PRECAST SOLUTIONS FOR REAL LIFE

Providing precast solutions in seismic areas:

HOLLOW CORE SLABS ADVANTAGEOUS FLOORING SOLUTION IN SEISMIC AREAS

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1. INTRODUCTION

When an earthquake occours in a seismic area, the buildings in this area are subjected to inertial seismic forces which rise for effect of ground accelerations, either vertical and horizontal.

These seismic forces are applied at floor level, where masses are placed (dead loads, superimposed permanent loads, live variable loads).

Vertical seismic loads generally do not influence the flooring design; instead, the lateral (horizontal) loads have a great influence; infact these lateral loads are to be transferred to the resisting bracing structures (columns, cores for lifters and stairs, shear concrete walls).

1. INTRODUCTION

The capacity of the floor to transfer the lateral loads to the vertical structures is called "diaphragm action".

Hollow core slabs used as floors or roof decks in buildings, are generally designed to support vertical loads; a natural extension is to use the slabs to resist also horizontal (or lateral) loads; in this case hollow core slabs are used as a diaphragm.

The function of a diaphragm is to receive these loads from the structures to which they are applied and transmit the loads to the lateral-resisting elements which carry the lateral loads to foundation.

1. INTRODUCTION

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The main issues in designing a hollow core diaphragm are:

- design of connections in order to get loads into the diaphragm
- to provide the diaphragm with the necessary ductility and strenght to transmit these loads to lateral-resisting structures
- design of the connections required to unload the lateral forces from the diaphragm to the lateral-resisting structures

1. INTRODUCTION

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The ductility and strenght requirements of a diaphragm subjected to seismic loads are significantly more important than the requirements for soil and wind loads,

but the common fundamental requirement is to provide a load path in the diaphragm, to transfer lateral loads to the resisting structure.

The load path is influenced by the position of bracing structures, by the flexibility of the diaphragm in its plan and by the width to depth ratio of the diaphragm itself;

The effect of diaphragm's flexibility is indicated in the following figure:

1. INTRODUCTION

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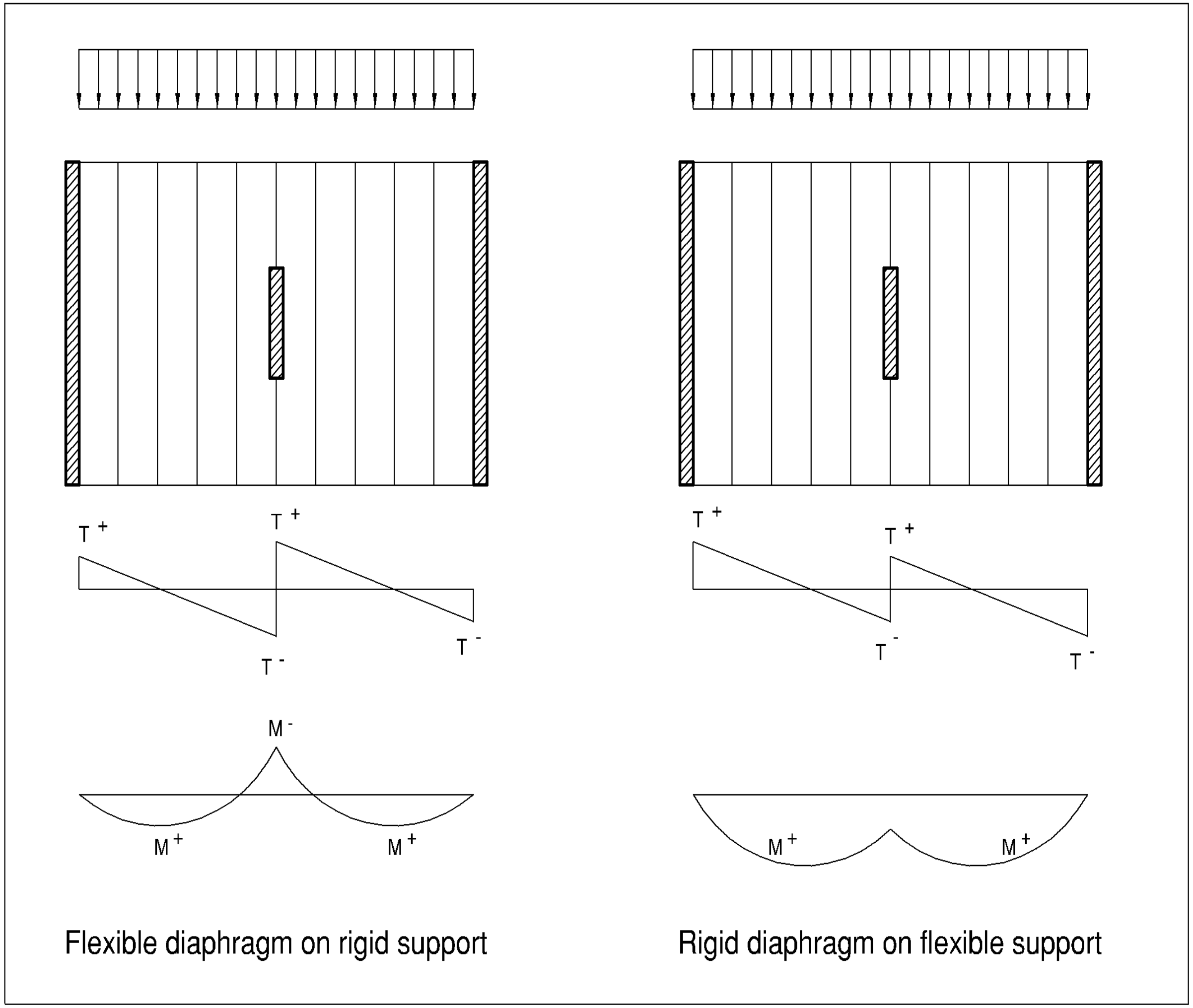
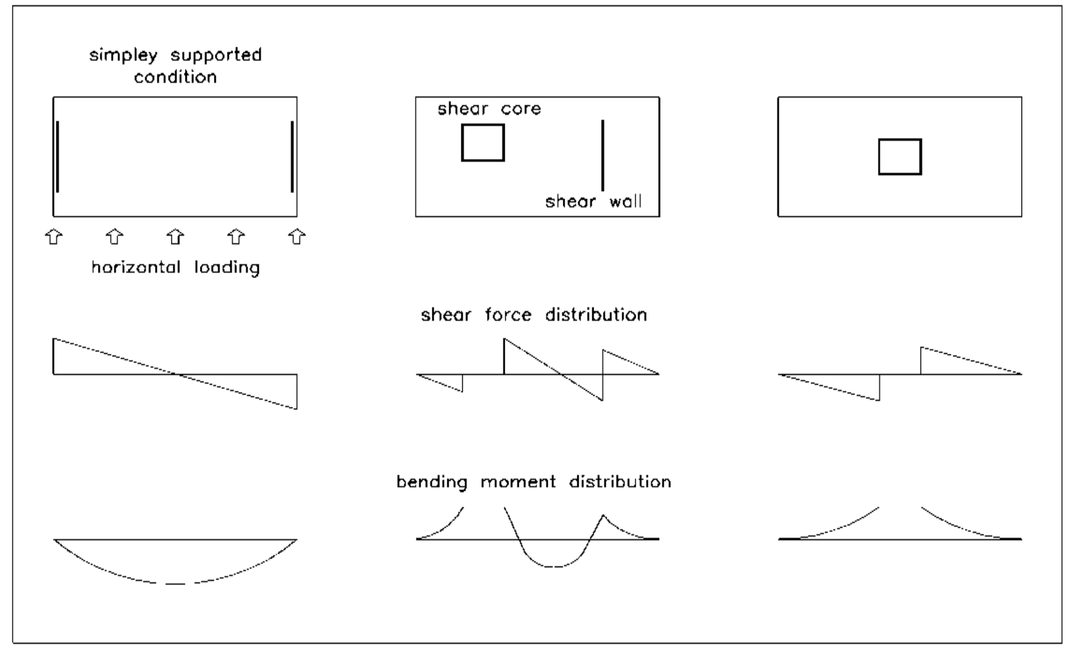


1. INTRODUCTION

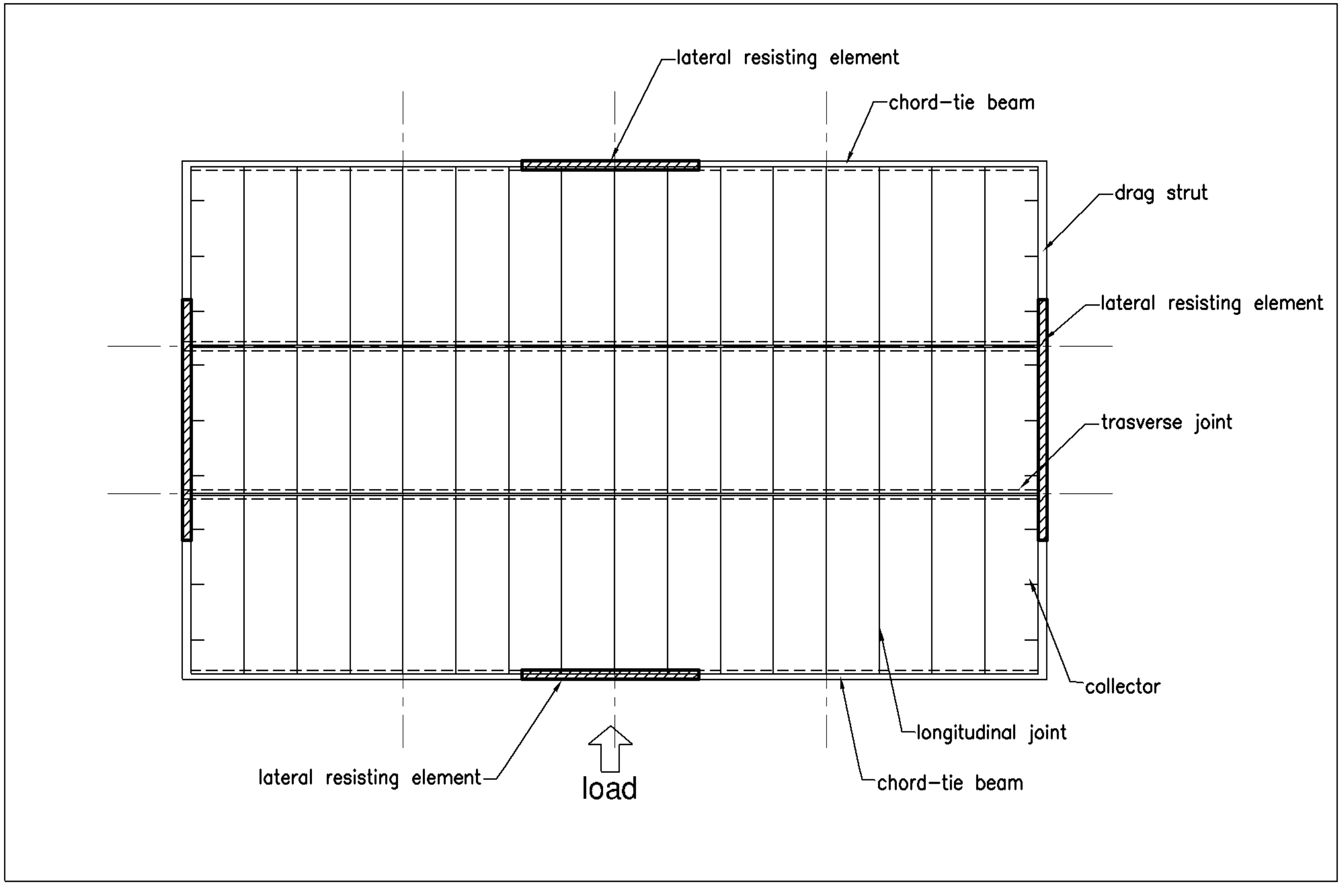
The effect of bracing structure's position is indicated in the figure:



In most of the buildings these models are inappropriate and a FEM computation has to be performed to investigate the load path; in these FEM model the diaphragm is considered rigid.

1. INTRODUCTION

The diaphragm elements are shown in the figure:



1. INTRODUCTION

Boundary element: edge member around the perimeter of the diaphragm or around an opening , which ties the diaphragm together; the boundary elements can also function as a chord (or tie beam); tension reinforcement is placed in the boundary element to allow the diaphragm to be considered like a deep horizontal beam.

Chord-tie beam: tension or compression element which develope flexural integrity in the diaphragm; the reinforcement in tie beam is obtained from the flexural moment, considering an inner lever calculated according to models for deep beam; this inner lever is function of the width to depth ratio.

Longitudinal joint: joint oriented parallel to the slab span; the mechanism of shear transfer in the joints is a shear friction mechanism (also known as shear wedging mechanism); this is developed only if reinforcements are provided in transverse joints.

Transverse joint: joint oriented perpendicular to the slab span; the reinforcements in the transverse joints provide the shear friction mechanism for shear transfer along the longitudinal joints.

Collector: element which transfers shear from the diaphragm to the lateral resisting elements and provides a complete load path In the diaphragm for lateral forces to the foundation.

Drag strut: element used to “drag” lateral loads into lateral resisting elements.

2. EXAMPLES

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Diaphgram elements for an hosptihal concrete precast structure, Italy

2. EXAMPLES

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Precast frame
(columns, beams and hollow core slab) of a Multilevel Shopping Mall,
Rome - Italy

2. EXAMPLES

Hollow core slabs for the erection of the Nice Allianz Arena, Nice - France

Detail of use of hollow core slabs for irregular shape floors, Rome - Italy

2. EXAMPLES

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Detail of collectors between hollow core slabs and shear wall

2. EXAMPLES

Diaphgram elements for a steel / hollow core slab structure, Rome - Italy

3. PRODUCT CODE REQUIREMENTS

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Informative requirements for diaphragm action of hollow core floors are given in EN 1168:2005+A3:2011
Annex D (informative):

3. PRODUCT CODE REQUIREMENTS

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Hollow core floors can act as diaphragms for the transfer of lateral forces to the bracing vertical structures if the following requirements are satisfied:

a) the shear forces should be resisted either by the joints parallel to the load or by special shear members along perpendicular joints or edges;

b) the calculation of the horizontal shear forces in longitudinal joints should be based on the theory of deep beams;

c) the model for a deep beam is usually a strut and tie model. The inner lever arm used for the determination of the force in the tensile tie should therefore be taken from code provisions pertaining to deep beams.

The resistance of the longitudinal joints to in-plane shear forces should be derived from 6.2.5 of EN 1992-1-1:2004.

If the design shear force exceeds this joint capacity, the capacity can be increased by:

— taking account of shear capacity of edge beams;

— application of special shear connectors.

If the diaphragm action is small, like in the case of low-rise housing, the tying system in non-seismic situations may be based on friction. Calculating the resistant friction forces, the actual bearing method should be taken into consideration.

In seismic zones, the design should be carried out considering the diaphragm behaviour of the hollow core floor with the longitudinal shear stress given in 10.9.3 (12) of EN 1992-1-1:2004, if one of the following requirements is satisfied:

— with a cast-in-situ topping of at least 40 mm for which shear at the interface is verified according to 6.2.5 of EN 1992-1-1:2004;

— in the absence of a cast-in-situ topping and all the hollow core slabs are provided with adapted indented lateral edges, as described in 6.2.5 of EN 1992-1-1:2004 (Figure 6.9);

3. PRODUCT CODE REQUIREMENTS

The second part of requirements refers to seismic zones, and it's clearly indicated that a hollow core floor can be used as a diaphragm either with a structural cast in situ topping, or without a topping.

When a structural topping is provided, the topping can be designed as diaphragm without consideration of the slabs; when the topping provides the strength and the stiffness for the diaphragm but the connections are made in the hollow core slabs, shear stresses will be present at interface topping-slab and shear connectors are to be provided.

In some countries practical rules are given to meet the requirements for diaphragm action.

4. TOPPED VS. UNTOPPED DIAPHGRAMS

The benefits of a structural topping are to increase stiffness and strenght of the diaphragm and to allow easier continuous ties in floors with irregular shapes or large openings.

It is suggested that a topping be used in high seismic areas, in buildings with plan irregularities or large width to depth ratios; normally, in high seismic areas, local codes limit the use of untopped hollow core diaphragms.

Untopped hollow core diaphragms can be used in low risk seismic areas and when the diapragm force system is easy to know and when some in the plane deflections can be accepted.

5. CONNECTIONS DETAILS

Here below are shown some seismic connections and support details used in Italy to transfer the seismic loads to horizontal structures and to vertical bracing structures:

5. CONNECTIONS DETAILS

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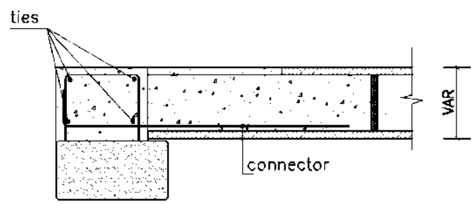
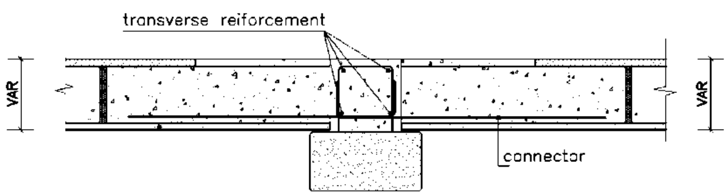
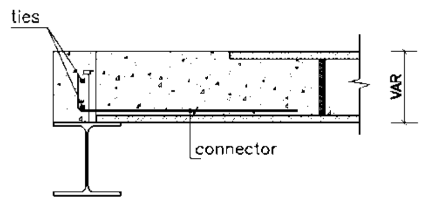


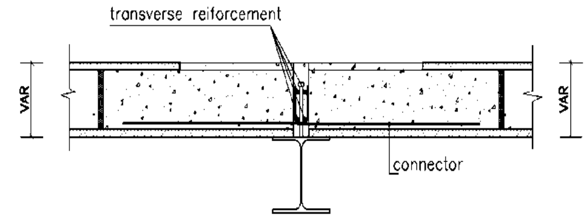
LATERAL CONNECTION DETAIL



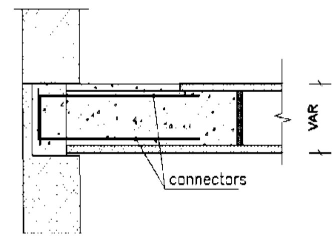
CONNECTION DETAIL



LATERAL CONNECTION DETAIL



CONNECTION DETAIL



SHEAR WALL CONNECTION DETAIL

6. ADVANTAGES OF HOLLOW CORE FLOORS IN SEISMIC AREAS

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The performance of a floor subjected to seismic lateral loads can be evaluated considering the following topics:

- in plane stiffness
- strength to resist the diaphragm loads
- possibility of executing easy and cheap connections and to allow easy continuous tie beams in floors with irregular shape
- dead weight
- price

According to our experience the following table shows a comparison between different flooring system; for each performance a vote has been printed; it's assumed that the lower is the vote the worst is the performance:

6. ADVANTAGES OF HOLLOW CORE FLOORS IN SEISMIC AREAS

IPHA
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	HOLLOW CORE		CAST IN SITU	PREDALLES	BEAM AND BLOCKS	SOLID PLANK	COMPOSITE STEEL AND CONCRETE	RIBBED PRECAST ELEMENTS	
	T	U			T	U		T	U
STIFFNESS	9	6	10	9	7	9	6	9	5
STRENGHT	9	7	10	9	7	9	6	9	5
CONNECTIONS AND TIES	9	7	10	9	8	7	8	9	2
WEIGHT	6	9	1	5	7	1	9	5	9
PRICE	6	8	2	4	5	3	6	4	6

T= Topped (topping tickness 5 cm)
U = Untopped
Element’s span = 7.0 m

6. ADVANTAGES OF HOLLOW CORE FLOORS IN SEISMIC AREAS

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Hollow core floor system, especially the untopped floor, is very advantageous in low risk seismic areas;

the advantage of topped hollow core floors in high risk seismic areas depends on the thickness of the floor which is influenced by span and vertical loads;

the more are the spans and the loads, the more hollow core floor is competitive.

7. REFERENCES

1 – PCI "Manual for the design of Hollow Core Slabs" 2° edition

2 – FIP Recommendations "Precast Prestressed Hollow Core Floors" 1988

3 – CEB-FIP Bulletin n. 6 "Special Design Considerations for Precast Prestressed Hollow Core Floors"

THANK YOU !

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