STATE-OF-THE-ART KNOWLEDGE OF PROTECTIVE ACTIONS APPROPRIATE FOR EARTHQUAKE EARLY WARNING

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EXECUTIVE SUMMARY

The purpose of this white paper is to summarize the scientific evidence and professional opinion concerning earthquake protective actions that can be taken by the public immediately before the ground starts to shake, in as many scenarios as possible.

Limited Existing Research on Protective Actions for Earthquake Early Warning

Although the advent of Earthquake Early Warning (EEW) in the U.S. provides a tremendous opportunity to reduce human, property, and economic losses, there are substantial, critical gaps in research needed to help guide the design and implementation of the U.S. system, ShakeAlert. Scholars and practitioners have amassed decades of research about actions to take during earthquake shaking; however, very little research has been conducted specifically on the unique context of EEW.

Evaluating General Earthquake Protective Actions

Due to the gaps in research around EEW, this white paper focuses on the strength of evidence that supports (or fails to support) general earthquake protective actions. The authors primarily summarize content from two key reports by FEMA and GHI, integrating dozens of additional literature sources and input from subject matter experts. The white paper examines more than a dozen protective actions, from “Stay Indoors” to “Pull Over and Stay in Vehicle”, noting whether each action is *recommended*, *recommended with caution*, or *not recommended* for inclusion in public education camapaigns.

To help guide emergency managers in their support of ShakeAlert, existing research must be assessed for its appropriateness in an EEW context, and the need for additional research to fill critical gaps in light of EEW implementation should be identified and conducted. In addition, crucial to this effort is having a clear understanding of the evidence base and strength of support for recommending different protective actions in various settings, including whether support is based on research findings, expert opinion, or simply on informed practice.

Importance of Public Training, Education, and Outreach

As part of preparing the U.S. public for the arrival of the ShakeAlert EEW system, it is essential that emergency managers and others provide earthquake safety education and training based on preparedness actions that make sense when an EEW message has been received, with some amount of time before ground shaking begins, as opposed to protective actions that are appropriate once shaking has begun.

In prioritizing protective actions recommended to the public before and during shaking, earthquake safety organizations must consider: (1) what general actions will lead to the greatest chance of survival for the most people, and (2) the likelihood that individuals will be able to perform those actions based on the situational characteristics. It is impossible for message providers to recommend the right protective action for every individual, in every circumstance, every time.

Emphasis on Teaching Situational Awareness

Based on all the evidence assembled in this report, the authors concluded there is no single, universally accepted protective action that is best to take in every context. Rather, the best course of action may vary significantly across types of buildings, situations, and time of day. Given this variability, it is ideal that people are aware of their environment and use their judgment to determine the most appropriate action in any given situation.

This approach—promoting situational awareness—assumes people can accurately assess their situation and use good judgment to determine the most appropriate action to take during an emergency and within a very short time-frame. For this approach to be successful, people must obtain specific knowledge about what to do in a variety of situations, as well as acquire and practice the skills necessary to take appropriate protective action quickly and effectively. This is the reason that effective, easy to follow protective action outreach, education, and training in the form of public messaging and drills are so important.

Conclusion

The findings and recommendations in this white paper may be used to help guide future research efforts, as well as messaging, outreach, training, and educational materials developed in support of general earthquake safety and EEW systems.

PROBLEM STATEMENT

Earthquakes cause substantial morbidity and mortality. Since 1990, earthquakes have claimed an average of more than 25,000 lives annually (Guha-Sapir, Vos, & Below, 2011) and have caused an estimated 1,497,242 deaths worldwide since 1996 (Glasser & Guha-Sapir, 2016). Injuries make up the overwhelming majority of health effects caused by earthquakes (Kano, 2005; Mahue-Giangreco et al., 2001; Peek-Asa et al., 2000; Shoaf et al., 1998). Most of these are orthopedic and soft-tissue injuries caused by being struck by non-structural objects (e.g., light fixtures, furniture) and by falls.

Without the ability to predict the onset of major earthquakes, preparedness and mitigation have been the primary strategies used to reduce losses. For example, the Great ShakeOut Drill is a training opportunity for participants to learn and practice earthquake protective actions. For the past decade, ShakeOut has informed earthquake preparedness education, training, and exercises as part of ongoing efforts to reduce injury, loss of life, and infrastructure damage from earthquakes.

Earthquake Early Warning (EEW) technology, however, can now detect earthquake shaking and provide seconds to tens of seconds of warning to populated areas. The U.S. Geological Survey (USGS) and university partners from California Institute of Technology; University of California, Berkley; the University of Oregon; and the University of Washington, along with state emergency management agencies, are currently developing and testing ShakeAlert, the new U.S. EEW system (Burkett, Given, Jones, Stauffer, & USGS, 2014; Given & USGS, 2014). A goal of ShakeAlert is to provide enough warning that the public can perform protective actions before heavy shaking arrives. Limitations of the current technology are false alerts, missed alerts, and little or no warning time in and around the earthquake epicenter (Given & USGS, 2014). Potential benefits include the ability to reduce the number of injuries and overall loss of life, mitigate property and infrastructure damages, and increase community resilience by reducing longer-term economic losses. The system is currently operating as a production prototype along the U.S. West Coast, in the states of California, Oregon, and Washington.

Although the advent of ShakeAlert provides a tremendous opportunity to reduce human, property, and economic losses, there are substantial, critical gaps in research needed to help guide the design and implementation of the system. In an EEW context, the time available to take protective action begins with receipt of an EEW message rather than the initiation of perceptible shaking, and ends when ground motion makes it difficult to take the protective action. Scholars and practitioners have amassed decades of research about warnings and the actions people take following the onset of earthquake shaking; however, very little research has been conducted (all of it in settings outside the U.S.) specifically on the unique context of EEW. Given that EEW is not yet available to the public on the West Coast, there are no studies in the U.S. that examine the behavior and protective actions individuals take in response to receiving warning of an earthquake.

In fact, we are still learning about best ways to craft EEW messages or about how they motivate people to take action. Moreover, there are technological limitations associated with EEW that present challenges for message design. For example, ShakeAlert technology is currently limited to sending a single, identical message to all recipients, regardless of users' location or situation. Consequently, ShakeAlert is being designed to send a single warning message to members of the public who will experience varying degrees of shaking intensity with varying amounts of time available to take protective action depending on their location, despite research demonstrating that personalized, detailed messages are more effective at motivating protective action than more general warnings (Frisby, Veil, & Sellnow, 2014; Lindell & Perry, 2012; Sellnow, Sellnow, Lane, & Littlefield, 2012; Sutton, Vos, Wood, & Turner, 2018; Wood et al., 2017). These challenges highlight the importance of providing effective preparedness and earthquake safety education and training.

As part of preparing the U.S. public for the arrival of the ShakeAlert EEW system, it is essential that emergency managers and others provide earthquake safety education and training based on preparedness actions that make sense when an EEW message has been received, with some amount of time before ground shaking begins, as opposed to protective actions that are appropriate once shaking has begun. The majority of research and analysis conducted thus far about earthquake protective actions assumes the latter.

To help guide emergency managers in their support of ShakeAlert, existing research must be assessed for its appropriateness in an EEW context, and additional research needed to fill critical gaps in light of EEW implementation should be identified and conducted. In addition, crucial to this effort is having a clear understanding of the evidence base for recommending different protective actions in various settings, including whether support is based on research findings, expert opinion, or simply on informed practice.

The purpose of this white paper is to summarize the scientific evidence and professional opinion concerning earthquake protective actions that can be taken by the public immediately before an earthquake, that is, 10 to 60 seconds before the ground starts to shake, in as many scenarios as possible. The paper focuses on the strength of evidence that supports (or fails to support) protective actions identified in the literature. Findings and recommendations may be used to help guide future research efforts, as well as messaging, outreach, training, and educational materials developed in support of general earthquake safety, and EEW systems.

BACKGROUND

Risk Communication and Warnings

Social science research on the topic of warnings began in the 1950s with two studies funded by the National Academy of Sciences (Mack & Baker, 1961; Wallace, 1956). Since then, a large body of knowledge has accumulated that may help inform the development, implementation, and refinement of EEW systems, such as ShakeAlert (Bean et al., 2015; Lindell & Perry, 1987; Lindell & Perry, 2000; Lindell & Perry, 2012; Mileti, 1975; Mileti et al., 2006; Mileti & Sorensen, 1990). Given the short amount of time from the issuance of an EEW alert to the arrival of earthquake shaking, warning research focused specifically on imminent hazards is most pertinent to EEW.

Warning Content

The research record on warnings provides evidence that public warning messages are more likely to motivate appropriate and timely public protective action-taking if they provide information on at least five topics: (1) a description of the *hazard* and its consequences; (2) protective action *guidance*; (3) the *location* and population at risk; (4) the *time* by which the public should begin taking and completing the protective action; and (5) the message sender or *source* (summarized in Mileti et al., 2006; Mileti & Sorensen, 1990). The Partnership for Public Warning, led by Art Botterell, incorporated the five elements in the design of the nation's Common Alerting Protocol and provided the foundation for the structure of messaging in the nation's Wireless Emergency Alert (WEA) service (Botterell, 2003; Wood, 2017; Wood et al., 2017). More recently, elements of hazard consequences, how protective action reduces conseequences, and message expiration time have been added to this list (Mileti, 2018).

Research has shown that messages containing high levels of guidance result in increased knowledge and efficacy (Frisby et al., 2014). Of the five key warning message elements, researchers have identified describing the *hazard* and providing *guidance* about what protective actions to take as the two most important message elements (Bean et al., 2015, December; Wood, Bean, Liu, & Boyd, 2015, August). Research has recommended that these elements be placed early in a warning message (Bean et al., 2014). These findings suggest that message providers should deliver specific guidance about recommended protective actions and include explicit information about how to take actions in messages.

Warning Length

Research has documented the importance of providing mobile alerts that contain sufficient information to satisfy the public's need to search for additional and confirming information following receipt of a warning (Wood et al., 2017). In the context of EEW, however, the longer the message takes to read, the less time is available to take self-protective action, presenting a substantial problem for imminent threat warnings with very short time frames. If a message is so brief that it lacks sufficient information to ensure that it will be understood, believed, considered personally relevant, and help people decide what action to take, then recipients will delay responding to the message as they search for additional and confirming information. On the other hand, if a warning message is long enough to contain enough information to satisfy peoples' need to confirm the message, then recipients will waste potentially life-saving seconds reading the longer message that could have been spent taking the protective action. Educating and training the public about the EEW system and about the appropriate self-protective actions *before* an event occurs, and then activating that prior education and training when an alert is issued, may be the best way to resolve this dilemma.

Warning Response

Understanding which protective actions and other behaviors are *actually* taken during an earthquake, as opposed to those that have been recommended, can help identify challenges and opportunities in communicating appropriate protective actions for EEW. Such information also can be useful in informing future earthquake safety education efforts.

To this end, research has used self-reported data to study behavioral and emotional response to earthquake ground motion. Arnold and colleagues found that among county office workers in the 1979 Imperial Valley earthquake (M6.5), the most frequently reported actions taken during ground motion were staying in place or getting under a desk, followed by moving to a doorway, avoiding falling objects, and moving to the main corridor or exiting the building (Arnold, Eisner, Durkin, & Whitaker, 1982). Research in Japan (Archea & Kobayashi, 1984; Ohta & Ohashi, 1985; Takuma, 1978) found that exiting buildings and turning off fuel outlets were common responses to earthquake ground motion. This research noted that family- and self-protective actions were more frequent when the social context included dependent children, and when they had prior earthquake experience, as well as the intensity of shaking. Archea (1990) found that in the Loma Prieta earthquake, people took refuge in a doorway in the room they were occupying, "rode it out", assisted others, or moved outside (evacuated). The researchers judged that following the earthquake, just half (51%) were in a "point of refuge", while 42% remained vulnerable. Goltz and colleagues (Goltz, Russell, & Bourque, 1992) found that following the 1987 Whittier Narrows earthquake, the most frequent behavioral response among people at home or work at the time of the earthquake was to take cover in a hall, doorway, or under furniture; the most frequent response among those who were driving was to move over and stop their vehicle on the side of the road. The authors concluded that behavioral response to the event was controlled, rational, and adaptive. Prati and colleagues examined emotional and behavioral response to earthquake shaking during the September 1997 Umbria-March earthquakes. Structured survey results indicated that more than a third (38%) reported "escaping" (evacuating) from buildings. Running outside was more frequent when individuals were alone or with strangers and when they were away from home; a mere 12% took cover during the shaking (Prati, Catufi, & Pietrantoni, 2012).

More recently, research examining various actions taken during the 2012 Emilia-Romagna earthquake found that the most common response to shaking was moving to another room (42%), followed by evacuating the home (36%), waiting in bed (33%), going downstairs (28%), getting dressed (19%), sheltering in a doorway (14%), sheltering near a supporting wall (14%), and sheltering under a table (2%) (Prati, Saccinto, Pietrantoni, & Pérez-Testor, 2013). (Some respondents reported taking more than one action). Self-reported survey research also has examined behavioral responses during the 2011 Christchurch and Tohoku earthquakes (Lindell et al., 2016). In this research, the most common response during the shaking was to freeze in place (34%), followed by evacuate immediately (20%), "duck," cover and hold on" (12%), protect people (8%), protect property (8%), and continue normal activities (2%).

Research on three California earthquakes (Goltz & Bourque, 2017) examined the actions people took during ground motion in a comparative analysis of survey findings. This study also found a wide range of actions during earthquake shaking. The researchers found an apparent causal relationship between fear and physical movement, with other factors also contributing to the particular response actions taken. For example, while fear seemed to motivate self-protective actions among women, in contrast, it seemed to motivate (unsafe) flight out of buildings among men. Other factors identified as influencing earthquake response behavior included social and contextual variables such as demographics (e.g., gender, ethnicity, education, age, income, and marital status), culture (e.g., length of California residence, level of earthquake preparedness), and situation or context (e.g., the presence and identities of others, severity of shaking, and location). The researchers concluded that public information campaigns had some degree of efficacy: earthquake responses were largely consistent with best practices that had been communicated locally leading up to and at the time of the events. Specifically, people generally adhered to local guidance recommending limiting movement and taking cover in a safe location, with few individuals running, running outside, or attempting to catch falling objects—behaviors that had been strongly discouraged by local emergency response agencies.

Using alternative methods and drawing on prior research, Lambie and colleagues developed the Closed Circuit Television Earthquake Behavior Coding Methodology, a common coding scheme to code actual human behavior during and immediately after an earthquake (Lambie et al., 2016). Such information can be used to help evaluate and improve the efficacy of protective action messaging. The researchers used the method to analyze public hospital video data from the February 22, 2011 New Zealand earthquake (Lambie et al., 2017), which caused shaking intensity rated as Modified Mercalli Intensity Scale (MMI) 9 that lasted for approximately 12-15 seconds. It is worth noting, too, that this was not the first strong earthquake shaking the area had experienced in recent history and prior earthquake experience may have affected behaviors. The behavior of 213 individuals was captured on video with 31 different camera views. Two-thirds of the individuals recorded (66%) were adult women. During the event, the most frequent action taken was to look around (30%). During shaking, walking was more common (11%) than running (4%). All individuals outside the hospital ran when the shaking began. Evacuation was uncommon (1%), and only one camera view—that of the emergency department waiting room—showed people running to the exit. The authors surmised this behavior was due to falling ceiling panels and a partially collapsed ceiling, among other factors. None of the individuals was recorded trying to protect property. Only 4% continued performing a task, 3% fell, 1% moved towards other individuals, and another 1% had an uncontrolled response (e.g., they were thrown from their current position). In terms of self-protective actions, 26% held onto something (e.g., furniture or walls) or someone, 10% bent forward, 1% dropped to the ground, and 1% attempted to move to a doorframe. Another 4% assisted another individual, while 3% received assistance. Researchers noted general noncompliance with local earthquake safety guidance to “drop, cover, and hold on” —New Zealand’s recommended protective action during strong earthquake shaking, as no individuals were observed to perform all of these behaviors in concert.

Situational Awareness

Providing specific guidance about recommended protective actions is important, but research conducted by GeoHazards International (GHI) concluded that there is no single earthquake protective action that is appropriate in all locations (GeoHazards International, 2015a, 2015b). For example, different building characteristics (e.g., adobe or reinforced masonry) may warrant different guidance, such as evacuation or “drop, cover, and hold on.” Likewise, the extra seconds now afforded by EEW significantly expands the number of different actions individuals have an opportunity to perform before shaking begins (Burkett et al., 2014). Based on this variability, GHI concluded that people should understand and assess the hazards posed by their geographic location and physical surroundings. This type of pre-event assessment can help people develop *situational awareness*, that is, an understanding of the things that can harm the individual in an earthquake, and the best ways to stay safe in the individual’s earthquake scenario. Specifically, emergency managers and other message providers should encourage people to develop situational awareness by learning basic earthquake safety principles, becoming more aware of their environment, and using their judgment to determine the best course of action to take in a given situation (GeoHazards International, 2015b, pp. 5-6, 20).

METHOD

The authors of this report conducted a literature review to identify and evaluate guidance about protective actions recommended for earthquakes and tsunamis that would be appropriate in an early warning context. The authors did not conduct new research on protective actions. This white paper is therefore limited by existing research and associated methodologies. EEW scenarios were generated by searching guidance documents about earthquake protective actions. These included locations and situations that would provide context for earthquake and tsunami protective action guidance. Because EEW is not available yet to the public on the U.S. West Coast, there are no studies in the U.S. that examine the protective actions individuals take when they receive advance warning of an earthquake. Similarly, researchers have not yet examined protective actions through a lens of EEW, and how the extra seconds of warning might influence behavior. There is little to no data on how EEW might alter the efficacy of self-protective actions.

Following the literature review, the authors obtained input from two subject matter experts to confirm and expand upon information obtained in the research. Experts referenced in this report include Mark Benthien, Associate Director, Southern California Earthquake Center at the University of Southern California, Global Coordinator for The Great ShakeOut Earthquake Drills, and Executive Director of the Earthquake Country Alliance; and James Goltz, PhD, Visiting Research Professor, Disaster Prevention Research Institute, Kyoto University, Japan and former Branch Chief of the Earthquake, Tsunami and Volcanic Hazards Program, California Governor's Office of Emergency Services.

Efficacy of Protective Actions Appropriate for EEW

This white paper summarizes content from two reports, integrating dozens of additional literature sources and input from subject matter experts. The paper references some, but not all, research highlighted in the key reports listed. Readers should refer to those reports for additional information. In addition, the authors of this white paper present protective action information based on various scenarios in which individuals may find themselves during an earthquake. As noted throughout the white paper, recommended protective actions vary based on one's location and other circumstances when an earthquake strikes.

The authors used the following schema (see Table 1) to characterize their assessment of support for educating and training the public about the various protective actions identified in the context of EEW. Other reports offer a different system for classifying protective actions.)

Table 1. Schema for Evaluating Protective Actions Appropriate for EEW

Protective Action (thick solid border)	Emergency management agencies and other message providers should educate/train the public on this Protective Action.
Protective Action (double border)	Emergency management agencies and other message providers may educate/train the public on this Protective Action, with caution. For example, educating the public may cause confusion or individuals cannot be expected to determine when this guidance may be appropriate quickly in an earthquake.
Protective Action (dotted border)	Emergency management agencies and other message providers should NOT educate/train the public on this Protective Action.

RESULTS

Key Literature Validating Protective Actions

Two recent key reports have extensively investigated and summarized protective actions recommended *during* earthquake shaking. The first report was published by GeoHazards International (GHI) (GeoHazards International, 2015b) and was accompanied by a series of background papers that provide a more detailed review of supporting evidence, written by subject matter experts (GeoHazards International, 2015a). The second report was drafted by the Federal Emergency Management Agency (FEMA, 2016, November 15; GeoHazards International, 2015a, 2015b). The FEMA report is in draft form. It is important to note that both reports assume the time available to take protective action will begin with the onset of ground shaking. For the present white paper, pertinent information has been extracted and assessed from these reports and others based on apparent appropriateness for the EEW context.

GHI Report

The GHI report, *"Developing Messages for Protective Actions to Take During Earthquake Shaking",* assembled and analyzed research literature, surveys, and expert opinion to provide guidance on developing messages for the public about what people should do during earthquake shaking to protect themselves from injury or death. The report describes key considerations for creating effective messages appropriate to different international contexts. The report also identified ten protective actions that, in our view, could be taken seconds prior to earthquake shaking in international settings (GeoHazards International, 2015b, pp. 15-18). Several actions in the GHI report are specific to settings with building stock and building codes very different from that available in the U.S. Thus, while the report includes useful information, only some of the recommendations are applicable to U.S. earthquakes.

Based on all the evidence assembled, the GHI report concluded there is no single, universally accepted protective action that is best to take in all contexts (p. 14). Rather, the best course of action may vary significantly across types of buildings, situations, and time of day. Given this variability, the report urged message writers to promote *"situational awareness"*—the notion that people should be aware of their environment and use their judgment to determine the most appropriate action to take (GeoHazards International, 2015b, pp. 6, 20). Communicating general concepts before an earthquake strikes, such as the following, can help people better protect themselves in a variety of situations (p. 50):

> *Sheltering under sturdy furniture can protect one from being struck and injured by falling objects. If cover is not available, making oneself small and protecting the head and neck can reduce the chances of being struck and injured. Making oneself small next to dense furniture that is unlikely to topple, such as a sofa or armchair, is safer than doing so next to taller, less dense furniture, such as bookshelves.*

This approach—promoting situational awareness—assumes people can assess their situation and use good judgment to determine the most appropriate action to take during an emergency situation and within a very short time-frame. For this approach to be successful, people must obtain specific knowledge about what to do in a variety of situations, as well as acquire and practice the skills necessary to take appropriate protective action quickly and effectively. This is the reason that simple, easy to follow protective action outeach, education, and training in the form of public messaging and drills are so important.

Finally, the report offered considerations for developing protective action message content, which included: (1) geographic area or jurisdiction (e.g., size and areas of responsibility); (2) existing understanding, beliefs, traditions, and customs; (3) local earthquake hazard, including time available to take protective action, local site conditions and effects, secondary hazards, and characteristics of building stock; (4) population exposure (e.g., location and density of people during a workday, at night, on weekends/holidays, across seasons); and (5) social and gender considerations. Specific contexts discussed included mobility impediments, neurological or sensory impairments, cognitive impairments, schools, large buildings where people assemble, hospitals, laboratories, and kitchens. The GHI report noted additional considerations that make protective action messages more effective, including using messages that: (1) are consistent and echo the same set of underlying principles, (2) are compatible with other messages provided elsewhere, (3) include some explanation of the rationale and underlying logic, (4) are specific and actionable, (5) are stated with confidence and certainty; and (6) use simple language or visuals to increase accessibility (pp. 54-55).

FEMA Report

The FEMA report, *"Protective Action Validation Report: Research Review of Natural Hazard Guidance for the Public"*, was prepared by the FEMA Protection and National Preparedness (PNP) office implemented by the Individual and Community Preparedness Division (ICPD) within the National Preparedness Directorate (NPD). This report is currently published as a draft for comment by members of the research and practitioner community (FEMA, 2016, November 15).

The purpose of the FEMA report was to provide a validation assessment of protective action guidance for twelve natural hazards, including earthquake and tsunami, based on the research literature (275 research studies and articles) and with input from more than 80 subject matter experts. The report catalogs more than 380 protective actions that are appropriate before, during, and after impact for the variety of hazards reviewed, and provides a validation assessment for each protective action. Of these, the authors of this present white paper identified 17 protective actions (and additional related actions) that are appropriate to consider and possibly recommend in the context of EEW and possible subsequent tsunami. In addition to summarizing the evidence supporting (or failing to support) each protective action, the FEMA report also presents implications for protective action guidance and educational messaging and suggests future research priorities to address gaps in the scientific literature. Although the FEMA report is extensive in scope, it does not explicitly address the need for protective action guidance in the context of EEW. The authors of this white paper encourage FEMA to reorganize the report in future revisions and present findings in a way that specifically identifies protective actions that could apply to EEW.

Guidance for Individuals with Disabilities or Access and Functional Needs

Individuals with disabilities or access and functional needs (DAFN) provide another type of EEW context discussed in the GHI report. Earthquake safety organizations and other experts recommend additional protective actions for such individuals. The authors of this white paper note that no formal research has been conducted specifically on the efficacy of these protective actions. Although the GHI report discusses actions that may be recommended for people with mobility, sensory, or cognitive limitations, the efficacy of these actions was not addressed. Rather, organizations and experts have provided guidance based on inferences from existing research, logic, and direction from people and organizations that provide services to individuals with DAFN.

Support for Protective Actions Appropriate for EEW

The next four sections detail the protective action guidance for four categories of earthquake scenarios: being indoors, outdoors, in a coastal region, and having DAFN.

Indoor Locations

This section describes earthquake safety guidance about situations when people are indoors.

1. Stay Indoors. Attempting to evacuate a building during an earthquake has been identified as a risk factor for death and injury. Research on the Whittier Narrows, Loma Prieta, and Northridge, California earthquakes found that moving from a building during an earthquake was associated with injury (Shoaf, Nguyen, Sareen, & Bourque, 1998). Among people who reported attempting to move during the Northridge earthquake, 10.4% reported injury, whereas just 6.1% of those remaining in place reported injury (Shoaf et al., 1998, p. 227). Falls – the leading cause of hospitalized injury in that event – were most commonly associated with movement from a building (Peek-Asa, Ramirez, Seligson, & Shoaf, 2003, pp. 462, 464). In that earthquake, very few serious, non-fatal injuries were associated with building collapse (Mahue-Giangreco, Mack, Seligson, & Bourque, 2001, p. 355). In California, residential housing is largely wood-framed, which is less prone to collapse than adobe, concrete, and masonry buildings (Peek-Asa et al., 2003, p. 65).

Recommended

According to FEMA, evidence for staying indoors is considered robust/sufficient (FEMA, 2016, November 15). In the U.S., multiple studies have shown that exiting a building to go outdoors during an earthquake increased the chance of death and injury resulting from falling and from being struck by falling debris.

2. Drop, Cover, Hold On. FEMA, earthquake safety organizations, and other subject matter experts describe “Drop, Cover, Hold On” (DCHO) as an alternative to evacuation, or movement within or from a building. The FEMA report evaluates the efficacy of each part of this combined protective action—drop, cover, and hold on—separately. Although the authors of the present white paper did not identify research that evaluates the efficacy of performing these three actions in concert, we chose to consider guidance for the DCHO action together, as the combined action is meant to maximize protection during earthquake shaking and the three actions are commonly taught together in earthquake preparedness activities.

The logic underlying the DCHO protective action is based on the documented risks associated with movement during an earthquake. For example, most hospital-admitted injuries in the 1994 Northridge earthquake were caused by falls or being hit by objects. Head and chest injuries were common among fatalities; extremity injuries were most common among those admitted to a hospital. The head was the most commonly injured area of the body among fatalities (48.5%), followed by thoracic injuries (42.4%) (Peek-Asa et al., 1998, p. 459). Research on the 2010/2011 Canterbury earthquakes found that tripping/falling was the most common cause of injury (26-28%) in both earthquakes (Johnston et al., 2014, p. 628). In the 1999 Kocaeli earthquake, 85% of deaths and injuries were attributable to being struck, caught under, cut or pierced by a falling or fallen object (Petal, 2009, p. 244). Across the Whittier Narrows, Loma Prieta, and Northridge earthquakes in California, non-structural items falling caused more injuries than taking any other single action (Shoaf et al., 1998, p. 227).

Recommended

FEMA considered evidence for each element of DCHO as robust/sufficient (FEMA, 2016, November 15). The authors of this report recommend providing guidance about this set of actions. People should be instructed to take as many of the DCHO actions as possible, to the extent of their ability in their given situation. There is a lack of research on performing the set of actions in combination. The following additional research is needed to further develop guidance about this protective action:

- Factors that may influence the decision to DCHO, and the efficacy of different types of cover, including research on when it would be preferable to move in a limited manner to improve cover;
- Definitions of and decision factors for taking different types of cover, such as sturdy furniture, low-lying furniture, using a pillow, or taking personal cover (see "c" below);
- How advanced warning of an earthquake may influence the decision to move within a building, evacuate a building, or DCHO.

Included, below, is a separate evaluation of each of the three DCHO behavioral actions, as well as several modifications that are recommended in scenarios in which people may be unable to fully perform one or more of the three actions.

a. Inside Building: Drop

The "drop" component of this protective action recommends that people drop to the floor on their hands and knees to avoid falling and allow for limited movement to attain or maintain cover. Based on data collected from the Gölcük, Turkey earthquake, researchers concluded that staying in place and sitting down was safer (i.e., resulted in fewer injuries) than taking other actions (Petal, 2009, p. 261). The research does not provide a science base for making decisions about when it would be appropriate to remain still while "dropped", and when it would be preferable to make limited movement to improve cover. Additional research is needed to provide better guidance on situations in which some limited movement to obtain better cover would be a valid option, particularly in the case of EEW.

Recommended

Dropping to the floor inside a building is recommended based on evidence documented in the FEMA protective action validation report (FEMA, 2016, November 15).

b. Take Cover Under Sturdy Furniture

This protective action involves taking cover under a sturdy piece of furniture and using personal cover (see "c" below). Earthquake safety organizations provide examples of sturdy furniture (e.g., a table or desk), although FEMA does not define the term "sturdy." Support for this protective action is based on the well-documented risk associated with being struck by falling objects. Numerous studies have concluded that falling objects are a major source of injury during earthquakes. In the 1999 Kocaeli earthquake, 85% of deaths and injuries were attributable to being struck, caught under, cut or pierced by a falling or fallen object (Petal, 2009, p. 244). Across the Whittier Narrows, Loma Prieta, and Northridge earthquakes in California, non-structural items falling caused more injuries than any other factor (Shoaf et al., 1998, p. 227). Based on the demonstrated risk associated with being struck by falling objects, FEMA considers evidence for this protective action robust/sufficient. However, there is a lack of research on whether taking cover under sturdy furniture is more effective than other options for building collapse.

Recommended

Taking cover under sturdy furniture is recommended based on evidence documented in the FEMA protective action validation report (FEMA, 2016, November 15).

c. Take Personal Cover

This protective action involves taking "personal cover", that is, using one's hands and arms to cover one's head and neck regardless of location, as an alternative when cover under sturdy furniture is not available or accessible. Personal cover is validated by research conducted on multiple hazards where falling, flying, and sliding debris causes deaths and injuries. Findings indicate that moving during shaking to obtain an item for cover could be dangerous and may also support using personal cover for such circumstances. Additional research about factors that may influence the efficacy of personal cover would be helpful. EEW can potentially provide sufficient time for people to find more appropriate cover (e.g., sturdy furniture) before shaking begins.

Recommended

Taking personal cover is recommended as a modification to taking cover under sturdy furniture when better cover is not available based on evidence documented in the FEMA protective action validation report (FEMA, 2016, November 15).

d. Take Cover in Corner/Near Interior Wall

In the absence of sturdy furniture such as a table or desk, individuals can crouch or get on their hands and knees in an inside corner or interior wall, covering their head and neck with their hands and arms. Although the authors of this white paper did not identify research specifically supporting this guidance, FEMA's subject matter experts reported that in typical construction, a corner may be safer because of the protection afforded by two walls as opposed to only one; a corner also may be a sturdier location (FEMA, 2016, November 15). For example, in a corner, objects may fall from fewer directions. Multiple factors should contribute to the decision to move to seek cover, and the protection afforded must be weighed against the potential risks associated with movement during shaking (FEMA, 2016, November 15). FEMA considers evidence for this protective action not robust/conditional (FEMA, 2016, November 15).

Recommended with Caution

The authors of this white paper agree that further research is needed to validate the relative efficacy of, and priority order for, modified types of cover, including taking cover in a corner or next to an interior wall.

e. Take Cover Near Low-Lying Furniture

In the absence of sturdy furniture such as a table or desk, individuals can get down on their hands and knees next to low-lying furniture (e.g., furniture that will not fall on them), covering their head and neck with their hands and arms. Although the authors of this white paper did not identify research specifically supporting this guidance, FEMA's subject matter experts reported that large, low-lying furniture may deflect some falling/flying/sliding objects (FEMA, 2016, November 15). FEMA recommended that this protective action be provided as one of several options for obtaining cover from falling debris (FEMA, 2016, November 15). Multiple factors should contribute to the decision to move to seek cover, and the protection afforded must be weighed against the potential risks associated with movement during shaking. FEMA considers evidence for this protective action not robust/conditional (FEMA, 2016, November 15).

Recommended with Caution

The authors of this white paper agree that further research is needed to validate the relative efficacy of, and priority order for modified types of cover, including taking cover next to low-lying furniture.

f. In Bed: Stay in Bed and Take Personal Cover with Pillow

There is some evidence to support the recommendation to stay in bed if an earthquake strikes at night while sleeping (Mahue-Giangreco et al., 2001, p. 356). The Northridge earthquake struck while many were asleep in bed. Research has shown that in this earthquake, those who remained in bed were less likely to become injured (Shoaf et al., 1998, p. 233). Similar findings were obtained in the 1999 Kocaeli earthquake, where being in bed and asleep was less hazardous than being in bed and awake, and being in bed in either case was less hazardous than standing or sitting still (Petal, 2009, p. 260). In addition, this white paper cites evidence of the risks associated with movement during shaking.

FEMA considers evidence for this protective action robust/sufficient and also suggests protecting one's head and torso with a pillow (FEMA, 2016, November 15). In the Whittier Narrows, Loma Prieta, and Northridge earthquakes, non-structural falling objects caused more injury than any other cause, leading the researchers to recommend taking personal cover with a pillow (Mahue-Giangreco et al., 2001, p. 356).

Recommended

Remaining in bed and taking cover with a pillow is recommended based on evidence documented in the FEMA protective action validation report (FEMA, 2016, November 15).

g. Take Cover in Doorway

Earthquake safety officials commonly encouraged individuals to take cover in doorways prior to 1970, when doorframes in masonry buildings were reinforced with wood (Petal, 2009, p. 78). Even after it became conventional practice to not reinforce doorways, the recommendation persisted. For most buildings, it is impossible to identify reinforced doorways. The relative benefit of standing in a doorway versus not standing in a doorway cannot be generalized across situations involving different types of doorframes (Aroni & Durkin, 1985).

FEMA has sufficient evidence that doorway structural characteristics provide minimal to no protective cover, and do not provide more protection than other locations (FEMA, 2016, November 15; Mahoney, 2014). Only recently have officials excluded the recommendation from public education materials. FEMA recommends that individuals avoid moving to a doorway, given the risk of injury associated with movement. Individuals who move across a room may be struck by falling/flying objects or may not be able to remain standing. Additionally, having multiple people crowded in a doorway may minimize cover and increase the risk of falls.

Not Recommended

Standing in doorways is not recommended. There is evidence that doorway structural characteristics provide minimal or no protective cover, and do not provide more protection than other locations (FEMA, 2016, November 15; Mahoney, 2014). It is important to educate the public about the risks associated with using a doorway for cover.

h. Hold On

“Holding on” to cover (e.g., holding the legs of a sturdy desk or table) can help people maintain cover, either by keeping the shelter from moving or by allowing people to move with the shelter, if necessary. Researchers studying the 2011 Christchurch, NZ earthquake using video recordings of human behavior observed that individuals who held onto something during earthquake shaking did not fall (Lambie et al., 2017, p. 1187). Additionally, there is research that supports guidance to minimize movement and maintain cover from falling objects. Based on this indirect evidence, FEMA has concluded that evidence for this protective action is robust/sufficient (FEMA, 2016, November 15).

Recommended

This guidance is recommended based on indirect evidence documented in the FEMA protective action validation report (FEMA, 2016, November 15).

3. Avoid Elevators. People who are in high rise buildings are currently advised not to enter elevators (Earthquake Country Alliance, 2016; Government of Canada, 2015), and those in elevators are advised to exit as quickly as possible by pressing the buttons for all floors (Government of Canada, 2015). No research was identified specifically focusing on the health effects of earthquakes for people in elevators. Rather, guidance is based on research associated with elevator performance during earthquake shaking, including the effects of shaking on elevators and elevator shafts and the potential risks associated with loss of power (Porter, 2007; Schiff, 1988; Suarez & Singh, 2000).

Recommended

Avoiding elevators is recommended based on concerns about loss of power and physical effects of the earthquake on elevators and elevator shafts.

4. Move to Nearby Safer Area. This guidance considers moving to a nearby safer area as quickly and as safely as possible (GeoHazards International, 2015b, p. 44), when remaining in the area may pose even greater risk to individuals than the dangers associated with movement to a different location. “Safer area” refers to a different, but close location such as a nearby room. This protective action can apply to situations in a kitchen or laboratory where hazards such as chemicals, glassware, ceramics, and open flames may exist. It also may apply to individuals in a downtown area, where individuals on a sidewalk or near buildings may be at risk of being struck by falling brick, glass, or other objects, with no opportunity for cover. It such cases, it may be safest to move quickly to the lobby of a nearby building (GeoHazards International, 2015b; Washington State Department of Health, 2016).

This protective action is controversial. There is risk of injury involved in remaining in a dangerous location with combustible items, open flames, and glass. There also is risk associated with moving during ground shaking, especially from falling objects when moving into or out of a building (Ardagh et al., 2012; Johnston et al., 2014; Peek-Asa et al., 1998; Petal, 2009; Petal, 2011; Shoaf et al., 1998; Spence & So, 2009). However, EEW may provide sufficient time to allow people in hazardous situations to get to safety before shaking begins. This possibility is a critical research priority.

ShakeAlert messages currently do not provide information about the amount of time until the arrival of ground motion, but it may in the future. Until such time, the safest way to help the public navigate these risks is to teach earthquake safety principles and situational awareness, and to provide training opportunities, so people can make informed decisions in such situations. For this protective action, it is crucial that individuals have situational awareness of: (1) risks associated with their present location, (2) other nearby locations that may be safer than their current location, and (3) the amount of time until the arrival of strong ground motion. The GHI report suggested that, “In jurisdictions very comfortable with relying on individuals’ situational awareness, judgment, and preparedness measures, message content might simply be, *wherever you go, find the safest place you could reach in five seconds after shaking starts* (GeoHazards International, 2015b, p. 44).”

Recommended with Caution

The authors of this white paper note the need to teach members of the public how to assess the safety of their location, especially when located in laboratories, kitchens, and outdoors in downtown areas near buildings. The extra seconds afforded by EEW may allow people who are located in such areas with minimal cover and many objects overhead that could potentially fall to move to safer locations. Teaching the public about general principles of earthquake safety and situational awareness is crucial in helping people decide what action to take after receipt of an EEW message. Additional research is needed to continue to evaluate this protective action.

a. Kitchen or Laboratory: Extinguish open Flames.

This protective action applies to situations in a kitchen or laboratory where flames may be burning (GeoHazards International, 2015b, p. 49; The Caribbean Disaster Emergency Management Agency, nd). Guidance is based on the fact that fire is one of the most deadly secondary disasters that can follow an earthquake, with severe shaking toppling stoves and other items that can ignite nearby objects (Noji, 1997, p. 149). Once again, awareness of potential threats in one's surroundings during an earthquake is important, and earthquake safety educators should emphasize the dangers posed by earthquake-induced fire.

Recommended
This protective action is recommended based on the dangers associated with fires following earthquakes. Research is recommended to evaluate guidance based on earthquake early warning.

5. Adobe Building with Heavy Roof / Non-Ductile Concrete Building: Evacuate. This protective action to "move outdoors" is directed towards individuals located in adobe buildings with heavy roofs and in non-ductile concrete buildings, which are more prone to collapse when an earthquake strikes (Coburn, Pomonis, & Sakai, 1989, p. 114; Mahoney, 2014; Noji, 1997, p. 151). FEMA subject matter experts reported that adobe buildings with heavy roofs make up a relatively small proportion of U.S. buildings (FEMA, 2016, November 15), and as discussed previously, there is substantial evidence that moving in or out of buildings during earthquake shaking bears increased risk of death and injury (see Protective Action #1).

There is international evidence supporting evacuation during earthquakes from buildings with relatively weaker constructions. In the 1988 Armenia earthquake, leaving a building after the first earthquake shock was protective; the odds of being injured were more than four times greater for those who remained indoors compared to those who ran outside (Armenian, Noji, & Oganesian, 1992, p. 254). In the 1976 Guatemala earthquake, adobe homes were the most lethal (Lechat, 1989, July). In the Gölcük, Turkey earthquake, the likelihood of death was 11 times higher for those who stayed in place compared with those able to run out of the building (Dedeoglu, Erengin, & Pala, 2000, pp. 2-9). Research in Armenia found that the odds of having injuries were 3.6 times larger for individuals in buildings with five or more floors compared with those in buildings with fewer than five floors, and that exiting buildings after the first earthquake shock was protective (Armenian et al., 1992, p. 251). This led to adjusted messages involving the immediate exit of such buildings: "After the Armenian earthquake, investigators suggested that communities with heavy concrete buildings prone to collapse adopt behavioral modification methods to teach people to escape when an earthquake occurs" (Ramirez & Peek-Asa, 2005, p. 50).

Not Recommended

FEMA considers the evidence for this protective action robust/conditional; however, FEMA does not recommend providing guidance about this action because there is a lack of systematic research on when it is safe to evacuate a building and because the guidance does not apply to most buildings in the U.S. (FEMA, 2016, November 15). To provide more complete guidance and to reevaluate this protective action in light of EEW, additional research is needed examining:

- Factors (including amount of time) necessary for individuals to exit a variety of common building types and building heights in the context of having only 10-60 seconds of warning.
- Inventory of the number and percentage of adobe/mud-brick buildings with heavy roofs located in earthquake hazard areas in the U.S.
- Inventory of the number non-ductile concrete buildings built prior to 1975 and located in earthquake hazard areas in the U.S.
- Factors determining when exiting buildings would reduce death and injury.

6. Unreinforced Masonry Building: Evacuate. This protective action to “exit the building” is directed towards individuals located on the ground floor of an unreinforced masonry building (URM), which is more prone to collapse when an earthquake strikes. URM buildings are prevalent throughout earthquake-prone regions of the central U.S., and most lack any degree of earthquake retrofit (Frankie, Gencturk, & Elnashai, 2012, pp. 400-401; Noji, 1997, p. 151). FEMA considers the evidence for this protective action insufficient. There is a lack of systematic research on when it is or is not safe to move or evacuate a building (FEMA, 2016, November 15), and researchers have not evaluated how quickly individuals can exit a building with 10-60 seconds of warning.

The evidence for this protective action is mixed. In countries where most structures are at risk of catastrophic collapse (e.g., in Armenia), running outside at the first evidence of earthquake may represent the “only chance of survival” (Armenian et al., 1992, p. 254). The number of floors matters. Research in Armenia found that the odds of sustaining injury were 3.6 times larger for individuals in a building with five or more floors compared with those in buildings with fewer floors. The same research found that exiting buildings after the first shock was protective (Armenian et al., 1992, p. 251). Among seven villages studied following the 1980 earthquake in Southern Italy, all cases of the death and injury occurring within the first two days following the earthquake were associated with the collapse of houses; the ability to escape being indoors was critical for survival and depended on building type (De Bruycker et al., 1985, p. 116). In Challis, Idaho, the only two earthquake-related fatalities that occurred were due to the collapse of an unretrofitted, unreinforced brick building (Applied Technology Council, 2009).

However, in the 1999 Kocaeli earthquake, evacuating URM buildings during shaking appeared to result in higher risk of injury (Petal, 2009, p. 117). In the 1976 Friuli Italy earthquake, more mobile individuals in the town of Venzone were at greater risk than those less agile, such as the elderly and very young, because they were able to run out into the narrow streets, where they were crushed by falling masonry (Armenian et al., 1992, p. 254; Hogg, 1980, pp. 176-177). Similarly, the 1970 Peru earthquake, in Callejon de Huaylas, those who evacuated immediately in response to initial tremors were then buried by rubble filling the narrow streets (Armenian et al., 1992, p. 254). Retrofitting is the primary approach for reducing seismic risk in URMs (Applied Technology Council, 2009).

Not Recommended

FEMA considers the evidence for evacuating unreinforced masonry buildings insufficient, and recommends not providing such guidance (FEMA, 2016, November 15). The FEMA report notes that there is insufficient research on developing appropriate public messaging around evacuating from URM buildings. The following additional research is needed to establish the efficacy of this protective action and to provide more complete guidance:

- Determine amount of time and other factors necessary for individuals to exit a variety of common building types and building heights with 10-60 seconds of warning.
- Develop an inventory of the number of URM buildings located in earthquake hazard areas in the U.S.
- Validate factors that may determine when exiting URM buildings would reduce death and injury.

7. "Triangle of Life." This recommendation is based on the notion that before a building completely collapses in an earthquake, individuals should identify locations that are likely to create a void or safe space (i.e., life-protecting triangle). In the U.S., buildings typically do not collapse in this manner, nor is it reliably possible – even with advance warning of an earthquake – to identify the location of a structural void prior to a building's collapse. These issues undermine the premise of this protective action. In addition, attempting to move during shaking bears its own risks, as discussed above. Rather than instructing individuals to move during earthquake shaking, experts recommend focusing on actions to protect oneself from injury from falls and falling objects, for which there is evidence. Earthquake Country Alliance, a public-private partnership of people, organizations, and regional alliances that work together to improve earthquake preparedness, mitigation and resiliency, provides instructions for responding to questions and concerns about the "Triangle of Life" (Earthquake Country Alliance, 2017a). FEMA agrees that there is no scientific evidence supporting this action (FEMA, 2016, November 15, pp. EQ-21). The GHI report notes there is no evidence that, "ordinary building contents create survivable, triangular shaped voids next to them during building collapses, except possibly in buildings with lightweight floors and roofs and which contain large and sturdy contents" (GeoHazards International, 2015b, p. 19).

Not Recommended

FEMA considers the evidence for the "Triangle of Life" insufficient (FEMA, 2016, November 15).

Outdoor Locations

This section reviews two earthquake scenarios: being outside and driving in a vehicle.

8. Stay Outdoors. This protective action instructs people who are outdoors when an earthquake strikes to stay outdoors and refrain from entering a building. In addition to the threat of death or injury from objects falling while entering a building and the less common but more lethal threat of building collapse, multiple studies provide evidence supporting this recommendation given that attempting to move during shaking results in injury related to falls and falling objects (Johnston et al., 2014, p. 628; Petal, 2009, p. 459).

However, some earthquake safety organizations recommend that people in a downtown area, such as on a sidewalk near a tall building, move to a lobby or doorway for protection (Washington State Department of Health, 2016). This guidance assumes that a building's doorway or lobby may provide at least some level of, admittedly minimal, protection from falling bricks, glass, and other objects, which pose significant risk of injury. This guidance, however, contradicts current messaging that warns against using doorways for protection (see Protective Action #2g). It also contradicts current messaging that warns against crossing through building doorways during shaking (see Protective Action #1). Exiting and entering buildings during an earthquake is dangerous because of risks associated with falling and with being struck by falling objects (e.g., from the roof, building exterior, etc.).

As noted throughout this white paper, for this protective action, it is crucial that individuals have situational awareness of: (1) the risks associated with their current location, (2) other locations that may be safer than their current location, and (3) the amount of time until the arrival of strong ground motion (GeoHazards International, 2015b, p. 44). It should be noted that current ShakeAlert technology does not anticipate providing this level of detail initially to the public, although the capability may be available in the future.

Recommended with Caution

FEMA considers the evidence for staying outdoors robust/sufficient (FEMA, 2016, November 15). Although the guidance may be appropriate in most EEW situations, the authors of this white paper note the need to teach members of the public how to assess the safety of their location, especially when located outdoors in downtown areas near buildings. The extra seconds afforded by EEW may allow people who are located in downtown areas with minimal cover and many objects overhead that could potentially fall, to move to safer locations. Situational awareness is crucial in deciding what action to take after receipt of an EEW message. Additional research is needed to continue to evaluate this protective action, including an assessment of the hazards and risks associated with downtown areas.

9. Vehicle: Pull Over and Stay in Vehicle. This protective action encourages individuals in a moving vehicle to pull over to a safe location and stay in their vehicle when an earthquake strikes. A safe location may be defined as clear from poles, overhead wires, bridges/overpasses, trees, and other such hazards. If a power line falls on the car, occupants should stay inside until a trained person removes the wire.

Research has found that during the Northridge earthquake, uncontrolled traffic and drivers who over-corrected in an attempt to navigate during shaking led to multiple deaths involving moving vehicles (Petal, 2009, pp. 461-462) and that damage to transportation infrastructure such as nonfunctioning traffic signals and road lighting were associated with fatal vehicle crashes (Ramirez & Peek-Asa, 2005, pp. 50-51). In a study using driving simulators to evaluate drivers' reactions during seismic motion, driver over-correction and delayed driver response time caused drivers to inadvertently maneuver their vehicles into adjacent traffic lanes (Maruyama & Yamazaki, 2004, p. 775). According to FEMA, evidence for this protective action is considered robust/sufficient (FEMA, 2016, November 15).

Recommended

According to FEMA, evidence for pulling over and staying in a vehicle is considered robust/sufficient (FEMA, 2016, November 15).

Coastal/Tsunami Areas

This set of protective actions is relevant for individuals who are near the coastline or in an area at risk for tsunami when an earthquake strikes.

10. Protect Yourself from the Earthquake. This protective action is for individuals in a coastal area who feel an earthquake. They are instructed to follow directions for self-protection during earthquake shaking (e.g., DCHO). To avoid lethal consequence of a potential tsunami, those in tsunami risk areas should stop earthquake self-protection and begin moving to higher ground or inland as soon as they are able to move safely. (See Protective Action #11, below.)

Recommended
According to FEMA, evidence in support of protecting oneself from earthquake-related injury is considered robust/sufficient (FEMA, 2016, November 15).

11. Move to Higher Ground or Inland (Evacuate). Tsunami can cause significant death, injury, and damage, which can potentially exceed that from the initial earthquake (Marano, Wald, & Allen, 2010; USGS, 2007). The protective action involves moving inland or to higher ground when an earthquake occurs, to prevent death or injury from a potential tsunami.

This protective action has involved some controversy. Previously, it was believed that people should begin moving to higher ground following an earthquake when the ground stopped shaking, and they should then listen for official guidance about evacuation. The FEMA report recommends that earthquake safety educators should consider communicating when to move to higher ground in coastal areas (p. EQ-24): "If you are near the coast, know the tsunami risk for your area. If you are in an area that may experience tsunamis, <u>when the shaking stops</u>, walk inland or head for higher ground immediately and listen for more information on the areas tsunami evacuation plans." In the State of Washington, this guidance is communicated in the following manner: "As soon as you feel it is safe, move immediately to higher ground or inland. Do not return until directed to do so. Tune to local media for additional information after you move to higher ground or inland."

FEMA subject matter experts advised against providing any guidance that implies self-evacuation by vehicle based on the amount of time shaking occurs. Rather, messaging should explicitly indicate walking briskly to get to high ground.

Unfortunately, there is no research that specifically addresses the issue of timing the separate protective actions for earthquake and tsunami. Former guidance instructed individuals to wait until the ground stops shaking to move to higher ground based on the previously noted risks associated with movement or attempted movement during ground motion.

Research has shown the critical importance of beginning tsunami evacuation as soon as possible, and suggests that significant life safety may be provided by early onset of tsunami protective action (Wood, Jones, Schmidtlein, Schelling, & Frazier, 2016). In contrast to prior guidance, the Earthquake Country Alliance has adjusted their own messaging, and now recommends that people who are near the coast and feel the ground move, DCHO immediately, and then move to higher ground *as soon as they are able to move*, rather than waiting until <u>all</u>

shaking stops, which could be several minutes in a very large earthquake, reducing the time available to get to a safer location (Earthquake Country Alliance, 2017d).

Given these considerations, advising individuals to begin moving to higher ground (or vertical evacuation to an upper floor of a tall, fortified structure) upon receipt of EEW, especially for potential alerts of the future, that could provide a relatively large window of warning (e.g., minutes), with instructions to protect oneself from the earthquake when shaking begins (e.g., DCHO), may provide life-saving lead time for a potential tsunami. Such guidance has not been tested, however, and the ramifications are unclear at present. Future research should seek to clarify this issue. Additionally, the FEMA report recommended future research to help clarify any difference in the public's understanding of the terms: "evacuating to higher ground", "moving to higher ground", and "evacuation" (in vehicles), and furthermore, should examine factors that may potentially support or advise against waiting for official evacuation direction.

Recommended with Caution

The FEMA report evaluated the evidence for protecting oneself from the earthquake until shaking stops before moving to high ground as not robust/conditional based on a lack of scientific evidence validating a specific timeframe for initiating tsunami protective action (FEMA, 2016, November 15). The FEMA report recommends messaging to convey when to move to higher ground when on the coast. Earthquake Country Alliance has revised its guidance associated with this protective action to instruct people to DCHO, and then move to higher ground *as soon as they are able to move safely* (rather than wait for shaking to stop). The State of Washington provides similar guidance. EEW may provide opportunity to move to higher ground prior to earthquake shaking. Future research on the issues surrounding this protective action is critical.

12. Move to Upper Floors (Vertical Evacuation). The FEMA report recommends first protecting oneself from earthquake shaking (e.g., getting into the DCHO position or taking other protective action) before taking specific actions to protect oneself from the tsunami. The report then recommends tsunami vertical evacuation—moving to the upper levels of a tall, fortified structure to minimize hazard exposure—for people in coastal areas when naturally occurring high ground outside the tsunami inundation zone is too far away to get to in time, or when there is insufficient warning time for community evacuation. Vertical evacuation to upper levels of structures that can resist the effects of a tsunami is a recommended alternative (Chock, 2016; Fraser, Leonard, Murakami, & Matsuo, 2012, p. 446; United States Department of Homeland Security, 2009, p. 1). The FEMA report suggests waiting until earthquake shaking has stopped, however some emergency managers advise people to take protective actions from the tsunami as soon as it is safe to do so.

The FEMA report further recommends that education efforts inform the public that some vertical evacuation structures are marked with the symbol of a cresting blue wave. The authors note, however, that very few buildings have been properly assessed to see if they would withstand a tsunami and universal tsunami signage for buildings in the U.S. does not yet exist.

Recommended

FEMA considers the evidence for vertical evacuation sufficient when shaking has stopped (or it is safe to move) and it is not possible to reach higher ground (FEMA, 2016, November 15). Future research is necessary to guide earthquake safety education about the risks associated with movement before earthquake shaking begins so that people can make informed decisions based on their individual circumstance, particularly if newer technology accurately and reliably communicates the amount of time remaining until shaking begins.

13. Boat on the Water: Remain at Sea. People who are in a boat on the water when they receive an EEW message should *not* return to port if at sea and a tsunami warning has been issued. Instead, they should remain at sea in a depth of at least 30 fathoms for distant earthquakes, and 100 fathoms for local earthquakes (United Nations Education). Boaters should face watercraft headlong into the direction of the tsunami swell and head further out to sea. Boats in the harbor should only be taken offshore if: (1) the local authority permits it, (2) there is sufficient time to get to deep enough water, and (3) there are supplies on hand to remain at sea for two or more days. If the tsunami is large and damaging, it may not be possible to return to one's home harbor or to other nearby harbors (Lynett, Borrero, Son, Wilson, & Miller, 2014, p. 2048; Lynett et al., 2012, p. 68; United Nations Education). [1]

Recommended

According to FEMA, evidence for this protective action is considered robust/sufficient (FEMA, 2016, November 15).

14. Trapped/Caught in Water: Grab Object to Stay Afloat. This protective action involves grabbing onto something that floats; people who are swept up by a tsunami should look for something to use as a raft (Atwater, 1999, p. 14). There is no scientific evidence for the efficacy of this guidance. In addition, research is needed to provide more detailed guidance about how to best perform this behavior.

Recommended with Caution

According to FEMA, the evidence is considered not robust/conditional; however, considering the dire circumstance and lack of alternative recommendation, it seems advisable to recommend this action. Research, including survivor research, is recommended to provide evidence and more detailed guidance for performing this protective action (FEMA, 2016, November 15).

[1] The descriptive label that was used in the FEMA protective action validation report to identify this protective action has been changed from "head out to sea" to "remain at sea" for use in this white paper, as the revision appears to better reflect the totality of guidance recommended in this scenario.

Protective Actions for Individuals with Access and Functional Needs

Guidance provided by earthquake safety organizations identified additional protective actions that have been recommended specifically for individuals with DAFN. A brief description of each follows.

15. In a Walker or Wheelchair: Lock Wheels, Take Cover, and Hold On. This protective action applies to those who use wheel chairs and walkers (Earthquake Country Alliance, 2016, 2017b, 2017c), and may apply to those using other devices with wheels, such as scooters. The protective action is not systematically documented and is based on prior research highlighting the importance avoiding movement and falling (Johnston et al., 2014, p. 628; Peek-Asa et al., 1998, pp. 462, 464; Petal, 2009, p. 261; Shoaf et al., 1998, p. 132).

Recommended
This protective action is recommended based on professional practice, logic, and on indirect evidence presented in the FEMA report (FEMA, 2016, November 15).

16. Using a Cane: DCHO or Sit on Bed/Chair, Take Cover, and Keep Cane Nearby. This protective action is meant for individuals who use a cane (Earthquake Country Alliance, 2017b). The action can provide stability for people who use canes, thereby helping them to avoid falling and becoming injured. It is a reminder to maintain contact with one's cane to avoid greater potential loss of mobility. Although research on this specific topic was not identified, the recommendation is based on logic and "common sense" that indicates the importance of avoiding fall-related injury and maintaining the ability to move.

Recommended
This protective action is recommended based on professional practice and common sense that underlines the importance of avoiding falling and becoming injured, and of maintaining access to one's cane to avoid restricted movement.

17. Using Service Animals: Protect Self; Do not Restrain Animals. This guidance is directed towards people with service animals and pets (ShakeOut BC, nd). The primary guidance is to protect oneself first. People are encouraged to hold animals when possible, but not to restrain those who resist so the animals can find safety on their own. Earthquake safety organization recommend that animals in crates should be left inside for protection. After the shaking stops, people are also encouraged to carefully look for animals that have sought protection, being aware of dangers associated with broken glass and other debris. No research studying this situation was identified; guidance has been based on professional practice and logic (ShakeOut BC, nd).

Recommended
This protective action is recommended based on professional practice, logic, and on indirect evidence presented in the FEMA report (FEMA, 2016, November 15).

DISCUSSION

This report examines existing earthquake and tsunami protective action guidance designed for use by members of the public when the ground begins to shake, as such guidance may apply in an EEW context. Specifically, the authors considered the earthquake and tsunami protective action guidance in light of how appropriate it may be when members of the public receive an EEW alert and there is time available to take action before shaking begins.

Future EEW technology and messages may be able to communicate to users the number of seconds remaining before shaking will arrive and how strong the shaking could be. Until such time, EEW messages and education and training of the public about EEW must contend with how to best empower individuals to make calculated decisions to protect their safety based on incomplete information. Existing research on earthquake health effects indicates that context matters a great deal. Our review of existing guidance for different scenarios underscores that there is no single message that is accurate and appropriate for every situation.

Although the body of literature conducted to date on the efficacy of earthquake protective actions is useful, there are a number of methodological challenges to understanding behavioral responses to earthquakes. As with all self-reported data, there are potential sources of bias (e.g., recall, response, etc.). In addition, the language used in the various questionnaires collecting self-reported survey data about post-event behavior is somewhat inconstant and, in some cases, vague (Lambie et al., 2016). The variety of study designs and methods used, as well as geographic and situational contexts, make it difficult to make meaningful comparisons across studies. Moreover, while some research suggests general compliance with local guidance, other research draws the opposite conclusion, with a wide range of different behaviors performed across events. Earthquake safety organizations should be aware of the relationship between recommended guidance and actual behavior at the local level, as much can be learned from developing a greater understanding of what people actually do. Education and training about protective actions can be more effective when they relate to real-world, locally-relevant scenarios. Finally, this body of literature examines behavior once shaking begins and does not focus explicitly on behavior following EEW, before the ground begins to move.

Implications

In prioritizing protective actions recommended to the public before and during shaking, earthquake safety organizations must consider: (1) what general actions will lead to the greatest chance of survival for the most people when there is an unknown amount of time available to act, and (2) the likelihood that individuals will be able to perform those actions based on the situational characteristics. It is impossible for message providers to recommend the right protective action for every individual, every time. Instead, officials can take one of two approaches: (1) share responsibility for determining the most effective protective action with members of the public by empowering individuals with the knowledge necessary to assess and respond to their own personal situations; or (2) provide instruction on and recommend the most commonly successful protective action(s) before or during shaking to everyone, regardless of context.

At a minimum, earthquake safety organizations should educate and train the public to DCHO, given that researchers recommend getting low to the floor, covering oneself, and holding onto a sturdy object for the majority of (but not all) scenarios. This combination of protective actions, designed to reduce the risk of falling and being struck by falling objects, may not be intuitive for all individuals (Lambie et al., 2017). And, although the DCHO guidance sounds simple, performing the complete set of actions may be more complicated than the instruction implies. The "cover" action may include covering oneself under sturdy furniture, with a pillow, near low-lying furniture, or with one's arms. "Dropping" next to a tall bookshelf, for example, is likely to be less safe than crouching next to a bare wall. "Hold on" may be more effective when the individual moves with the object and when the object is as sturdy as possible.

The authors of this report recommend that earthquake safety organizations educate and train the public about general principles of earthquake safety (e.g., getting low to the ground reduces the likelihood of falling down, making oneself "small" reduces the likelihood of being struck by falling objects, turning off flames reduces the likelihood of starting a gas fire) as well as the importance of relying on situational awareness. ShakeAlert messages are limited by current technology—it is not currently possible to deliver personalized messages to the public based on the anticipated intensity of shaking or time until impact. And, generic messages provide incomplete information. Earthquake safety experts should train individuals to identify and quickly assess the unique risks around them in the event of an earthquake, and to take the actions most appropriate for their circumstances. The current technical limitations of ShakeAlert underscore the importance of providing scenario-based education and training on earthquake and tsunami protective actions.

FEMA has provided the following guidance as an example of how to promote situational awareness (FEMA, 2016, November 15, p. EQ16). These instructions require individuals to have a sense of the risks associated with their surroundings:

> *DROP down to the floor on your hands and knees. This position protects you from falling and provides some protection for vital organs. This position also allows you to crawl a short distance to the closest cover to get away from falling/flying/sliding debris or to better cover. There are multiple factors affecting the advisability of attempting to move, even by crawling, to seek better cover, including: (1) your ability to move given the intensity of the shaking, (2) the extent of falling/flying/sliding debris where you are, in the path you would need to take to other cover, and (3) how close you are to significantly better cover.*

Helping members of the public develop situational awareness is undoubtedly a challenge. Without regular, consistent practice via drills and other exercises, one cannot assume that people will implement the protective actions they previously learned about, when an actual earthquake strikes (Lambie et al., 2017). It is likely that substantial public education and risk communication about earthquake protective actions before an earthquake alert is issued will greatly increase alert efficacy (Wood et al., 2017).

Recommendations

This white paper includes the following recommendations:

1. EEW-related protective action information should be organized and presented in ways that distinguish the actions that should be taken in various situations and locational contexts.

2. EEW-related protective action information campaigns and other related programs should address the importance of situational awareness and communicate general earthquake safety concepts that can be applied in unanticipated situations and locations.
3. Conduct effective, easy to follow protective action outreach, education, and training in the form of public messaging and drills.
4. Earthquake drills should incorporate a variety of EEW-relevant scenarios and should help participants practice situational awareness.
5. This white paper should be updated when the public comment FEMA report is finalized.
6. There are many unstudied settings where individuals may find themselves when earthquakes occur (e.g., stairwells, subway stations, etc.). Research should be conducted on additional potential settings and scenarios.
7. This white paper should be updated as social science research is conducted addressing future EEW-related needs.
8. Research on protective actions for people with DAFN, as it relates to EEW, should be incorporated into public information campaigns and other earthquake safety efforts.
9. Research on what people actually do during an earthquake should be used to help design and refine existing and future protective action information campaigns and other programs for EEW. Findings should be compared to research results conducted using similar methods in countries that have implemented EEW.
10. EEW messaging should include information on how to respond to tsunamis, if tsunami is a possible secondary hazard.

Future Research

Several earthquake and tsunami protective actions have not been studied rigorously (FEMA, 2016, November 15). This includes guidance provided to individuals with disabilities or access and functional needs. Future research should attempt to fill these gaps. In addition, existing research examining protective actions taken in response to the onset of earthquake shaking should be studied under EEW conditions, when warning is provided and there is time to take action before shaking begins. In particular, future research should examine the risks and benefits of movement to a safer location within and out of buildings, and situations in which the risks associated with movement outweigh the risks of remaining in a potentially hazardous location (e.g., labs, kitchens, glass rooms, congested downtown sidewalk areas, etc.). Effective strategies for communicating basic earthquake safety principles (e.g., Drop, Cover, Hold On; making oneself as small as possible to reduce target size, etc.) should be examined, as should the relative efficacy of various DCHO modifications (e.g., taking cover under sturdy furniture, under a pillow, near low-lying furniture, and using personal cover). Such research also could examine the role situational awareness plays in how people respond to receipt of ShakeAlert messages. Additional topics are outlined in the FEMA protective action report (FEMA, 2016, November 15).

Program evaluation research for ShakeAlert also is needed. ShakeAlert developers and emergency managers should work with researchers to develop criteria and methods for collecting information on and assessing the efficacy of EEW, as noted in the Pacific Northwest

Strategy for EEW Outreach, Education, and Training (Nusura, Cascadia Region Earthquake Workgroup (CREW), Oregon Office of Emergency Management, & State of Washington Emergency Management Division, 2018, January). Ideally, this would include formative evaluation to help refine messaging, formative evaluation; to assess the quality and implementation of ShakeAlert and its related education and training activities, process evaluation; and to examine the extent to which ShakeAlert influences people to take more or better protective actions, outcome evaluation.

This white paper, limited by existing research, draws conclusions based on research that includes convenience samples and self-reported survey data. Although these approaches may be useful for guiding initial efforts on EEW training and education, more rigorous research should be conducted on the protective actions individuals with advance notice have or have not taken, and how those actions have reduced the earthquake's impact. In general, stronger study designs can improve the validity of earthquake protective action research. Population-based and longitudinal research designs can help increase scientific rigor and validity of research examining behavioral response to EEW. Multi-method research designs that examine behavioral response to EEW can help improve understanding about why people in a given event chose the particular actions they performed.

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