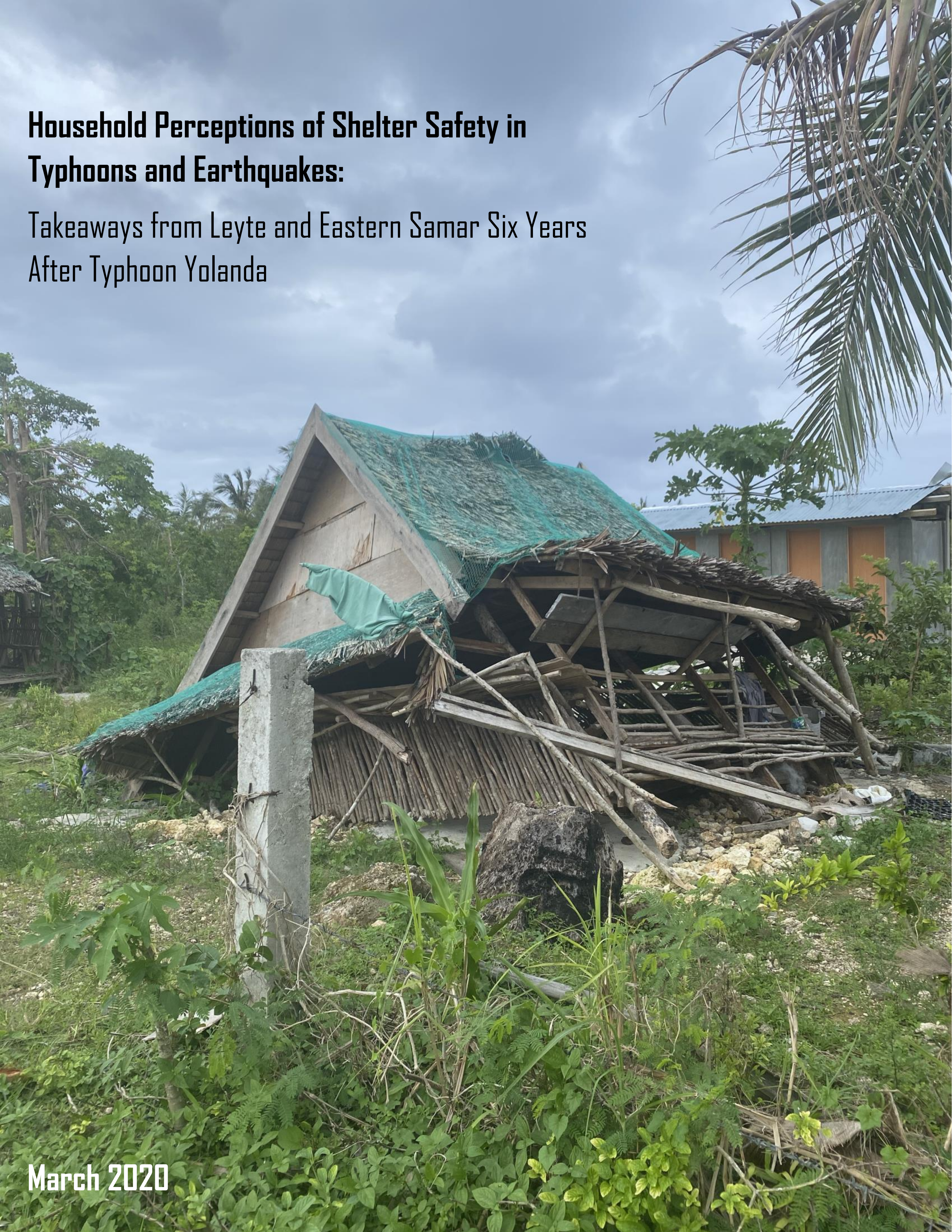
Household Perceptions of Shelter Safety in Typhoons and Earthquakes:

Takeaways from Leyte and Eastern Samar Six Years After Typhoon Yolanda



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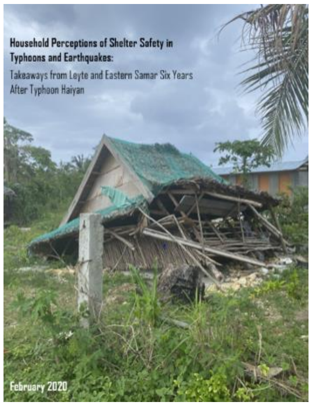

Cover

A shelter in Eastern Samar which collapsed during
Typhoon Ursula in December 2019.

Photo by Abbie Liel

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Executive Summary

Improving shelter safety is an important goal of post-disaster shelter reconstruction programs. Shelter safety depends on both the initial design and construction of the shelter and on the maintenance and modifications made by the household over the shelter's lifespan. Thus, both designers' and households' knowledge and perceptions of safety influence the achieved safety.

With the long-term goal of improving shelter safety, we conducted research in Leyte and Eastern Samar in the Philippines to (1) characterize household perceptions of shelter safety through survey administration and statistical analysis, (2) assess structural performance of shelters in future hazards through engineering assessments, and (3) understand alignments and differences between household perceptions and engineering assessments through interviews and qualitative analysis. **Overall, while we found that households' perceptions of which shelter components were safe or vulnerable generally aligned with engineering assessments, households often did not fully understand how components worked together as a shelter system and, thus planned to modify their shelters in ways that could make their shelter more susceptible to damage in hazards.** We recommend that shelter practitioners include additional training and education on shelter as a system and how design choices influence shelter safety in future shelter programming.

- Impact of planned modifications: Households reported a number of planned modifications. Often the modifications households planned to make to their shelters either 1) could increase the likelihood of damage to their shelter, 2) would likely not be the most effective in making their shelter safer or 3) could make shelter safer in one hazard but more vulnerable in another. The most common planned modifications and their impact are shown below.

Planned Modification	Reasoning	Impact
Strengthening the roof truss system	Concerned with coconut lumber in the truss	Likely not as effective in improving roof safety as improving the attachment of the roof covering
Strengthening roof system connections	Improve the safety of the roof	Over-strengthening the roof compared to the walls could lead to wall failure and collapse
Replacing amakan walls with a stronger material	Improve the strength and durability of the wall panels	Strengthening the wall panels without strengthening the connections in the wall frame could lead to wall failure
Extending the eaves of the roof	Protect against rain/water intrusion	Could increase the likelihood of roof damage from wind

- Importance of materials: The material used in a shelter's main structural system had a considerable effect on whether households perceived their shelter to be safe. Concrete was desired due to its strength in typhoons and its durability. The use of coconut lumber negatively influenced how safe households perceived wooden shelters to be, for the coconut lumber in these shelters had often deteriorated due to moisture and insects. Although nearly all roof systems used similar designs and were constructed with coconut lumber, households in shelters with concrete frames perceived their roofs to be safer than those in shelters with wooden frames.

- Influence of hazard type: Most households desired a shelter that was safer in a typhoon but perceived their shelter to be less safe in typhoons than earthquakes. Households described what they would do in different hazard events, indicating that they intended to escape their shelter in an earthquake, but needed a place to stay that could protect them from the elements for a long period of time in a typhoon. This reasoning influenced their preference for a concrete house.

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Introduction

A common goal of today's post-disaster shelter responses is to 'Build Back Better' (Clinton 2006), or to rebuild in a way that facilitates safer shelter and enhances the capacity of communities to build and maintain shelters that are safer than what existed before. Long-term shelter safety depends on the latter, for how a household modifies and interacts with their shelter over its lifespan affects its ability to safely resist different future hazards. Furthermore, as international nongovernmental organizations (INGOs) are only able to provide assistance to a small fraction of affected households (estimates range between 10-30%) (Parrack et al. 2014), enabling households to construct safe shelters on their own is crucially important. To build this capacity, a majority of shelter programs employ some combination of training, education, and participation.

Shelter programming recognizes the importance of sharing knowledge of safe design and construction practices to enable communities and households to build safe shelter. While a lack of knowledge or resources may limit the capacity to create safe shelter, socio-cultural values and understandings of what is safe may also be at odds with engineering best practices. In this project, we recognize that households often have different perceptions about shelter than practitioners, and as a result, we seek to understand what households perceive as safe, how these perceptions might differ from engineering best judgment, and most importantly, why households have these perceptions.

Previous research has shown that perceptions of safety are influenced by prior experience and feelings of worry and dread about those prior experiences (Miceli et al. 2008; Slovic et al. 2004). It has also been shown that, when drawing from prior experience, prevailing perceptions of safety can differ from engineering knowledge. For example, in Haiti, prior to the 2010 earthquake, the most worrisome and relevant hazard for most people were hurricanes, as there had been four damaging storms in the 2008 season, and there had not been a considerable earthquake on the island for more than century despite the presence of active faults. Thus, households perceived heavier houses constructed out of concrete and masonry to be safe because these types of houses had proven to be safe in the strong winds of the frequent hurricanes (Marshall et al. 2011; Mix et al. 2011). This perception, along with poor construction practices, then contributed to catastrophic damage when an earthquake did occur.

While the example from Haiti is extreme, perceptions of risk have repeatedly been shown to influence actions households take to mitigate risk (e.g., Thistlethwaite et al. 2018). When households perceive their location to be safe and they are less worried about hazards, then they are less likely to take mitigating actions. However, when they believe they are unsafe and are, thus, more worried about the consequences of a hazard event, they are more likely to take action (Paton et al. 2000). These actions, in turn, have consequences for the safety of a structure. Yet not all household actions intended to mitigate risk do. For example, two case studies in Turkey found that when households perceived their home to be unsafe, they took actions which resulted in households being less safe. In one instance, due to cracks in the walls, households did not believe their concrete apartment building was safe (the cracks were in the plaster and superficial, and the building was safe), so they abandoned the structure and had to search for shelter elsewhere (Sucuoğlu 2013). In another study, households did not trust local engineers because of corruption and did not believe that what they were building was safe, so they relied instead on family and friends for construction, resulting in houses which were much more vulnerable to earthquake damage (Green 2008). **Perceptions of safe housing and construction influence mitigating actions but may not actually lead to achieved mitigation.**

We hypothesize that households that receive shelter assistance hold deeply engrained perceptions of what is and is not safe. These perceptions impact whether households maintain or modify their homes and how they choose to do so. The results of these household choices determine shelter safety over time and in future hazard events. Shelter programs that recognize communities' existing beliefs are therefore more likely to support "building back better." Through this research we characterize current perceptions of safety, factors affecting these perceptions, and the implications of these perceptions. **By identifying where specific perceptions differ from engineering assessments, we are able to highlight where shelter program interventions would be most beneficial.**

What does 'safe' mean?

In this study we define 'safe' as a state where a shelter "will not fail under foreseeable demands, leading to loss of life [or] injury" (Elms 1999 p. 313). The foreseeable demands of interest are typhoons with wind speeds ranging from 30 – 230 mph and a moderate earthquake (M_w =6.5). We are concerned with components of a shelter that, if damaged, can injure people. For example, roof failure can lead to roof components falling on individuals. Wall and foundation failure can lead to shelters collapsing on families inside a home. Thus, in this project, damage to foundations, walls, roof structure, and/or roof panels in a hazard event equates to a lack of safety. While we recognize that damage to windows, doors, and household contents have important economic and emotional consequences, we do not believe they will cause injury and do not include them in our assessment of safety.

Philippines Context

On November 8, 2013, Typhoon Yolanda, struck the Philippines, affecting over 16 million people (National Disaster Risk Reduction and Management Center 2014) and damaging or destroying over 1.1 million homes (Shelter Cluster 2014). Particularly affected were the islands of the Eastern Visayas, Leyte and Samar, and the municipalities of Guiuan and Tacloban City. Global support and assistance led to a variety of shelter programs and shelter designs being implemented in this region. With this variety, we are able to ask questions about shelter safety and households' perceptions of shelter safety.

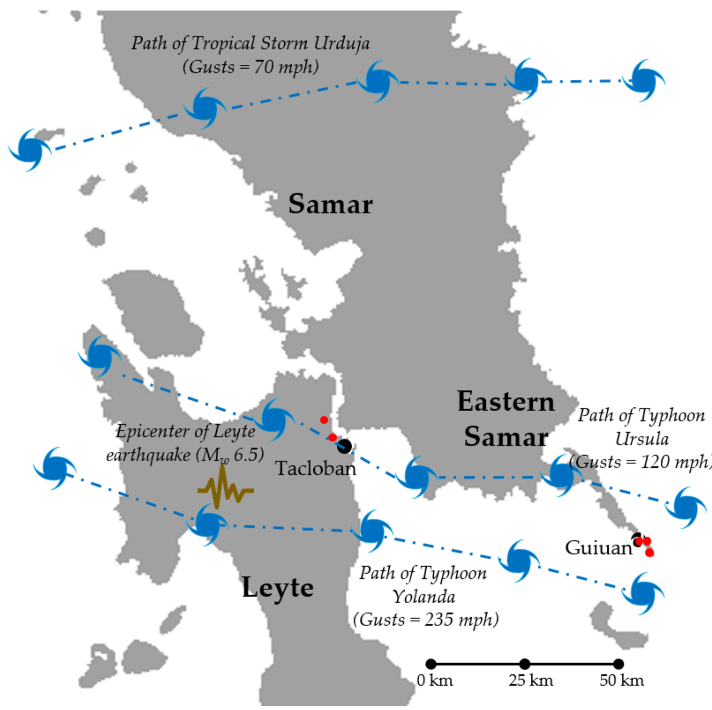


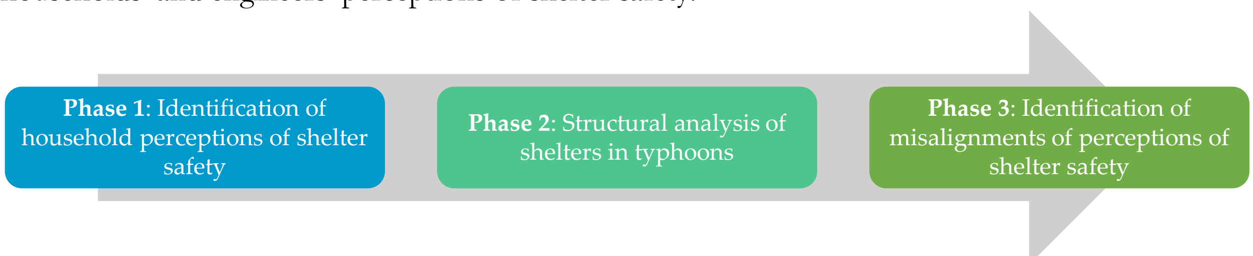
Figure 1: Location of studied communities (red dots) and recent hazards.

Since Yolanda, the Eastern Visayas has been affected by various other hazard events, including typhoons and earthquakes (see Figure 1). Annually, the Philippines has more typhoons enter its waters than any other country (Holden and Marshall 2018), and many of these typhoons originate off the eastern coast of Samar. Additionally, the islands of Leyte and Samar sit between the Central Leyte Fault and the Philippine Trench, the two most seismically active regions of the Philippines (Philippine Institute of Volcanology and Seismology

2017). Leyte and Eastern Samar are particularly prone to hazards and are thus are opportune places to understand perceptions of shelter safety.

Identifying Household Perceptions and Assessing Shelter Safety

To understand how household perceptions align or differ with engineering assessments of shelter safety, we conducted research in three phases. In the first phase, we sought to identify and characterize household perceptions of shelter safety in typhoons and earthquakes through a household survey. We then conducted structural analyses to assess the safety of shelter in typhoons. In phase three, after identifying how the results of the survey and structural assessments aligned or differed, we conducted semi-structured interviews to understand why households hold certain views about shelter safety and further investigate misalignments, or differences between households' and engineers' perceptions of shelter safety. In the following pages, we present key results of the household survey and engineering assessments and then discuss the emerging findings related to the alignment, or misalignment, of households' and engineers' perceptions of shelter safety.



Community Selection

This report presents results from five communities (see Table 1; Figure 2), including survey findings related to perceptions of safe shelter, engineering assessments of shelter in wind hazard events, and results from exploratory interviews on (mis)alignments between the two. The five sites represent a diverse cross-section of shelter designs: selected shelters are constructed of reinforced concrete or coconut lumber (the two primary materials used in post-Yolanda shelter construction); wall materials vary between plywood, amakan *(i.e.,* woven bamboo), and concrete masonry units (CMU); roof shape is either hip or gable; and, with the exception of one design, the roof material used is corrugated galvanized iron (CGI). Additional design elements, such as the crucially important connection details (*e.g.*, connections between the roof truss and walls), also vary amongst the selected shelters. Construction quality, determined through observations of current construction practices and shelter damage and conversations with households, varied both within and between the selected communities.

The selected communities also vary in terms of the type of assistance and the shelter programs were administered. Two sites, Community C and E, were relocation sites that were constructed following Typhoon Yolanda. Residents in Community C were relocated from two barangays into a new section of an existing barangay. In contrast, residents from Community E were relocated from numerous barangays into an entirely new barangay that lacks many basic services, in particular a barangay-wide water system and employment opportunities. Communities A, B, and D existed prior to Typhoon Yolanda and shelters were reconstructed in the same location as households' previous homes.

Table 1: List of communities included in this study.

Community	# of households	Shelter type	Shelter design
A	63	Permanent, core	1-story, coconut lumber frame, gable roof, amakan OR plywood walls OR 1-story, concrete frame, flat roof, CMU walls
B	105	Transitional	1-story, coconut lumber frame, hip roof, amakan walls
C	119	Transitional and permanent, relocation site	1-story, coconut lumber frame, hip roof, amakan walls OR 1-story, concrete frame, hip roof, CMU walls
D	150	Permanent, core	1-story, concrete frame, gable roof, CMU and plywood walls
E	1000	Permanent, relocation site (provided by government)	1-story with option to add interior 2nd floor, concrete walls, gable roof

Figure 2: Examples of shelters built in each community. (3 shelter types in Community A; 2 shelter types in Community C). (Photos A-B by Dina Pelayo).

INGOs administered the shelter programs in Communities A, B, C, and D, while the Philippine National Housing Authority (NHA) oversaw the design and construction of houses in Community E. Shelters in Communities A, D, E were intended to be permanent, while shelters in Communities B and C were transitional and built for shorter life spans. In Community B, households were told that the shelters would last for 5 years and after those 5 years they would be provided with a permanent house. Permanent houses have yet to be provided. In Community C, it was expected that households would occupy the transitional shelters for 2-3 years before receiving a permanent house from the Department for Social Welfare and Development (DSWD) – the local government. At the time of writing, approximately two-thirds of the residents in Community C have received a permanent house while those still living in transitional shelter do not know when they will receive their permanent house.

Household Survey

In the five communities included in this report, we administered 228 household surveys. Prior to administering the survey, we determined the necessary number of survey responses required to achieve a confidence level of 90 percent and an acceptable sampling error of 5 percent. We selected households using a combination of cluster and convenience sampling. Using maps either collected from community officials or created by walking the community, we divided each community into geographic clusters and determined the proportional number of surveys needed from each cluster. We then selected households within each cluster using convenience sampling. The surveys were administered orally in the local language – Waray-Waray – and responses were recorded on tablets.

Table 2: Survey and interview numbers for each community.

Community	Surveys Administered	Interviews Conducted	# of Households
A	35	23	63
B	33	16	105
C	51	19	119
D	41	16	150
E	68	19	1000

To capture households' perceptions of the safety of their shelter, respondents were asked to estimate the damage to the foundations, walls, roof covering (*e.g.*, CGI), and roof structure (*e.g.*, truss) in two events: a typhoon similar to Typhoon Yolanda and an earthquake similar to the 2017 Leyte earthquake. Possible answer choices were *no damage, minor damage, major damage,* or *completely destroyed,* and photo references of different damage levels were provided to aid respondents in determining their expected level of damage. For analysis, responses of *completely destroyed* were scored as 0, *major damage* as 1, *minor damage* as 2, and *no damage* were scored as 3.

Structural Assessment of Wind Performance

After completing the survey administration and analysis, we assessed the safety of the selected shelters in typhoons. While flooding, storm surge, and wind-borne debris are hazards that impact safety in typhoons, we chose to focus solely on wind because it is the wind hazard that engineers and households are most able to address in design and construction decisions. For example, mitigating the impacts of storm surge often requires relocating to a site further from the coastline, but mitigating the impacts of wind can often be addressed with roof anchorage or different CGI panels.

In assessing shelter safety, we were interested in three possible failure modes: 1) removal of the CGI panels, 2) damage or removal of the roof structural system, and 3) damage or collapse of the wall system. Studies of houses damaged in typhoons and our own reconnaissance after Typhoon Ursula in December 2019 (Signal 3, maximum wind gusts = 120 mph), indicate these are the most likely failure modes. After any of these items fail, pressures are reduced, effectively "protecting" other components of the structure.

We wrote a single structural analysis program in Matlab that can analyze the safety of all the shelters in extreme wind events. First, we created scripts to determine the wind pressures on each shelter, accounting for the specific geometry (*i.e.*, height, width, and roof pitch) of each shelter. Wind pressures were determined using the appropriate Component & Cladding or Main Wind Force Resisting System procedures from ASCE 7-16 (ASCE 2016) due to the lack of wind-tunnel test pressures available for these types of structures.

Once the pressures had been determined, the Matlab scripts would calculate the critical forces on each component of interest using static analysis. The capacity of each component was either taken directly from literature (e.g., the capacity of CGI panel connections from Thurton et al. 2012), modified from a value from literature (e.g., the tear-out capacity of CGI sheets from Mahaarachchi and Mahendran 2000), or calculated directly (e.g., the shear capacity of nailed wooden connections). When the forces acting on a component exceeded its capacity, the component was assumed to have failed.

The goal of these analyses was to determine the wind speed at which these components is likely to happen for the different structures, and to identify the likely progression of failure. The wind speed at predicted failure is a measure of the vulnerability of the housing in typhoons.

Follow-Up Interviews

With the survey and wind analysis complete, we then compared the results from each to determine where they aligned and differed. For example, from the survey, we knew that in one community all respondents expected the roof structure to be completely destroyed, but the wind analysis revealed that neither the truss nor the connection between the truss and wall would fail and, rather, the roof covering was vulnerable. We classified this as a misalignment between engineering assessments and household perceptions. After completing the comparisons between household perceptions and engineering assessments for each community, we developed an interview script to further explore why these misalignments exist and what underlying factors influence perceptions of safety. We aimed to confirm the identified misalignments and investigate the reasons for perceptions with more open-ended questions, such as, '*Can you describe a house in your community that you believe is safer than yours? Why is it safer?*'

Interviews were approximately 30-45 minutes long and were conducted with a local research assistant who would translate between English and Waray-Waray. The number of interviews conducted in each community is listed in Table 2.

Household Perceptions of Shelter Safety

Overall, when asked about the construction quality of their shelter, sixty percent of survey respondents stated that they feel safe in their shelter. However, when examined by community, these percentages vary considerably (see Figure 3). The majority of the 93 respondents who did not feel safe in their shelter live in either Community B or E. Shelters in Community B were 1-story, constructed with coconut lumber, and had amakan walls; while, in Community E, shelters had concrete walls and were built to be able to add an interior second floor. To better understand what evoked feelings of safety or worry, we asked households specifically about the foundations, walls, roof structure, and roof covering of their shelter. These questions were asked for two hazard events – a typhoon similar to Typhoon Yolanda and an earthquake similar to the 2017 Leyte earthquake; **on average, households perceive their shelters to be safer in earthquakes than in typhoons.**

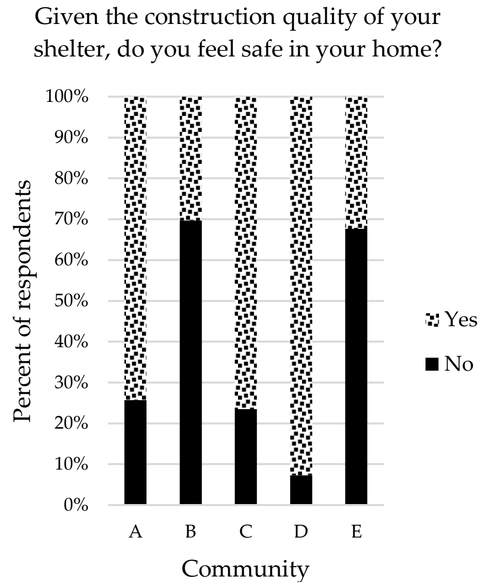


Figure 3: Percent of respondents, by community, who feel safe in their shelter.

Perceptions of Safety in Typhoons

Expected damage to each component in typhoons by community is shown in Figure 4. In general, households perceive their roof covering (*i.e.,* CGI) and roof structures (*i.e.,* trusses) to be the least safe during typhoons, with most households, notwithstanding those in Community D, expecting these components to be destroyed or have major damage during a typhoon. In Communities B and C, where either all or a majority of households live in shelters with amakan walls, households also expect substantial damage to the walls during a typhoon due to the perceived fragility of the wall materials. Additionally, residents in these communities are concerned with the deterioration of the bottom of the wooden columns and the risk of wall collapse due to the reduced column cross-section. In Community E, which has tall concrete-like walls, two-thirds of households expected their walls to be destroyed due to the unsupported height of the walls and the poor construction quality. Community D, which had a reinforced concrete frame, CMU skirt walls and plywood walls, had the highest perceived safety scores; in contrast, Community B, which had a coconut lumber frame and amakan walls, was perceived to be the least safe. In conversations with residents of Community B, this perception seems to be due to apparent deterioration of wooden trusses and columns from water and termites, as well as dissatisfaction with the material choice. Although Community B had one of the strongest roofs, because of its hip shape and the use of wind straps, all households expected the entire roof system to be destroyed; again, this perception was driven by concerns with the quality of the wooden truss.

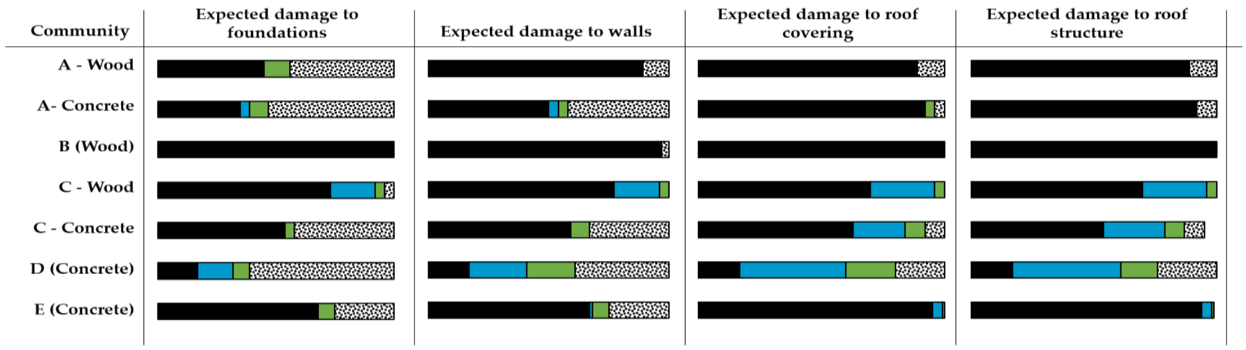


Figure 4: Expected damage to various shelter components in typhoons. The percent of respondents living in a specific shelter type in each community that expect a given component to be *destroyed* is shown in black, have *major damage* in blue, have *minor damage* in green, and have *no damage* in hatched pattern.

Influence of Materials

We also compared safety perceptions based on whether the household lived a wooden or concrete shelter (see Figure 5). For every component, those who live in wooden shelters expect more damage during typhoons. While it is perhaps not surprising that those in wooden shelters would perceive their walls (either plywood or amakan) to be less safe than those living in concrete shelters with CMU walls based on households' experience with damage to wooden houses in Yolanda, the difference in expected damage to both the roof panels and roof structure is a potential misalignment. With the exception of the concrete shelters in Community A, all the concrete shelters have CGI roof panels. The roof structure for all but Community E are wooden trusses; **therefore, the only difference in roof structure and covering between wooden and concrete shelters is how the components are connected, yet those living in wooden shelters perceived the roofs to be less safe.**

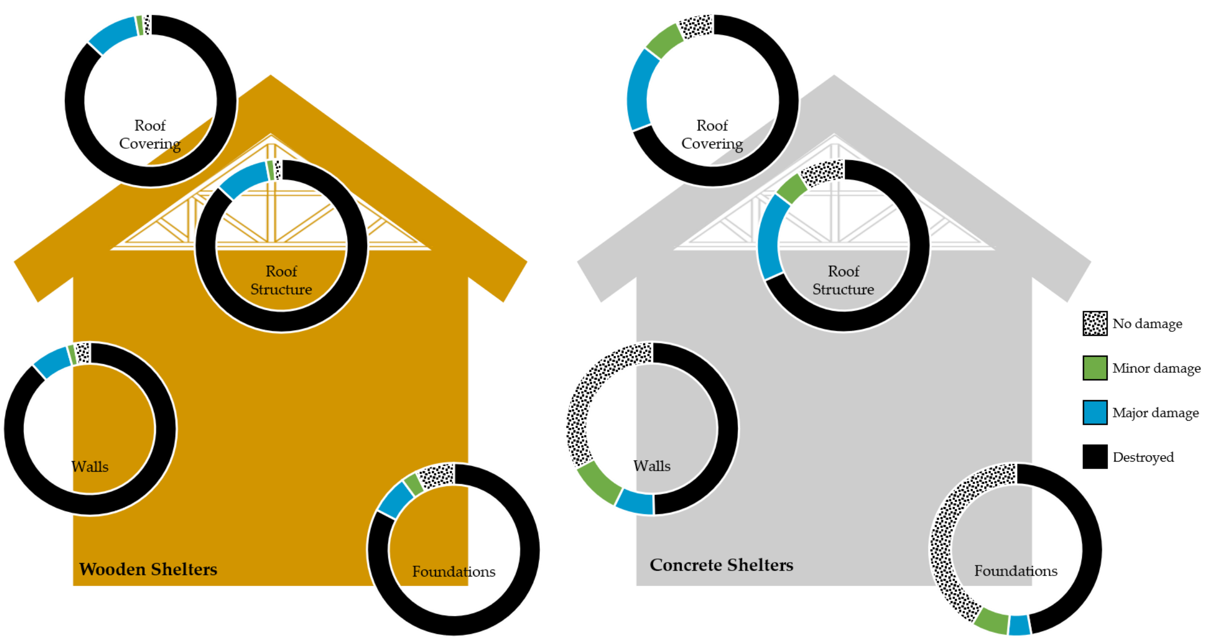


Figure 5: Expected damage to various shelter components for different shelter materials. Perceptions of those living in wooden shelters are shown on the left, and for those living in concrete shelters, on the right. Percentage of households that expect a certain damage level are represented in the pie charts for each component. For all components, those in concrete shelters expect less damage than those in wooden shelters.

Perceptions of Safety in Earthquakes

For earthquakes, households living in the same shelter designs had divergent perceptions of the expected level of damage (see Figure 6). With the exception of Community D, most households expected components to have either no damage or be completely destroyed in an earthquake similar to the 2017 Leyte earthquake ($M_w = 6.5$), with few households expecting minor or major damage.

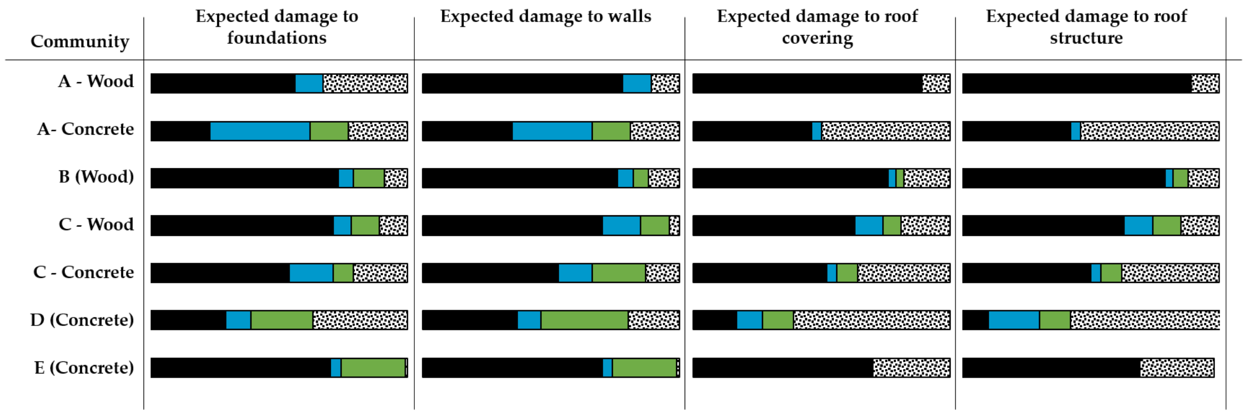


Figure 6: Expected damage to various shelter components in earthquakes. The percent of respondents living in a specific shelter type in each community that expect a given component to be *destroyed* is shown in black, have *major damage* in blue, have *minor damage* in green, and have *no damage* in hatched pattern.

To compare respondents' perceptions of safety in typhoons and earthquakes, we calculated a *difference score.* Difference scores were calculated by subtracting *earthquake safety scores* from *typhoon safety scores.* Safety scores were calculated by summing responses for each component (foundations, walls, roof covering, roof structure) where a response of *destroyed = 0, major damage = 1, minor damage = 2,* and *no damage = 3.* As *safety scores* increase, households perceive their shelters to be safer, and as *difference scores* increase, the greater the difference in perceived safety in typhoons and earthquakes. Figure 7 presents respondents' *difference* scores. As shown in Figure 7, the largest number of respondents have a *difference score* of 0, meaning they expect the same amount of damage to their shelter in both an earthquake and typhoon. Of the remaining two-thirds, more respondents perceive their shelters to be safer in earthquakes than in typhoons.

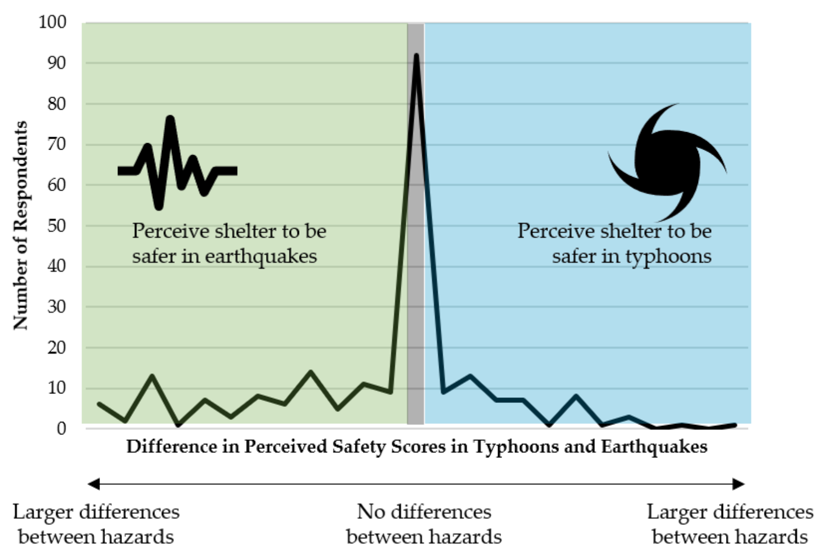


Figure 7: Differences in perceived safety in typhoons and earthquakes. As the x-axis moves towards the edge of the plot, the larger the *difference scores.* The number of respondents with a particular *difference score* is represented on the y-axis.

We believe that there is greater perceived safety in earthquakes than typhoons due to less experience with earthquakes in these communities. While there have been earthquakes in nearby communities in recent years, these have not been large in magnitude, and most households have not experienced damage beyond minor cracking from earthquakes. Surprisingly, nearly as many households expected their roofs to have as much damage as their walls and foundations in an earthquake. In interviews, we learned that this was not because households expect damage to originate at the roof, but because they expect that if a wall is damaged, then the roof will ultimately collapse.

Safety of Shelter in Typhoons

It would be nice to design and build structures that can always withstand extreme storms. However, this would impose a large cost on owners and donors. Given the limited resources of shelter programs, the objective, in agreement with the current U.S. design philosophy for earthquakes, should be to design and construct shelters that will not be damaged at frequent storms and will fail in a preferred (least catastrophic) order at more intense and infrequent storms. The preferred order of failure of the three critical failure modes in wind is shown in Table 3 and a sketch of roof components is provided in Figure 8 for reference. **The structural analysis revealed that five of the seven shelter typologies are likely to fail in the preferred order.** Below we discuss the expected failures and implications for safety for each shelter.

Table 3: Preferred order of failure modes of shelters in wind.

Failure Order	Failure Mode	Failure Mechanism	Reason
1	Removal of CGI panels	Connection between CGI panels and purlins	Removal of the CGI panels will drastically decrease the pressure on other components, saving them from failure. Replacing CGI panels is relatively easy and inexpensive; however, panels flying around in the wind could cause injury or damage to surrounding structures.
2		Connection between purlins and truss	After this connection fails, several CGI panels are likely to be removed from the shelter, decreasing the pressure on other components, saving them from failure. Repairs include only CGI panels and purlins.
3	Damage or removal of roof truss	Connection between truss and wall/columns	If this connection fails before either of the two other roof components, the entire roof (truss, purlins, and CGI) is likely to be damaged or removed, requiring extensive repairs. Failure can also lead to collapse of roof structure onto household occupants. In certain situations, failure of this connection can also lead to wall collapse.
4	Damage or collapse of wall system	Wall system	Racking of the wall system will lead to either considerable tilting that is unsafe and difficult to repair or collapse of the entire house, endangering the lives of household occupants. Out-of-plane failure of CMU is also likely to cause significant injury to occupants.

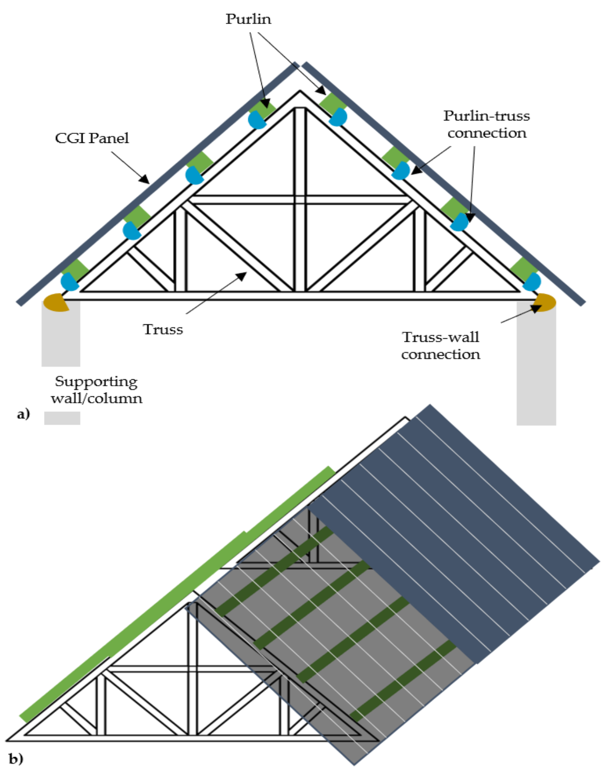


Figure 8: Sketch of roof components. a) Front view of all roof components and connections. b) 3-D view of roof truss, purlins, and CGI panels.

Roof Failures

As described in Table 3, we investigated roof failure at three connections: the CGI panel-purlin connection, the purlin-truss connection, and the truss-wall connection. Figure 9 presents the speed at which fifty percent of a given roof component are likely to fail for each shelter design. For example, fifty percent of the CGI-purlin connections on the wooden shelter with amakan walls in Community A are expected to fail by once wind speeds reach 180 mph. The component with the lowest failure speed is expected to fail first. While there is a concrete design for Community A, it is not included in this analysis since the roof is a flat, concrete slab roof that does not have CGI, purlins, or truss elements and was assumed not to fail in wind. Community E is also not included in Figure 9 because it does not have the typical purlin-truss configuration.

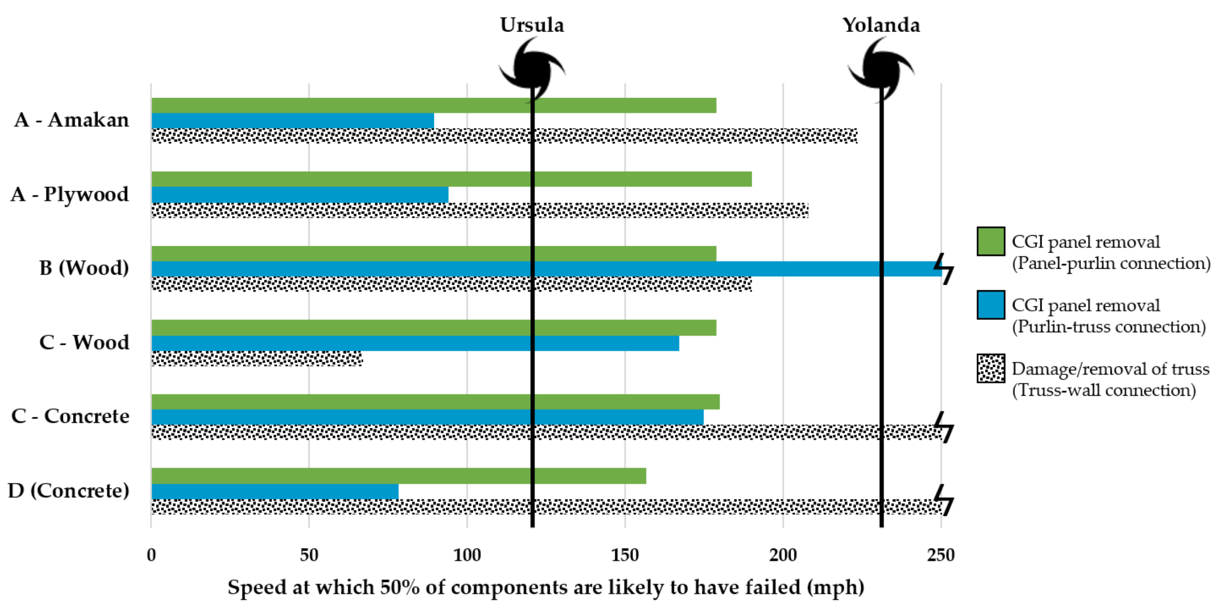


Figure 9: Wind speed at which 50% of roof components are expected to fail. Failure of the panel-purlin or purlin-truss connection at the lowest wind speed results in the removal of the CGI panels. If the truss-wall connection fails at the lowest wind speed, the expected failure is damage or removal of the roof truss. Components that are expected to have 50% failure at wind speeds above 250 mph are represented by a break (ϟ).

With the exception of Community B and the wooden shelter in Community C, the expected roof failure mechanism is the failure of the purlin-truss connections (see Figure 11). This is the second-most preferred type of failure, for the failure of these connections and subsequently the CGI panels will save the rest of the roof system, mainly the truss. In Community B, the CGI panel-purlin connections are expected to be the first failure of the roof components, also leading to the removal of the CGI panels. In the case of the wooden shelter in Community C, the failure of the truss-wall connection first is not preferred and is likely to lead to the damage and potential collapse of the entire roof system, significantly decreasing the safety of these shelters. Compared to the other shelter designs, the trusses in the wooden shelters in Community C are connected to the wall using only small wooden cleats (see Figure 10) – a weak and vulnerable connection that should be replaced with either bolts or wind straps.

Figure 11: Truss-wall connection in Community C wooden shelter.

Figure 10: Examples of purlin-truss connections. a) A wind strap is used to connect the purlins to the truss. b) Wooden cleats are used to connect the purlins to the truss.

Wall Failures

When examining the wall systems, we were concerned with two failure mechanisms: an out-of-plane failure of walls constructed with CMU and in-plane failures of walls constructed with wood. There were four designs with CMU (Community A – Concrete, Community C – Concrete, Community D, and Community E); analysis of the bending strength of the CMU walls, using conservative material properties, revealed that the out-of-plane failure in these shelters is highly unlikely. Therefore, we are not concerned with failure of the wall systems for these designs. However, for the four other designs, we determined the wind speed of the first wall failure. Only in Community B was wall failure likely to occur before roof failure.

In Community B, the shape of the roof and the use of wind straps in connecting the purlins to the truss and the truss to the wall makes the roof strong compared to the walls. Thus, the wind speed at which the first wall failure occurs is less than the wind speed where any of the roof components fail, resulting in the least desired failure mode. The failure of the walls before any of the roof elements can lead to considerable tilting and complete collapse (see Figure 12) – outcomes experienced by nearly 50 of the shelters in Community B during Typhoon Ursula, which struck Guiuan and Tacloban on December 24, 2019, with wind gusts up to 120 mph.

Figure 12: Examples of shelters that experienced wall failure due to failure of the column-foundation connection. a-b) Wall racking led to tilt and partial collapse. c-d) Wall racking led to complete collapse with roofs landing on the shelter. (Photos a & b by Abbie Liel).

Predominant Failure Mode

After conducting the roof and wall analysis, we were able to predict the predominant failure mode for each of the shelter types and estimate the damage to the roof covering (*i.e.,* CGI panels), roof structure (*i.e.,* truss), and walls in a typhoon with wind gusts greater than 150 mph in order to compare to the results of the household survey.

Table 4: Expected failure modes and damage to selected shelter designs in typhoons with gusts greater than 150 mph.

Shelter Design	Failure Mode	Roof Covering	Roof Structure	Walls
A – Amakan	Removal of CGI panels	Major damage	No/minor damage	Minor damage
A – Plywood	Removal of CGI panels	Major damage	No/minor damage	Minor damage
B (Wood)	Wall collapse	No/minor damage	No/minor damage	Major damage
C – Wood	Damage/removal of roof truss	Major damage	Major damage	Minor damage
C – Concrete	Removal of CGI panels	Minor damage	No/minor damage	No/minor damage
D (Concrete)	Removal of CGI panels	Major damage	No/minor damage	No/minor damage
E (Concrete)	Removal of CGI panels	Major damage	Minor damage	No/minor damage

(Mis)Alignments of Perceptions and Assessments

Presented above were perceptions of shelter safety in typhoons for each community, the influence of shelter material on safety perceptions, and the differences in perceptions in typhoons and earthquakes. Below we discuss what factors influence these results and how they compare to engineering assessments of shelter safety in wind.

Where do perceptions align with engineering assessments?

Roofs

Figure 13: Example of wrapped rebar connection.

In all communities, often unprompted, respondents commented on how a roof with four sides – a hip roof – was preferred to a gable roof with only two sides. They described that by having four sides and corners the wind did not act as strongly on their house. This is congruent with engineering knowledge, for the wind pressures acting across hip roofs are less than the pressures on a gable roof.

For those living in concrete shelters with wooden roofs, when asked about what they like about their roof or what they think contributes to it being safe, a majority of respondents pointed out the connection between the truss and the wall. In these shelters, this connection was the rebar from the concrete column wrapped around the wooden truss (see Figure 13). This agrees with the assumptions we made about the strength of the wrapped rebar connection.

We posed the following question to households: If you knew a typhoon was coming next week, what would you do today to protect your shelter? The most common answers were that they would 1) replace the CGI with thicker CGI panels, 2) add additional nails connecting the CGI to the purlins, or 3) tie or weigh down the roof. These changes are the same as the improvements suggested by the engineering assessments, reflecting that households' perceptions and knowledge of what makes for a safe roof are in line with engineering best practices. **Either through experience, training, or word-of-mouth, households have learned how to make a roof safer, even with limited resources.**

When perceptions and assessments align: Roof design
Overall, households have a strong understanding of what is required for a safe roof (*e.g.*, shape, thickness, types and numbers of connections). When households are concerned about the safety of their roof, they are most often concerned with the quality of materials (*e.g.,* thin CGI).

Concrete

An overwhelming majority of households perceived concrete to be safe in typhoons and knew that it could be potentially dangerous in earthquakes. In general, this aligns with engineering judgment, for while concrete can be a safe building material for earthquakes, it must be constructed properly and follow design details, such as rebar size and spacing. Only a handful of respondents believed that concrete and CMU were undoubtedly safer than wood in earthquakes.

For those living in wooden shelters, many desired to change the material from wood to concrete and CMU because, from their experience, these materials will protect them from a typhoon. As discussed above, a majority of households are more concerned with the safety of their shelter in typhoons than earthquakes. Our original hypothesis was that the recency and severity of typhoons compared to earthquakes was mostly responsible for this perception, and while interviews did confirm that the memory of typhoons is stronger, behavior in each of these hazard types is also an important contributing factor. We were repeatedly told by respondents that they are more worried about typhoons because in a typhoon they need to find a safe place to stay for a long period of time during the storm; whereas, in an earthquake, they can run out into the street and will be safe. Thus, when we asked households if they would be concerned with the safety of a concrete shelter in an earthquake, they stated that earthquakes are less likely to occur than typhoons and they can easily escape danger by going outside. **It was not that households were unaware of the risk or potential damage from concrete in earthquakes, it is that they were prioritizing other needs based on the duration and frequency of typhoons.**

When priorities misalign: Hazard behavior and probability

While households understood the likely performance and risks of different materials in different hazards, their preferences and decisions reflected their needs during different hazards. It was therefore more important for them to have a concrete shelter that is safe during the more frequent and longer typhoons than a wooden shelter that would be safe in an earthquake. The hazard-based behavioral needs of households should thus be considered when selecting materials in future shelter reconstruction projects.

Where are perceptions misaligned with engineering assessments?

Walls

Households living in wooden shelters are more concerned with the safety of their walls than those living in concrete shelters. While this difference in perceptions of wall materials aligns with engineering assessments in typhoons, the reasons given for concerns with the wall material are often different. For instance, those living in wooden shelters with amakan walls expressed the most discontent with their walls and often pointed out portions of their walls that had deteriorated, torn, or needed to be replaced with tarps or CGIs. This discontent with amakan walls was so strong in Community B (where wall failure led to the collapse of numerous shelters) that when posed with choosing either 1) having a strong roof that remains intact but walls that collapse or 2) having the walls remain intact but portions of the roof damaged, the common response was to choose option 1 because it allowed for them to replace their walls with a material they preferred.

When perceptions and assessments misalign: Wall safety

While households expressed concern with both the amakan wall material and the column-foundation connection, they were most concerned with and most likely to change the wall material. Only strengthening the wall panels could increase the forces on the wall frames and make the shelter more vulnerable to collapse. Organizations should discuss these consequences with households during training and encourage strengthening of the column-foundation connection.

While worries with the walls most often dealt with the durability of the wall panel material, it is a failure of the wall frame at the connection between the column and roof beam and the column and concrete foundation, that leads to wall damage and collapse. In Community B, our field reconnaissance indicates that it was a deterioration of the column at the connection with the foundation and a failure of the metal strap connecting the wooden column and concrete footing (see Figure 14) that led to collapse.

Figure 14: Example of metal strap connecting column and foundation.

It is sometimes assumed that weaker wall materials, like amakan, will blow out during typhoons, protecting the frames from collapse. However, as we witnessed in Community B, this was not the case and the amakan was not as vulnerable to wind damage as assumed. Nevertheless, for comfort and durability reasons, households wish to replace amakan with a stronger material (*e.g.,* plywood). Weakness at the column-foundation connection can lead to wall collapse when the roof is strong and there is a strong wall material. **Therefore, strengthening the material of the walls, which was discussed by households more frequently, while not strengthening the connections within the structural system, can lead to more shelter damage in typhoons.**

Strengthening Roofs Compared to Walls

Survey responses indicated that households perceived the roof to be the least safe part of their shelter. As discussed above, when we asked households what they would do to prepare their shelter if they knew a typhoon was coming in the next week, all responses were related to the roof, particularly the CGI panels, reflecting households concern with roof safety. While we are concerned with roof safety and want to ensure that the roof will not be damaged, roof failure is the preferred mechanism, as discussed in the wind analysis section above. A failure of CGI panels is likely to protect the rest of the shelter from collapse, and over-strengthening the roof can lead to a collapse of the wall system, as we witnessed in Communities B. **Households' concerns with the roof as compared to the walls of their shelter could lead to more damage in a strong wind storm; thus, it is important for organizations, both when designing shelters and in providing training and other assistance, to discuss the implications of an overly strong roof in overall shelter safety.**

When perceptions and assessments misalign: Wall vs roof strength

Households were most concerned with roof safety and were more likely to strengthen the roof than the walls. An overly strong roof could lead to collapse of the entire house. Thus, it is important for organizations to share how shelters work together as a system.

Order of Failure of Roofs

A common theme in all of the studied communities, except Community D, was that nearly all households expected both the CGI roof panels and wooden roof trusses to be completely destroyed. While we do expect major damage to the CGI panels in typhoons with gusts exceeding 100 mph, only in the Community C-Wood design do we expect that the roof structure will actually have considerable damage due to the weak connection between the truss and the wall. However, households living in wooden shelters did not express that they were worried about the connection between the truss and the wall when describing they were worried about the roof (as opposed to those living in concrete shelters as described above). Instead, in conversations with community members, we learned that concerns with the safety of the roof structure is commonly due to it being constructed out of coconut lumber as opposed to 'good lumber.' **The concern with the roof structure (*i.e.*, the roof truss) in conjunction with or in lieu of the roof covering can lead to households making modifications that are not as useful as others.** For example, we expect that adding nails to or tying down the CGI panels is more likely to prevent roof damage than strengthening the truss, and improving the connection of the panels to the purlins is often the best use of resources for roof safety.

When perceptions and assessments misalign: Most effective modifications

Concerns with the quality of roof trusses could lead households to focus their modifications on changing the trusses; whereas, focusing on the connections between the CGI panels and purlins and the purlins and truss are more likely to be more effective in increasing roof safety.

Definitions of Safety

We uncovered different definitions of safety through the follow up interviews. The definition of safety used by our research team related to injury and loss of life. **However, safety for the households included in this study relates more to feelings of security and comfort.** For example, one of the most common complaints about the shelters that we heard was that water would get in the house, either through the roof or the walls. In Community E, a relocation site where most households did not previously know their neighbors, one of their most important concerns was with protecting their shelter from thieves. This is why the most common modifications made in this community were adding grates to the windows and gates to the front door. Safety assessments of these shelters, when focusing solely on a structural perspective, would never reveal this concern, but as highlighted in interviews with community members, the threat of robbery should be discussed in shelter design and programming.

When priorities misalign: Definition of safety

To conduct this research, we adopted a definition of safety that was concerned with preventing injury and loss of life. However, safety can have additional definitions related to economic loss, comfort, or security. Households represented in this study had their own definitions of safety that differed from our definition, and these definitions influenced the components of their shelter they were worried about and the changes they wish to make to their shelter. Issues such as water intrusion, flooding, and robbery should thus be accounted for in future shelter designs.

Other Types of Hazards – Water Intrusion

Water intrusion was mentioned by a majority of households as a reason they do not feel safe in their shelter during a typhoon. Respondents would point to holes in their CGI panels caused by the nails or screws used to connect the panels to the purlins as examples of how the water leaks into their shelter, getting both them and their belongings wet. Households highlighted how the wood in their shelter had deteriorated due to, in their opinion, the water leaks. While leaks are unlikely to cause injury, they do contribute significantly to quality of life within one's home, and unsurprisingly this is an issue households are most eager to resolve. If they had not already, households said that they would stop the rain from leaking in by sealing nail holes with vulcaseal, a widely available sealant. Others wanted to extend the eaves of their shelter in order to protect the walls and windows from rain. While this action would provide an additional rain barrier, it could also ultimately lead to greater damage, as wind acts more strongly on eaves, and roofs with longer eaves are more likely to have the CGI panels removed during a typhoon. **Thus, designing and building shelters that protect against the rain will not only make occupants feel safer in their shelters, it could potentially prevent them from making quality-of-life modifications that could make their shelter less safe in a typhoon.**

When perceptions and assessments misalign: Rain protection

The most common concern households had with their shelter was that it leaked when it rained, either through the roof or the walls. This water intrusion made them feel unsafe in their shelters during storms. Protecting themselves from the rain, either by adding another wall material, extending the eaves, or filling the holes in the CGI, was the modification households most wanted and were most likely to make. Extending eaves, while protecting against rain, could make shelters more vulnerable to wind damage.

Other Types of Hazards – Deterioration, Bugs, and Coconut Lumber?

There was considerable dissatisfaction with the coconut lumber used to construct most of the shelters after Yolanda. Given the shelter demand and limited access to other types of lumber, coconut lumber was an obvious choice. However, this choice was seen as a poor one by many households. Most households said that they wished their shelter had been constructed with 'good lumber.' Few respondents referred to a specific wood species, but nearly all differentiated between coconut and good lumber and did not expect good lumber to have the same deterioration and bug-infestation as coconut lumber. We did not investigate how other wood species would deteriorate as a part of this project but can confirm that there is little, if any, trust in coconut lumber as a safe material. While there was rot and decay in the wood in many shelters and many households reported that they have termites, these issues, although worrisome and a negative impact on comfort, are not likely to destroy a shelter (unless rot occurs at the base of the wooden column). **In the future, if organizations are to use coconut lumber, or an unfamiliar wood species, properly treating the wood and instilling confidence in the material would be important.**

When perceptions and assessments misalign: Lumber strength

There was considerable concern with deterioration and strength of coconut lumber compared to other types of lumber. While we did not test the deterioration of other types of lumber, coconut lumber strength is comparable to other structural lumber. Worry with coconut lumber was often caused by NGOs milling and using young and weak portions of the tree during reconstruction.

Conclusions

This project sought to understand what households perceive to be safe in relation to shelter and identify how these perceptions align or differ with engineering assessments. Overall, households' knowledge of what parts of their shelter were safe or vulnerable agreed with engineering assessments. However, how households plan to modify their shelters to make them safer often does not align with engineering best judgment and could make the shelters less safe in future hazard events or introduce additional vulnerabilities in a multi-hazard environment.

In general, households perceived their shelter to be less safe in a typhoon than in an earthquake and wish to make their shelters safer during typhoons. This typically meant that they wished to strengthen the roof. While many households said they would add additional nails to the CGI panels or tie down their roof in a typhoon, many households expressed that they felt their roof was unsafe because of its coconut lumber truss. If households were to address their concerns with the coconut lumber by strengthening the truss, this likely would not improve roof safety as much as strengthening the CGI or improving the connections between the purlins and the truss, for the roof covering is more likely to be damaged than the roof truss.

Additionally, because households were more concerned with their roofs than their walls in a typhoon, focusing only on strengthening the roof could potentially lead to more damage. If the roof is strong enough to not be damaged during a typhoon and has greater capacity than the wall system, the walls could fail, leading to collapse of the shelter. Some households were concerned with their walls and wished to replace the wall panels with a stronger material. However, if the connections of the wall frame and between the columns and foundation are also not improved, strengthening the wall panels can increase the pressure on the frames and also lead to collapse.

Lastly, we learned that the hazards households are worried about are, at times, different than those we assessed in this study. Daily concerns, such as water intrusion and security from thieves, were often more pressing concerns than ensuring that one's shelter would be safe in a typhoon or earthquake. The modifications to address these issues, particularly water intrusion, could potentially make shelters less safe in future typhoons or earthquakes.

Overall, households have a strong understanding of what parts of their shelter are most likely to be damaged and methods to improve the safety of individual components. What is often lacking, however, is an understanding of how all the components of a shelter work together as a system and how modifications to one component could impact the performance of another and thus the safety of the overall shelter. It is important for shelter practitioners to recognize and address this gap in knowledge in future shelter programming. Training should not only provide information on how to safely build a house, but also address how shelter is a system. By considering how shelters will perform over their lifetime and how changes to a shelter will impact its lifetime performance, we hope that households will be better able to modify their shelters to improve comfort without sacrificing safety.

Our research will continue to explore this topic through 2022, expanding this study into three additional communities in Tacloban City, Philippines and numerous communities in Puerto Rico. We will also conduct seismic assessments in order to understand how shelters will perform in future earthquakes and how perceptions of shelter safety vary in relation to earthquakes.

Case Studies

Community A

Shelter program details:	Households were responsible for securing materials and labor with cash received in a three-tranche system. Two INGOs provided shelter designs and used three different designs. Households reported varying levels of participation in the design and construction of their house.
Relocation site?	No
Structural system:	Coconut lumber or reinforced concrete
Wall material:	Amakan or plywood (coconut lumber frame), CMU (concrete frame)
Roof system:	Gable shape, CGI (coconut lumber frame); flat, concrete (concrete frame)
Key design elements:	Double cleats used to connect purlins to trusses and bolts used to connect trusses to columns (coconut lumber frame). Columns partially extended to allow for construction of second story (concrete frame).
Prevailing perceptions of safety:	Regardless of whether they lived in a concrete or wooden shelter, households expected the same level of damage to their shelter. The only considerable difference was expected damage to walls – those in concrete shelters expected less damage to walls than those in wooden shelters.
Important (mis)alignments:	Water intrusion was one of the biggest concerns in this community; therefore, the desired changes more often addressed how to stop water from leaking into the shelter instead of how to make the shelter safer from a structural perspective.

Photos by Dina Pelayo

Community B

Shelter program details:	Core shelters designed by an INGO. Households participated in procuring coconut lumber and received varying amounts of training on construction and maintenance. Shelters were intended to last for 5 years with community members understanding that permanent houses would be provided after 5 years.
Relocation site?	No
Structural system:	Coconut lumber
Wall material:	Amakan
Roof system:	Hip shape, CGI
Key design elements:	Hurricane straps used to connect purlins to truss and truss to wall
Prevailing perceptions of safety:	Households perceived the entire shelter to be unsafe, particularly in typhoons. There was no confidence in the roof or the walls, driven largely by concerns with the quality of coconut lumber and amakan.
Important (mis)alignments:	Households underestimated the safety of the roofs of these shelters despite the roofs having multiple design elements that make them safe. Concerns with material quality drove perceptions regardless of improved design features.

Photo by Dina Pelayo

Photo by Abbie Liel

Community C

Shelter program details:	Transitional shelter provided by an INGO in partnership with local government. Local government has transitioned a portion of the shelters into permanent housing. Households did not participate in the design or construction of either the transitional shelter or permanent houses.
Relocation site?	Yes
Structural system:	Coconut lumber (transitional), reinforced concrete (permanent)
Wall material:	Amakan (transitional), CMU (permanent)
Roof system:	Hip shape, CGI (transitional and permanent)
Key design elements:	'Flat bar' connecting edge of roof panels to concrete piers (transitional), 'wrapped rebar' connection between concrete columns and wooden roof truss (permanent)
Prevailing perceptions of safety:	In general, households living in concrete shelters perceived their shelters to be safer than households living in wooden shelters, particularly as it relates to foundations and walls. Regardless of material, households expected the entire roof system to be destroyed in a typhoon.
Important (mis)alignments:	In this community it first became clear that there are different concerns with different types of hazards, and because of the duration of and need to stay inside during a typhoon, households preferred concrete to wood. Households acknowledge that concrete can be less safe in earthquakes, but their priority is having a shelter that is safe in a typhoon.


Photo by Matt Koschmann


Photo by Dina Pelayo

Community D

Shelter program details:	Core shelter provided to households who owned or could purchase plot of land. If shelter was not constructed in 10 days, households were responsible for finishing the construction.
Relocation site?	No
Structural system:	Reinforced concrete
Wall material:	Half-height CMU and plywood
Roof system:	Gable shape, CGI
Key design elements:	'Wrapped rebar' connection between columns and trusses. CMU skirt is not tied to concrete columns
Prevailing perceptions of safety:	Perceptions of safety were most divergent in this community. A majority of households expected the roof covering and structure to be damaged but not destroyed in a typhoon, and most did not expect the foundations or walls to be damaged.
Important (mis)alignments:	In this community, perceptions aligned most closely with engineering assessments. A common modification households wished to make was changing the walls of their shelter to full-height instead of half-height CMU. Because of the small columns in this shelter, this change could make the shelters more prone to damage, particularly in earthquakes.

Community E

Shelter program details:	Row houses designed by the local government and constructed by government-hired contractor. Households had no participation in the design or construction and were assigned a shelter using a raffle system.
Relocation site?	Yes
Structural system:	Load-bearing walls
Wall material:	Reinforced concrete or hardiflex
Roof system:	Gable shape, CGI
Key design elements:	No roof trusses, steel purlins. Houses designed so that an internal second floor could be added.
Prevailing perceptions of safety:	Nearly all households expected the roof to be destroyed in a typhoon, and most expected the walls to be destroyed. The height of the walls, the shelters being connected to each other, and the construction quality were issues that influenced perceptions of safety. Security from robbery was a top concern.
Important (mis)alignments:	While households' concerns about construction quality and the safety of tall walls agreed with the engineering assessments, households likely underestimated the safety of their roofs. In this community, households were more concerned with damage from earthquakes, which aligns with assessments. Because of the height, poor concrete quality, and being connected to other shelters, earthquakes are more likely to cause damage.

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