Revision of IAEE Guidelines for Earthquake Resistant Non-Engineered Construction

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SUMMARY:
A large majority of houses and buildings in the world can be classified as non-engineered construction, e.g. (1) un-reinforced masonry, (2) confined masonry, (3) wooden construction, (4) earthen construction (adobe or tapial). Most of the loss of life in past earthquakes has occurred due to the collapse of these houses and buildings. Because of the continued use of such construction, it is essential to introduce earthquake resistant features in their construction. The International Association for Earthquake Engineering (IAEE) published the "Guidelines for Earthquake Resistant Non-Engineered Construction" in 1986. More than twenty years have passed since the publication and the guidelines are still used in many parts in the world, the revision of the guidelines was discussed among three of the committee members for the 1986 edition. The revision is going to be completed with the supports of UNESCO and the International Institute of Seismology and Earthquake Engineering (IISEE), JAPAN.

Keywords: non-engineered construction, masonry, wooden construction, earthen construction

1. INTRODUCTION

A large majority of houses and buildings in the world can be classified as non-engineered construction. Most of the loss of life in past earthquakes has occurred due to the collapse of these houses and buildings. Because of the continued use of such construction in the world, the International Association for Earthquake Engineering (IAEE) published the "Guidelines for Earthquake Resistant Non-Engineered Construction" in 1986 (see Fig.1). More than twenty years have passed since the 1986 edition and also the guidelines are still used in many parts in the world, the revision of the guidelines will be helpful to minimize the damage and loss of lives caused by earthquakes. The revised draft with a number of pictures (see Figs. 2-8) can be downloaded at the web site of IISEE (http://iisee.kenken.go.jp).

2. NON-ENGINEERED CONSTRUCTION

Many buildings are spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and/or engineers. Some types of the non-engineered construction are (1) un-reinforced masonry (stone, brick or concrete block masonry) (see Figs.3 and 5), (2) confined masonry (see Fig.4), (3) wooden construction (see Fig.6), (4) earthen construction (adobe or tapial, i.e. rammed earth) (see Fig.7), etc.

In un-reinforced construction, masonry walls consist of fired bricks, solid concrete blocks, hollow concrete or mortar blocks, etc. The main weaknesses in un-reinforced masonry construction are a) heavy and stiff buildings, attracting large seismic inertia forces, b) very low tensile and shear strength, particularly with poor mortars, c) brittle behaviour in tension as well as compression, d) weak connections between walls, etc. Therefore, use of mud or very lean mortars is unsuitable.

Confined masonry consists of masonry wall of clay brick or concrete block units and horizontal and vertical reinforced concrete members that confine the masonry wall panels at four sides. Vertical members are called “tie-columns”, and though they resemble columns in reinforced concrete (RC) frame construction they are of much smaller cross-section. Horizontal elements, called “tie-beams”, resemble beams in RC frame construction, but also of much smaller section. It must be understood that the confining elements are not beams and columns in the way these are used in RC frames. Rather they function as horizontal and vertical ties or bands for resisting tensile stresses.

Wood has a high strength per unit weight and is very suitable for earthquake resistant structure. However, heavy cladding walls impose high lateral loads on a wooden frame beyond its structural capacity. Although seismically suitable, use of timber is declining in building construction even where it used to be the prevalent material on account of vanishing forests due to population pressure. The situation in many countries of the world has in fact become rather alarming on account of the ecological imbalance. Hence use of timber must be restricted in building construction for seismic strengthening weaker construction such as adobe and masonry. Wooden construction is suitable in those areas where wood is still abundantly available as a renewable resource.

In earthen construction, walls are the basic structural elements and can be classified as a) hand-formed by layers, b) adobe or blocks, c) tapial or pise (rammed earth), and d) wood or cane mesh frameworks with mud. This material has clear advantage of costs, aesthetics, acoustics, heat insulation and low energy consumption, but it has some disadvantages such as being weak under earthquake forces and water action. However, technology developed to date has allowed some reduction of its disadvantages. Earthen construction is, in general, spontaneous and a great difficulty is experienced in the dissemination of knowledge about its adequate use. The recommendations are applicable to earthen construction in general, but they are especially oriented to popular housing, aiming to enhance the quality of spontaneous, informal construction which cause the greatest loss of life and damage during seismic events. Therefore, not included are solutions involving the use of stabilizers (cement, lime, asphalt, etc.) to improve the strength or durability. But to enhance the dynamic behaviour of the structure economically, minimum use of the expensive materials (concrete, steel, wood, etc.) is indicated.

3. IAEE GUIDELINES IN 1986

The “Guidelines for Earthquake Resistant Non-Engineered Construction” was published by the International Association for Earthquake Engineering (IAEE) in 1986 (see Fig.1). It is a revised and amplified version of “Basic Concepts of Seismic Codes, Vol.1, Part II, Non-Engineered Construction”, published also by IAEE in 1980. The revision resulted from the work of an ad-hoc Committee, integrated by Anand S. Arya, Chairman (India), Teddy Boen (Indonesia), Yuji Ishiyama (Japan), A. I. Martemianov (USSR), Roberto Meli (Mexico), Charles Scawthorn (USA), Julio N. Vargas (Peru) and Ye Yaoxian (China).

The guidelines start with the presentation of the basic concepts that determine the performance of constructions when subjected to high intensity earthquakes, as well as with the sensitivity of that performance to the basic geometrical and mechanical properties of the systems affected. This information is later applied to the formulation of simplified design rules and to the presentation of practical construction procedures, both intended to prevent system collapse and to control the level of damage produced by seismic excitations. Emphasis is placed on basic principles and simple solutions that can be applied to different types of structural systems, representative of those ordinarily used in low-cost housing construction in different regions and countries in the world.

The guidelines consist of nine chapters, i.e. 1) The Problem, Objective and Scope, 2) Structural Performance during Earthquakes, 3) General Concept of Earthquake Resistant Design, 4) Buildings in Fired-Brick and Other Masonry Units, 5) Stone Buildings, 6) Wooden Buildings, 7) Earthen Buildings, 8) Non-Engineered Reinforced Concrete Buildings, 9) Repair, Restoration and Strengthening of Buildings, and Appendices.

4. REVISION OF THE GUIDELINES

Three members of the committee for the 1986 edition, i.e. Anand S. Arya, Teddy Boen and Yuji Ishiyama met in Tokyo, Japan during “The International Symposium 2008 on Earthquake Safe Housing”, which was held on November 28 and 29 in 2008. Since more than twenty years had passed after the publication and also the guidelines are still used in many parts in the world, they discussed the possible revision of the guidelines and agreed to make a working group in IAEE including the original members who are willing to participate in it and some new members who are also willing to join it. Since there is no special fund allocated to the working group in IAEE, the revision is mainly done through e-mail communications. The activities on the revision have been supported in parts by UNESCO and the International Institute of Seismology and Earthquake Engineering (IISEE), JAPAN. The three members met in Delhi, India in April, 2010 and in Singapore in March 2011. The draft for the IAEE Guidelines can be downloaded at the website of IISEE (http://iisee.kenken.go.jp).

Since the principles included in the Guidelines still apply until now, this revised edition essentially retains the Guidelines in the original form except for some minor editorial changes and modifications. Some building damage photographs from recent earthquakes have been included for illustration (see Figs.2, 3, 5, 6 and 7) so that the concept of the guidelines will be easily understood. A major addition is Confined Masonry in Chapter 4 (see Fig.4) and Appendices in Chapter 10 giving the MSK Intensity Scale as related to buildings, a table for assessment of seismic safety of a masonry building, and examples of posters on brick (see Fig. 8) and wooden buildings.

As to the confined masonry, the finished appearance looks similar to the ordinary RC frame construction with masonry infills, but they are very different. The differences are related to the construction sequence, as well as to the manner in which these structures resist gravity and lateral loads. In RC frames, columns and beams are constructed, then the masonry wall units infill the frames. In confined masonry, usually masonry walls are constructed and then the tie-columns and tie-beams are constructed. In RC frames, the RC columns and beams carry the vertical gravity as well as the lateral loads from earthquakes or wind storms unaided by the masonry infills. In the case of confined masonry buildings, the wall panels are the main load carrying elements (both vertical and horizontal) aided by the confining elements (tie-columns and tie-beams) for resisting tensile forces.

5. CONCLUDING REMARKS

The revision of the IAEE Guidelines for Earthquake Resistant Non-Engineered Construction is going to be completed. The guidelines will be updated and the latest version can be downloaded at the website of IISEE. Those who have interests for the revision are recommended to send their comments to: Anand S. Arya (India): asarun3155@gmail.com, Teddy Boen (Indonesia): tedboen@cbn.net.id, or Yuji Ishiyama (Japan): to-yuji@nifty.com.

AKCNOWLEDGEMENT

The meetings and activities for the revision of the guidelines have been supported in parts by UNESCO, IISEE (International Institute of Seismology and Earthquake Engineering) in Japan, etc. Their assistance is gratefully acknowledged.

REFERENCE

Arya, A.S, Boen, T., Ishiyama, Y., et.al. (1986). Guidelines for earthquake resistant non-engineered construction, the International Association for Earthquake Engineering, 1-158.

GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION

Revised Edition of "Basic Concepts of Seismic Codes" Vol. I, Part 2, 1980

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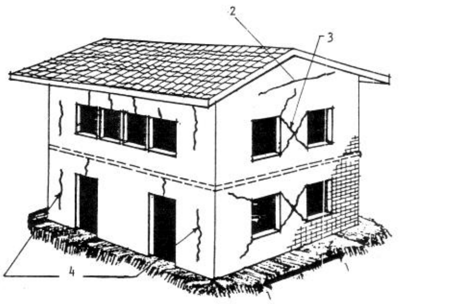
October 1986

(a) Title page of IAEE Guidelines (1986)



1-1 Earthquake motion, 2-Horizontal crack in gables, 3-Diagonal cracks due to shear, 4-Cracks due to bending of wall.

FIG.4.1. CRACKING IN BEARING WALL BUILDING DUE TO BENDING AND SHEAR.

ii) A wall can fail as a bending member loaded by seismic inertia forces on the mass of the wall itself in a direction, transverse to the plane of the wall. Tension cracks occur vertically at the centre, ends or corners of walls. Longer the wall and longer the openings more prominent is the damage (Fig.4.1.). Since earthquake effects occur along both axes of a building simultaneously, bending and shearing effects occur often together and the two modes of failure are often combined. Failure in the piers occurs due to combined action of flexure and shear.

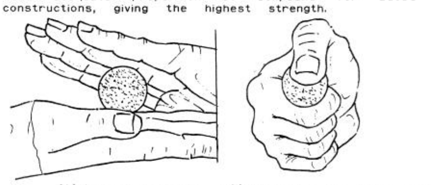
iii) Unreinforced gable end masonry walls are very unstable and the strutting action of purlins imposes additional force to cause their failure. Horizontal bending tension cracks are caused in the gables.

iv) The deep beam between two openings one above the other is a weak point of the wall under lateral in-plane forces. Cracking in this zone occurs before diagonal cracking of piers (Fig.4.2.). In order to prevent it and to enable the full distribution of shear among all piers, either a rigid slab or r.c. band must exist between them.

(b) Easy to read with illustrations

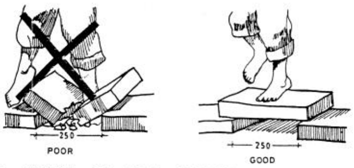
b. <u>Fissuring Control Test</u>

At least eight sandwich units are manufactured with mortars made with mixtures in different proportions of soil and coarse sand. It is recommended that the proportion of soil to coarse sand vary between 1:0 and 1:3 in volume. The sandwich having the least content of coarse sand which, when opened after 48 hours, does not show visible fissures in the mortar, will indicate the most adequate proportion of soil/sand for adobe constructions, giving the highest strength.



(i) Making the ball (ii) Crushing the dried ball

(a). DRY-BALL STRENGTH TEST FOR SOIL.



(b). TESTING OF ADOBE STRENGTH.

FIG.7.3 FIELD TESTING OF STRENGTH OF SOIL AND ADOBE.

<u>Strength Test of Adobe</u>

The strength of adobe can be qualitatively ascertained as follows: After 4 weeks of sundrying the adobe it should be strong enough to support in bending the weight of a man (Fig.7.3.b). If it breaks, more clay and fibrous material is to be added. Quantitatively, the compressure strength may be determined by testing 10cm cubes of clay after completely drying them. A minimum value of 1.2N/mm^2 will be desirable.

(c) Applicable at construction site

7.8. <u>SUMMARY OF DESIRABLE FEATURES</u>

The desirable features for earthquake resistance of earthen houses are briefly illustrated in Fig.7.14.

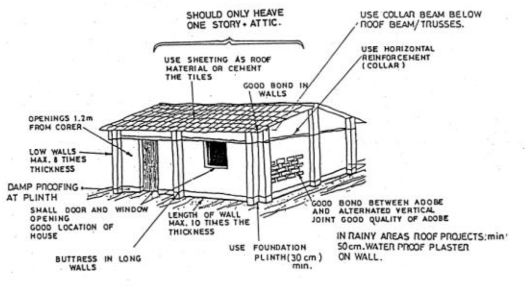


FIG.7.14. GOOD FEATURES OF EARTHQUAKE RESISTANT CONSTRUCTION.

7.9. <u>WORKING STRESSES</u>

7.9.1. <u>Unit Compressive Strength</u>

The compressive strength of the unit is an index of its quality and not of the masonry.

It will be determined by testing cubes of approximately 100mm. The compressive strength (fo) is the value exceeded by 80% of the number of specimens tested.

The minimum number of specimens is six (6) and they should be completely dry at the time of testing. The minimum value of (fo) is 1.2 N/mm^2.

(d) Desirable features of earthen construction

Figure 1. IAEE Guidelines for Earthquake Resistant Non-Engineered Construction (1986)

(a) 1992 Flores Earthquake (b) 2004 Ache Earthquake

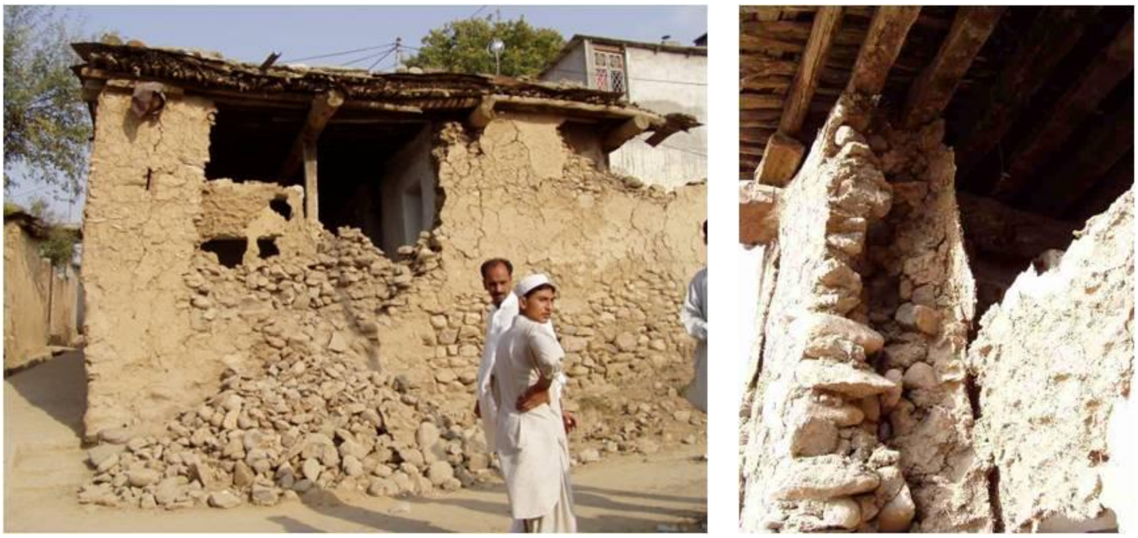
Figure 2. Damage caused by tsunami (Indonesia)

(a) 1994 Liwa Earthquake (b) 2006 Central Java Earthquake

Figure 3. Out-of-plane failure of brick masonry wall (Indonesia)

(a) Single storey house (Ache) (b) Two storey house under construction (Jawa)

Figure 4. Construction of confined masonry (Indonesia)



(a) Unreinforced stone masonry (b) Damage to the stone masonry wall

Figure 5. Damage to stone masonry (2005 Northern Pakistan Earthquake)

(a) Damage concentrated to the first storey (b) Detail of the damaged wooden house

Figure 6. Damage to wooden houses (1995 Kobe Earthquake, Japan)

(a) Damaged adobe (2007 Pisco Earthquake) (b) Damaged tapial (1990 Rioja Earthquake)

Figure 7. Damage to earthen buildings (Peru)

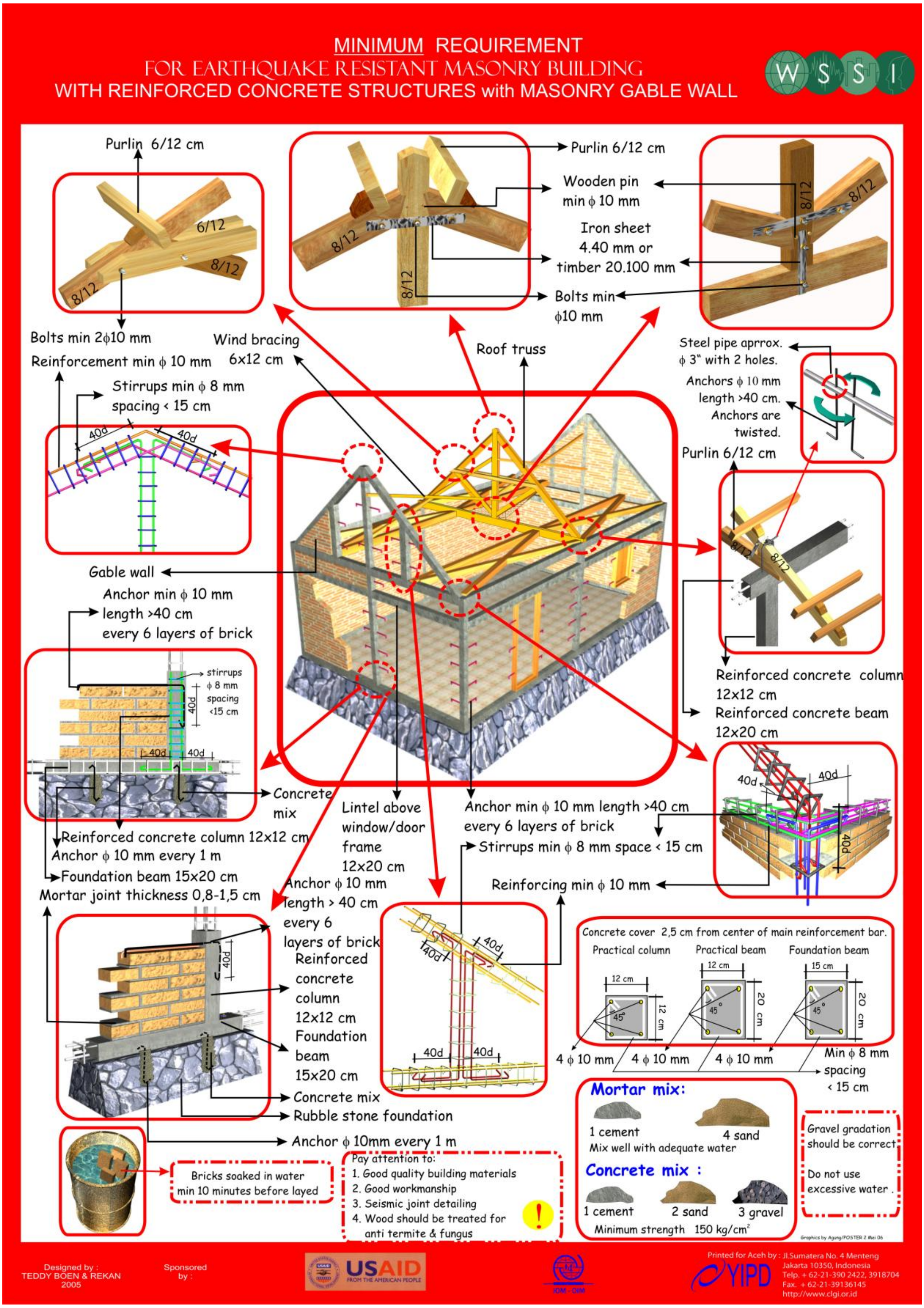


Figure 8. Poster for half brick confined masonry