Planning
MEMO 56
Seismic proposal

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1. Basic design philosophy

In seismic design the ductility of a structure is a central concept, defined as follows:
Ductility is the ability to deform beyond the elastic limit without losing strength or function.
In seismic events the actions will vary dynamically, primarily with equal magnitude in opposite directions. To maintain strength and function during a seismic event, three conditions must be satisfied:

- The materials must have sufficient deformation capability.
- The components (joints, beams, columns, slabs, diaphragms and shear walls) must be able to absorb large repetitive deformations, strains or curvatures.
- The load carrying structure must be composed of the ductile components to form a deformation mechanism.

2. Ductility classes

The European standard on seismic design [EN 1998-1:2004, Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings. (EC8), reference \1\] defines three ductility classes:

- Ductility Class Low (DCL).
- Ductility Class Medium (DCM).
- Ductility Class High (DCH).

3. Relationship between design calculations and ductility classes.

In DCL the design can be carried out according to the usual standards used for calculation of capacities. EC8 is used only to determine the actions from the earthquake.

In DCM a ductile deformation mechanism must be identified. The mechanism is normally secured by using an "overstrength" factor for areas of the structure where plastic hinges may make the deformation mechanism unstable. The design procedure will lead to seismic actions smaller in DCM than in DCL. EC8 has detailed requirements to the calculation procedure and execution at the site.

Designing in DCH is carried out as in DCM, the difference being that there are stricter and more detailed requirements to the calculation procedure and execution at the site.

4. Damage experiences with precast structures

There are several articles written to try to take advantage of the experiences and conclusions that can be drawn from earthquakes, notably references \2\, \3\, \4\ and \5\.

Conclusion in reference \4\: "Most of the precast buildings behaved remarkably well because they had better regularity and higher concrete grade than ordinary reinforced concrete structures."

Conclusion in reference \5\ (encompassing nine different earthquakes): "Not one concrete building with shear walls has collapsed. Buildings with normal reinforced shear walls, reinforced brick walls and frames with in-filled brick walls have capacity to withstand large earthquakes, in many cases without serious damage."

5. Important design rules based on earthquake experiences.

There are many approaches and design rules for seismic design of precast structures. However, experience is telling us that the principles with regularity horizontally and vertically are important. It also seems that buildings with shear walls (increased stiffness) give a better safety against collapse than flexible frames alone.

Frame structures with large deformation capability are overrepresented in number of collapses, especially buildings with so-called soft stories. A soft story is a building where the stiffness of one floor is less than that of the others. Normally this will be the ground floor, but not necessarily.

Figure 1a. Example of soft story collapse.

Figure 1b. Example of soft story collapse.

In this category we also find one story industrial buildings with cantilevering columns and hinged column-beam connections. The large movements of the top of the columns require a firm connection between column and beam in both directions, which still have to allow for the movements.

For further information and design aid several references are given in section 7: Some are dealing with limitations and requirements, others discussing design methods and special considerations for precast structures.

Figure 1c. Example of soft story collapse.

6. Examples of possible solutions with Invisible connections™

The horizontal forces are carried by reinforcement on top of the beam through holes in the columns, as well as reinforcement in the joint between the floor slabs and the beam. The number, size and positioning of the reinforcing bars will depend on necessary negative moment capacity and the magnitude of the earthquake forces.

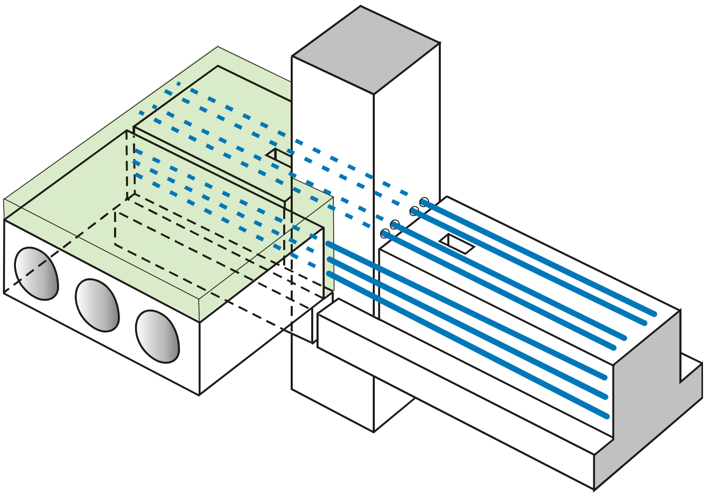
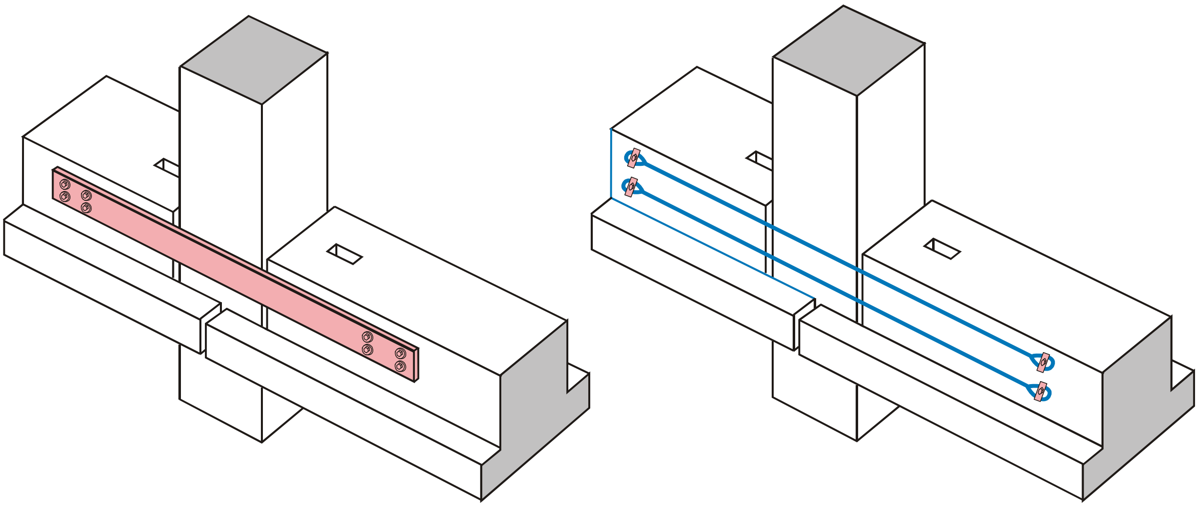


Figure 2. Inverted T-beam with topping.



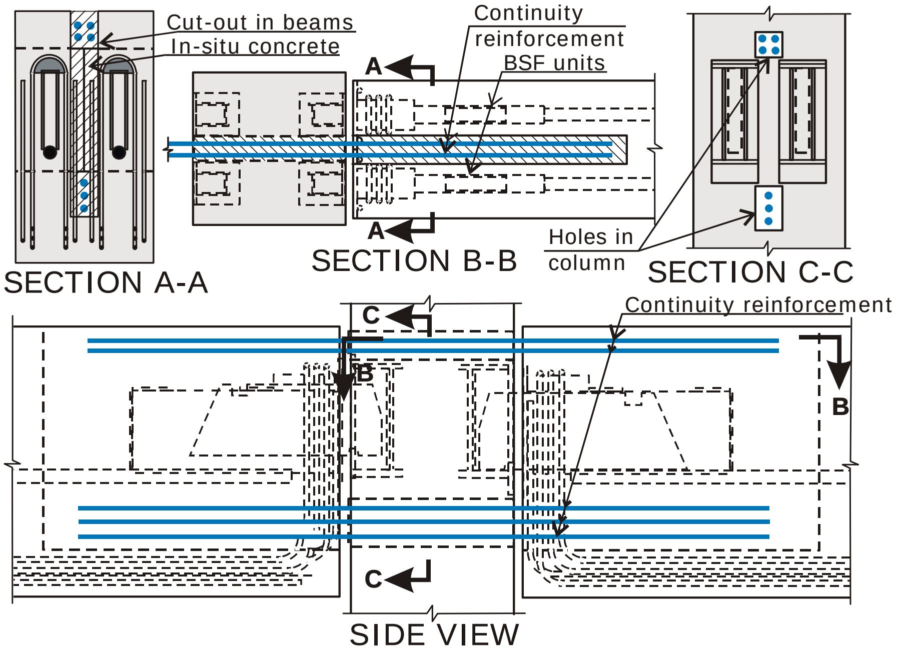
a) Flat steel for continuity.

b) Wires for continuity.

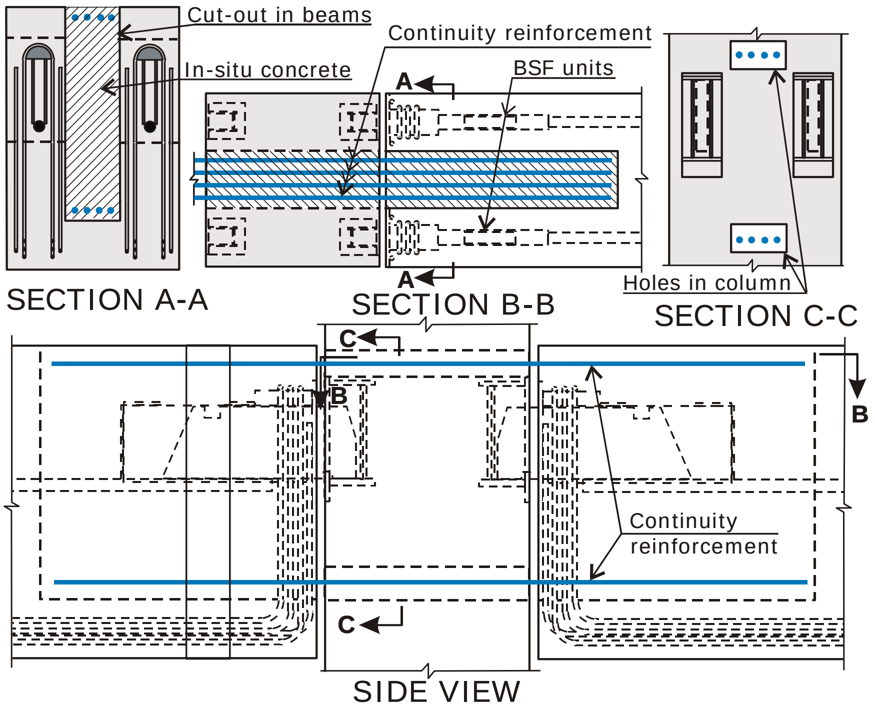
Figure 3. Inverted T-beam.

The horizontal forces are taken by either flat steel or wire straps bolted to the beam, in both cases hidden behind the end of the floor slabs. The size of the flat steel and number of bolts, as well as the number of wire straps to be determined from the magnitude of the seismic forces.

This solution is suitable when the forces from the earthquake are strong, and the beam and column dimensions are comparatively large. It permits quick precast erection, and the insitu concreting is independent of the erection schedule.



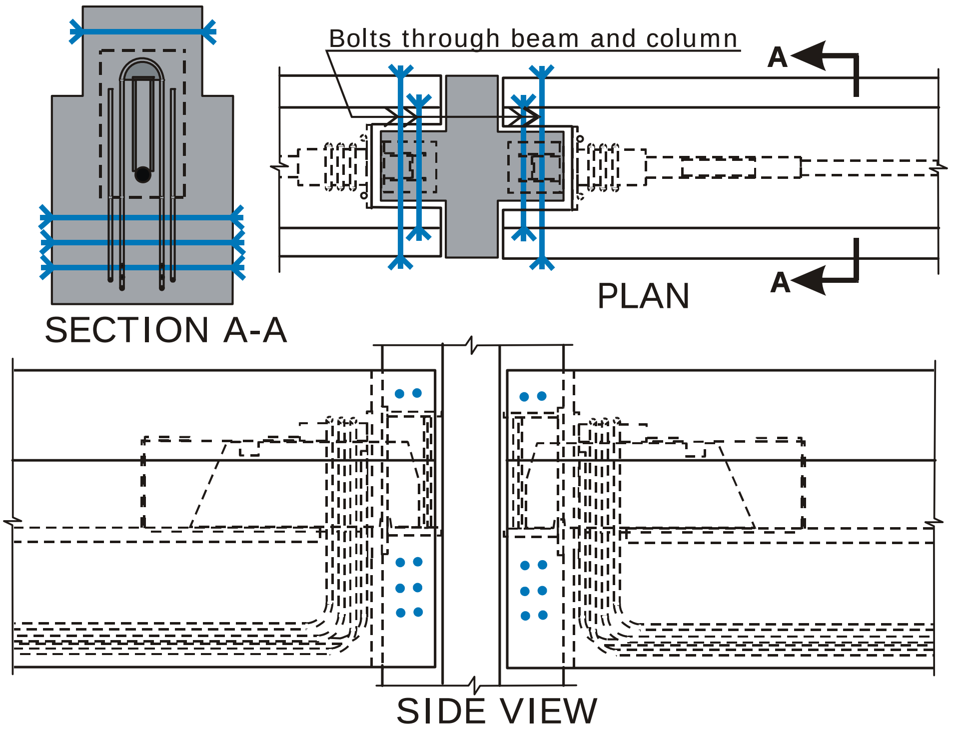
a) Two BSF units in a relatively small beam section, for example BSF 200/20 in a beam b×h = 360×600.



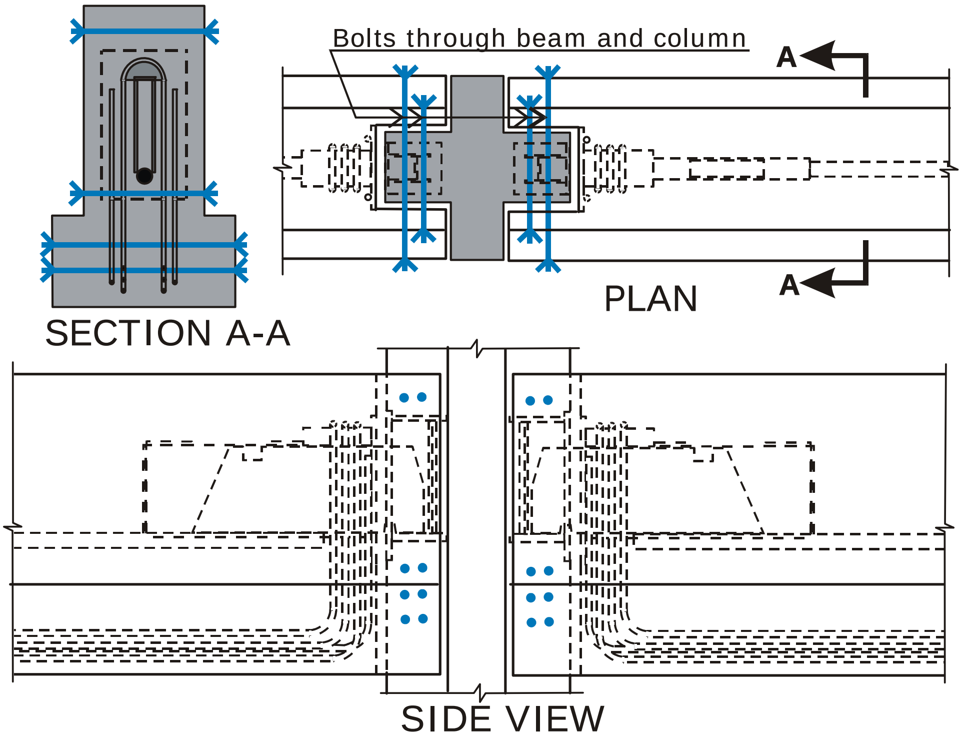
b) Two BSF units in a larger beam section, for example BSF 200/30 in a beam 600×1000.

Figure 4. Precast U-beams with insitu concreting.

This solution is suitable for moderate to large horizontal forces. The installation of the bolts can be carried out independent of the precast erection sequence.



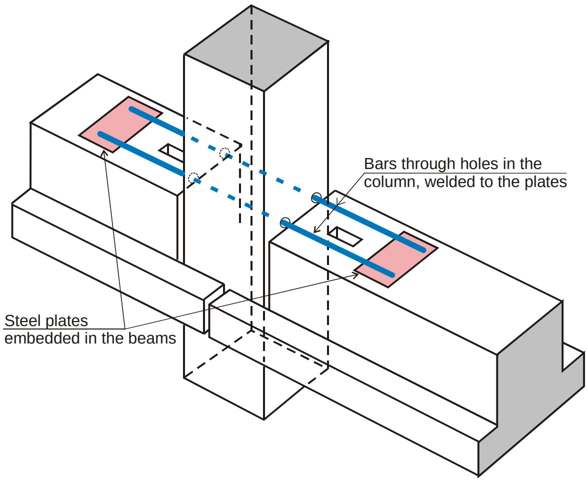
a) Beam ledge for slender slabs (i.e. hollow core).



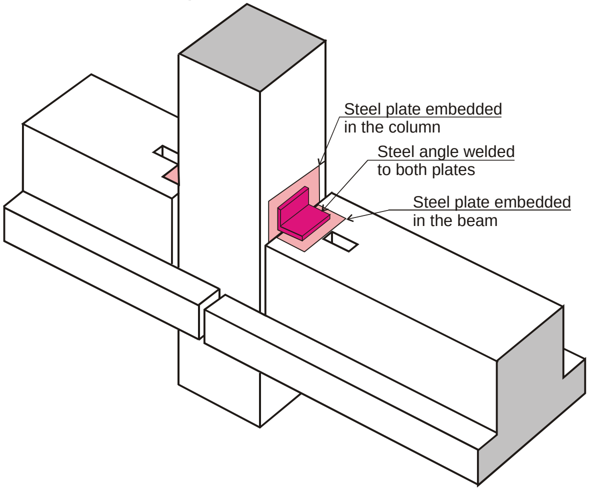
b) Beam ledge for deep slabs (i.e. double T).

Figure 5. X-shaped column with forked beam end.

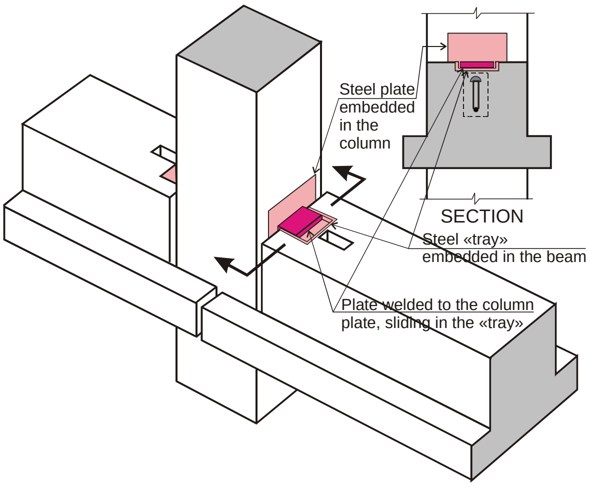
These solutions are suited for relatively small seismic forces. The beams functions as freely supported for dead loads, and as continuous for live loads and seismic forces in solutions a) and b). Solution c) is freely supported also for live loads.
The connections have also a capacity for torsional moments and horizontal forces. The anchorage of the welding plates and size of welds depends on the magnitude of the forces.



a) Bar(s) through column.



b) Angle.



c) Steel plate.

Figure 6. Beams with extra connection in top only.

For the RVK and TSS units, that generally are used to support stairs, we recommend that no special allowances are made to transfer horizontal forces. Provided the stair shaft is designed for the expected action from an earthquake, we believe it is better to let the stairs "float" inside the stiff stair shaft that is functioning as shear walls. This way the stairs will not be damaged, and can serve as an escape route in case of an earthquake.

However, if transfer of horizontal forces is required, we can suggest the solutions shown here:

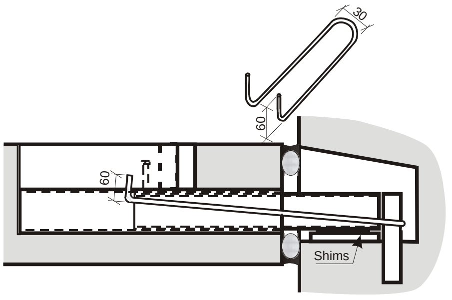


Figure 7. Hairpin anchorage
A pin is embedded in the recess in the wall. A U-shaped rebar is put through the inner tube and looped around the pin.The bar must be inserted from the front and then turned 90°. The recess

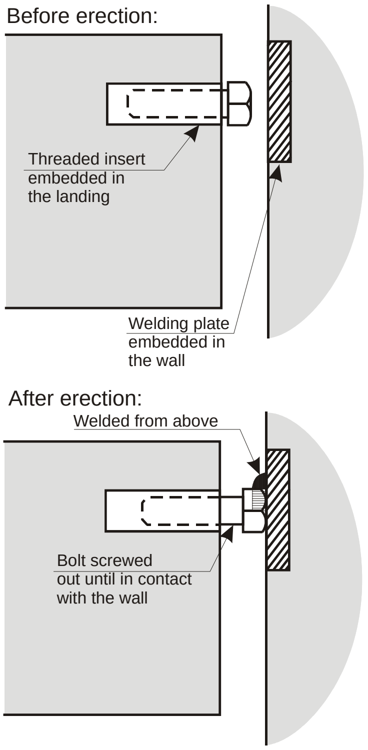


Figure 8. Welding solution.

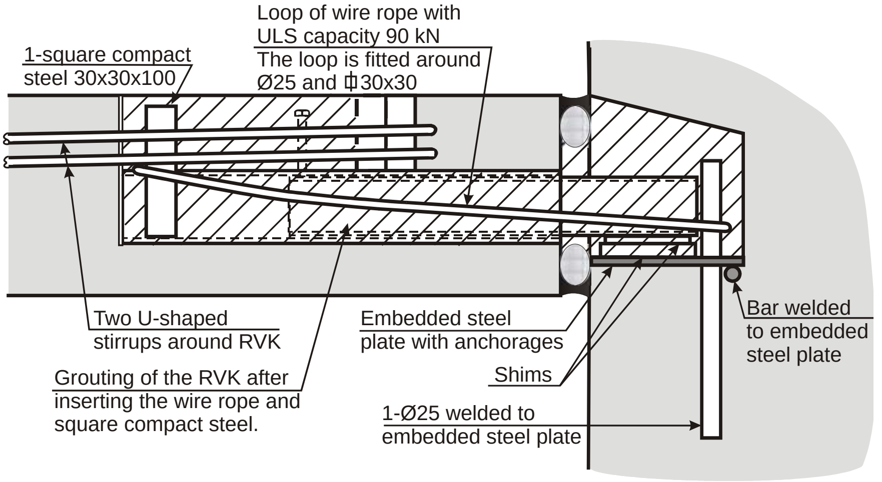
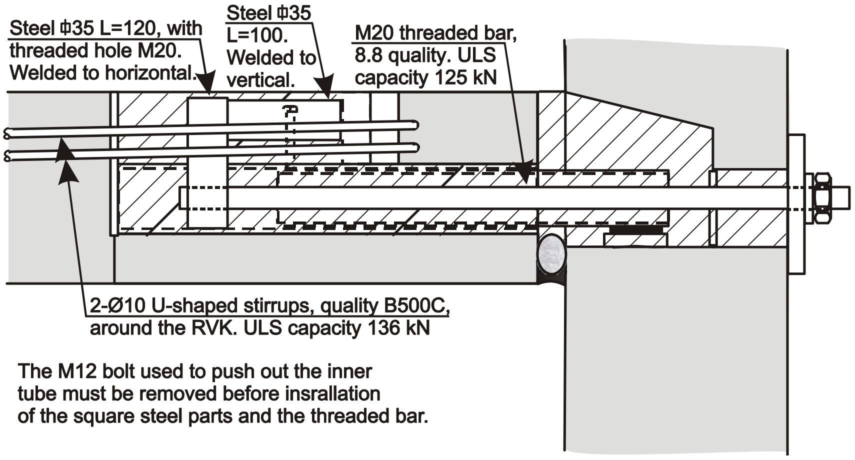


Figure 9. Wire loop.



The M12 bolt used to push out the inner tube must be removed before insrallation of the square steel parts and the threaded bar.

Figure 10. Bolt through wall.

7. References / recommended literature

Referred to in the text:

\1\ EN 1998-1:2004, Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings (EC8).

\2\ Menegotto, M.: Seismic Diaphragm Behavior of Untopped Hollow-Core Floors. FIP XII International Congress. 1994.

\3\ Menegotto, M.: Precast floors under seismic actions. Proceedings 2nd International Symposium on Prefabrication. Helsinki, Finland. 2000.

\4\ H. Muguruma, M. Nishiyama, F. Watanabe: Lessons learned from the Kobe Earthquake. PCI Journal no. 4, 1995.

\5\ Mark Fintel. Performance of Buildings With Shear Walls in Earthquakes of the Last Thirty Years. PCI Journal no. 3, 1995.

Precast earthquake design:

\6\ Structural connections for precast concrete buildings. fib bulletin 43. 2008.

\7\ Menegotto M. and Monti, G.: Waved Joint for Seismic-Resistant Precast Floor Diaphragms. ASCE Journal of Structural Engineering, Vol. 131, No 10. 2005.

\8\ Park, R.: Perspective in Seismic Design of Precast Concrete Structures in New Zealand. PCI Journal, May/June 1995.

\9\ Yee, A.A.: Design considerations for Precast Prestressed Concrete Building Structures in Seismic Areas. PCI Journal May/June 1991.

\10\ Displacement-based seismic design of reinforced concrete buildings. fib bulletin 25. 2003.

\11\ Seismic design of precast concrete building structures. fib bulletin 27. 2003.

\12\ Ned Cleland, S. K. Gosh: Seismic design of precast/prestressed concrete structures. PCI 2007.

\13\ PCI Design Handbook, PCI 2004.