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STRENGTHENING STRATEGIES FOR IMPROVED SEISMIC PERFORMANCE

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ABSTRACT

There has been a tremendous increase in recent years of strengthening buildings for improved seismic performance in regions of high and moderate seismicity, both after and in anticipation of strong earthquakes. Many structural engineers are more accustomed to designing new buildings and need guidance on the art of strengthening existing buildings.

This brief paper is intended to give simple, straightforward guidance to engineers on the advantages and disadvantages of various strengthening strategies and directions to follow. The methods are applicable to concrete, masonry and steel-framed buildings.

KEYWORDS

Seismic strengthening, existing buildings, shear walls, braced frames, infilled walls, shotcrete, jacketing of frame members

INTRODUCTION

In recent years, there has been a dramatic increase in buildings being strengthened for improved seismic performance, both after damaging earthquakes or in anticipation of expected earthquakes. Many structural engineers have spent most of their career designing new buildings and may find themselves not fully prepared for the challenges of seismically strengthening existing buildings for improved seismic resistance. This paper/poster is intended as a brief summary of the basic advantages, disadvantages, design guidance and references for various strengthening methods. Engineers with extensive experience in seismic strengthening will find this paper quite elementary, but the author feels that many engineers need this basic guidance.

The selection of a seismic strengthening scheme depends on many factors. The scheme must correct the identified deficiencies in the existing building's seismic resisting system and the new strengthening elements must be structurally compatible with the existing structural system. It must be functionally and sometimes aesthetically compatible and complimentary to the existing building. In historic buildings, the added elements must be placed in consideration of preserving historic fabric and historic ambiance. The scheme must be responsive to the owner's performance goals, whether they be life-safety, an essential facility or some form of limited damage for prompt return to full operations after the earthquake. If the building is to remain occupied during the strengthening work, minimizing disruption to occupants may become the overriding issue in selecting an appropriate strengthening solution. In occupied buildings, strengthening solutions in the building's perimeter with most work done from the exterior usually are most satisfactory.

ADDING NEW SHEAR WALLS

Uses

For strengthening concrete or steel framed structures. Can also be used in masonry buildings but shotcrete usually more economical. New shear walls suggest complete walls with boundary elements and walls for which the new construction is complete within itself.

Advantages

Adds much strength and considerable stiffness to existing frame buildings. Stiffness reduces damage to structural and nonstructural elements. While new walls are complete to themselves, they need to be tied into existing structure to mobilize sufficient dead load to resist overturning uplift. Perhaps the most straightforward way to strengthen framed buildings.

Disadvantages

The added concrete or masonry walls are heavy and add mass to the building. New footings are required to support weight and on soft soils or in pile-supported structures, this can be a major disadvantage.

Design Guidelines

The first is to find locations where walls can be added that align full height of the building and are well located to minimize torsion. Verify the amount of dead load which the wall can mobilize to resist overturning uplift. Frequently walls must be extended in plan in the lower stories or basement to mobilize sufficient dead weight. Locate walls such that wall ties into existing floor framing with minimal demolition. It is often desirable to locate walls adjacent to the beam between columns so only minimal slab demolition is necessary while connections can be made to beam sides and columns. Wall design is similar to new construction. Since the wall must be connected to all floor diaphragms to transfer forces into the new wall, it is usually best to also connect to columns in all stories if they are adjacent to keep deformations compatible.

ADDING INFILLED WALLS

Uses

For strengthening reinforced concrete or steel framed buildings. Generally most applicable for one- to three-story buildings although can be utilized up to about five stories. Infill can be reinforced concrete, shotcrete or masonry or precast concrete elements.

Advantages

Infilled walls can utilize beam and column frame members and often replace existing partitions. Demolition through floor not necessary but must add dowels to existing frame members around each infill.

Disadvantages

Wall adds mass to building and added dead load of wall usually requires new footing between existing spread footings. Added footing requirement a significant disadvantage in pile-supported buildings. Doors and windows create added design effort in most infill panels. Existing columns with short compression splices may become weak link.

Design Guidance

Infill wall capacity usually governed by column dead load to resist overturning uplift. Calculate building seismic loads and shear and uplift from single bay, full-height infill wall. Determine how many bays of infill wall needed in both directions to prevent uplift and locate walls in appropriate bays. Design transfer to new infill panels using shear friction. If columns have compression splices weak in tension, strengthening of column splices will be necessary. May require modification of splices or connections by welding shorter lapped reinforcing bars, strengthening steel column splices, adding new vertical edge bars or other methods. Insure concrete or mortar is placed tight to overhead beam or shearing of column may result. Sometimes necessary to epoxy inject this overhead joint.

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ADDING SHOTCRETE TO EXISTING MASONRY

Uses

Ideal solution in unreinforced masonry building when masonry is not strong enough or there is not enough solid piers to resist seismic loads.

Advantages

Shotcrete has compatible stiffness values to the masonry walls. With epoxied dowels at about 1 meter (3 foot) centers each way, shotcrete and masonry will work compositely for out-of-plane stability do relatively thin 100 to 125mm (4 to 5 inch) shotcrete wall often sufficient.

Disadvantages

Shotcrete is messy with rebound which is awkward in occupied buildings. Transfer through floor system requires special details. Some increase in weight requires review of existing foundation capacity.

Design Guidance.

Install sufficient shotcrete to reduce loads in remaining masonry to a level where failure of unreinforced section can be prevented. Shotcrete can sometimes close some windows to make design efficient and effective. Design shotcrete for shear demand and generally ignore bonded masonry. Can utilize other masonry walls to limited capacity to help resist total building lateral forces.

REFERENCES

Appendix Chapter 1, Uniform Code for Building Conservation, 1994 Edition, by International Conference of Building Officials, for evaluation of existing masonry.

ADDING JACKETS TO CONCRETE COLUMNS AND BEAMS

Uses

Strengthening nonductile concrete frames when functional uses preclude the addition of new walls.

Advantages

Minimal loss of floor area. Jackets may be of steel plate or reinforced concrete or shotcrete.

Disadvantages

Columns are relatively easy to jacket, beams are more difficult and beam-column joints the most difficult. Since jackets do not add much stiffness to building, often necessary to jacket all frames in building. Utility lines next to columns complicate installation. The tops of beams are very hard to enclose except at building exterior or where floor fills exist as top of most beams is finished floor.

Design Guidance

Steel plate jackets require welds at corners, solid grouting and epoxied anchors on sides longer than 12 to 18 inches to be effective. Concrete jackets require many closely spaced ties and dowels on longer sides. Column jackets can correct short lap splices of existing column reinforcement and provide confinement to columns. Beam jackets can provide confinement, shear capacity and continuous longitudinal reinforcement where it may be missing, but top of beam hard to jacket and slab may have to be drilled. Joint jackets are most difficult and usually require connecting the beam and column jackets through or around the joint region. Where framing does not fully make the joint region, jackets can provide joint confinement. Design must ensure that correcting one deficiency does not merely transfer the failure location to another part of the system which is also vulnerable to the high forces of actual earthquakes.

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ADDING STEEL BRACING

Uses

Strengthening most all types of concrete, masonry or steel-framed buildings.

Advantages

Steel bracing is lightweight so it results in minimal impact on foundations and building weight. Many configurations of bracing geometry are possible to minimize conflicts with doors, mechanical systems, etc.

Disadvantages

Steel bracing is usually more flexible than masonry or concrete buildings so the masonry or concrete often must crack significantly before the steel bracing will be effective resisting lateral loads.

Design Guidance

Steel bracing is relatively light so determine the amount or bays of bracing considering available dead load of structure that can be mobilized to resist overturning uplift. Bracing bays usually require vertical columns at ends to resist overturning forces as chords of a vertical cantilever truss and horizontals at the roof and each floor to be connected to the horizontal diaphragms as collectors. An appropriate system of diagonals can then be added to complete the truss network. Tension only braces should be avoided except for light, simple buildings. Braces should have relatively low slenderness ratios so they function effectively in compression. Suggest l/r ratios of 60 or 80 or lower. Select members to provide acceptable slenderness ratio and to make simple connections. Connections should develop the strength of the members. If structural tubes are used, ensure that the b/t ratio is less than 110 $\sqrt{fy}$ (fy in ksi) to preclude local buckling leading to brace failure.

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CONCLUSION

Design guidance has been offered in an abbreviated format for various strengthening methods for improved seismic performance of reinforced concrete, steel frame and masonry buildings. Many other variations are possible. A strengthening solution must correct the identified deficiencies in the existing structural system, satisfy the established performance criteria of the owner and be compatible with functional and other building-specific criteria. Economy is best achieved by finding solutions with minimal disruption to building systems and ease of construction.