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NRC Guidelines on Techniques for Seismic Upgrading of Building Structures

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ABSTRACT

Seismic rehabilitation of existing buildings is an increasing activity in structural engineering practice. To overcome difficulties in application of the National Building Code seismic requirements to existing buildings, the NRC Guidelines on Seismic Evaluation of Existing Buildings were published in 1993. As a complement to the NRC evaluation guidelines a new NRC Guideline on Techniques for Seismic Upgrading of Building Structures will be available in 1995.

The new NRC guideline describes various techniques that have been shown to be effective for seismic upgrading of existing building structures. These include special techniques such as supplementary damping, base isolation and FRP/FRC overlays, as well as conventional techniques such as anchorage, shear walls and bracing. Relative merits of these alternatives are discussed as they relate to the specific requirements for each building, including those related to cost, disruption, building function and aesthetics/heritage, as well as structural safety. This paper provides a synopsis of the new Guideline.

INTRODUCTION

Because of difficulties in applying the National Building Code to the seismic rehabilitation of existing buildings, alternative procedures for evaluating existing buildings have been prepared by NRC in the Guidelines for Seismic Evaluation of Existing Buildings (NRC, 1993-1). A rapid screening method has also been developed to identify the buildings most in need of detailed evaluation (NRC, 1993-2). The NRC Guideline on Techniques for Seismic Upgrading of Existing Building Structures (called the Guideline in this paper) was prepared to help engineers design the seismic upgrading using appropriate techniques for correcting the seismic deficiencies identified using the NRC evaluation guidelines. The Guideline restricts itself to the building structure, although the engineer must take into account the role played by non-structural components in the

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overall structural behaviour of the building. Because seismic upgrading of non-structural components can often be carried out as a part of 'maintenance', a stand-alone guideline on the seismic evaluation and upgrading of non-structural building components is also under preparation.

The design of upgrading for existing buildings involves a greater number of uncertainties and constraints than the design of new buildings. Consequently more judgment is needed for design of the upgrading, including the choice of techniques, than in the design of new buildings. In addition, seismic upgrading is a relatively new activity, involving innovative techniques under development. *The Guideline, therefore, places more emphasis on principles, experience, and access to information than on specific requirements and criteria.*

The Guideline on upgrading techniques is based partly on the NEHRP Handbook for Seismic Rehabilitation of Existing Buildings (FEMA, 1992), but is much shorter (56 vs. 195 pages) with less on conventional techniques and more on special techniques and project circumstances such as disruption of building operation. The Guideline does not provide specific design criteria although reference is made to criteria contained in other documents such as for unreinforced masonry in Appendix A of NRC (1993-1). Once upgrading is triggered using the 0.6 reduction factor in the NRC (1993-1), upgrading to the full NBC load level is generally recommended. Current thinking, however, suggests more flexibility on risk level, depending on project circumstances.

PRINCIPLES OF SEISMIC UPGRADING OF THE BUILDING STRUCTURE

There are a number of objectives for the seismic rehabilitation of any building, including life safety, that must be considered in the choice and design of the seismic upgrading:

(1) life safety

(2) control of seismic damage to building components and contents

(3) minimum disruption of building use during upgrading

(4) proper function of the building after upgrading

(5) acceptable building appearance and heritage value

(6) minimum cost

Objectives (3) to (6) are usually interrelated in the sense that they seek *minimum structural intervention*, provided the objectives of life safety and damage control are met. *Minimum intervention* will vary substantially from building to building and its achievement is very much a practice-oriented exercise involving considerable interaction of the engineer with others (owner, architect, contractor, etc.). The Guideline helps the engineer in this task by a discussion of structural considerations related to seismicity and structural behaviour, and other considerations related to the upgrading construction process, the effect of upgrading on the function and appearance of the building, and cost. The principal considerations are summarized as follows:

Seismicity: Table 1 lists the types of seismic deficiencies that occur in existing building structures for both low and high seismicity. For low seismicity the main concern is the integrity of the structure, specifically anchorage of masonry walls to the floors and roof diaphragms and lateral support of parapets, precast panels and masonry partitions. This means that provision of anchorage and lateral support are likely to be the principal upgrading techniques used for most buildings. For medium to high seismicity a broader range of potential deficiencies listed in Table 1 must be addressed. Often these deficiencies occur simultaneously, for example high torsion combined with inadequate strength and excessive drift. In such cases it is desirable to use a technique such as well-placed shear walls or bracing that simultaneously resolve these three major deficiencies.

Table 1: Seismic Deficiencies of the Building Structure Versus Seismicity

Low Seismicity	Medium to High Seismicity
Lack of Integrity	*Lack of Integrity/Redundancy*
	Inadequate Strength/Ductility
	Inadequate Stiffness/Adjacent Buildings
	Irregularities/Load Transfer

Irregularities: These include soft storeys, dissymmetry resulting in high torsion, short columns in concrete frames and discontinuities in the vertical structure, such as offset shear walls. The most effective technique is to reduce the irregularities by improving the load path. This is achieved by adding new components such as shear walls or bracing or by removing existing components such as partial infills which create short columns. Where this is not feasible, local strengthening may be required for load transfer.

Compatibility: This term refers to the ability of parallel elements of the vertical structure to work together to provide a system which behaves well in an earthquake. For example, a very ductile but flexible moment frame is not compatible with a stiff brittle shear wall.

System Behaviour: System behaviour includes considerations of integrity, composite action, redundancy, and *fuse behaviour.* An example of composite action is shear anchorage of existing masonry walls to the floor/roof diaphragms to make the masonry function as shear walls. *Fuse behaviour* is achieved by making the structure perform in such a way that it 'yields' rather than 'fractures' (also called 'capacity design'), thereby dissipating energy and preventing a sudden or progressive collapse. In assessing the effectiveness of *fuse behaviour* the sequence of the failure modes of various components of the system (yielding, buckling, rupture, uplift, etc.) should be determined under increasing lateral load (push-over method). Examples of *fuse behaviour* include yielding vs. brittle connections, plastic beam vs. brittle column frame mechanism, yield of floors/partitions vs. shear fracture of masonry, rocking (uplift) vs. fracture of concrete/masonry walls, and supplementary damping or base isolation.

Damage Control: Control of damage to non-structural building components and to building contents may be required for life-safety (falling components, blockage of exits, release of dangerous materials such as natural gas), to protect investment, or to maintain building function following an earthquake. The three main upgrading techniques for controlling damage are anchorage of non-structural components, control of displacements between floors and base isolation. Further details will be provided in the guideline for non-structural components currently under development.

Foundations: Foundation upgrading is usually expensive and, depending on the use of the building, can be very disruptive. Often it is possible to upgrade the building structure without upgrading the foundations, particularly in regions of low to medium seismicity. There are various techniques to avoid foundation upgrading, including incorporating new shear walls/bracing in existing frames (on firm ground), using long rather than short shear walls, and supplementary damping or allowing foundation uplift to reduce seismic loads. For further information on foundation upgrading and soil instability see Lo et al. (1995).

Accessibility: This refers to the ability to gain access for the upgrading work, including the repair or replacement of building components and materials, the need for scaffolding, cranes, etc. and the ability to carry out the work in the available space. Difficult access is a major factor affecting cost and disruption, and consequently the choice of upgrading techniques.

Disruption: Disruption of the use and occupancy of the building is a major consideration if the building remains in operation during the upgrading. For this reason seismic upgrading of the building structure is best carried out during a major renovation of the building when building is unoccupied. When this option is not available upgrading must be carried out in stages, shifting people and operations around, undertaking work outside business hours, etc., which, in turn, increases the cost of upgrading. Alternatively, either exterior bracing systems or exterior buttresses can be used.

Building Function: New structural components, such as shear walls or bracing, can negatively affect layout (traffic flow), daylight, aesthetics or other features of the building which relate to its use. For this reason, moment frames may be preferable to shear walls in certain locations. Possibilities should be explored in the initial stages of the project with the architect, owner and users.

Aesthetics: Some upgrading techniques are aesthetically pleasing, and some are not. Again, consult with the architect.

Heritage Values: Preservation of existing building components having heritage value is especially challenging. The principles described above of integrity, composite action and, if fabric damage is not a problem, *fuse behaviour* can be used to achieve minimum structural intervention with the least alteration to the heritage value of the building. It is essential that the engineer, architect and heritage experts interact during the conceptual design phase of the project.

UPGRADING TECHNIQUES - CONVENTIONAL

Conventional seismic upgrading techniques include standard strengthening methods - placing connectors (anchors, nails, bolts, welds, dowels, splices, etc.) between existing structural components; connecting new components (members, overlays, infills) to existing components: building new subsystems such as shear walls, bracing systems or foundations and connecting them to the existing structure. Sometimes components such as partial infills (which result in brittle concrete columns attracting large seismic forces) or even complete stories of the building can be removed to make the existing structure safe. Some of these conventional techniques are shown in Figures 1 to 6. Figures 1 to 6 are generic to illustrate concept; each detail must be designed to be workable under the conditions that actually exist. The relative merits of different techniques and their design are discussed in more detail in the Guideline based on the principles outlined above.

UPGRADING PROCEDURES - SPECIAL

Supplemental Damping: Damping devices between stiff bracing (or cladding) and a flexible frame structure reduce considerably the seismic storey displacements of the frame from that which would occur without the devices. In effect the seismic energy dissipation is shifted from the building components (non-structural as well as structural) to the damping devices, thereby avoiding building damage that would occur without the devices. Another potential benefit is a reduction in the seismic foundation forces, avoiding possible need for foundation upgrading. The design of upgrading involving supplemental damping devices, however, requires more effort than design involving conventional upgrading techniques. Tentative design criteria are contained in FEMA (1994).

Base Isolation: Base isolation uncouples the building from its foundation, allowing it to 'float' on 'flexible' components. The isolators reduce the overall lateral stiffness of the building and, as a result, the fundamental period of the building is shifted outside the period region over which most of the seismic energy is concentrated. Base isolation, however, is generally unsuitable for buildings on very soft soil or for tall buildings whose fundamental lateral frequency without base isolation approaches that for the building mass resting on the base isolators. Base isolation results in a substantial reduction of building accelerations, thereby preventing damage to the building and its contents, important for critical communications buildings or buildings containing sensitive equipment or precious artifacts. Requirements for design and for testing and maintenance of base isolators are contained in FEMA (1994).

FRP/FRC Overlays and Encasements: Fibre-reinforced plastics (FRP) and fibre-reinforced cements (FRC) incorporating glass, carbon and other materials are now being used for seismic upgrading of buildings. Current applications include FRC overlays of masonry walls and partitions (New Zealand) and FRP encasement of concrete columns (United States). The FRC overlays strengthen existing masonry for both shear and lateral force. FRP encasement of concrete columns, post-tensioned by epoxy injection, strengthens the column against shear and bond failure at lap locations and, as a consequence, a ductile flexural behaviour is achieved (fuse behaviour).

SUMMARY

The NRC Guidelines on Techniques Seismic Upgrading of Building Structures provides guidance to qualified structural engineers on the choice of seismic upgrading techniques from a broad range of alternatives and on the design of the upgrading of the building structure. Because upgrading techniques and design methods are under constant development, it is expected that revisions to the guidelines will be made in the future.

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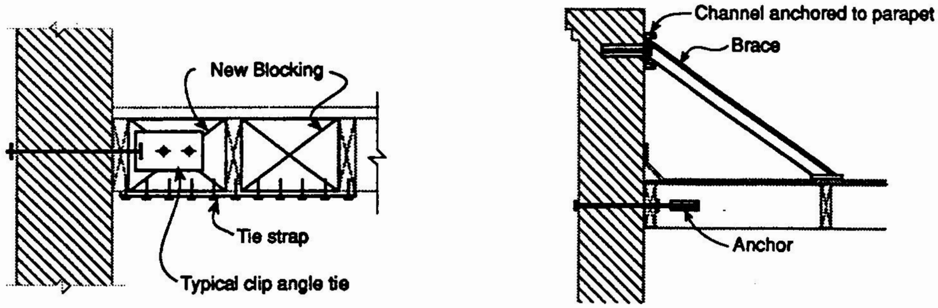

Figure 1. Anchorage of Walls and Parapets

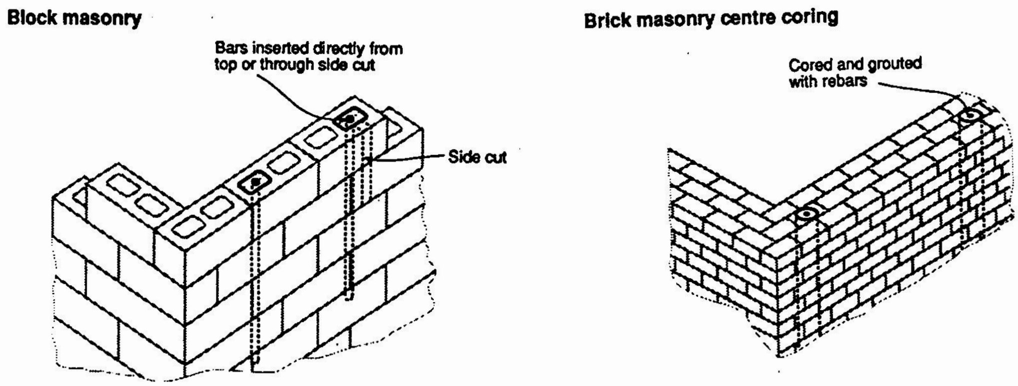

Figure 2. Reinforcing Existing Masonry

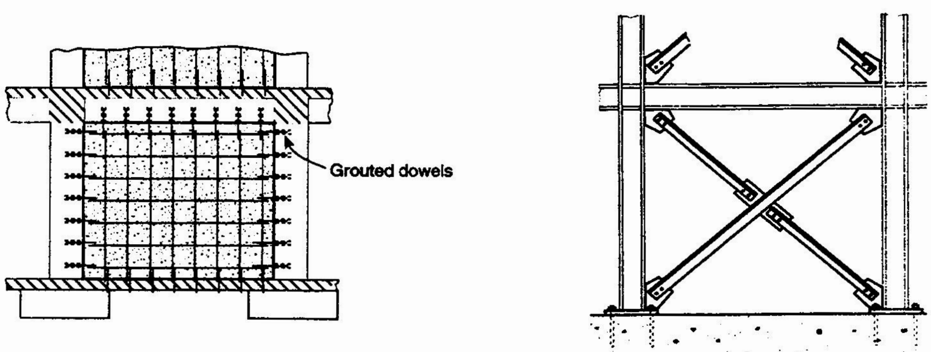

Figure 3. New Shear Walls or Bracing

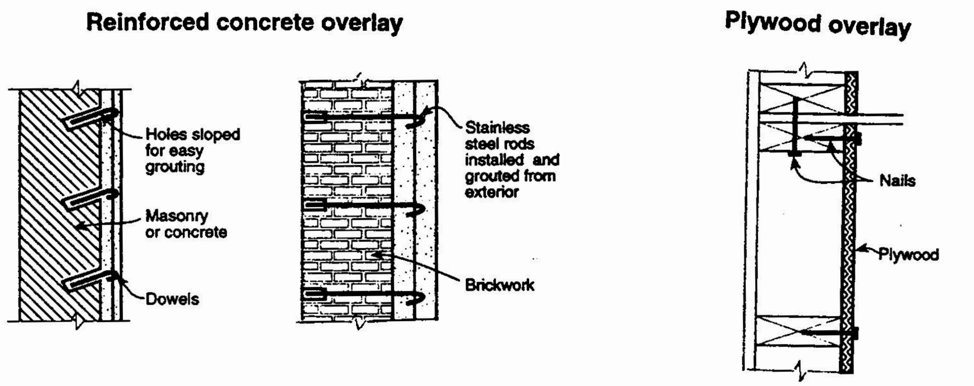

Figure 4. Vertical Overlays

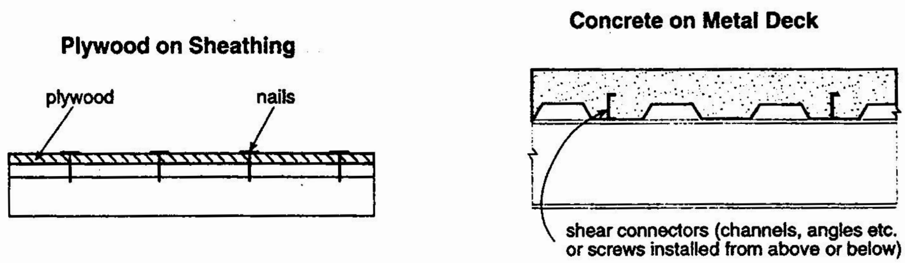

Figure 5. Horizontal Overlays

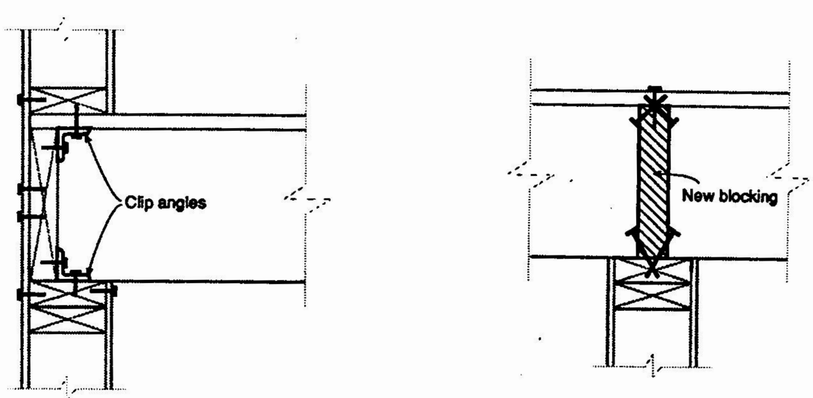

Figure 6. Shear Transfer (Wood Construction)