

INCREASING SHEAR CAPACITY WITHIN EXISTING REINFORCED CONCRETE STRUCTURES

Keywords: external steel reinforcement; fiber-reinforced polymer; section enlargement; shear reversal; shear strengthening.

Introduction

Rehabilitation projects often involve the need to increase the load-carrying capacity of members within existing concrete structures that are deficient due to increased load demand associated with change of use, deficiencies in the original design or construction, or deterioration. Such strengthening often includes increasing shear capacity. Shear strengthening may also be necessary when a structure requires flexural strengthening to ensure a ductile failure mechanism in seismic loading situations. The accessibility difficulties normally encountered in concrete structures, as well as general lack of design standards, may lead to building official limitations on what strengthening may be accepted.

Question

What options are available to increase the shear capacity of members within existing reinforced concrete structures?

Answer

The following are descriptions and some examples of various techniques for shear strengthening. Note that, unless indicated, the shear strengthening measures described are specific to nonseismic applications. Chapter 5 of ACI 546R-04 (ACI Committee 546 2004) and ACI 440.2R-02, 440.1R-06, and 437R-03 (ACI Committee 440 2002, 2006; ACI Committee 437 2003) provide additional information on structural strengthening. All shear strengthening should be performed under the guidance of a licensed engineer familiar with the selected technique.

1. *External steel reinforcement*—The shear capacity of concrete members, such as columns, beams, slabs, and shear walls, can be increased by attaching steel plates (Fig. 1) to the concrete surface with epoxy bonding, mechanical anchorage, or both. Steel rods or reinforcing bars, either post-tensioned or non-post-tensioned, are another form of external steel shear reinforcement that is well suited to beams (Fig. 2);

2. *Section enlargement*—Section enlargement can be accomplished by using concrete, shotcrete, reinforced concrete, or mortar that is bonded to the concrete element (Fig. 3). For example, columns can be strengthened by using jackets (Fig. 4 and 5), beams by increasing the section, shear walls by increasing the wall thickness, and ribbed slabs by filling the open spaces between the ribs. The columns in Fig. 4 and 5 were strengthened to increase the vertical shear capacity of the beam seat, and not the column shear associated with moment interaction;

3. *Internal steel and FRP reinforcement*—Additional steel or fiber-reinforced polymer (FRP) reinforcement can be installed by drilling holes, inserting steel or FRP dowels, and grouting (Fig. 6). Several grouting materials have been used successfully to bond the dowels to the concrete;

4. *Near-surface-mounted reinforcement*—Near-surface-mounted reinforcement (NSMR) involves inserting steel or FRP rods or reinforcing bars into grooves cut into the surface of the concrete section. The grooves are typically not deeper than the existing reinforcement cover

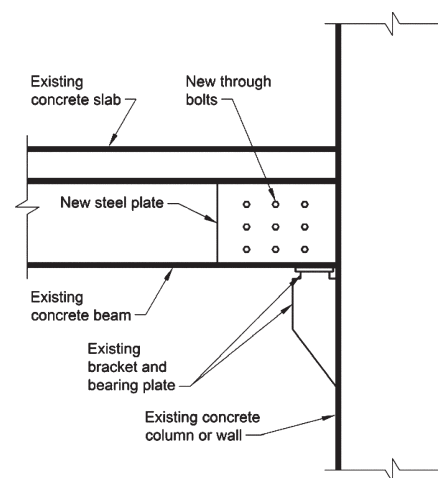


Fig. 1—External reinforcement with steel plate.

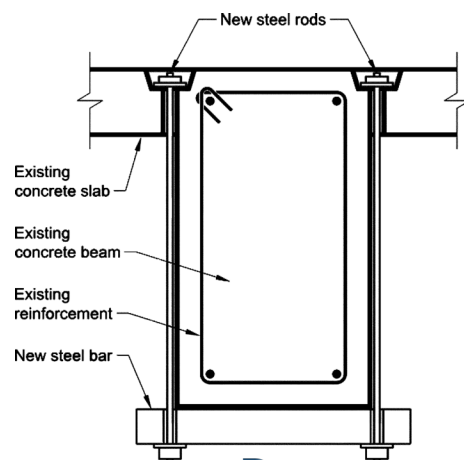


Fig. 2—External shear reinforcement with steel rods or reinforcing bars.



Fig. 3—Section enlargement with supplemental reinforcement covered by shotcrete (Raina 1994).

the additional effect of shell action, although not usually included in design, and the ability to use bidirectional fibers to resist shear reversals. Although fibers positioned at an angle may be optimal, a nearly equivalent amount of fibers are often required as compared with vertically arranged fibers when shear reversals are considered. The FRP is typically bonded to the concrete with a structural-grade epoxy. There are many forms of FRP suitable for shear strengthening, including fabric sheets impregnated with resin on site using a process called wet layup; preimpregnated sheets of fabric; and precured shapes, such as rods, and flat, L-shaped, and U-shaped plates. Codified approaches are available (ACI Committee 440 2002); however, research projects intended for both seismic and nonseismic applications have primarily focused on the nonuniformity of strains in adjacent FRP shear reinforcing elements at the intended design limit (Schuman 2004; Wong and Vecchio 2003; Carolin and Täljsten 2003). It should also be noted that, along with seismic applications, research has shown that certain conditions, such as at deep beams and negative moment regions, may require anchorage to obtain a measurable strengthening effect (ACI Committee 437 2003). Anchorage comes in many forms, including steel-bonded anchors with a bearing plate, bundled FRP fiber anchors that are integrated into the FRP shear reinforcement, fully wrapped sections, and ribbed inserts into the flange region. An example of an external application is the wrapping of beams with carbon FRP (CFRP) U-shaped strips (Fig. 7); this is a good example of how FRP anchors can be integrated into the system with minimal visibility and optimum performance. Pultruded L-shaped plate stirrups (Fig. 8) are another form of externally bonded FRP shear strengthening.

Discussion

The selection of the most suitable method for a given application depends on many factors, including:

- Reason for strengthening (note that a majority of the methods will not prevent concrete cracks from forming; rather, they will limit the opening and propagation of shear cracks after crack formation. If crack prevention is critical, one should focus on section enlargement, supplemental

dimension. The grooves are then filled with a polymer or grout to provide compatibility (that is, load transfer) of the reinforcement with the concrete. The advantages of this method are easy access, limited chance of disturbing existing reinforcing bar as compared with internal steel reinforcement, and increased protection and bonded surface area of the reinforcement as compared with the use of external shear reinforcement;

5. *Supplemental members*—Supplemental structural members, such as posts or beams, can be added to reduce shear stress. When architectural constraints allow, this can often be a cost-effective and practical solution; and

6. *FRP plates or strips*—FRP materials may be used as either externally bonded plates or strips. The advantage of using strips is that they do not entrap moisture in the structure and more closely resemble conventional shear reinforcement. The advantages of using plates that

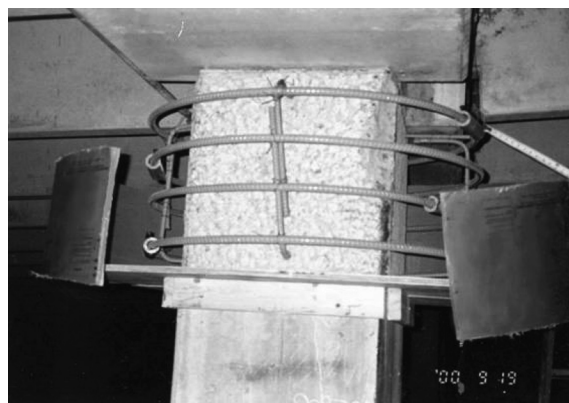


Fig. 4—Section enlargement with jackets.

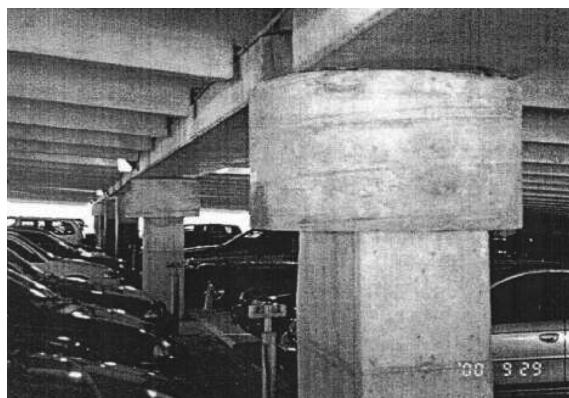


Fig. 5—Completed section enlargement with jackets.

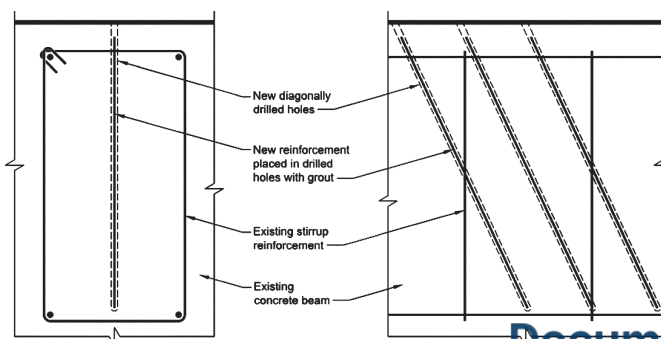


Fig. 6—Internal steel reinforcement.