Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1169

REPAIR OF DAMAGED BUILDINGS -- A DILEMMA

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ABSTRACT

The practice of earthquake engineering is in a state of constant flux; earthquake design provisions in building codes have been revised on a nearly continual basis over the past four decades. In general, seismic design force levels continue to increase, and requirements for materials and details become progressively more restrictive. For new construction, where the design starts from scratch, the economic impact of these changes is not great and the benefits generally outweigh the increased costs. However, for existing buildings that might be subject to upgrades to comply with current seismic requirements, the cost-benefit analysis is not nearly as clear-cut. The *International Existing Building Code* (IEBC) is in its third edition, and provisions of it are in the 2009 *International Building Code* (IBC). This paper examines the potential unintended consequences of an "existing building code" on the repair of buildings. Experiences encountered during various projects will be used to illustrate difficulties in resolving issues of repair and seismic upgrading. While a goal to make buildings safe and sustainable is laudable, if the provisions for repair are too restrictive, they may lead economic and societal costs that are difficult to justify. Recommendations are made on how to better address these issues.

Introduction

The practice of earthquake engineering is in a state of constant flux; earthquake design provisions in building codes have been revised on a nearly continual basis throughout the past four decades. As more data on earthquake ground motion is obtained and lessons are learned from building performance observed during earthquakes, building codes are revised. Over the years, the design force levels have generally continued to increase, and requirements for materials and details have become progressively more restrictive. For new construction, where the design and construction starts from "scratch", the economic impact of these incremental changes is not great and the benefits generally outweigh the increased costs. However, for existing buildings that might be subject to seismic upgrades to comply with current seismic requirements, the cost-benefit

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analysis is not nearly as clear-cut.

Over the decades there have been attempts to codify criteria for seismic strengthening of existing buildings. Generally, these criteria would be triggered when an existing building was to be modified, enlarged with additions, or repaired due to damage or deterioration. Some local authorities have developed ordinances to cover existing buildings (e.g. San Francisco, Oakland, and Los Angeles in California), but often there are controversies in interpretation and implementation of the provisions. In other words, there have been difficulties in developing consensus criteria that cover all circumstances and address economic, social, and safety issues to the satisfaction of all stakeholders. Now, with the development of the *International Existing Buildings Code* and the incorporation of many of its triggers into the 2009 *International Building Code,* there is a concern that these new provisions will have unintended consequences that could adversely affect the inventory of existing buildings and post-earthquake recovery efforts.

A Brief History of Prior Codes and Ordinances

Prior to the 1979 *Uniform Building Code (*UBC), buildings in seismic zones of the western United States that underwent additions, alterations, or repairs that involved more than 50 percent of the value of the building had to be upgraded to current code requirements. This upgrade trigger had the unintended effect of discouraging maintenance and repairs and of encouraging deterioration of the existing building stock (ICBO 1998). Starting with the 1979 UBC and continuing on through the 1997 UBC, those earlier repair provisions were substantially modified, and required only that the repair itself conform to current code; there were no overall triggers in the main body of the UBC that required upgrading of structures as a result of damage or repairs. Historically, when the UBC was adopted by local jurisdictions, it could be adopted in whole or with modifications that were pertinent to the local jurisdiction. For example, the State of California would adopt the UBC with modifications and then cities or counties would add additional modifications within certain limits allowed by the state.

This left cities like Oakland, San Francisco, San Jose, and Los Angeles free to establish their own criteria for modification, additions, and repairs of building. These cities had previously had their own building codes prior to adopting the UBC as a standard and thus had various criteria pertinent to existing buildings already on the books. The thinking behind these criteria went like this:

- If an old building remains essentially as is, without significant modification, and if it was in compliance with the code that was in place at the time of construction, no upgrade was required.
- However, if the building were to undergo substantial modifications to improve its use and increase its value, upgrade to or nearly to current code standards should be required. This philosophy was based on a general understanding that the added code upgrade would not add an unbearable expense to the project if the project already involved substantial renovation costs. In some cases, the cost of the code upgrade would be limited to a percentage of the cost of the modification without the upgrade. A justification for this upgrade was that the modification added a longer life to the original building.
- If a building was being expanded by an addition, it was fairly easy to determine whether or not an upgrade should be required, based on whether or not the addition had an

adverse effect on the existing building. If it could be shown that the additions had no significant adverse effect on the existing structure, then generally no code upgrade would be required

- The final case -- that of repairing a damaged building -- is much trickier to resolve. Considerations include the cause of damage, the extent of the damage and the socio-economic effects of requiring full code compliance. For example, should a building that experiences partial damage to the roof during a fire be subjected to a full seismic upgrade? Generally, the common-sense answer in major cities in California was no.

This latter case is the subject of this paper, especially as related to damage caused by earthquake ground motion.

Oakland Earthquake Damage Ordinance

The 1989 Loma Prieta earthquake caused extensive damage to buildings in downtown Oakland. After the initial assessments were made of damaged buildings, the City of Oakland developed an emergency ordinance requiring re-assessment of the damage and criteria for repairing the buildings. The ordinance defined a limit on acceptable damage, which when exceeded would trigger a requirement for a seismic upgrade of a building. Sometime later, prior to adopting a final ordinance on earthquake damage and repair, meetings were held with a coalition of interested parties to be able to address the concerns of the public (Freeman 1992).

The Oakland emergency ordinance required structural upgrades of structures that had experienced a loss of the capacity to resist lateral forces greater than a set limit (10% to 20% depending on the size and construction of the building) during the 1989 earthquake. Adoption of the ordinance was driven largely by the understanding that the earthquake had caused "disproportionate damage" to a significant portion of the City's older building stock. Essentially, there was a concern that Oakland had experienced what was, for the most part, relatively minor to moderate earthquake ground shaking, and that any buildings that were significantly damaged would consequently represent unacceptable hazards in the event of a larger, postulated earthquake occurring on the nearby Hayward fault. However, on the basis of the one downtown ground motion record, this concern may have been overstated for some buildings. There is a bulge in a portion of the response spectrum indicating demands in the 0.8 to 1.5 second range approaching characteristics of a design code ground motion (Mahaney *et al.* 1993 and Searer *et al.* 2006).

In an evaluation of the effects of Oakland's earthquake damage repair ordinance 15 years after the earthquake (Searer *et al.* 2006), it was concluded that The Oakland earthquake damage ordinance resulted in some benefits to the community (e.g. some structures that were clearly potentially hazardous were structurally upgraded) but also had significant drawbacks (e.g. a number of structures were left abandoned, damaged, and vacant for many years). In some cases, the loss-of-capacity calculation prescribed by the ordinance was manipulated to avoid costly upgrades for buildings without insurance, to cause costly upgrades for buildings with insurance, and to allow demolition for buildings that may not have otherwise been permitted to be demolished. Some of the upgrades triggered by the ordinance were reasonable in scope and cost, while others were excessively expensive. Most upgrades were not terribly unreasonable, but even for these, the ordinance requirements added significant expense to owners with inadequate financial resources. The ordinance also adversely affected some historic buildings in Oakland's downtown; historic structures that could not be economically upgraded were torn down. Other historic buildings, however, were upgraded and thus preserved for future generations. As it turned out, the ground motion in downtown Oakland during the Loma Prieta earthquake was significantly stronger than expected for such a distant earthquake, particularly in the period range of 0.8 to 1.5 seconds, as discussed above. Given that adoption of the Oakland ordinance was driven by the concern that structures that were damaged by relatively minor or moderate ground shaking could pose a significant risk to life-safety during a much larger earthquake, but also recognizing that some buildings that performed consistent with the intent of the code during a near-design-level event for new buildings (i.e. significant structural damage may occur, but collapse should not) were essentially proof-tested; upgrade of those structures that were proof-tested may not have been fully justified.

To this day, Oakland has an earthquake damage upgrade ordinance on the books; however, unlike the original ordinance, which was adopted with the understanding that a moderate earthquake had revealed the presence of relatively vulnerable portions of the existing building stock, the current ordinance is not "keyed" to the size of any future earthquake or to the concept of "disproportionate damage". Thus, if a major earthquake causes significant damage (which would not be unexpected, even for new buildings designed to the latest codes), many existing buildings would have to be upgraded to current code, even though this would probably not be warranted. Consequently, the authors believe that requiring seismic upgrades due to seismic damage only makes sense if upgrades are limited to buildings that were disproportionately damaged by minor and moderate earthquakes.

San Francisco Repair Ordinance

San Francisco has had a long history of requiring upgrades for modifications, additions and repairs that is generally referred to as Section 104(f), having been named from a past San Francisco building code. The triggers for repair were generally applied to loss of capacity to resist vertical loads. For example, if the capacity of vertical load bearing elements supporting a story of a building was sufficiently damaged by a fire, the whole building could be required to undergo a code upgrade. Following the Loma Prieta earthquake, this provision was interpreted to apply to earthquake damaged buildings. Although San Francisco experienced damage similar to that of Oakland, the emphasis on damage repair regulations focused on the extensive damage to wood-framed buildings in the Marina district. There was some controversy with respect to the application of the earthquake damage repair provisions, and many of the problems encountered in Oakland also have occurred in San Francisco. San Francisco is in the process of attempting to improve its earthquake repair provisions and one of the items being considered is a methodology to include intensity of the damaging ground motion in any determination of the scope of required repair or strengthening. Such a consideration is from the perspective of the authors necessary if triggers for upgrading following an earthquake are to be sensible.

Published studies support the perspective that triggers in codes have never worked very well and probably will not work well in the future. The Structural Engineers Association of Northern California was tasked with evaluating the San Francisco repair triggers and concluded the following (SEAONC 2008):

- Percentage loss-of-capacity triggers “have proven problematic after past earthquakes”;
- There exists “no consensus methodology to calculate loss of capacity. This uncertainty causes controversy and delays in critical post-earthquake situations”;
- Requiring seismic upgrades as a result of all types of damage (fire, vehicle impact, decay, insect, water, and earthquake) is often “onerous and essentially unenforceable”;
- Fire damage “is typically much different from earthquake damage and enforcement of the same repair standards seldom makes sense”;
- Triggers tend to “encourage repair of damage without building permits and [without] inspection controls to avoid the seismic trigger”; and
- In the event of a large, damaging earthquake, “many or most buildings may reach [the trigger threshold] including those that are relatively low risk. Requirements to upgrade such a large stock of buildings could put an undue economic burden on the private sector and delay regional recovery.”

San Jose Repair Ordinance

The City of San Jose, California recently adopted repair upgrade triggers based on loss-of-capacity provisions taken from the 2006 IEBC. A fire in the top floor of a three-story apartment building tested the application of the provisions and found them lacking in specificity, and flawed in terms of implementation, as discussed herein. Although the fire damage was limited to approximately a third of the top floor, the fire suppression efforts saturated some of the gypsum board wall finishes on the floors below which were removed by the contractor. Since the top two floors relied on numerous gypsum board finishes as part of the lateral force resisting system in addition to some plywood sheathed walls, the building ended up with significant structural damage. In a meeting with the City, the authors were told that although the wording of the repair upgrade triggers might imply that a complete lateral force upgrade of the building could be required, the City takes an extremely flexible interpretation of these provisions in the event of *fire* damage and related fire-suppression efforts, and that the City would not require any global upgrade of the structure.

While the City’s decision not to implement a strict interpretation of their ordinance was welcome and not unreasonable (since the structure was regular, with long lengths of walls in both orthogonal directions, and probably posed little risk of collapse in the event of even a large earthquake even before the gypsum board was replaced with structural wood sheathing), the authors question how engineers can determine in advance just how strictly a jurisdiction may enforce such an ordinance -- particularly when the requirements are waived informally depending on the cause of the damage. Further, we note the apparent inconsistency between the wording of the ordinance and the relaxation of its plain language during implementation of repairs. Over the last two decades, the authors have observed a trend of communities -- particularly in California -- trying to force FEMA to pay for seismic upgrades of structures after an earthquake that the communities themselves were unwilling to fund before the earthquake, with FEMA balking at paying due to those same communities not requiring seismic upgrading when every day disasters --- like fires --- occur. In response, it appears that some communities may be adopting ordinances that suggest that seismic upgrading is required when everyday disasters occur --- without actually requiring those upgrades. This greatly complicates the job of an engineer who must "intuit" what provisions will be loosely enforced and which will be rigidly enforced. Of course, some responsibility for these problems rests with FEMA, since FEMA has been pushing for seismic upgrades of structures during repairs, regardless of the cause of the damage; and has taken the position that unless their philosophy is adopted, they will not fund seismic upgrades after an earthquake. Further discussion regarding this issue can be found in Searer and Paret (2008).

Implementation Problems - Replacement of Non-Conforming Materials

Replacement of non-conforming elements (such as gypsum board and cement plaster (stucco) finishes) as part of a repair has long been problematic in terms of code enforcement and in terms of determining what is reasonable and/or allowed. Architectural finishes, for instance, are generally considered nonstructural; however, in many older wood-framed residential structures (including single family dwellings and condominium and apartment buildings), gypsum board and stucco were also used to resist lateral forces such as wind and seismic. Prior to the 1997 UBC, gypsum board shear walls were assigned allowable capacities that ranged from 75 to 250 pounds per linear foot (plf) depending on their construction, and stucco was assigned an allowable capacity of 180 plf. With the adoption of the 1997 UBC, however, allowable capacities for gypsum board were cut in half for seismic loads, but only in Seismic Zones 3 and 4 -- though how a gypsum board wall's actual performance or behavior during an earthquake would depend on the seismic zone where it is located is unclear. In the 2000 IBC, stucco was also hit with a 50% reduction in allowable load in Seismic Design Category D, and both stucco and gypsum board walls were prohibited from engineered use in Seismic Design Categories E and F. Both materials were still able to be used to resist lateral forces in areas of high seismicity for conventional (non-engineered) construction, though they were so heavily penalized that they were essentially only permitted on the top story of a single-family wood-framed structure, and the required amount of solid wall required was extreme -- many times what had been allowed in prior codes. In the 2006 IBC, the penalties for gypsum board and stucco were again revised; the R-factor for their design was reduced from 4.5 to 2.0, which increased the design forces for these elements to 225% of pre-1997 design levels, or, looked at another way, effectively reduced their allowable capacities to only 44% of their pre-1997 UBC capacities, which made it difficult if not impossible to use these materials in an engineered lateral force resisting system. Further, the reduction of their R-factors resulted in much larger design forces for other portions of the lateral force resisting system, including through-floor shear transfer, holddowns, and foundations.

One might question what drove these massive changes in how gypsum board and stucco are used in design; unfortunately, the record is extremely sketchy. The 1999 *Recommended Lateral Force Requirements and Commentary* (SEAOC 1999), which served as the basis for the 1997 UBC, contains no substantive information that might shed light on why gypsum board and stucco were penalized so heavily compared to prior codes. It is our general understanding that immediately after the 1994 Northridge earthquake, the City of Los Angeles made unilateral and for the most part arbitrary reductions in the allowable load capacities for a number of structural elements, including gypsum board and structural wood sheathing (i.e. plywood), and later sought support for those changes via a laboratory testing program. Although structures that relied on gypsum board and stucco finishes for their lateral force resisting systems did experience some damage, sometimes significant, during the 1994 Northridge earthquake, the most dramatic failures of these structures generally occurred in structures located on steep hillsides or where the structures had soft or weak stories, typically created by "tuck-under" parking -- and not in the average residential structure that lacked such detrimental configurations. Indeed, the typical wood-framed residential structure that relies on gypsum board and stucco is generally regarded by the earthquake engineering community as being relatively and reasonably safe, so the impetus for the massive penalties that have been levied on gypsum board and stucco is unclear.

It is important to note that while older code provisions typically did not require that the repaired *elements* conform to code -- meaning that the materials used for repair were required to be code-conforming but that the repaired *elements* were not required to be "re-designed" or upgraded -- in the event that a damaged non-conforming element had to be replaced (as opposed to locally repaired), it has become increasingly difficult to determine how to replace these elements if so required as part of a repair -- in large part due to the thorough gutting of the capacities of these non-conforming materials. For example, in the case of fires, the structural integrity of gypsum board finishes may not be adversely affected to a significant degree, yet these finishes are routinely removed and replaced to address smoke and water damage. Under prior editions of the UBC and IBC, this left the engineer designing the replacement elements in a predicament, since Chapter 34 of the 2003 IBC, the 2000 IBC, and the 1997 UBC (and most prior codes) required that the repair conform to current code provisions for design of new construction, so if existing elements were replaced, these would have to comply with current code. Chapter 34 of the 2006 IBC has since modified this requirement and does not require that repair of damaged elements conform to the current code provisions for design of new construction. Fortunately, as discussed below, recent changes to the repair provisions of the IBC have rendered these considerations moot.

Recent Changes

Although the 2006 IBC dropped the requirement that repairs need to conform to current code, it does require that "uncovered structural elements [that] are found to be unsound or otherwise structurally deficient" shall be made to conform to the requirements for new structures." Due to the lack of clarity in these phrases, the terms "unsound" and "otherwise structurally deficient" were dropped from the 2009 IBC (ICC 2008); however, the 2009 IBC, although not adopted yet in many jurisdictions, has incorporated repair upgrade triggers that depend on the amount of "loss of structural capacity"; structures that have lost more than the triggering limit will require seismic upgrades, regardless of the cause of the damage. Unfortunately, calculation of "loss of structural capacity" is itself problematic because, with the exception of concrete and masonry shear wall structures, there generally do not exist commonly accepted methods for calculating "loss of structural capacity", which again opens the engineer up to professional standard-of-care issues. The above discussion notwithstanding, the authors also note that Section 3410, Compliance Alternatives, of the 2006 IBC allows repairs to structures without requiring upgrades as long as the repairs do not result in the structure being less safe than it was prior to the repairs, thus providing better insight into the intent of the code with respect to repairs.

Further complicating the issue, despite the fact that engineers in California were largely responsible for the 2009 IBC seismic upgrade triggers that are soon to be adopted throughout the country, the same committees apparently realized that the 2009 IBC repair triggers had gone "too far", and have since submitted code change proposals to substantially reduce the scope of the upgrade triggers; these code change proposals were recently accepted by the IBC Structural Committee and, barring any concerted public effort to stop the changes, will in all likelihood be adopted into the 2012 IBC. Although the upgrade triggers will still rely on "loss of structural capacity", the upgrade trigger was changed from a 20% loss of lateral capacity to a 33% loss of lateral capacity; triggers were excluded for all one- and two-family dwellings, and for structures in Seismic Design Categories A, B, and C unless the damage was caused by earthquake. As part of the reason statement for the proposed change, the National Council of Structural Engineers Association (NCSEA) concluded that the risk posed by one- and two- family dwellings is "especially low" and that seismically upgrading structures in areas of low seismicity serves "no significant purpose" if the damage was not caused by earthquake (NCSEA 2009). Although we agree with the relaxation of the 2009 requirements, we are confused by the stated NCSEA reasoning; one could also argue that if a building was damaged by an earthquake in an area of low or moderate seismic hazard, then perhaps that building has already seen the design level earthquake and worse damage in the unlikely event of another damaging earthquake is even more unlikely. Thus, repair-only would seem to make sense in areas of low seismicity, even if the damage was caused by earthquakes.

Engineers, building officials, and the general public trying to make sense of these whipsaw actions regarding repair provisions in the building code must necessarily question whether the engineering profession actually knows what it is doing. To boldly conclude that gypsum board and stucco are so dangerous as to be essentially precluded from use in high seismic areas, and then to proclaim that most of such structures actually pose an especially low risk makes one question both the decision-making of the engineering profession as well as the code development process.

Triggers and Defining Loss of Capacity

The idea of using loss-of-capacity as a triggering tool seems like a reasonable approach to determining when upgrades are required after a building is damaged from an earthquake -- but only up until the time to define and actually implement such an approach. In the case of earthquake (and wind), the loss to be calculated is most likely based on a loss of lateral capacity. For fire, as in the case of San Francisco, the loss to be calculated is typically loss of vertical load carrying capacity. The problem gets more complicated if the repair criteria apply for any cause of damage. In other words, should a fire or a car damaging a wall or post trigger a complete seismic upgrade? There are various reasons for requiring seismic upgrades. For example, some feel the need to try to bring all existing buildings up to code; thus, any reason to mandate an upgrade is to be encouraged. This would be considered an extreme position that does not take into account socio-economic concerns. The other extreme would be to let owners do as they wish, which would perhaps allow structurally significant damage to remain unrepaired.

Another method for determining when upgrades are required is to base the trigger on a ratio of cost of repair-only to the market value or replacement value of the structure; when the cost of repair-only exceeds the trigger percentage, the building must be upgraded. This approach is currently used in the IBC to mandate upgrades in flood-prone areas and was used for many years in editions of the UBC prior to 1979. In other words, if the costs of repair-only is small compared to the worth of the building and brings the building back to its original capacity, it seems reasonable not to require an expensive upgrade. On the other hand, if repair costs are significant, the added *incremental* expense to upgrade may be justified. Again, however, while a reasonable sounding concept, this system was scrapped by ICBO in 1979 because it was proven to not work well and to be detrimental to the communities in which it was used.

Although loss-of-capacity triggers can be problematic, if loss of capacity is to be used to define triggers, the authors believe that an appropriate way to approach the problem is the following:

- Define the term "loss of capacity", provide guidelines for quantification that are consistent with the fundamental principles of structural engineering and engineering mechanics, and allow reasonable flexibility in interpretation and implementation.
- Address the cause-of-damage issue, with different triggers for various causes of damage, including earthquake, wind, fire, etc.
- For earthquake damage, consider the intensity of the damaging earthquake (i.e. large or moderate) in determining the trigger to upgrade.

Recommendations and Conclusions

In general, upgrade triggers that are linked to repairs are problematic and can lead to significant unintentional consequences. Engineers who specialize in repairing existing structures know that it is typically a sufficient challenge to design repairs for a damaged building; having to upgrade buildings at the same time as a repair merely adds to the difficulty. The upgrade triggers adopted by both Oakland and San Francisco, and which form the basis for the upgrade triggers in the 2009 IBC and all versions of the IEBC to date, have clearly demonstrated the problematic nature of these triggers. Triggers based on loss-of-structural-capacity are almost impossible to implement from a technical standpoint, since no general consensus as to methods for calculating "loss-of-structural-capacity" exists, and are likely to lead to increased and almost limitless potential for dispute, including significant questions regarding standard-of-care of design professionals who work on these types of projects.

Although the authors admit that we appear to be fighting an uphill battle, it does appear that a small amount of sanity has begun slowly creeping back into our profession. For the 2012 IBC, as stated above, seismic upgrade triggers will likely be substantially blunted, with the loss-of-lateral-capacity trigger increased from 20 percent to 33 percent, with buildings in seismic design categories A, B, and C being eliminated from the scope of the upgrades (unless the damage was caused by earthquake), and with one- and two-family dwellings being exempted from the upgrades altogether. These are remarkable steps that have been taken by the engineering profession, which should be applauded for trying to bring reason back into the process of developing triggers. Further work remains, however, including developing reasonable methods to reliably determine loss-of-structural-capacity and further "grandfathering" older lateral force resisting systems that rely on nonconforming materials, such as gypsum board and stucco, but that do not exhibit structural irregularities and weaknesses known to lead to significant life-safety issues (such as soft/weak stories, short columns, and torsional irregularities). Self-policing of the engineering profession also appears to be a non-starter at this point, though we continue to hope that this will occur.

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