SHEAR WALLS

Buildings that use shear walls as the lateral force-resisting system can be designed to provide a safe, serviceable, and economical solution for wind and earthquake resistance. Shear walls make up most common lateral force-resisting systems in the precast, prestressed concrete industry. The excellent performance of shear-wall buildings throughout the world that have been subjected to earthquakes and high winds can testify to their effectiveness.

BASIC PRINCIPLES

Shear walls act as vertical cantilever beams, transferring the lateral forces acting parallel to the face of the wall, from the superstructure to the foundation. Shear walls should be oriented to resist lateral loads applied to the building along both of the structure's principal axes.

Ideally, there should be at least two shear walls oriented to resist lateral loads along each principal axis. If only one shear wall is oriented along one principal axis, two shear walls should be provided along the orthogonal axis to resist diaphragm torsion. It also is acceptable to orient the three shear walls in any non-collinear position.

Shear walls should be designed as loadbearing panels whenever possible. The increased dead load acting on the panel is an advantage because it increases the panel's resistance to uplift and overturning.

The distribution of the total lateral force acting on a building to each individual shear wall is influenced by four factors:

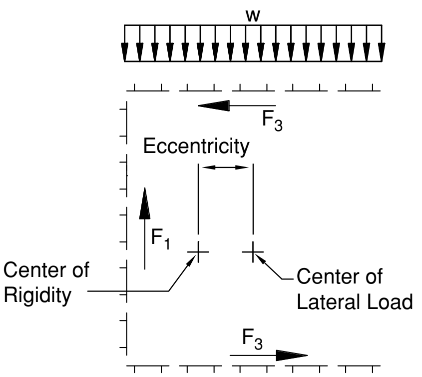
1. The supporting soil and footings.
2. The stiffness of the floor and roof diaphragms.
3. The relative flexural and shear stiffness of the shear walls and of connections.
4. The eccentricity of the lateral loads to the center of rigidity of the shear walls.

Generally, #1 can be neglected when distributing shear forces among shear walls.

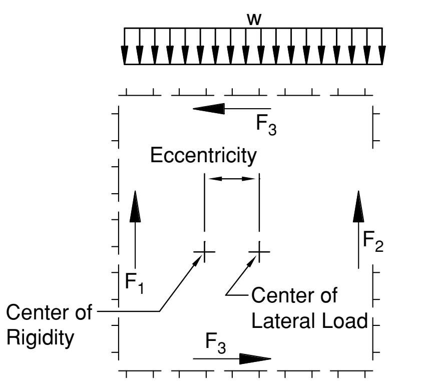
With regard to #2, if the depth-to-span ratio of a diaphragm is small, it will be flexible and may deflect significantly when subjected to lateral loads. Flexible diaphragms distribute shears to each shear wall in proportion to the tributary width of diaphragm loading each shear wall.

If the diaphragm's depth-to-span ratio is large and is adequately connected, the diaphragm will be rigid and not deflect as significantly as a flexible diaphragm when subjected to lateral loads. Rigid diaphragms distribute shears to each shear wall in proportion to the shear wall's relative stiffness. In precast concrete building design, it is common to assume that floor and roof diaphragms act as rigid diaphragms.

Unsymmetrical Shear Walls



(a) Frequently Occurs in Large Buildings with Expansion Joints



(b) Frequently Occurs in Buildings with Large Door Openings

PRECAST CONCRETE DESIGNS

The design for precast concrete shear walls typically has followed principles used for cast-in-place structures, with modifications made as appropriate for the jointed nature of a precast concrete structural system. Design methods used to achieve successful performance of precast shear-wall structures have been left largely to the judgment of the structural engineer.

Observations of performance of structures in earthquakes show that where adequate strength and stiffness were provided to limit interstory drift (lateral displacement) to about 2% (relative to a point at the story below), the resulting displacements and damage were within acceptable levels.

In regions of low and moderate seismic activity, bolted or welded connections with small grout joints are generally used. In regions of high seismic activity, connections to the foundation and connections between precast concrete walls generally use details that emulate cast-in-place behavior and may include post-tensioning.

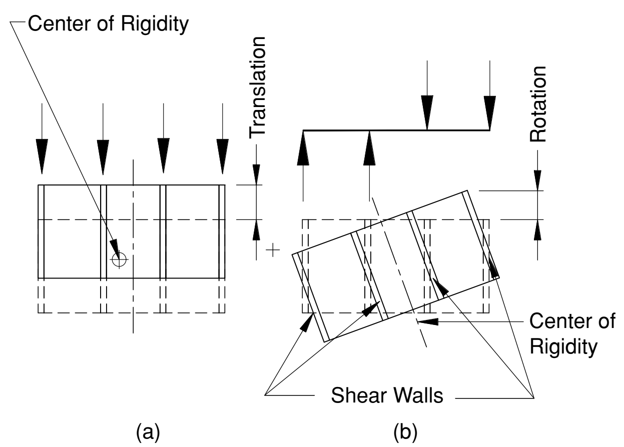
DESIGN GUIDELINES

The steps in designing structures that have shear walls as the primary lateral load-resisting elements include eight key steps that are carried out by the structural engineer of record (EOR) or the precast concrete specialty engineer subject to the EOR's approval:

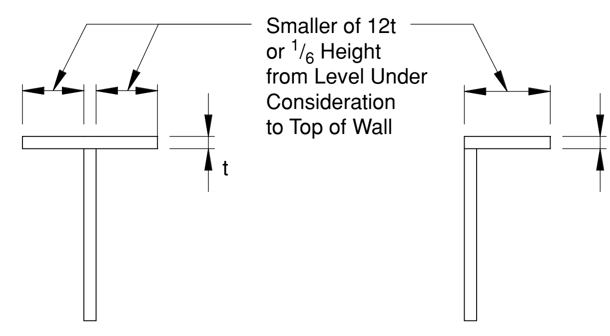
Evaluate the building function and applicable precast concrete frame. In a warehouse-type structure, for instance, it is common to include the exterior walls as part of the lateral force-resisting system. In parking structures, shear walls can be located at stair and elevator towers, at the ends of ramped bays, at selected locations on the perimeter of the structure, or at any combination of the above.

Develop a preliminary design for the shear-wall system. This requires six steps:

1. Provide at least three non-collinear walls to ensure torsional as well as direct lateral resistance.
2. Determine if shear walls can also function as bearing walls, as overturning often will be the governing criterion.
3. Arrange shear walls so they minimize restraint due to volume changes.
4. Consider whether the shear walls could be individual full-height walls (vertical joints only).
5. Consider the practicality of transportation and erection when selecting the size of wall panels.
6. Balance the design requirements of the shear walls with the design requirements of the associated diaphragms.



Translation and rotation of rigid diaphragms.



Effective width of wall perpendicular to shear walls.

Determine the vertical and lateral loads. First determine the applicable vertical gravity loads, then use the appropriate seismic-design criteria to determine the magnitude of lateral load for each floor and compare that with wind loading.

Create a preliminary load analysis. Determine the overturning moment, the lateral in-plane shear, and the axial load at the base of each of the shear walls.

Select the appropriate shear wall. Review the preliminary choice and modify the number, location, and dimensions as necessary to satisfy the requirements at the base of each. It is economically preferable that the foundations not be subjected to uplift.

Determine the final load analysis. Perform the final lateral-load and vertical-load analyses to determine the design load for each shear wall, based on its final location and dimensions.

Create the final shear-wall design. Design shear-wall reinforcement and connections for the associated diaphragms. If there is insufficient length of shear wall available to accommodate the necessary number of shear connectors, consider using an element in the plane of the diaphragm (drag strut) as an extension of the shear wall to pick up additional connectors. Also, consider the added requirements necessary to satisfy the structural-integrity provisions of the code.

Design the diaphragms. They should respond elastically to applied lateral loads to prevent formation of plastic regions in any diaphragm. They need to be designed as beams, provide the necessary tensile reinforcement for each chord, and provide shear connectors or shear reinforcement using shear-friction methods. Additional requirements needed to satisfy the structural-integrity provisions of the code also should be considered.

LOADBEARING WALL PANELS

Often the most economical application of architectural precast concrete is as a loadbearing component, which resists and transfers loads applied from other components. These loadbearing members cannot be removed without affecting the strength or stability of the building.

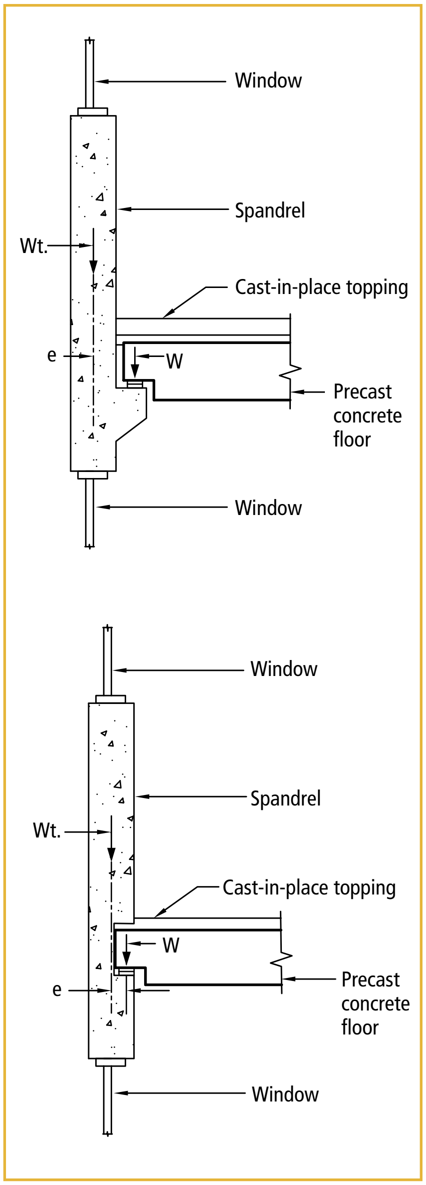
Concrete components normally used for cladding applications, such as solid-wall panels, window walls, or spandrel panels, have an impressive structural capability. With few modifications, many cladding panels can function as loadbearing members. The reinforcement required to physically handle and erect a unit is often more than necessary for in-service loads.

The slight increase in costs for loadbearing wall panels, due to reinforcement and connection requirements, can be offset by the elimination of separate structural frames (beams and columns) for exterior walls or by a reduction of interior shear walls. This savings is most apparent in buildings with a large ratio of wall-to-floor area. The increase in interior floor space gained by eliminating columns can be substantial and, depending on the floor plan, flexibility of partition layout can be improved.

To realize the full potential of these components with no sacrifice in aesthetic advantages, the structural engineer should be involved from the initial-concept stage. Considerations should include the load effects on member dimensions, coordination of temporary bracing, connections, and erection sequencing.

Loadbearing panels can be supported by continuous footings, isolated piers, grade beams, or transfer girders. The bearing-wall units can start at an upper-floor level with the lower floors framed with beams and columns.

The all-precast concrete structural system includes double tees, inverted tee beams, shear walls, and loadbearing precast walls. The system is a common approach to design in the Rocky Mountain region.



Loadbearing spandrels.

Window-wall panels also can be loadbearing if desired. Since these panels are usually custom-made for specific projects, the designer can take advantage of the self-contained columns and girders inherent in the cross section of these panels by designing haunches to provide bearing for floors. Spandrels can also be made into loadbearing components.

DESIGN CONSIDERATIONS

Most design considerations for non-loadbearing wall panels must also be considered in the analysis of loadbearing wall panels. The design and structural behavior of exterior architectural precast concrete bearing-wall panels is dependent upon the panel shape and configuration, and they should consider the following:

- **Gravity loads and the transfer of these loads to the foundation.** Vertical (gravity) loads are parallel to the plane of the wall at an eccentricity influenced by the geometry of the wall, location of the load, and manufacturing and erection tolerances.
- **Magnitude and distribution of lateral loads,** both wind and seismic, and the means for resisting these loads using shear walls and floor diaphragms. Loads in the horizontal direction may be both parallel to and perpendicular to the plane of the wall. For typical precast concrete structures, improved redundancy and ductility are achieved by connecting members into a load path to the lateral force-resisting system, which must be continuous to the foundation.
- **Location of joints to control volume-change movements** due to concrete creep, shrinkage, and seasonal temperature changes.
- **Connection concepts and types of connections** required to resist the various applied loads. In some cases, local practice may suggest one type of connection over another, such as the use of bolts rather than welds. All connections need to be accessible and allow for tolerances and adjustment.
- **Tolerances required for the structure** with regard to production and erection for both precast concrete units and connections, including tolerances for interfacing of different materials.
- **Specific design requirements during the construction** that may control designs, such as site accessibility.

The design of exterior walls using loadbearing architectural panels follows typical engineering procedures. However, designers must recognize the role that is played by precast concrete panel production and erection in the overall design process. Similarly, usually accepted procedures and code requirements apply to the design of an individual precast concrete panel and its connections.

In most cases, the gravity dead and live load conditions for most precast concrete exterior bearing-wall structures will control the panel's structural dimensions rather than load combinations, which include lateral loads.

Panels may be designed to span horizontally between columns or vertically between floors. The choice depends primarily on handling and erection requirements and the methods or details selected for making connections. When spanning horizontally, panels are designed as beams or, if they have frequent, regularly spaced window openings, they are designed as Vierendeel trusses. If a large portion of the panel contains window openings, it may be necessary to analyze it as a rigid frame.

SHAPES AND FINISHES

In multistory buildings, the loadbearing wall panels can be several stories in height up to the maximum transportable length, or they can be one-story high and connect at every floor level. The architectural requirements generally govern the design. The variety of shapes and surface finishes commonly associated with cladding can be provided, if the structural and other technical requirements can be satisfied.

By extending loadbearing panels vertically through several stories, complex connection details are minimized and the economic advantages of loadbearing wall panels are increased.

Architectural requirements normally dictate that building elevations have wall panels of the same appearance. As a result, the wall panels receiving the greatest gravity loads should be determined and panel units should be designed interchangeably with the same reinforcing in all panels. This allows any panel to be installed at any point on the structure's exterior, since the floor plan of a loadbearing panel building is usually the same on all stories, producing uniform loads on the building perimeter.

In most cases, there is little need to be concerned with differential foundation settlement. This is one of the most important advantages for high-rise, loadbearing panel structures where the bearing walls also serve as shear walls.