Briefing Paper 4

Seismic Response of Concrete & Masonry Buildings

Part C: The Role of Shear Walls and Frames

Introduction

Briefing Paper 4, *Seismic Response of Concrete and Masonry Buildings*, consists of four parts. Part A provides a brief overview of how earthquakes affect reinforced concrete and masonry buildings. Part B describes the detailed response of a floor (or roof) diaphragm to the horizontal forces generated within it, and how the forces are transmitted horizontally to the building walls and frames. This Part C describes the vertical load path carrying the horizontal loads down the building walls and frames, through the foundations and into the ground. Part D explains that as well as providing the load paths, some specific components must have the ductility necessary to handle the large distortions from major earthquakes.

Shear Wall Seismic Behavior

Reinforced concrete and masonry shear walls are vertical seismic elements that resist lateral loads in their plane. They are like vertical diving boards extending upward from the foundation. The earthquake forces act horizontally in the plane of this vertical cantilever. After the diaphragm shear force has been transmitted into the shear wall, the shear wall behaves like an almost rigid diaphragm to resist these forces. In reinforced walls, the reinforcing bars (rebar) are usually laid out in a regular rectangular pattern, with bars running in both horizontal and vertical directions at uniform spacing.

Shear walls develop bending forces as well as shears, and all forces are transmitted to the foundation elements, which resist the tendency of the seismic forces to push the wall over in its own plane (Figure 1). This moment, which wants to rotate the shear wall, is called an overturning moment. It increases from the top to the bottom of the building. This is why reinforced shear walls have extra vertical bars placed at the ends. This boundary reinforcing resists the bending forces, alternating vertical tension and compression, in the wall. In new construction, there are usually smaller bars placed like column ties around the boundary reinforcing to ensure confinement and ductility of the concrete. The concept of confinement and ductility is discussed more in Part D of Briefing Paper 4. Bending forces can also develop around large openings in walls. This is why additional trim bars are added at the edges of wall openings. Horizontal construction joints in walls rely on shear transfer mechanisms such as built-in bumps or blocks, like the vertical joints in rigid floor diaphragms.

Damage patterns in reinforced walls following earthquakes reflect their relative strengths in shear and bending. Walls that are stronger in bending than shear exhibit shear damage:

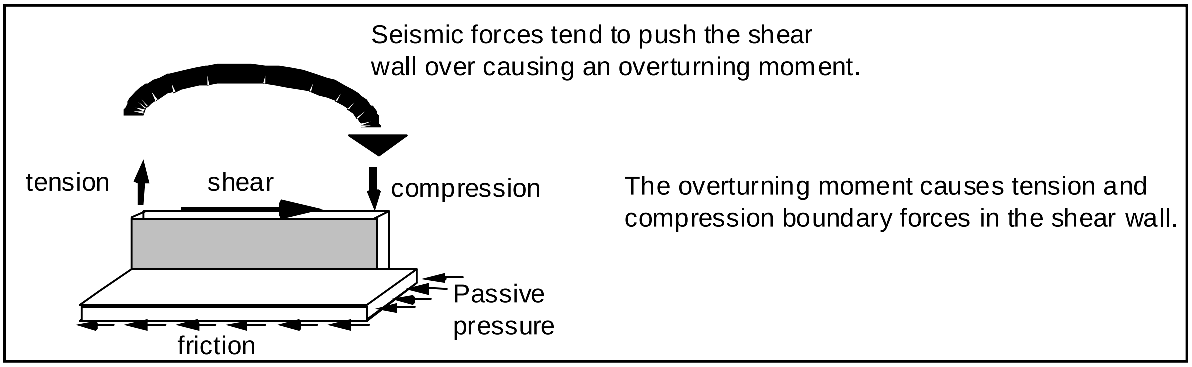

Figure 1. Resistance to overturning moment and shear at foundation level.

inclined, often X-shaped, cracking patterns. This behavior is acceptable if there is adequate shear reinforcing; however, in the absence of adequate reinforcing, shear-controlled walls can lose strength rapidly. Retrofit measures include the addition of concrete overlays to increase the shear strength of walls. Walls weaker in bending than in shear are typically more ductile as they suffer bending damage, but do not fail abruptly. Bending cracks in walls tend to be horizontal and at the base.

Experience from past earthquakes has shown that it is very important that columns be stronger than beams.

Sometimes walls in the same plane are connected together with horizontal beams, called spandrels or coupling beams, at floor and roof levels. During earthquakes, these components can also sustain damage similar to that observed in walls. New construction standards require reinforcing patterns that favor the more desirable, ductile behavior.

In new construction, all shear walls are required by code to be reinforced. Unreinforced masonry walls are common, however, in older existing construction. These walls have a limited capacity to resist shear forces. Their behavior initially is similar to that of the reinforced walls, but shear-controlled behavior, usually evidenced by X-cracks, is particularly perilous in URM construction (Figure 2). Bending-controlled behavior in these walls can result in less onerous rocking of individual walls or wall piers. URM buildings require strengthening to resist earthquakes. Reinforced concrete or shotcrete overlays on existing walls are a common retrofit technique. In other instances, new reinforced walls or steel braced frames are added to the building.

Frame Seismic Behavior

Frames rely on a different mechanism to resist lateral loads. Frames are composed of vertical components (columns) and horizontal components (beams). As earthquake forces displace the frame sideways, the rectangles that were defined by the beams and columns tend to be distorted into parallelograms. The joints do not permit this, and the resulting distortion causes the beams and columns to bend and develop forces called bending moments. Bending moments cause tension on one face of a beam or column and a corresponding compression on the opposite face. In reinforced concrete and reinforced masonry frames, longitudinal reinforcing bars are installed to resist the tension forces. The shear forces are resisted by the concrete or masonry, and by the smaller transverse reinforcing bars placed around the longitudinal bars. Transverse reinforcing is horizontal (called ties) in columns and vertical (called stirrups) in beams. Transverse reinforcement is particularly important in frames to provide ductility and confinement, which is discussed in Part D of this Briefing Paper 4.

Experience from past earthquakes has shown that it is important that columns be stronger than beams. Damage is then concentrated in the beams and avoided in the columns, which are required to support, with no damage, the vertical

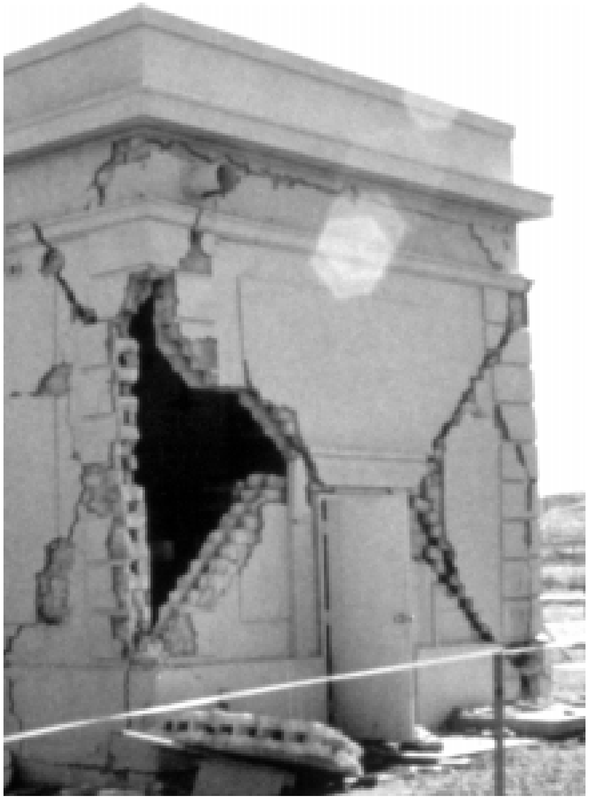

Figure 2. Earthquake-induced shear cracks in unreinforced masonry wall building.

loads. The appropriate relative strength in shear and bending is also important for frames. Some serious failures have occurred when deep beams cause shear failures in so-called “short columns”. Joints in frames between beams and columns are subject to high shear forces and have suffered damage in past earthquakes (see Figure 3).

Foundation Behavior

Foundations can be shallow or deep. Shallow foundations are supported by the vertical pressure of the earth directly below. They can be square or rectangular conventional spread footings placed beneath individual columns, or continuous, relatively narrow, rectangular footings underneath walls or frames. Deep foundations have either steel or concrete piles driven into the ground, or concrete piers that have been drilled and poured in place. These components are supported vertically by end bearing and by skin friction along their length. Footing components are often connected together by grade beams or slabs on grade. Shear forces are transferred to foundation components from walls and frames. Dowels from the footings must match in total cross-section, both boundary reinforcing in walls and bending reinforcing in frame columns to resist overturning. In fact, all vertical reinforcing in walls and frames must be matched by foundation dowels. Great care should be exercised in the field to make sure that these dowels are in place.

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Seismic shear forces are transmitted to the earth in two ways. First, horizontal friction develops on the lower face of shallow footings and slabs (See Figure 1). Second, if the seismic forces are greater than the shear capacity, the building is normally restrained from movement by passive soil pressures acting on the sides of footings, grade beams, piles, piers, basement walls, or other similar components.

Overturning forces on shallow foundations are

Figure 4. Beam-column joints damaged during 1994 Northridge earthquake.

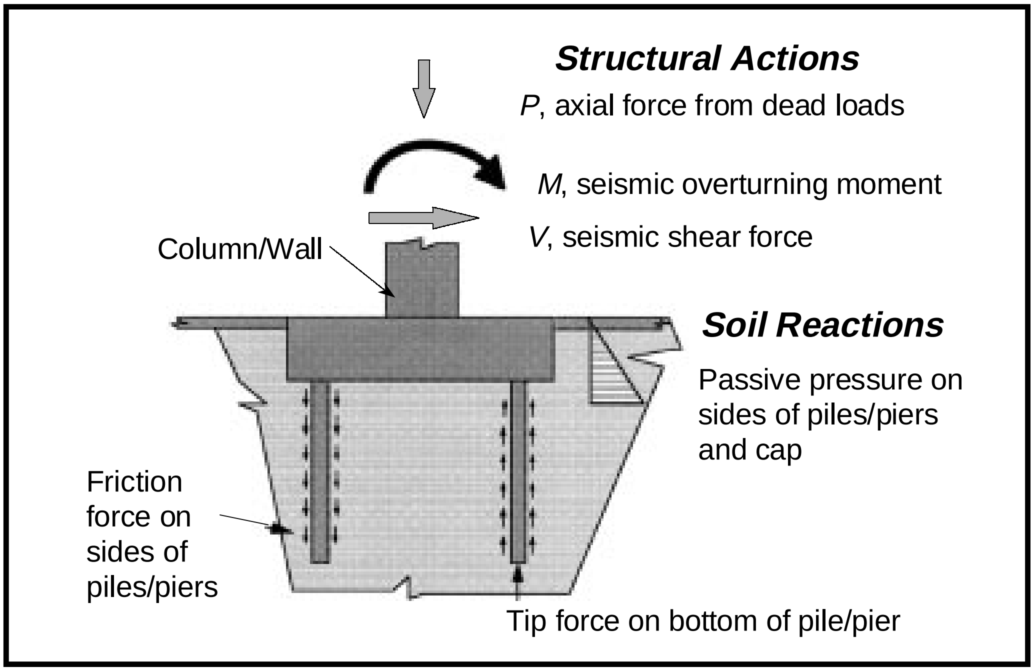

Figure 4. Seismic loading of deep foundations.

resisted by a redistribution of the pressure supporting the vertical loads. In all earthquakes, since all soils have some elasticity, rocking occurs. In major earthquakes, as the limit of the restoring capability is approached, more rocking can occur. This is not always a bad phenomenon, since it limits the level of the internal building forces. Overturning forces in deep foundations (see Figure 4) cause an increase in some pile or pier loads and a decrease in others. In fact, the initial compression in some edge locations might be overcome, resulting in tension in the piles or piers located there.

Resources

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Briefing papers in this series are concise, easy-to-read summary overviews of important issues and topics that facilitate the improvement of earthquake-resistant building design and construction quality.

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