Precast Structures: Design Consideration For Precast - BIS and Other international codes

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Precast structures

Advantages

- Speed of Construction
- Quality
- Economy of Scale

Challenges (Structural)

- Continuity
- Load Transfer and Distribution
- Quality

Precast and Performance Based Design

Performance-based Design

Methodology in which structural criteria are expressed in terms of achieving a performance objective

Conventional method

Prescriptive structural criteria are defined by limits on member forces resulting from load demands

Precast and Performance

Performance requirements

- ❑Material perspective
- ❑Structures

Factory made elements

- Tighter material control
- Quality control

→ **Assured performance**

Continuity

- Precast Structures are individual elements which are connected to gather

- Issues
  - Continuity between elements forming Member
  - Continuity between members
  - Load transfer between members

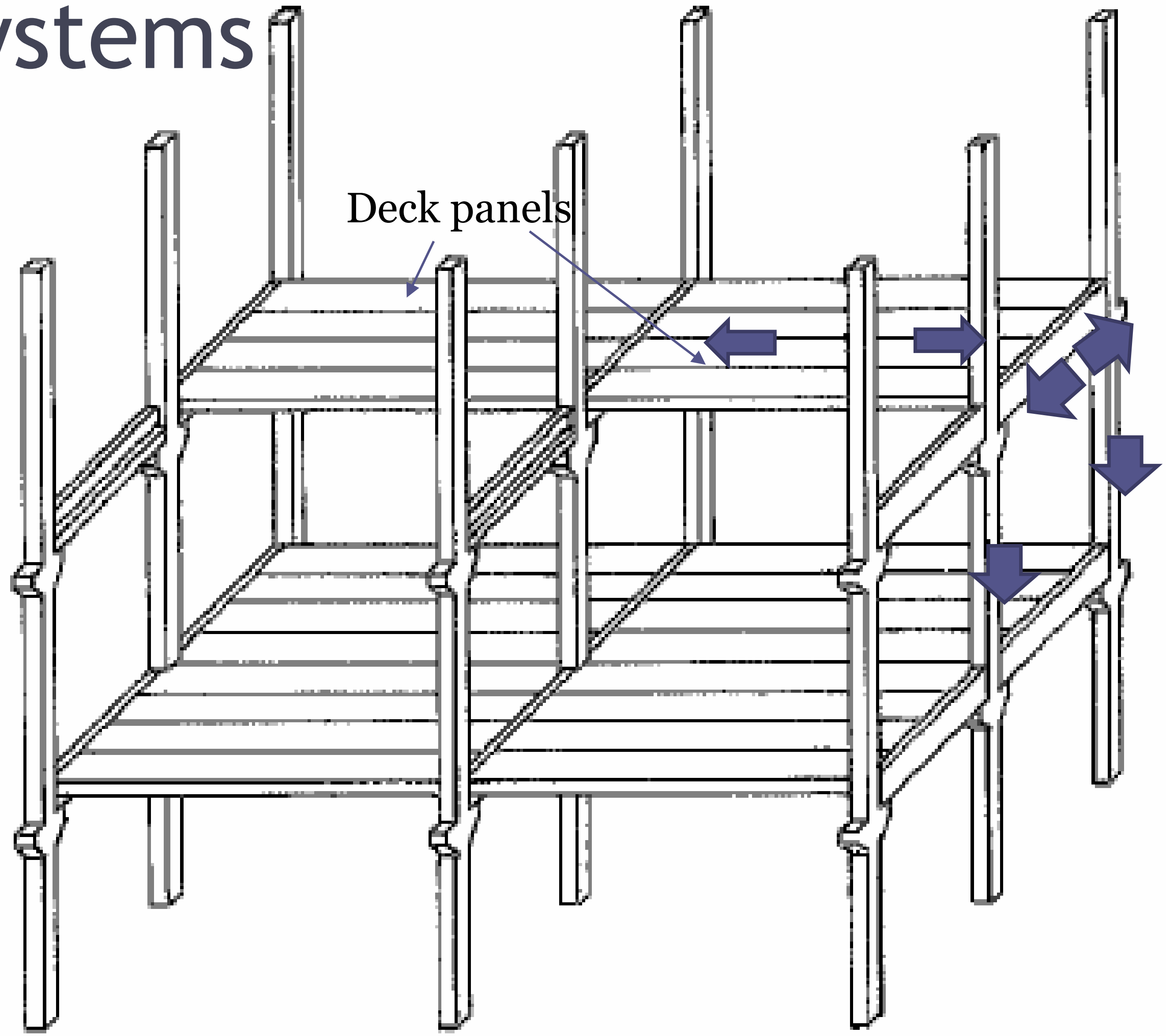
Interlocking of elements for continuity

Building Systems

- Load Path
- Role of Joint and Connection

Building Systems

Skeletal System



Load Path

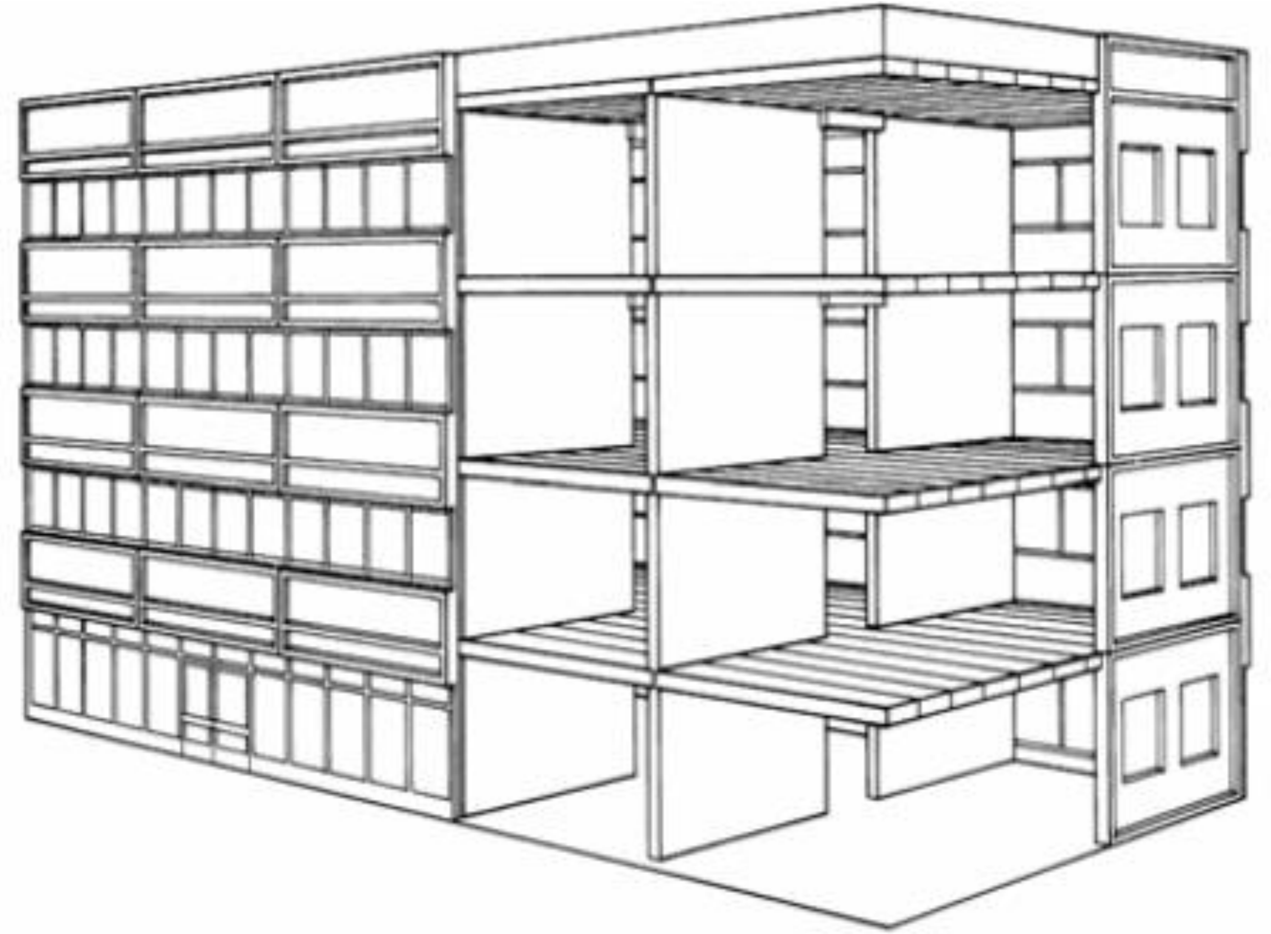
Building Systems

Skeletal System

Building Systems

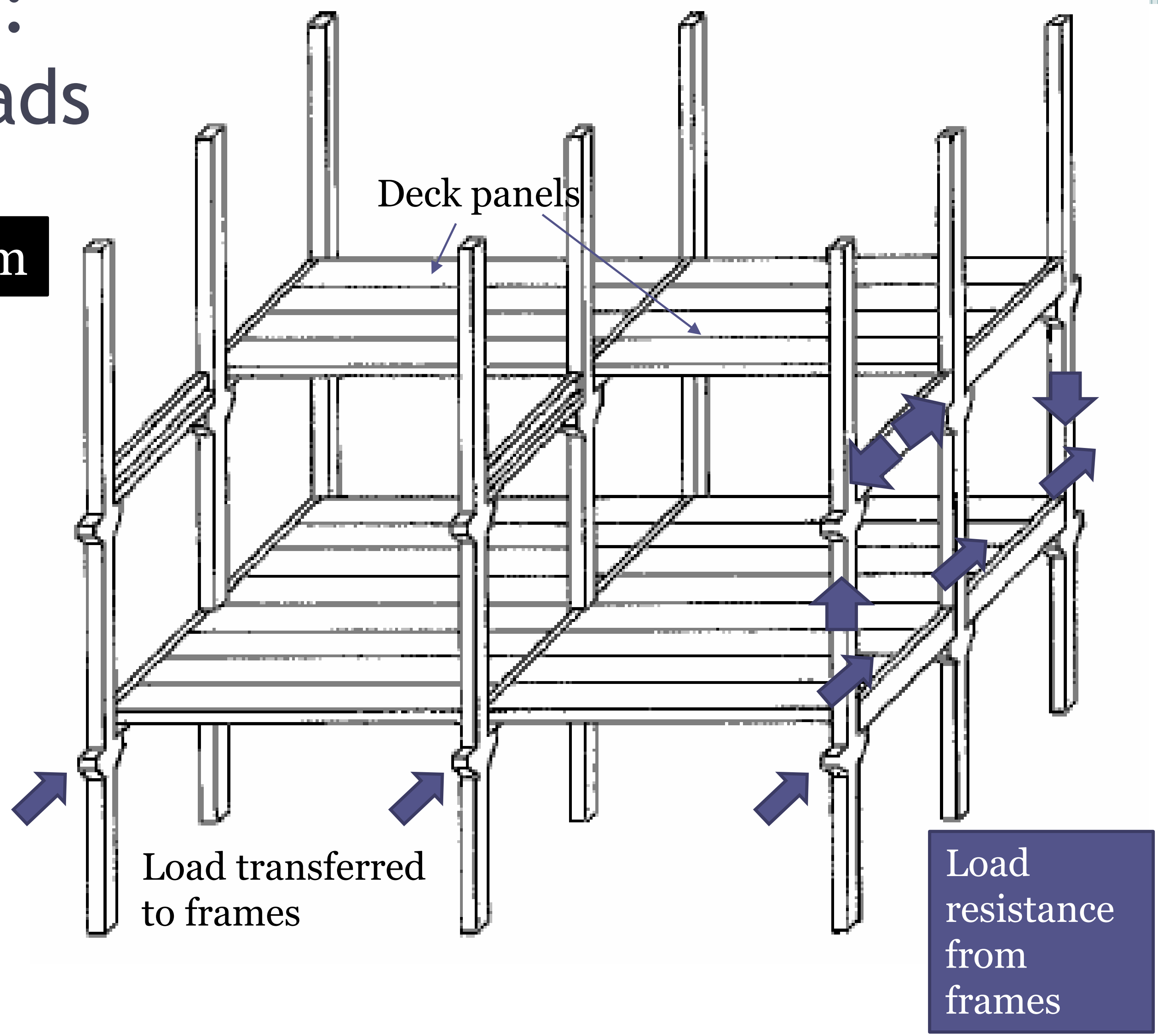
- Integrated Wall system

- Structural walls function as vertical load carrying members
- Walls tied to slab panels for structural system

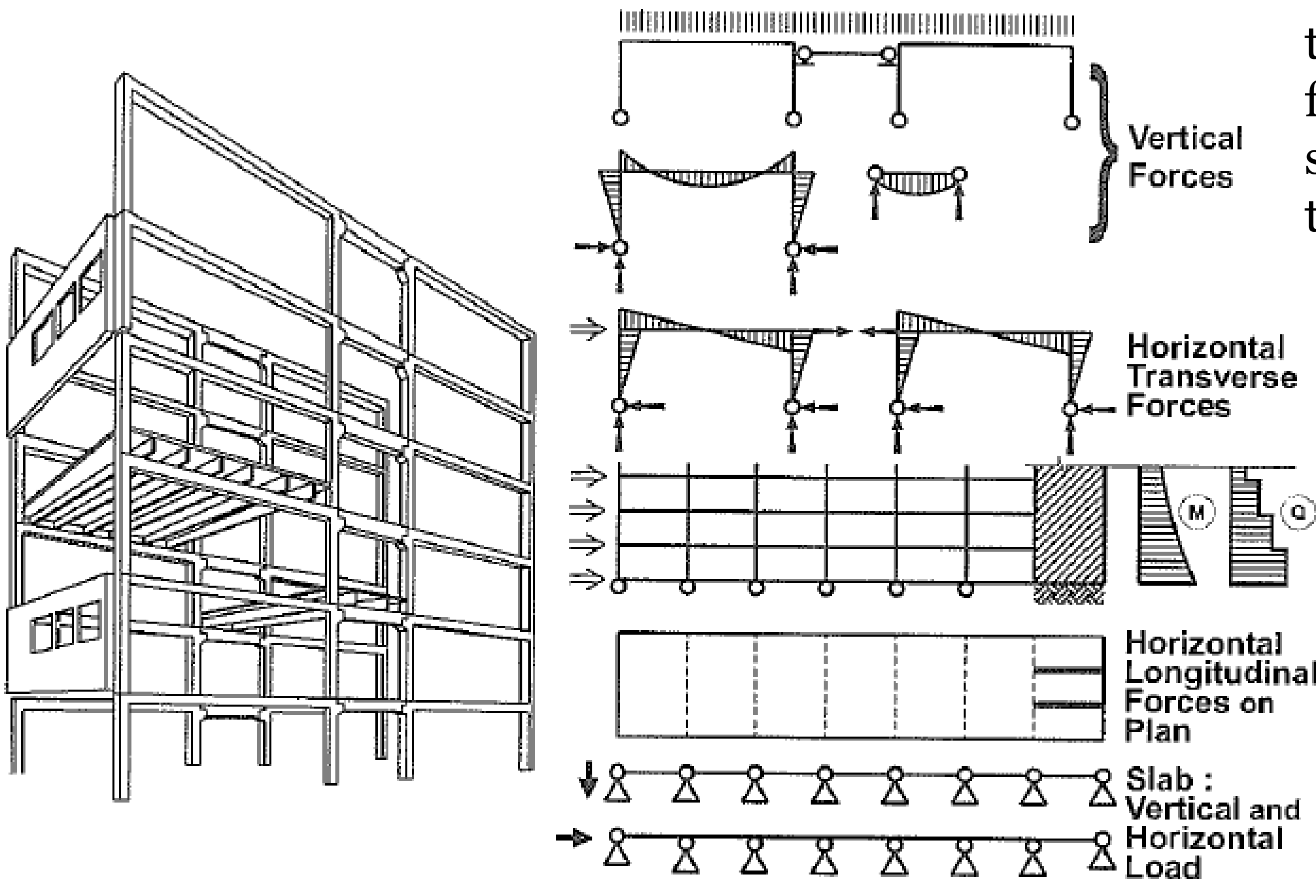


Load Path: lateral loads

Skeletal System



Load Path description under gravity and lateral loads



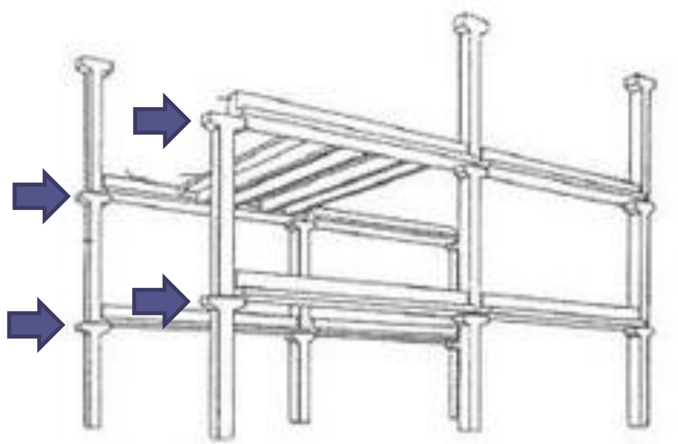
Vertical load transmitted from floor slab (simply supported) to beams to frames

Lateral force from floor slab by diaphragm action to frame

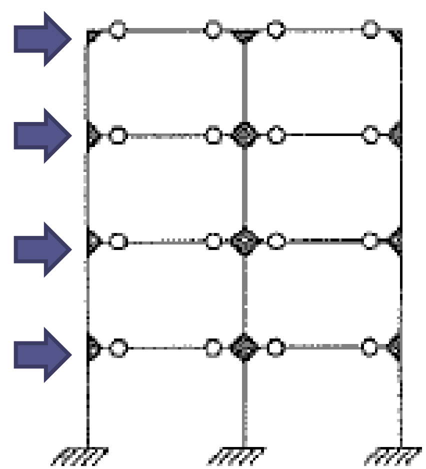
In braced frames, the walls act as vertical beams restrained at foundation

Continuity

- Analysis for component demands



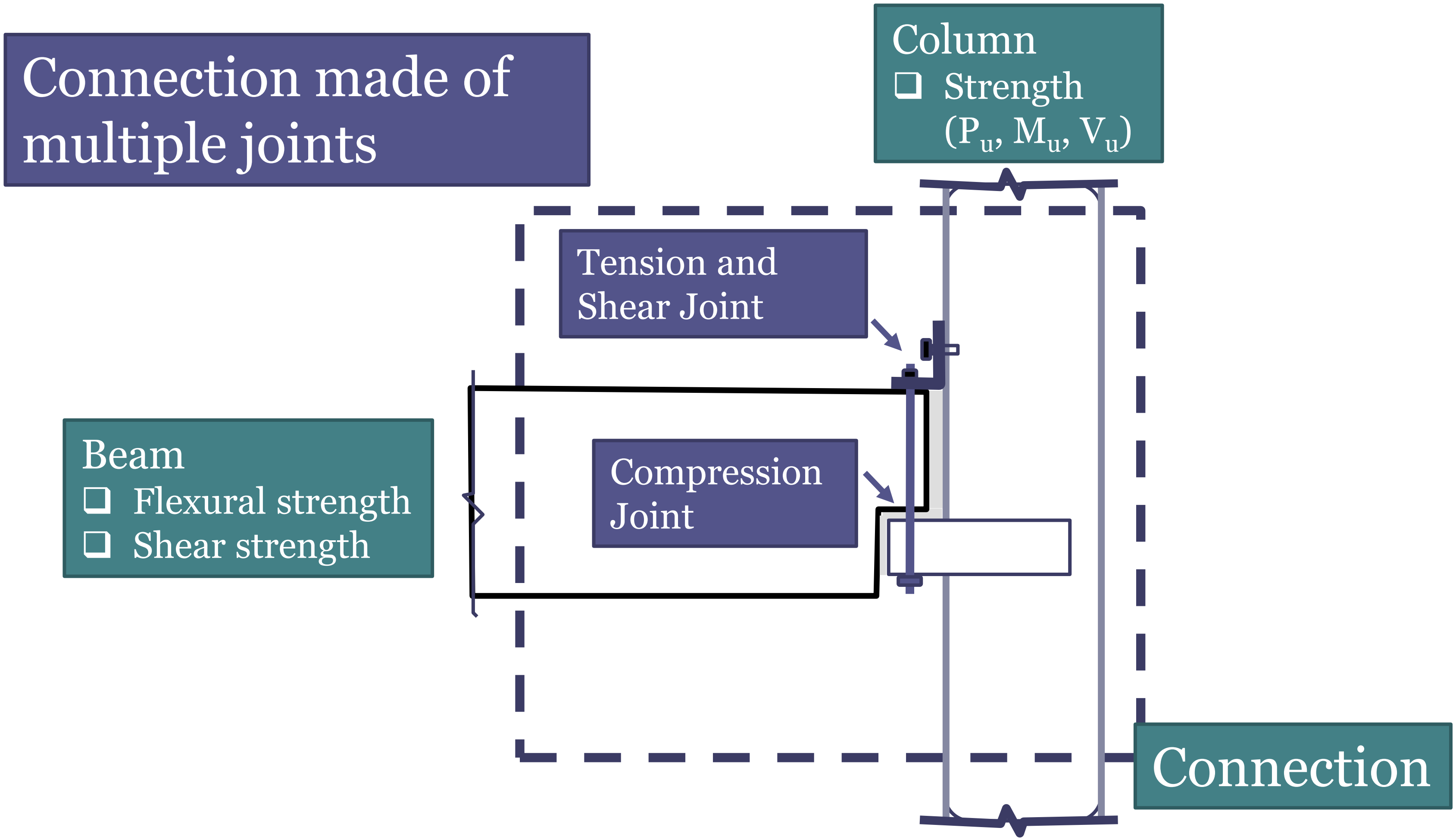
Structure subjected to lateral load



Equivalent frame representation

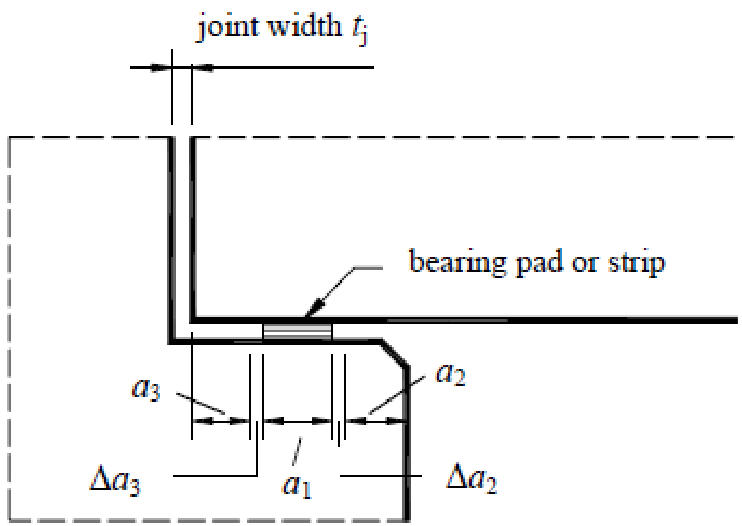
Member demands

Joints and Connections

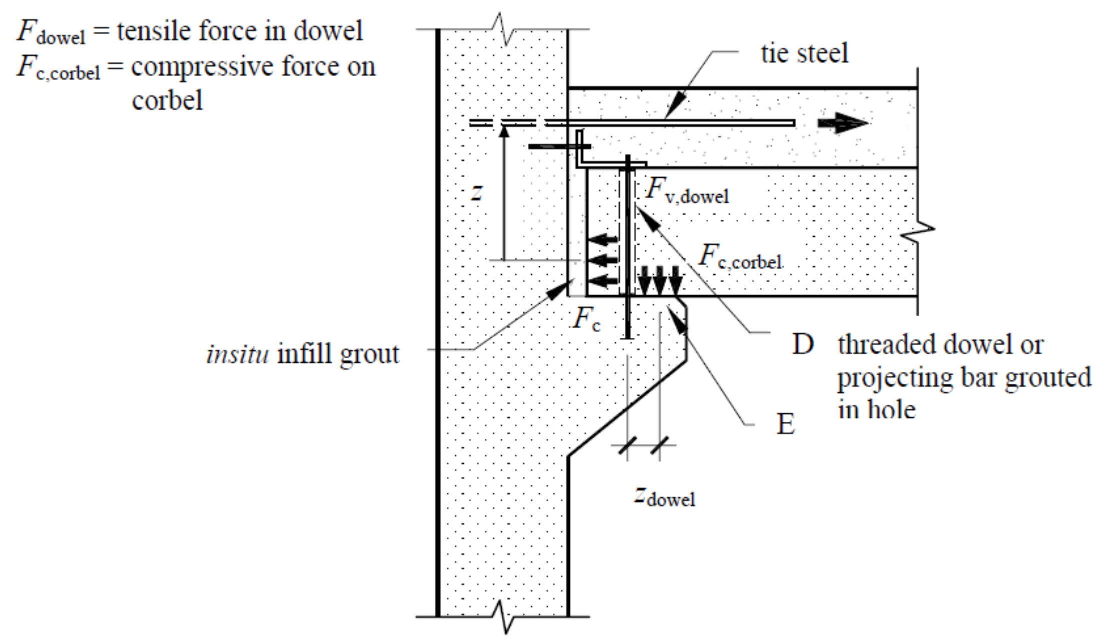


Continuity

- Level of continuity can be decided

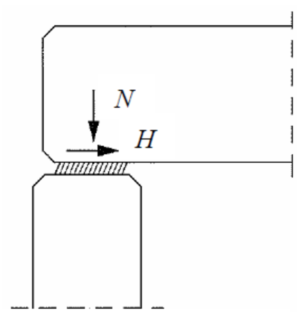


Bearing Type Connection

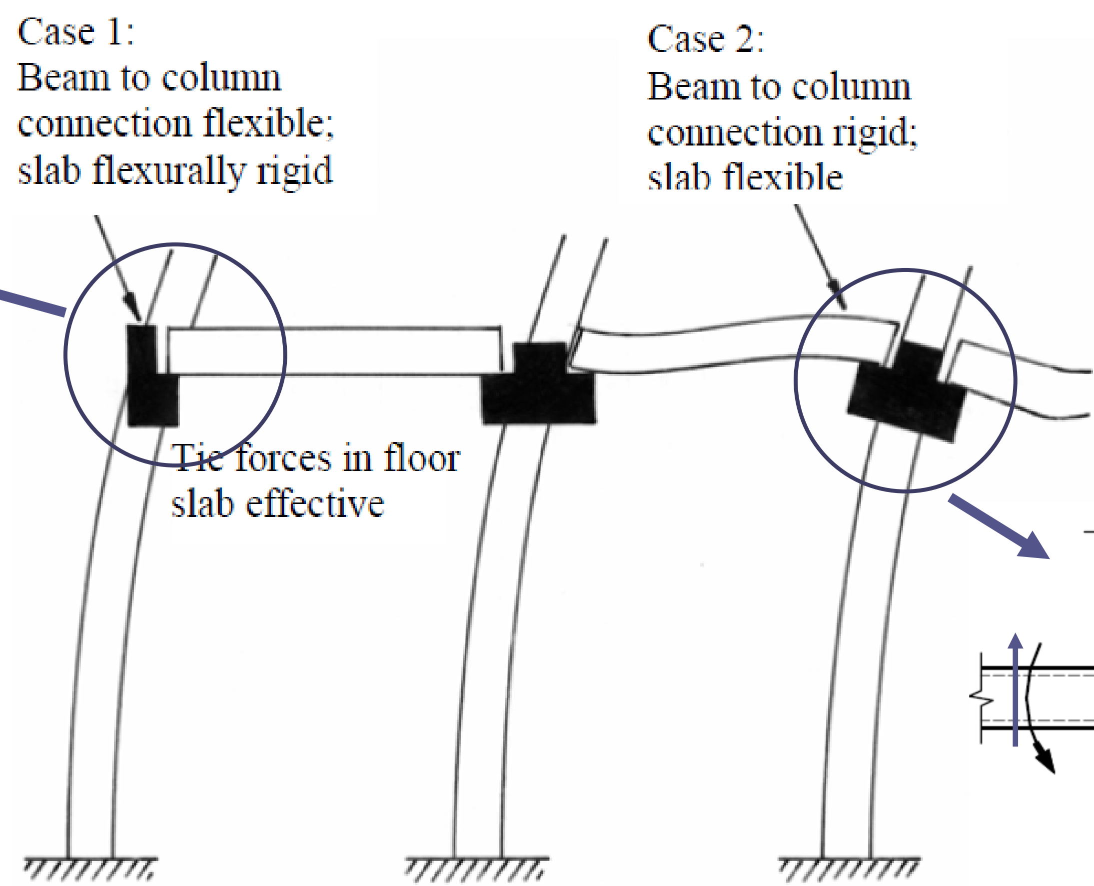


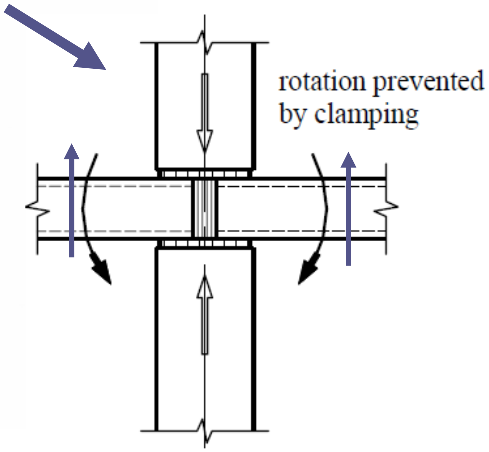
Structural Connection with Partial to Full Moment Fixity at ends

Consequences of Continuity
Lateral loads



Demand on connection



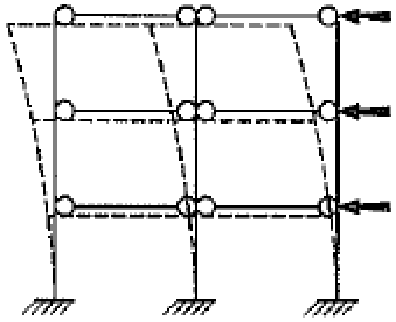


Demand on connection

Consequences of Continuity
Lateral loads

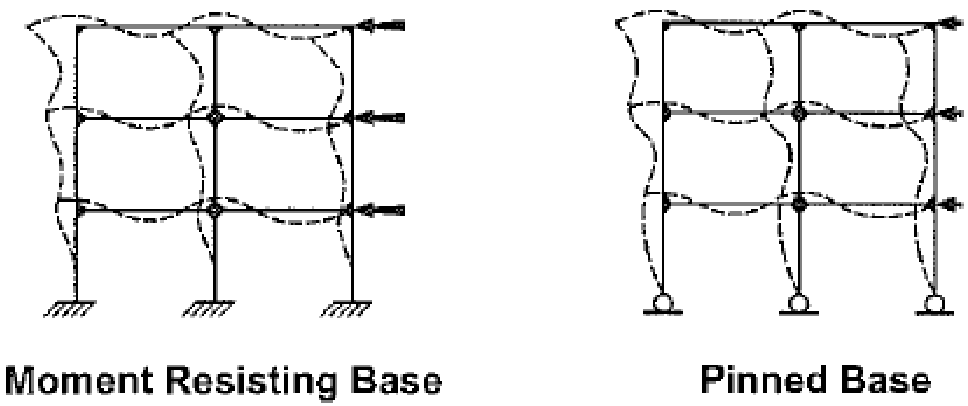
Unbraced frame

Beam column connections are pinned (designed as shear connections)



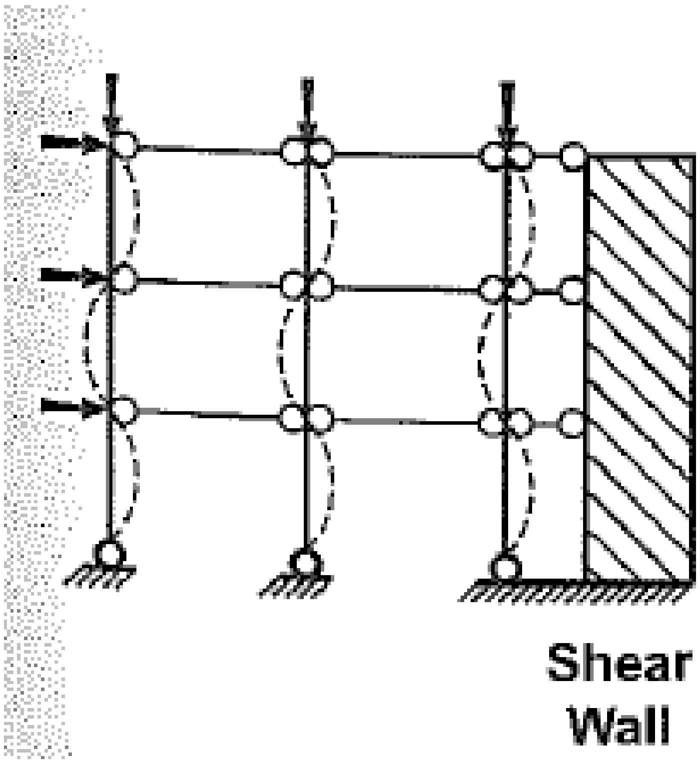
(a) Cantilevered Columns

Beam column connections are rigid (flexural and shear continuity)

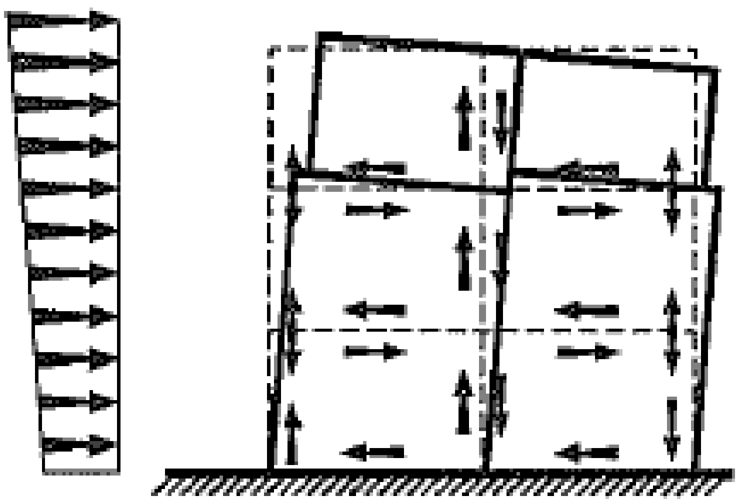


(b) Continuous Frames

Support System for Lateral loads



Bearing Wall and façade – Bearing walls including load bearing facdes form the lateral and gravity load system



Braced skeletal system – Lateral stability from shear walls

Failures – Precast Structures

Damage caused to precast structures in recent earthquakes.

- Christchurch [New Zealand] - 2011
- L’Aquila [Italy] - 2009
- Emilia [Italy] - 2012
- Bhuj [India] - 2001

Unseating of precast concrete beams off corbels of columns (*fib 43)*

Brittle failure of beam-column pin connection at top of corner column
(1994 Northridge earthquake)

Bhuj, India 2001

Good performance of elements, poor performance of connections

- 6,000 school buildings using precast structures for speedy construction.
- Constructed during Apr 1999 to Nov 2000
- About 75% of such newly built classrooms were damaged.

Slabs and Beams were unseated due to Insufficient Anchorage leading to **Connection failure!**

[NICEE, IITK]

Lessons from Lateral Load Response

Failure of Joints

Progressive collapse

→

Basis of the codes

- ❑ Continuity requirements
- ❑ Shear/Flexure Joints

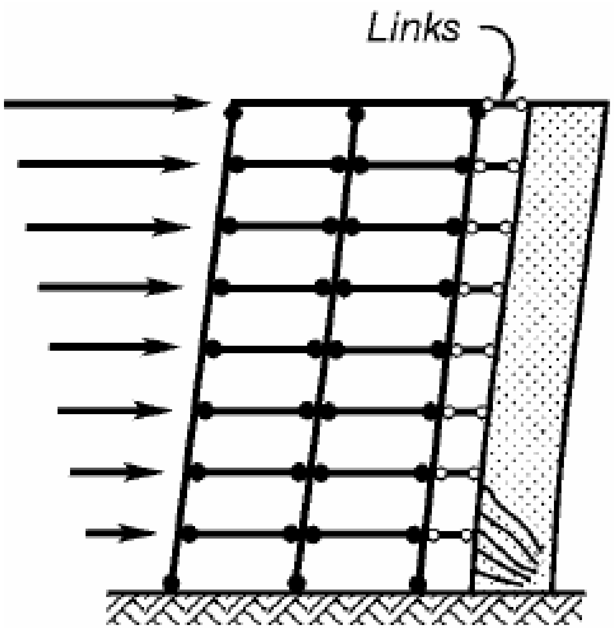
Design for Lateral Loads

detailing for **ductility** includes:

(1) nonlinear locations of the structure have the ability to deform as required without strength degradation,

and

(2) **other elements in the structure have sufficient strength** to ensure that nonlinear behavior occurs in the intended nonlinear locations.



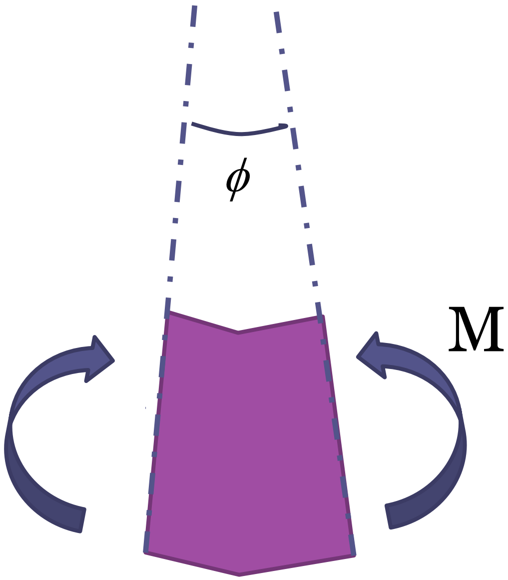
(a) Weak beam-strong column behaviour of frame

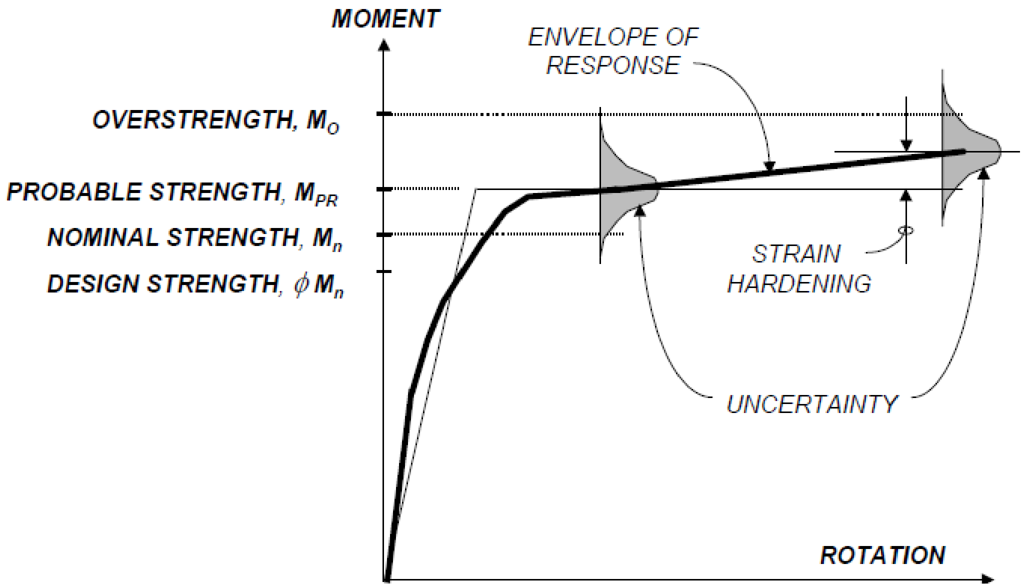
Ductility provisions for nonlinear locations

- **Equivalent monolithic precast systems** have **flexural plastic hinges** as their nonlinear locations

and

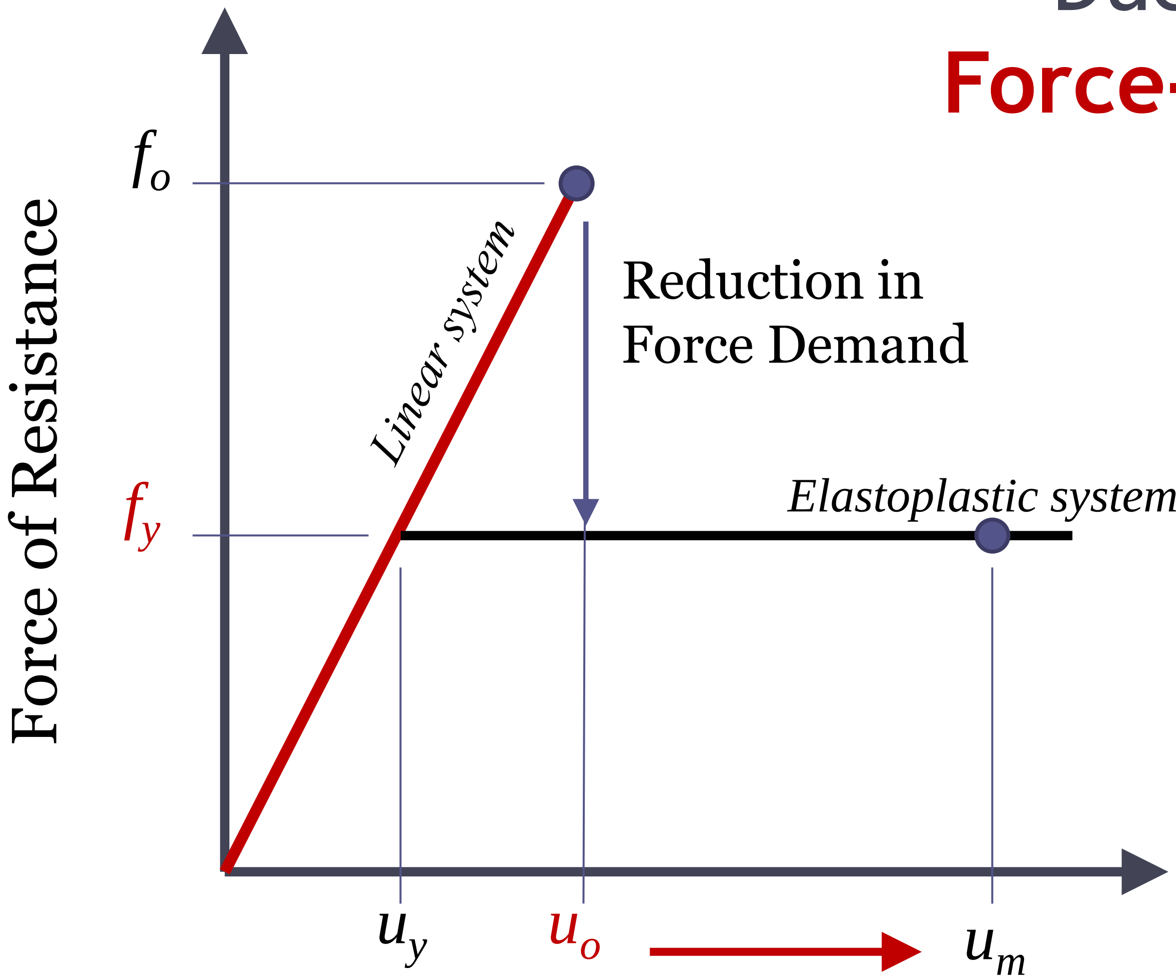
- **Detailing requirements** for the plastic hinges **are the same** as those established for **cast-in-place concrete**





Ductility Demand

Force-based Design



Increase in displacement demand

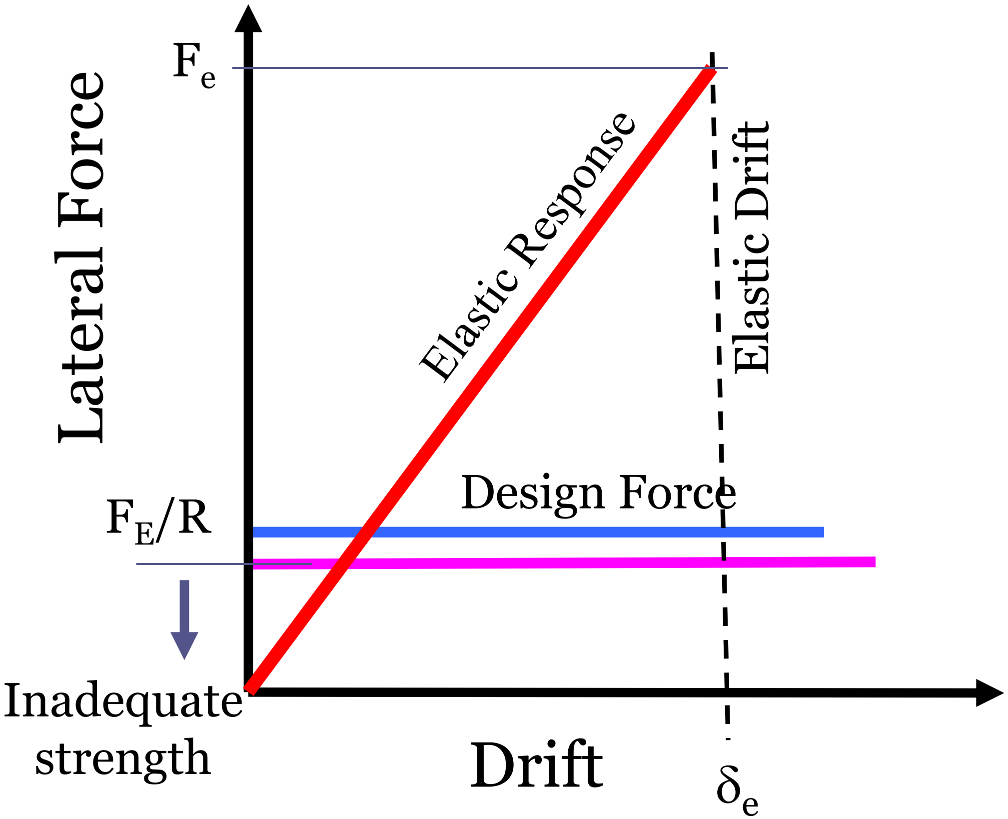
Design for reduced force demand

$$V_d = \frac{V_E}{R} = \frac{S_a W}{R}$$

R - Response Reduction

Ductility Demand

Force-based Design



$$V_d = \frac{V_E}{R} = \frac{S_a W}{R}$$

Where

$$R = R_\mu R_S R_\xi R_R$$

R_μ – Ductility Factor

R_S – Strength Factor

R_ξ – Damping Factor

R_R – Redundancy Factor

R values vary between different codes

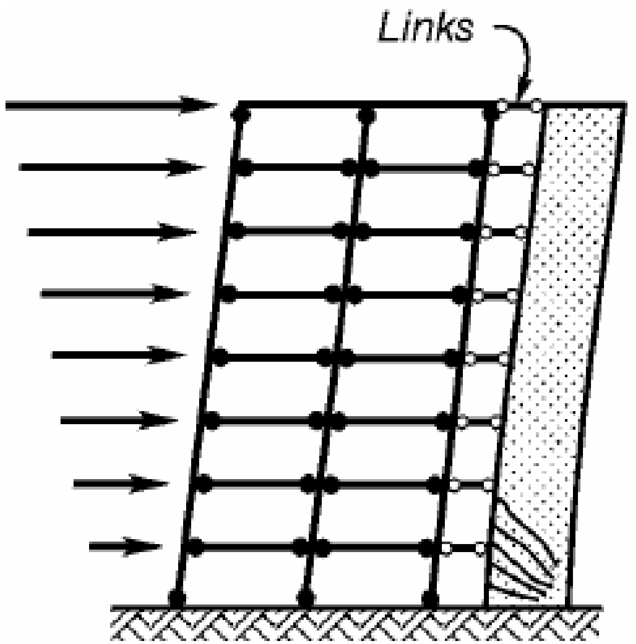
Detailing for Ductility Demand

Joint detailing for **plastic hinges** at the required location

- **In plastic-hinge regions, longitudinal reinforcement should be continuous**

Walls with **flexural plastic hinges** at the base

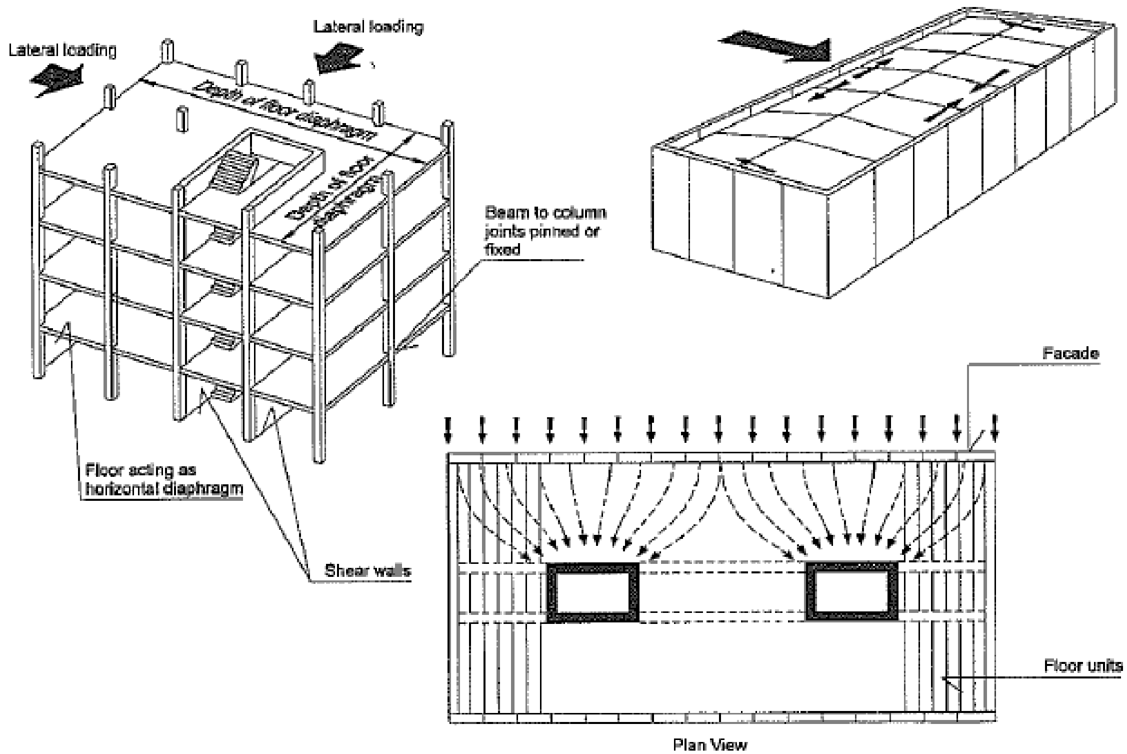
- **Preventing shear failures or sliding shear failures prevents a concentration of deformation occurring over a single story**



(a) Weak beam-strong column behaviour of frame

Detailing for Ductility Demand

rigid horizontal diaphragm action, the total shear in any horizontal plane is **distributed** to the various vertical elements of lateral forces resisting system



Floor and roof diaphragms, collectors should have adequate strength.
The strength of these elements should be sufficient to force the nonlinear behavior into the intended locations of the seismic-force resisting system.

Ductility Demand
Force-based Design

Fundamental period is estimated based on the structural form, and building height, rather than on geometry and member stiffness

$$T = C_1(h_n)^{0.75}$$

Base shear must not be less than that calculated from the height-dependent period equation

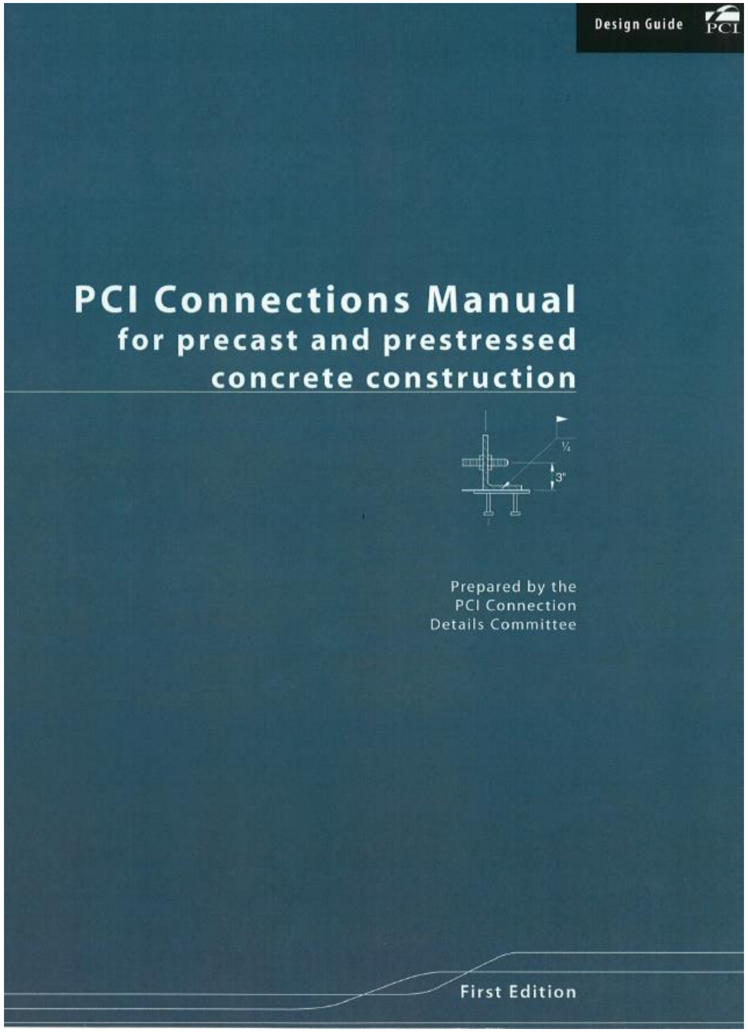
Height-based equation generally results in

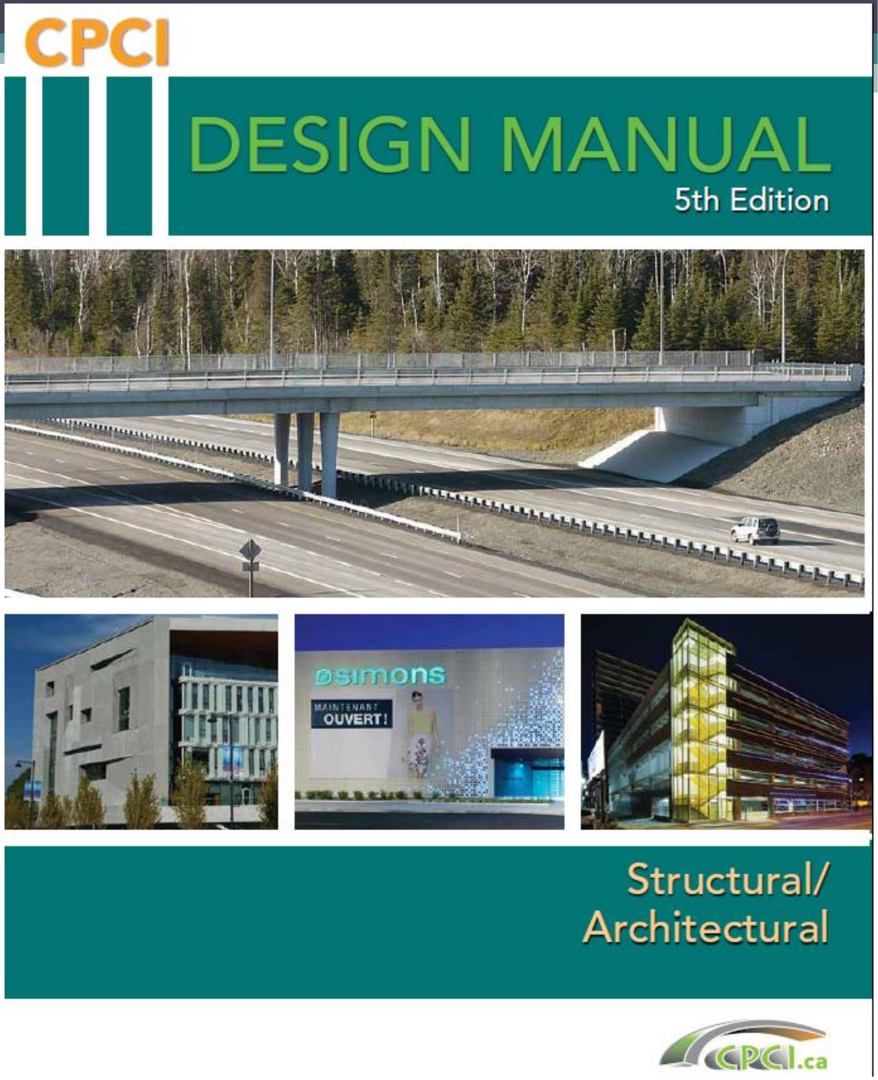
- ❑ shorter periods than would result from structural analysis

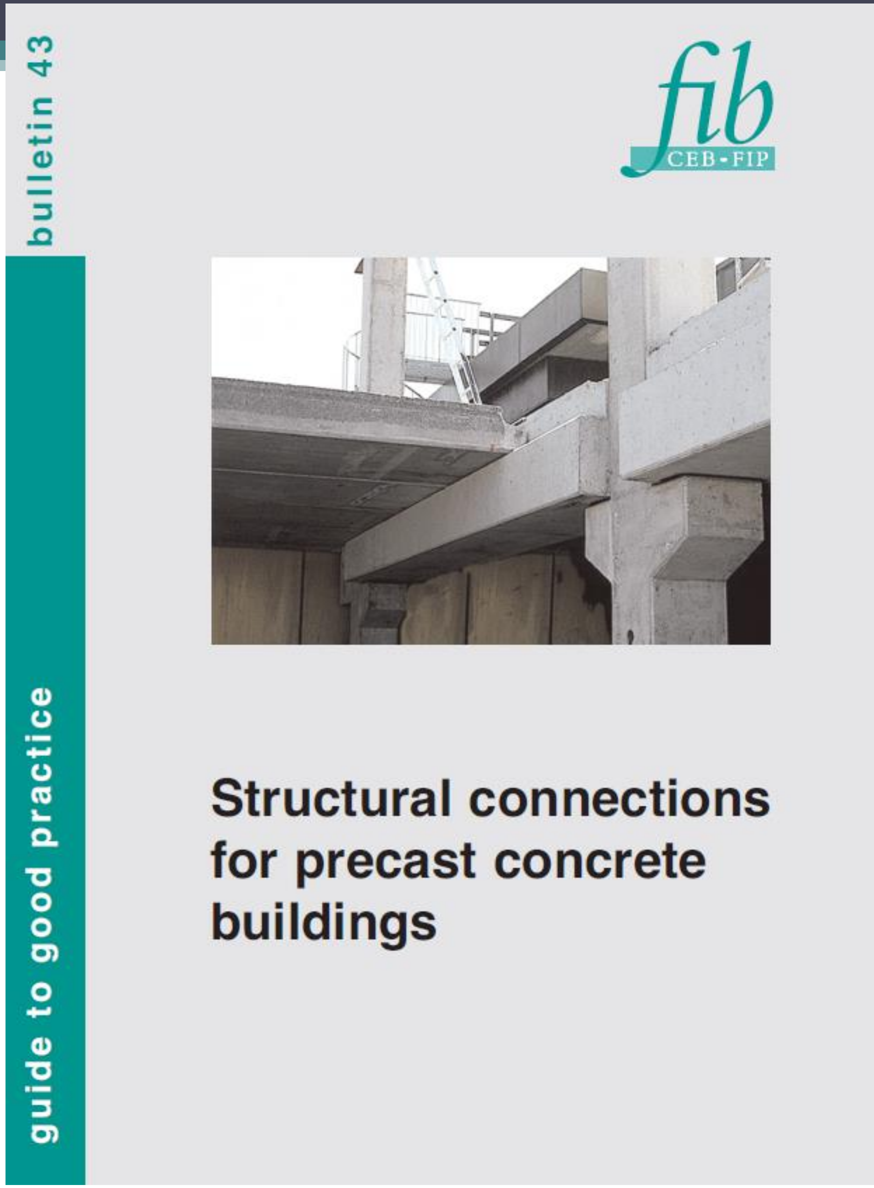
And

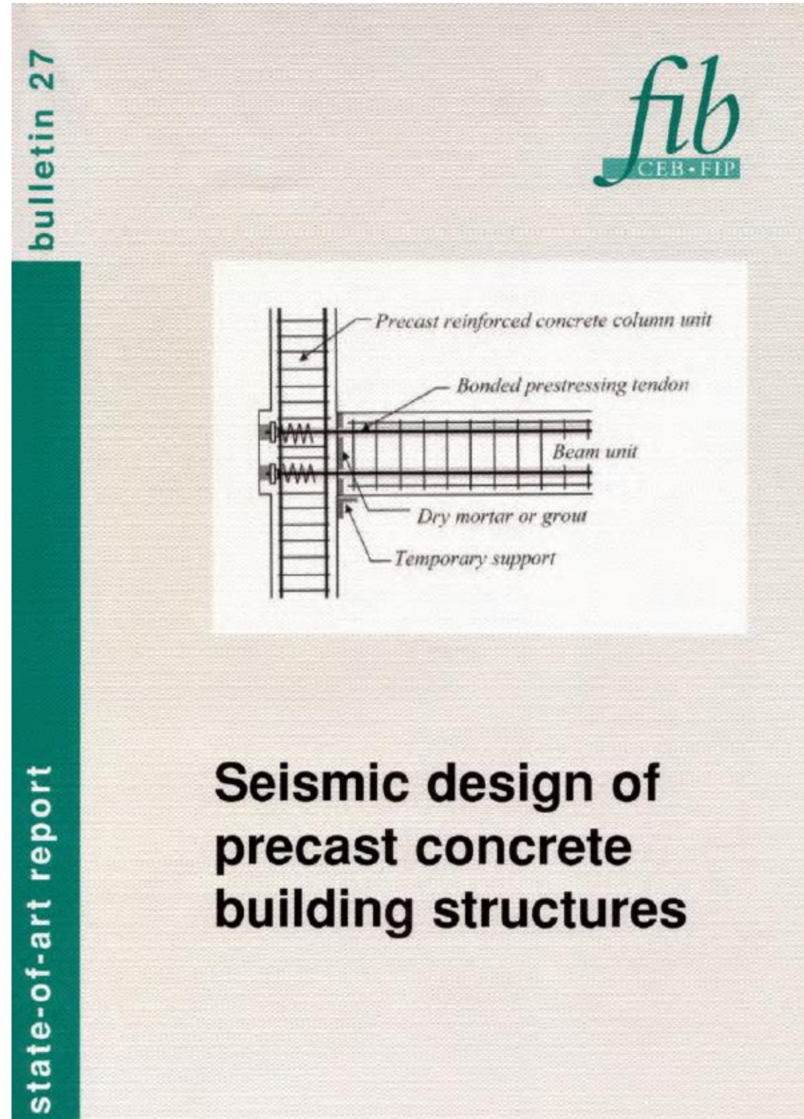
- ❑ Higher forces

Codes of Practise









fib guide and state-of-art report

भारतीय मानक
Indian Standard

IS 15916 : 2020

पूर्व संविचरित कंक्रीट प्रयुक्त भवन का डिजाइन
और स्थापन — रीति संहिता
(पहला पुनरीक्षण)

Building Design and Erection Using
Prefabricated Concrete —
Code of Practice
(First Revision)

ICS 91.040.01

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.gov.in www.standardsbis.in

December 2020 Price Group 14

IS 15916

Prefabricated Building — The partly/fully assembled and erected building, of which the structural parts consist of prefabricated individual units or assemblies.

भारतीय मानक
Indian Standard

IS 15916 : 2020

Building Design and Erection Using Prefabricated Concrete — Code of Practice

Basic Module — The fundamental module used in modular co-ordination, the size of which is selected for general application to building and its components.
NOTE — The value of the basic module has been chosen as 100 mm for the maximum flexibility and convenience. The symbol for the basic module is *M*.

6 COMPONENTS

6.1 The dimensions of precast elements shall meet the design requirements. However, the **actual dimensions shall be the preferred dimensions as follows**:

a) *Flooring and roofing scheme* — Precast slabs or other precast structural flooring units:

1) *Length* — Nominal length shall be in multiples of 1 *M*;

b) *Beams*:

1) *Length* — Nominal length shall be in multiples of 1 *M*;
2) *Width* — Nominal width shall be in multiples of 0.1 *M*; and
3) *Overall depth* — *Overall depth of the floor zone shall be in multiples of* 0.1 *M*.

Section 8.1 Design Considerations

- **Resistance to horizontal loading** shall be provided by having appropriate moment and shear resisting joints or placing shear walls (in diaphragm braced frame type of construction) in two directions at right angles or otherwise.
- Precast structures could be **analyzed** either as an **emulative systems** or as a **jointed system**.

Component level design

- The components of the structure shall be designed for loads in accordance with IS 875 (Parts 1 to 5) and IS 1893 (Part 1).
- **Members shall be designed for handling, erection and impact loads that might be expected during handling and erection**.

Component level design

7.3.1 *Types of Prefabrication Components*

The prefabricated concrete components, such as those given below may be used which shall be in accordance with relevant Indian Standards, such as IS 2185 (Parts 1 to 4), IS 3201, IS 6072, IS 6073, IS 9893, IS 10297, IS 10505, IS 11447, IS 12440, IS 13990, IS 14143, IS 14201 and IS 14241, where available:

Design of components -- specific codes

IS 6072 -- Aerate autoclaved wall panels
IS 10505 -- construction of floors using precast waffle units
IS 10297 -- Ribbed and hollow core slabs
IS 11447 -- Construction with prefabricated elements

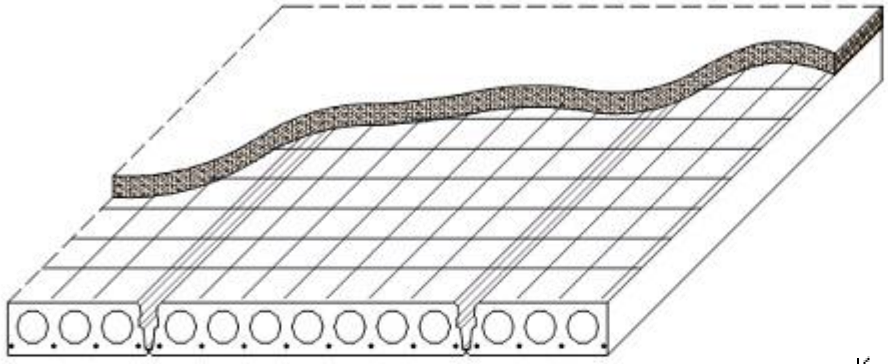
Design for handling

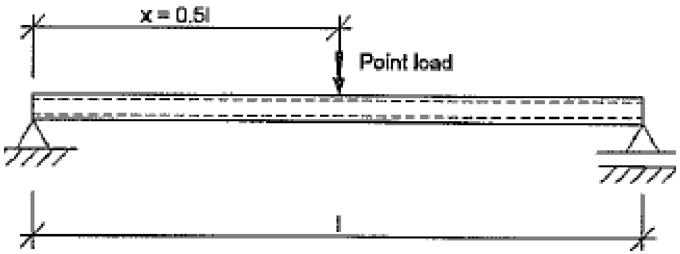
Stresses during hoisting/erection

Prestressing of beams

Section 8.1

The individual components shall be designed, taking into consideration the appropriate end conditions and loads at various stages of construction.



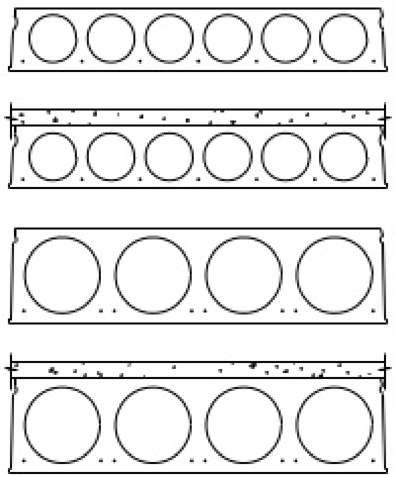


Simply-supported for self weight and slab weight

Live load supported by composite action

PCI Design charts

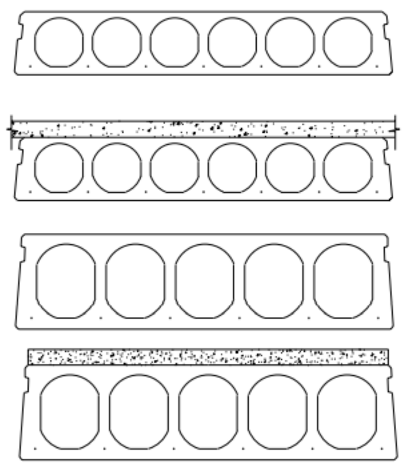
Trade name: Ultra-Span
Licensing Organization: Ultra-Span Technologies, Inc., Winnipeg, Manitoba, Canada



Section width x depth	Untopped A in^2	Untopped y_b in	Untopped I in^4	Untopped wt psf	with 2" topping y_b in	with 2" topping I in^4	with 2" topping wt psf
4'-0" x 4"	154	2.00	247	40	2.98	723	65
4'-0" x 6"	188	3.00	764	49	4.13	1641	74
4'-0" x 8"	214	4.00	1666	56	5.29	3070	81
4'-0" x 10"	259	5.00	3223	67	6.34	5328	92
4'-0" x 12"	289	6.00	5272	75	7.43	8195	100

Note: All sections are not available from all producers. Check availability with local

Trade name: Elematic®
Equipment Manufacturer: Mixer Systems, Inc., Pewaukee, Wisconsin

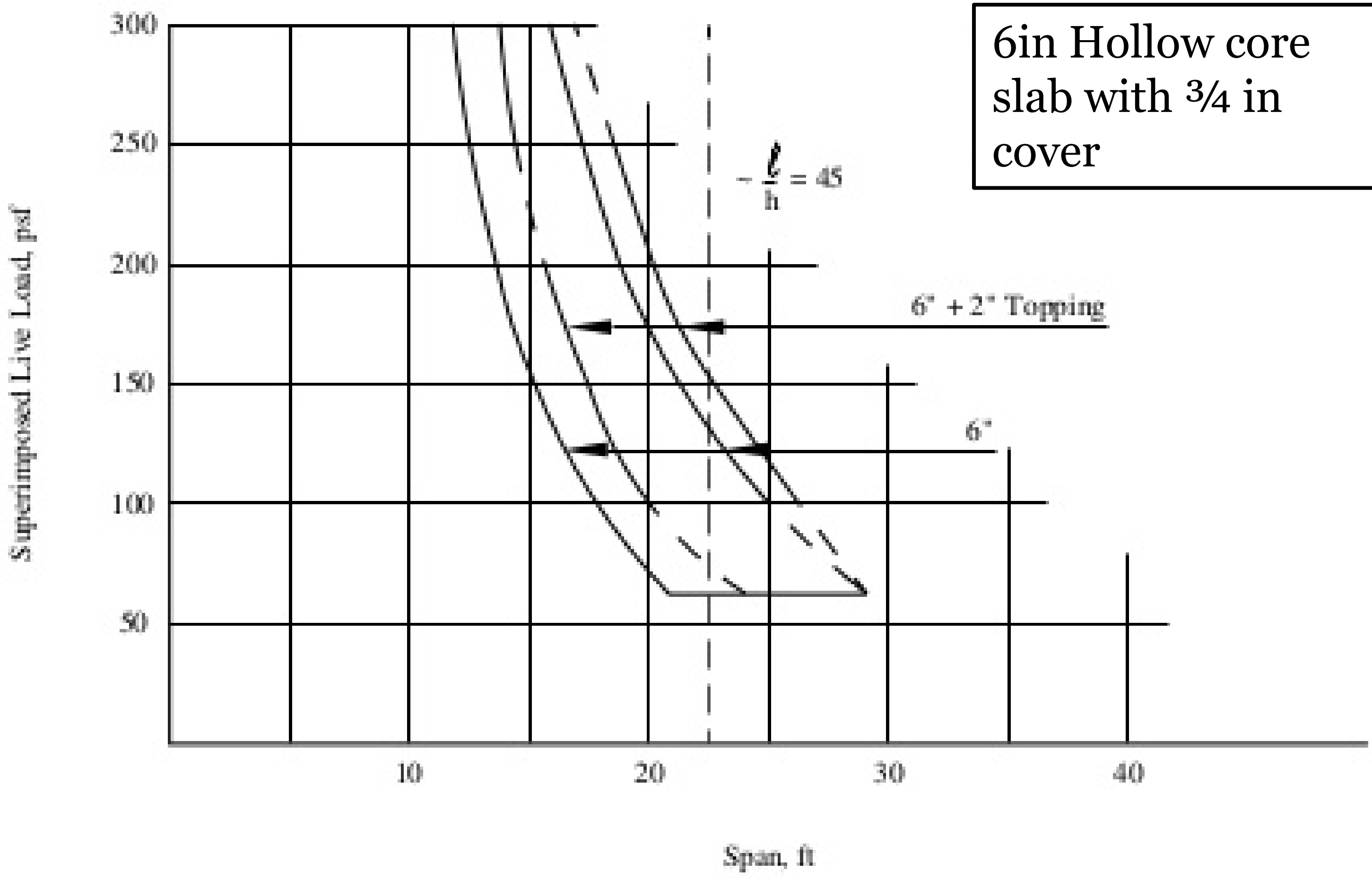


Section width x depth	Untopped A in^2	Untopped y_b in	Untopped I in^4	Untopped wt psf	with 2" topping y_b in	with 2" topping I in^4	with 2" topping wt psf
4'-0" x 6"	157	3.00	694	41	4.33	1557	66
4'-0" x 8"	196	3.97	1580	51	5.41	3024	76
4'-0" x 10"(5)	238	5.00	3042	62	6.49	5190	87
4'-0" x 10"(6)	249	5.00	3108	65	6.44	5280	90
4'-0" x 12"	274	6.00	5121	71	7.56	8134	96

Note: Elematic is also availble in 96" width. All sections not available from all producers. Check availability with local manufacturers.

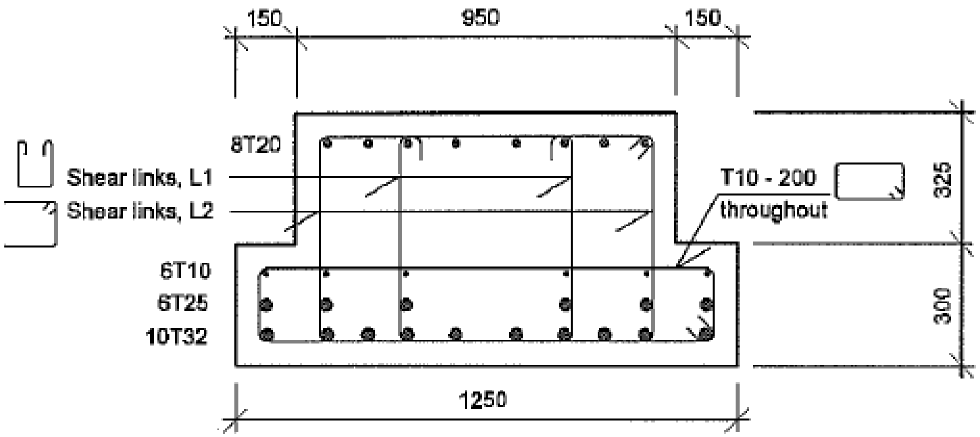
PCI Design charts

Slab load ranges



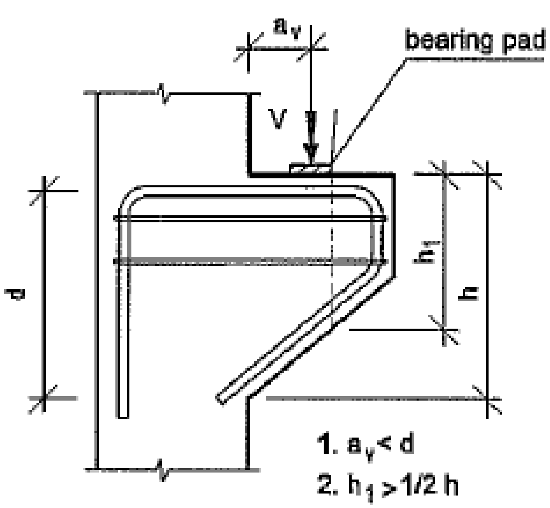
6in Hollow core slab with ¾ in cover

Component level design



Inverted T beam support slabs on flange

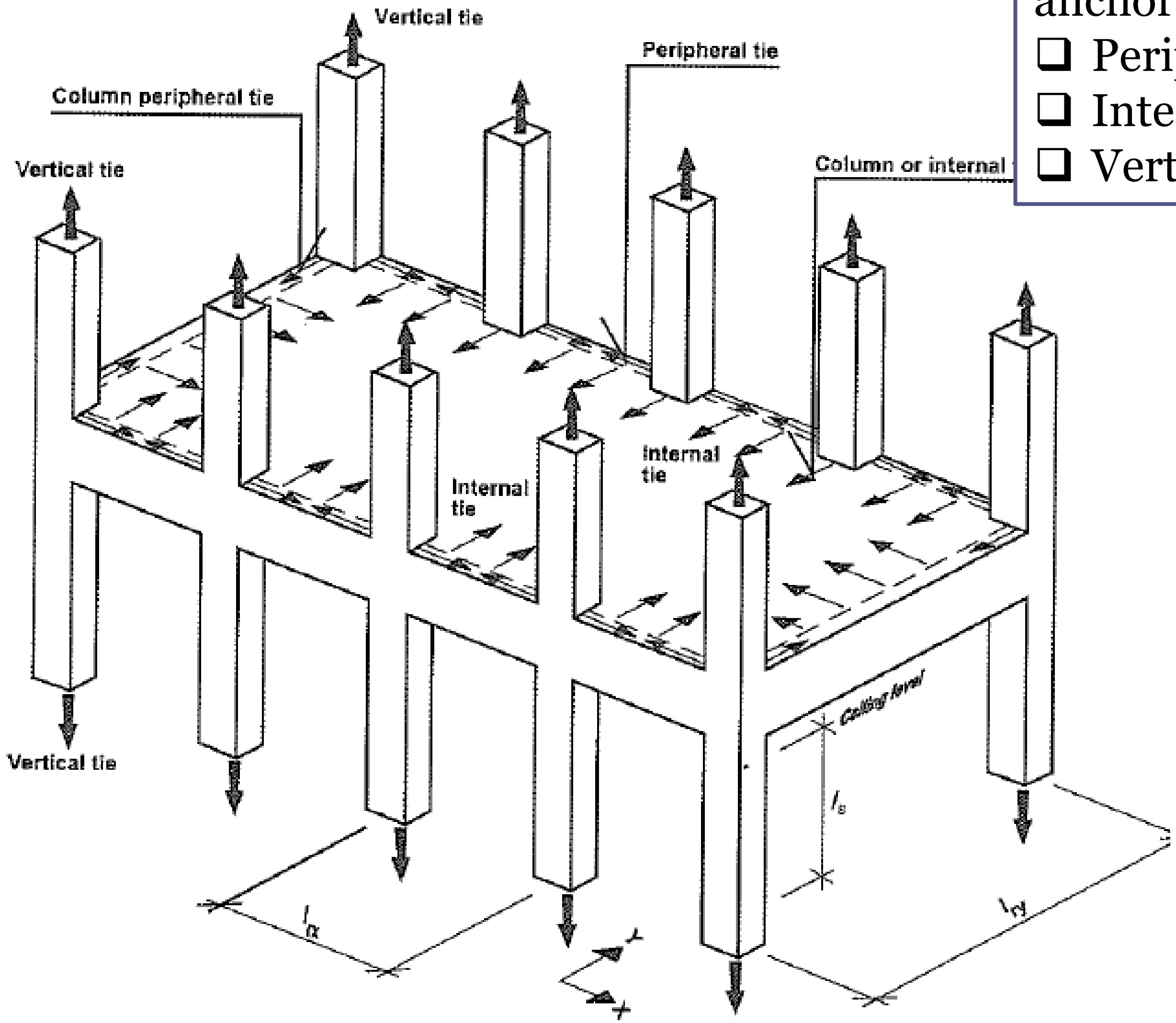
- As per IS 456



Corbel for supporting beams

- As per IS 456

Structural Integrity ties

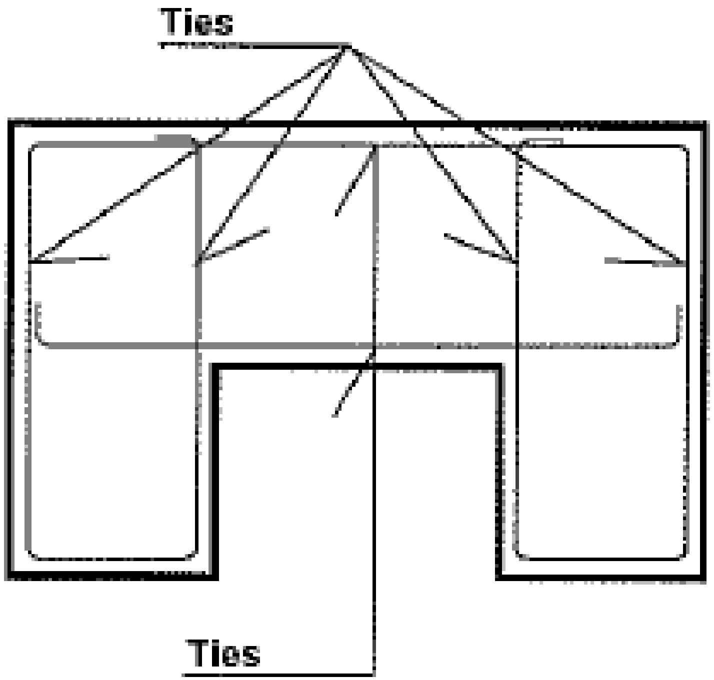


Structural ties are fully anchored tension elements

- ❑ Peripheral ties
- ❑ Internal ties
- ❑ Vertical ties

8.2.3.1 *Peripheral ties*

- At each floor and roof level an effectively continuous tie should be provided.



Peripheral ties in floor layout with internal edges

Prescriptive requirement

- The tie should be capable to resist a tensile force of F_t equal to
  - 60 kN or
  - $(20 + 4N)$ kN, whichever is less, where N is the number of storeys (including basement).

8.2.3.2 *Internal ties*

- To be provided at each floor and roof level in two directions approximately at right angles.
- Ties should be effectively continuous throughout their length and be anchored to the peripheral tie at both ends

Prescriptive requirement

The tensile strength, in kN/m width shall be the greater of :

$$\frac{(g_k + q_k)}{7.5} \cdot \frac{l_r F_t}{5} \text{ and } F_t$$

where, $(g_k + q_k)$ is the sum of average characteristic dead and imposed floor loads, in kN/m^2, and l_r is the greater of the distance between the centre of columns, frames or walls supporting any two adjacent floor spans in the direction of the tie under consideration

3.7 Emulative Detailing System — A connection detailing system for precast concrete structures that has structural performance equivalent to that of a conventionally designed, cast *in-situ*, monolithic concrete structure.

Section 9.4

Precast Joint Connections

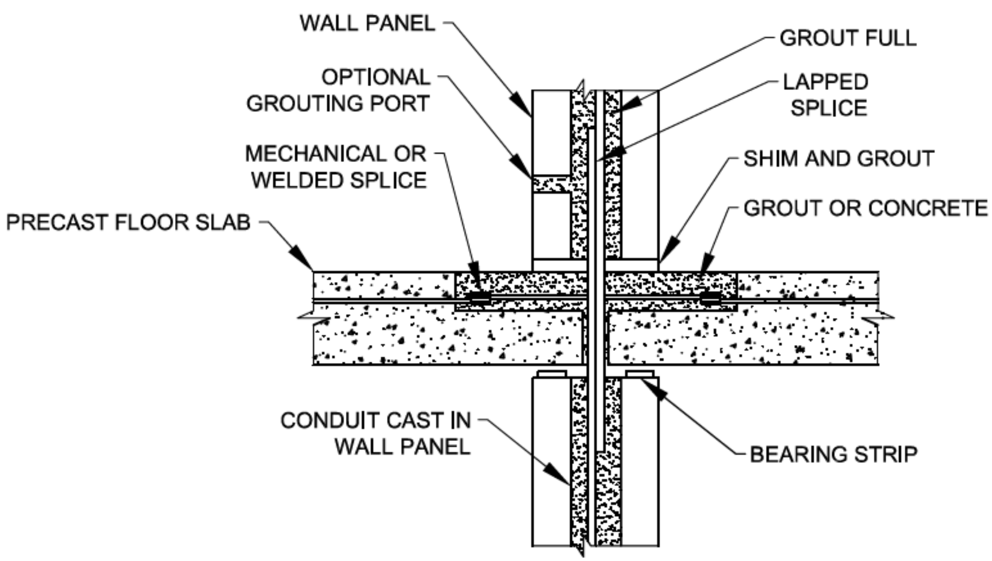
Typical figures of some of the common precast joint connections are given in Annex C.

ANNEX C

(*Clause* 9.4)

COMMON PRECAST JOINT CONNECTIONS

C-1 Typical figures of some common precast joint connections are given in Fig. 10 to Fig. 27.



Design Codes and Ductility

Idealization of Structural System – for analysis of Demand
Hysteretic behavior ?

Presumed Ductility – Connections
While all codes (IS Codes included) talk of requirement of ductility – Ductile detailing not covered

IS 13920 – Cl 1.1.2: Provisions not applicable for Precast RC

Thank You!