Capacitación en construcción sismorresistente con adobe de una comunidad andina

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Palabras clave: Adobe, construcción sismorresistente, transferencia tecnológica.

Resumen:
En las últimas décadas, los investigadores de la Pontificia Universidad Católica del Perú (PUCP) han desarrollado diversas técnicas de refuerzo sísmico para las construcciones de tierra (adobe o tapial). Sin embargo, ninguna de éstas ha sido adoptada masivamente por las personas a quienes van dirigidas, debido principalmente a su alto costo y a la falta de difusión. Por ello, la dirección académica de Responsabilidad Social (DARS-PUCP) está actualmente desarrollando un proyecto de capacitación en construcción sismorresistente con adobe que busca contribuir a mitigar el inaceptable riesgo sísmico de las poblaciones rurales. Se eligió como población piloto al distrito de Pullo de Ayacucho, ubicado en una zona sísmica de la sierra peruana, donde más del 80% de los pobladores viven en casas de adobe y más del 60% en condiciones de pobreza o pobreza extrema (INEI, 2007). Se está trabajando con los pobladores para que tomen conciencia de la vulnerabilidad de sus viviendas de adobe no reforzado y para que aprendan, de forma práctica, una técnica de refuerzo con mallas de cuerdas de nylon. Los resultados iniciales del proyecto muestran que los materiales y herramientas de comunicación y capacitación utilizados ayudan a incrementar la conciencia sísmica de la población y despiertan su interés en la construcción sismorresistente con adobe.

1. INTRODUCCIÓN

Las viviendas de adobe son usuales en muchas áreas sísmicas alrededor del mundo debido a su bajo costo, pese a su pobre desempeño sísmico. Cuando ocurre un sismo, las pesadas paredes de tierra no son capaces de resistir las fuerzas de inercia que se generan, la edificación se daña gravemente y puede llegar a colapsar, con las consecuentes pérdidas humanas y económicas (Blondet y Rubiños, 2014). Sin embargo, el adobe es el único material de construcción accesible para muchas familias, especialmente en áreas rurales donde los materiales de construcción industrializados son poco comunes. Por lo general, las familias construyen sus propias viviendas en colaboración con otros miembros de la comunidad, y sin ningún tipo de asistencia técnica. En consecuencia, la mayoría de comunidades rurales localizadas en áreas sísmicas, como en los Andes peruanos, viven en condiciones de riesgo sísmico inaceptables. Por ello, es urgente difundir y capacitar a la población en el empleo de técnicas de refuerzo simples y económicas para proteger a sus viviendas de adobe de los dañinos efectos de un sismo.

2. SOLUCIÓN TÉCNICA SIMPLE Y DE BAJO COSTO

Los investigadores de la PUCP y de otras instituciones vienen estudiando cómo mejorar el comportamiento estructural de las viviendas de adobe localizadas en áreas sísmicas desde hace más de 40 años (Vargas et al, 2005). Recientemente, un programa experimental de la PUCP presentó un modelo a escala de vivienda de adobe, previamente dañado, reparado con inyecciones de barro y reforzado con una malla externa de cuerdas de nylon tensadas con templadores de metal (figura 1). El comportamiento estructural del modelo reparado y reforzado, durante una secuencia de simulaciones sísmicas unidireccionales de intensidad creciente, se consideró excelente. La malla de refuerzo externa ayudó a mantener su integridad y estabilidad estructural, además de prevenir el colapso de los muros al mantener unidas las porciones separadas durante el movimiento. (Blondet et al, 2013; Blondet et al, 2014).

Figura 1. Modelo reforzado

Figura 2. Nudo de amarre propuesto

Pese a los esfuerzos de los investigadores de la PUCP y otras instituciones, la construcción espontánea de viviendas de adobe sismorresistentes en áreas rurales sigue siendo nula, debido principalmente al alto costo y a la falta de difusión del sistema de refuerzo propuesto. La malla de cuerdas tiene gran potencial para ser usada como material de refuerzo sísmico en viviendas autoconstruidas ya que es mucho más barata y accesible que los refuerzos previamente estudiados (Blondet et al., 2008a). Además, los templadores metálicos pueden ser reemplazados por un nudo pequeño y fácil de implementar (figura 2) como una alternativa de bajo costo para tensar las cuerdas (Mattsson, 2015).

3. HERRAMIENTAS PARA LA TRANSFERENCIA TECNOLÓGICA

Diversos investigadores han desarrollado técnicas de reforzamiento para mejorar la seguridad sísmica de las construcciones de tierra (Smith y Redman, 2009). Sin embargo, comunidades enteras continúan construyendo sus viviendas de la manera tradicional, sin refuerzo sísmico, y viviendo en alto riesgo sísmico (Blondet et al, 2008a). Es necesario, entonces, reducir la brecha de comunicación entre el mundo académico y las comunidades que construyen con adobe. A continuación, se presentan las herramientas de transferencia tecnológica desarrolladas por el equipo de investigación de la PUCP.

3.1. Mesa vibratoria portátil

Se diseñó y construyó una mesa vibratoria portátil para demostrar la importancia de incluir el refuerzo sísmico en las viviendas de adobe (Blondet y Rubiños, 2014). Esta herramienta permite a los pobladores observar las diferencias entre el desempeño sísmico de un modelo de adobe no reforzado y otro reforzado. El primero, que representa las casas de adobe construidas de manera tradicional, colapsa durante la simulación sísmica, mientras que el segundo se mantiene en pie y únicamente presenta daño leve o reparable. Los modelos a escala tienen una base de 400 x 240 mm y una altura de 210 mm. Las unidades de adobe utilizadas son de 40 x 40 x 10 mm. El modelo que representa una vivienda de adobe tradicional tiene dinteles en la puerta y las ventanas, pero no tiene viga collar que amarre los muros. El modelo reforzado tiene dinteles en la puerta y las ventanas, viga collar, y las paredes están envueltas con hilos que representan las mallas de cuerdas. Estas demostraciones representan de manera simple la efectividad del refuerzo sísmico: los hilos previenen el colapso del modelo a escala reducida, en forma similar a la malla de cuerdas que previene el colapso de las viviendas de adobe a escala natural.

3.2. Manual de construcción sismorresistente con adobe reforzado

El manual de construcción es un documento técnico que describe con detalle la construcción de una casa de adobe reforzada con malla de cuerdas, y está dirigido a los constructores, maestros de obra y pobladores de áreas rurales donde la construcción informal con adobe es predominante y la asistencia técnica es poco accesible. Cada parte del proceso constructivo está explicado con lenguaje simple e ilustraciones paso a paso (figura 3). Además, se proponen tres tipos de casas con diferente número de habitaciones, y se incluyen los planos de construcción.

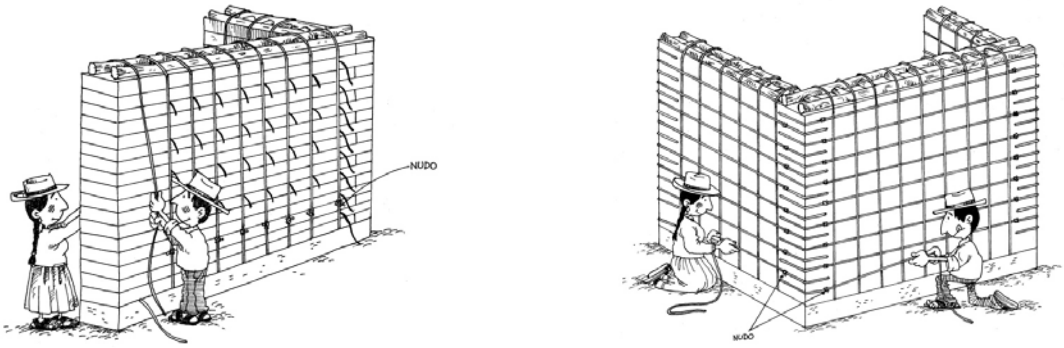

Figura 3. Ilustraciones del manual de construcción

Este manual contiene toda la información necesaria para construir una casa de adobe reforzada con malla de cuerdas: condiciones de riesgo, ubicación de la vivienda, selección de materiales, elaboración de unidades de adobe, cimentación, reforzamiento de muros y techo.

4. CASO DE ESTUDIO: PROYECTO DARS-PUCP EN LOS ANDES PERUANOS

El proyecto de capacitación tiene como idea central que las personas que viven en casas inadecuadas e inseguras no deberían simplemente recibir ayuda externa en forma pasiva. Por el contrario, deberían ser agentes de su propio desarrollo y adquirir la capacidad para construir sus propias viviendas saludables y seguras. Se trata de un proyecto interdisciplinario planteado por etapas para incrementar las probabilidades de aceptación y apropiación de la técnica de refuerzo con malla de cuerdas.

4.1. La comunidad andina de Pullo

En agosto 2014, un movimiento sísmico de 6.6 grados en la escala de Richter tuvo lugar en la región de Ayacucho de los Andes peruanos. El distrito de Pullo (figura 4) fue uno de los muchos lugares afectados por este evento. Los reportes iniciales indicaron que el 25% de los daños se concentró en este distrito: 150 heridos, 30 viviendas inhabitables y otras 150 afectadas (INDECI, 2014). Pullo es una región de alto riesgo sísmico, por lo que es urgente capacitar a sus pobladores en la construcción de viviendas de adobe sismorresistente.

(a) Ubicación geográfica (b) Plaza de armas

Figura 4. El distrito de Pullo.

Alrededor del 80% de las viviendas del distrito están hechas de adobe y han sido construidas sin ninguna asesoría técnica. Su construcción se realiza a través del proceso andino tradicional, utilizando barro de la localidad: La tierra “duerme” por un par de días y luego se mezcla con paja cortada; la mezcla se coloca en moldes de madera, se la desmolda y se la seca a la intemperie; más adelante se utiliza el mismo barro como mortero para unir los adobes y como recubrimiento de las paredes. Además de tener un efecto estético, el recubrimiento protege a las unidades de adobe de las fuertes lluvias propias de la región y de su efecto erosivo (Cribilleros et al, 2014).

Los pobladores de Pullo tienen un conocimiento empírico del pobre comportamiento sísmico de las viviendas de adobe tradicionales, no reforzadas. En promedio, las viviendas tienen más de 50 años de antigüedad y no reciben mantenimiento por parte de sus propietarios. Además, la baja conciencia sísmica de la población hace que los propietarios no inviertan en reforzar sus viviendas. En consecuencia, el daño observado responde claramente a la falta de criterios de diseño sismorresistente durante el proceso constructivo (ausencia de viga collar y juntas de mortero de gran espesor).

4.2. Sensibilización de la población

En mayo 2015 se inició en el distrito de Pullo la primera etapa del proyecto de capacitación en construcción sismorresistente con adobe reforzado con cuerdas. La sensibilización tuvo un enfoque interdisciplinario, y estuvo a cargo de ingenieros civiles, una comunicadora y una psicóloga. Para conseguir el interés de los pobladores se realizaron entrevistas e invitaciones individuales sin discriminación de ningún tipo y se convocó a personas de toda edad y género (hombres y mujeres adultos, ancianos y niños). Además se realizaron entrevistas grupales con los principales actores de la comunidad, para así comprometerlos en la difusión del taller. La asistencia fue voluntaria y no hubo ningún tipo de condicionamiento o incentivo monetario.

La metodología de sensibilización consistió en la presentación de los objetivos del proyecto, acompañada de videos motivacionales intercalados con preguntas a los asistentes. Se mostró un video del sismo de Huaraz (Perú, 1970), seguido de la pregunta abierta: "¿Alguna vez se han sentido así?". Luego, se presentó un video motivacional sobre la construcción con adobe sismorresistente (Blondet et al, 2008b) y videos de los ensayos en el Laboratorio de Estructuras de la PUCP, siempre enfatizando la pregunta: "¿Creen que la construcción con adobe pueda ser sismorresistente?". Las respuestas de los pobladores evidenciaron su miedo a perder la vida durante los terremotos, su falta de confianza en el adobe y su desconocimiento previo de técnicas de reforzamiento que ellos pudieran aplicar en sus viviendas. Para finalizar, se invitó a todos los participantes a que vieran la demostración con la mesa vibratoria portátil y luego a intentar "derrumbar" el modelo reforzado y comprobar por ellos mismos su resistencia (figura 5).

Figura 5. Demostraciones con la mesa vibratoria portátil PUCP

4.3. Capacitación de la población

En septiembre 2015 se inició la segunda etapa del proyecto de capacitación. El equipo de trabajo viajó previamente a la comunidad para coordinar y difundir el taller. Se realizó una pequeña campaña de difusión

mediante la colocación de afiches en lugares estratégicos de la comunidad, llamadas telefónicas a personas clave para recordar la fecha y horarios de las sesiones, y anuncios con el megáfono local.
Primero se introdujo de manera general la técnica de reforzamiento con malla de cuerdas. Se explicaron las características de una vivienda sismorresistente y los pobladores pudieron observar dichas características en un modelo a escala reducida, que fue puesto a prueba en la mesa vibratoria portátil PUCP. Se enseñó el proceso de amarre del nudo propuesto, y se entregaron porciones de driza para que los participantes practiquen. Por último, los participantes practicaron la colocación de las cuerdas horizontales y verticales en un muro de cerco de un local comunal (figura 6).

Figura 6. Sesión práctica de colocación de cuerdas horizontales y verticales en muro de cerco

Las siguientes sesiones de capacitación estarán orientadas al aprendizaje práctico de la construcción sismorresistente con adobe, mientras se realiza la construcción de un local público. Cada sesión girará en torno a un tema específico: la elaboración de adobes; la colocación de cimientos y sobrecimientos; el levantamiento de muros; la importancia y colocación de la viga collar; la colocación de la malla de cuerdas y su recubrimiento; y finalmente, la colocación del techo. Los trabajos de construcción serán llevados a cabo por los participantes del taller y, al finalizar, se darán certificados de capacitación.

5. RELEVANCIA DEL ESTUDIO DE CASO

El estudio de caso ha permitido validar la metodología de sensibilización propuesta con los pobladores de una comunidad andina. La demostración con la mesa vibratoria portátil impactó positivamente a la población y ejemplificó, de manera adecuada, el comportamiento que las viviendas de adobe reforzadas y no reforzadas tienen durante un sismo. Más aún, la población identificó sus viviendas con el modelo a escala reducida no reforzado y admitió en voz alta la importancia del refuerzo sísmico (hilos de nylon) en el modelo a escala reducida reforzado. Se concluye, entonces que la metodología de sensibilización incrementó la confianza de la población en el refuerzo sísmico y además incrementó su interés en los siguientes talleres de capacitación ofrecidos.

Se sugiere, entonces, incluir una etapa previa de sensibilización para futuras investigaciones y proyectos de capacitación que tengan por objetivo la transferencia de conocimientos en comunidades rurales. Más aún, se espera que las herramientas y metodologías desarrolladas sean utilizadas y distribuidas en futuros proyectos de capacitación en otras comunidades donde predomine la construcción con adobe. De esta manera, se logrará que más familias puedan tener acceso a viviendas de adobe sismorresistentes y se mitigará el inaceptable riesgo sísmico de muchas poblaciones rurales.

6. COMENTARIOS FINALES

La construcción tradicional con adobe, sin refuerzo sísmico, debería evitarse en áreas sísmicas. Sin embargo, es una realidad problemática que debe solucionarse con urgencia. El desafío no sólo está en encontrar soluciones técnicas accesibles y de bajo costo para las poblaciones rurales, sino también en desarrollar herramientas de comunicación y capacitación efectivas que permitan difundir dichas soluciones entre las poblaciones rurales ubicadas en áreas sísmicas.

El éxito inicial de la metodología de sensibilización es alentador. Sin embargo, se requiere un esfuerzo sostenido para lograr un impacto verdadero. Entrevistas personales y conversaciones informales evidenciaron el interés de los pobladores en ser capacitados. Hubo, sin embargo, dificultades para la programación de los talleres. Se sugiere la utilización de medios de comunicación masivos, como la radio, para lograr un mayor alcance y aumentar el número de participantes en el proyecto.

El trabajo no ha sido sencillo y aún no ha finalizado. Si bien los involucrados en este proyecto son optimistas y creen que sus esfuerzos ayudarán a mejorar las condiciones de vida de decenas de familias en el poblado de Pullo, ésta sólo es una de las muchas comunidades rurales sísmicamente vulnerables alrededor del mundo. Es una necesidad urgente difundir y capacitar a la población en la construcción sismorresistente con adobe reforzado, especialmente allí donde el riesgo sísmico sea inaceptable, ya que sólo así podrá evitarse la trágica pérdida de vidas humanas en futuros eventos sísmicos de gran magnitud.

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Sustainable Dissemination of Earthquake Resistant Construction in the Peruvian Andes

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Abstract

This article describes the challenges and initial accomplishments of a project developed by the Pontifical Catholic University of Peru (PUCP) to disseminate technology and to train low-income families in the Andes Mountain region to build earthquake-resistant homes made of adobe bricks. The initiative has focused on improving the livability of households through affordable seismic reinforcement of traditional construction processes as a means to enhance the social sustainability of housing in the area. We selected the rural Andean community of Pullo as a case study because of its preponderance of non-reinforced adobe construction and poverty. The research team developed tools and methodologies for technology transfer, worked with local residents to raise awareness of the high seismic vulnerability of indigenous dwellings, and introduced the concept of seismic reinforcement. This article explores the barriers to disseminating earthquake-resistant technology in the study area and presents adaptive measures to overcome these challenges. Initial results demonstrate the positive impact of educational workshops to raise seismic awareness and to introduce earthquake-resistant construction among rural dwellers. The project is deemed to have wider applicability to other communities in seismic areas with similar housing, social, and economic conditions.

Keywords: adobe, housing, safe construction, technology transfer

Introduction

Researchers at the Pontifical Catholic University of Peru (PUCP) and other institutions have been working to improve the structural safety of earthen houses located in seismic areas of Peru for the last four decades (Vargas et al. 2005; Blondet & Aguilar, 2007). The project has resulted in development of reinforcement techniques for reconstruction and training programs by nongovernmental organizations (NGOs) following major earthquakes (Blondet et al. 2008a; Macabuag & Quiun, 2010). Unfortunately, efforts to encourage the uptake of these technologies in local communities have largely failed. People continue to build in the traditional way and not one person in the rural Peruvian Andes has independently built his or her house using the proposed reinforcement techniques (Blondet & Aguilar, 2007; Macabuag & Quiun, 2010). In an attempt to solve this problem, PUCP has developed a new training program in earthquake-resistant adobe construction that incorporates a previous educational campaign to increase acceptance among dwellers. This article examines the value and success of this project for disseminating new building technologies.

The research reported here contributes to literature on sustainability education and the social aspects of housing in the Peruvian Andes. The intention is not to assess the sustainability of a single reinforcement technology, but rather to investigate the effectiveness of the technology after educating the population about the importance of seismic reinforcement. In particular, we address the challenges of taking technology from the academic world, where it is conceived in a theoretical way, and implementing it in rural towns where reality is much more complex. The study area is located in the Peruvian Andes and we focus in particular here on work carried out in the rural community of Pullo which has been selected because of its high seismic vulnerability, both in terms of poverty and building techniques, and the hazard signaled by recent seismic events.

This article is structured as follows. It begins with background on the initiative and the proposed technology, including the technology-transfer tools relevant to the project. We then identify the major challenges of technology transfer that the research group encountered, focusing on issues, pertinent in the rural town, of trust, literacy, cultural differences, lack of permanent personnel, and transportation. It also highlights the adaptive measures taken to overcome those challenges such as audiovisual resources, creative advertising methods, private transportation, among others. Next, it describes the familiarizing educational experience and concludes with a brief discussion about the proposed technology, the technology-transfer experience, and the initiative's success.

Background

To provide a more complete picture of the work presented in this article and how it contributes to sustainable implementation of earthquake-resistant housing in rural Andean communities, we describe some of the background context. This section also discusses the relationship between social sustainability and housing to provide a deeper understanding of the importance of communicating about earthquake-resistant construction. We then present the PUCP initiative as an example of the human development-capability approach, which provides an opportunity to apply innovative technology-transfer tools and to critically assess their effectiveness for future projects. Finally, it describes the seismicity of the study area and develops an overall characterization of its housing conditions to create a more detailed depiction of the Andean area of Peru.

Social Sustainability and Housing

Sustainable development of a community is based on achieving balanced economic growth, environmental protection, and social progress (McKenzie, 2004; Adams, 2006). Development should provide an acceptable quality of life both for individuals and communities and maintain healthy financial markets while preserving natural resources by assuring that depletion does not occur more rapidly than replenishment (Fisher & Amekudzi, 2011). Balancing these objectives means that the various sustainability dimensions are not isolated, but that an integrated view is maintained. For example, social and environmental aspects of sustainability are interwoven because degraded natural resources can compound social inequity and segregation, conflicts, instability, and dissension (Chiu, 2003).

Social sustainability is essential for sustainable development, although there is no consensus on how to incorporate it in practice (Cuthill, 2010; Casula Vifell & Soneryd, 2012). Sustainable communities are places where people want to live and work, now and in the future (ODPM, 2006), and socially sustainable communities need to feature equitable outcomes, diversity, connectivity, and democratic governance to provide a high quality of life (WACOSS, 2000). However, despite the importance of social sustainability, the economic and environmental dimensions are prioritized in planning housing and communities (Woodcraft, 2011) and this neglect of social sustainability is particularly paramount in the case of housing (Dempsey et al. 2011).

The social dimension of sustainable housing includes different physical and non-physical aspects of construction, design, and livability that residents consider as an acceptable quality of housing (Chiu, 2003; Dempsey et al. 2011). Decent housing provides shelter, basic to community well-being (Magis and Shinn, 2009). However, beyond shelter, housing should also promote social integration and safeguard the environment to preserve the ability of future generations to meet their needs (Murphy, 2012). Furthermore, housing only promotes well-being if planners understand what people need from the places in which they live and work (Woodcraft, 2011).

Therefore, to achieve social sustainability at the community scale, housing should promote well-being and not only meet basic needs. This objective can be achieved by improving the livability of structures where livability is understood to create conditions for healthy, safe, affordable, and secure households within a neighborhood with access to utilities, transport, healthcare, and education (Mitlin & Satterthwaite, 1996). This article concentrates on how to implement safe and affordable housing as a first step to improving the livability of households and thus the social sustainability in rural communities of the Peruvian Andes, though the lessons can be more widely applied.

The PUCP Training Project

The technology-transfer initiative described in this article is part of a larger PUCP training project that aims to provide sustainable earthquake-resistant housing for Andean communities. The effort is based on experiences from a small-scale reconstruction program developed by PUCP and CARE-Peru (a nongovernmental organization (NGO) specializing in development) after the Pisco earthquake of August 2007 (Blondet et al. 2008a). The project is interdisciplinary, bringing together partners from engineering, psychology, anthropology, history, and communications with the goal of achieving acceptance of seismic reinforcement among homeowners and residents in Andean communities.

The central idea of the initiative is that people should not be mere recipients of external aid, but become agents of their own development by acquiring the skills to live the life they want (Sen, 2000). In this project, this means that people living in adobe dwellings should learn how to build earthquake-resistant houses by themselves. Therefore, the program consists of training community members in the construction of safer adobe houses using a simple low-cost reinforcement technique. The expectation is that the acquired skills will allow community members to continue improving their housing conditions once the project is over, thus enhancing their quality of life in an ongoing and sustainable way. There is the additional prospect that trained community members could use their acquired skills to earn income as technicians on construction projects.

The PUCP training initaitive is divided into three phases to increase acceptance of the reinforcement technique, ease the technology-transfer process, and create a platform where trained people can work on similar projects:

- *Phase One*: Familiarizing educational workshops that includes field demonstrations using a portable shaking table and scaled models. The main objectives are to educate community members about the high seismic vulnerability of their dwellings and to show the value of building earthquake-resistant adobe houses.
- *Phase Two*: Training workshops that consist of teaching community members how to build an improved earthquake-resistant adobe house using a simple low-cost reinforcement technique through an illustrated construction manual. The main objectives are to train community members through practical skills and to provide a reference document for future construction. The developed skills (capacities) are applied in the construction or reinforcement of a community building with the collaboration of all inhabitants.
- *Phase Three*: Assessment based on identifying improvements for future training programs. The project’s success is evaluated by the application of the technique beyond the structures built during the training (e.g., the number of independently built or reinforced houses). Another potential outcome to assess is the extent to which local governments have developed similar training programs.

The Andean Community of Pullo

Pullo is a small rural community located in the Ayacucho region of the Peruvian Andes (Figure 1). Earthquakes are relatively common in this area because it sits near the boundary between the Nazca and South American tectonic plates, and local news report an average of one seismic event per yearIn August 2014, an earthquake registering 6.6 on the Richter scale injured almost 150 people, adversely affected 150 houses, and rendered 30 of these structures uninhabitable (INDECI, 2014). After this last event, Cáritas, a local NGO, asked the Academic Direction of Social Responsibility of the PUCP (DARS-PUCP) to assess the post-earthquake situation in Pullo in terms of both structural damage and psychological effects. The team also identified community leaders (e.g., local and church authorities and the Commoners' Association) who might serve as potential collaborators for organizing and advertising future projects (Cribilleros et al. 2014).

(a) Geographical location. (b) Main square.

Figure 1. The Andean community of Pullo.

Despite the region's seismicity, almost 80% of houses in the area are made of traditional adobe (sundried mud bricks) and built without technical assistance or seismic reinforcement techniques. Dwellers know that non-reinforced adobe houses have very poor seismic performance (Figure 2). However, sadly, more than 30% of the rural population lacks access to industrialized materials and more than 60% live in poverty or extreme poverty without access to utilities like water and electricity (INEI, 2007). Therefore, adobe is the only affordable and available housing for many families. Furthermore, lack of awareness of construction techniques prevents homeowners from investing additional time and money on seismic reinforcement or repair of existing damage (Blondet et al. 2008b). As a consequence, observed damage corresponds to lack of seismic-resistant building techniques during construction (absence of collar beams and presence of excessive thickness of mortar joints) and insufficient maintenance over the years (Cribilleros et al. 2014).

Figure 2. Inhabited damaged adobe house.

Technology

Adobe buildings are highly vulnerable to earthquakes, although over the years several reinforcement techniques have been developed to strengthen structures against seismic events (Zegarra et al. 1997; Minke, 2001; Iyer, 2002; El Gadawy et al. 2004; San Bartolomé et al. 2004; Blondet et al. 2006; Turer et al. 2007; Smith & Redman, 2009). However, the availability of technical solutions is not sufficient because this knowledge is mainly limited to academics (Blondet & Rubiños, 2014). Entire communities continue to build houses with the traditional non-reinforced adobe-construction technique, leaving them exposed to extremely high seismic risk (Blondet & Aguilar, 2007). Therefore, the first step toward sustainable earthquake-resistant housing is reducing the communication gap between academia and earthquake-prone communities. The next section briefly presents one simple, low-cost, and highly available seismic reinforcement, the nylon-rope mesh, and the communication strategies and educational tools PUCP previously developed to disseminate this technology in the Peruvian Andes.

Nylon Rope-Mesh Reinforcement

The nylon-rope mesh is a recent reinforcement technique developed by PUCP (Blondet et al. 2013). In 2013, a pilot project demonstrated that a previously damaged full-scale adobe model could be repaired via mud injection combined with an external mesh made with nylon strings (Figure 3). The reinforcement procedure consisted of covering the walls with a mesh made of horizontal and vertical ropes tightened by turnbuckles; later, the mesh on both faces of each wall were joined together by thinner ropes (crossties). During a sequence of unidirectional earthquake motions of increasing intensity, the structural behavior of the repaired and reinforced model was considered excellent. The external reinforcements worked to maintain structural integrity and stability and prevented the partial collapse of wall portions that had separated during the shaking (Blondet et al. 2014).

Figure 3. Full-scale adobe model reinforced with nylon rope mesh.

The PUCP training project selected the nylon-rope mesh due to its great potential as a sustainable reinforcement technique for low-cost earthen dwellings in seismic areas (Blondet et al. 2013, 2014). The reinforcement procedure is considered simple enough to be learned without any previous technical knowledge in construction; it does not require extra machinery, and it produces no additional pollution compared to non-reinforced adobe construction. Additionally, nylon ropes are widely available at local stores, while most natural reinforcement materials are not easily obtained in large quantities in the Peruvian Andes. Furthermore, the nylon-mesh technique costs US$120 at most for reinforcing a typical single-floor two-room adobe house, which is less than other industrialized reinforcements (Blondet & Aguilar, 2007; Blondet et al, 2008a).

Portable Shaking Table Demonstrations

The portable shaking table is a tool developed to raise awareness of the high seismic vulnerability of non-reinforced adobe dwellings and to build confidence in reinforced adobe construction among rural communities (Blondet & Rubiños, 2014). During demonstration sessions, two reduced-scale adobe models were tested simultaneously, with the differences in their seismic performance easily observed (Figure 4). The non-reinforced adobe model collapses just like traditional Andean adobe houses during an earthquake, but the reinforced model does not collapse even though it can suffer light, moderate, severe or even unrepairable damage. The nylon-thread mesh prevents the collapse of the reinforced model as the nylon-rope mesh did on the test program, thus showing the effectiveness of the nylon-rope mesh to protect adobe houses from earthquakes.

Figure 4. Differences on seismic performance of reduced scale adobe models.

The Construction Manual

The construction manual is a technical document that describes in detail how to reinforce an adobe house with nylon ropes. Each step of the construction process is described with familiar, simple language and clearly illustrated with easy-to-follow drawings (Figure 5). Furthermore, the manual presents three types of houses that differ in the number of rooms and shows their construction plans in detail. This educational tool is mainly directed to masons and residents of rural areas where informal construction with adobe is prevalent and technical assistance is not easily available.

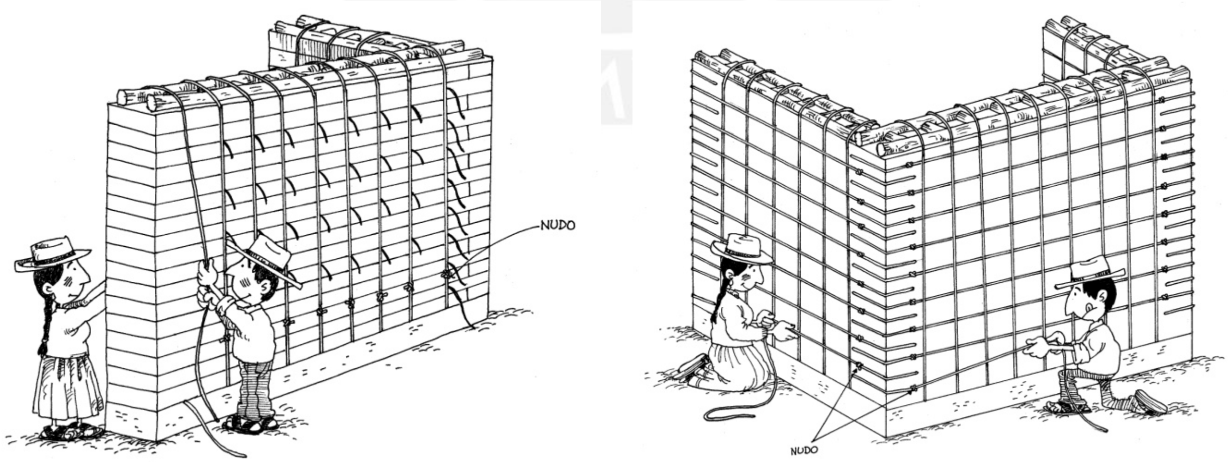

Figure 5. Illustrations from the construction manual.

Dissemination Challenges and Adaptive Measures

The reinforcement systems that the PUCP project team has studied have proven that adobe construction can be earthquake resistant. Indeed, the application of technical solutions would provide enough structural safety to prevent collapse of earthen buildings, thus, protecting human life (Blondet et al. 2008b). Moreover, low-cost reinforcement technologies would allow dwellers to improve livability of their households, building social sustainability into construction design. However, despite the benefits of safer affordable housing, disseminating earthquake-resistant technology faces a number of impediments among dwellers, as discussed below.

Trust

Many adobe dwellers resist changing their building techniques because they dislike external interference in their traditional practices (Blondet, 2011). Therefore, the first challenge of disseminating earthquake-resistant technology is to build trust in the research group and the proposed technology. When first mentioned at the beginning of the workshop, the idea of earthquake-resistant housing raised suspicion and skepticism among residents who consider adobe extremely vulnerable to earthquakes and aspire to masonry structures considered to be "noble" and "resistant" but unaffordable for most rural dwellers (Blondet et al. 2008b; Cribilleros et al. 2014).

We employed two different strategies to overcome this distrust. First, we presented ourselves, the motivation for the project and what we hoped to achieve in the community to community leaders in order to build trust with the research group and regarding the project, as unknown strangers or projects are easily considered hostile and suspicious. This allowed us to establish an initial relationship, so that community leaders later helped engage the population (Pérez-Salinas et al. 2014). Second, during the workshop we included selected motivational and laboratory test videos from previous projects that showed the effectiveness of seismic reinforcement in addition to the live portable shaking-table demonstration.

Literacy

Another challenge we encountered while assessing the earthquake preparedness in Pullo was illiteracy. Most community members only have an elementary school-level education and close to 15% of the population is not able to read (INEI, 2007), requiring explanations using simple language. More importantly, a high illiteracy rate required us to consider inclusiveness in the training program since required skills could lead to social exclusion, lack of access, and conflicts (Khan et al. 2015). To overcome this barrier, we planned the educational familiarizing and training phases of the project around audiovisual resources, oral explanations, live demonstrations and exercises, and step-by-step illustrated printed materials.

Cultural Differences

One obstacle during training-session planning was finding dates and schedules that respected the cultural expectations in the Pullo community. A culture is a set of acquired forms and ways to understand the world, to think, to speak, to express oneself, to perceive, to act, to socialize, to feel, and to value oneself as an individual and part of a group (Heise et al. 1994). Peruvian rural villages have different traditions and festivities from each another and from the country's urban areas. For instance, Pullo has a flag-raising ceremony on Sundays which also serves as an open space to bring up community issues. In addition, Andean communities have subsistence economies based on agricultural activity and residents prioritize certain times of day to farm and take care of cattle.

In this context, we used several strategies to find appropriate meeting times and places. In particular, we considered the different civil and religious traditions and festivities to respect community beliefs. Special events, such as the *chacco de vicuñ* (a traditional Andean wool-shearing process), were avoided in planning activities, as were agricultural working hours. As a result, two-hour Saturday afternoon and two-hour Sunday morning sessions were validated with community members and main leaders. Additionally, we followed traditional protocol by asking local authorities to welcome participants at the beginning of each session.

Lack of Personnel in the Study Area

Perhaps the biggest challenge that we encountered during this initiative was the lack of university representatives in the study area. Institutions organizing educational workshops would benefit from local familiarity and the ability to assemble 80 to 150 people (InWent & Mesopartner, 2005). Lack of such an institution made it difficult to coordinate and advertise educational and training sessions when other communication was limited.

The project team implemented several strategies to overcome this problem such as conducting personal and group interviews with community leaders to enroll their help with advertising; greeting participants upon arrival and departure using a megaphone; placing posters with simple, familiar, and inviting language in strategic places such as the main square and local stores; making regular telephone and cellular calls to remind community leaders of upcoming sessions; and finally, using some specific field trips for promoting the events. However, these adaptive measures had to be continuously assessed to improve less successful components.

Transportation

Transportation was a logistics challenge on our first trip to the Pullo community because of the number of different legs required to reach the village. The trip entails a seven-hour bus ride from Lima to Nazca, a two-hour minivan ride from Nazca to Acari, and a four- to six-hour truck ride from Acari to Pullo. The duration of the truck part of the trip depends on the different routes, including dirt roads frequently closed due to mudslides during the rainy season. More importantly, transportation became a bigger dilemma while transporting the portable shaking table, which was too big and heavy to take in the bus or the minivan. We had to hire special private transportation for the first trip, and on following journeys a truck replaced the minivan.

The difficulty reaching Pullo also highlights the need for this project. External aid from the government, NGOs, and other institutions is minimal due to Pullo's remoteness, and so its inhabitants must rely their own wherewithal in the face of earthquake emergencies (Cribilleros et al. 2014). However, knowledge of the attendant risks, and ability to anticipate and reduce potential consequences of a disaster (resilience), could increase the speed of recovery after a seismic event (Fitzgerald & Fitzgerald, 2005).

Familiarizing Educational Experience

In May 2015, we began the PUCP training program in earthquake-resistant construction in the district of Pullo. We assembled an interdisciplinary team, which included three civil engineers, one psychologist, and one communicator, to travel to the community. The main objective of the trip was to conduct a familiarizing educational workshop with participants from all ages and genders. Attendance was free and voluntary; participants did not receive any form of compensation. However, to increase community interest in the educational workshop, we conducted a small promotional campaign on arrival.

Fifty-three community members, including men, women, seniors, and children, attended the two-hour familiarizing educational workshop. First, we presented ourselves and the results from the evaluation conducted during the first visit, then we presented the motivation for the project and what we hoped to achieve in the community. The team was careful to avoid misunderstanding or misinterpretation: participants would not be given construction materials but would receive training in earthquake-resistant adobe-construction techniques.

As an introduction to the familiarizing educational part of the workshop, we showed a video from the 1970 earthquake in northern Peru. The team asked participants open questions (e.g., “How did you feel watching the video?”) that allowed community members to express their thoughts—and fears—about earthquakes and how they perceived their adobe houses. Participants confirmed the need for safer housing in Pullo. They regarded adobe to be a brittle material, but the only one they could afford; thus, they feared losing their households and their lives to earthquakes.

Next, the project team elicited responses to one specific question: “Do you believe construction with adobe can be earthquake resistant?” Participants unanimously answered in the negative. Expecting this answer, the team showed previously selected technical and motivational videos showing the effectiveness of seismic reinforcement, while adding commentaries and questions for the audience. The final video presented the full-scale adobe model reinforced with the nylon-rope mesh and tested in the full-scale shaking table at PUCP. Some questions from the participants showed their interest (e.g., “How thick do the ropes have to be?”) while others showed skepticism (e.g. “So those thin ropes are going to protect my house from earthquakes?”).

We later conducted the shaking table test on the reduced scale models in front of all the participants. This live demonstration allowed community members to observe up close the expected seismic performance of a non-reinforced adobe house during an earthquake (Figure 6). When we asked them which house behaved like theirs during an earthquake, they identified the non-reinforced model. After the shaking table test, they commented on the importance of seismic reinforcement for the enhanced model. Finally, we repeated the description of the PUCP training project and its main objectives and asked participants if they wanted to register for future training workshops.

Figure 6. Dynamic test with the portable shaking table.

Discussion

The Technology

Nylon ropes are well known, available, and affordable in rural areas, unlike other industrialized materials such as polymer mesh or wire mesh with cement mortar. On arrival in the Pullo community, the team found the nylon ropes needed to reinforce a dwelling at two different local stores in various colors and sizes. While reinforcing with the nylon rope-mesh technique increases a dwelling's cost by US$3–4 per square meter, this is considered affordable as very poor and poor families in Peru have an average income of US$700–1,000 per year and usually invest US$20–30 per square meter in constructing their dwellings (Macabuag & Quiun, 2010). However, the team noted that the metal turnbuckles used in the laboratory tests are relatively unknown and expensive for the Peruvian Andes; additional research at PUCP suggests that residents could replace them with knots (Blondet et al. 2015).

The nylon-rope mesh and other reinforcement techniques studied by PUCP researchers have only been developed for one-story buildings (Vargas et al. 2005; Blondet & Aguilar, 2007). However, in the rural Peruvian Andes, building adobe dwellings without technical assistance often leads to the unregulated construction of two- or three-story earthen buildings despite their illegality under the Peruvian Building Code. Therefore, the team was concerned when community members asked if this technology could be applied on their already existing two-story dwellings. Unfortunately, as of now the nylon-rope mesh has only been used to reinforce one-story dwellings and further research is needed to examine if this technology can also be used with similar results for multi-story dwellings.

Educational Experience

The educational workshop applied many strategies to sharing knowledge about earthquake-resistant construction in the Peruvian Andes. The schedule for these events and the small promotional campaign was aimed at increasing the number of participants. In addition, the live portable shaking table demonstration and the selected audiovisual materials were focused on overcoming barriers to trust while also avoiding social exclusion due to illiteracy.

Using the portable shaking table as a communication tool generated a playful environment that raised interest and confidence among community members. After the live demonstration, the team asked participants to raise their hands if they believed earthquake-resistant construction with adobe was possible. The answer was affirmative and unanimous (Figure 7). Later, through informal conversation, participants confirmed this belief to the different members of the team. This interaction appeared to successfully motivate Pullo's inhabitants and establish relationships with the team. Moreover, by bringing elements of research into the field, the team was able to show people the efforts made by PUCP to find sustainable housing solutions for them. Therefore, we considered the educational workshop successful as it increased confidence in the nylon-rope mesh as seismic reinforcement and raised interest in upcoming training workshops.

Figure 7. Participants raising hands as a sign of confidence in the proposed technology.

Despite the initial success overcoming barriers to trust, the number of participants represented only approximately 1% of the total population of Pullo, much of which is scattered across farming lands. Therefore, we plan to repeat the educational methodology using the live portable shaking table demonstration to reach a wider audience and to reinforce trust with community members.

Success of the Initiative

In the long term, the success of the PUCP training project will be measured by the number of repaired houses and new houses that use nylon rope-mesh reinforcement. Full assessment of the technique's acceptance is not possible at this early stage, but one optimistic indicator occurred at the end of the educational workshop when 32 out of 45 adult participants signed up for upcoming training sessions. The registration process involved community members writing their full names, providing identity-card numbers, and signing; illiterate participants could dictate their information to team members (Figure 8). In total, over 70% of participants committed to the training program

Figure 8. Participants registering for upcoming training sessions.

Conclusion

Technical solutions to reinforce adobe dwellings exist although they vary in cost and accessibility. The main challenge is not to develop affordable and more sustainable solutions (Ness & Akerman, 2015), but rather to disseminate these alternatives to communities. Greater emphasis must be placed on developing educational tools and methodologies that can handle the difficulties and unexpected challenges that arise during the technology-transfer process.

Our initial success reaffirms the importance of a familiarizing educational phase to achieve sustainable dissemination of earthquake-resistant construction. The educational workshop succeeded among inhabitants of Pullo as it raised awareness and willingness to participate despite multiple challenges. We recommend that future studies and training programs include a familiarizing phase when working with technology transfer in rural communities. More importantly, the project team envisions that, if the project succeeds, the communication and educational tools that we have developed might be applicable in other areas where people build with earth—specifically in the poorer areas of Peru and other Andean countries—with the hope of improving household livability for more families.

Our work has not been easy and is not finished. The project team continues to conduct research in rural Andean communities and this ongoing learning process is aimed at planning and improving appropriate workshops. Without such understanding, community members are unlikely to adopt the proposed technology despite its benefits. However, the people involved in this initiative are optimistic that their efforts will improve household livability for many families and contribute to a process toward social sustainability of housing in the Peruvian Andes.

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