Appendix to Chapter 9

UNTOPPED PRECAST DIAPHRAGMS

Although not directly addressed in the code, untopped precast components have been used as diaphragms in high seismic regions. Untopped hollow-core planks with grouted joints and end chords have performed successfully both in earthquakes and in laboratory tests, (Elliot et al., 1992; Menegotto, 1994; Priestley et al., 1999). Experience has also demonstrated the unsuccessful use of cast-in-place concrete topping as diaphragms (Iverson and Hawkins, 1994). Where problems have occurred, they have not been inherently with the precast construction, but the result of a failure to address fundamental requirements of structural mechanics.

This section provides conditions that are intended to ensure that diaphragms composed of precast components are designed with attention to the principles required for satisfactory behavior. Each condition addresses requirements that should be considered for all diaphragms, but which are particularly important in jointed construction. Specific attention should be paid to providing a complete load path that considers force transfer across all joints and connections.

A9.2 DESIGN REQUIREMENTS

A9.2.1 Configuration. Out-of-plane offsets in the vertical elements of the seismic-force-resisting system place particularly high demands on the diaphragm in providing a continuous load path. Untopped precast diaphragms are not suitable for this condition. It must be recognized that the demand on diaphragms in buildings with these plan irregularities requires special attention. In accordance with Sec. 4.6.3.2 the design force for the diaphragm should be increased by at least 25 percent when such irregularities are present in structures assigned to Seismic Design Category D, E, or F.

A9.2.2 Diaphragm demand. Following the principle that the diaphragm is not generally an appropriate location for inelastic behavior and, in particular, for untopped precast diaphragms, specific direction is provided that elastic models should be used for diaphragm analysis. Connections are subject to a combination of load effects (Fleischman et al., 1998). The distribution of loads may change after yielding, and therefore the design of the diaphragm should avoid yielding.

Since the diaphragm is not generally an appropriate location for inelastic behavior, it should be designed to a level of strength that is intended to ensure that the ductility and yield strength of the seismic-force-resisting system can be mobilized before the diaphragm yields. While research (Fleischman et al., 1998) suggests that the diaphragm demand will not exceed twice the equivalent lateral forces used for the vertical system design, Table 4.3-1 prescribes an overstrength factor, Ω_0, and Sec. 4.3.3 prescribes a redundancy factor, ρ, for the systems that should be used. If an analysis of the probable strength of the seismic-force-resisting system is made to determine a lower demand on the diaphragm, the design force used should still be sufficient to attempt to ensure that the diaphragm remains elastic. For that reason a 1.25 factor is specified.

A9.2.3 Mechanical connections. Although the design procedures prescribed in these sections are intended to ensure elastic behavior at the level of the code design forces, it is recognized that catastrophic events may exceed code requirements. Under such circumstances, it is important that the connections possess ductility under reversed cyclic loading. The intent, in these sections, is for the connection capacity to be limited by steel yielding of the connector and not by brittle concrete failure or weld fracture.

Substantiating experimental evidence to demonstrate through testing and evaluation that mechanical connections satisfy the principles specified in ACI T1.1-01 and ATC-24, and can develop the required capacity and ductility, should meet the following criteria:

Test Procedures:

1. Prior to testing, a design procedure should have been developed for prototype connections having the generic form that is to be tested for acceptance.
2. That design procedure should be used to proportion the test specimens.
3. Specimens should not be less than two-thirds scale.
4. Test specimens should be subject to a sequence of reversing cycles having increasing limiting displacements.
5. Three fully reversed cycles should be applied at each limiting displacement.
6. The maximum load for the first sequence of three cycles should be 75 percent of the calculated nominal strength of the connection, E_n.
7. The stiffness of the connection should be defined as 75 percent of the calculated nominal strength of the connection divided by the corresponding measured displacement, δ_m.
8. Subsequent to the first sequence of three cycles, limiting displacements should be incremented by values not less than 1.0, and not more than 1.25 times δ_m.

Acceptance Criteria:

1. The connection should develop a strength, E_{max}, greater than its calculated nominal strength, E_n.
2. The strength, E_{max}, should be developed at a displacement not greater than $3\delta_m$.
3. For cycling between limiting displacements not less than $3\delta_m$, the peak force for the third loading cycle for a given loading direction should not be less than $0.8\ E_{max}$ for the same loading direction.

Results of reversed cyclic loading tests on typical connections are reported in Spencer (1986) and Pincheira et al. (1998).

A9.2.4 Cast-in-place strips. Successful designs may include a combination of untopped precast components with areas of concrete topping in locations of high force demand or concentration. Such topping can allow for continuity of reinforcement across joints. For such designs, the requirements for topping slab diaphragms apply to the topped portions.

A9.2.5 Deformation compatibility. An important element in the *Provisions* is attention to deformation compatibility requirements. Reduction in effective shear and flexural stiffness for the diaphragm is appropriate in evaluating the overall effects of drift on elements that are not part of the seismic-force-resisting system. This approach should encourage the use of more vertical elements to achieve shorter spans in the diaphragm and result in improved system redundancy and diaphragm continuity. Redundancy will also improve the overall behavior should any part of the diaphragm yield in a catastrophic event.

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