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Nonstructural approaches developed after the Loma Prieta Earthquake

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ABSTRACT: Several new approaches to reducing nonstructural earthquake risks were developed as a result of concerns raised by the 1989 Loma Prieta Earthquake. One of the approaches is to use software to facilitate the survey and inventory process, which is an essential initial step. Another approach, of a non-engineering nature, is staff training to obtain cooperation with facilities efforts to improve workplace safety. Another approach concerns the training of facilities personnel who carry out many of the required nonstructural solutions. The last example relates to building-specific advance planning and training for post-earthquake nonstructural safety inspections. The types of institutions represented by these case studies are school systems, a state government, and a large corporation with research and manufacturing facilities.

ELEMENTS OF NONSTRUCTURAL PROTECTION PROGRAMS

Different researchers and consultants divide up the steps involved in establishing and carrying out a successful nonstructural earthquake protection program in different ways, but there are some essential similarities. Initial phases involve setting goals and budgets for the effort, selecting in-house or consultant sources of expertise, and then conducting a survey. The survey can be limited to listing hazards that by some pre-tabulated criteria pose significant life safety, property, or functional risks. The approach discussed here concerns a study that was both detailed and large-scale, with software solving the problem of how to keep the large amount of data from being confusing.

Once decisions are made as to which vulnerable nonstructural components require and merit attention, the particular solutions must be devised. Another of the case studies presented here was intended to implement the self-help approach of training facilities and maintenance staffs to be able to reliably retrofit common nonstructural components. In this approach, the people who come into contact with nonstructural items such as light fixtures, file cabinets, shelving, etc. in their daily work are trained to be able to implement inexpensive solutions within their scope of work and expertise.

There are other possible solutions that do not involve retrofits. One approach is to implement purchasing guidelines to prevent the addition of new hazards to the facility. Even if all present hazards are dealt with through retrofits--and even organizations with the largest of earthquake budgets have chosen not to retrofit all vulnerable nonstructural items--there is still a need to look toward the future with wise purchasing decisions.

Another approach that is also distinct from the obvious "nuts and bolts" technique of anchoring and bracing components is to motivate and train employees to cooperate with nonstructural hazard reduction efforts. As an example, if anchoring a file cabinet to a wall is the preferred solution, and if the furnishing has been arranged by the occupant in the middle of the room, some communication and cooperation is required

before the technical solution can be smoothly implemented.

Still another approach distinct from the traditional route of retrofitting and anchoring is to provide a customized method for evaluating the post-earthquake nonstructural safety and functionality of particular buildings. This case is illustrated with regard to a large manufacturing and research facility.

SURVEY SOFTWARE

For the Berkeley Unified School District in Berkeley, California, a project was begun in 1990 after parents and school personnel were concerned with the effects of the Loma Prieta earthquake of 1989 (Reitherman and Kustu, 1990). This project included the detailed survey of all spaces in approximately two million square feet of school facilities. The client desired a detailed inventory and cost estimate for all hazards even of a minor scale. The consultants projected from their experience and estimated that the final use of the data would be to select only the more major hazards for attention, because of cost limitations, and to look first only at the basic patterns, because the individual conditions are so numerous. Therefore software was developed to organize the data as it was collected with these eventual uses in mind.

Approximately 100 different pre-tabulated categories of nonstructural items were used in the field surveys by engineers. Quantities of various kinds (unit counts, lineal or area amounts, etc.) were entered for each kind of item. Each of these items, in addition, could be in an ordinary occupancy room where people normally are located, or it could be in a low occupancy space such as a boiler room or storage closet. The location by room or area, by building (approximately 100), and by site (17), were further ways in which the data had to be divided. Furthermore, it was known in advance that it would be desirable to slice the resulting data according to hazard category--three levels of risk based in most cases on life safety--and by construction-related grouping, such as the category of ceiling-related components. The result? Thousands of lines of data, hundreds and hundreds of densely printed tables and graphs. Having looked ahead to the problem of dealing with a mountain of data, the software used to compile the information was designed to produce readily understandable summary facts, such as answers to the following:

How much will it cost to fix all hazards?

How much will it cost to fix only the worst hazards?

How much will it cost to fix the worst hazards at one particular site or building?

How much will it cost to deal with a category of hazards--ceiling-related components, hazardous materials, mechanical equipment, etc.?

What proportion of the total hazard is represented by nonstructural items that are short-lived (and will be replaced within a few years due to ordinary maintenance)?

What proportion of the total hazard is represented by nonstructural items whose retrofits will require the cooperation (such as room re-arrangments) of employees?

These kinds of answers turned out to be relevant to those making decisions about what to do with the hazards. The more detailed layers of data--how many unanchored gas or electric water heaters there were in a given building, for example--are of use at the implementation stage after more basic decisions are made. The software devised allowed for graphs to quickly summarize the data. Something as simple as a pie graph was useful for showing the distribution of the hazard.

Perhaps the most basic lesson of this approach is that it is unnecessary to survey a building to list all conceivable hazards--because no one ever fixes everything. If the client can formulate some reasonable goals in advance, that will make the survey process more efficient. If not, the survey data should be collected with eventual prioritization and simplification in mind. Very rough pre-survey estimates of cost ranges should be discussed in advance, to allow the client to

"get under the weight" of the idea that small unit costs multiplied by thousands of items will add up to a significant total.
For example, if a round number estimate for an extensive nonstructural retrofit of a given facility is five dollars per square foot of floor area, and if the facility has a million square feet, the reasonableness of a $5 million price tag can quickly, if hypothetically, be discussed prior to devising the inventory procedure. Perhaps it will obviously be necessary to produce an alternative that will cost no more than one tenth of that for an initial effort. Perhaps only selected types of components need to be inventoried and analyzed to satisfy the needs of the program that will be funded.

OCCUPANT COOPERATION

Consider the seemingly simple case of a tall file cabinet or bookshelf unit. In a school, these furnishings are often found in the middle of the room. In this location, they divide up the space into different study areas and perform the role of surrogate partitions. They also pose a greater injury risk to students than if they were located in a corner. Once the school decides to anchor such hazardous contents they are more difficult to contend with if located in the middle of the room: The only anchorage surface is the floor, which means putting holes through the flooring finish material. The location of these contents will change almost annually, and the noles in the flooring are often considered unacceptable.

An alternative is to carefully install "surface-mounted blocking," or "seismic moulding" to one or more areas along the walls. This can be an architecturally pleasing piece of woodwork, but selected and anchored to provide adequate support for any contents to be screwed to it. When a file cabinet must be moved a few inches to allow for a different room arrangement, it is a quick task to re-screw it to the horizontal band on the wall. In light metal or wood frame construction, accurately locating studs is time-consuming, and this task is done only once when the seismic moulding is installed. Subsequent rearrangments can be quickly accomplished.

All of this is quite feasible from the architectural and engineering standpoints, but the real problem is getting the teachers, office workers, or other occupants to cooperate with the effort. This requires a combination of education and policy. In the case of the Berkeley Unified School District, a staff nonstructural earthquake safety booklet was prepared (Reitherman, 1990a) and a portion of a one-day earthquake training session was devoted to the topic of room arrangement as it relates to nonstructural safety. The other requirement is policy: A memo, safety directive, personnel policy, or other appropriate administration document must make the location of hazardous nonstructural contents an enforceable rule.

Other aspects of a room's nonstructural earthquake hazards under the control of the occupants include how items are stored on shelves. A twenty pound rock on the top shelf may be just where it has to be to fit in nicely with a teacher's geology exhibit, but if this is explicitly in violation of the school's safety rules, an acceptable alternative arrangement will always be found.

Occupants have learned that they cannot obstruct exit doors, cannot pile boxes up until they touch fire sprinklers overhead, and can't take a fire extinguisher off the wall just because it is taking up a spot that would be useful for a bulletin board. Parallel earthquake rules have a similar rationale, but simple seismic policies for occupants have yet to be institutionalized in most settings.

Another key aspect of involving the occupants in increasing their own nonstructural safety is to re-emphasize the importance of quickly taking cover beneath desk or table: Some instances of unacceptable nonstructural performance, such as a falling light fixture, will only result in property loss and not injury if the occupant is protected by a piece of furniture. This is the only feasible and reliable advice for most applications, especially when the time it takes to safely exit a building during an earthquake is considered. And in very strong earthquakes people fall down merely trying to stand up, letting alone trying to run or go down stairs.

PURCHASING GUIDELINES

Concerning the same case of the Berkeley schools, another approach was developed that went beyond the traditional retrofit effort. Purchasing guidelines (Reitherman, 1990b) were prepared to suggest ways to prevent hazards from being added into the buildings in the future, and to point out ways that existing hazards could be phased out if wise purchasing decisions were made.

For example, once laboratory shelving is purchased that provides no built-in restraint for chemicals, it is often time-consuming to try to design retrofits and the results can be architecturally unappealing. File cabinets can be purchased with strong latches for about the same price as those with flimsy latches or without any latches at all. Once the wrong kind is bought and moved into a building, it's usually too late. Even if the cabinet is anchored, the drawers are still likely to lurch out. If mechanical equipment on springs is replaced via a standard vendor agreement, without any engineering review or language referring to seismic anchorage requirements, even in an area such as California where seismic codes have long been enforced the result may well be a seismically vulnerable new piece of equipment.

Depending upon the type of nonstructural component, the expected lifespan may be an acceptable period of time to be exposed to seismic risk, using the deferred protection approach. But if the "correct it when the new one is installed" option is selected, when the new one is installed five years from now a different person may be handling the purchase order. It is essential to institutionalize a few seismic purchasing criteria or controls into the ongoing way the organization does its business with contractors and vendors.

MAINTENANCE TRAINING

For the State of Idaho a project was produced which included a training manual (Reitherman, 1991) and a travelling seminar intended for facilities and maintenance staffs of school districts in Idaho. The basic concept, devised by Clark Meek of the Idaho Bureau of Disaster Services, was to deliver instruction directly to the personnel who typically install and repair nonstructural items in the course of their daily work. Details for anchoring a small number of recurring items were provided.

This raises the question of whether this has any benefit for the larger or more complex types of items that require engineering. A large boiler, for example, is outside the scope of this approach, but many of the same maintenance personnel or facilities managers receiving the training will be involved in purchasing decisions of new boilers and similar equipment in the future. If they have enough technical background to know that special seismic anchorage is required, and even a feel for the fact that a few bolts the size of their finger are probably inadequate for an object the mass of a large boiler, they may be able to raise the right concerns at the right time to prevent the installation of a new nonstructural hazard.

Many seminars or presentations on nonstructural earthquake protection are basically motivational in nature--they help convince people that there is a problem, but don't really train them how to fix it. Dealing directly with the people who will do the fixing has the advantage of narrowing down the audience, permitting greater emphasis on technical details. In the Idaho training seminars, examples of good hardware and anchorage details were passed around and contrasted with examples of inadequate models of expansion bolts, toggle bolts, screws, etc. Combined with sheet-by-sheet explanations of anchorage details, videotapes showing nonstructural damage and how it occurs, and a walk-through nonstructural tour of several different kinds of rooms in a school, the training immediately allows the participants to make practical progress when they return to their facility.

POST-EARTHQUAKE INSPECTIONS

The following brief summary of a project draws on my experience as a consultant on a

Jack R. Benjamin & Associates project managed by Charles Kircher for a large industrial and high technology client. The problem was how to integrate a detailed building-by-building nonstructural inspection procedure into the structural inspection protocol that was being developed. The structural approach capitalized on previous ground motion records and structural analyses to provide on-site facilities personnel with a step-by-step list of where to look in a given building for damage, and how to interpret what was seen or measured.

The result of the nonstructural project was building-specific checklists and diagrams. While it may seem easy to go into a building and see if anything nonstructural has fallen, in a complicated industrial setting it is much more complicated. Even sorting out the precise sequence of where to go first, which doors to unlock, which catwalks to use, etc., can be a great benefit. Also necessary is the provision of safe/unsafe criteria, or criteria that allow for re-entry after certain stabilization measures are taken. Without detailed guidance and training of the people who will be on site to perform the immediate surveys, there are the risks that either an unconservative or excessively conservative determination will be made.

In this effort, the work that has become a standard in the United States for post-earthquake evaluations (Applied Technology Council, 1988) was used as the starting point. The goal was to make the nonstructural indicators of unacceptable hazard more detailed with regard to specific buildings. Especially for large buildings or those with complex nonstructural systems, and where there are facilities/maintenance staffs dedicated to specific buildings, there is great potential for applying this approach. The benefit of accurately and quickly identifying nonstructural conditions that pose life safety risks is augmented by the benefit of more rapidly identifying the steps necessary to bring a facility back to full function. The functional aspect is critical with regard to essential business operations and governmental emergency response facilities. The prevalence of hazardous materials today also means that special problems are posed in the post-earthquake setting. On the other hand, there is an opportunity for using the information in hazardous materials inventories compiled for non-seismic reasons into post-earthquake nonstructural inspection procedures.

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