ENGINEERING INVOLVEMENT IN POST-NORTHRIDGE DAMAGE ASSESSMENT AND REPAIR OF WOOD-FRAME DWELLINGS

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SUMMARY

The low death toll in Northridge demonstrates the great progress the engineering community has made addressing the life safety aspect of the seismic hazard. On the other hand, the engineering response to the earthquake, with respect to structural damage assessment and repair recommendations, demonstrates the lack of progress in preparing ourselves for post-earthquake engineering evaluations. In general, and particularly for wood-frame buildings, the public was ill served by the engineering response to Northridge. Rather than assisting in a speedy recovery from a natural disaster, the specious advice from the engineering community has prolonged the recovery and inflated its cost. Going forward, we must recognize post-event damage assessment and repair as an essential component of earthquake hazard mitigation. Development of general guidelines for damage assessment and repair should be a top priority of the earthquake engineering community. Damage assessment and repair should become an essential aspect in development of new structural systems and a normal consideration in building design, not an afterthought addressed in the chaotic, post-earthquake environment.

INTRODUCTION

The January 17, 1994 Northridge earthquake (Northridge) was the first earthquake in which large numbers of engineers were engaged to assist in the evaluation and repair of damage in single-family wood-frame dwellings. It was a task for which the engineering community was ill prepared. The principal problems with engineering involvement in the damage assessment process were: lack of consistent structural damage assessments, and lack of clear communication/translation between engineers and their clients. Inconsistencies between damage assessments from various consultants resulted from a shortage of experienced engineers coupled with the lack of consensus engineering guidelines for investigation, assessment, and repair of earthquake damage to single-family wood-frame dwellings. Communications were a problem because many engineers were being asked to provide engineering consultation outside their familiar, comfortable environment, that is, producing or following plans and specifications for construction based on building code requirements. Poor communications and inexperience led to acceptance of questionable engineering assessments and dubious repair recommendations.

STATE OF EARTHQUAKE ENGINEERING PRACTICE WITH RESPECT TO SINGLE-FAMILY DWELLINGS PRIOR TO NORTHRIDGE

Throughout recorded human history, the severity of an earthquake has been recorded in terms of its human toll, which has ranged from tens of thousands to hundreds of thousands fatalities for significant earthquakes. Thus, for most of the Twentieth century, the focus of earthquake engineering research and practice has been to reduce the high loss of life through measures directed toward prevention of building collapses. Indeed, most progress in earthquake engineering has been driven by the prominent structural failures of each significant earthquake. For the earthquake engineering community, the built environment is the ultimate laboratory, where design and construction practices are tested from time to time. The vast majority of published research has been directed

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toward fundamental principles, improved aseismic design codes and methods, and assessment and retrofit of existing structures, portions of which are applicable to single-family wood-frame structures.

The intent of U.S. building codes is to prevent collapse in major seismic events, and to limit damage in moderate seismic events. By design, the buildings are “protected” from collapse by controlled damage mechanisms by which the energy of the earthquake is absorbed or dissipated. In fact, the fundamental seismic design philosophy implicit in U.S. building codes contemplates and encourages selective structural and non-structural damage as excellent means of dissipating seismic energy. As a result, the bulk of engineering research and practice has not only ignored the potential for expensive damage, but has, in a sense, encouraged it.

Results of earthquake engineering research include ongoing refinement of aseismic design provisions of the building codes, improved construction practices, and retrofit requirements for recognized structural deficiencies (at least in California). In the later part of the century, the focus of earthquake engineering research has shifted from basic life safety toward minimizing damage and maintaining the operation of buildings even in major earthquakes. See [SEAOC] for example.

Prior to Northridge, single-family wood-frame dwellings received very little attention from the earthquake engineering community, principally because past performance had shown that these structures already exceed the life safety performance levels of U.S. building codes. Indeed, modern, single-family wood-frame houses, as a class, are generally recognized to be one of the safest places to be in an earthquake. For instance, it is generally considered that the very early hour of the Northridge earthquake saved many lives, since people were at home in bed rather than commuting or in commercial buildings.

Also, engineering research on the performance of single-family wood-frame houses has not been a priority because these structures are typically not designed by structural engineers or architects, rather, they have historically been constructed, modified and repaired by the construction trades on the basis of local custom and practice and prescriptive code requirements. Code compliance is achieved by conforming to the conventional construction practices as contained in local codes. In fact, designers of one- and two-story single-family wood-frame houses are exempt from state registration laws governing architects and engineers, although “irregular” structures and certain components of “regular” structures may require design by a licensed engineer.

Structural engineers (and some architects) are trained in the application of building code requirements to building design. Engineering work is generally perceived as “precise” and orderly: two engineers presented with the same problem should be able to plug the correct numbers into the appropriate equation and arrive at the same answer. Unfortunately, earthquake damage investigation, assessment, and repair are not exact sciences, and there are no standards, codes, or guidelines to follow. In typical practice, design engineers have little opportunity to study earthquake-damaged buildings and thus lack practical experience as well. This situation is noted in [ATC-20-2] in the context of safety evaluations:

> *“Since earthquake are infrequent, engineers and building inspectors do not often practice building safety evaluation and have even less opportunity to verify their decisions. It is therefore unlikely that the safety evaluation methodology will ever become an exact procedure. Research leading to an improved methodology would be highly beneficial to the earthquake recovery process.”*

Education of civil engineers in the U.S. is focused on analysis and design of new structures and the basis of associated building code requirements. Curriculum emphasis is on structural systems and materials (structural steel and reinforced concrete) used predominantly for commercial buildings and bridges, although some schools offer a single course in analysis and design of heavy timber or new light-frame wood construction. This emphasis is reflected in the body of engineering textbooks, reference works, and professional journals. While there are numerous texts, references, and professional papers on the subject of seismic aspects of structural analysis and design of commercial structures, there are relatively few publications on the subject of seismic design of light-frame wood structures. For instance, two of the most widely referenced handbooks on seismic design, [Naiem] and [Wiegel], each have chapters devoted to design of steel and concrete structures, and neither addresses light frame wood construction. There is little if any study of damage evaluation and repair, and technical guidelines for practicing engineers are non-existent.

The scarcity of attention to single-family wood-frame structures has resulted in a scarcity of damage evaluation and repair guidelines. While much published work addresses repair of earthquake damaged reinforced concrete and steel structures, there is no published work on repair of earthquake damaged wood-frame structures. While several publications address general issues of the seismic performance of single-family wood-frame dwellings, as part of a larger effort, the subject of practical, post-earthquake damage assessment is absent in the published literature.

In summary, an engineer engaged to inspect a single-family wood-frame house in 1994 would likely have no experience and little training in earthquake damage assessment and would find little guidance in the technical literature. For wood frame construction, guidelines or recommendations regarding the scope, methods, and guiding principles for a competent damage investigation (as a function of outward manifestations of damage) simply do not exist in the technical literature; there are no guidelines for assessment and characterization of damage, for distinguishing between earthquake damage and unrelated conditions, or for repair of damage once it is identified. Those engineers that had the knowledge, experience, time, and resources could develop reasonable investigation protocols based on available technical literature. Others were left to improvise and opine with little technical foundation.

NORTHRIDGE ENGINEERING RESPONSE

In the months following the main shock, demand for engineering evaluations of damaged structures was unprecedented, and quickly outstripped the capacity of experienced consulting firms. In general, the engineers that stepped in to fill the void were ill-prepared, in terms of experience, training and access to technical standards, to respond to that demand and provide consistent, objective damage evaluations and repair recommendations for single-family dwellings. This lack of knowledge and experience resulted in widely divergent and inconsistent engineering assessments and recommendations.

It is a common and reasonable public presumption that engineers licensed to practice in California know how to investigate, assess, and repair earthquake damaged single-family wood-frame buildings, thus one engineer is perceived to be as competent as the next. Consequently, the consumers of engineering services were generally unaware of differences in engineering expertise among licensed practitioners and did not suspect that their evaluations and recommendations may have been flawed. As engineers, architects, and contractors with various credentials rushed in with a wide range of often poorly supported opinions, there was much confusion amongst property owners and the insurance industry regarding the true nature, extent and appropriate repair of the damage. Thus, the ability of the engineering profession in general to conduct effective inspections, provide objective assessments, and recommend appropriate repairs of earthquake damage fell short of reasonable public expectations for professional engineering practice.

Determining the nature, extent and proper repair of earthquake damage is the principal post-earthquake engineering task. Engineers are often asked to characterize the damage as either cosmetic or structural. Cosmetic damage, by definition, is visible, whereas structural elements, and presumably damage to those elements, could be hidden behind wall, ceiling, and floor coverings. Rarely is it feasible to remove large areas of finishes, and thus direct examination of concealed structural elements and connections is not possible. The engineer must instead rely on indirect measures to assess the presence or absence of underlying structural damage. Such indirect measures include cosmetic damage to finishes, historical performance of wood frame houses, ground motion records, occupant observations, and the presence or absence of design and construction features that would make the particular property more or less susceptible to earthquake shaking.

In the months following the earthquake, discrimination between various degrees of damage became increasingly clouded for a variety of reasons. While some severely damaged houses were rendered unsafe, eventually some engineers argued that any amount of damage rendered a house unsafe. When concealed damage in steel framed buildings became widely known, every house was presumed by some engineers to have concealed damage. While earthquake-induced soil failure damaged some foundations, to some engineers every foundation crack was proof of serious earthquake damage. While the stucco, plaster, and drywall of some buildings were damaged beyond repair, some engineers interpreted any crack in a wall or ceiling as serious damage requiring complete replacement of all finishes. And so on.

Another cause of confusion is that many earthquake damage assessments are multidisciplinary and not easily addressed by a single engineer. For example, competent investigation of foundation cracks could require knowledge of concrete material properties, petrography, residential construction practices, geotechnical engineering, structural engineering, earthquake ground motions, and concrete repair methodologies. For instance, ignorance of concrete and Portland cement plaster shrinkage cracking on the part of some engineers led to fraudulent notions of “monolithic concrete foundations” or “monolithic stucco” - notions that were eventually used as the basis for complete removal and replacement of either undamaged or readily repairable building foundations and wall finishes.

A common example of the poor engineering response was evaluation of foundation damage. Assessment of earthquake induced foundation damage was greatly complicated by soil conditions in the affected area. Earthquake-induced soil failure is a generally recognized mechanism of foundation damage and was documented at numerous locations of limited extent following the Northridge earthquake. However, damage to residential foundations in the absence of soil failure has never been reported in the literature. Yet, as a result of expansive soils, hillside development on ancient landslides or creeping soils, development on poorly constructed fills, poor construction quality, and particularly restrained shrinkage, virtually all foundations and slab-on-grade floors in the greater Los Angeles region exhibit some degree of “distress” in the form of cracks. In the aftermath of the Northridge earthquake, much of that “distress” was attributed to the earthquake, with little or no supporting evidence or analysis, and often in spite of clear evidence to the contrary. Repair proposals often went far beyond repair of earthquake damage, and addressed the underlying cause of the distress (such as a poorly constructed fill placement), with no effort to identify possible causal contribution(s) of the earthquake. Thus, while objective studies and sound engineering principles indicated that foundation damage was limited to areas of ground failure, the measure of damage employed by some engineering consultants suggest nearly universal damage to foundations and their supporting soils.

COMMUNICATION

Compounding the problem of specious engineering advice was poor communication by and with engineers. Northridge engineering reports were in general long on observations and conclusions and short on logical analysis of causation or the criteria and rationale of repair recommendations. Given the infrequent occurrence of earthquakes, most parties involved in post-earthquake damage assessment and repair are operating in unfamiliar territory. Engineers, adjusters, property owners/occupants, contractors and building officials are thrown together, each with their own perspectives, objectives and jargon. Accordingly, effective engineering involvement in earthquake damage assessment and repair requires effective communication between the engineer, their clients, and the public in general if a common understanding of the technical issues is to be achieved.

Engineering involvement begins with a clear request for services from the client. This step was generally highly abbreviated: insurance carriers, concerned with the appearance of directing or limiting the engineer’s work often requested only an “inspection and report.” Likewise, property owners requested “earthquake inspections” of their properties. These phrases have no common meaning amongst engineers. As discussed previously, there were no consensus guidelines for an engineer to follow. Thus, there was from the outset, no common understanding of objectives or scope of the engineer’s work. Accordingly, the engineering response ranged from brief visual inspections and one-page reports to comprehensive destructive inspection and development of construction documents to retrofit the entire structure.

While causation and scope of earthquake damage are of paramount importance to damage assessment for insurance purposes, correction of deficiencies and retrofit to current code requirements are the primary focus of most engineers. It was thus common for an engineer, regardless of the extent of work done, to provide reports that addressed neither of the adjuster’s paramount needs. It is only through several cycles of communication that the appropriate questions were formulated and answered.

A subtle, but most insidious aspect of adjuster/engineer communication was an engineer being asked by an adjuster to provide technical justification for adjusting decisions that had already been made. In an effort to resolve a claim, an adjuster would include repair of various elements attributable to earthquake damage. The engineer would be told of that decision and asked to include such “earthquake” damages in the engineering report. As there was no immediate downside, many engineers were all too happy to participate. Very quickly however, the context was lost and the “helpful” statements in engineering reports became accepted technical wisdom. A good example of this is the repair of slab-on-grade floors, driveways and garage slabs. Cracking of these elements in the absence of earthquake ground motion is virtually inevitable, whereas even severe ground shaking is unlikely to crack these elements in the absence of ground failure. However, because cracking was exposed and conspicuous, and because an apparent “easy fix” was available, thousands of non-structural slabs-on-grade with old, pre-existing cracks were either demolished and replaced or repaired by injection of structural epoxy adhesives, in order to restore them to a fictitious, uncracked, pre-earthquake condition.

With respect to the property owners/occupants, an engineer’s primary responsibility is to address concerns regarding safety of the structure and interpret the meaning and severity of observed damage, and to recommend appropriate repairs. As part of this process, an engineer should elicit owner/occupant observations of conditions and events at the property prior to, during, and following an earthquake. However, engineers must recognize the difference between lay observations and engineering reality, and weigh the occupants' remarks accordingly. Too frequently engineers accepted as fact owner/occupant observations and statements that conflicted with physical evidence and engineering principles.

PROFESSIONAL QUALIFICATIONS AND OBLIGATIONS

Northridge raised a number of issues regarding the qualifications and obligations of engineers involved in the investigation, assessment and repair of earthquake damage.

The legal requirements and obligations of an engineer practicing in the State of California are set forth in the Professional Engineers Act [Cal Act], and in the Rules of the Board of Registration for Professional Engineers and Land Surveyors [Cal Rules]. The Professional Engineers Act defines civil engineering very broadly; within that broad umbrella Board Rules restrict registered engineers to practice "only in the field or fields in which s/he is by education and/or experience fully competent and proficient." Preparation of plans, drawings, or specifications for wood-frame dwellings not more than two stories in height nor more than four units per lot is exempt (to the extent that the design falls within the limitations of the conventional framing provisions of the Uniform Building Code) from requirements of the engineering registration law.

The requirements/limitations for engineering involvement in post earthquake damage investigations were discussed in a brief article by [Brandow], a member of the Board of Registration's Structural Engineering Technical Advisory Committee. Brandow concludes that "when a building inspection report is prepared and there is any expectation that engineering judgement and expertise will be applied to reach conclusions and make recommendations, the stamp and signature of a responsible professional engineer is required." The term "responsible" is defined in [Cal Act] §§ 6703 'The phrase "responsible charge of work" means the independent control and direction by the use of initiative, skill, and independent judgment, of the investigation or design of professional engineering work or in the direct engineering control of such projects. …' Specific examples of work requiring a responsible professional engineer cited in the article are:

- Opinions on structural condition and/or adequacy based on observation, engineering judgment or calculations.
- Recommendations about required or recommended structural upgrades, strengthening or seismic mitigation.
- Statements comparing structural capacities to Uniform Building Code requirements or other standards (loading capacity, seismic resistance, vibration issues, deflections, durability, etc.).

These rules and guidelines set the minimum requirements for professionals engaged in post-earthquake damage assessments. Beyond the state requirements cited above, there are no other legal requirements governing the practice of engineering in California.

Because engineering work is generally viewed as objective and precise, there has been little attention to the ethical dilemmas faced by engineers when they venture into problems and issues that do not have clear-cut answers. The American Society of Civil Engineers has maintained a general Code of Ethics for many years that emphasizes honesty, impartiality, competence, and public safety health and welfare [ASCE].

The Earthquake Engineering Research Institute recently issued a "white paper" entitled *Ethical Issues and Earthquake Risk Reduction* [EERI 98] that, in part, examines ethical issues through workshop discussions of various engineering engagement scenarios. One such scenario involves professional services associated with an earthquake insurance claim. Some participants of that workshop opined that the contractual obligations of insurance claim work, where there are no consensus standards and code issues are vague at best, necessitate the role of engineer as advocate, with the responsibility of achieving the best possible settlement for their client. Under these guiding principles, it is easy to understand how consultants may stray from objectivity and neutrality, and how recommendations from consultants employed by different client may diverge.

> *It was mentioned earlier that engineers and scientists are trained to maintain a high degree of objectivity and impartiality in their work. This training is valued highly. And yet the Acme Hotel example (Situation 6, Appendix B) represents how the ambiguity, uncertainty and conflicting information common to many damage claim situations can create pressures that may push the consultant away from objectivity and neutrality, when superimposed upon the adversarial environment created by monetary negotiations. When code requirements are vague and there is no consensus on standards of practice, it is not surprising that different consultants will come to different*

conclusions about what should be done in a particular situation. A basic question, though, is whether consultants should always maintain the same position regardless of who has hired them and what the client's interests may be. Consultants can be in the difficult position of balancing their duty to be objective experts with their obligations to their clients. Their training, which emphasizes the sharing of facts and knowledge rather than acting as an advocate, contributes to the difficulty. The dilemma is that society expects objectivity and impartiality from its technical experts, yet clients often expect their consultants to be their advocates. We must also accept that it is difficult for consultants to advocate a client's position in some engagements and claim objectivity and neutrality in others. Even when attempting to be as objective as possible, consultants can be perceived as biased if they advocate a particular position, especially when that position is perceived as being in the consultant's self-interest.

EERI has also recently established a web site devoted to "Ethical Dilemmas in Earthquake Risk Reduction" to explore the ethical issues engineers encounter in the course of consulting "outside the box." [EERI 99]

In the adversarial environment associated with large monetary disputes, it is difficult to resolve technical differences without the appearance of ulterior and less-than-honorable motives. The ethical dilemmas imposed on the engineer by the insurance adjusting process contributed to the chaos and wildly divergent damage and repair assessments. In the end, many engineers were all to eager to participate as advocates for their client's financial interest, often at the expense of technical accuracy and objectivity.

REPAIR VS. RETROFIT - AN ENGINEERS OBLIGATIONS

A common issue post-Northridge was an engineer's obligations regarding questions of scope of repair in the context of earthquake insurance. Specifically, is it appropriate for an engineer to propose a scope of repair that remedies all earthquake damage but does not consider structural retrofit or upgrade requirements that may be required by building codes or other ordinances?

First, an engineering context for the question must be established. The traditional, and most common, activity of engineers (civil, structural, and geotechnical) is the preparation of design documents (i.e. plans and specifications) for new construction and modification of existing structures. An explicit expectation for such activity is that the design documents present a design that complies with applicable building codes, and hence in a larger sense, implicitly meet society's most current standards for earthquake safety. However, engineers are frequently engaged for activities other than preparation of design documents and are asked to address issues that go beyond the scope of the building code. Examples of such activities include:

- Condition assessments of existing structures,
- Seismic vulnerability assessments of existing structures,
- Safety assessments of damaged structures,
- Damage assessment of structures following a loss,
- Construction defect investigations
- Feasibility studies for remodeling or change of use.

These activities may be performed for owners, prospective purchasers or tenants, investors or financial institutions, or the insurance industry (brokers, underwriters, or adjusters). Depending upon the project specific circumstances, building code retrofit requirements may or may not be included in the engineer's scope of services.

Furthermore, the concept of performing an engineering evaluation based on varying criteria (life safety, damage assessment, etc.) is recognized in [ATC-20]. ATC-20 outlines procedures for performing building safety evaluations and earthquake damage assessments of buildings, and distinctly excludes evaluation of compliance with the code or evaluation of design or construction deficiencies.

Depending upon the client's needs, an engineer may propose repair and/or retrofit work to satisfy a variety of criteria (basic life safety; varying degrees of damage control;, repair of damaged elements; bring the building or portions thereof up to code; or provide enhanced restoration that exceeds code requirements or considers issues not directly addressed in the building code).

One common question posed by clients is the nature and extent of damages caused by an earthquake (or other event), and what repairs are necessary to bring the property back to the condition it was in before the earthquake. In this context, the proposed scope of repair work would generally not address current building code requirements in general, or specific code retrofit requirements triggered by the nature or extent of damage. In making these recommendations, it is prudent for the engineer to explicitly state the scope of engineering services provided and the philosophy of the repair recommendation. For example:

> *"The recommended repairs are intended to correct earthquake damage. This scope of repair work will not necessarily upgrade the structure to current standards and may not reflect work that may be required by local building officials. All structural repairs should be carried out under the observation of a State Licensed Civil or Structural Engineer"*

ATC-20 addresses the issue of ambiguity associated with developing repair criteria for earthquake damaged buildings:

> *When a community experiences a damaging earthquake, both the oldest and the newest buildings may be damaged. This leads to a very difficult problem. What criteria should be used to place a whole class of older, structurally damaged buildings back into service? Should they be restored to their original condition, in which case they may be greatly under strength in terms of the toughness and ductility required for new construction, or should they be strengthened to levels required of new construction?*

This concept of varying repair criteria is addressed in [ATC-43] which addresses the investigation and evaluation of earthquake damage in concrete and masonry structures and discusses policy issues related to the repair and upgrade of earthquake-damaged buildings. Volume 3 of the ATC-43 project report discusses the policy issues pertaining to the repair of earthquake-damaged buildings and illustrates how the procedures developed for the project can be used to provide a technically sound basis for policy decisions. It also provides guidelines for the repair of damaged components. This document distinguishes three alternatives for dealing with a building that has been damaged by an earthquake: 1) accept the building for continued use in its damaged condition; 2) restore the building to its pre-event condition; and 3) upgrade the building to a condition of improved seismic performance compared to its pre-event condition. A clear distinction is made between formulating repairs to restore the performance of a building to that of the undamaged building (as a measure of the loss from damaging ground motion), and formulating repairs or upgrades to be implemented in accordance with local jurisdiction code requirements, seismic performance objectives, or appropriate policy for safety and economy.

POST-NORTHRIDGE STATE OF THE PRACTICE & PENDING WORK

A key factor in the inflation of insured losses, and much of the post-earthquake controversy regarding adjustment of loss, is the chaos surrounding engineering damage assessment and repair recommendations. To this day, consensus guidelines for the investigation, analysis, and repair of earthquake damage to structures in general, and wood-frame construction in particular, do not exist. That lack of guidelines combined with an influx of inexperienced and ill-prepared engineers resulted in wildly divergent engineering assessments of earthquake damage and even more dramatic differences in repair recommendations.

Northridge was the impetus for numerous research projects that are in various stages of completion. The most ambitious undertaking was the [SAC] Steel Moment Frame project, which developed consensus guidelines for the inspection, evaluation, repair and new design of structural steel moment frames. A similar, but less extensive, undertaking was [ATC-43], which compiled consensus guidelines for inspection, evaluation, and repair of reinforced concrete shearwalls. While both of these projects address problems unique to commercial structures, the necessity of these projects in the earthquake aftermath confirms the absence of pre-Northridge guidelines.

Most significant and relevant for wood-frame construction is the research project "Earthquake Hazard Mitigation of Woodframe Construction," a joint effort of Caltech and a consortium of California's leading universities known as California Universities for Research in Earthquake Engineering [CUREe]. This project has recently gotten underway with partial funding from the Federal Emergency Management Agency (FEMA) and the California Governor's Office of Emergency Services (OES). As currently structured, the project is focused on issues related to design and construction. However, pending funding, there is an opportunity to expand the project to address issues of damage assessment and repair. In addition, a new task, consisting of development and publication of technical guidelines tentatively entitled "Assessment and Repair of Earthquake Damage in Residential Wood-Frame Buildings" would be added.

The CUREe project is focused on developing technical information and guidelines for the earthquake engineering community (structural and geotechnical engineers, building officials, and researchers). Published research and guidelines will greatly improve the level of knowledge amongst the engineering community and lead to more rapid, effective and consistent evaluation and repair of earthquake damaged wood frame structures. More reliable predictability of earthquake damage and repair, should, in the long term, lead to improved loss estimation models and perhaps, more affordable earthquake insurance premiums.

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