The Earthquake Closet: Rendering Early-Warning Useful

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Summary: Early-warning of imminently approaching strong shaking that could have fatal consequences is a research field that has made great progress. However, its potential to save lives has a serious Achilles heel: The time for getting to safety is five to ten seconds only, in many cities. Occupants of the upper floors cannot get out of their buildings and narrow streets are not a safe place in strong earthquakes. Thus, only about 10% of a city's population can benefit from early-warnings, unless they have access to an earthquake protection unit that is strong enough to improve their chances of survival and not being injured by factors of 1,000 to 30,000. In this paper, we propose a concept for improved safety for occupants of buildings exposed to strong earthquake shaking.

1. INTRODUCTION

In early-warning research, methods have been developed by which the location and ultimate size of an earthquake rupture can be estimated within seconds of its initiation and before its rupture has finished (e.g. Allen and Kanamori, 2003; Festa et al., 2008, Tsuboi et al., 2002). Based on smart, self-organizing sensor networks (e.g. Fischer and Kühnlenz, 2008; Heglmeier., et al, 2008) warnings can be transmitted at an early time to the population of large cities near faults that are in the process of rupturing in an earthquake. Early-warning can be useful for cities such as Mexico City because it is located more than 300 km from the source of great earthquakes along the Pacific cost, but buildings collapse due to strong shaking because of poor soil conditions. In this case, the large amplitude waves take about one minute to arrive in the city. Sensors placed along the cost will have recorded the event shortly after its beginning, the population can be warned of the approaching strong shaking, and people can save themselves by escaping to open spaces such as parks. Istanbul (13 million inhabitants) is located at a distance of about 40 km from a segment of the North Anatolian fault that is capable of a magnitude 7.5 earthquake (e.g. Kuvvet et al., 2002), and San Francisco (1 million inhabitants) is separated only by its Bay from the Hayward fault, capable of magnitude 6.5 earthquakes (Working Group, 2003). Both of these faults are ranked among the most probable locations for earthquakes near major population centers during the next decades. When these faults will rupture, the warning times will be not more than 10 and 5 seconds, respectively.

We estimate that only about 10% of the population could benefit from an early-warning with such a short lead time. Assuming the number of floors in large cities in earthquake-prone regions is on average five, only 20% of the population resides on the ground floor from where they could exit within 10 seconds. In addition, it is not advisable to run out into a narrow street, where debris is falling in a strong earthquake. Assuming that approximately half the streets are too narrow for safety in an earthquake, only 10% of the population could get to safety in large cities, after they have received an early-warning by smart expert systems.

The chance to survive an earthquake depends upon the buildings ability to withstand strong shaking, the position of the occupants in the building, and their familiarity with measures to protect themselves. To decrease the casualty rates in upper floors of residential buildings, we propose installations of protection units that can be reached in a few seconds on each floor.

2. EARTHQUAKE PROTECTION UNIT

2.1. Concept

We define an ***earthquake protection unit*** (EPU) as a part of the building with greater resistance to strong shaking than the rest. The EPU might be a separate room or part of an existing room. One can envisage a range of structural strengths and costs, resulting in a range of improved chances of surviving in a damaged or collapsing building. If the EPU resistance is much higher then the resistance of the building's principal load bearing system, then the benefit is significant. To assess approximately the possible benefit, we considered:

- EPU in: (1) modern reinforced concrete high-rise residential buildings, and (2) traditional residential masonry buildings.
- Casualties pertinent to structural damage only.

In the first case, we assumed that an EPU of a resistance corresponding to vulnerability class F of the European Macroseismic Scale (Grunthal, 1998) is placed in a building that belongs to vulnerability class D. We estimate the increase in the probability of a person inside the EPU to survive, or escape injuries, from the ratio of the respective fatality and patient rates (Figure 1). With these assumptions, the EPU is most effective to prevent fatalities at intensity IX, where the chance to survive is more than 5,000 times better inside the unit. The probability of ending up as a patient inside the unit is about 100 times less than outside, in the range of intensity IX to X.

The benefit is higher when the principal load bearing system is of vulnerability class B and the EPU of class E (case 2). Thus, the chances of survival, or being not injured, are 30,000 and 150 times better, respectively, for intensity VIII. At intensity IX and X, the probability to survive inside the EPU is about 3,000 and 500 times better, respectively, than outside.

We calculated the casualty rates using the loss estimation module (Trendafiloski et al., 2009) in the computer tool QLARM (http://qlarm.ethz.ch). The contribution of the nonstructural damage (damage to partition walls, glass, overturning of furniture) to the casualty potential is not considered in the above calculation. In the 2003 M6.3 Northern Miyagi earthquake in Japan, 51% of the injuries were attributed to objects falling and furniture overturning (Sato et al., 2006). The EPUs we propose prevent injuries of this type. Thus, we estimate that the total chance of escaping injuries is about a factor of two larger than calculated in the previous section.

In spite of the fact that the survivability ratios are 5-6 times smaller on a single floor for the case 1 than for case 2, the sum of the benefit of using EPU in high-rise residential buildings is very high, given the large number of occupants in them.

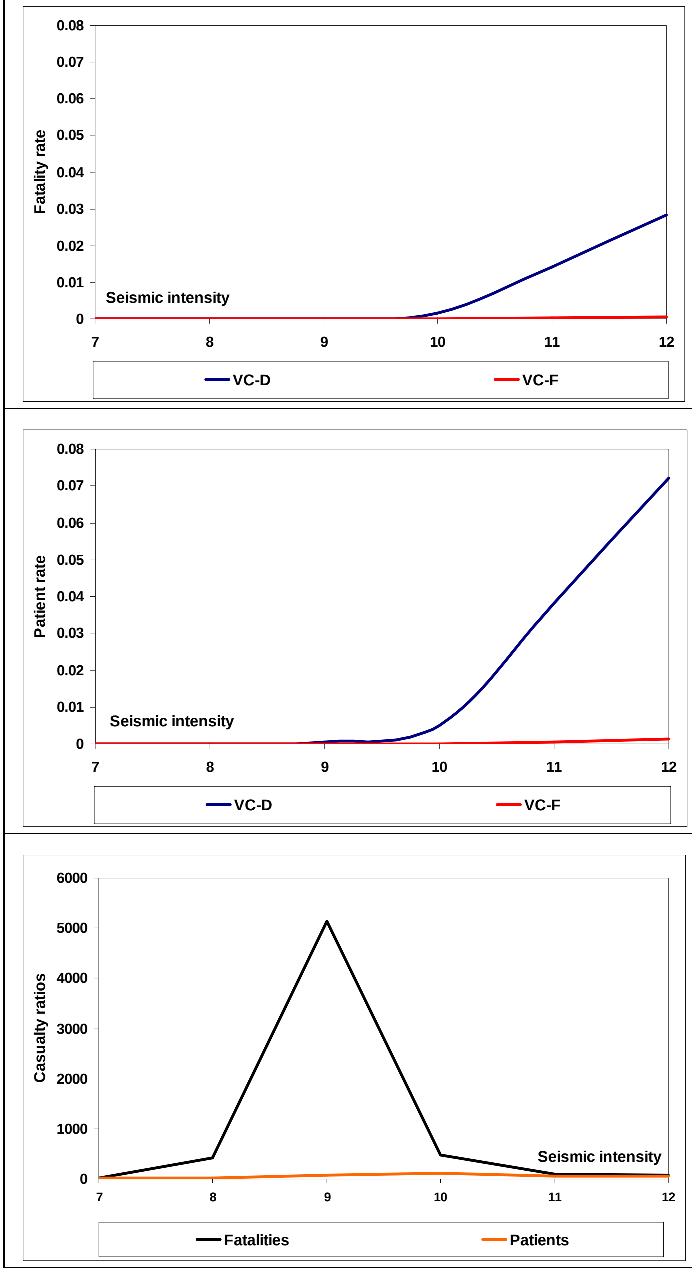

Figure 1. (A) Fatality and (B) patient rates for vulnerability classes D (VC-D) and F (VC-F) as a function of seismic intensity of shaking for buildings located in large cities in Latin America. (C) Casualty ratios for persons in a building of fragility class D, compared to a person inside an earthquake closet, equivalent to fragility class F, as a function of intensity.

2.2. Types of EPU

In general, the type of EPU may vary greatly from case to case, however one can group them considering the:

- Material of construction: reinforced concrete, steel, plastic, or wood.

- Occupancy characteristics: individual or collective protection.
- Implementation: in existing or newly constructed buildings.

Two EPU examples are given bellow.

The earthquake closet belongs to the EPU group for individual (single family) protection. Few prototypes are already registered in US and Japan, such as the one with patent number US 6,349,508 B1 (2002). We envision the earthquake closet as a small strong room that will not collapse, even if the floor above it comes crashing down on it. The dimensions should be enough to accommodate a family of four to five persons. The structure of the earthquake closet may vary from case to case and it depends on whether it is implemented in an existing or in a new building. We propose that a closet could be built in a part of the apartment, where the overall building structure offers the strongest resistance to collapse. A construction, using steel might be most favorable, but strong plastic molds might be used alternatively. One side of the closet could be left open to allow fast entrance and to keep the space inside the closet available for daily use. An example of an earthquake closet in a brick masonry building is given in Figure 2. It is derived from an existing room in the apartment by partitioning, strengthened with a steel frame structure consisting of columns, beams, and braces. The use of steel is preferred in such a case, mainly due to its high stiffness characteristics, low increase of mass, and inertial forces.

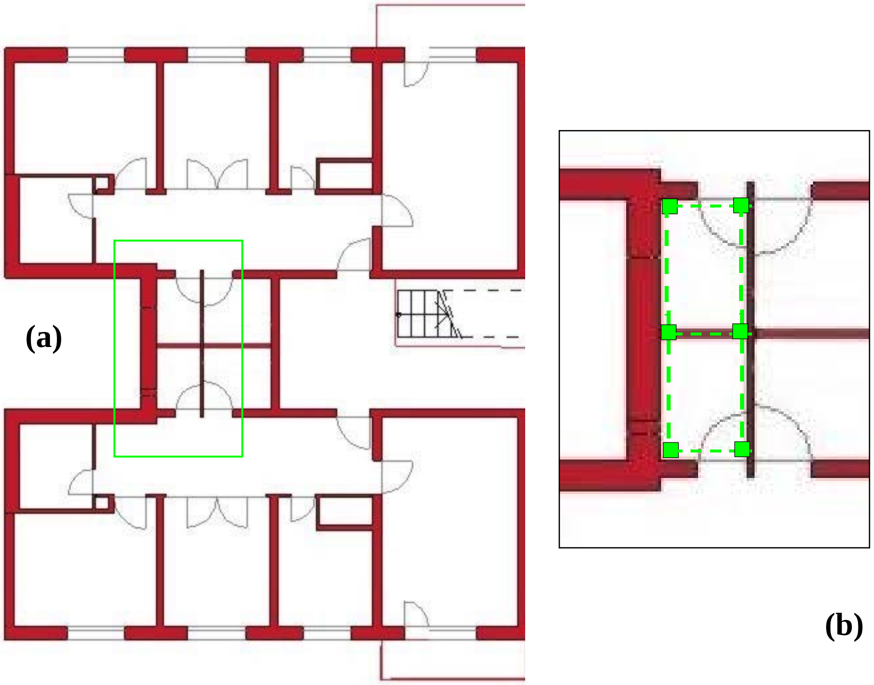

Fig. 2. An example of earthquake closet in a brick masonry building.
(a) Floor plan of apartments with a room adapted as earthquake closet (marked with green rectangle). (b) Floor plan of the earthquake closets. The steel structure used to strengthen the room consists of columns (green rectangles), breams, and braces (green dashed lines).

In this paper we emphasize the case of highly earthquake-prone mega-cities in which the collective protection of the occupants in the higher floors is a top priority. This kind of protection would be achieved in new buildings by constructing a strong-tower, consisting of the elevator shaft, the staircase, plus earthquake shelters; one on every floor (Figure 3). The ***earthquake shelter*** shaft would be of reinforced concrete shear walls. We propose that the central strong shaft, including the shelter be isolated from the main building structure. Thus, the principal load bearing system would absorb the earthquake forces and the shelter would provide an environment of increased safety. The inside walls of the shelter might be padded and several intake vents for air might be placed strategically. If there is a door, it should be constructed in such a way that it cannot jam, but can be dismounted, in case the closet is severely deformed in the earthquake.

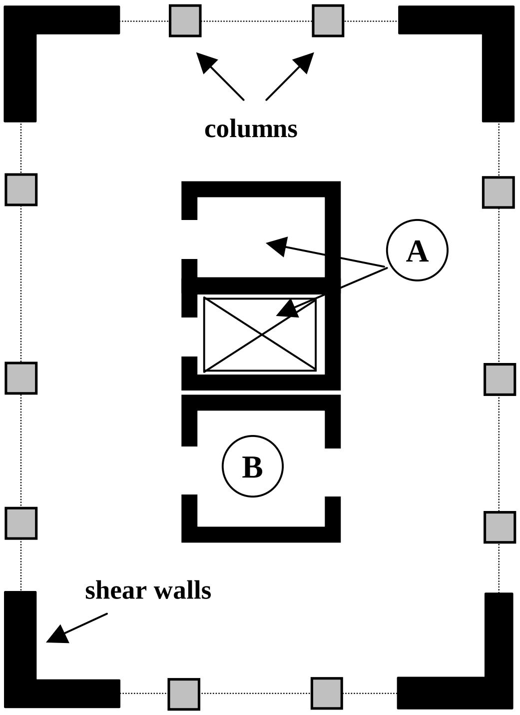

Fig. 3. Conceptual floor plan of a reinforced, concrete dual system building (frames + shear walls). (A) Vertical communication shaft consisting of an elevator (marked with crossed rectangle) and stairs. (B) Shelter shaft.

The survival gear stored in the shelter should include water, food, emergency crank-radio and transmitter, breathing filters to protect from inhaling dust, a first aid kit, a chemical toilet, tools, warm clothing, and a small library.

3. IMPLEMENTATION

A few decades ago, nobody wore seatbelts in cars, now it is the law to wear them. It may be the same with earthquake shelters in cities near major faults. At first, the idea is bound to meet with resistance from some interest groups. The most ready acceptance may come from homeowners who value their lives and may build a simple structure in an existing bathroom or in the corner of a larger room. An awareness campaign, followed by access to workshops and training programs, where the techniques of building a small closet in a single or double residence will be taught, may serve the needs of self-reliant homeowners. The raising of awareness and the training of how to behave in an earthquake that goes along with the proposed protection unit is in itself an important element in reducing casualties.

The owners of office buildings may find that it will be more cost-effective to install earthquake closets on each floor, rather than risk litigation by the families of employees that may die at the workplace, once earthquake closets become accepted as a means of protecting the population from the consequences of earthquakes.

Developing a most resistant design and choosing the best suited materials will require some discussion among engineers. The cost-benefit ratio is an aspect that will have to be investigated in detail. Ready-made earthquake closets should be developed that can be installed in an apartment.

The question of what weight lies above a planned closet and what support the closet has from below will have to be investigated in multi-floor buildings. Construction companies and consultants may specialize in this skill, so the cost of such an analysis may not be overwhelming.

The cost of an earthquake closet may vary from country to country and depend on the type of material. For developing countries from the region of South-Eastern Europe such as Macedonia, the cost may range from 2,000 to 4,000 €, if the closet is added to an existing building, which would amount to one to several percent of the value of the building. The EUROCODE8 (2004) design of the proposed earthquake shaft shelter would apply an elastic spectrum at least 50% higher (behavior factor $q \geq 1.5$) than the spectrum for the design of the rest of the structure. Thus, our approximate estimation is that such structures may increase the cost of a new apartment building in South-Eastern Europe by 10%-15%. To estimate more accurately the possible increase of the cost we propose to design various prototype buildings, in which we will include the proposed concept of an earthquake shelter. We also plan to consider alternative design solutions of the earthquake shelter that might decrease its cost.

The usefulness of installing earthquake shelters and the type of construction will vary as a function of the development of a country. In highly developed countries with enforced building codes, the need for earthquake-closets may be moderate, but the economic strength of owners of buildings may allow them to implement a device that will decrease the chance of becoming an earthquake casualty by factors of 1,000 to 30,000 without much hesitation. In countries with poor construction and no enforcement of building codes, poverty may be such that funds are not available, even for the cheapest type of closets. In emerging countries, with a mix of modern and outdated buildings, the usefulness of earthquake shelters may be highest because recent constructions are often almost as unsafe as old buildings.

In awareness campaigns, people should be taught to dash into their closets at the slightest shaking. All earthquakes emit **P**rimary and **S**econdary waves. The amplitudes of the P-waves are approximately 10 times smaller than those of the later arriving S-waves. Hence the P-waves provide early warnings of several seconds. During the P-wave shaking, it is easily possible to walk to the closet from any location in an apartment because the amplitudes are not large enough to knock people off their feet.

Earthquake-closets are bound to increase tolerance to false alarms. If all one has to do when feeling a P-wave, or receiving an early warning, is to cross a room or two to reach the closet, one is far more willing to accept false alarms, than if one would have to run down several flights of stairs and away from the building to reach safety.

Early-warning by experts and authorities, using smart networks of measuring devices and computers, is not useless, although it cannot save most of the population. Turning off dangerous processes in nuclear power and chemical plants, to stop sensitive equipment, and to slow fast trains all will benefit from early-warnings by professionals.

4. CONCLUSIONS

While advances in locating an earthquake rapidly, and in estimating its magnitude even before the rupture is finished, is spectacular and scientifically exciting, the proximity of capable faults to cities limits early-warning times for many cities so severely that only 10% of the population may benefit. As a remedy, we propose that earthquake-closets should be installed on floors above the ground floor of apartments, office buildings, and residences. These constructions will take little space, about 2 to 10 m^2, will remain intact, even if their building is heavily damaged, and increase the chances of surviving by several orders of magnitude. By teaching the owners of earthquake-closets to dash to safety in case they feel shaking due to a primary wave, they may reach safety, using Mother Nature’s own early-warning signal.

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