A Proposal for a Comprehensive Approach to Safer Non-engineered Houses

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Abstract

Reducing earthquake disasters in non-engineered houses is an acute issue because they are a main cause of human casualties worldwide. Since non-engineered houses differ from engineered houses in many respects, the authors conducted a comparative study and clarified the characteristics of the former. Based on this study, they found that reducing disasters in non-engineered houses would require appropriate seismic technologies to be adopted by communities and effective channels to disseminate technical knowledge. Further, a comprehensive approach covering a wider field of activity and effort was found to be necessary as users/dwellers of non-engineered houses are low/middle-income people and a professional housing supply sector usually does not exist for such houses. This paper reports on the characteristics of non-engineered houses, indicates the items to be tackled in reducing earthquake disasters in such dwellings, and proposes an approach to safer non-engineered houses consisting of key issues and a comprehensive approach.

Keywords: earthquakes; disaster reduction; non-engineered houses; comprehensive approach

1. Introduction

Every large-scale earthquake causes widespread social damage and, most tragically, human casualties. The 2008 Wenchuan earthquake in China reminded us of this once again. The main cause of human casualties is the collapse of houses of common people (Fig.1.), often called "non-engineered" houses because they are built with little or no intervention by engineers. In spite of this critical situation, few researchers and engineers have paid attention to such houses. The report "Living with Risk: 2004 Version," by the UNISDR (United Nations International Strategy for Disaster Reduction), clearly describes the situation: "It remains something of a paradox that the failures of non-engineered buildings that kill most people in earthquakes attract the least attention from the engineering profession."

The authors have been involved in several projects on safer non-engineered houses, have conducted collaborative research and development with researchers in Asian countries, and recognize that non-engineered houses are different in various respects from engineered houses. This paper compares non-engineered with engineered houses, analyzes the characteristics of non-engineered houses, and proposes an approach to mitigate disasters caused by earthquakes. Their findings are based on field surveys of damage caused by earthquakes and on their experience with projects involving non-engineered houses listed below.

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This paper describes the general state of non-engineered houses in the following chapters though the authors found several exceptions of traditional houses which show good seismic performance. It discusses approaches for safer non-engineered houses focusing on construction of new houses as another issue of retrofitting of existing houses which has different aspects and should be covered under another paper.

Field surveys of damage caused by earthquakes:
- Northern Pakistan earthquake, October 2005
- Central Java earthquake, May 2006
- Pisco earthquake, August 2007
- Wenchuan earthquake, May 2008

Technical contribution to reconstruction projects and technical cooperation projects:
- Reconstruction project following earthquake and tsunami disasters in Aceh and North Sumatra, Indonesia, in December 2004, by the Multi Donor Fund (MDF) managed by the World Bank (activity duration: May 2006 – August 2006)
- Reconstruction project following earthquake disasters in Central Java, Indonesia, in May 2006 by the Japan International Cooperation Agency (JICA) (activity duration: October 2006 – March 2007)
- Reconstruction project following earthquake disasters in Ica Province, Peru, in August 2007 by the Japan International Cooperation Agency (JICA) (activity duration: February 2008 – April 2009)
- Dissemination of low cost technology for seismic houses in Peru, Part II, by the Japan International Cooperation Agency (JICA) (activity duration: April 2007 – May 2010)
- Earthquake Disaster Reduction Program in the South Asia Region by the United Nations Development Program (UNDP) and Asia Disaster Reduction Center (ADRC) (activity duration: May 2008 – May 2010)

Research and development project
- Collaborative Research and Development Project for Disaster Mitigation on Network of Research Institutes in Earthquake Prone Areas in Asia by the Building Research Institute (BRI), National Research Institute for Earth Science and Disaster Reduction (NIED), National Graduate Institute for Policy Studies (GRIPS), and Mie University financed by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) (activity duration: July 2006 – March 2009)

2. Comparison of Non-engineered and Engineered Houses

A great variety of non-engineered houses exist in the world: adobe or earthen houses in dry areas; stone masonry houses where stones are easily obtained; wood houses where timber is available; and brick houses where people have accepted and begun to manufacture new materials. In its 1986 publication *Guideline for Earthquake Resistant Non-engineered Construction*, the International Association of Earthquake Engineering (IAEE) characterized non-engineered houses as "buildings which are spontaneously and informally constructed in the traditional manner without intervention by qualified architects and engineers in their design." (This is a pioneer publication and still one of the most reliable and complete technical documents in the field.) In spite of the variety of materials that comprise non-engineered houses, we can find certain common characteristics, as shown in Table 1. Table 1 shows that differences between engineered and non-engineered houses exist not only in technical respects, but also in workers and users/dwellers, implying that the problems of non-engineered houses are not only technical, but are broadly related to social and economic issues.

![Fig.2. Comparison of Non-engineered and Engineered Houses](image)

| Items                          | Non-engineered | Engineered |
|-------------------------------|----------------|------------|
| **Materials**                 | Available in the area | Usually controlled in size, quality etc |
| **No control in quality etc** | Non- or semi skilled workers | Skilled workers |
| **Construction Workers**      | Little or no intervention | Intervention in design, construction procedures |
| **Technical Intervention**    | Low or middle income | Middle or high income |
| **Users/dwellers**            | Poor/Unsafe     | Good/Safe  |

3. Characteristics of Non-engineered Houses

Fig.2. illustrates the comparison of non-engineered and engineered houses. The gray circle, representing the distribution of non-engineered houses, is situated in the lower left quadrant, showing that the quality of most such houses falls under the level required by building codes or guidelines (the vertical axis), and the workers, mostly non- or semi-skilled (often the house
dwellers themselves), who have little opportunity to receive technical information/training, fall under the required level (the horizontal axis). The size of the gray circle also shows that the range of quality of non-engineered houses and workers is wider. In contrast, the circle representing the distribution of engineered houses is situated in the upper right quadrant, as the quality of both houses and workers are usually above the required level. The workers are trained and often qualified by several types of qualification schemes, and construction of the houses themselves are subject to institutional procedures such as building permits, in which the design, detailing, and quality of materials must meet technical standards and professional inspections.

We should also acknowledge the different structures of the respective housing supply sectors (i.e., the relations between relevant stakeholders). In the case of engineered houses, the manufacture of materials and availability of professional workers with technical knowledge together constitute a formal “housing supply sector,” as shown in Fig.3. In the case of the non-engineered houses however, the manufacture of materials and the workers of non-engineered houses are nearer to the users/dwellers, usually of the same community. Sometimes the users/dwellers manufacture their own materials, such as adobe or timbers, and construct houses with the help of family members or friends. These are usually untrained people with little access to engineering knowledge, information, or training. The resulting gap between engineered and non-engineered houses is shown in Fig.4.

4. Two Approaches to Bridge the Gap

In order to improve the quality of houses, the authors usually implement lectures, workshops, and/or training programs aimed at enhancing the skills of workers who build engineered houses. This approach is shown by the arrow pointing in the up/right direction in Fig.5. This approach can also be effective for non-engineered houses. The authors find many good practices in training programs for non-engineered house builders in the world. Care must be taken to provide a well-designed curriculum and tools such as illustration, models, and/or mockups to help trainees with little technical knowledge to understand the training easily.

In the case of non-engineered houses, another significant approach is one that does not rely on improving the skills of workers. We should explore this approach because in comparison with workers and engineers building engineered houses, the builders of non-engineered houses do not have adequate capacity to absorb technical knowledge. An approach that aims to improve the quality of houses without the direct improvement of technical knowledge is shown by the upward pointing arrow in Fig.5. This approach should be pursued through easier detailing, the provision of effective equipment and machines, and the supply of well-designed components. For example, the bending of rebar is one of the most crucial issues...
in the construction of reinforced concrete members (columns, beams, etc.), and we often find inadequate detailing at the connections of beams and columns on construction sites (Fig. 7.). This is not only because of the poor workmanship of the builders, but also because detailing the overlapping of rebar as required by the drawing (Fig. 6.) cannot be accomplished with the simple tools available on the site (Fig. 7.). Easier detailing and construction methods or more effective tools and facilities are typical improvements this approach would favor.

Supervision can also be categorized in this approach. Users/dwellers of non-engineered houses usually cannot afford to employ professional supervisors. We could train users/dwellers themselves to play this role or encourage them to turn to housing facilitators employed in community-based projects to support users. To promote this approach, dissemination activities are essential to enhance people’s awareness of potential earthquake risks and basic knowledge of seismic construction.

5. Key Issues for Safer Non-engineered Houses: Appropriate Technologies and Their Dissemination

As shown by the example of confined masonry in Indonesia, the simple application of the technology of engineered houses does not work for non-engineered houses where the facilities and tools are limited and the skill and knowledge of workers insufficient (Fig. 6. and 7.). We need seismic construction technologies which are feasible for the facilities and tools on existing construction sites and which are suitable for local workers with limited technical knowledge. These must also be affordable for users/dwellers, as most of those living in non-engineered houses are of low income and cannot afford to spend much on safety. The authors call these kinds of technologies "Appropriate Technologies" and they are key to the reduction of disasters.

How can appropriate technologies be delivered to the relevant people? In industrialized countries, building codes and technical standards are the usual measures for the dissemination of technical information. Dissemination to practicing engineers by professional associations and institutions, construction businesses, manufacturers, and researchers is also common. Furthermore, in developed countries we expect the diffusion of technologies through administrative procedures such as building permits and supervision by officials.

But these measures are not effective for non-engineered houses. We need to deliver technical knowledge to workers like the people in Fig. 6. and encourage them to apply it in their construction work. As a housing supply sector consisting of people in the engineering professions does not exist, we cannot rely on professionals to disseminate technologies. In addition, government administration services are usually not effective for non-engineered houses. In any case, non-engineered houses are not a governmental priority because each house is small and its individual impact on the environment negligible, even though the number of such houses is very large. We therefore need to seek other effective channels for disseminating technologies in order to achieve safer non-engineered houses.

6. A Comprehensive Approach Embracing All Relevant Items for Safer Non-engineered Houses

Discussion of key issues and lessons from the authors’ experience suggests that a comprehensive approach extending beyond key issues to wider socio-economic realities is needed in order to realize a reduction in earthquake damage in practice. The relevant items are discussed individually below and shown in Table 2.

6.1 Technical Solutions for Safer Houses

Appropriate technologies (C1 in Table 2.) cover structural engineering, structural design, and construction methods. In addition to such expertises, we must pay attention to materials and components (C2 in Table 2.) and to improving on-site construction practices (C3 in Table 2.) (see Fig. 9. for the poor result of low quality of materials and construction practices). The latter can be accomplished by improving or introducing effective tools and facilities, as well as practical construction methods and procedures.

6.2 Dissemination of Technologies

We need an effective way to deliver technical knowledge to workers (D in Table 2.). Various approaches have been tried by governments, donors and international organizations, including the distribution of leaflets and the implementation of
In addition to supply side activities that target workers (D1 in Table 2.), a demand side approach (D2 in Table 2.) should also be pursued because users/dwellers could be the most reliable supervisors of the construction of their own non-engineered houses. In most cases, users/dwellers cannot expect supervision by government or afford to employ professionals. They themselves could be reliable supervisors if they acquire sufficient technical knowledge. For this purpose, donor and NGO should organize workshops and demonstrations targeting users (Fig.10.). In the same context, workshops and training could be aimed at housing facilitators who are employed by donor-funded, community-based projects to facilitate the construction of houses by users/dwellers (Fig.11.).

6.3 Characteristics of Targeted Housing Types

We need precise and reliable technical information on the characteristics of each targeted housing type (B in Table 2.). Most information accumulated so far is based on field surveys done after earthquakes; the collapsing procedures are not yet fully clarified. The authors therefore conducted strength tests of materials and components, cyclic loading experiments, and shaking table experiments to comprehend the behavior of structures during shaking motion (Fig.12. and 13.). To understand actual on-site construction practices, the authors conducted monitoring surveys on construction sites for three months to grasp all procedures, from earth work, foundation, brick work, RC work, and roof construction to the finishing work on confined masonry and adobe houses. This survey succeeded in obtaining useful information for the generation of technical solutions for safer houses.

6.4 Potential Risks in Case of Earthquake

Potential risk is the starting point of all efforts for safer houses (A in Table 2.). Scientific expectations concerning the scale of earthquakes occurring in each area and their reoccurrence period are essential information (A1). In order to predict damage, we also need research results on the effect of the ground motion.
| Items | Sub items | Action | Expertise/Fields |
|-------|-----------|--------|------------------|
| A     | Potential risks in case of earthquakes | 1 Potential of earthquake occurrence | Anticipate future earthquakes with the magnitudes and return period | Seismology, Geology |
|       |           | 2 Seismic ground motion | Determine propagation and amplification of vibration and anticipate ground motion | Seismology, Geology, Soil Dynamics, Earthquake Engineering |
|       |           | 3 Potential risks of building damages | Estimate damages of buildings by anticipated ground motion | Earthquake Engineering, Structural Engineering |
| B     | Characteristics of targeted housing types | 1 Structures | Determine characteristics that influence earthquake damages, such as materials, supporting members against lateral forces (walls, reinforcing, etc.), number of stories, etc. | Structural Engineering |
|       |           | 2 Materials and components | Specify physical characteristics of structural materials and components such as compression/tensile strength, ductility and their dispersion | Engineering on Building Materials |
|       |           | 3 Construction technologies | Specify characteristics of construction methods/procedures and tools/facilities of construction works | Construction Engineering |
|       |           | 4 Skills of workers | Determine skills of workers who build targeted housing type | Construction Management |
| C     | Technical solution for safer houses | 1 Appropriate construction technologies | Promote structural engineering, structural designs, construction method, appropriate for each housing type for earthquake safety | Structural Engineering, Construction Engineering, Construction Management |
|       |           | 2 Appropriate materials and components | Improve materials and components or introduce new ones to promote earthquake safety | Engineering on Building Materials, Construction Engineering, Construction Management |
|       |           | 3 Improvement of on-site practices | Improve or introduce tools/facilities and construction methods/procedures for earthquake safety | Construction Engineering, Construction Management |
| D     | Dissemination of technologies | 1 Industries, engineers/workers and administration (supply side) | Disseminate technical information/recommendation to relevant groups such as construction workers, manufacturers of materials and components and government officials | Engineering Education, Dissemination of Technologies, Training of Engineers and Workers, R&D on Materials and Components, Circulation of Materials and Components, Policy for Building Industry, Building Permit |
|       |           | 2 People and community (demand side) | Educate and motivate users/dwellers and their family members, community members (neighbors etc.) and their supporters like housing facilitators and volunteers | Disaster Education, Community Based Disaster Reduction |
| E     | Supports for building users/dwellers and community | 1 Economic support | Provide subsidies, loans, donation of materials etc. to encourage investment in earthquake safety | Community Development, Policies and Strategies for Poor Groups |
|       |           | 2 Social supports | Support users’/residents’ access to economic support and administrative procedures, such as building permits and settling of legal issues like land tenure, migration control | Community Development, Policies and Strategies for Poor Groups |
|       |           | 3 Collaboration | Collaborate with initiatives targeting low- and middle-income groups, such as public health, improvement of living condition, and community development projects | Community Development, Development Aid, International Cooperation, NGO Activities |
|       |           | 4 Collaboration platform for all stakeholders (governments, donors, engineers, NGOs and international organizations) | Establish a platform to support collaboration by stakeholders involved in activities E1, E2, and E3 | Development Aid, International Cooperation, NGO Activities |
| F     | International platform for exchange of information, lessons, and good practices | Establish an international platform to enhance the human resources devoted to reducing earthquake damage | All the relevant fields and sectors above |
| G     | Environment for sustainable development and a movement for safer houses | Prepare an environment to facilitate sustainable development that requires less financial and human resources through the activation of local economies and community development | Community Development, Development Aid, International Cooperation |
by earthquake on construction (A2) and vulnerability data for each housing type to evaluate the risks of damage to houses (A3). This information should be delivered to stakeholders to motivate them to work for safer houses.

6.5 Support for Building Users/Dwellers and Communities

Since houses are expensive properties and safer houses require further investment, economic encouragement in the form of subsidies, loans, or the donation of materials is necessary (E1 in Table 2.). Social support is also needed as most users/dwellers of non-engineered houses are unfamiliar with administrative and documentation procedures such as building permits and application for subsidies (E2 in Table 2.). Housing facilitators in community-based projects can lend support of this type (Fig.11.). In the reconstruction project after the 2006 Central Java earthquake, the authors also found that a division of local government dedicated to consulting with people on building permits and building subsidy applications could meet this challenge (Fig.14.).

Fig.12. Shaking table experiment with a confined masonry structure common in Indonesia, July 2008, at the National Research Institute for Earth Science and Disaster Reduction (NIED) in Tsukuba, Japan, organized by NIED and Mie University in cooperation with BRI

Fig.13. Cyclic loading experiments of confined masonry walls (9 specimens), February and March 2009, at the Research Institute for Human Settlements, Department of Public Works (RIHS/DPU), Bandung, Indonesia, organized by Bandung Institute of Technology (ITB) and BRI. Setting up of specimen and measurement equipment (left) and final stage of cyclic loading (right).

Collaboration with other initiatives targeting low- and middle-income groups (E3) is another effective way to support building users/dwellers, as these are more commonly and continuously implemented than those aimed at either reduction of earthquake disasters or reconstruction after earthquake disasters. The authors can report the successful continuation in Peru of a Training Program for Seismic Adobe Houses – a JICA (Japan International Cooperation Agency) project – by the international NGO CARITAS. CARITAS conducts initiatives for community development in mountainous areas in Peru aimed at the enhancement of agricultural productivity and the improvement of living conditions. They find that adobe is a suitable type of housing construction there and employ the seismic design
of adobe houses as trained by JICA (Fig.5.). The participants in JICA training programs play a very big role in CARITAS initiatives (Fig.16.).

6.6 Collaborative Platform for All Stakeholders

Initiatives and activities to reduce disaster in non-engineered houses require various stakeholders, including local and central governments, professional consultants, engineers, and social workers, donors, NGOs, and international organizations. The number of stakeholders and the complexity of their activities requires a platform for the exchange of information and coordination of activities to ensure effective implementation in each area or country (E4 in Table 2.).

6.7 International Platform

The reduction of earthquake disasters in non-engineered houses is an urgent global issue. As the accumulation of lessons and experience is by itself insufficient, it is desirable to establish an international platform to support advances in all relevant fields and sectors (F in Table 2.). We find such remarkable initiatives as the World Housing Encyclopaedia (WHE), by the Earthquake Engineering Research Institute (EERI), and ISEE Net, by the International Institute of Seismology and Earthquake Engineering of the Building Research Institute (IISEE/BR1), already in existence. These are platforms for researchers in the fields of earthquake engineering and seismology, which cover items A, B, and C in Table 2.; platforms are needed that cover items D, E and G.

6.8 Environment for Sustainable Development and a Movement for Safer Houses

Finally, the authors suggest that an environment be prepared for sustainable development and a movement for safer houses, in which each community is supported once in the reduction of risk from earthquakes and is expected to continue the movement with less financial and human resource support from outside (G in Table 2.). Since the number of communities which need support for disaster reduction is enormous and resources are limited, we need to prepare the environment for a sustainable movement.

6.9 Proposing a Comprehensive Approach

Fig.8. illustrates the relationship between the relevant items discussed above. It suggests that a comprehensive approach that features awareness of all items and collaboration between all stakeholders could enhance the effectiveness of the efforts of each.

7. Conclusion

The reduction of disasters in non-engineered houses is a very urgent issue that contains not only technical but also social and economic aspects. Despite the challenges, several initiatives and many enthusiastic people are tackling this tough issue. Because resources are limited, collaboration to share knowledge and lessons and a comprehensive approach to attaining safer non-engineered houses is highly recommended.

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