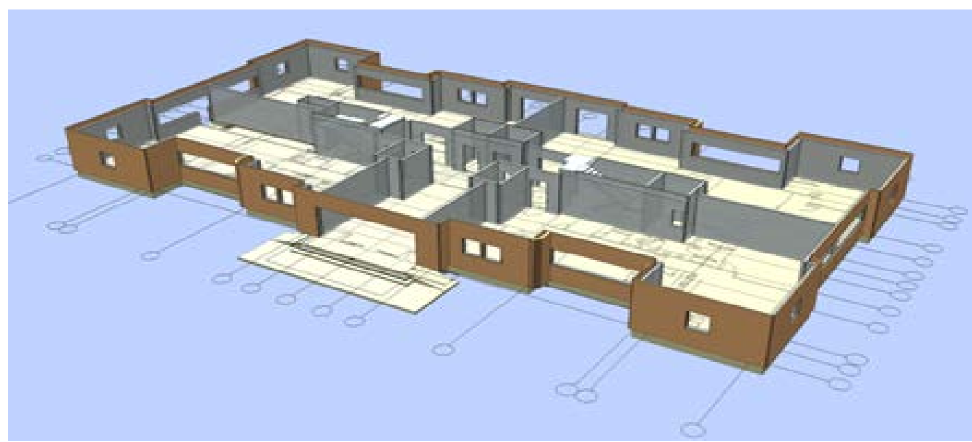


Integral wall system



Enveloppe wall system



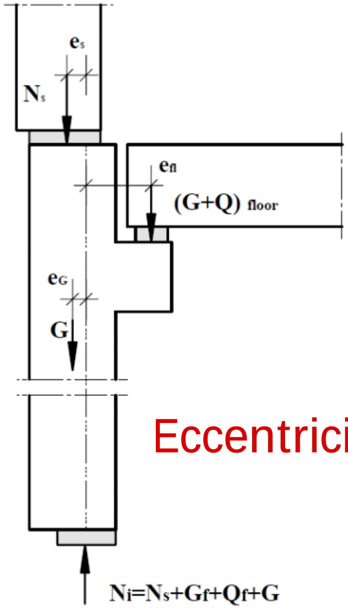


Cross wall system

Spine wall system

Structural stability

- Elements
  - Eccentricity of floor support
  - Eccentricities between superposed walls
  - Geometrical deviations
- Horizontal stability
- Robustness



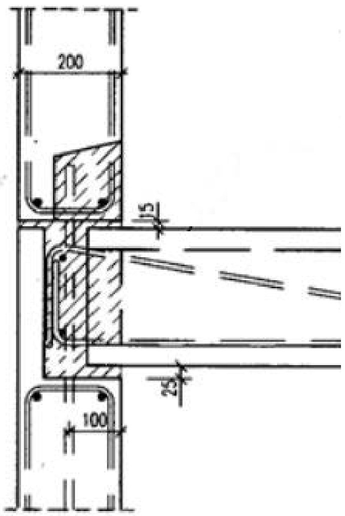
Eccentricities

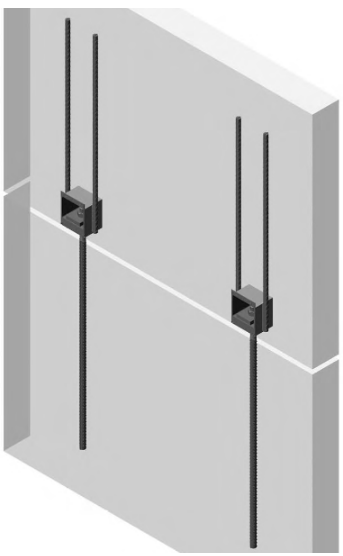
Cores and lift shafts

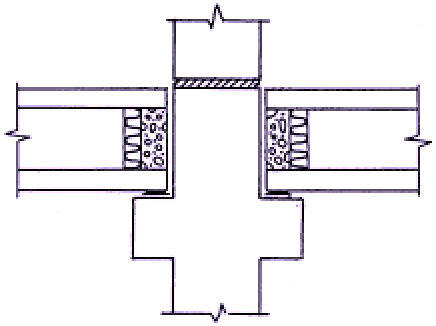
Tube action

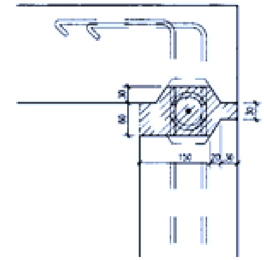
Typical connections

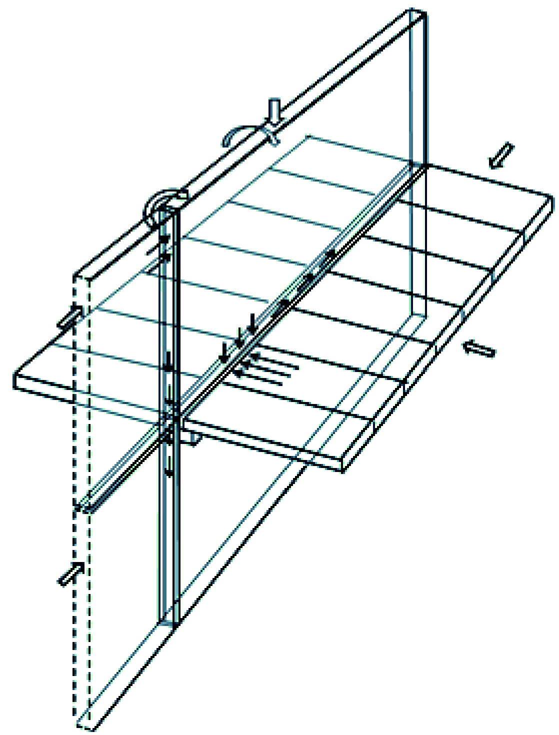
- Wall to wall connections
- Wall to floor connections

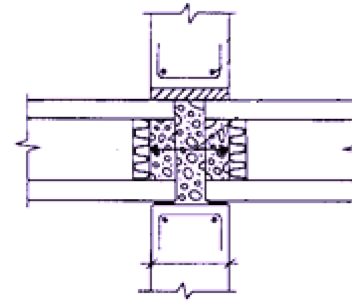


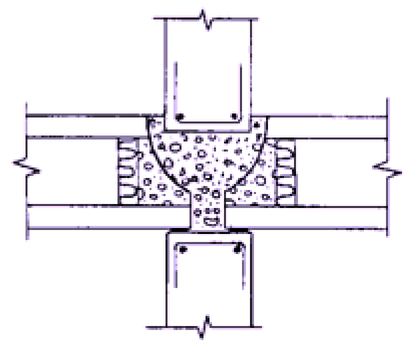












Chapter8

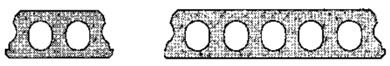
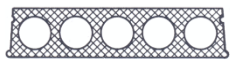
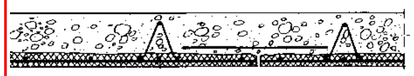
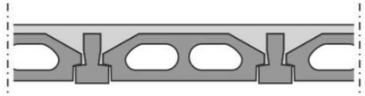
FLOORS & ROOFS

Floors and roofs

- Main types of precast floors
- Concrete roof elements
- Stairs
- Modulation
- Design of the floor elements
- Design of the complete floor
- Transverse load distribution
- Examples of typical connections

Overview

types and characteristics

Floor and roof types	Max. span in m	Floor thickness mm	Unit width m	Unit weight kN/m²
	7	120 - 200	300 - 600	2,1 – 3,2
	20	120 - 500	600 – 1200 - 2400	2.2 – 5.2
	12	175 – 355	2400	1.2 – 1.8
	24 -30	200 – 800	2400 – 3000	2.0 – 5.0
	6	100 - 200	300 - 600	0,7 – 3,0
	7 - 10	100 – 400	600 – 2400	2.4 – 4.8
	6	200 - 220	515 - 635	1,7 - 2,3

Main types of floors and roofs

- Hollow core and ribbed floors
  - Types and dimensions
  - Modulation
- Concrete roof elements
- Floor plates
- Stairs
- Modulation

Hollow core floors

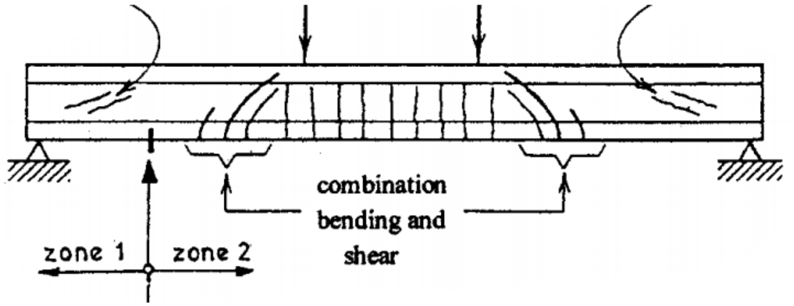
Precast stairs

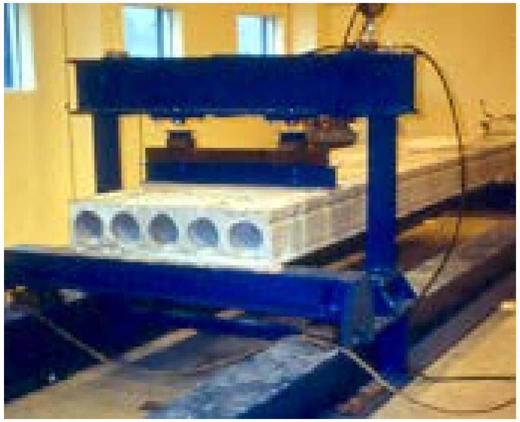
Ribbed floors

Floor-plate floors

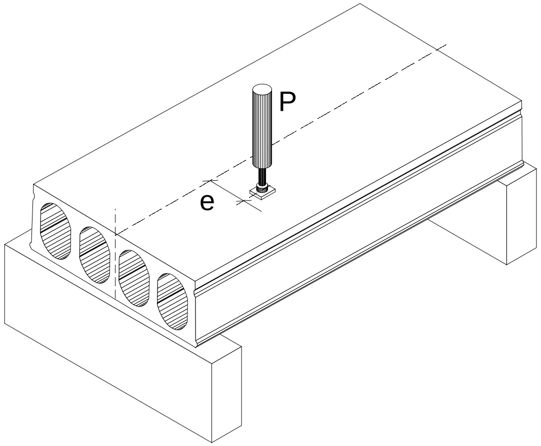
Design of precast floor elements

- Prestressed hollow core floors units
  - Shear capacity
  - Punching resistance
- Ribbed floor units
- Floor plates

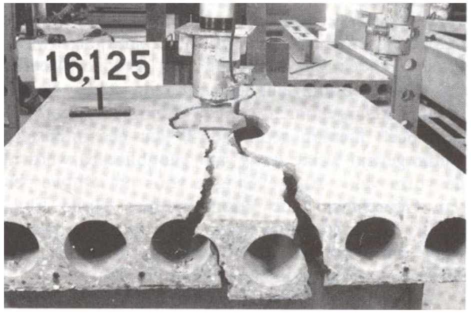




Shear capacity



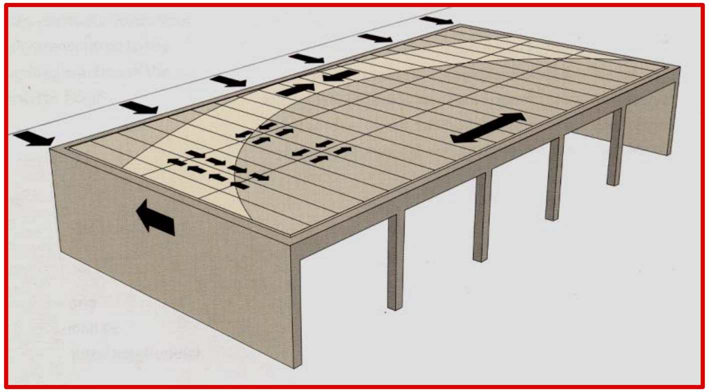
Shear & torsion



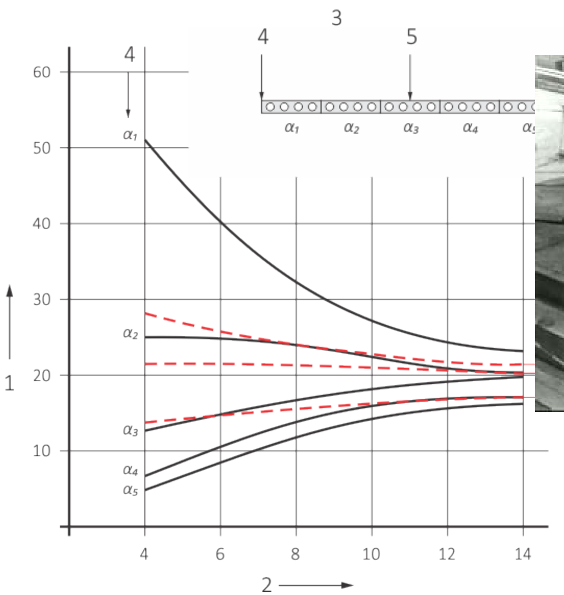
Punching resistance

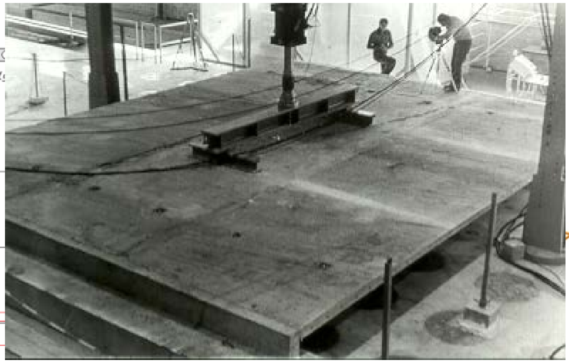
Design of the complete floor

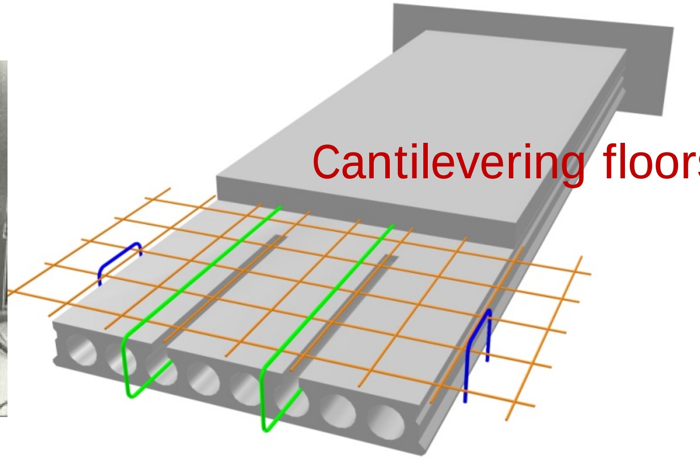
- Structural integrity
- Diaphragm action
- Transversal load distribution
  - Hollow core floors
  - Ribbed floors
  - Composite floors
- Cantilevering floors and balconies



Diaphragm action







Cantilevering floors

Transversal load distribution

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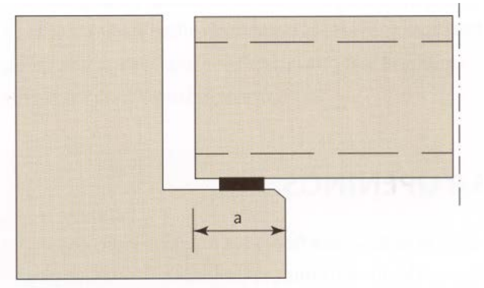
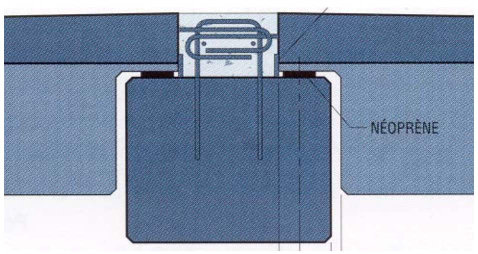
Typical connections

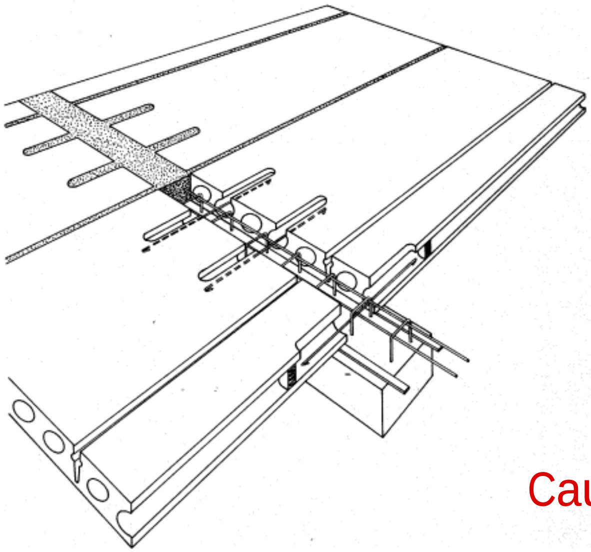
- Support connections
  - Support length
  - Tie arrangements
- Connections at lateral joints

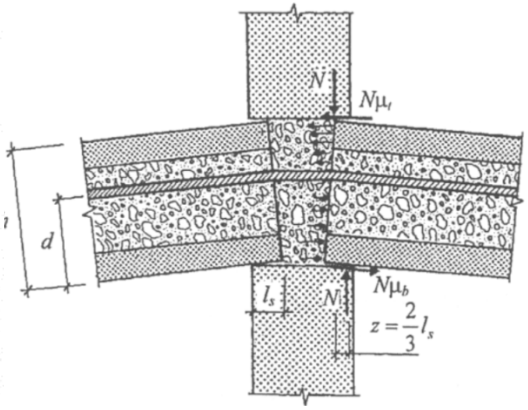
Mixed structure



Support connection







Causes of unintended restraint

Chapter 9

ARCHITECTURAL
CONCRETE FACADES

Architectural concrete facades

- Precast façade systems
- Structural stability
- Principles of design and dimensioning of the units
- Other design aspects
- Shape and dimensions of the elements
- Surface finishing
- Thermal insulation
- Panel fixings
- Weathering joints

Architectural concrete facades

Examples of applications

Housing

Industry

Offices

Schools

Hotels Sport facilities

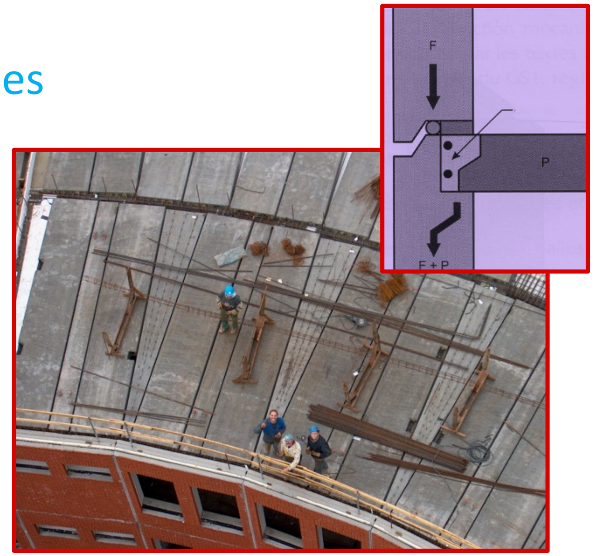
Shopping malls

Culture

Shops

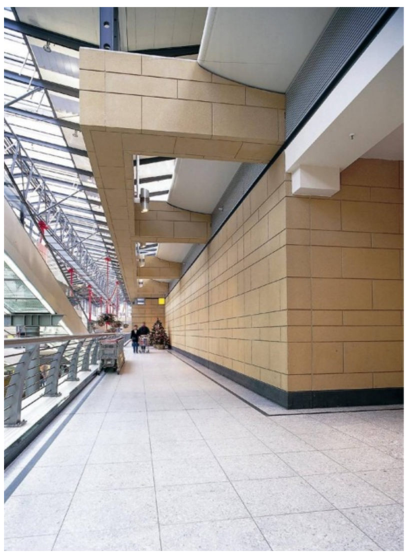
Structural systems

- Load bearing façades
- Non-load bearing façades
- Twin skin façades
- Cladding panels



Load bearing façades

Non-load bearing façades

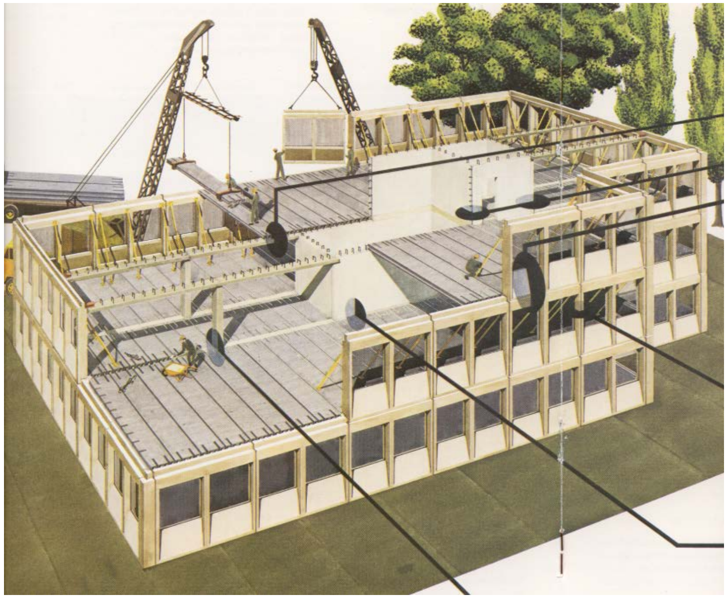


Cladding panels

Twin skin system

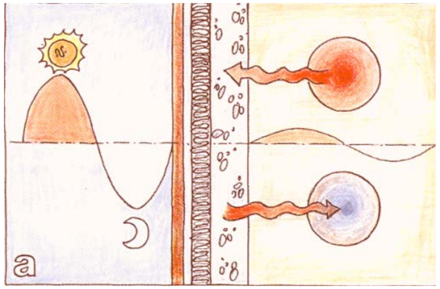
Structural stability

- Stability provided by core and shear wall action
- Stability provided by the façade
- Differential deformations



Cores and shear walls

Load bearing façades



Differential thermal deformations

Shape of the units and finishing

- Shape in relation to moulds
- Preferential dimensions
- Modulation
- Surface finishing
- Faced panels

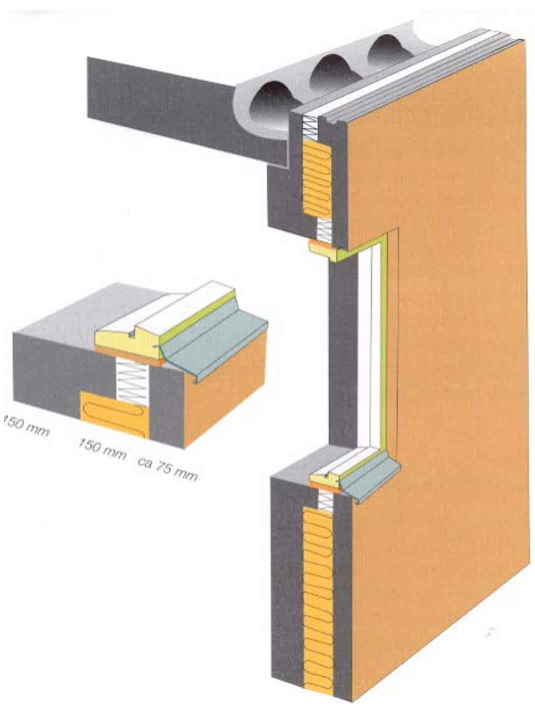
Storey high panels

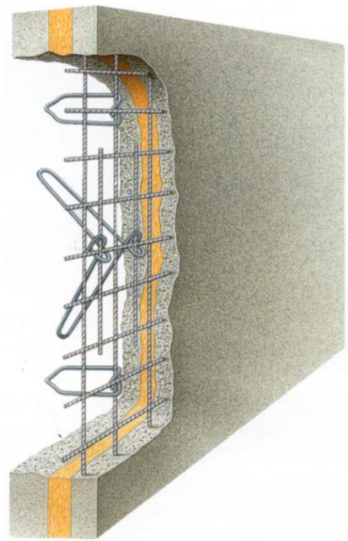
Granite facing

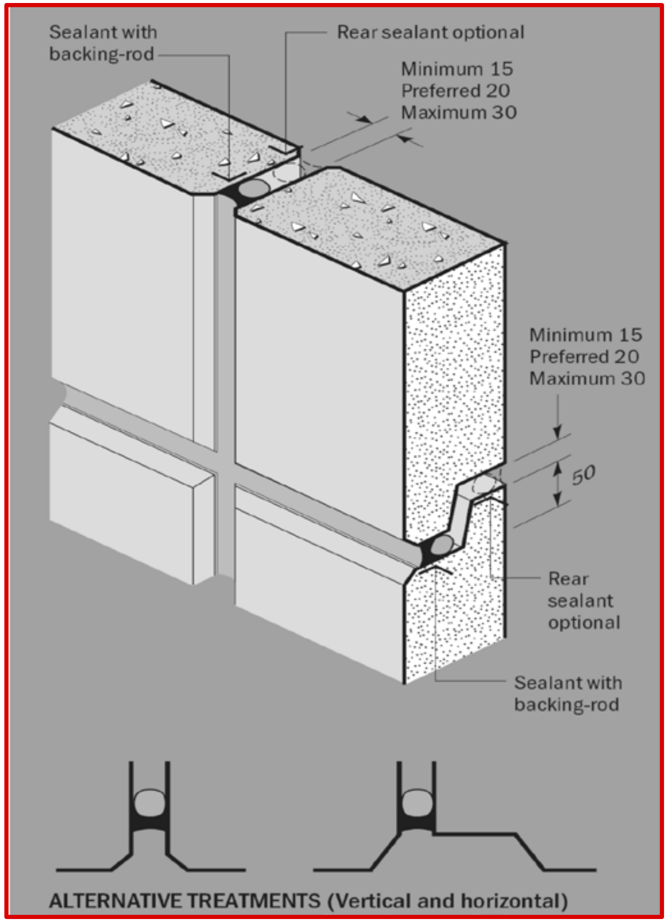
Polishing

Building physics

- Thermal insulation (sandwich panels)
- Weathering joints







Joint sealants

Sandwich Panels

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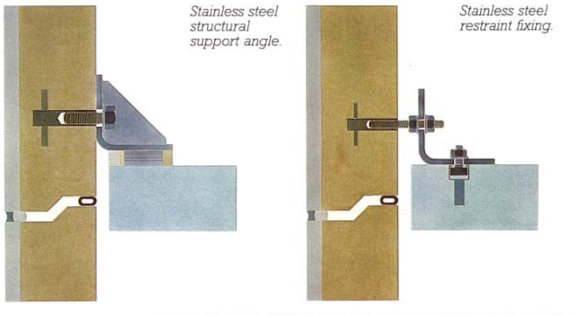
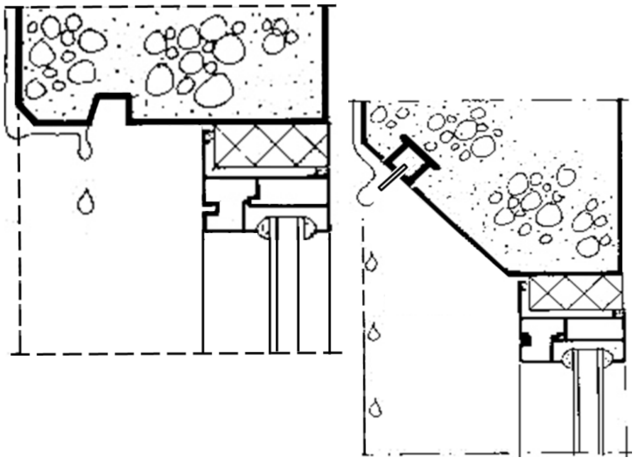
Typical connections

- Projecting bars
- Bolted and welded connections
- Durability



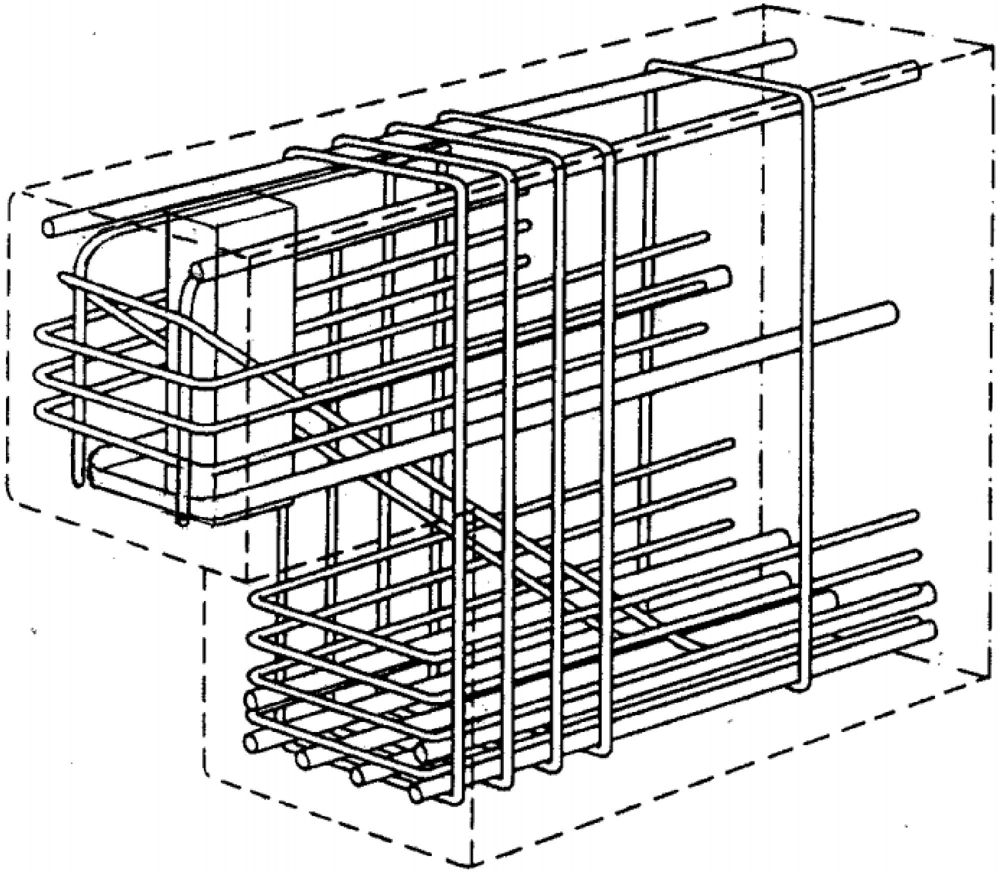
Bolted connections

Projecting bars with in-situ concrete



Weathering joints

Projecting bars in grout holes



Chapter 10

CONSTRUCTIONAL DETAILING

AND DIMENSIONAL TOLERANCES

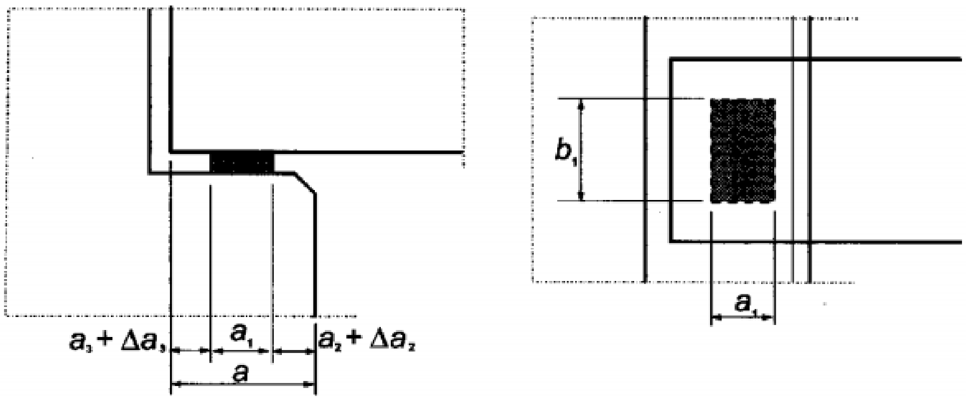
CONSTRUCTIONAL DETAILING

and dimensional tolerances

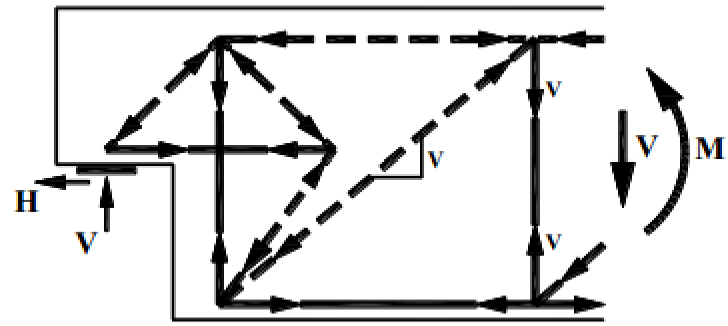
- Support connections
- Concrete corbels
- Openings and voids
- Inserts
- Special reinforcement detailing

Supports

- Support length



Normal support



Half joints

$$a = a_1 + a_2 + a_3 + \sqrt{\Delta_2^2 + \Delta a_3^2}$$

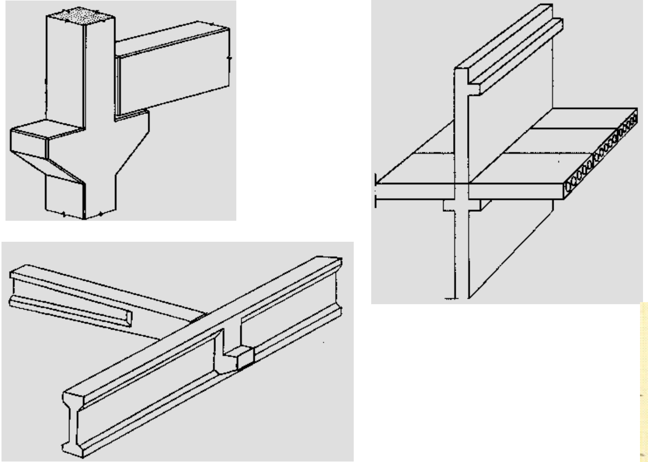
->Table with practical values for nominal support length

Nominal support length "a"

Supported element	Supporting structure	Slab thickness h or beam length l	Minimum nominal support length
Hollow core floors	concrete/steel	h ≤ 300 mm	60 - 80 mm
		h > 300 mm	100 - 120 mm
	masonry	h ≤ 250 mm	100 mm
		h > 250 mm	120 mm
Floor planks	concrete		
	– with propping	-	30 mm
	– without propping		50 mm
	masonry	-	
	– with propping		40 mm
	– without propping		50 mm
Ribbed floors	concrete	ℓ ≤ 15 m	150 mm
Secondary roof beams	concrete	ℓ ≤ 8 m	140 mm
Floor beams	concrete	ℓ = 12 - 20 m	200 - 230 mm
Roof beams	concrete	ℓ ≤ 24 m	195 mm
		ℓ ≤ 40 m	225 mm

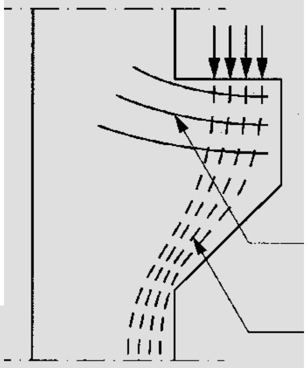
Concrete corbels

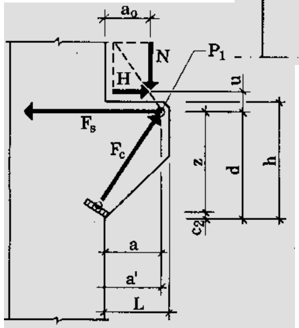
- Types of corbels
- Corbel design
- Detailing of corbel reinforcement
- Two-step corbels
- Hidden corbels

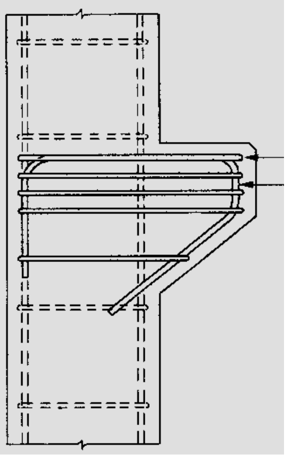


Types of corbels

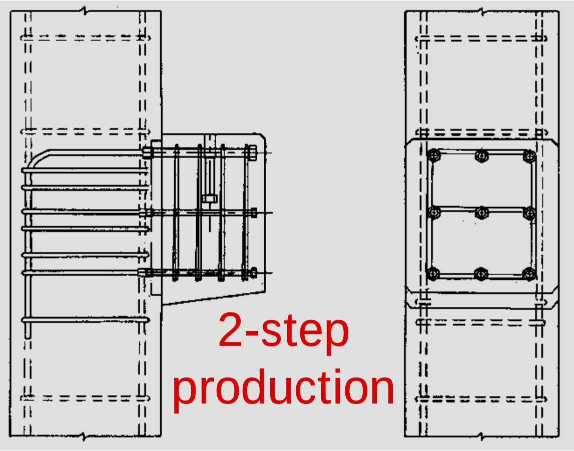
Stress trajectoria



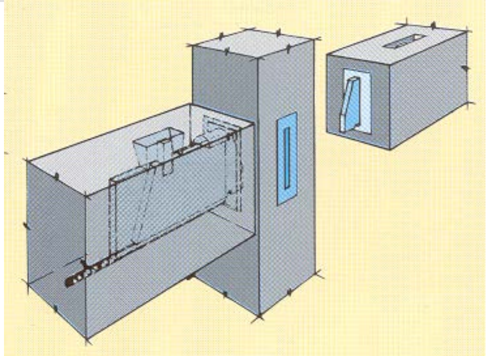




Detailing of reinforcement



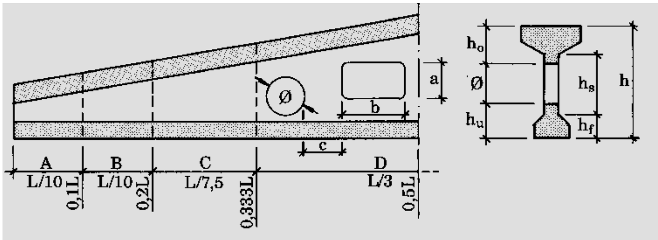
2-step production

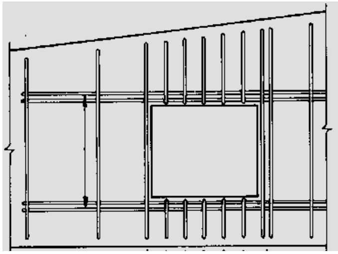


Hidden corbel

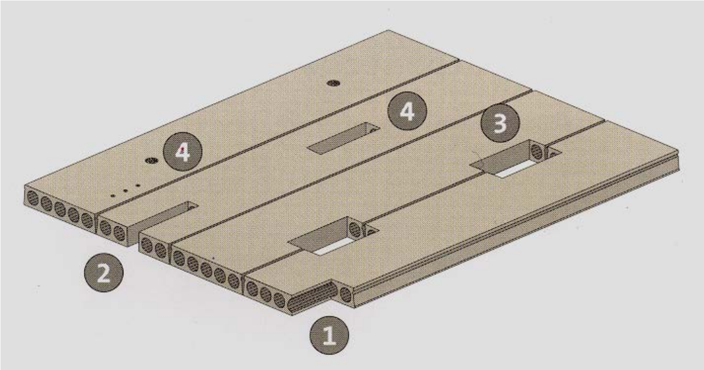
Openings and cut-outs

- Design and dimensions of openings in floors and beams

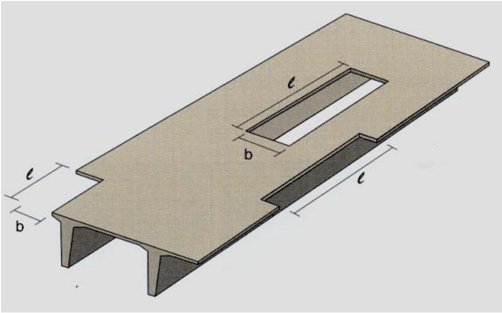




Openings in roof beams



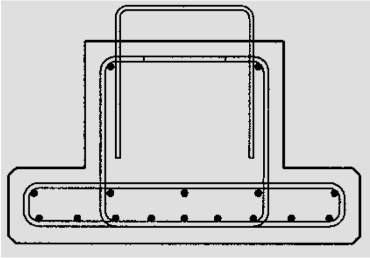
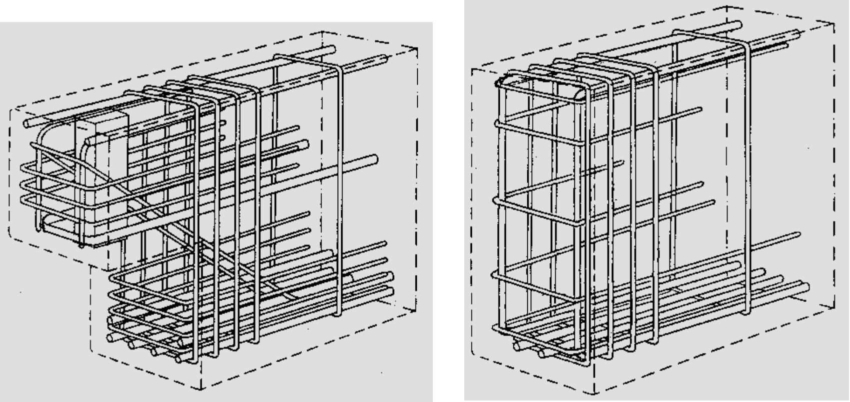
Openings in HC floors



Openings in ribbed elements

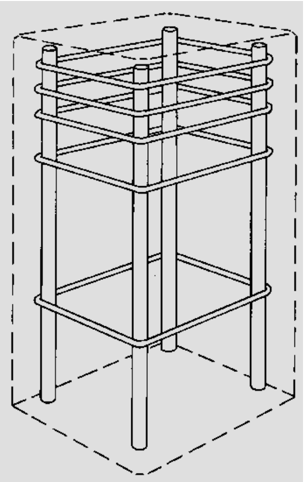
Special reinforcement

- Anchorage zones of prestressed components
- Column ends
- Boot beams

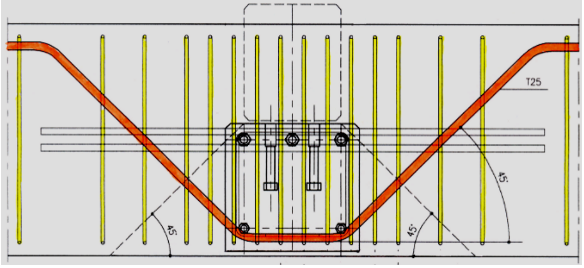
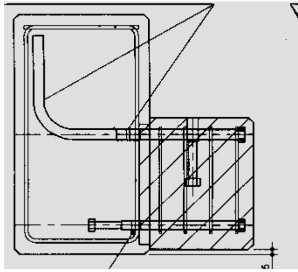
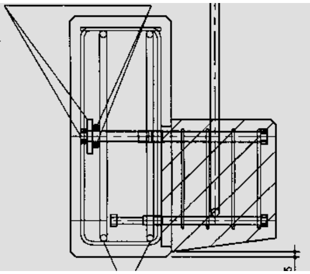



Boot beam reinforcement

Transfer zone of prestressing



Hooping reinforcement

Beam corbel reinforcement

Chapter 11

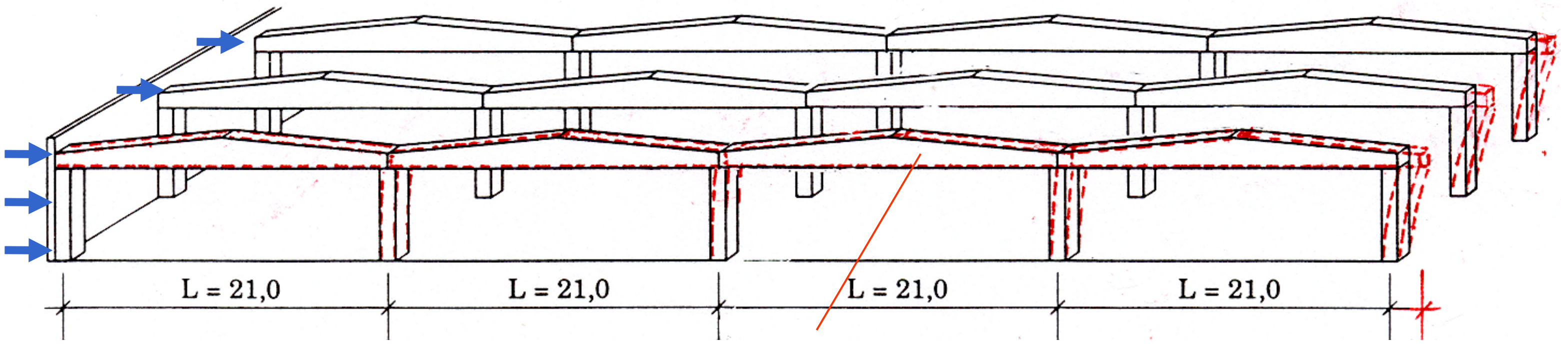
FIRE RESISTANCE

Fire resistance

- Basic requirements
- Fire actions
- Global structural analysis
- Member analysis
- Fire resistance of precast concrete elements
- Fire resistance of structural connections

Fire actions

- Reduction of material performances
- Thermal expansion
- Transverse deformation of the cross-section



Large expansion may lead to incompatibility of connections

Structural fire design

- Global analysis
- Member analysis

Fire is an accidental action

- Design only for ULS
- Quasi permanent values for actions
- Partial safety factors = 1.0

Failure modes

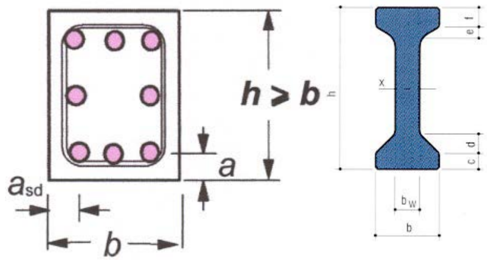
Depending on the type of structure, four theoretical failure mechanisms may appear in precast concrete structures exposed to severe fire

1) Bending failure for columns, beams and floors
2) Shear and anchorage failure, mainly for beams and floors
3) Excessive compression in the bottom section specifically for flat floors
4) Spalling of concrete; in this Lecture, spalling is not dealt with since it is a material property independent of structural calculations.

Member analysis

Tabulated data

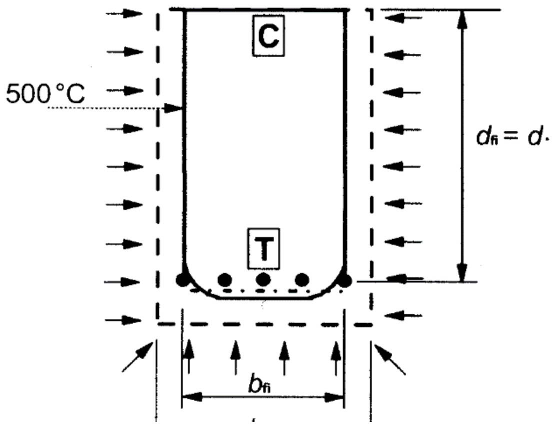
Standard fire resistance	Minimum dimensions (mm) Possible combinations of a and b_{min} where a is the average axis distance and b_{min} the width of the beam				Web thickness b_w
(1)	(2)	(3)	(4)	(5)	(6)
R60 R90 R120 R180 R240	b_{min} = 120 a = 40 etc.	b_{min} = 160 a = 35 etc.	b_{min} = 200 a = 30 etc.	b_{min} = 300 a = 25 etc.	80



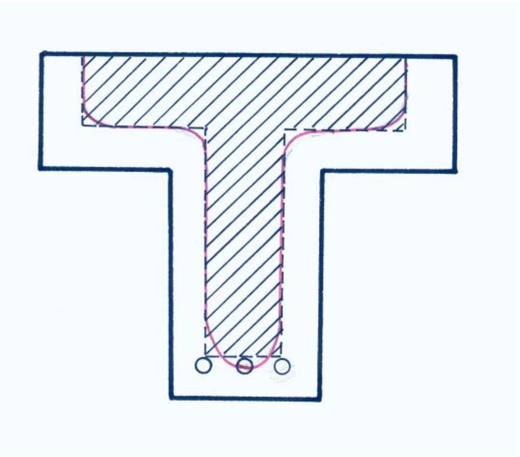
Typical lay-out of Table

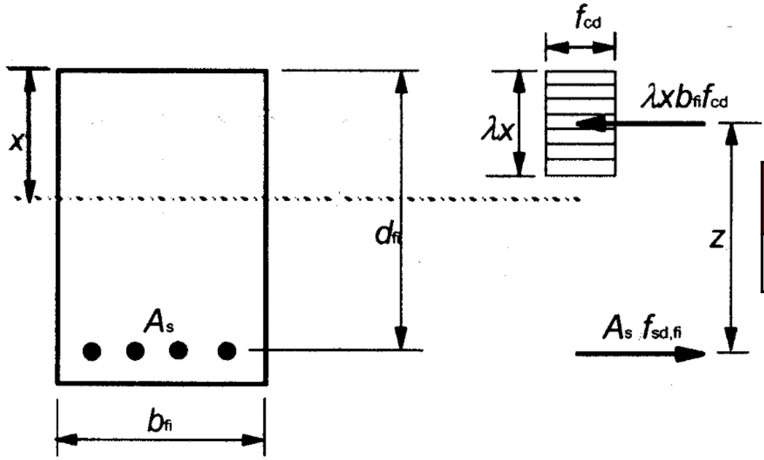
Member analysis

simple calculation method



Calculation of the bending capacity

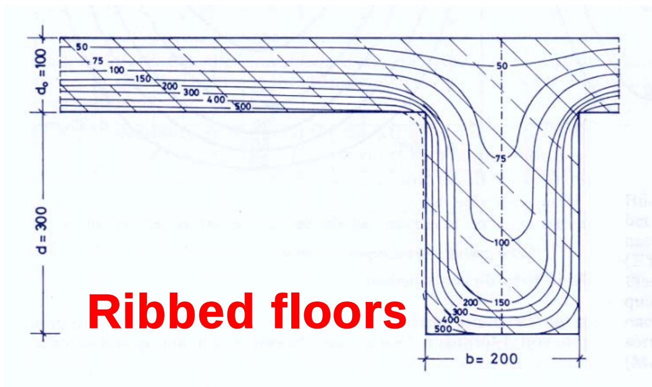




Fire resistance	R60	R90	R120	R180	R240
Minimum width b	90	120	160	200	280

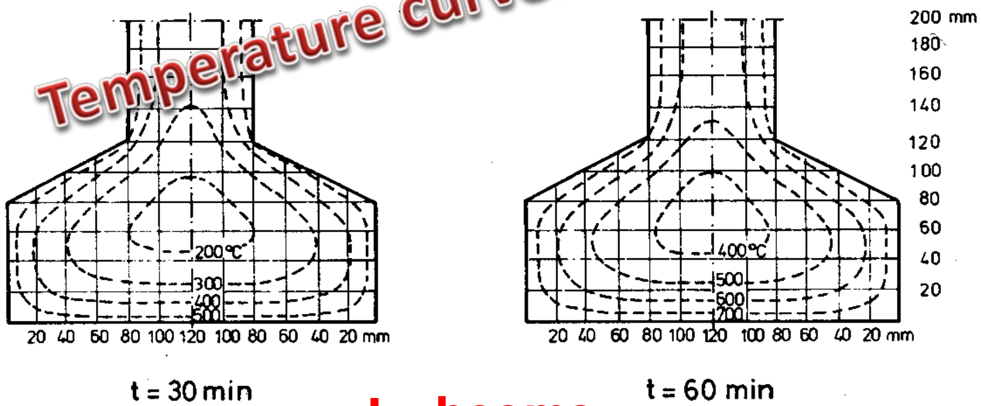
Simple calculation method

determination of material characteristics

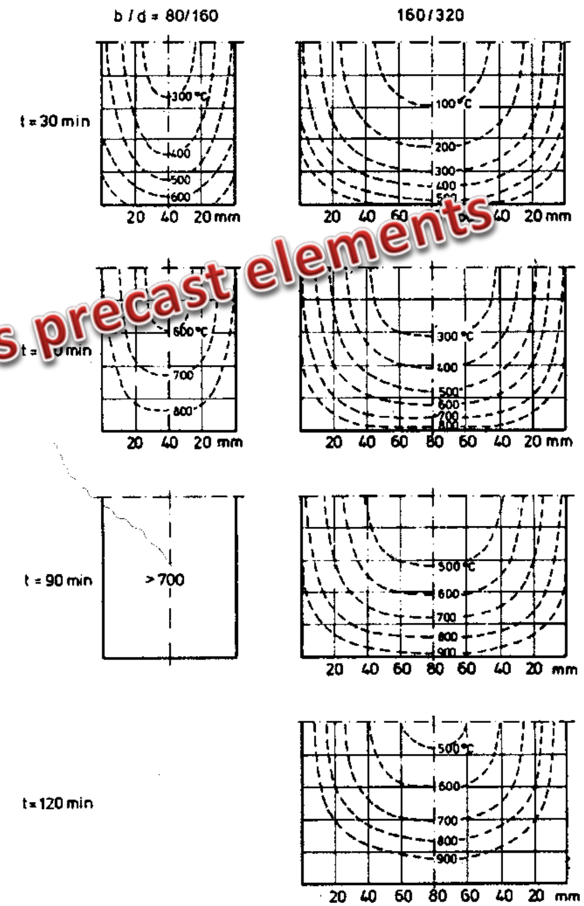


Ribbed floors

Temperature curves for different types precast elements



I - beams



Rectangular beams

Fire resistance precast elements

- Columns
- Beams
- Walls
- Prestressed HC floors

Failure test roof beam after repair

Test on precast industrial hall

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Thank you…

…for choosing Precast.

The software company Nemetschek Scia headquartered in Belgium, kindly offered to redraft all technical drawings in order to get a uniform presentation for the whole Handbook.