ABSTRACT

The objective of this report is to develop a pre-engineered retrofit scheme for Assam style hillside homes in the city of Aizawl, India. The report first investigates the development of the “Standard Plan Set for Seismic Retrofitting”, or “Plan Set A” as a model for encouraging community wide voluntary retrofit. Understanding what made this program successful will help inform the development of a similar plan set for Aizawl. Additionally, issues particular to hillside homes are explored by looking towards some of the research, and provisions developed in response to earthquake damaged homes after the 1994 Northridge earthquake. Finally a prescriptive plan set specific to the hillside homes in Aizawl will be developed. This plan set will give important consideration to creating an effective design that can easily and affordably be implemented, while also addressing the particular risks these hillside homes face.

Introduction

In the eastern Indian state of Mizoram lies the city of Aizawl. It is the capital and economic hub to the surrounding region and sits at the precipice of substantial growth with estimates showing the population doubling in the next 20 years [1]. The city spills over the steep green hillsides and ridges of the Burma Range, which offer evidence of the hazards that lie beneath. These mountains are the product of rock and sediment that has been scraped, or accreted, off the Indian plate as it is subducted under the Sunda plate. The city of Aizawl sits directly over this active megathrust subduction zone. As a result of this tectonic activity the city faces a significant seismic hazard.

Recently GeoHazards International, a nonprofit specializing in raising awareness of seismic risk, conducted a scenario for the city of Aizawl to show government leaders what level of risk they faced. The report detailed the level of damage the city might expect under a Magnitude 7 earthquake (a plausible level of shaking for a larger event). Under this earthquake the report estimated that between 29% and 37% of the buildings in Aizawl could collapse leaving between 90,000 and 115,000 people, or one third of the population, homeless. Of these buildings at risk of collapse 35% of them are traditional Assam style houses made vulnerable by their precarious position on the steep hillsides [1]. This report aims to develop a possible community wide solution to protect these vulnerable homes through the use of a standard retrofit plan set.

A Standard Plan for Seismic Retrofitting

Plan Set A, is a prescriptive tool developed in the San Francisco Bay Area for wood framed homes that have a cripple wall between the foundation and the first story. In many existing buildings built before the 1960s these cripple walls can be a weak point for earthquake resistance due to poor connections and inadequate bracing [2]. During an earthquake, the flexible cripple walls can deflect and collapse under the house. Figure 1 shows a house that has undergone a severe collapse from failure of the cripple wall. The use of a standard plan set has been successful for the voluntary retrofit of weak cripple walls.
because it addresses a specific common problem, and it offers a fast and cost effective solution.

Plan Set A sets specific criteria to narrow the pool of candidates to a certain subset with a specific seismic deficiency. It only addresses single or two family homes, with cripple walls under 4 feet, and that meet certain size and construction requirements. Despite this strict set of criteria, in the Bay Area alone, approximately 200,000 homes remain candidates, including nearly every single family home built before the 1940s and even many homes built afterwards [3]. Plan Set A offers a retrofit scheme tailored for this large at risk population, and provides an efficient way to fix such a large community wide issue.

Many homeowners are not willing to voluntarily invest the time and money required to retrofit their homes, so the standard plan set offers an attractive streamlined process. It is set up in the manner of a worksheet, where the user needs only to fill in certain details, and sketch out a plan specific to their home using pre-qualified construction details. The building department, who is familiar with the standard plan set, can then quickly review it and issue a permit. The process is also made less expensive because there is no need to hire an engineer. Some cities including Oakland and Berkeley even offered financial incentives ranging from $5000 in rebates to a refund of 0.5% of the real estate transfer tax [4]. All of this helped to eliminate barriers and encourage homeowners to voluntarily retrofit. After implementing financial incentives, the number of seismic retrofit permits issued by Oakland went up from 6 to 360 within two years. In Berkeley, between 600 and 800 homeowners have taken advantage of the offer [4].

The standard plan set offers an excellent model for retrofitting the unstable Assam houses in Aizawl. The hillside Assam houses represent a common and specific seismic deficiency. Analogous to the weak cripple walls undermining the seismic integrity of California homes, the Assam houses also suffer from a weak understory that threatens to collapse an otherwise seismically well performing structure. In the city of Aizawl, Assam type homes represent approximately 47% of the building stock, and of these as many as a quarter may be seismically deficient [1]. A standard plan set would offer an efficient solution to retrofit these homes.

**Assam Construction**

For more than 200 years Assam has remained a common form of construction in the northeastern region of India [5]. This style uses lightweight timber construction, typically has rectangular plan dimensions ranging from 6 to 12 meters in either direction, and is only one to two stories. The walls are traditionally built by infilling the timber frame with matting made from either ikra reeds or bamboo and then plastered with a mixture of mud and dung. The roof is traditionally made from a thick layer of the ikra reed [5]. More modern versions of these buildings, including most of those found in Aizawl, use corrugated sheet metal for the roofing and asbestos panels for the walls [1]. Assam buildings are used primarily as residences. In the city of Aizawl, 94% of Assam type buildings are used as residences and they represent 42% of the total building stock [1].

Assam style homes have proven seismically resilient in past earthquakes. Due to the lightweight nature of the building, Assam houses generate lower forces during ground shaking. In addition, the
regular plan dimensions, the number of wall lines, flexible connections, and the low number of openings in the walls all help to make the structure more resilient to seismic forces. The World Housing Encyclopedia rates the seismic vulnerability of Assam structures as “Very Low Vulnerability” [5]. The document does concede that, when built on hillsides with long slender supports, the buildings are susceptible to asymmetric shaking that would likely make them vulnerable to collapse. Because the post supports under these buildings have only a modest number of braces, the understory is considerably more flexible than the main structure above. As a result much of the displacement concentrates here, and the building has the propensity to lean over and collapse. In fact GeoHazards International estimates that around 19% to 25% of Assam structures in Aizawl will collapse during an earthquake due to this collapse of the understory [1]. This would represent a collapse of approximately 10% of the total buildings in Aizawl, a substantial loss.

**Performance of Hillside Homes in Earthquakes**

The fact that the building sits on a hillside also has a significant impact on the performance during an earthquake. Due to the unequal length of the supports, the structure has a considerable torsional irregularity. First consider shaking in the down slope direction. Due to the flexible understory, the building can displace on the order of 5 cm pulling away from the hillside. The stiff connections between the main structure and the uphill foundation likely do not have the capacity or ductility to resist this kind of deformation. As a result they can become damaged or fail, resulting in serious damage, and possible collapse of the structure. Figure 2 depicts this behavior.

Next consider shaking in the cross-slope direction. As the building shakes parallel to the hillside, the edge of the building along the uphill side is nearly rigid and doesn’t displace much at all, while the edge along the downhill side is quite flexible will undergo more significant displacements. As a result, the entire building will undergo some rotation as seen in Figure 3 below. Due to this torsion, one corner tends to pull away from the uphill side foundation. This displacement highlights a torsional couple created at the ends of the floor diaphragm along the down slope walls. If the connections at the corners of these walls to the foundation don’t have enough strength and ductility to resist the rotation they can become damaged. When the earthquake reverses direction it pulls away at the other uphill corner, possibly damaging these connections as well. Cycling back and forth in this manner, the earthquake can begin to “unzip” the building from its uphill foundation.

This behavior has been most extensively documented after the 1994 Northridge Earthquake in Los Angeles. In response, the City of Los Angeles developed a set of prescriptions for voluntary retrofitting hillside homes titled Division 94. This document offered guidance to engineers in retrofitting
these hillside homes. The main components of the retrofit plan included the use of primary anchors to form a stronger and more ductile connection between the floor diaphragm and the uphill foundation in order to keep it from pulling away. It also called for secondary anchors to provide additional shear capacity, and for either shear walls or bracing to be designed to limit the deflections to 0.5% of the story height [7].

**Conclusion**

Assam houses built on hillsides are highly vulnerable to earthquake damage. Due to their long slender post supports they are at risk to excessive sidesway during an earthquake. Furthermore, as a result of their hillside location, these structures can undergo a torsional mode during an earthquake, damaging the structure’s connection to the hillside. In the city of Aizawl these vulnerable homes are a common problem that if not addressed could greatly impact the resiliency of the city after an earthquake. Under a scenario M7.0 earthquake, the collapse of hillside Assam houses could leave approximately 30,000 to 40,000 people homeless [1]. In an effort to address this widespread issue, a standard plan set has been developed that utilizes ductile anchorages between the structure and the hillside, as well as wood bracing to control lateral displacements. This plan set is only one step in encouraging homeowners to voluntarily retrofit.

The success of this standard plan set hinges on the support of the local community and the local government. Plan Set A in California was not successful just due to a well engineered plan, but also due to the support from the local Bay Area governments. Financial incentives, a streamlined permitting process, and educational information all helped to propel Plan Set A forward. Similarly, this plan set would require support from the city of Aizawl, the local Mizo carpenters associations, and community leaders. It would require financial incentives so that people can afford to retrofit, as well as a technical understanding and acceptance from the local carpenters so that these retrofits can be implemented effectively. Lastly, it would require education for homeowners, so that they can better understand their risks, and make informed decisions about retrofitting their home.

**References**